2007 LCCMR Recommendations
for the Environment and Natural Resources Trust Fund
for FY08

Section 1 MINNESOTA RESOURCES

Total Appropriations - $23,366,000				
Environment and Natural Resources Trust Fund State Land and Water Conservation Account (LAWCON)				**$22,866,000** **$500,000**
Subd. 3 LCCMR and Contract Administration - $1,318,000				
Subd	**Para**	**Title**	**Affiliation**	**$ Recommended**
3	(a)	Administration	LCCMR	$1,278,000
3	(b)	Contract Administration	DNR	$40,000
Subd. 4 Land - $14,835,000				
Subd	**Para**	**Title**	**Affiliation**	**$ Recommended**
4	(a)	Forest Legacy Conservation Easements	DNR	$2,000,000
4	(b)	Minnesota's Habitat Corridors Partnership - Phase IV	Pheasants Forever/DNR/11 Partners	$4,200,000
4	(c)	Metro Conservation Corridors - Phase III	DNR/6 Partners	$2,500,000
4	(d)	Prairie Stewardship Assistance for Private Landowners	DNR	$220,000
4	(e)	State Park and Trail Land Acquisitions	DNR	$1,500,000
4	(f)	Metropolitan Regional Park System Land Acquisition	Metropolitan Council	$2,500,000
4	(g)	Non-metropolitan Regional Parks and Natural and Scenic Area Acquisitions	DNR	$1,000,000
4	(h)	LAWCON Federal Reimbursements	DNR	$500,000
4	(i)	Biological Control of European Buckthorn and Garlic Mustard	DNR	$300,000
4	(j)	Neutralization of Reed Canary Grass Root Exudates	MN State University - Mankato	$115,000

2007 LCCMR Recommendations
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Subd	Para	Title	Affiliation	$ Recommended
Subd. 5 Water Resources - $5,051,000				
Subd	**Para**	**Title**	**Affiliation**	**$ Recommended**
5	(a)	Local Water Management Matching Challenge Grants	BWSR	$350,000
5	(b)	Protection of Rare and Unique Rock Outcrop Wetlands	Renville & Redwood SWCD/BWSR	$563,000
5	(c)	Land Retirement Effects on Minnesota River Basin Streams	BWSR	$275,000
5	(d)	Demonstrating Benefits of Conservation Grasslands on Water Quality	Science Museum of Minnesota	$374,000
5	(e)	Improved River Quality Monitoring Using Airborne Remote Sensing	MN State University - Mankato	$159,000
5	(f)	Evaluating Riparian Timber Harvesting Guidelines: Phase 3	U of M	$400,000
5	(g)	Innovative Springshed Mapping for Trout Stream Management	U of M	$270,000
5	(h)	Intra-Lake Zoning to Protect Sensitive Lakeshore Areas	DNR	$110,000
5	(i)	Water Resource Sustainability	U of M	$292,000
5	(j)	County Geologic Atlas Program Acceleration	MN Geological Survey - U of M	$400,000
5	(k)	Minnesota's Water Resources: Impacts of Climate Change- Part 2	U of M - NRRI	$300,000
5	(l)	Pharmaceutical and Microbiological Pollution	U of M	$302,000
5	(m)	Threat of Emerging Contaminants to Upper Mississippi Walleye	St. Cloud State University	$97,000
5	(n)	Cedar Creek Groundwater Project using Prairie Biofuel Buffers	U of M	$659,000
5	(o)	Pyrolysis Pilot Project	U of M	$500,000
Subd. 6 Natural Resource Information - $2,002,000				
Subd	**Para**	**Title**	**Affiliation**	**$ Recommended**
6	(a)	Minnesota County Biological Survey	DNR	$1,500,000
6	(b)	Soil Surveys	BWSR	$400,000
6	(c)	Field Guide for Evaluating Vegetation of Restored Wetlands	Bonestroo, Rosene, Anderlik & Associates, Inc.	$53,000
6	(d)	Natural Resource Data Collection and Mapping	LCCMR	$49,000
Subd. 7 Establishment of an Emerging Issues Account - $160,000				
Subd	**Para**	**Title**	**Affiliation**	**$ Recommended**
7	----	Emerging Issues Account		$160,000

2007 LCCMR Recommendations
for the Environment and Natural Resources Trust Fund
for FY08

2007 LCCMR Recommendations
for the Environment and Natural Resources Trust Fund
for FY08

2007 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Forest Legacy
PROJECT MANAGER: Richard Peterson
AFFILIATION: Minnesota Department of Natural Resources Forestry
MAILING ADDRESS: 1810-30th St. NW
CITY/STATE/ZIP: Faribault, MN 55021
PHONE: 507/333-2012 x222
FAX: 507/333-2008
E-MAIL: Richard.F.Peterson@state.mn.us
WEBSITE: [If applicable] www.dnr.state.mn.us
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chapter 30, Section 2, Subdivison 4a and Subdivision 4b where applicable; ML 2009, Chapter 143, Section 2, Subdivision 16 Carryforward

APPROPRIATION AMOUNT: $2,000,000

Overall Project Outcome and Results
The Blufflands landscape of southeastern Minnesota has been identified by the Department of Natural Resources as an important area for conservation. The mix of forest, bluff prairies, and rivers provides habitat for numerous rare and declining species as well as many common species, and the oak forests are an important source of hardwood logs for area sawmills. Conserving and protecting large blocks of priority forest habitat through working forest conservation easements is a cost effective method to protect forests in an area where nearly 90% of the land is in private ownership.

The goal of this project was to identify and protect the highest priority parcels with working forest conservation easements. All applications were reviewed and ranked according to program ranking criteria (project size, location, forest quality, adjacency to public land, etc). Five applicants from a group of seventeen applicants were selected and appraisals were completed and certified during 2009 and 2010.

Two projects were completed and closed in December 2009, two in June 2010 and the final project closed in October 2010. A total of 1911.61 acres of private forestland and associated habitats in southeastern Minnesota were protected at an average cost of about $1,055/acre. Total funds expended were $2,017,454.4 and includes $1,975,724 from the Environment and Natural Resources Trust Fund and $41,730.4 from Capital Bonding.

The easements will be held by the State of Minnesota, Department of Natural Resources and monitored on a regular basis beginning in 2011.

These five projects are strategically located or nearby other publicly protected lands and these acquisitions help maintain larger blocks of deciduous forest adjacent or nearby public forests and buffer the publicly owned forest land and provide habitat linkages between publicly owned lands. They also contain productive forest resources of predominantly native forest species that have not been subject to any extensive development and which provide valuable habitat for a diversity of wildlife species.

Project Results Use and Dissemination
Project information will be reported in the Forest Legacy Information System for projects used to provide matching funds for the Koochiching Forest Legacy Project which was completed during this Project period. Project information has been used in a recent StarTribune graphic included in a December 15, 2010 article on the forest legacy program accomplishments.

Trust Fund 2007 Work Program Final Report

Date of Report: December 28, 2010
Trust Fund 2007 Work Program Final Report
Date of Work program Approval: October 9, 2007; Amendment approved on September 24, 2008
Project Completion Date: December 31, 2010

I. PROJECT TITLE: Forest Legacy Conservation Easements

Project Manager:	Richard Peterson
Affiliation:	Minnesota Department of Natural Resources Forestry
Mailing Address:	1810-30th St. NW
City / State / Zip :	Faribault, MN 55021
Telephone Number:	507/333-2012 x222
E-mail Address:	Richard.F.Peterson@state.mn.us
FAX Number:	507/333-2008
Web Page address:	www.dnr.state.mn.us
Location:	Wabasha County, MN

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$ 2,000,000**
	Minus Amount Spent:	**$ 1,975,724**
	Equal Balance:	**$ 24,276**

Legal Citation: ML 2007, Chapter 30, Section 2, Subdivision 4a and Subdivision 4b where applicable; ML 2009, Chapter 143, Section 2, Subdivision 16 Carryforward

Appropriation Language: (a) Forest Legacy Conservation Easements $2,000,000 is from the trust fund to the commissioner of natural resources to acquire permanent working forest conservation easements on private forests in northern Minnesota, the Mississippi blufflands, and other areas identified through the state forest legacy program. Priority must be given to acquiring easements on private lands within existing Minnesota state forest boundaries. Any easements acquired must have a sustainable forestry practice management plan. Land subject to easements acquired under this appropriation is not eligible for payment under Minnesota Statutes, chapter 290C. The commissioner must report to the Legislative-Citizen Commission on Minnesota Resources with proposed minimum standards for forest conservation easements by June 1, 2007. The commission shall consider the proposed standards as part of the work program approval by June 30, 2007. No funds shall be expended until the commission has reviewed and approved minimum standards for forest conservation easements funded by the trust fund.

2009 Appropriation Language: The availability of the appropriations for the following project is extended to June 30, 2010: Laws 2007, chapter 30, section 2, subdivision 4, paragraph (a), forest legacy conservation easements.

II. and III. FINAL PROJECT SUMMARY:

Overall Project Outcome and Results

The Blufflands landscape of southeastern Minnesota has been identified by the Department of Natural Resources as an important area for conservation. The mix of forest, bluff prairies and rivers provides habitat for numerous rare and declining species as well as many common species and the oak forests are an important source of hardwood logs for area sawmills. Conserving and protecting large blocks of priority forest habitat through working forest conservation easements is a cost effective method to protect forests in an area where nearly 90% of the land is in private ownership.

The goals of this project identify and protect the highest priority parcels with working forest conservation easements. All applications were reviewed and ranked according to program ranking criteria (project size, location, forest quality, adjacency to public land, etc). Five applicants from a group of seventeen applicants were selected and appraisals were completed and certified during 2009 and 2010. The 5 selected applicants include 5 out of the top 6 ranked projects-one project was dropped when the landowner lost interest. The Division of Forestry biennial acquisition plan dated October 9, 2009 is attached and which includes the scoring criteria on page 7.

Two projects were completed and closed in December 2009, two in June 2010 and the final project closed in October 2010. A total of 1911.61 acres of private forestland and associated habitats in southeastern Minnesota were protected at an average cost of about $1,055/acre.

Total funds expended were $2,017,454.4 and includes $1,975,724 from the ETF and $41,730.4 from Capital Bonding.

The easements will be held by the State of Minnesota, Department of Natural Resources and monitored on a regular basis beginning in 2011.

These five projects are strategically located or nearby other publicly protected lands and these acquisitions help maintain larger blocks of deciduous forest adjacent or nearby public forests and buffer the publicly owned forest land and provide habitat linkages between publicly owned lands. They also contain productive forest resources of predominantly native forest species that have not been subject to any extensive development and which provide valuable habitat for a diversity of wildlife species.

IV. OUTLINE OF PROJECT RESULTS:

Result 1: Acquire Conservation Easements.

Description: The State of Minnesota will acquire perpetual Forest Legacy Conservation Easements on approximately 1,900 acres of private forestland.

Summary Budget Information for Result 1: | **Trust Fund Budget:** ~~$1,900,000~~ $1,886,126
Amount Spent: $ 1,861,850
Balance: $ 24,276

Deliverable	Completion Date	Budget	Status
1. Complete easements	10 /04/2010	~~$1,900,000~~ $1,886,126	Completed

Completion Date: 10/04/2010

Result Status as of December 28, 2010: Five easements have been acquired, two completed December 2009, two completed June 2010, and one completed October 2010. The acquisition costs were slightly less than the amount budgeted and $24,276 will be returned to the Environmental Trust Fund.

Four projects were acquired at the appraised value; a fifth project was acquired at $5,000 over appraised value (approximately 0.4% over appraised value) when a late discovery of a garbage dump on the property resulted in a 2 acre reduction in the subject property. At that point the landowner was not willing to renegotiate the sale price which had already been agreed on after several months of negotiating. The State agreed to the purchase over appraised value price of $1,225,000 (appraised at $1,220,250). The Landowner Bill of Rights and the signed option are attached for this transaction.

Result Status as of December 15, 2009: No easements have been acquired, but 4 properties are optioned and 2 are anticipated to close in December 2009. An offer has been made on a fifth offer. A total of $636,850 has been encumbered for the 4 optioned projects. The attachment A has been revised to show a reduction of Budget for Result 1 to $1,900,000 and a corresponding increase in Budget for Result 2 to $100,000. These numbers will likely be revised in the final report to reflect final costs of acquisition and professional services after projects are completed.

Result Status as of *August 31, 2009*: No easements have been acquired. The start of the work was delayed due to the delay in LCCMR approval of the work plan. With that taken care of, the projects are now moving ahead.

Result Status as of December 31, 2008: No easements have been acquired. Following approval of the work program amendment that allowed up to 25 non-forest land as part of the easement property, 2 projects were modified to increase the area under easement. Appraisal and other acquisition work are proceeding.

Result Status as of August 5, 2009: No easements have been acquired. Four projects have been appraised and three have been optioned with a fourth pending. A fifth project is being appraised and a sixth project will likely be added due to lower than expected appraisals.

Result 2: Complete acquisition processes

Description: The State of Minnesota will undertake conservation easement drafting, survey, appraisal, title work, baseline property reports, environmental reports, management plans, and other necessary and required steps to complete acquisition of perpetual conservation easements.

Summary Budget Information for Result 1:Trust Fund Budget: $~~100,000~~ $113,874
Amount Spent: $113,874
Balance: $0

Deliverable	Completion Date	Budget	Status
1. Complete acquisition processes	**6/30/10**	**$~~100,000~~$113,874**	
2.		**OTHER FUNDS: $ 41,730.4**	
3.			

Completion Date: 12/28/2010

Result Status as of December 28, 2010: Professional services were underestimated and have exceeded the revised estimate by nearly $31,000 due in part to the need to create several abstracts for the final project and the requirements for field surveys for three of the projects. $13,874 of the additional funding was from the ETF and a total of $41,730.4 of other funds (2005 Capital Bonding) was also expended for professional services.

Total funds expended by category are shown on the table below.

Expenditure Category	ETF Funds	Other Funds (State Capital Bonding)	Total
Attorney General	$0	$10,066.3	$10,066.3
Appraisal	$24,600	$5,300	$29,900
Survey	$51,303	$5,040	$56,343
Abstracting Fees	$2,256	$3,560	$5,816
Professional Services	$35,715	$17,442.1	$53,157.1
Recording Fees	$0	$322	$322
Professional Services Subtotal	**$113,874**	**$41,730.4**	**$155,604.4**
Acquisition	$1,861,850	$0	$1,861,850
Totals:	**$1,975,724**	**$41,730.4**	**$2,017,454.4**

A total of $24,276 will be returned to the Environment and Natural Resources Trust Fund.

Result Status as of December 15, 2009: Professional services were underestimated and, to date, have exceeded the initial estimate by 50%. Costs increased, in part, due to changes that came as a result of the work program amendment that allowed additional non-forest acres to be included which necessitated revised legals, revised easement language, etc. Additionally, costs for appraisals were higher than anticipated as were survey costs. Professional service costs to date include 5 appraisals, 5 appraisal reviews, 2 on-site surveys, some title work, and other costs associated with conservation easement acquisition. At this time, I estimate that total professional services will cost approximately $100,000 and have revised Attachment A to reflect this amount.

Result Status as of August 31, 2009: There has been no expenditure of funds for professional services.

Result Status as of December 31, 2008: There has been no expenditure of funds for professional services.

Result Status as of August 5, 2009: Funds have been expended for professional services including preparation of legal descriptions by the survey staff, appraisals, appraisal reviews, and options.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services:
Equipment:
Development: $ (improvement to land or building)
Restoration: $ (how many acres)
Acquisition, including easements: $ ~~1,900,000~~ $1,886,126 of perpetual conservation easements on up to 7,800 acres to be held by the State of MN DNR.
Acquisition Services: $~~100,000~~ $113,874
TOTAL TRUST FUND PROJECT BUDGET: $2,000,000

Explanation of Capital Expenditures Greater Than $3,500:

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

B. Other Funds Proposed to be spent during the Project Period: $1,750,000 from U.S. Forest Service Forest Legacy Grant (Pending FFY08 request with no assurance at this time of funding). No Federal Legacy Grants were received for this project, however $9,956,000 in Federal Forest Legacy Funds were received for the Koochiching Project which closed in December 2010. A total of $41,730.4 in other funds (2005 Capital Bonding) were expended on these projects, all for professional services.

C. Past Spending:

D. Time: Project time lines with acquisitions are uncertain and may require an extension request.

VII. DISSEMINATION: Any projects completed with Federal funds or which will serve as matching funds for the Forest Legacy Program will be reported in the Forest Legacy Information System and provided as information in periodic reports. No Federal funds were received for these projects, however all or some of these projects may be used for match dollars against the federal grants received during the project period for the Koochiching Forest Legacy Project.

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than every 6 months on December 15, 2007, June 15, 2008, December 15, 2008, June 15, 2009, and December 15, 2009. A final work program report and associated products will be submitted between June 30 and August 1, 2010 as requested by the LCCMR.

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: Forest Legacy

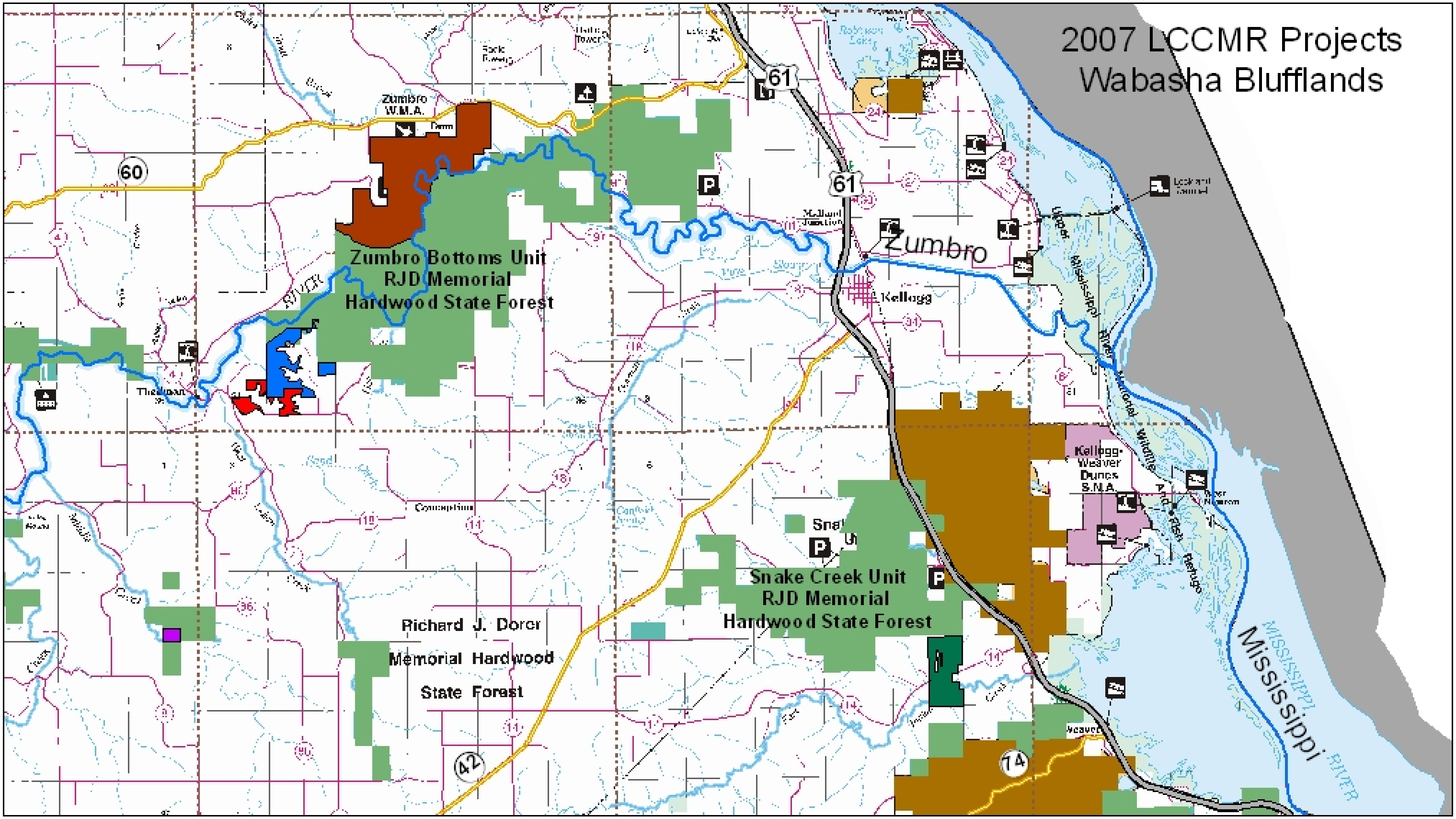
Project Manager Name: Richard Peterson

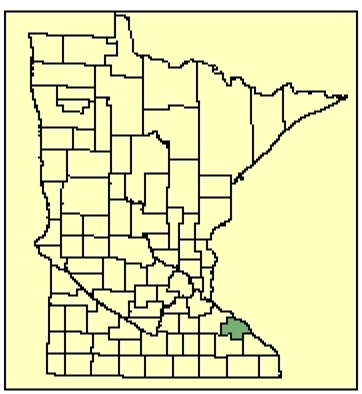
Trust Fund Appropriation: $ 2,000,000

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

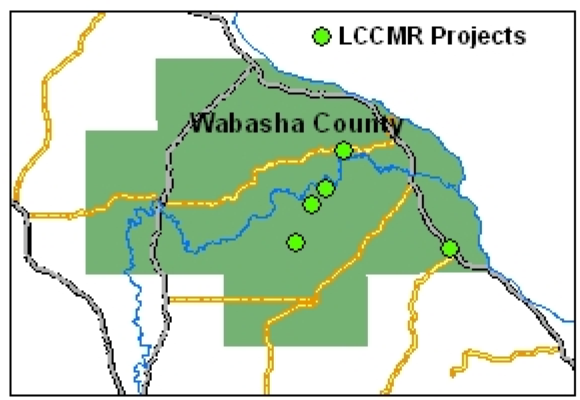
2007 Trust Fund Budget	**Result 1 Budget:**	**Revised Result 1 Budget: (12/28/2010)**	**Amount Spent** (12/28/2010)	**Balance** (12/28/2010)	**Result 2 Budget:**	**Revised Result 2 Budget: (12/28/2010)**	**Amount Spent** (12/28/2010)	**Balance** (12/28/2010)	**TOTAL BUDGET**	**TOTAL BALANCE**
BUDGET ITEM										
PERSONNEL: wages and benefits				0				0	0	0
Contracts				0				0	0	0
Land acquisition				0				0	0	0
Land rights acquisition *(less than fee)*	~~1,900,000~~	1,886,126	1,861,850	24,276					1,886,126	24,276
Professional Services for Acq.				0	~~100,000~~	113,874	113,874	0	113,874	0
COLUMN TOTAL	**~~$1,900,000~~**	**$1,886,126**	**$1,861,850**	**$24,276**	**~~$100,000~~**	**$113,874**	**$113,874**	**$24,276**	**$2,000,000**	**$24,276**





Legend

- 2007 LCCMR Forest Legacy Project 1
- 2007 LCCMR Forest Legacy Project 2
- 2007 LCCMR Forest Legacy Project 3
- 2007 LCCMR Forest Legacy Project 4
- 2007 LCCMR Forest Legacy Project 5
- State Forest
- State Wildlife Management Area
- Township Level Public Land Survey - Lines



2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Prairie Stewardship Assistance for Private Landowners
PROJECT MANAGER: Jason Garms
AFFILIATION: MNDNR Ecological Resources - SNA
MAILING ADDRESS: 500 Lafayette Rd Box 25
CITY/STATE/ZIP: Saint Paul, MN 55155
PHONE: 651-259-5130
FAX: 651-296-1811
E-MAIL: jason.garms@dnr.state.mn.us
WEBSITE: www.dnr.state.mn.us
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: $220,000 is from the trust fund to the commissioner of natural resources to develop stewardship plans and implement prairie management on private prairie lands on a cost-share basis with private or federal funds.

APPROPRIATION AMOUNT: $220,000

Overall Project Outcome and Results

This project provided voluntary, long-range conservation planning and management assistance to private landowners with native prairie. Native prairie is Minnesota's most threatened natural habitat. Less than 1% of the state's native prairie survives — and most of this is on private land. This project provided native prairie landowners with stewardship plans that inventoried and evaluated native prairie and other land resources on their property, identified the landowner's goals and objectives, and recommended ecologically sound management strategies. A total of 25 Prairie Stewardship Plans were created with this project's funds. Landowners were also given an opportunity to participate in 3 different workshops and field days where they could learn more about appreciating and managing their prairies. Furthermore, this project helped landowners with existing stewardship plans to implement their plans by providing cost-share assistance for management practices. Examples of practices cost-shared include prescribed burning (349 acre completed), invasive species treatments (65 acres completed), prairie reconstruction (33 acres completed), and woody encroachment removal (273 acres completed).

Project Results Use and Dissemination

Copies of Stewardship Plans are provided to local DNR managers and used by the landowner with other agencies and programs.

Trust Fund 2007 Work Program Final Report

Date of Report: August 17, 2009
Trust Fund 2007 Work Program Final Report
Date of Work program Approval: June 5, 2007
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Prairie Stewardship Assistance for Private Landowners (4d)

Project Manager: Jason Garms
Affiliation: DNR Ecological Resources, Scientific and Natural Areas Program
Mailing Address: 500 Lafayette Rd Box 25
City / State / Zip: Saint Paul, MN 55155
Telephone Number: 651-259-5130
E-mail Address: jason.garms@dnr.state.mn.us
FAX Number: 651-296-1811
Web Page address: www.dnr.state.mn.us

Location: The 'prairie' portions of Minnesota. This includes: Tallgrass Aspen Parkland, Prairie Parkland, and portions of the Eastern Broadleaf Forest ECS Provinces (map attached)

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$ 220,000**
	Minus Amount Spent:	**$ 216,423**
	Equal Balance:	**$ 3,577**

Legal Citation: ML 2007, Chap. 30, Sec.2, Subd.4(d).

Appropriation Language: $220,000 is from the trust fund to the commissioner of natural resources to develop stewardship plans and implement prairie management on private prairie lands on a cost-share basis with private or federal funds.

II. AND III. FINAL PROJECT SUMMARY:
This project provided voluntary, long-range conservation planning and management assistance to private landowners with native prairie. Native prairie is Minnesota's most threatened natural habitat. Less than 1% of the state's native prairie survives — and most of this is on private land. This project provided native prairie landowners with stewardship plans that inventoried and evaluated native prairie and other land resources on their property, identified the landowner's goals and objectives, and recommended ecologically sound management strategies. A total of 25 Prairie Stewardship Plans were created with this project's funds. Landowners were also given an opportunity to participate in 3 different workshops and field days where they could learn more about appreciating and managing their prairies. Furthermore, this project helped landowners with existing stewardship plans to implement their plans by providing cost-share assistance for management practices. Examples of practices cost-shared include prescribed burning (349 acre completed), invasive

species treatments (65 acres completed), prairie reconstruction (33 acres completed), and woody encroachment removal (273 acres completed).

IV. OUTLINE OF PROJECT RESULTS*:*

This project provides voluntary, long-range conservation planning and management assistance to private landowners with native prairie. Trust Fund dollars will leverage additional funding from the Landowner Incentive Program (LIP), a federal program, which assists states working with private landowners to benefit habitat for “at-risk species”.

<u>Need</u>: Native prairie is Minnesota’s most threatened natural habitat. Less than 1% of the state’s ‘old growth’ prairie survives — *and most of this is on private land (100,000+ acres)*. The condition of these sites is frequently deteriorated due to encroachment by woody species, competition from non-native plants, and lack of fire. Many have not received active management for over 50 years. There are an estimated 3000 private landowners with native prairie. To date, 72 landowners (6054 ac) have enrolled in the Prairie Bank easement program, 79 have LIP agreements for habitat enhancement, and 443 (17,593 ac) are in the MN Prairie Tax Exemption program. When approached, they are almost always interested in improving the stewardship of their native prairie remnant, but often lack the expertise or resources to address this growing backlog of management needs. While prairies on public land also need accelerated management, this project is the only source of assistance directed specifically to private landowners with native prairie.

Result 1: Prairie Stewardship Planning and Education

Description: Trust Fund and LIP funding will result in technical assistance and stewardship plans for approximately 25 landowners within the prairie region of the state covering an estimated 2000 acres of private land. DNR prairie specialists and qualified private-sector prairie professionals who competitively bid their services will assist landowners complete a prairie stewardship plan. Together the landowner and natural resource professional will prepare a plan that inventories and evaluates native prairie and other land resources on the property, identifies landowner goals and objectives, and recommends ecologically sound management strategies. Landowners are also provided information about federal, state, and non-government programs available to assist them in protecting and managing their prairie.
In addition, 1-2 workshops/field days on practices such as managing native prairie pastures, prairie restorations, and/or other topics will be developed for targeted groups of landowners. These will be designed and hosted with partners such as the MN Dept of Agriculture, Sustainable Farming Association of MN, Working Lands projects, etc.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$ 65,000**
	Amount Spent:	**$ 63,197**
	Balance:	**$ 1,803**

Deliverable	Completion Date	Budget	Status
1. 2 Workshops/field days developed for landowners	50% by June, 2008; and 100% by June 30, 2009	$3,000	3 workshops completed
2. Stewardship plans provided to 25 landowners	25% will be completed by January 30, 2008; 50% by June, 2008; 75% by January 30, 2009, and 100% by June 30, 2009	$62,000	25 plans written

Result 1 Final Report Summary:
With ETF funds: Competitive contracts were awarded to 2 professional consultants who completed 24 prairie stewardship plans (listed below). Staff from the DNR's Scientific and Natural Areas Program is also wrote one stewardship plan. DNR staff hosted a prescribed burn workshop (3/8/08) for private landowners – providing instruction on the ecological and operational principles of managing prairie with fire. DNR staff also participated in the MN Cattlemen's Association's summer grazing conference (7/15/08) and field tours - supplying materials and technical assistance related to sustainable grazing practices on native rangelands. A second private landowner prescribed workshop was held (4/4/09), but the demonstration burn scheduled for the same day was cancelled due to unfavorable weather conditions (the reason for unspent funds).

Prairie Stewardship Planning sites (PB = Native Prairie Bank easements)

Site Name	County	Site Name	County
1. Home Lake 28 PB	Norman	14. Hantho 25 PB	Lac Qui Parle
2 .Rogers PB	Clay	15. Minnesota Falls 3 PB	Yellow Medicine
3. Marsh Grove 36 PB	Marshall	16. Agassiz 23 PB	Lac Qui Parle
4. Spring Prairie 22	Clay	17. Otrey 26 PB	Big Stone
5. Bilden PB	Wilkin	18. Johnson PB	Big Stone
6. Nidaros 21 PB	Otter Tail	19. Norway Lake 5 PB	Kandiyohi
7. Lund 2 PB	Douglas	20. Moulton 10 PB	Murray
8. Wittwer	Pope	21. Moulton 11 PB	Murray
9. Woodke PB	Grant	22. Altona 31 PB	Pipestone
10. Olson PB	Grant	23. Linden 6 PB	Brown
11. Lund 21 PB	Douglas	24. Storden 4-1 PB	Cottonwood
12. Walls 18 PB	Traverse	25. Fredin	Cottonwood
13. Johnsonville 30 PB	Redwood		

Result 2: Prairie Management Practices

Description: Trust Fund and LIP funding will result in habitat improvement on approximately 1500 acres with 50 landowners. Landowners can request financial assistance for management practices they implement themselves, or have DNR prairie staff carry out practices they do not feel qualified to do. In many cases, DNR will package groups of projects, such as prescribed burns, into larger contracts for professional vendors to competitively bid on — maximizing efficiencies and minimizing costs for landowners.

Summary Budget Information for Result 2: **Trust Fund Budget: $ 155,000**
Amount Spent: $ 153,226
Balance: $ 1,774

Deliverable	Completion Date	Budget	Status
1. Habitat improvement on approximately 1500 acres with 50 landowners	25% will be completed by January 30, 2008; 50% by June, 2008; 75% by January 30, 2009, and 100% by June 30, 2009	$155,000	

Result 2 Final Report Summary:
With ETF funds: Plans and firebreaks were developed for 15 prescribed burns, with 14 burns being completed in 349 acres. Invasive species treats were applied to 8 different project sites for a total of 65 acres. Treatments included Leafy Spurge and Purple Crown Vetch control with both targeted chemical applications and bio-control agents. While the actual areas that received invasive species treatments is 68 acres, the total surrounding area benefitted is much greater. Woody encroachment removal projects were completed on 12 projects for a total of 273 acres cut and 1100 acres benefitted. A total of 9 prairie reconstruction practices were completed on 3 project sites. Reconstructions practices include seed harvesting, seed bed preparation, seed installation, and posting seeding weed treatments. The prairie reconstruction project sites total 33 acres.

V. TOTAL TRUST FUND PROJECT BUDGET:

<u>**Budget Item**</u>	
Staff or Contract Services: NR Specialists, NR Technicians, NR laborers	$90,000
Stewardship Plan Consultants	$50,000
Equipment: project supplies, vehicle fleet costs (e.g. ATV, Pick-up, ASV tracked vehicle)	$23,000
Development:	$0
Restoration: Landowner reimbursements; contracts for prescribed burning, prairie reconstructions, woody encroachment, etc	$57,000
Acquisition: *(perpetual Prairie Bank easements will be acquired with appropriated bonding funds)*	$0
TOTAL TRUST FUND PROJECT BUDGET:	**$220,000**

Explanation of Capital Expenditures Greater Than $3,500: none

Explanation of Personnel costs:

- Funds will be used to extend existing DNR seasonal crews or natural resource technicians and specialists undertaking projects in this work program. These positions are unclassified and classified (all AFSME employees must be classified as per contract).
- Only time spent on approved projects will be charged to these funds. Without these funds, none of the projects in this work program would be completed. They are an acceleration of related initiatives.
- To implement projects in the work program, specialized skills (prescribed burning, knowledge of sites and management implications) are often required. DNR employees with the training, experience and certifications required to do these specialized tasks are used to directly implement these projects, and work with landowners and contractors to design, direct and certify completion of projects they carry out.
- Contracts with outside vendors are used when possible, but contractors are not available for some projects.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

- Landowner Incentive Program: Faith Balch, Landowner Incentive Program Coordinator, DNR Ecological Services – *No LCCMR funding requested*
- DNR Area Wildlife Managers & Ecologists: Work with consultants on plans and landowners on project implementation – *No LCCMR funding requested*

B. Other Funds Proposed to be spent during the Project Period:

- **Landowners**: Landowners in total contribute 10% or more in cash or in-kind services on stewardship plan implementation.
- **Native Prairie Bank easements**: Approximately $950,000 in 2006 bonding funds will be spent during the project period to provide permanent protection to prairie on private land.

Budget Item	**LCCMR**	**Landowner In-kind**
Staff or Contract Services: NR Specialists, NR Technicians, NR laborers	$90,000	$0
Stewardship Plan Consultants	$50,000	$0
Equipment: project supplies, vehicle fleet costs (e.g. ATV, Pick-up, ASV tracked vehicle)	$23,000	$0
Development:	$0	$0
Restoration: Landowner reimbursements; contracts for prescribed burning, prairie reconstructions, woody encroachment, etc	$57,000	$12,000
Acquisition: *(perpetual Prairie Bank easements will be acquired with appropriated bonding funds)*	$0	$0
	$220,000	**$12,000**

C. Past Spending: This project continues the success of several previous Trust Fund projects, which provided prairie stewardship assistance for private landowners (1999, 2001, 2003, & 2005).

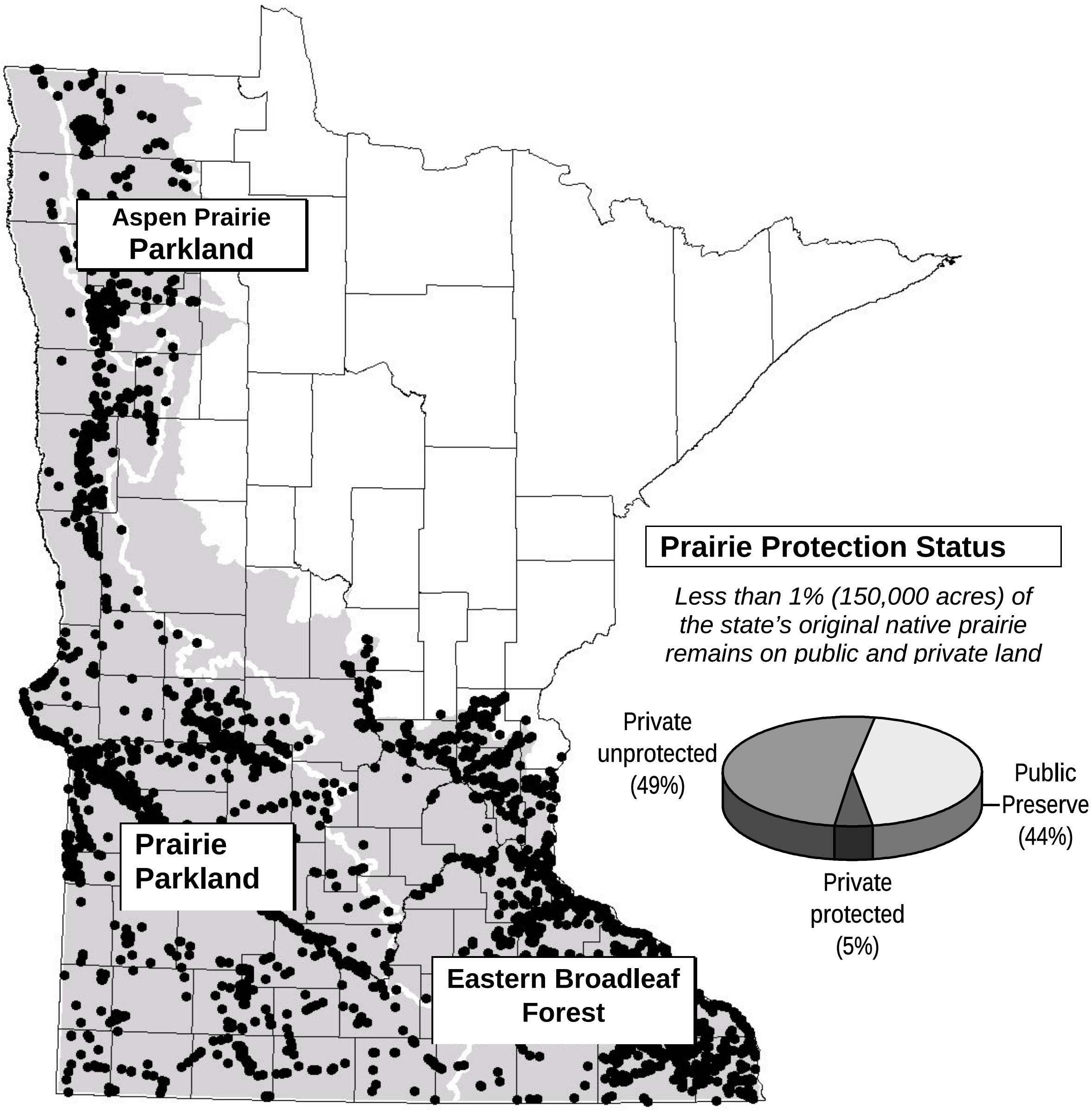
Funding Source	**FY06**	**FY07**
Landowner Incentive Program (federal funds)	$174,000	$150,000
Prairie Stewardship of Private Lands (5d)	$50,000	$50,000
Habitat Corridors Partnership (2k)	$23,000	$23,000
Prairie Management on Public and Private lands	*(pvt lands portion)*	*(pvt lands portion)*

D. Time: 2 years are needed to complete the project. 25% will be completed by January 30, 2008; 50% by June 30, 2008; 75% by January 30, 2009, and 100% by June 30, 2009.

VII. DISSEMINATION: Copies of Stewardship Plans are provided to local DNR managers and used by the landowner with other agencies and programs.

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than January 30, 2008, June 30, 2008, January 30, 2009, and June 30, 2009. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR.

IX. RESEARCH PROJECTS:



Known occurrences of 'old growth' native prairies and associated rare species in the Prairie Parkland, Aspen Parkland, and Eastern Broadleaf Forest ECS Provinces*.
Over 50% of these are on private land

Prepared by Peter Buesseler
Data source: DNR Natural Heritage Database
**Ecological Classification System Version 99A*

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: Prairie Stewardship Assistance for Private Landowners (Subd. 4d)

Project Manager Name: Jason Garms

Trust Fund Appropriation: $220,000

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 2 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Prairie Stewardship Planning and Education			Prairie Management Practices				
BUDGET ITEM								
PERSONNEL: wages and benefits (represents .5FTE/yr; NR specialist, DNR laborers)	12,000	11,319	681	78,000	78,000	0	90,000	681
Contracts			0	0		0	0	0
Professional/technical (Stewardship Plan Consultants)	50,000	50,000	0	0		0	50,000	0
Other contracts (contracts for prescribed burning, prairie reconstructions, woody encroachment, etc)			0	57,000	56,594	406	57,000	406
Equipment / Tools (project supplies, vehicle fleet costs (e.g. ATV, Pick-up, ASV tracked vehicle)	3,000	1,878	1,122	20,000	18,632	1,368	23,000	2,490
COLUMN TOTAL	**$65,000**	**$63,197**	**$1,803**	**$155,000**	**$153,226**	**$1,774**	**$220,000**	**$3,577**

2007 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: State Park and Trail Land Acquisition
PROJECT MANAGER: Larry Peterson (Parks) and Stan Linnell (Trails)
AFFILIATION: Department of Natural Resources, Division of Parks and Trails
MAILING ADDRESS: 500 Lafayette Road
CITY/STATE/ZIP: St. Paul, MN 55155
PHONE: Larry Peterson: 651-259-5593, Stan Linnell: 651-259-5626
E-MAIL: Larry.Peterson@state.mn.us and Stan.Linnell@state.mn.us
WEBSITE: www.dnr.state.mn.us
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, [Chap. 30], Sec.[2], Subd. 4e.

APPROPRIATION AMOUNT: $ 1,500,000

Overall Project Outcome and Results

Environment and Natural Resources Trust Fund funding allowed for the following State Parks and State Trails fee title land acquisition projects:

- Ownership of approximately 48 acres within the statutory boundary of William O'Brien State Park. Acquisition of this the land eliminated the potential for development on this parcel and its associated impacts to the park, and buffered the park from existing residential development in the area. This parcel added to the existing 1,580 acres already protected within William O'Brien State Park within a Metro Wildlife Corridors Project Area that follows the St. Croix River valley. Preservation of this upland parcel protects the water quality of the adjacent wetlands and sub-watershed leading to the St. Croix River. This parcel provides a route for the proposed Gateway State Trail extension.
- Ownership of approximately 87 acres within the statutory boundary of Frontenac State Park. This parcel consists of primarily wetlands adjacent to Wells Creek delta, a significant migratory waterfowl stopover. The property also includes about 400 feet of shoreline on Lake Pepin and supports many "species of concern" identified in the County Biological Survey. The site is also surrounded by park ownership and is located within a Metro Wildlife Corridors Project Area
- Ownership of 360 acres within the statutory boundary of George Crosby Manitou State Park. Acquisition of this parcel provided protection to one of the largest and highest quality old-growth northern hardwood forest complexes in the Lake Superior Highlands.
- Ownership of approximately 175 acres along the authorized Casey Jones State Trail corridor. Acquisition of this property secured a location for the future development of approximately one mile of trail corridor for the Casey Jones State Trail along Plum Creek, between Lake Shetek State Park and the community of Walnut Grove.

All acquisitions were from willing sellers, within the statutory boundaries of state parks and for statutory authorized state trails as determined by the Commissioner.

Trust Fund 2007 Final Report

Date of Report: October 22, 2010
Date of Work program Approval: June 5, 2007
Project Completion Date: April 30, 2010

I. PROJECT TITLE: State Parks and Trails Land Acquisition

Project Managers: Larry Peterson (Parks) and Stan Linnell (Trails)
Affiliation: Department of Natural Resources, Division of Parks and Trails
Mailing Address: 500 Lafayette Road
City / State / Zip: St. Paul, MN 55155
Telephone Number: Larry Peterson: 651-259-5593, Stan Linnell: 651-259-5626
E-mail Address: larry.Peterson@dnr.state.mn.us and stan.Linnell@dnr.state.mn.us
FAX Number: 651-296-6532 (Parks) 651-297-5475 (Trails and Waterways)
Web Page address: www.dnr.state.mn.us

Location: Acquisitions include, but not limited to, William O'Brien State Park and the Gateway State Trail near Marine on St. Croix (55047) in Washington County, Frontenac State Park near Frontenac (55026) in Goodhue County, George Crosby Manitou State Park near Little Marais (55614) in Lake County and Casey Jones State Trail near Walnut Grove (56180) in Murray County.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$ 1,500,000.00**
	Minus Amount Spent:	**$ 1,500,000.00**
	Equal Balance:	**$ -0-**

Legal Citation: ML 2007, [Chap.30], Sec.[2], Subd. 4e.

Appropriation Language: (e) State Park and Trail Land Acquisition: $1,500,000 is from the trust fund to the commissioner of natural resources to acquire land for state trails and in-holdings for state parks. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner.

II. PROJECT SUMMARY AND RESULTS: LCCMR funding allowed for the acquisition of approximately 48 acres located within the boundary of William O'Brien State Park that was listed for sale by a willing landowner. Adding this parcel provided up to a one-mile connection of the Gateway Trail and reduced the impacts of the development that would otherwise have occurred on the property. The acquisition funding also made it possible to acquire approximately 87 acres at Frontenac State Park. This land is primarily wetland adjacent to Wells Creek delta and preserves 400 feet of Lake Pepin/Mississippi River frontage. This funding also acquired approximately 100 acres at George Crosby Manitou State Park. Acquisition of this parcel provided protection to one of the largest and highest quality old-growth northern hardwood forest complexes in the

Lake Superior Highlands. The acquisition funding also provided the opportunity to acquire approximately 175 acres along the Casey Jones State Trail corridor, providing for the future development of up to one mile of new recreational trail.

III. FINAL REPORT SUMMARY:

In September 2007**,** acquisitions were initiated for 48 acres within William O'Brien State Park and 87 acres at Frontenac State Park. In December 2007, the acquisition of approximately 100 acres at George Crosby Manitou State Park was initiated. The George Crosby Manitou acquisition funding was matched by a Coastal Zone Management land acquisition grant. The acquisition of 175 acres along the Casey Jones State Trail corridor was initiated by December 2007.

In April 2008, an offer was made and accepted for 87 acres within Frontenac State Park with an anticipated completion due June 2008. An offer for 48 acres at William O'Brien State Park was made June 2008. An offer on 360 acres at George Crosby Manitou was made in May 2008. A $100,000 land acquisition grant from Coastal Zone Management was awarded and will supplement this acquisition. The acquisition of 175 acres along the Casey Jones State Trail corridor was appraised and with an expected completion date of June 2008.

In September 2008, the acquisition of 87 acres within Frontenac State Park and 360 acres within George Crosby Manitou State Park were completed. Title review was performed with an anticipated completion date of December 2008 for the acquisition of 48 acres at William O'Brien State Park. The acquisition of 175 acres along the Casey Jones State Trail corridor was appraised and started the negotiation process.

In November 2008, the 48 acres acquisition at William O'Brien State Park was acquired. On February 23, 2009, the 175 acre acquisition along the Casey Jones State Trail corridor was optioned. The State's commitment to purchase (called Notice of Election to Purchase) as anticipated to be completed by mid-June. Work program amendments were requested for Result 1 and Result 4 due to budget shifting.

In November 2009, the DNR clarified the facts surrounding the Casey Jones State Trail corridor agreement and subsequent legal opinion from our legal counsel regarding the State's binding effect of an option agreement. The 175 acre acquisition along the Casey Jones State Trail corridor was optioned on February 23, 2009. The option agreement for the acquisition is a binding contract. Paragraph 12 of the executed option agreement reads as follows:

> "BINDING EFFECT. This option becomes effective when signed by all of the Sellers and shall then apply to and bind each of the Sellers and their heirs, executors, administrators, successors, and assigns."

The Option Contract for the Casey Jones acquisition is in effect for nine months from February 23, 2009. As provided for under Minn. Stat., sec. 84.0274, subd. 6(d), the

Option Agreement is for nine months due to the requirement for a formal boundary survey. The remaining balance of $381,217.60 was encumbered to this project on March 6, 2009 following acceptance of the Option. The property survey was completed and the Notice of Election to Purchase was issued on July 13, 2009.

Under the terms of a sale to the State/DNR the seller must provide the State marketable title to the property. To determine if the specific title is marketable, the Attorney General's office must review an up-to-date title abstract. In the approximately 5 months since the Notice of Election to Purchase there was a series of delays in obtaining an abstract of title from the seller as a result of a charitable trust. The Abstract for the property was received from the Trustee for the charitable trust on November 13, 2009 and the required update was expected from the local abstract company in December 2009. When marketable title was established, the anticipated closing was prior to April 1, 2010. The DNR closed the transaction and obtained marketable title fee title interest on the Casey Jones State Trail corridor on March 26, 2010.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Ownership of approximately 48 acres within the statutory boundary of William O'Brien State Park.

Description: The Department of Natural Resources, Division of Parks and Recreation and Division of Trails and Waterways will appraise, negotiate and acquire this parcel. Acquiring the land will eliminate the potential for development on this parcel and its associated impacts to the park, and buffer the park from existing residential development in the area*.* This parcel will add to the 1,580 acres already protected within William O'Brien State Park within a Metro Wildlife Corridors Project Area that follows the St. Croix River valley*.* Preserving this upland parcel will protect the water quality of the adjacent wetlands and sub-watershed leading to the St. Croix River. This parcel will also provide a route for the proposed Gateway State Trail extension.

Summary Budget Information for Result 1:

Trust Fund Budget:	**$617,669.40**
Amount Spent:	**$617,669.40**
Balance:	**$ -0-**

Deliverable	Completion Date	Budget	Status
1. 48 Acres Acquired	**November 2008**	**617,669.40**	**Completed**

Final Report Summary: This acquisition was completed on November 24, 2008.

The acquisition was initiated by September 2007 and an appraisal was performed in April 2008. In September 2008, funds in the amount of $101,000 were requested to be re-allocated to the remaining three projects within this work program as a result of lower than the budget allocation estimate of $750,000. The appraised value also came in less than projected. And, due to a bargain sale, $20,000 of RIM funds were utilized towards this acquisition. The remaining funds in the amount of$31,217.60 were not needed for this project and were approved to be re-allocated to Result 4, Casey Jones State Trail.

Result 2: Ownership of approximately 87 acres within the statutory boundary of Frontenac State Park.

Description: The Department of Natural Resources, Division of Parks and Recreation will appraise, negotiate and acquire this parcel. This parcel consists of primarily wetlands adjacent to Wells Creek delta, a significant migratory waterfowl stopover. The site includes about 400 feet of shoreline on Lake Pepin and supports many "species of concern" identified in the County Biological Survey. The site is also surrounded by park ownership. This parcel and all of Frontenac State Park are within a Metro Wildlife Corridors Project Area.

Summary Budget Information for Result 2:

Trust Fund Budget:	**$397,272.00**
Amount Spent:	**$397,272.00**
Balance:	**$ -0-**

Deliverable	Completion Date	Budget	Status
1. 87 acres acquired	**May 1, 2008**	**$397,272.00**	**Completed**

Final Report Summary: This acquisition was completed on May 1, 2008.

The acquisition was initiated by September 2007. An appraisal was performed, and offer was made and accepted in April 2008. This project's appraised value and administrative costs were $57,272, higher than expected. We utilized extra funds from the William O'Brien SPK project to make up this difference.

Result 3: Ownership of 360 acres within the statutory boundary of George Crosby Manitou State Park.

Description: Acquisition of this parcel will provide protection to one of the largest and highest quality old-growth northern hardwood forest complexes in the Lake Superior Highlands.

Summary Budget Information for Result 1:

Trust Fund Budget:	**$103,841.00**
Amount Spent:	**$103,841.00**
Balance:	**$ -0-**

Deliverable	Completion Date	Budget	Status
1. 360 acres acquired	**June, 2008**	**103,841.00**	**Completed**

Final Report Summary: This acquisition was completed on June 18, 2008.

The acquisition was initiated in December 2007. An appraisal was completed and a matching funds grant was approved in April 2008. The acquisition was completed on June 18, 2008. This project's appraised value and administrative costs were $3,841 higher than expected. Additional funds were utilized from the William O'Brien State Park project to make up this difference.

Result 4: Ownership of approximately 175 acres along the authorized Casey Jones State Trail corridor.

Description: The Department of Natural Resources, Division of Trails and Waterways has completed an appraisal for the referenced 175-acre property and will negotiate and acquire this parcel. Acquiring the property will secure a location for the future development of approximately one mile of trail corridor for the Casey Jones State Trail along Plum Creek, between Lake Shetek State Park and the community of Walnut Grove.

Summary Budget Information for Result 4:

Trust Fund Budget:	**$381,217.60**
Amount Spent:	**$381,217.60**
Balance:	**$ -0-**

Deliverable	**Completion Date**	**Budget**	**Status**
1. 175 Acres Acquired	**April, 2010**		

Final Report Summary: This acquisition was completed on March 26, 2010.

Discussions and negotiations with the landowner were initiated in July 2007 with ongoing discussions occurring throughout the year. An appraisal was completed in the summer of 2008. The offer was negotiated and funds in the amount of $39,887 were approved to be reallocated from the William O'Brien State Park for this acquisition project. The 175 acre acquisition along the Casey Jones State Trail corridor was optioned on February 23, 2009. The State's commitment to purchase, called Notice of Election to Purchase, was anticipated to be completed by mid-June. The Notice of Election to Purchase occurred on July 13, 2009. The Abstract of Title for the property was received from the property owner in Mid-November 2009. The $381,217.60 remaining balance was encumbered for this project on March 6, 2009 following state approval of the Purchase Option. This acquisition was completed on March 26, 2010.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: Appraisal Services and Professional Services from DNR, Division of Lands and Minerals and the Attorney General's Office
Equipment: None
Development: $ -0-

Restoration: $ -0-
Acquisition, including easements: 410 Acres, State of Minnesota (DNR)

TOTAL TRUST FUND PROJECT BUDGET: $1,500,000.00

Explanation of Capital Expenditures Greater Than $3,500:

VI. OTHER FUNDS & PARTNERS:

A. **Project Partners**: Local state park support groups and the Parks and Trails Council of Minnesota. Project partners will only receive market value of project sites in their ownership. Project partner may receive up to $1500 reimbursement for appraisal costs.

B. Other Funds Proposed to be Spent during the Project Period: Bonding 2006 funds; RIM Match funds when appropriate; Coastal Zone Management (CZM) Program is providing a $100,000 matching grant for an acquisition at George Crosby Manitou State Park.

C. Past Spending:

Land Acquisition for the previous Division of Parks and Recreation

M.L. 2005 $2,000,000
M.L. 2003 $1,500,000
M.L. 2001 $1,726,000
M.L. 1999 $ 500,000
M.L. 1998 $2,250,000
M.L. 1997 $2,500,000
M.L. 1995 $2,190,000
M.L. 1993 $1,000,000

Land Acquisition for the previous Division of Trails and Waterways (State Trails)

State Trail property acquisition efforts have been supported by legislative appropriations through Capital Bonding, Dedicated User Accounts, the General Fund, the Legislative Commission of Minnesota Resources and Federal appropriations through the Federal Highway Administration.

D. Time: To be acquired by June 30, 2009

VII. DISSEMINATION: *NA*

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports were submitted quarterly starting in September 2007 through June 2009. A final work program report and associated products were provided October 12, 2010.

IX. RESEARCH PROJECTS: NA

SEE ATTACHMENT A - LCMR 2007 Budget Detail

Attachment A: Budget Detail for 2007 Projects - **Summary and a Budget page for each partner (if applicable)**

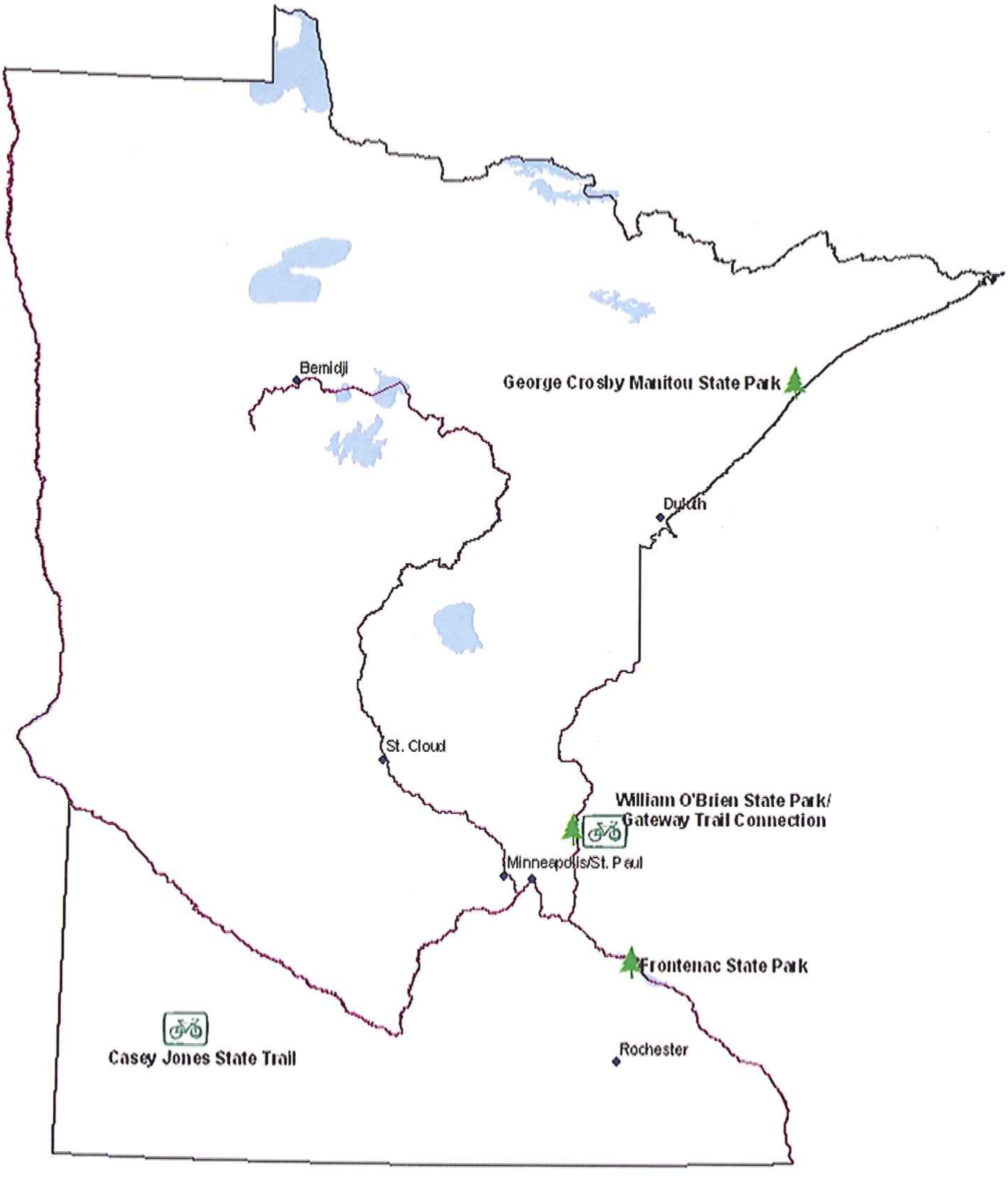
Project Title: State Park and Trail Land Acquisition

Project Manager Name: Larry Peterson and Ron Potter

Trust Fund Appropriation: $1,500,000.00

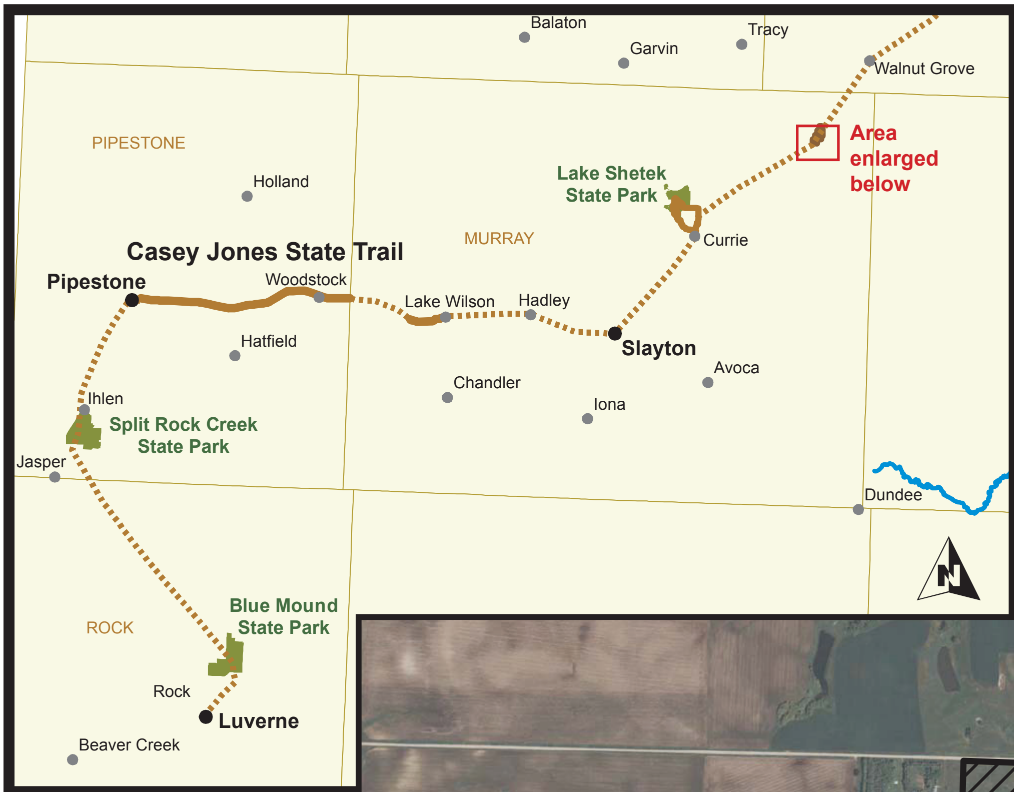
2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(date)*	**Balance** 10/22/10	**Result 2 Budget:**	**Amount Spent** *(date)*	**Balance** 10/22/10	**Result 3 Budget:**	**Amount Spent** *(date)*	**Balance** 10/22/10	**Result 4 Budget:**	**Amount Spent** *(date)*	**Balance** 10/22/10	**TOTAL BUDGET**	**TOTAL BALANCE**
	Ownership of 48 acres within William O'Brien State Park and Gateway State Trail			Ownership of 87 acres within Frontenac State Park			Ownerhsip of 100 acres within George Crosby Manitou State Park			Ownerhsip of 175 acrs for the Casey Jones State Trail				
BUDGET ITEM													1,500,000	1,500,000
Land acquisition	617,669	617,669	0	397,272	397,272	0	103,841	103,841	0	381,218	381,218	0	1,500,000	0
Professional Services for Acq. such as Appraisal, Survey, Title Work and Professional Services													0	0
COLUMN TOTAL	**$617,669**	**$617,669**	**$0**	**$397,272**	**$397,272**	**$0**	**$103,841**	**$103,841**	**$0**	**$381,218**	**$381,218**	**$0**	**$3,000,000**	**$1,500,000**

LCCMR 2007
State Park and Trail Land Acquisition



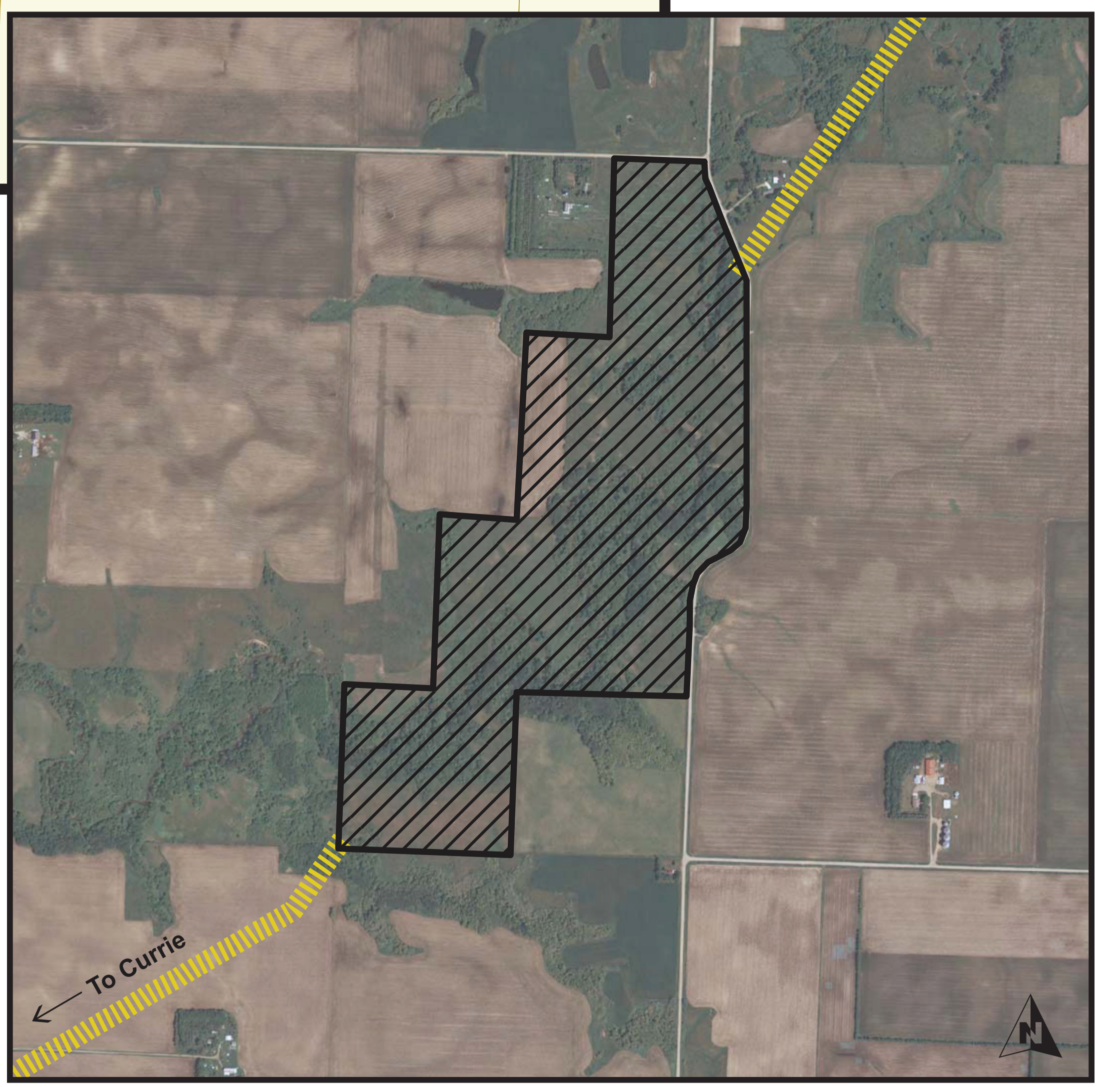
2007 LCCMR Acquired Property
State Trails Land Acquisition

Casey Jones State Trail Proposed Corridor



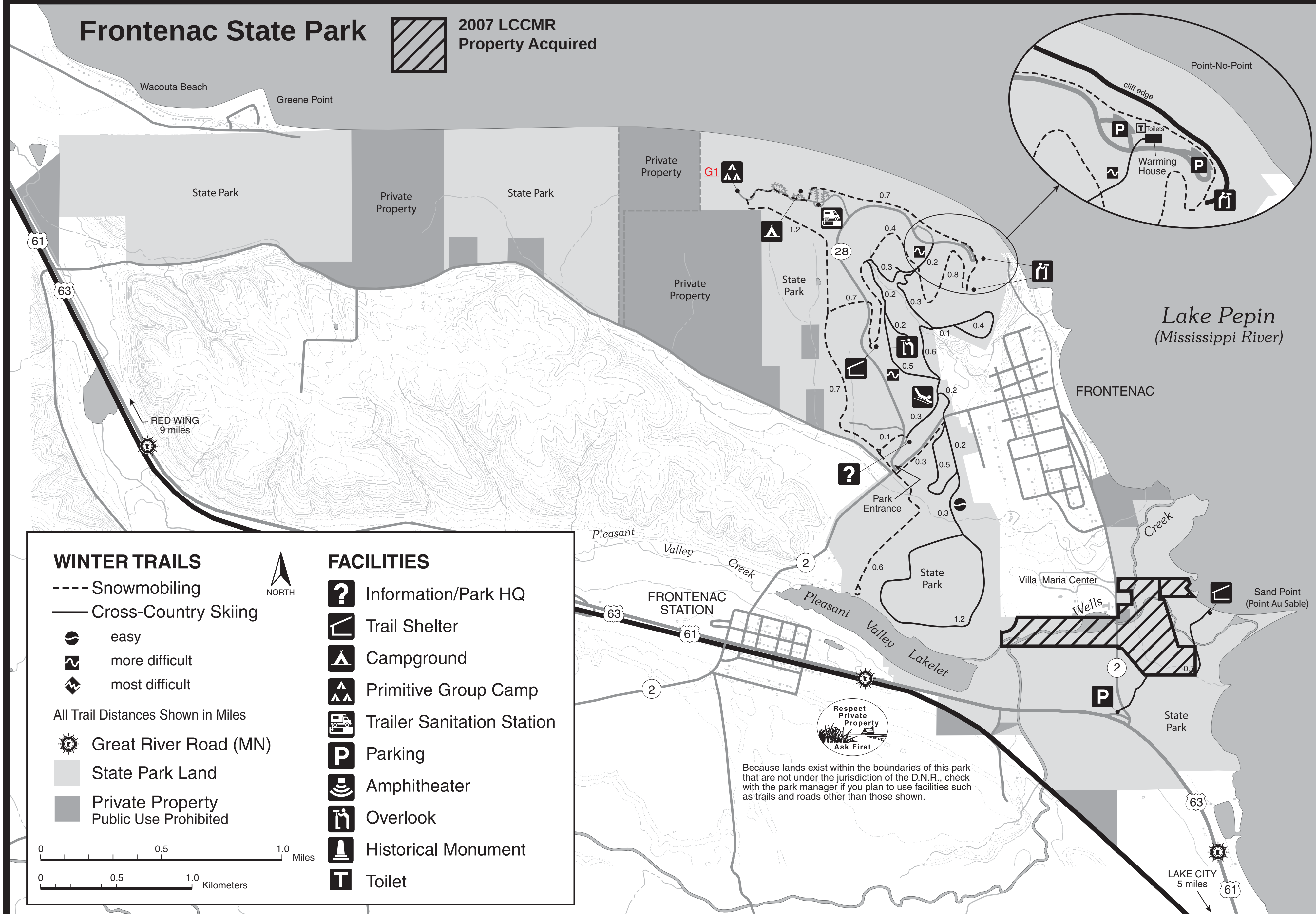
LEGEND

- Existing Trail
- Proposed Trail Corridor Legislatively Authorized
- 2007 LCCMR Property Acquired
- State Parks
- Area enlarged



Casey Jones State Trail Land Acquired and Proposed Corridor

2007 LCCMR Acquired Property
State Parks Land Acquisition



FRONTENAC STATE PARK
WINTER TRAILS

FOR MORE INFORMATION
Frontenac State Park
29223 County 28 Blvd.
Frontenac, MN 55026
1-651-345-3401

Department of Natural Resources
Information Center
500 Lafayette Road
St. Paul, MN 55155-4040

(651) 296-6157 (Metro Area)
1-888-646-6367 (Toll Free)

TDD (Telecommunications
Device for Deaf)
(651) 296-5484 (Metro Area)
1-800-657-3929 (Toll Free)

FRONTENAC STATE PARK is a 2,317-acre park located on U.S. Highway 61, ten miles southeast of Red Wing on the shore of Lake Pepin. Highway map index: M-18.

Many millions of years ago, most of Minnesota was covered by shallow seas. At the bottom of these seas, sediment accumulated and slowly hardened into rock. This rock now makes up the bluffs along the Mississippi River in southeastern Minnesota.

During the last million years, this ancient rock was shaped by the erosive power of water. Most of the landscape in the Frontenac area was carved by the Glacial River Warren. This powerful river flowed from the south end of Glacial Lake Aggasiz, a lake larger than all the Great Lakes combined. It covered much of northwestern Minnesota extending into North Dakota and Canada.

Glacial River Warren cut the large valley through which the Minnesota River now flows. In what is now eastern Minnesota it picked up increased force from the waters of the Upper Mississippi and the St. Croix Rivers and flowed southeast sculpting the Mississippi River Valley. When the river was at its peak, most of Frontenac was under water. The park's bluff was an island.

On the bluff below the park's picnic area is a stone quarry, inactive for more than 50 years. Time has softened the harshness of its vertical face with flowers growing in its crevices. For 100 years, the high-quality limestone from this and other quarries in the area was popular for building. In 1883 architects John LaFarge and George L. Heins chose limestone from this quarry to construct part of the Cathedral of St. John the Divine in New York City.

HISTORY: In 1976 the Minnesota Historical Society researched Frontenac's rich history through the excavation of archaeological sites.

The Havana Ridge Site dates from 400 B.C. to 300 A.D. and represents the northern edge of the Hopewellian culture. Some sites in the park were habitation sites and others served as burial grounds.

The Dakota and Fox Indians hunted and fished on the shores of Lake Pepin. In the park is a stretch of high ground covered by woods and meadows that was sacred to the Indians in the region. The focal point of the area was In-Yan-Teopa, a giant rock perched on the edge of the bluff overlooking Lake Pepin.

In 1680, Father Louis Hennepin led the first European exploration to this section of the Mississippi River.

In June 1727, an expedition left Montreal to set up a post in the land of the Dakota. From this post, explorers planned to go west in search of the best route to the Pacific Ocean.

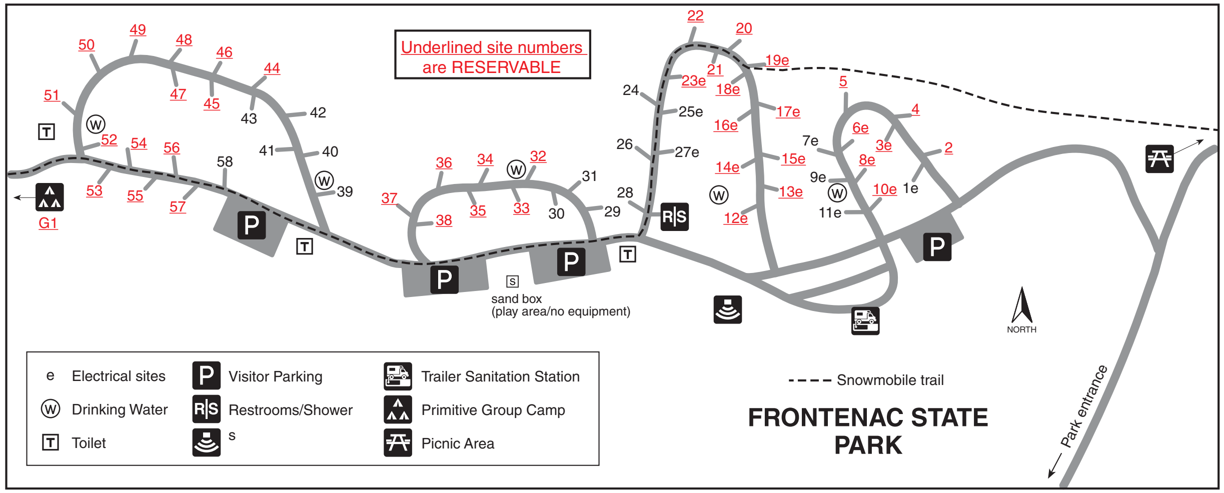
Rene Boucher and his men landed in the vicinity of the park on September 17, 1727. Within four days they had built a log stockade and named it Fort Beauharnois in honor of the Marquis de Beauharnois, governor general of New France (Canada).

In the fort, two Jesuit missionaries, Michel Guignas and Nicholas de Gonnor established what may have been Minnesota's first church, the Mission St. Michaels the Archangel.

In 1763, when the Treaty of Paris ended the Seven Year War, Great Britain became heir to France's claim to much of North America. This led to the abandonment of Fort Beauharnois. Field work has failed to uncover the exact location of the fort and chapel. All evidence of their location has vanished.

The first permanent pioneer resident in the area was a fur trader, James "Bully" Wells. By 1840, he had built a trading post and a home where the town of Frontenac now stands.

As the fur trade declined, logging increased. By the mid-1800's, most of the woodlands around the park had been cleared. Logging operations on the Upper Mississippi, St. Croix, and the Chippewa Rivers sent huge log rafts down the Mississippi to sawmills.
In 1854, Israel Garrard came to Frontenac to hunt. He was so impressed with the region that he decided not to return home.



Three years later, Evert Westervelt, a Dutch immigrant who had bought out the interests of Bully Wells, platted a 320-acre town with Israel Garrard. Originally, it was named Westervelt, but in 1859, when Israel Garrard bought out Evert Westervelt, he changed the name to Frontenac in honor of Comte de Pallusa et de Frontenac who served as governor of New France from 1671 to 1698. Governor Frontenac was responsible for many early exploration expeditions.

Israel Garrard recruited laborers and within a short time Frontenac was under construction. The Civil War interrupted the town's development. After the war, Israel Garrard returned as a general and brought with him skilled craftsmen from the south. They worked in the sawmill and the quarry and built the town's many buildings, including St. Hubert's Lodge (Israel Garrard's home named in honor of the patron saint of hunters), the Lake Side Hotel (a three-story, white-framed structure with double porch), and Christ Episcopal Church (which still has services every Sunday).

In the 1870s and '80s, Frontenac was in its heyday. During the steamboat days following the Civil War, Frontenac became one of the most fashionable summer resorts in the country. High society of New Orleans, St. Louis, and St. Paul came to stay at the Lake Side Hotel and to relish the peace and charm of Frontenac.

In 1870 the railroad came to southeastern Minnesota. As railroad traffic increased, steamboat travel decreased. Many towns up and down the river had hoped to become important trade centers, but as the use of the river waned so did the importance of the river towns. Old Frontenac remains a nostalgic reminder of Minnesota's past.

The history of the park dates back to 1935 when the National Park Service pointed out the potential of the area. Early attempts to establish a park failed. In 1954, a group of citizens formed the Frontenac Park Association. They felt the area should be set aside to preserve its natural beauty and historical significance. A bill was introduced in the 1955 state legislature, but because of funding priorities, it was not passed. When an important tract of land was put up for sale, the Frontenac Park Association raised funds for its purchase. Spurred by the commitment of the local people, the 1957 legislature established Frontenac State Park.

WILDLIFE: Since 1900 Frontenac has been recognized as an excellent place to watch bird migration. Most famous for its variety of warblers, the bottomland hardwood forest of Frontenac is one of the few areas in Minnesota that provides nesting habitat for the prothonotary warbler. Over 200 species of birds can be observed in the area every year, including two of the world's greatest travelers—the sanderling and the ruddy turnstone. These robin-sized waders travel from southern South America to the Arctic and back every year.

In winter, bald and golden eagles frequent the area. The United States Fish and Wildlife Service has re-introduced the peregrine falcon in the area.

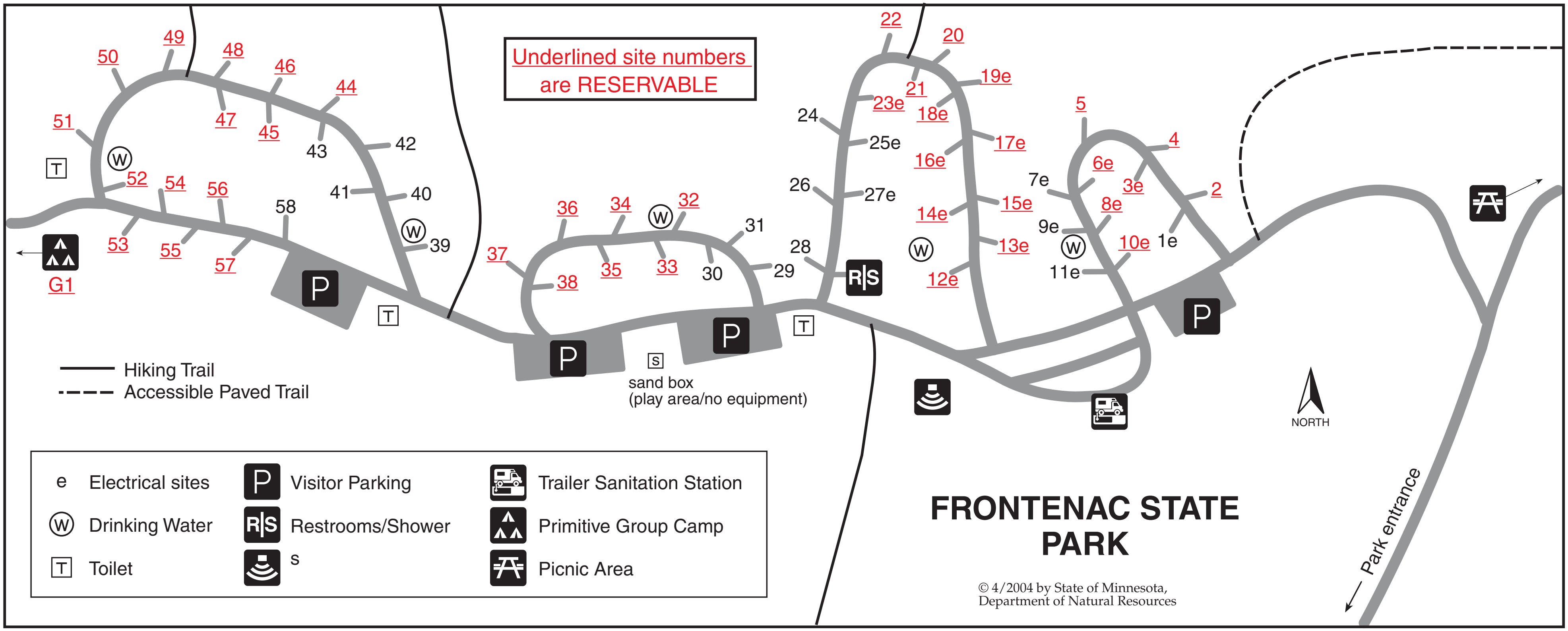
Of particular interest is the timber rattlesnake. It is not numerous and offers little or no threat to park visitors. If one should encounter a rattler on the trail, leave it alone! Do not attempt to capture or kill it. There is no danger unless it is frightened or provoked. All wildlife in state parks is protected by state law.

Lake Pepin contains a variety of fish—walleye, northern pike, crappie, bluegill, and channel catfish. Unfortunately, PCBs (poly-chloro-byphenols) have found their way into the lake's fish, particularly in carp. Human consumption of the lake's fish should be limited. Consumption guidelines are available at the park office.

SO EVERYONE CAN ENJOY THE PARK. . .

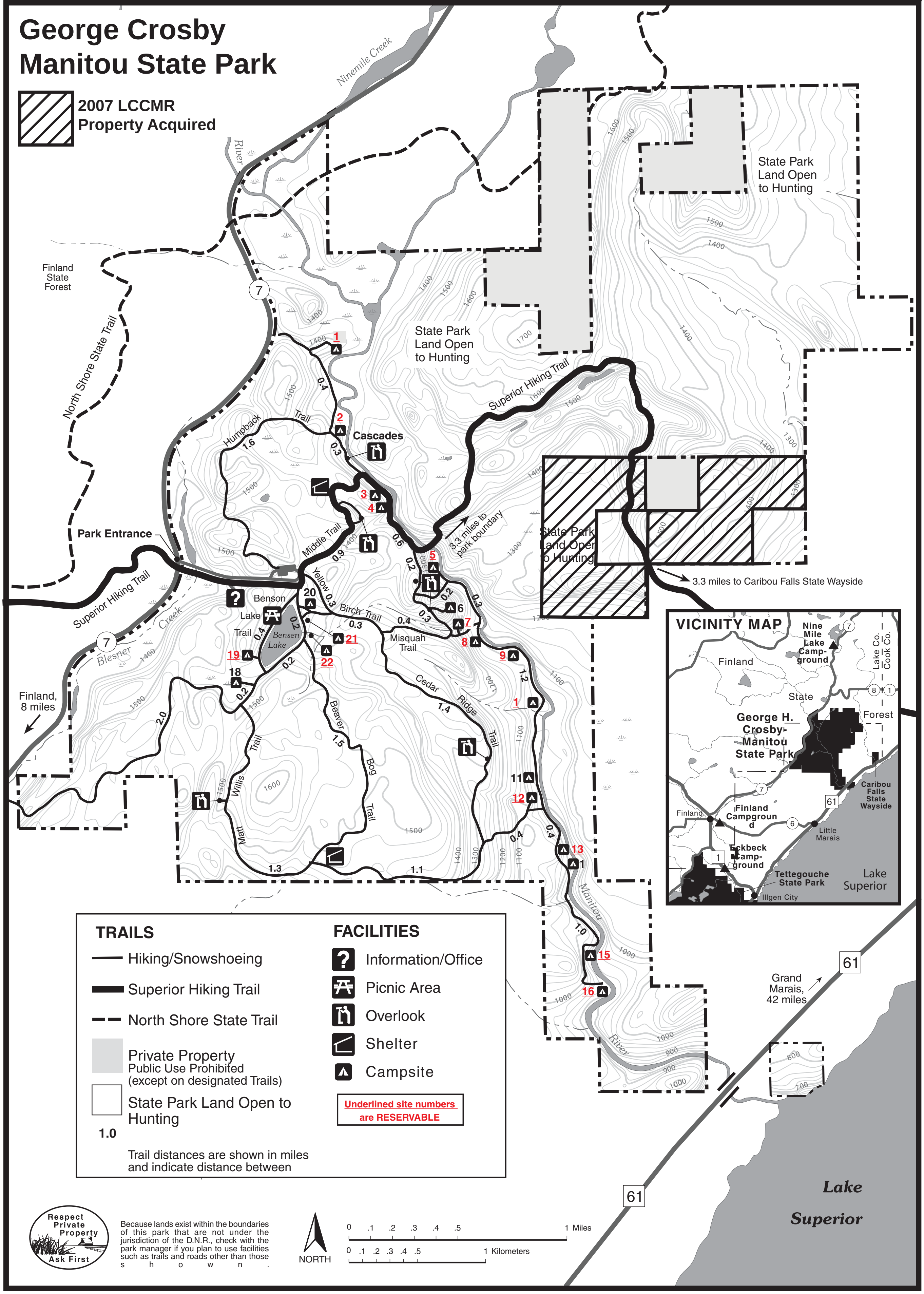
- The park belongs to all Minnesotans. Please treat it with respect and help us to protect it by following the rules.
- The park is open year-round. On a daily basis, the park is closed from 10:00 P.M. to 8:00 A.M. the following morning except to registered campers. Loud noises and other disturbances are not allowed after 10:00 P.M. in the campground.
- Camp only in designated locations.
- The use of firearms, explosives, air guns, slingshots, traps, seines, nets, bows and arrows, and all other weapons is prohibited in state parks.
- Pets must be restrained on a leash no longer than six feet. Pets are not allowed in park buildings.
- Park in designated areas only.
- Motor bikes and other licensed vehicles are allowed only on park roads, not on trails.
- Enjoy the park wildlife and plants, but please respect them. Do not pick or dig up plants, disturb or feed animals, or scavenge dead wood.
- Build fires in designated locations—fire rings or fireplaces. Wood is available for purchase from park staff. Portable stoves or grills are permitted.
- Daily or annual permits are required for all vehicles entering a state park. They may be purchased at the park headquarters or the Information Center in St. Paul (see "FOR MORE INFORMATION" to left).

Minnesota DEPARTMENT OF NATURAL RESOURCES
DNR Maps

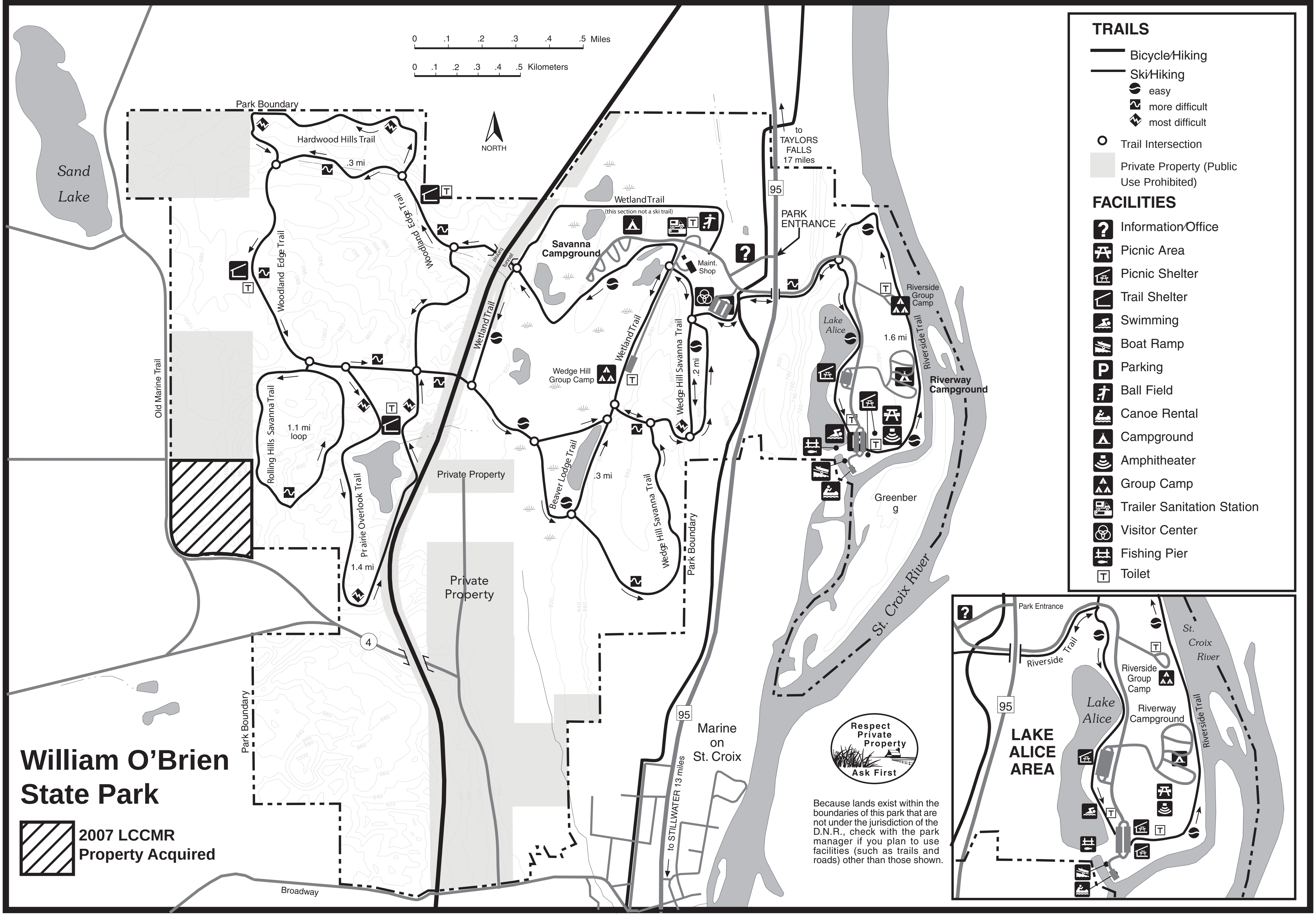


Note: This park ***may*** have RESERVABLE sites other than in the main campground.
See the main park map for the locations of any additional camping or lodging sites.

2007 LCCMR Acquired Property
State Parks Land Acquisition



2007 LCCMR Acquired Property
State Parks Land Acquisition



2007 Project Abstract
For the Period Ending October 22, 2008

PROJECT TITLE: Metropolitan Regional Park System Land Acquisition
PROJECT MANAGER: Arne Stefferud
AFFILIATION: Metropolitan Council
MAILING ADDRESS: 390 North Robert Street
CITY/STATE/ZIP: St. Paul, MN 55101
PHONE: 651-602-1360
FAX: 651-602-1467
E-MAIL: arne.stefferud@metc.state.mn.us
WEBSITE: www.metrocouncil.org
FUNDING SOURCE: Minnesota Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 4(f)

Overall Project Outcome and Results
This appropriation leveraged a total of $18.1 million of other funds to acquire 528 acres for the Metropolitan Regional Park System as follows:

- 61 acres on the southern shore of Cedar Lake for Cedar Lake Farm Regional Park in Scott County ($600,000 Environment Trust Funds, $400,000 Metro Council bonds and $3,526,192 of Scott County funds for a total of $4,526,192).
- 8.2 acres including shoreline on the Mississippi River for Grey Cloud Island Regional Park in Washington County ($109,256 Environment Trust Funds, $72,838 Metro Council bonds, and $273,141 Washington County funds for a total of $455,235).
- 3 acres including shoreline on Lake Waconia for Lake Waconia Regional Park in Carver County ($600,000 Environment Trust Funds, $400,000 Metro Council bonds and $1,530,000 Carver County funds for a total of $2,530,000)
- 456 acres which encompasses the entire park for Empire Wetlands Regional Park in Dakota County ($1,020,000 Environment Trust Funds, $680,000 Metro Council bonds, $800,000 other Metro Council grant approved in 2006, $6 million of 2006 State bonds, $3,444,000 of Dakota County funds for a total of $11,940,000)
- 47 acres including shoreline of St. Catherines Lake for Doyle-Kennefick Regional Park in Scott County ($170,744 Environment Trust Funds, $677,625 Metro Council bonds and $282,789 of FY 2009 Metro Greenways Grant for a total of $1,1131,158)

Project Results Use and Dissemination
Each regional park agency that received a grant or grants from this appropriation informs the public about the land acquisitionwith its own website and news releases. The Metropolitan Council also publishes a “Regional Parks Directory and Map” that informs the public about the recreation activities available at each regional park and trail and includes website addresses and phone numbers for each park agency for more information. Finally, the Metropolitan Council’s website includes an interactive parks map that contains the same information as the paper version of the “Regional Parks Directory and Map” at www.metrocouncil.org/parks/r-pk-map.htm

Trust Fund 2007 Work Program Final Report

Date of Final Report: October 22, 2008
Date of Work program Approval: June 20, 2007
Project Completion Date: June 30, 2010

I. PROJECT TITLE: Metropolitan Regional Park System Land Acquisition

Project Manager: Arne Stefferud
Affiliation: Metropolitan Council
Mailing Address: 390 North Robert Street
City / State / Zip: St. Paul, MN 55101
Telephone Number: 651-602-1360
E-mail Address: arne.stefferud@metc.state.mn.us
FAX Number: 651-602-1674
Web Page address: www.metrocouncil.org

Location: 7-county Twin Cities Metropolitan Area. See attached map titled "Result 1: Acquisition Opportunity Grants" for locations of where land could be acquired. Land within the master plan boundaries and land where the Metropolitan Council has approved a master plan for a park or trail search area could be acquired with this appropriation.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	**2,500,000**
	Minus Amount Spent (10/22/08):	**$**	**2,500,000**
	Equal Balance (10/22/08):	**$**	**0**

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 4(f).

Appropriation Language: $2,500,000 is from the trust fund to the Metropolitan Council for subgrants for the acquisition of lands within the approved park unit boundaries of the metropolitan regional park system. This appropriation may not be used for the purchase of residential structures. Subdivision 12 applies to grants awarded in the approved workprogram. This appropriation must be matched by at least 40 percent of nonstate money and must be committed by December 31, 2007, or the appropriation cancels. This appropriation is available until June 30, 2010, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II and III. FINAL PROJECT SUMMARY

This appropriation leveraged a total of $18.1 million of other funds to acquire 528 acres for the Metropolitan Regional Park System as follows:

- 61 acres on the southern shore of Cedar Lake for Cedar Lake Farm Regional Park in Scott County ($600,000 Environment Trust Funds, $400,000 Metro Council bonds and $3,526,192 of Scott County funds for a total of $4,526,192).

- 8.2 acres including shoreline on the Mississippi River for Grey Cloud Island Regional Park in Washington County ($109,256 Environment Trust Funds, $72,838 Metro Council bonds, and $273,141 Washington County funds for a total of $455,235).
- 3 acres including shoreline on Lake Waconia for Lake Waconia Regional Park in Carver County ($600,000 Environment Trust Funds, $400,000 Metro Council bonds and $1,530,000 Carver County funds for a total of $2,530,000)
- 456 acres which encompasses the entire park for Empire Wetlands Regional Park in Dakota County ($1,020,000 Environment Trust Funds, $680,000 Metro Council bonds, $800,000 other Metro Council grant approved in 2006, $6 million of 2006 State bonds, $3,444,000 of Dakota County funds for a total of $11,940,000)
- 47 acres including shoreline of St. Catherine's Lake for Doyle-Kennefick Regional Park in Scott County ($170,744 Environment Trust Funds, $677,625 Metro Council bonds and $282,789 of FY 2009 Metro Greenways Grant for a total of $1,1131,158)

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Acquisition Opportunity Fund Grants

Description: Awarded subgrants to regional park agencies to acquire land within approved regional park unit boundaries when acquisition CIP funds had been spent by that agency. 528 acres were acquired. Grants were awarded when land was available to purchase. Trust Funds financed 60% of each subgrant and Metropolitan Council bonds financed 40% of each subgrant. The Metropolitan Council determined the maximum amount a regional park implementing agency could receive from this appropriation. The premise for the subgrant limit to a park agency is that it provides at least partial funding for large scale acquisitions in several locations. The limit per park agency has the affect of leveraging additional money beyond the Trust Funds and Metro Council funds. Regional park implementing agencies have identified up to $28 million of land that could be acquired in the near future. Consequently limiting the amount an agency could receive from this appropriation and Council bond match is not a problem. The attached map illustrates the locations where land acquisition could have occured. The "search areas" are eligible for acquisition funding if the park agency also submits and the Metropolitan Council approves a land acquisition master plan for that park or trail search area concurrently with a request for an acquisition opportunity fund grant.

October 22, 2008 Final Summary Budget Information for Result 1:

Trust Fund Budget:	**$**2,500,000
Amount Spent (10/22/08):	$2,500,000
Balance (10/22/08):	**$** 0

#	Deliverables	Completion Date	Budget	Status
1	61 acres	October 10, 2007	$ 600,000	Grant closed
2	8 acres	November 2, 2007	$ 109,256	Grant closed
3	2.94 acres	June 2008	$ 600,000	Grant closed
4	456 acres	May 29, 2008	$1,020,000	Grant closed
5	47 acres	October 2008	$ 170,744	Grant closed

When the Metropolitan Council authorizes subgrants to regional park agencies to acquire land under this appropriation, a description of that land will be described as a “Deliverable”, along with the date it was acquired as the “Completion Date”, the amount of the appropriation spent on the land will be listed under “Budget”, and the status of the grant will be stated under “Status”. More detail on each acquisition, including the expenditure of the non-State match and related expenditures such as legal fees and property tax equivalency payments required to be paid on each acquisition is shown in Attachment A: Budget Detail.

Result Status as of March 21, 2007: Initial workprogram submittal.

Result Status as of October 22, 2008:
Deliverable 1: $600,000 of Trust Fund appropriation matched with $400,000 of Metropolitan Council bonds that partially financed acquisition of 61 acres including shoreline of Cedar Lake as part of Cedar Lake Farm Regional Park in Scott County. Scott County provided $3,526,192 to fill the gap needed to acquire this land.

Deliverable 2: $109,256 of Trust Fund appropriation matched with $72,838 of Metropolitan Council bonds that partially financed 8 acres including shoreline of the Mississippi River at Grey Cloud Island Regional Park in Washington County. Washington County provided $273,141 to fill the gap needed to acquire this land.

Deliverable 3: $600,000 of Trust Fund appropriation matched with $400,000 of Metropolitan Council bonds granted on Feb. 27, 2008 that partially financed acquisition of 2.94 acres including 215 feet of Lake Waconia shoreline as part of Lake Waconia Regional Park in Carver County. Carver County will provide up to $1,530,000 to fill the gap needed to acquire this land.

Deliverable 4: $1,020,000 of Trust Fund appropriation matched with $680,000 of Metropolitan Council bonds granted on April 23, 2008. It partially financed the acquisition of the 456 acre Empire Wetlands Regional Park in Dakota County. In addition to these funds the following amounts are being provided for this acquisition which will cost $11,940,000:

Dakota County up to $3,440,000
2006 State bond appropriation of $6 million
Metro Council grant SG-06-123 of $800,000

Deliverable 5: $170,744 of Trust Fund appropriation matched with $677,625 of Metropolitan Council bonds granted on June 25, 2008. It partially financed the acquisition of 47 acres including 3,500 feet of shoreline of St. Catherine’s Lake for Doyle-Kennefick Regional Park in Scott County. An FY 2009 Metro Greenways grant of $282,789 completed the funding for the acquisition’s $1,131,158 total cost.

V. TOTAL TRUST FUND PROJECT BUDGET: $2,500,000

Staff or Contract Services: $0. The non-State fund match will be used to finance staff or contract services related to acquiring the land financed with this appropriation.
Equipment: $ 0 not applicable
Development: $ 0 not applicable
Restoration: $ 0 not applicable
Acquisition, including easements: $ 2,500,000. 528 acres were acquired.

Explanation of Capital Expenditures Greater Than $3,500:
No capital expenditures will be financed with this appropriation.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

The following regional park implementing agencies are eligible to receive an Acquisition Opportunity Grant from this appropriation. The amount each agency actually receives is dependent on the amount needed for a particular subgrant and will be reported in future status reports in Attachment A:Budget Detail.

Regional Park Agency Contact	Regional Park Agency Name
John VondeLinde	Anoka County Parks Dept.
Randy Quale	City of Bloomington Parks Dept.
Marty Walsh	Carver County Parks Dept.
Steve Sullivan	Dakota County Parks Dept.
Mike Kimble	Minneapolis Park & Recreation Board
Greg Mack	Ramsey County Parks Dept.
Jody Martinez	City of St. Paul Parks Dept.
Mark Themig	Scott County Parks Dept.
Boe Carlson	Three Rivers Park District
John Elholm	Washington County Parks Dept.

B. Other Funds Proposed to be Spent during the Project Period:

$1,666,000 of Metropolitan Council bonds will be used as a match to the $2,500,000 Trust Funds. An accounting of the Council bonds along with its match to the Trust Funds appropriation is provided in Attachment A: Budget Detail for each acquisition subgrant when it was authorized by the Metropolitan Council.

C. Past Spending:

From 2001 to January 2007, the Metropolitan Council has authorized subgrants to regional park agencies financed with Metropolitan Council bonds to acquire land under its “Acquistion Opportunity Fund Grant” program. A total of 980 acres have been purchased with the grants, which totaled $5.3 million. The regional park agencies have provided $6.9 million, and other entities such as watershed districts have provided $6.2 million to partially finance these acquisitions. There have also been donations via sales at below market prices which have a value of $5.8 million.

D. Time:
All subgrants awarded with this appropriation will be authorized, and the land will be acquired between the time the appropriation goes into effect and June 30, 2010 unless the appropriation timeline is extended by future legislation.

VII. DISSEMINATION:
The Metropolitan Council will use its website www.metrocouncil.org to publish requests for subgrants financed with this appropriation as part of its consideration of those subgrant requests. The public may comment on those subgrant requests at meetings conducted by the Metropolitan Parks and Open Space Commission and the Metropolitan Council.

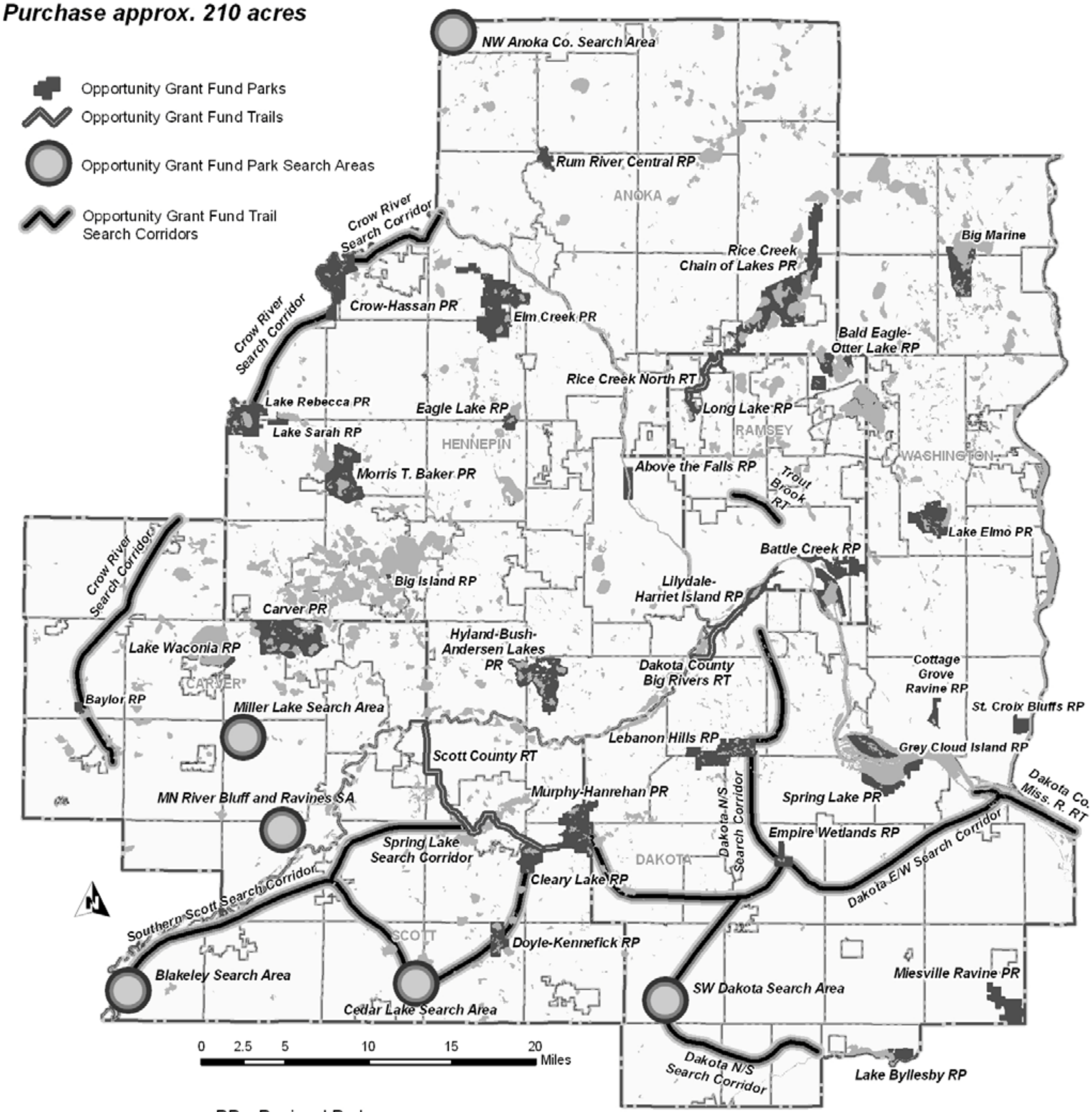
VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted in January 2008, July 2008, January 2009, July 2009, January 2010 and a final report in August 2010.

IX. RESEARCH PROJECTS: Not applicable.

Result 1: Acquisition Opportunity Grants

Land Acquisition Areas That Would Be Eligible for Acquisition Opportunity Grant Fund

$2.5 million Trust Funds
$1.6 million Met Council Bonds
Purchase approx. 210 acres



RP = Regional Park
PR = Park Reserve
RT = Regional Trail
Search Area = Proposed park location; boundary determined by master plan
Search Corridor = Proposed trail alignment; location determined by master plan

Metropolitan Council

Deliverable 1: Acquire 61 acres including shoreline of Cedar Lake as part of Cedar Lake Farm Regional Park in Scott County

Deliverable 2: Acquire 8 acres including shoreline of the Mississippi River at Grey Cloud Island Regional Park in Washington County

Deliverable 3: Acquire 2.94 acres including 215 feet of Lake Waconia shoreline as part of Lake Waconia Regional Park in Carver County

Deliverable 4: Acquire 456 acre Empire Wetlands Regional Park in Dakota County

Deliverable 5: Acquire 47 acres including 3,500 feet of shoreline of St. Catherine's Lake for Doyle-Kennefick Regional Park in Scott County

Attachment A: Budget Detail for 2007 Projects - **Summary and Budget Page**

Status Report Date: October 22, 2008

Project Title: Metropolitan Regional Park System Land Acquisition, 4(f)

Project Manager Name: Arne Stefferud

Trust Fund Appropriation: $2,500,000

1) See list of non-eligible expenses, do not include any of these items in your budget sheet
2) Remove any budget item lines not applicable

2007 Trust Fund Budget	Result 1 Budget:	Deliverable 1 amount spent (April 9, 2008)	Deliverable 2 amount spent (April 9, 2008)	Deliverable 3 amount spent (October 22, 2008)	Deliverable 4 amount spent (October 22, 2008)	Deliverable 5 amount spent (October 22, 2008)	TOTAL AMOUNT SPENT (October 22, 2008)	TOTAL BALANCE (October 22, 2008)
Trust Funds	$ 2,500,000	$ 600,000	$ 109,256	$ 600,000	$ 1,020,000	$ 170,744	$ 2,500,000	$ -
Metro Council bond match	$ 1,666,666	$ 400,000	$ 72,838	$ 400,000	$ 680,000	$ 113,828	$ 1,666,666	$ -
Total	$ 4,166,666	$ 1,000,000	$ 182,094	$ 1,000,000	$ 1,700,000	$ 284,572	$ 4,166,666	$ -
BUDGET ITEM								
Park agency recipient of subgrant and description of land acquired with subgrant (grant number, park unit name, acres acquired)		Scott County, Grant SG-2007-33, Cedar Lake Farm Regional Park, 61 acres	Washington County, Grant SG-2007-114, Grey Cloud Island Regional Park, 8.19 acres	Carver County, Grant SG-2008-013, Lake Waconia Regional Park, 2.94 acres	Dakota County, Amendment to Grant SG-2006-138, Empire Wetlands Regional Park, 456 acres	Scott County, Grant SG-2008-086, Doyle-Kennefick Regional Park, 47 acres	575.13 acres acquired	
Trust Fund used to partially finance subgrant for deliverable		$ 600,000	$ 109,256	$ 600,000	$ 1,020,000	$ 170,744		
Metro Council match to Trust Funds for that subgrant		$ 400,000	$ 72,838	$ 400,000	$ 680,000	$ 113,828		
Land acquisition (portion of purchase price)		$ 1,000,000	$ 182,094	$ 1,000,000	$ 1,700,000	$ 284,572		
Land rights acquisition *(less than fee)*		$ -	$ -	$ -	$ -	$ -		
Professional Services for Acq. (list legal fees for services related to acquiring the land, appraisal fees, and related fees for obtaining clear title)	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense
Payment in Lieu of Property Tax as required by State law	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense
Other land improvement for stewardship activities such as capping wells	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense	Subgrant not used for this expense
COLUMN TOTAL FOR RESULTS	**$ 4,166,666**	**$ 1,000,000**	**$ 182,094**	**$ 1,000,000**	**$ 1,700,000**	**$ 284,572**	**$ 4,166,666**	**$ -**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Nonmetropolitan Regional Parks and Natural and Scenic Area Acquisitions
PROJECT MANAGER: Wayne Sames
AFFILIATION: Department of Natural Resources
MAILING ADDRESS: OMBS, Box 10, 500 Lafayette Road
CITY/STATE/ZIP: St. Paul, MN 55155-4010
PHONE: (651) 259-5559
FAX: (651) 296-6047
E-MAIL: wayne.sames@state.mn.us
WEBSITE: www.dnr.state.mn.us
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 2(g)

APPROPRIATION AMOUNT: $1,000,000

Overall Project Outcome and Results

These programs provide competitive state matching grants to help and encourage local governments to acquire non-metropolitan regional parks and natural areas to meet current and future needs. For the regional park project, every $3 of state grants was matched with $2 of local funds. For the natural and scenic area projects, every dollar of state grants was matched by a dollar of local funds. Three acquisition grants were completed: one Regional Park Grant and two Natural And Scenic Area Grant. The total acreage acquired through all three projects was 310 acres. Approximately one mile of lake shore line was protected.

Regional Park Grant: One Regional Park Grant totaling $548,000 was made to Stearns County for the acquisition of 265 acres for a new regional park on Kraemer Lake near St. Joseph. Acquisition of this land provides the only publicly owned access to the lake. Much of the property was identified by the County Biological Survey as a significant native plant community. This land, part of the Avon Hills area, was acquired by the county in November, 2007.

Scenic and Natural Area Grant: Two grants were made for natural and scenic areas. In November 2007 the City of Prior Lake acquired 30 acres on Pike Lake for a new city park and natural area with a state grant of $230,000. This acquisition protects one of the largest remaining areas of undeveloped shoreline in the city. In 2008 the City of Red Wing acquired 15 acres for an addition to an existing 72 acre Bluff Land Conservation Area with a state grant of $156,000.

The remaining $66,000 covered DNR administrative/personnel costs for the program.

Project Results, Use and Dissemination

Profiles and photos of these projects are available on the DNR web site at www.mndnr.gov. Click on “Grants” and then “Land Conservation” to find the links to the Regional Park Grants and Natural and Scenic Areas programs. Click on “Park Profiles” or “Project Profiles”. Then go to the individual project profiles for a photo of the site, brief summary and links to local web pages.

Trust Fund 2007 Work Program Final Report

Date of Report: August, 2008
Trust Fund 2007 Work Program Final Report
Date of Work program Approval: June 5, 2007
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Nonmetropolitan Regional Parks and Natural and Scenic Area Acquisitions

Project Manager: Wayne Sames
Affiliation: Department of Natural Resources
Mailing Address: OMBS, Box 10, 500 Lafayette Road
City / State / Zip : St. Paul, MN 55155-4010
Telephone Number: (651) 259-5559
E-mail Address: wayne.sames@state.mn.us
FAX Number: (651)296-6047
Web Page address: http://www.dnr.state.mn.us

Location: Natural and Scenic Area grants are available statewide. Regional Park Grants are available for eligible regional park projects outside the Twin Cities Metro Area. Projects will be in various locations throughout the state.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$1,000,000**
	Minus Amount Spent:	**$1,000,000**
	Equal Balance:	**$0**

Legal Citation: ML 2007, Chap. 30, Sec. 2 , Subd. 2(g)

Appropriation Language: "$1,000,000 is from the trust fund to the commissioner of natural resources to provide matching grants to local governments for acquisition of natural and scenic areas, as provided in Minnesota Statutes, section 85.019, subdivision 4a, and regional parks outside of the metropolitan area, as defined in Minnesota Statutes, section 473.121, subdivision 2. The local match required for a grant to acquire a regional park or regional outdoor recreation area is $2 of nonstate money for each $3 of state money. For the purposes of this paragraph, the match may be either cash or a qualifying land donation. Recipients may receive funding for more than one project in any given grant period. Subdivision 12 applies to grants awarded in the approved work program."

II. and III. FINAL PROJECT SUMMARY:

<u>Overall Project Outcome and Results</u>
These programs provide competitive state matching grants to help and encourage local governments to acquire non-metropolitan regional parks and natural areas to

meet current and future needs. For the regional park project, every $3 of state grants was matched with $2 of local funds. For the natural and scenic area projects, every dollar of state grants was matched by a dollar of local funds. Three acquisition grants were completed: one Regional Park Grant and two Natural And Scenic Area Grant. The total acreage acquired through all three projects was 310 acres. Approximately one mile of lake shore line was protected.

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Project Results, Use and Dissemination

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IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Nonmetropolitan Regional Parks

Description: One grant of $548,000 was made to Stearns County for acquisition of 265 acres for a new regional park on Kraemer Lake. The property was acquired in November 2007. About one-half mile of shore land was protected, along with a large area of woods that is identified by the County Biological Survey as a significant native plant community. The land is part of the Avon Hills area. The county match exceeded $1 million.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$548,000**
	Amount Spent:	**$548,000**
	Balance:	**$0**

Deliverable	Completion Date	Budget	Status
1. Grant to Stearns County for acquisition	November 2007	548,000	Done

of 265 acres for a new regional park on Kraemer Lake.

Completion Date: November 2007

Final Report Summary: See Description above.

Result 2: Natural and Scenic Areas

Description: Two grants were made for natural and scenic areas. In November 2007 the City of prior lake acquired 30 acres on Pike Lake for a new city park and natural area with a state grant of $230,000. This acquisition protects one of the largest remaining areas of undeveloped shoreline in the city, about one-half mile of frontage. In 2008 the City of Red Wing acquired 15 acres for an addition to an existing 72 acre Bluff Land Conservation Area with a state grant of $156,000. The local match for both projects exceeded the state contribution.

Summary Budget Information for Result 2: **Trust Fund Budget: $386,000**
Amount Spent: $386,000
Balance: $0

Deliverable	**Completion Date**	**Budget**	**Status**
1. Two grants for acquisition of 45 acres of natural and scenic areas in Prior Lake and Red Wing.	2008	$386,000	Done

Completion Date: 2008

Final Report Summary: See Description above.

Result 3: Administrative/Personnel Costs

Description: The requested funding was used to support personnel costs for administering the grant programs. Grants staff were involved in grant solicitation, evaluation and ranking, grant agreement management, project billings, project inspections, and compliance monitoring.

As shown in Attachment A, work program approval was requested for personnel expenses incurred by three DNR classified staff involved in administering these grant programs. Payment of classified staff with Trust Fund money did not result in supplanting of the regular budget. A cost coding system was used to document the hours spent by each staff person in administering the program. The total Full Time Equivalent (FTE) staff contribution was about 3/4 FTE over the biennium, or about 3/8 FTE per year.

Summary Budget Information for Result 3: **Trust Fund Budget: $66,000**
Amount Spent: $66,000
Balance: $0

Deliverable	Completion Date	Budget	Status
1. Solicitation/evaluation/ranking	June, 2008	20,000	Done
2. Grant agreements	Fall, 2007	10,000	Done
3. Reimbursements/closeouts	June, 2009	20,000	Done
4. Pre and post completion inspections	June, 2009	16,000	Done

Completion Date: June 2009

Final Report Summary: Se Description above.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $66,000
Equipment: $0
Development: $0
Restoration: $0
Acquisition: $934,000 (310 acres acquired; local government grant recipients hold the title to the land)

TOTAL TRUST FUND PROJECT BUDGET: $1,000,000

Explanation of Capital Expenditures Greater Than $3,500:

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: Partners were Stearns County and the cities of Prior lake and Red Wing. They provided match dollars as well as covering in-kind costs of appraisals, any required archeological/historical surveys, permits, etc. Appraisal and survey costs alone could total approximately 5,000-10,000 per project. They also assumed all ongoing operations and maintenance costs.

B. Other Funds Proposed to be Spent during the Project Period: The local government recipients provided a match well in excess of the required minimum of $751,333.

C. Past Spending: The 2005 Trust Fund appropriation for these two grant programs was $1.1 million. The local match exceeded $700,000. The 2006 bonding for these programs totaled $2 million and the 2006 federal Land and Water Conservation Fund dollars totaled over $260,000. The local match exceeded $1.9 million.

D. Time: The projects were completed within the authporized project period.

VII. DISSEMINATION: Information about completed projects is included in the respective grant program sections of the DNR web site at dnr.state.mn.us.

VIII. REPORTING REQUIREMENTS: Completed as required.

IX. RESEARCH PROJECTS:

2007 ETF Project Descriptions
OMB / Local Grants Unit

Year	Proj_#	Title - Recipient	Scope	Acres Acquired
2008	LW27-01378	**Pike Lake Nature Area** City of Prior Lake	Acquire two parcels totaling 30.14 acres with 2,790 feet of shoreline on Pike Lake in the City of Prior Lake in northern Scott County to protect and preserve habitat for native species of fish and wildlife and to provide natural resource-based outdoor recreation and nature study. This acquisition project adds to the existing 14-acre park owned by the City.	30.14
2008	NS08-001	**Billings-Tomfohr Blufflands** City of Red Wing	Acquisition of 15 acres of additional land in the Billings-Tomfohr Blufflands Conservation Area.	15
2008	RP08-001	**Kraemer Lake Regional Park** County of Stearns	Acquire fee title to approximately 262 acres of forested land with 3/4 miles of lake shore on Kraemer Lake near the city of St. Joseph, MN. 2005 ETF $500,000 2007 ETF $598,000	263
Total		3 Projects		308

\Attachment A: Budget Detail for 2007 Projects

Project Title: Nonmetropolitan Regional Parks and Natural and Scenic Areas ML 2007, Chap. 30, Sec. 2, Subd. 2(g)

Project Manager Name: Wayne Sames

Trust Fund Appropriation: $1,000,000

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent 8/2008	Balance 8/2008	Result 2 Budget:	Amount Spent 8/2008	Balance 8/2008	Result 3 Budget:	Amount Spent 8/2008	Balance 8/2008	TOTAL BUDGET	TOTAL BALANCE
	Regional Park Grants			Natural and Scenic Area Grants			Administrative Costs				
BUDGET ITEM											0
PERSONNEL: wages and benefits							66,000	66,000	0	66,000	0
Land acquisition	548,000	548,000	0	386,000	386,000	0			0	934,000	0
COLUMN TOTAL	**$548,000**	**$548,000**	**$0**	**$386,000**	**$386,000**	**$0**	**$66,000**	**$66,000**	**$0**	**$1,000,000**	**$0**

2007 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: LAWCON Federal Reimbursements
PROJECT MANAGER: Wayne Sames
AFFILIATION: MN Department of Natural Resources
MAILING ADDRESS: 500 Lafayette Road
CITY/STATE/ZIP: St. Paul, MN, 55155-4010
PHONE: (651) 259-5559
FAX: (651) 296-6047
E-MAIL: wayne.sames@state.mn.us
FUNDING SOURCE: State Land and Water Conservation Account
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 2(h)

APPROPRIATION AMOUNT: $500,000

Overall Project Outcome and Results
The appropriation was used to pay for the state's administration of the LAWCON program. This included administration of annual LAWCON grant solicitations for local projects, all grant management activities related to funded projects, all federal reporting requirements, management of funds used for state projects , management of several conversions of previously funded projects, and all monitoring and inspection activities required as a condition of acceptance of the federal funds. The cost of these administrative activities was $252,844.

In addition, $125,000 was used to fund purchase of picnic tables and fire rings/grates, most of which are accessible, for several state parks as follows:

State Park	Total # Tables	Accessible Table	Fire Rings*
Crow Wing	25	25	15
Father Hennepin	0	0	9
Fort Snelling	10	10	6
Frontenac	25	6	15
Maplewood	53	9	34
McCarthy Beach	25	8	15
Sibley	0	0	31
Upper Sioux Ag.	25	25	15
Wild River	25	10	15
Afton	4	2	4
Total	**192**	**95**	**159**

* All fire rings are accessible.

An additional $110,000 was spent on a new information center (providing self-registration, park information and some interpretive information), an office/shop building and additional park improvements at Great River Bluffs State Park.

This project was consistent with action priorities outlined in the state's 2008-2012 State Comprehensive Outdoor Recreation Plan (SCORP) including:

- "Maintain and adequately fund current infrastructure, including improvements for safety, accessibility and energy efficiency."

- “Identify and address barriers to outdoor recreation, including economic issues, facility design, public awareness, and safety and security concerns.”

Project Results Use and Dissemination: See chart above for location of funded tables and fire rings.

Trust Fund 2007 Work Program Final Report

Date of Report: November 17, 2010

Trust Fund 2007 Work Program Final Report

Date of Next Status Report: N/A
Date of Work program Approval: March, 2007
Project Completion Date: June 30, 2010

I. PROJECT TITLE: LAWCON Federal Reimbursements

Project Manager: Wayne Sames
Affiliation: MN Department of Natural Resources
Mailing Address: 500 Lafayette Road
City / State / Zip : St. Paul, MN, 55155-4010
Telephone Number: (651) 259-5559
E-mail Address: wayne.sames@state.mn.us
FAX Number: (651) 29606047
Web Page address:

Location: Projects may be located anywhere in the state; to be determined when grants are approved.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$500,000**
	Minus Amount Spent:	**$487,844**
	Equal Balance:	**$12,156**

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 2(h)

Appropriation Language: “$500,000 is from the state land and water conservation account (LAWCON) in the natural resources fund to the commissioner of natural resources for priorities established by the commissioner for eligible state projects and administrative and planning activities consistent with Minnesota Statues, section 116P.14, and the federal Land and Water Conservation Fund Act. Subdivision 12 applies to grants awarded in the approved work program. This appropriation is contingent upon receipt of the federal obligation and remains available until June 30, 2010, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.”

II. and III. FINAL PROJECT SUMMARY: This report is amended from the one submitted in August 2010. The amendment is requested because of confusion and miscommunication within the DNR regarding use of funds for a state park project. Part of this confusion was due to the early stages of a transfer of responsibility for managing the LAWCON program from the Office of Management and Services to the Parks and Trails Division. The misunderstanding involved the use of $110,000 of the 2007 LAWCON appropriation for the Great River Bluffs State Park project rather than using the 2009 LAWCON funds for that purpose. This resulted in the addition of the Great River Bluffs State Park project to the Result 1, State Projects section of the final report.

The appropriation was used to pay for the
state's administration of the LAWCON program. This included administration of annual LAWCON grant solicitations for local projects, all grant management activities related to funded projects, all federal reporting requirements, management of funds used for state projects, management of several conversions of previously funded projects, and all monitoring and inspection activities required as a condition of acceptance of the federal funds.

In addition, $125,000 was used to fund purchase of picnic tables and fire rings/grates, most of which are accessible, for several state parks as follows:

State Park	Total # Tables	Accessible Table	Fire Rings*
Crow Wing	25	25	15
Father Hennepin	0	0	9
Fort Snelling	10	10	6
Frontenac	25	6	15
Maplewood	53	9	34
McCarthy Beach	25	8	15
Sibley	0	0	31
Upper Sioux Ag.	25	25	15
Wild River	25	10	15
Afton	4	2	4
Total	**192**	**95**	**159**

* All fire rings are accessible

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: State Projects

Description: Of the total appropriation, $125,000 was used to fund the purchase and installation of new picnic tables and fire rings/grates at ten state parks. About one-half of the picnic tables and all of the fire rings/grates are accessible. The fire rings/grates are also of a safer design compared to previous models. A total of 192 picnic tables and 159 fire rings/grates were purchased (see the table above for details).

An additional $110,000 was spent on a new information center (providing self-registration, park information and some interpretive information), an office/shop building and additional park improvements at Great River Bluffs State Park. (See the attached information on this project).

The entire amount allocated to this result was spent.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$235,000**
	Amount Spent:	**$235,000**
	Balance:	**$0**

This project was consistent with action priorities outlined in the state's draft 2008-2012 State Comprehensive Outdoor recreation Plan (SCORP) including:

- "Maintain and adequately fund current infrastructure, including improvements for safety, accessibility and energy efficiency"
- "Identify and address barriers to outdoor recreation, including economic issues, facility design, public awareness, and safety and security concerns"

Result 2: Administrative Expenses Necessary to Maintain Eligibility for the Federal Land and Water Conservation Fund

Description: The requested budget supported three years of DNR personnel and administrative costs required not only to maintain eligibility for future LAWCON funding, but also to fulfill the state's contractual obligations to ensure that the $70 million in federal investments in state and local outdoor recreation made over the past 40 years are properly and fully carried out. This included staff time required to implement annual grant solicitations, an open project selection process, processing reimbursement requests and payments, pre and post completion project inspections, long term project monitoring that included hundreds of project inspections per year, submitting required reports and updates to the National Park Service, and processing conversions when requests were made to change the use of assisted project areas. It also included staff time and expenses needed to complete an updated State Comprehensive Outdoor Recreation Plan (SCORP), which was required to be submitted to the National Park Service for review and approval by the end of calendar year 2007.

The balance is due, in part to an overlap in funding from the previous appropriation which extended into the first year of the 2007 project period. There was also a reduction in LAWCON apportionments during the FFY 2006 and 2007 periods, which resulted in a smaller number of funded projects from those years and a reduction in staff time required.

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$265,000**
	Amount Spent:	**$252,844**
	Balance:	**$12,156**

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $252,844
Equipment:
Development: $125,000 (purchase accessible and safe picnic tables and fire grates for various state parks.); $110,000 (develop new information center and other improvements at Great River Bluffs State park).
Restoration: $
Acquisition, including easements: $
Balance: $12,156
TOTAL TRUST FUND PROJECT BUDGET: $500,000

Explanation of Capital Expenditures Greater Than $3,500: See table on picnic tables/grates expenditures and information on Great River Bluffs State Park improvements.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: DNR Division of Parks and Trails

B. Other Funds Proposed to be Spent during the Project Period: Division of Parks and Trails staff time was used for the purchase and installation of the picnic tables and fire rings/grates as well as DNR staff time spent on the Great River Bluffs State Park improvements..

C. Past Spending: In 2005 the Legislature appropriated $1,600,000 for this activity.

D. Time: Project funds were encumbered by June 30, 2010.

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

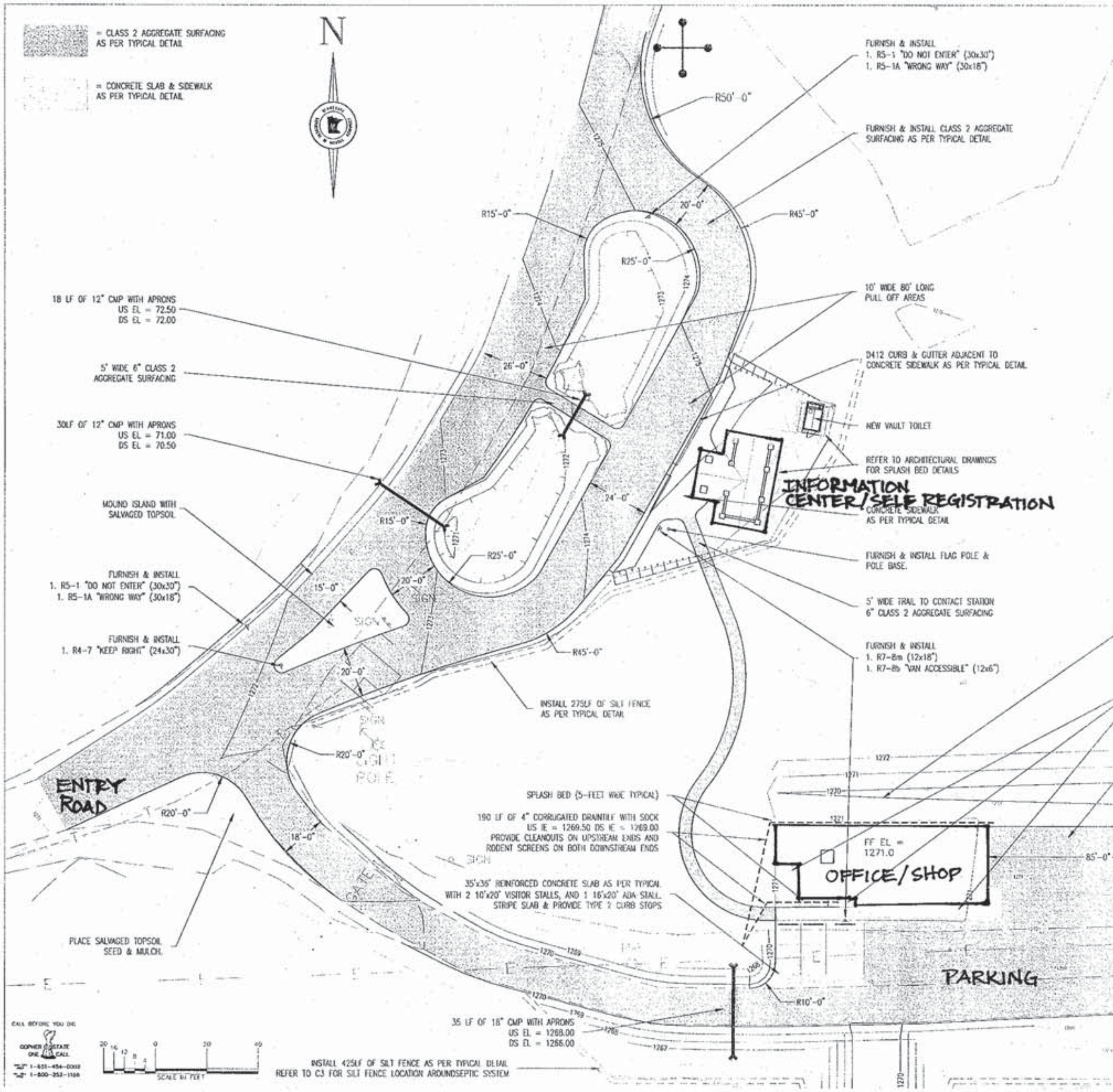
Project Title: LAWCON Federal Reimbursements 2(h)

Project manager name: Wayne Sames

Trust Fund Appropriation: $500,000

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent 11/2010	Balance Nov. 2010	Result 2 Budget:	Amount Spent 11/2010	Balance Nov. 2010	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	State Projects			Administrative Expenses				
PERSONNEL: wages and benefits				265,000	252,000	12,156	265,000	12,156
Development: Accessible tables/fire rings; acq. for Split Rock Lighthouse State Park	235,000	235,000	0				235,000	0
COLUMN TOTAL	**$235,000**	**$235,000**	**$0**	**$265,000**	**$252,000**	**$12,156**	**$500,000**	**$12,156**

J:\SHARE\WORKFILE\ML2007\2007 WP_Subd. 4 Land\4h LAWCON\2010-11-22 Revised Attach A.xls



NOTES:

1. PLACE SOD WITHIN EACH ISLAND AND PLACE A 4' WIDE STRIP AROUND THE PERIMETER OF ROADWAY AT PLAZA. A 4' WIDE STRIP OF SOD SHALL BE PLACES AROUND NEW PLAZA AND OFFICE/STORAGE BUILDING.
2. ALL REMAINING DISTURBED AREAS SHALL BE SEEDED AND MULCHED WITH DNR ALL PURPOSE MIX. PLACE 3" OF SALVAGED TOPSOIL WHERE REQUIRED.
3. EXPOSED SOILS ON SITE SHALL BE TEMPORARILY MULCHED PRIOR TO ANY WORK STOPPAGE GREATER THAN 7 DAYS. THIS SHALL BE CONSIDERED INCIDENTAL TO TURF ESTABLISHMENT.
4. CONTRACTOR SHALL USE ADEQUATE PROTECTION METHODS TO ENSURE RETAINED TREES REMAIN UNDAMAGED.
5. QUANTITIES LISTED BELOW ARE APPROXIMATE. THE CONTRACTOR IS RESPONSIBLE FOR VERIFYING QUANTITIES PRIOR TO BIDDING AND MOBILIZATION.

Item No	Spec Ref.	Description	Unit	Est. Qty
1	1.151B	Mobilization	L.S.	1.0
2	2231	Clear & Grub	L.S.	1.0
3	2232	Re-Locate Tempoary Contact Station	L.S.	1.0
4	2301	Excavation (P)	C.Y.	700.0
5	2301	Granular Borrow (LV)	C.Y.	500.0
6	2370	Silt Fence	L.F.	750.0
7	2620	4-inch Polyethelene Corrugated Drainage Tubing	L.F.	180.0
8	2630	12 inch C.M. Pipe Culvert	L.F.	48.0
9	2630	12 inch C.M. Aprons	EACH	4.0
10	2630	18 inch C.M. Pipe Culvert	L.F.	35.0
11	2630	18 inch C.M Aprons	EACH	2.0
12	2730	Aggregate Base	TON	1,225.00
13	2770	Parking area Striping	L.S.	1.0
14	2770	R4-7 Keep Right Sign (24"x30")	EACH	1.0
15	2770	R5-1 Do Not Enter Sign (30"x30")	EACH	2.0
16	2770	R5-1a Wrong Way Sign (30"x18")	EACH	2.0
17	2770	R7-8m (12"x18")	EACH	2.0
18	2770	R7-8b Van Accessible (12"x6")	EACH	2.0
19	2842	Pre-Cast Concrete Curb - Type 2	EACH	3.0
20	2851	Splash Bed	L.F.	220.0
21	2920	Sod	S.Y.	1,500.0
22	2920	Turf Establishment (0.5 acre approx)	L.S.	1.0
23	3300	D412 curb & Gutter	L.F.	95.0
24	3300	4-inch Thick Fibre Reinforced Concrete	S.F.	920.0
25	3300	6-inch Thick Reinforced Concrete	S.F.	1,230.0

Minnesota DEPARTMENT OF NATURAL RESOURCES

Management Resources
Safety
Facilities
Materials
Equipment
Field Operations
Information Management

DNR Division of Parks and Trails

Information Center and New Office/Storage Bldg.

Great River Bluffs St. Park

Winona County — Near Dakota
Section 13 Township 5 N Range 106 W

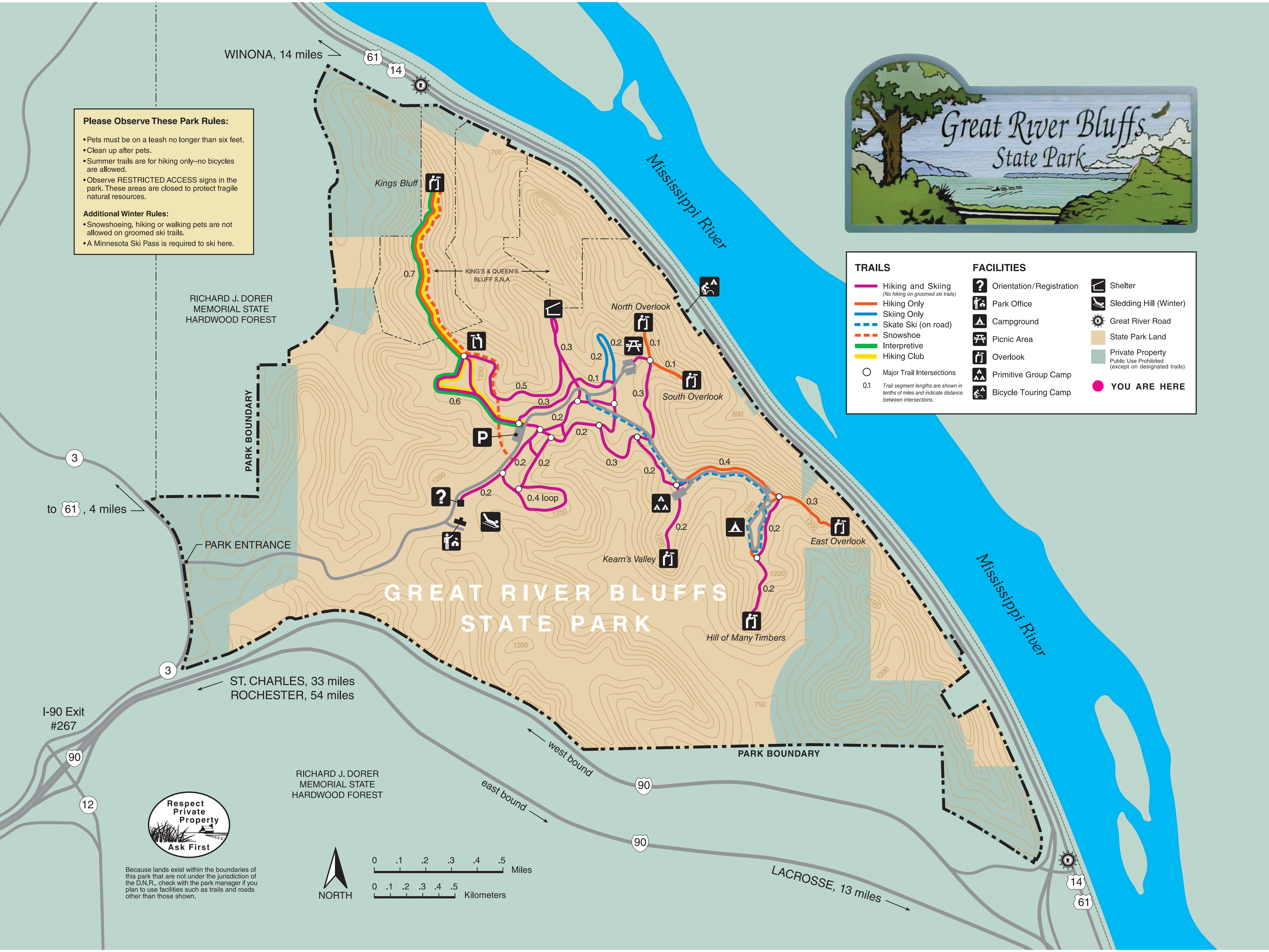
I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION, AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA

Name: Kim W. Wald
Date: 10/6/2009
Reg. Number: 12721

Site Plan

Sheet: C2

Proj. Number: HP090410
Facility: SPK00241.00.10.63



Great River Bluffs
State Park
Please Observe These Park Rules:
• Pets must be on a leash no longer than six feet.
• Clean up after pets.
• Summer trails are for hiking only–no bicycles are allowed.
• Observe RESTRICTED ACCESS signs in the park. These areas are closed to protect fragile natural resources.
Additional Winter Rules:
• Snowshoeing, hiking or walking pets are not allowed on groomed ski trails.
• A Minnesota Ski Pass is required to ski here.
TRAILS
Hiking and Skiing
(No hiking on groomed ski trails)
Hiking Only
Skiing Only
Skate Ski (on road)
Snowshoe
Interpretive
Hiking Club
Major Trail Intersections
0.1 Trail segment lengths are shown in tenths of miles and indicate distance between intersections.
FACILITIES
Orientation/Registration
Park Office
Campground
Picnic Area
Overlook
Primitive Group Camp
Bicycle Touring Camp
Shelter
Sledding Hill (Winter)
Great River Road
State Park Land
Private Property
Public Use Prohibited
(except on designated trails)
YOU ARE HERE
GREAT RIVER BLUFFS
STATE PARK
Mississippi River
Mississippi River
WINONA, 14 miles
61
14
Kings Bluff
KING'S & QUEEN'S BLUFF S.N.A
North Overlook
South Overlook
East Overlook
Kearn's Valley
Hill of Many Timbers
0.4 loop
PARK ENTRANCE
PARK BOUNDARY
PARK BOUNDARY
RICHARD J. DORER
MEMORIAL STATE
HARDWOOD FOREST
RICHARD J. DORER
MEMORIAL STATE
HARDWOOD FOREST
to 61, 4 miles
3
3
ST. CHARLES, 33 miles
ROCHESTER, 54 miles
I-90 Exit
#267
90
12
90
90
west bound
east bound
LACROSSE, 13 miles
14
61
Respect
Private
Property
Ask First
Because lands exist within the boundaries of this park that are not under the jurisdiction of the D.N.R., check with the park manager if you plan to use facilities such as trails and roads other than those shown.
NORTH
0 .1 .2 .3 .4 .5 Miles
0 .1 .2 .3 .4 .5 Kilometers

2007 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Biological Control of European Buckthorn and Garlic Mustard
PROJECT MANAGER: Luke Skinner
AFFILIATION: Minnesota Department of Natural Resources
MAILING ADDRESS: 500 Lafayette Road, Box 25
CITY/STATE/ZIP: St. Paul, MN 55155-4025
PHONE: 651-259-5140
E-MAIL: luke.skinner@state.mn.us
WEBSITE: [If applicable]
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2007, Chap. 30, Sec.2 Subd. 4(i).

APPROPRIATION AMOUNT: $300,000

Overall Project Outcome and Results

Garlic mustard (*Alliaria petiolata*) and European/common buckthorn (*Rhamnus cathartica*) are non-native invasive plants that severely threaten native plant communities and degrade wildlife habitat. This project focused on development of biological control as a long-term management strategy for these species. Reports describing the garlic mustard and buckthorn research in detail are attached to this document. Garlic mustard biocontrol agents have not yet been approved for release in the US. Garlic mustard research focused on monitoring the 12 field sites for pre-release research. Garlic mustard monitoring data from 2005 to 2009 showed that garlic mustard populations can vary considerably from year to year. Garlic mustard plants are occurring at high population densities (mean densities up to 133 adult plants/m^2 and 720 seedlings/m^2) and are currently experiencing very little herbivore attack in Minnesota. Work will continue on monitoring the field sites, developing rearing methods, and conducting field releases once insects are available. Buckthorn biocontrol research carried out in 2007–09 concentrated on a leaf-feeding moth, a leaf-margin gall psyllid, and a seed-feeding midge as potential biocontrol agents. The moth was found to lack enough host-specificity and was eliminated from consideration as a biocontrol agent. Host-specificity testing will continue for the leaf gall psyllid as larvae did not develop on the North American *Rhamnus* species tested. One complication is that the phytoplasma '*Candidatus* Phytoplasma rhamni' has been detected in the leaf gall psyllid. Future work will explore the implications of this phytoplasma for using the leaf-gall psyllid as a biocontrol agent. Initial success in rearing a population of the seed-feed midge will allow for future host-specificity testing of this insect. Future work will concentrate on 3 promising potential biocontrol agents, 2 psyllids and the midge.

Project Results Use and Dissemination

The results of the garlic mustard and buckthorn research projects have been shared widely. Updates on the garlic mustard monitoring and biocontrol research and buckthorn biocontrol research were presented at the Minnesota Invasive Species Conference (Oct. 26-29, 2008, Duluth MN). Updates on these projects will be presented at the upcoming Minnesota-Wisconsin Invasive Species Conference (Nov. 8-

10, 2010, St. Paul, MN). In addition, results have been shared across the state through such venues as County Agriculture Inspector meetings, DNR meetings, and Master Gardener meetings. There is considerable interest in these programs and enthusiasm for the potential for biological control of garlic mustard and buckthorn. The results of the garlic mustard monitoring research were reported in the article "Population Biology of garlic mustard (*Alliaria petiolata*) in Minnesota hardwood forests" by L. Van Riper, R. Becker, and L. Skinner in 2010 in the journal Invasive Plant Science and Management (3:48-59). Results of the buckthorn research were reported in the article "Use of native range surveys to determine the potential host range of arthropod herbivores for biological control of two related weed species, *Rhamnus cathartica* and *Frangula alnus*" by A. Gassmann, I. Tosevski, and L. Skinner in 2008 in the journal Biological Control (45:11-20).

2007 Trust Fund Work Program Final Report

Date of Report: August 16, 2010
Final Report
Date of Work program Approval: June 5, 2007
Project Completion Date: June 30, 2010

I. PROJECT TITLE: Biological Control of European Buckthorn and Garlic Mustard

Project Manager: Luke Skinner
Affiliation: Minnesota Department of Natural Resources
Address: 500 Lafayette Road, Box 25
St. Paul, MN 55155-4025
Telephone number: 651-259-5140
Email: luke.skinner@state.mn.us
Fax: 651-296-1811

Location: State, county, and federal parks, forests, nature preserves and wildlife management areas; roadsides private woodlots and agricultural lands statewide.

Total Biennial LCMR Project Budget:	**LCMR Appropriation:**	**$300,000**
	Minus Amount Spent:	**$270,748.38**
	Equal Balance:	**$29,251.62**

Legal Citation: M.L. 2007, Chap. 30, Sec.2 Subd. 4(i).

Appropriation Language: Biological Control of European Buckthorn and Garlic Mustard. $300,000 is from the trust fund to the commissioner of natural resources to research potential insects for biological control of invasive European buckthorn species for the third biennium and to introduce and evaluate insects for biological control of garlic mustard for the second biennium. This appropriation is available until June 30, 2010, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II and III. FINAL PROJECT SUMMARY AND RESULTS:
Garlic mustard (*Alliaria petiolata*) and European/common buckthorn (*Rhamnus cathartica*) are non-native invasive plants that severely threaten native plant communities and degrade wildlife habitat. This project focused on development of biological control as a long-term management strategy for these species. Reports describing the garlic mustard and buckthorn research in detail are attached to this document. Garlic mustard biocontrol agents have not yet been approved for release in the US. Garlic mustard research focused on monitoring the 12 field sites for pre-release research. Garlic mustard monitoring data from 2005 to 2009 showed that garlic mustard

populations can vary considerably from year to year. Garlic mustard plants are occurring at high population densities (mean densities up to 133 adult plants/m^2 and 720 seedlings/m^2) and are currently experiencing very little herbivore attack in Minnesota. Work will continue on monitoring the field sites, developing rearing methods, and conducting field releases once insects are available. Buckthorn biocontrol research carried out in 2007–09 concentrated on a leaf-feeding moth, a leaf-margin gall psyllid, and a seed-feeding midge as potential biocontrol agents. The moth was found to lack enough host-specificity and was eliminated from consideration as a biocontrol agent. Host-specificity testing will continue for the leaf gall psyllid as larvae did not develop on the North American *Rhamnus* species tested. One complication is that the phytoplasma '*Candidatus* Phytoplasma rhamni' has been detected in the leaf gall psyllid. Future work will explore the implications of this phytoplasma for using the leaf-gall psyllid as a biocontrol agent. Initial success in rearing a population of the seed-feed midge will allow for future host-specificity testing of this insect. Future work will concentrate on 3 promising potential biocontrol agents, 2 psyllids and the midge.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Investigate potential insects as biological control of European Buckthorn

Description: Researchers from the Center for Applied Bioscience (CABI) in Switzerland will continue to locate, identify and collect potential natural enemies of *Rhamnus cathartica* and *Frangula alnus* of *Rhamnus* spp in Europe. Host specificity studies (make sure the insects will not eat plants native to MN and the U.S.) will continue on the high priority insect species. Insects will be prioritized based on their perceived potential to cause damage to buckthorn by impairing growth and/or reproduction, reduce vigor, or cause structural damage. These factors can potentially lead to buckthorn mortality. Expected results include a priority list of potential control agents with preliminary information of their host specificity to native buckthorn species and other plants as determined. This information will guide future research and eliminate candidate insects that are not good potential agents. Testing is done in Europe due to availability if insects and reduce risk of importing any species prior to release. Most species are collected from the wild as cuttings or as seed. Precautions are taken to ensure no soil or other plant parts are shipped with the test plants. The plants are then grown by the researcher in Switzerland and used in testing the insects. Testing procedures are determined once the insects have been identified.

Summary Budget Information for Result 1:	**Trust Fund Budget**	**$165,000**
	Amount Spent	**$135,950**
	Balance	**$29,050**

Completion Date: 6/30/10

Deliverable	**Completion Date**	**Budget**
1. Write contract with CABI	2/28/08	$0
2. Field surveys and collection of agents	8/30/08	$20,000
3. Host specificity testing completed for 2008	2/28/09	$40,000
4. Field surveys and collection of agents	8/30/09	$40,000

5. Host specificity testing completed for 2009 2/28/10 $45,000
6. Final Report with findings and recommendations 6/30/10 $20,000

Final Report Summary:

Contracts were written with CABI-Europe Switzerland to carry out the LCCMR funded buckthorn research in Europe. This is in part due to previous contracts with CABI (with funding from the LCMR 2005). This allowed for continuous work on buckthorn biological control without duplication. Additionally, since garlic mustard and the potential biocontrol agents are native to Europe, research did not need to be conducted in a quarantine facility as it would in the United States.

Common buckthorn biocontrol research carried by CABI concentrated on the leaf-feeding moth *Philereme vetulata*, the leaf-margin gall psyllid *Trichochermes walkeri* and the seed-feeding midge *Wachtiella krumbholzi* as potential biocontrol agents. *P. vetulata* was found to lack enough host-specificity and will not be tested further. A few species in the genus *Rhamnus* (*R. alnifolia*, *R. alaternus*, *R. prinoides*) appear suitable hosts for oviposition by *T. walkeri* in no-choice and/or choice conditions but neither gall nor larval development were recorded on any of the North American *Rhamnus* species. The phytoplasma '*Candidatus* Phytoplasma rhamni' has been detected in two populations of *T. walkeri* in Switzerland. *T. walkeri* is the first insect host record for this phytoplasma. Future work will explore the implications of this phytoplasma for *T. walkeri* as a biocontrol agent. Successful oviposition of *W. krumbholzi* was obtained, allowing for future host-specificity testing of this insect. Work will continue on *T. walkeri* and *W. krumbholzi* as they demonstrated enough specificity to warrant further testing.

The full $165,000 appropriated for this project was not spent. The balance of $29,050 is the result of a break between contracts with CABI. There was a two month break between contracts as we assembled a panel of 6 outside experts in the fields of biocontrol research, entomology, and pathology. We asked panelists to review the work carried out and provide feedback on future research directions. The panelists were impressed with the work carried out and provided recommendations for future research to focus on *T. walkeri* and the phytoplasma, *W. krumbholzi* host-specificity testing, and causes of buckthorn seedling mortality in Europe (including pathogens).

See the following attached reports for additional information on the buckthorn biocontrol research:

1. "Report 2008-2009: Biological Control of buckthorns, *Rhamnus cathartica* and *Frangula alnus*" by A. Gassmann, I. Tosevski, J. Jovic, N. Guazzone, and D. Nguyen, March 2010.
"Buckthorn Annual Report 2008-09.pdf"

2. Gassmann, A., I. Tosevski, and L. Skinner. 2008. Use of native range surveys to determine the potential host range of arthropod herbivores for biological control of two related weed species, *Rhamnus cathartica* and *Frangula alnus*. Biological Control 45:11-20.
"Gassmann et al 2008 buckthorn.pdf"

Result 2: Introduction and evaluation of Garlic Mustard biological control agents in MN

Description: Activities will include selection of potential release sites, collection of pre-release plant community data, development of rearing methods for control agents, introduction of control agents and initial evaluation of establishment of agents. In anticipation of biological control agents becoming available for garlic mustard, 12 field sites have been selected in different habitat types to implement a biological control program in Minnesota. At these chosen sites, we will continue to collect data on the abundance of both garlic mustard and native plants prior to release, to establish a baseline for assessing the long-term impact of introduced biological control insects. Work will also take place to develop rearing methods for control agents. Once biological control insects are introduced, we will evaluate insect establishment and plant community response to the biological control. Unclassified staff will used by Minnesota Department of Agriculture for the purpose of developing and implementing rearing protocols.

Summary Budget Information for Result 2:	**LCMR Budget**	**$135,000**
	Amount Spent	**$134,798.38**
	Balance	**$201.62**

Completion Date: 6/30/10

Deliverable	**Completion Date**	**Budget**
1. Write contract with University of MN	2/28/08	$0
2. Monitor garlic mustard field sites	8/30/08	$10,000
3. Introduction of first bio-control agent	2/28/09	$30,000
4. Monitor sites; implement rearing	8/30/09	$40,000
5. Draft of insect rearing protocol completed	2/28/10	$40,000
6. Final Report with findings and recommendations	6/30/10	$15,000

Final Report Summary:

Contracts were written with the University of Minnesota to carry out the LCCMR funded research on garlic mustard. The main goal was to continue monitoring established permanent plots to monitor garlic mustard populations in anticipation of biological control insect release. In 2005, 12 garlic mustard sites, spread across eight MN counties, were chosen for long-term monitoring. From 2005-present, sites have been surveyed twice yearly with data collected on garlic mustard population density, percent cover, insect damage, and heights and numbers of siliques of the second year plants. In addition, data was collected on litter cover and depth and the identity and cover of all other plants in the monitoring plots.

In 2008, a proposal was submitted to USDA-APHIS Technical Advisory Group, petitioning to have the weevil *Ceutorhynchus scrobicollis* approved for release in the United States, to be used as a biological control agent for garlic mustard. In 2009, the Technical Advisory Group recommended additional host-specificity testing of western mustard plant species and a few additional horticultural mustard species. At present, research is continuing to address these concerns and a revised proposal will be submitted in the future. The lack of any biocontrol agents approved for release meant that work had to concentrate on research on garlic mustard populations and not on insect introductions or evaluations of biocontrol establishment or field insect rearing.

Garlic mustard monitoring data from 2005 to 2009 showed that garlic mustard populations can vary considerably from year to year. Garlic mustard plants are occurring at high population densities (mean densities up to 133 adult plants/m^2 and 720 seedlings/m^2) and are currently experiencing very little herbivory in Minnesota. Low herbivory indicates that garlic mustard is not heavily impacted by insects already present in Minnesota and that biocontrol agents could have a large impact. This study examined the fluctuations of garlic mustard populations over time and their relationship with native species, levels of leaf litter, photosynthetic radiation, and insect herbivores. At half of the 12 monitoring sites, garlic mustard populations showed strong two-point cycling with alternating dominance of the first- and second-year life stages. Increased garlic mustard cover was negatively correlated with native species richness and cover. All sites had litter layers that had been significantly impacted by earthworms. Light was a key factor in understanding garlic mustard populations. Adult plant cover is higher where light is more abundant, but high cover of adult plants produces shade and can cause low cover of seedling plants. We found that less than 2% of garlic mustard leaf area is currently being damaged by herbivores in Minnesota. These results have implications for both the release of potential biological control agents and restoration of garlic mustard invaded sites. When working to restore a site that has been heavily invaded by garlic mustard, the level of earthworm impact, the number and abundance of native species that remain, and any changes to the light available from the canopy should all be considered as factors that could influence the recovery of the site, in addition to the potential decrease in garlic mustard. Future work will focus on monitoring the field sites, developing rearing methods, and conducting field releases once insects are available.

See the following attached reports for additional information on the garlic mustard biocontrol research:

1. "Monitoring garlic mustard (*Alliaria petiolata*) in anticipation of future biocontrol release (2005-2009): Report to the Legislative-Citizen Commission on Minnesota Resources" by L. Van Riper, R. Becker, and L. Skinner, February 2010.
"2010 Garlic mustard monitoring LCCMR report.pdf"

2. . Van Riper, L. C., R. L. Becker, and L. C. Skinner. 2010. Population Biology of garlic mustard (*Alliaria petiolata*) in Minnesota hardwood forests. Invasive Plant Science and Management 3:48-59.
"Van Riper et al 2010 garlic mustard.pdf"

V. TOTAL TRUST FUND PROJECT BUDGET:

Contract Services: $270,748.38 (CABI (buckthorn) and Univ. of MN (garlic mustard))

TOTAL TRUST FUND PROJECT BUDGET: $300,000

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

Dr. Andre Gassmann, Center for Applied Bioscience International (CABI), Delemont, Switzerland was under contract to continue the ongoing buckthorn research ($165,000). CABI has been working on buckthorn biological control since 2001. CABI is responsible for research on purple loosestrife bio-control agents and many leafy spurge bio-control agents that are currently used in the U. S. and Canada.

Drs. David Ragsdale, Roger Becker, Elizabeth Stamm Katovich, and Laura Van Riper, University of Minnesota, carried garlic mustard biological control research under contract

($134,904.44). This amount may change based on future role of Minnesota Department of Agriculture; see below). Drs. Becker, Ragsdale, and Katovich spent 10% of their time on this project. Dr. Van Riper spent 100% of her time on garlic mustard.

Monika Chandler, MN Department of Agriculture, was anticipated to work closely with DNR staff to rear biological control agents and implement evaluations of garlic mustard biological control in the field ($30,000). Ms. Chandler would have spent ~5% of her time (in-kind) on this project. Additional unclassified MDA staff would have been included for implementing rearing of control agents. Funding directed to this activity would have been used once there was approval to remove the control agents from quarantine. Insects were not approved for release during this LCCMR grant period, so MDA staff did not spend time implementing rearing as originally expected.

B. Other Funds Proposed to be Spent during the Project Period:
Buckthorn related spending: The Department of Natural resources contributed $44,871 to pay for indirect costs billed by CABI.

C. Required Match (if applicable): Not applicable

D. Past Spending:
Buckthorn related spending: The DNR spent $20,000 in 2001 to initiate research on buckthorn bio-control. The DNR received $125,000 from the U.S. EPA (2001-2005) to continue the buckthorn research. Currently, $110,000 of LCMR recommended funding along with an additional $30,000 from the United States Fish and Wildlife Service (through Minnesota Department of Natural resources) is being used to continue this research. The Department of Natural Resources will contribute additional funding (up to $30,000). We will also continue to pursue other funding sources for this effort from other states and federal agencies, which are likely to help pursue bio-control efforts if some potential agents are identified.
Garlic mustard related spending: The DNR spent $25,000 in 1999 supporting garlic mustard biological control research. Between 2002 and 2006, the DNR received $225,000 from the U.S.D.A.-Forest Service to continue host specificity testing of garlic mustard agents. LCMR funding (2005) and DNR funding were used as match for a portion of the federal funding. We will continue to use LCCMR recommended funding as match source to leverage Federal funding (up to $50,000).

E. Time:
Development and implementation of biological control for buckthorn could take up to ten years. This research will determine whether there are suitable bio-control agents, whether further research into these potential agents is warranted, and make recommendations for future work. If potential control agents are found, further research would be needed to continue screening the insects to ensure they are host specific and won't feed on other plants. Several insects for garlic mustard control are near completion of host specificity testing and one or more species are expected to be approved for introduction in the United States in the next few years. Our time will be spent over the next 5-7 years evaluating the success of the insects introduced. Both European buckthorn and garlic mustard biological control efforts will follow research processes similar to

those used for highly successful purple loosestrife and leafy spurge programs that have been funded through the LCCMR process.

VII. DISSEMINATION: It is expected that the results of this project will be published in peer-reviewed scientific journals and also in special publications and newsletters. Results also will be presented at national, regional and state scientific meetings to peers in the field, as well as to resource managers and planners who will use the results of this project.

Results have been published in the following scientific journals:

Van Riper, L. C., R. L. Becker, and L. C. Skinner. 2010. Population Biology of garlic mustard (*Alliaria petiolata*) in Minnesota hardwood forests. Invasive Plant Science and Management 3:48-59.

Gassmann, A., I. Tosevski, and L. Skinner. 2008. Use of native range surveys to determine the potential host range of arthropod herbivores for biological control of two related weed species, *Rhamnus cathartica* and *Frangula alnus*. Biological Control 45:11-20.

Updates on the garlic mustard monitoring and biocontrol research and buckthorn biocontrol research were presented at the Minnesota Invasive Species Conference (Oct. 26-29, 2008, Duluth MN). Updates on these projects will be presented at the upcoming Minnesota-Wisconsin Invasive Species Conference (Nov. 8-10, 2010, St. Paul, MN). In addition, results have been shared across the state through such venues as meetings of County Agriculture Inspectors, DNR staff, and Master Gardeners.

Supplementary materials submitted in addition to this Work Program Final Report include:

1. Gassmann, A., I. Tosevski, and L. Skinner. 2008. Use of native range surveys to determine the potential host range of arthropod herbivores for biological control of two related weed species, *Rhamnus cathartica* and *Frangula alnus*. Biological Control 45:11-20.
"Gassmann et al 2008 buckthorn.pdf"

2. "Report 2008-2009: Biological Control of buckthorns, *Rhamnus cathartica* and *Frangula alnus*" by A. Gassmann, I. Tosevski, J. Jovic, N. Guazzone, and D. Nguyen, March 2010.
"Buckthorn Annual Report 2008-09.pdf"

3. Van Riper, L. C., R. L. Becker, and L. C. Skinner. 2010. Population Biology of garlic mustard (*Alliaria petiolata*) in Minnesota hardwood forests. Invasive Plant Science and Management 3:48-59.
"Van Riper et al 2010 garlic mustard.pdf"

4. "Monitoring garlic mustard (*Alliaria petiolata*) in anticipation of future biocontrol release (2005-2009): Report to the Legislative-Citizen Commission on Minnesota Resources" by L. Van Riper, R. Becker, and L. Skinner, February 2010.
"2010 Garlic mustard monitoring LCCMR report.pdf"

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than February 2008, August 2008, February 2009, August 2009 and March 2010. A final work program report and associated products will be submitted by August 16, 2010.

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Date: 8/13/2010

Project Title: *Biological Control of European Buckthorn and Garlic Mustard*

Project Manager Name: *Luke Skinner*

Trust Fund Appropriation: $

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 2 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 3 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Investigate potential insects as biological control of European buckthorn			*Introduction and evaluation of Garlic Mustard biocontrol agents in MN*			*not applicable*				
BUDGET ITEM	0		0			0			0	0	0
Contracts			0			0			0	0	0
Professional/technical *(with whom?, for what?) Result 1: Contracts with CABI-Europe Switzerland for host-specificity testing of buckthorn biocontrol agents. Result 2: Contracts with the University of Minnesota for garlic mustard research*	$165,000.00	$135,950.00	$29,050.00	$135,000.00	$134,798.38	$201.62			$0.00	$300,000.00	$29,251.62
COLUMN TOTAL	**$165,000.00**	**$135,950.00**	**$29,050.00**	**$135,000.00**	**$134,798.38**	**$201.62**	**$0.00**	**$0.00**	**$0.00**	**$300,000.00**	**$29,251.62**

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ScienceDirect
Biological Control 45 (2008) 11–20
Biological Control
www.elsevier.com/locate/ybcon

Use of native range surveys to determine the potential host range of arthropod herbivores for biological control of two related weed species, *Rhamnus cathartica* and *Frangula alnus*

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Received 5 June 2007; accepted 19 December 2007
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Abstract

The buckthorn species, *Rhamnus cathartica* and *Frangula alnus*, are shrubs and small trees of Eurasian origin that have become invasive in North America. A program was initiated in 2001 to reassess the potential for biological control of these two species taking into consideration increasing concerns over potential non-target impacts of biological control agents. The key question was whether *R. cathartica* and *F. alnus* are distantly enough related that they would not share the same arthropod complex in Europe, and, if so, which arthropod species would be less likely to use native North American buckthorns as hosts. Some 1000 insect samples collected at 99 sites in Europe indicated that the arthropod-species richness is higher on *R. cathartica* than on *F. alnus* and includes more species that are presumed to be host-specific at the species or genus level. This discrepancy supports the hypothesis that the genus *Rhamnus* in the temperate Old World has evolved in isolation of the genus *Frangula* in the Neotropics and that taxonomic isolation has an effect on species richness of specialized herbivores. The fauna was dominated by Lepidoptera (22 species), followed by Hemiptera (8 species), Diptera (4 species), Acarina (4 species) and Coleoptera (1 species). At least 12 arthropod species were found exclusively on *Rhamnus*, some of which may be specific to *R. cathartica*. Several species usually associated with *Rhamnus* were found rarely on *F. alnus* but the field host range of these species still needs to be confirmed. Only one species was found exclusively on *F. alnus.* The findings indicate that, with one exception, there are no species or genus-specific agents available for biological control of *F. alnus* at this stage. However, additional field surveys may reveal other host-specific species.

Keywords: *Rhamnus cathartica*; *Frangula alnus*; Buckthorn; Biological control; Species richness; Food niche; Center of origin; Taxonomic isolation; Host plant phylogeny

1. Introduction

Rhamnus cathartica L. (common buckthorn) and *Frangula alnus* Miller (glossy buckthorn) (Rhamnaceae) are two shrubs and small trees of Eurasian origin which have become invasive in North America.

Rhamnus cathartica is found throughout Europe, but is absent from most parts of Scandinavia and the Iberian Peninsula, and from the extreme south (Tutin, 1968; http://linnaeus.nrm.se/flora/di/rhamna/rhamn/rhamcat.html). The species is also present in European Russia, in south-western Siberia, in the northern Caucasus as well as in the Province of Xinjiang in China (D. Jianqing, personal communication, 2001). In Europe, *R. cathartica* prefers mesic to mesic-dry, warm open or half-shaded habitats. It grows in well drained calcareous alkaline or neutral soils, but it can also be found occasionally in swampy areas (Rameau et al., 1989).

Rhamnus cathartica was introduced to North America as an ornamental shrub in the late 1800s and was originally used for hedges, farm shelter belts, and wildlife habitats

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(Gourley, 1985; Randall and Marnelli, 1996; Gale, 2001). It has spread extensively and is currently found in most Canadian provinces (Nova Scotia to Saskatchewan) and 27 states predominantly in the north central and northeastern portion of the United States (Gale, 2001; USDA/NRCS, 2001). *Rhamnus cathartica* invades mainly woodlands and savannas, although it also occurs on prairies and open fields.

Frangula alnus has a slightly wider distribution than *R. cathartica* extending from northern Scandinavia in the boreal zone up to the Iberian Peninsula and a southernmost enclave in western North Africa (Tutin, 1968; Scamoni, 1985; Medan, 1994; http://linnaeus.nrm.se/flora/di/rhamna/frang/franaln.html). *Frangula alnus* is also present in European Russia, in south-western Siberia, in the northern Caucasus as well as in the Province of Xinjiang in China (D. Jianqing, personal communication, 2001). In Europe, *F. alnus* prefers mesic to mesic-moist acid soils in open or half-shaded habitats but it can also be found occasionally in dry calcareous stands (Rameau et al., 1989).

Frangula alnus was imported to North America prior to the 1900s as horticultural stock for landscape plantings, and has become naturalized in the northeastern US and southeastern Canada (Catling and Porebski, 1994; Randall and Marnelli, 1996; Haber, 1997). Currently, *F. alnus* occurs from Nova Scotia to Manitoba, south to Minnesota, Illinois, New Jersey and Tennessee incorporating 23 states in the US (Converse, 2001; USDA/NRCS, 2001). *Frangula alnus* is most problematic in fens and other wetlands but also can invade uplands and sandy soil forests.

Both species are very adaptable, forming dense thickets that shade and inhibit the growth of native forbs, shrubs, and tree seedlings (Heidorn, 1991; Randall and Marnelli, 1996). Both species are alternate hosts for the fungus, *Puccinia coronata* Corda, which causes oat rust disease (Harder and Chong, 1983; Leonard, 2003). *Rhamnus cathartica* and *F. alnus* are also overwintering hosts for the Asian soybean aphid, *Aphis glycines* Matsumura, a pest of soybean, *Glycine max* (L.) Merrill, which was first recorded in North America in 2000 (Voegtlin et al., 2005). American robins (*Turdus migratorius* L.) nesting in *R. cathartica* experience higher rates of predation than conspecifics nesting in native shrubs (Schmidt and Whelan, 1999).

The systematics of buckthorns has a long history of complexity and uncertainty. Linnaeus described *Rhamnus cathartica* and *Rhamnus frangula* in 1753 (Linnaeus, 1753). In 1754, Miller described the genus *Frangula*, and in 1768, transferred glossy buckthorn to this genus under the name *Frangula alnus* (Miller, 1754/1768). The generic recognition of *Frangula* has been disputed and for many years *F. alnus* has gone under the name *R. frangula* L. A recent molecular study by Bolmgren and Oxelman (2004) supports the generic recognition of *Frangula*. The global sample of *Frangula* used in their study represents a well-supported monophyletic sister clade to the rest of *Rhamnus* in its widest sense. Given the lack of resolution in the *Frangula* clade, *R. cathartica* may be considered more distantly related to the American *Rhamnus* native community than *F. alnus* is to the American native *Frangula* community.

It is difficult to obtain an accurate count of *Rhamnus* and *Frangula* species, in particular in the Old World tropics and eastern Palearctic. Grubov (1949) suggested that *Rhamnus* s.l. consists of almost 200 species but this number was reduced to 125 by Johnston and Johnston (1978). Work by the same authors on Neotropical *Rhamnus* s.l. suggests that *Frangula* has an area of diversification in the mountainous areas of the Neotropics with its southern limit in Northern Argentina. Of the 21 species recognized by Johnston and Johnston (1978) in the Neotropics, 20 belong to *Frangula* and one, *Rhamnus serrata* Humb. and Bonpl. ex J.A. Schultes, to the genus *Rhamnus*. In Europe, the genus *Rhamnus* includes 23 taxa and the genus *Frangula* includes only four taxa (Tutin, 1968; Hampe et al., 2003). In the United States, *Frangula* and *Rhamnus* include five and seven native taxa, respectively, but another two *Rhamnus* subspecies and 10 *Frangula* subspecies have been recorded (USDA/NRCS, 2001). Thus, it appears that *Rhamnus* and *Frangula* are predominant in the Old World and New World, respectively. In North America, the geographical distribution of the two invasive buckthorn species overlaps most with the native species *Rhamnus alnifolia* L'Hér., *Rhamnus lanceolata* Pursh and *Frangula caroliniana* (Walt.) Gray, making these key-species in host range studies of potential biological control agents.

Research to develop biological control for buckthorns was initiated in 1964. Surveys for potential arthropod biological control agents were carried out mostly in Eastern Austria in summer 1964 and 1965 and preliminary screening tests in 1966–1967 (Malicky et al., 1970). A new program was initiated in 2001 to reassess the potential of biological control of buckthorns with regard to the work carried out by Malicky et al. (1970). In recent years there have been ever-increasing concerns over potential non-target impacts of biological control agents and greater demands for high levels of specificity (e.g. Louda et al., 1997; Pemberton, 2000). The key question was whether *R. cathartica* and *F. alnus* are sufficiently distantly related that they would not share the same arthropod complex in Europe and, consequently which arthropod species could be selected for further host range studies, and possibly later on be used for biological control without damaging native North American buckthorns.

The aim of this study was to use both a literature review and field surveys to identify the specialized herbivorous arthropods on *R. cathartica* and *F. alnus* and to determine their host use patterns and preferences in the field. We report results of surveys carried out in Europe in 2002–2005 and review previous studies on the biological control of buckthorns for North America.

2. Materials and methods

Between 2002 and 2005, extensive surveys for presumed-specialized insect species (defined here as a species restricted to one plant genus) on *Rhamnus* and *Frangula* spp. were carried out in Switzerland, Germany, Italy, the Czech Republic, Austria, Serbia and Montenegro. More intensive surveys were concentrated in the areas which had been sampled in previous years by Malicky et al. (1970), i.e. eastern Austria, Germany and Switzerland. In Serbia and Montenegro, selective surveys were carried out for a few specific insect species that had not been found in the other surveys. With the exception of the Czech Republic and Italy, most sites were sampled twice per season or more, or at different periods of the year for more than 1 year. Fruits were sampled in 2004–05 only. Leaves, stems and fruits were carefully examined for herbivory and symptoms of herbivory. Immature and mature phytophagous arthropods were handpicked or aspirated from young and mature buckthorn plants. In total, we surveyed *R. cathartica* and *F. alnus* at a total of 99 sites and 1000 samples were examined separately. In addition, *Rhamnus alpina* L. and *Rhamnus saxatilis* Jacq. were opportunistically surveyed at two and four sites, respectively, as they can co-occur with *R. cathartica* in the surveyed areas. Juvenile insects were reared on their field host plants in ventilated plastic containers in a shade house. Unhealthy fruits, shoot tips or small branches were collected for dissection or emergence of specific insects. Pheromone traps using a commercial lure developed for *Synanthedon myopaeformis* (Borkh.) by Plant Research International, Wageningen UR, The Netherlands, were used to detect the presence of the root-boring moth *Synanthedon stomoxiformis* Hb. The frequency of occurrence of each arthropod collected was calculated for each buckthorn species surveyed. The sampling unit was the whole habitat/site.

3. Results

In total, 39 specialized arthopods were recorded from *R. cathartica* and *F. alnus* in Europe (Table 1). Lepidoptera (22 species) largely dominated, followed by Hemiptera (8 species), Diptera (4 species), and Acarina (4 species). There was only one specialized beetle species, *Oberea pedemontana* Chevrolat, recorded on these two buckthorn species in Europe. The feeding guild on *R. cathartica* and *F. alnus* was dominated by leaf feeders (18 species), followed by sap-suckers (9 species) and flower or fruit feeders (6 species) of which four species were gall midges reported to induce galls either in the flowers or fruits of buckthorn. In addition to the gall midges, the larvae of *Hysterosia sodaliana* Haw. developed within the fruits of buckthorn and those of *Sorhagenia rhamniella* Zeller lived gregariously between spun blossoms of *R. cathartica*. There were only three shoot/root borers. The larvae of *Sorhagenia janiszewskae* Riedl developed in the shoot-tips and those of *O. pedemontana* in the branches. The larvae of *S. stomoxiformis* mined the roots of buckthorn. Of the leaf feeding phytophages, five species (i.e. *Bucculatrix frangutella* Goeze, *Bucculatrix rhamniella* Zeller, *Calybites quadrisignella* Zeller, *Stigmella catharticella* Stainton and *Stigmella rhamnella* H.-S.) mined in the leaves of buckthorn partially or during their entire life cycle. Finally, there were three leaf gall forming species, *Trichochermes walkeri* Foerster, *Trioza rhamni* Schrank and *Phyllocoptes annulatus* (Nal.). Comparatively, Brändle and Brandl (2001) found 29 specialists for a total of 91 herbivores on *Frangula* and *Rhamnus* in a study on herbivore species richness on 25 native trees in Germany.

The number of specialized arthropods was much larger on *R. cathartica* than on *F. alnus*. Twenty-two species were mostly associated with *R. cathartica* and other species in the genus *Rhamnus* (Tables 1 and 2). Of these 22 species, only eight species have also been occasionally recorded on *F. alnus* and among those, five consist of literature records, i.e. *S. rhamniella*, *Triphosa sabaudiata* Dup., *C. quadrisignella*, *S. rhamnella* and *H. sodaliana*, which were not confirmed during surveys for biological control. However, host affiliations can vary geographically (Fox and Morrow, 1981). For example, *S. rhamniella* is known from *F. alnus* in England (Emmet, 1969), an area that was not surveyed for biological control agents. Another eleven species have been found occurring on both *R. cathartica* and *F. alnus*. Of those, three species, *Ancylis apicella* Den. and Schiff., *Gonopteryx rhamni* L. and *S. janiszewskae* were found more often on *F. alnus* than on *R. cathartica* (Table 2).

The leaf-hopper *Zygina suavis* Rey was the only species found on *F. alnus* but not on *R. cathartica*, although the literature record list *R. cathartica* as a host of *Z. suavis* (Ossiannilsson, 1981). In addition to *Z. suavis*, literature records indicated another five arthropod species known from *F. alnus*, i.e. *Contarinia rhamni* Ruebs., *Dasyneura frangulae* Ruebs., *Lygocoris rhamnicolla* Reuter, *Aristotelia pancaliella* Stgr. and *Eriophyes rhamni* (Pgst.).

Records of presence or absence of most arthropods associated with *R. cathartica* and *F. alnus* in the areas surveyed in Europe in 2002–2005 matched well with those from Malicky et al. (1970) (Table 2). In contrast, the frequency of occurrence of several species differed considerably reflecting a non-random sampling method focussing on pre-selected specialized species in our surveys. *Trichochermes walkeri*, *T. rhamni* and to a slightly lesser extent *Philereme vetulata* Den. and Schiff. and *Triphosa dubitata* L., best represented the specific arthropod community associated with *R. cathartica* in Europe.

Frangula alnus was best represented by *Z. suavis*, *G. rhamni* and *A. apicella* while *B. frangutella* and *O. pedemontana* were recorded equally on both buckthorn species. *Sorhagenia janiszewskae* has been recorded on *F. alnus* and *R. cathartica* in Austria only. The occurrence of this species has not been confirmed on *R. cathartica* in Switzerland and Germany. The frequency of occurrence of most of the other species collected was too low to draw conclusions about host specificity, but our observation matched those of Malicky et al. (1970), indicating that most of the additional species are not associated with *F. alnus* in the areas surveyed.

Table 1
Specialized arthropods associated with *Rhamnus cathartica* and *Frangula alnus* in Europe (*field records from our surveys; **Malicky et al., 1970; remaining records from literature as indicated)

Species	Host plants	Specificity[a]	Food niche	References
Coleoptera				
Cerambycidae				
Oberea pedemontana Chevrolat	*R. cathartica**, *F. alnus**, *R. alpina*, *Lonicera*?	O?	Stem, woodboring	Horion (1974); Lekic and Mihajlovic (1976); Contarini and Garagnani (1980); Baronio et al. (1988); Demelt and Franz (1990); Frisch (1992)
Diptera				
Cecidomyiidae				
Contarinia rhamni Ruebs.	*F. alnus*	M	Gall forming (flowers)	Houard (1909); Barnes (1951); Buhr (1965); Zerova et al. (1991)
Dasyneura frangulae Ruebs.	*F. alnus*	M	Gall forming (flowers)	Barnes (1951); Buhr (1965)
Lasioptera kozarzewskella Mar.	*R. cathartica*	M	Gall forming (fruits)	Stelter (1975); Zerova et al. (1991)
Wachtliella krumbholzi Stelter	*R. cathartica**	M	Gall forming (fruits)	Stelter (1975)
Heteroptera				
Miridae				
Heterocordylus erythrophtalmus Hb	*R. cathartica***, *F. alnus***	O	Sap sucking	Gollner-Scheiding (1972)
Lygocoris rhamnicola Reuter	*F. alnus*	M	Sap sucking	Coulianos (1998)
Homoptera				
Aphididae				
Aphis commensalis Stroyan	*R. cathartica*	M	Gall forming? (leaves)	Buhr (1965); Heie (1986)
Aphis mammulata Gimingh. & HRL	*R. cathartica*	M	Sap sucking, free living	Heie (1986); Blackman and Eastop (1994)
Cicadellidae				
Zygina suavis Rey	*F. alnus**/*R. cathartica*	O	Sap sucking, free living	Ossiannilsson (1981)
Psyllidae				
Cacopsylla rhamnicola (Scott)	*R. cathartica**/**/*F. alnus***	O	Sap sucking, free living	Ossiannilsson (1992)
Triozidae				
Trichochermes walkeri Foerster	*R. cathartica**/**	M	Gall forming (leaves)	Buhr (1965); Okopnyi and Poddubnyi (1983); Meyer (1987); Zerova et al. (1991); Ossiannilsson (1992); McLean (1993)
Trioza rhamni Schrank	*R. cathartica**/**/*F. alnus***	O	Gall forming (leaves)	Buhr (1965); Ossiannilsson (1992)
Lepidoptera				
Bucculatricidae				
Bucculatrix frangutella Goeze	*R. cathartica**/**/*F. alnus**/**/*R. alpina**/**	O	Leaf miner/leaf chewer	Hering (1957); Heath and Emmet (1985)
Bucculatrix rhamniella H.-S.	*R. cathartica*	M	Leaf miner/leaf chewer	Hering (1957); Buszko (1992)
Cosmopterigidae				
Sorhagenia lophyrella Douglas	*R. cathartica***/*R. saxatilis***	O	Leaf roller	Baran (1997); Malicky et al. (1970)
Sorhagenia janiszewskae Riedl	*R. cathartica**/**/*R. alpina***/*F. alnus**/**/	O	Shoot miner	Malicky et al. (1970)
Sorhagenia rhamniella Zeller	*R. cathartica***/*F. alnus*	M?	Flower feeder	Malicky et al. (1970); Emmet (1969)
Gelechiidae				
Aristotelia pancaliella Stgr.	*F. alnus*	M	Leaf chewer	Ivinskis et al. (1982)
Geometridae				
Odontognophos dumetata Treitschke	*R. cathartica*	M	Leaf chewer	Forster and Wohlfahrt (1981)
Philereme transversata Hufnagel	*R. cathartica**/**/*R. saxatilis***/*R. orbiculata***/*F. alnus***	O		(Skinner, 1984)
Philereme vetulata Den. and Schiff.	*R. cathartica*,*/**/*R. alpina***	O	Leaf chewer	Forster and Wohlfahrt (1981); Skinner (1984)

Table 1 (*continued*)

Species	Host plants	Specificity[a]	Food niche	References
Triphosa dubitata L.	*R. cathartica**/**/*R. alpina**/**/*F. alnus**/**/ *Prunus* ?/ *Fraxinus* ?/ *Crataegus* ?	O?	Leaf chewer	Blaschke (1914); Forster and Wohlfahrt (1981); Skinner (1984); Jacobi and Menne (1991)
Triphosa sabaudiata Dup.	*R. cathartica***/*R. saxatilis***/*R. orbiculata***/*F. alnus*/*R. alpina*	O	Leaf chewer	Blaschke (1914); Forster and Wohlfahrt (1981)
Gracillariidae				
Calybites quadrisignella Zeller	*R. cathartica**/**/*F. alnus*	M?	Leaf miner/leaf chewer	Hering (1957)
Nepticulidae				
Stigmella catharticella Stainton	*R. cathartica**/**/*R. alaternus*	M?	Leaf miner	Hering (1957); Heath (1976); Speight and Cogan (1979); Puplyasis (1984); Puplesis (1994); Michalska (1996)
Stigmella rhamnella H.-S.	*R. cathartica**/**/*R. alpina**/*F. alnus*	O	Leaf miner	Hering (1957); Puplesis (1994); Michalska (1996)
Pieridae				
Gonopteryx rhamni L.	*R. cathartica**/**/*R. orbiculata**/*F. alnus**/**	O	Leaf chewer	Frohawk (1940); Bergmann (1952); Pollard and Hall (1980); de Freina (1983); Bibby (1983); Rippey (1984); Heath and Emmet (1989); McKay (1991); Gutierrez and Thomas (2000)
Pyralidae				
Acrobasis romanella Mill.	*R. cathartica**/*R. alaternus***	O	Lchewer	Malicky et al. (1970)
Trachycera legatea Haw.	*R. cathartica***/*R. saxatilis***	O	Leaf chewer	Mihajlovic (1978)
Sesiidae				
Synanthedon stomoxiformis Hb.	*R. cathartica**/*F. alnus**/ *Sorbus aria*?/*Coryllus avelana* ?	O?	Root miner	Doczkal and Rennwald (1992); Stadie (1995); Bittermann (1997); de Freina (1997); Spatenka et al. (1999)
Tortricidae				
Ancylis apicella Den. & Schiff.	*R. cathartica**/**/*F. alnus**/**/*R. alpina***/ *Ligustrum* ?/ *Cornus* ?/ *Prunus* ?	O?	Leaf chewer	Razowski (2003)
Ancylis derasana Hb. (=*unculana* Haw.)	*R. cathartica**/**/*F. alnus**/*Corylus* ?/*Rubus* ?/*Populus* ?	O?	Leaf chewer	Razowski (2003)
Ancylis obtusana Haw.	*R. cathartica*/*F. alnus*	O	Leaf chewer	Razowski (2003)
Hysterosia sodaliana Haw.	*R. cathartica***/*F. alnus*	O	Fruit feeder	Hannemann (1964); Razowski (1970)
Acari				
Eriophyidae				
Aceria rhamni Roiv.	*R. cathartica*	M	Sap sucker, free living	Amrine and Stasny (1994)
Eriophyes rhamni (Pgst)	*F. alnus*	M	Leaf erineum ?	Amrine and Stasny (1994)
Phyllocoptes annulatus (Nal.)	*R. cathartica**	M	Leaf erineum	Amrine and Stasny (1994)
Tetra rhamni Roiv.	*R. cathartica*	M	Sap sucker, free living	Amrine and Stasny (1994); Petanovic, personal communication (2005)

[a] M, monophagous, restricted to *R. cathartica* or *F. alnus*; O, oligophagous, restricted to species in the genus *Rhamnus* and/or *Frangula*.

In Serbia and Montenegro, *O. pedemontana* and *S. stomoxiformis* were recorded on *R. cathartica* and *F. alnus*, and *Wachtiella krumbholzi* Stelter reared from the fruits of the former species (Gassmann et al., 2006). According to M. Skuhrava (personal communication, 2005), *W. krumbholzi*, which was known from Northern Germany and the Czech Republic only, cannot be considered to be cecidogenous, but it is rather a seed feeder.

Rhamnus cathartica and *F. alnus* were observed growing sympatrically in 20 sites. Host plant records for 18 arthropod taxa associated with *R. cathartica* and *F. alnus* were similar in allopatric and sympatric sites (Table 3). None of the species known exclusively from *R. cathartica* in allo-

Table 2
Frequency of occurrence of specialized buckthorn arthropods in 2002–05 in Italy, Austria, Switzerland, Germany and the Czech Rep. (records from Malicky et al. (1970) are presented on shaded columns)

	Rhamnus cathartica		*Frangula alnus*	
Total # of sites sampled :	52	214	47	83
Number of sites with (%):				
LEPIDOPTERA :				
Bucculatricidae :				
Bucculatrix frangutella [4]	7 (13.5)	44 (20.6)	6 (12.8)	11 (13.3)
Cosmopterigidae :				
Sorhagenia janiszewskae [4]	13 (25.0)	9 (4.2)	14 (29.8)	14 (16.9)
Sorhagenia rhamniella	-	14 (6.5)	-	-
Sorhagenia lophyrella [3]	-	27 (12.6)	-	-
Gracillariidae :				
Calybites quadrisignella	3 (5.8)	10 (4.7)	-	-
Nepticulidae:				
Stigmella catharticella	2 (3.8)	25 (11.7)	-	-
Stigmella rhamnella [4]	1 (1.9)	2 (0.9)	-	-
Pyralidae :				
Acrobasis romanella [1]	1 (1.9)	--		-
Trachycera legatea [3]	-	3 (1.4)	-	-
Pieridae :				
Gonopteryx rhamni [2] [4] [5]	7 (13.5)	18 (8.4)	21 (44.7)	22 (26.5)
Geometridae :				
Philereme vetulata [4]	14 (26.9)	68 (31.8)	-	-
Philereme transversata [2] [3]	8 (15.4)	38 (17.8)	-	1 (1.2)
Triphosa dubitata [2] [4]	22 (42.3)	42 (19.6)	-	3 (3.6)
Triphosa sabaudiata [3]	-	2 (0.9)	-	-
Tortricidae :				
Ancylis apicella [1] [3] [4]	5 (9.6)	2 (0.9)	7 (14.9)	2 (2.4)
Ancylis derasana	6 (11.5)	9 (4.2)	3 (6.4)	-
Cochylidae:				
Hysterosia sodaliana	-	14 (6.5)	-	-
HOMOPTERA				
Psyllidae :				
Cacopsylla rhamnicola	5 (9.6)	6 (2.8)	-	1 (1.2)
Triozidae :				
Trichochermes walkeri	43 (82.7)	67 (16.8)	-	-
Trioza rhamni [4]	36 (69.2)	36 (16.8)	-	1 (1.2)
Cicadellidae :				
Zygina suavis	-	-5	(10.6)	-
HETEROPTERA				
Miridae:				
Heterocordylus erythrophtalmus	-	6 (2.8)	-	1 (1.2)
COLEOPTERA				
Cerambycidae:				
Oberea pedemontana	2 (3.8)	-2	(4.3)	-
ACARI				
Eriophyidae				
Phyllocoptes annulatus	9 (17.3)	--		-

[1] Also recorded on *Rhamnus alaternus* (Malicky et al. 1970)
[2] Also recorded on *R. orbiculata* (Malicky et al. 1970)
[3] Also recorded on *R. saxatilis* (Malicky et al. 1970)
[4] Also recorded on *R. alpina* (Malicky et al. 1970; personal observations)
[5] Also recorded on *Frangula rupestris* (Malicky et al. 1970)

patric sites have been recorded on *F. alnus* in sympatric sites, i.e. when given a proximate choice. In sympatric sites, *S. janiszewskae* and *G. rhamni* were the only species that were recorded more often on *F. alnus* than on *R. cathartica.*

Preliminary screening tests with *P. vetulata*, *T. dubitata* and *T. walkeri*, confirmed host plant use observed in the field and the unsuitability of *F. alnus* for insect species associated with *Rhamnus* in their native range (unpublished data). In contrast, both *Rhamnus* and *Frangula* species were suitable hosts for the larvae of *A. apicella* and *S. stomoxiformis*, two species which were recorded on both buckthorns in Europe.

4. Discussion

Assessing the risk to non-target species by a biological control agent has been a fundamental part of classical biological weed control for many decades. When developing biological control for *R. cathartica* and *F. alnus*, minimizing the risk of potential non-target effects might require the selection of agents which are specific to either *R. cathartica* or *F. alnus*. Several of the European arthropod species commonly found in areas that were surveyed during this study are considered monophagous on *R. cathartica*, or oligophagous on species in the genus *Rhamnus*.

Among the leaf chewing species associated with the genus *Rhamnus*, a geometrid, *P. vetulata*, appears to be the most specialised. Among the gall formers and sap-suckers that have been studied so far, the leaf margin gall psyllid *T. walkeri* seems to be monospecific on *R. cathartica*. There is considerable interest in this species because it attacks *R. cathartica* later in the season than *P. vetulata*. In North America, the high rate of seed production is an important element contributing to the invasiveness of *R. cathartica* (Knight et al., 2007). The seed-feeding midge, *W. krumbholzi* is considered a key candidate biocontrol agent because it could significantly reduce the seed production of common buckthorn in North America. The psyllids *C. rhamnicolla* and *T. rhamni*, the leaf miners *S. catharticella*, *C. quadrisignella* and *B. rhamniella*, the leaf chewers *T. dubitata* and *P. transversata*, and the mites *A. rhamni* and *T. rhamni* are probably specific to *R. cathartica* or to a few species in the genus *Rhamnus* and should be considered in a future phase of the project. With the possible exception of *S. janizewskae*, the few shoot borers and root borers associated with buckthorns in Europe lack host specificity at the genus level.

There are few genus-specific arthropods on *F. alnus*. Besides the leaf-hopper, *Z. suavis*, which was the most host-specific species found in this study, literature records indicate the existence of another five arthropod species known from *F. alnus* only. None of these were encountered during this study and additional surveys are needed to confirm their host ranges in the field in Europe. Current indications are that finding species-specific or genus-specific agents for biological control of *F. alnus* will be difficult.

Large numbers of herbivores are known to be associated with plants with larger geographical ranges (Lawton and Schroeder, 1977; Strong et al., 1984). *Rhamnus cathartica* and *F. alnus* have similar geographical distributions in Europe (Tutin, 1968), so range should not account for differences in the arthropod richness associated with the two

Table 3
Comparison of the frequency of occurrence of specialized buckthorn arthropods on *R. cathartica* and *F. alnus* in 59 allopatric and 20 sympatric sites (2002–05, Italy, Austria, Switzerland, Germany and the Czech Rep.)

	Allopatric sites		Sympatric sites		
Total No. of sites sampled:	32	27	20		
	Rhamnus cathartica	*Frangula alnus*	*Rhamnus cathartica*	*Frangula alnus*	*R. cathartica* and *F. alnus*
	Number of sites (%) with:		Number of sites (%) with:		
Bucculatrix frangutella	4 (12.5)	4 (14.8)	1 (5.0)	—	2 (10.0)
Sorhagenia janiszewskae	12 (37.5)	8 (29.6)	—	5 (25.0)	1 (5.0)
Calybites quadrisignella	1 (3.1)	—	2 (10.0)	—	—
Stigmella catharticella	1 (3.1)	—	1 (5.0)	—	—
Stigmella rhamnella	—	—	1 (5.0)	—	—
Acrobasis romanella	—	—	1 (5.0)	—	—
Gonopteryx rhamni	1 (3.1)	14 (51.9)	2 (10.0)	3 (15.0)	4 (20.0)
Philereme vetulata	6 (18.8)	—	8 (40.0)	—	—
Philereme transversata	3 (9.4)	—	5 (25.0)	—	—
Triphosa dubitata	17 (53.1)	—	5 (25.0)	—	—
Ancylis apicella	3 (9.4)	5 (18.5)	1 (5.0)	1 (5.0)	1 (5.0)
Ancylis derasana	3 (9.4)	2 (7.4)	2 (10.0)	—	1 (5.0)
Cacopsylla rhamnicola	4 (12.5)	—	1 (5.0)	—	—
Trichochermes walkeri	26 (81.3)	—	17 (85.0)	—	—
Trioza rhamni	23 (71.9)	—	13 (65.5)	—	—
Zygina suavis	—	3 (11.1)	—	2 (10.0)	—
Oberea pedemontana	—	—	—	—	2 (10.0)
Phyllocoptes annulatus	6 (18.8)	—	3 (15.0)	—	—

species. Centers of diversification of weed tribes or genera, which in turn are reflected by the highest number of congeneric or contribal species, are known to be the richest source of suitable herbivore species on certain weeds (Wapshere et al., 1989). Several studies found that taxonomic relatedness contributed significantly, though slightly, to arthropod species richness (e.g. Lawton and Schroeder, 1977; Neuvonen and Niemelä, 1981; Kennedy and Southwood, 1984). This is because related plants are likely to have the same chemical and physical traits and so are more likely to share herbivore insect species. Thus, plants with close relatives in a region (low taxonomic isolation) should have more herbivore species than those growing in isolation. In a study on the species richness of phytophagous insects and mites associated with 25 native tree genera in Germany, Brändle and Brandl (2001) concluded however that the importance of taxonomic isolation affecting herbivore species richness remains ambivalent. Contradictory results may be the consequence of the degree of taxonomic isolation (genus vs tribe or family), or the origin of the plant species considered (native vs introduced), the level of specificity of the herbivores considered (specialist vs generalist) or whether only a subset of the arthropod community is included in the study.

The genera *Rhamnus* and *Frangula* are predominant in the Old World and New World, respectively. In Europe there are 23 *Rhamnus* taxa as compared to four *Frangula* taxa. Thus, it appears that the evolution of *Rhamnus* and *Frangula* in isolation has led to specialization of arthropods on *Rhamnus* and *Frangula* species, with only a few specialist species on *F. alnus* in its native range in Europe and few species which are equally associated with both buckthorn species. Although we did not consider other sources of variability in the species richness of the arthropod fauna, such as plant abundance, this work supports the hypothesis that the species richness of specialized herbivores on native trees is affected by the taxonomic isolation of their hosts. It also shows that the search for, and selection of, potential biological control agents for a target weed can be facilitated by studying the arthropod species associated with related host plants from different lineages in centers of diversification.

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Population Biology of Garlic Mustard (*Alliaria petiolata*) in Minnesota Hardwood Forests

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Garlic mustard, a biennial forb native to Europe, has invaded native ecosystems in forested regions in the United States. In anticipation of a biological control program being implemented in the United States for this plant, a garlic mustard monitoring program was initiated. The objective of this study was to characterize garlic mustard populations and the associated plant communities and their response to environmental conditions in Minnesota hardwood forest ecosystems. Additionally, we developed a baseline for long-term studies to determine future benefits and impacts of biological control agents on plant communities infested with garlic mustard, should they be released. To monitor garlic mustard populations, we used a nationally standardized protocol in which data were collected on garlic mustard population density and cover, garlic mustard plant heights and silique production, insect damage to garlic mustard, cover of the associated plant community, and litter cover. We also collected data on available photosynthetically active radiation in the understory. The results underscore the variability in garlic mustard population dynamics. At only 6 of 12 sites did garlic mustard densities follow the predicted two-point cycles due to their biennial life cycle, with the first- or second-year life stage dominating in any given year. Available light did not differ strongly among sites, but shading by adult plants is implicated in keeping the populations of first-year plants low. Sites with greater garlic mustard cover had lower native species richness and cover than sites with lower garlic mustard cover. Absent biological control agents, garlic mustard is currently experiencing very little herbivory in Minnesota with an average of 2% of leaf area removed by herbivores. Our work shows the importance of pre-release monitoring at multiple sites over multiple years to adequately characterize populations. Without control, garlic mustard will likely continue to have negative impacts on northern forests.

Nomenclature: Garlic mustard, *Alliaria petiolata* (Bieb.) Cavara & Grande.

Key words: Pre-release monitoring, invasive species, biological control, herbivory, population cycling, biennial.

Garlic mustard [*Alliaria petiolata* (Bieb.) Cavara & Grande] is an invasive, nonnative species that is invading forested regions throughout the United States (Cavers et al. 1979; Meekins et al. 2001; Rodgers et al. 2008). Garlic mustard is a concern because of its ability to invade relatively undisturbed, diverse forests; form dense populations; and decrease abundance of native species (Blossey et al. 2001; Nuzzo 1999). Garlic mustard is part of a complex community, and how it interacts with members of that community is not clear. Abundant native deer and nonnative earthworms are likely facilitating garlic mustard invasion (Eschtruth and Battles 2009a; Nuzzo et al. 2009). Nonnative earthworms have invaded many forests and denuded the litter layer, altered soil processes, and decreased native species abundance (Bohlen et al. 2004; Hale et al 2005). Bartuszevige et al. (2007) found that garlic mustard seedlings had the greatest establishment in plots with litter removed vs. control or litter added plots. Blossey et al. (2005) observed that garlic mustard was often found in areas with little to no litter layer, indicating that garlic mustard may succeed in sites that have been invaded by earthworms. They observed that the overpopulation of deer in many areas has put additional pressure on native plants, noting that garlic mustard was generally grazed less than native plants and so may have done better than natives in sites with high deer population density.

High light availability can increase the biomass and seed production of garlic mustard plants (Meekins and

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Interpretive Summary

Invasive garlic mustard (*Alliaria petiolata*) has become abundant in many forested regions of the United States. This study examined the fluctuations of garlic mustard populations over time and their relationship with native species, levels of leaf litter, photosynthetic radiation, and insect herbivores. At half of the 12 monitoring sites, garlic mustard populations showed strong two-point cycling with alternating dominance of the first- and second-year life stages. Increased garlic mustard cover was negatively correlated with native species richness and cover. All sites had litter layers that had been significantly impacted by earthworms. Light was a key factor in understanding garlic mustard populations. Adult plant cover is higher where light is more abundant, but high cover of adult plants produces shade and can cause low cover of seedling plants. We found that less than 2% of garlic mustard leaf area is currently being damaged by herbivores in Minnesota.

These results have implications for both the release of potential biological control agents and restoration of garlic mustard invaded sites. The current lack of strong herbivory indicates that garlic mustard populations may be highly impacted by the release of biological control insects. If insects are to be released, it is useful to monitor the site for several years prior to release to determine the current densities of garlic mustard and normal fluctuations in population. If a site is strongly cyclical, it may be beneficial to time the release of biological control insects to match the life stage of the insect with the correct life stage of garlic mustard. When working to restore a site that has been heavily invaded by garlic mustard, the level of earthworm impact, the number and abundance of native species that remain, and any changes to the light available from the canopy should all be considered as factors that could influence the recovery of the site, in addition to the potential decrease in garlic mustard.

McCarthy 2000; Myers et al. 2005), ultimately influencing garlic mustard population size. Site differences in garlic mustard cover may be due to the amount of light a site receives (Eschtruth and Battles 2009b). Adult garlic mustard plants can shade out the seedlings growing beneath them, causing one life stage to dominate the other.

Presence of garlic mustard may change soil properties in forests. Garlic mustard has allelopathic root exudates that can inhibit germination in some species (Prati and Bossdorf 2004). The root exudates have also been found to have a negative impact on mycorrhizal fungi (Stinson et al. 2006; Wolfe et al. 2008). Many late-successional native species are dependent on mycorrhizae, so the loss of mycorrhizae can negatively affect native species abundance.

Due to the number of negative impacts of garlic mustard, a program was initiated to develop biological control agents for North America (Blossey et al. 2001). Currently, three weevil species are being tested at the University of Minnesota quarantine facility in cooperation with CABI Europe-Switzerland to determine their host specificity and suitability as biological control agents. The three species are the root-crown feeding weevil *Ceutorhynchus scrobicollis* Nerensheimer and Wagner and the stem-mining weevils *Ceutorhynchus alliariae* Brisout and *Ceutorhynchus robertii* Gyllenhal (Blossey et al. 2001; Katovich et al. 2005). It is anticipated that the release of biological control agents will cause a reduction in the cover, density, height, and reproductive output of garlic mustard plants and an increase in the amount of visible leaf damage. A petition to approve the release of *C. scrobicollis* was submitted to the United States Department of Agriculture (USDA)-Animal and Plant Health Inspection Service (APHIS) Technical Advisory Group in 2008. In 2009, the Technical Advisory Group recommended host-specificity testing for a few additional key plant species prior to approval. The additional tests are currently underway, and completion is expected in early 2010.

Historically, the benefits and impacts of biological control agents on plant communities have been difficult to assess due to the lack of pre-release baseline data (Blossey 1999). Garlic mustard is a biennial species whose population densities can fluctuate significantly from year to year (Meekins and McCarthy 2002) requiring several years of plant monitoring data to characterize invaded plant communities. By monitoring other plant populations growing with garlic mustard, we can gain a better understanding of the relationship and impacts of garlic mustard on native and nonnative plant species. The objective of this study was to characterize garlic mustard populations and the associated plant communities and their response to environmental conditions in Minnesota hardwood forest ecosystems. These data are a baseline for long-term studies from which to determine future benefits and impacts of biological control agents—should they be released—on plant communities infested with garlic mustard. By monitoring garlic mustard populations, we have a greater understanding of the role of density-dependent population dynamics, and the relationship between garlic mustard and factors such as light, litter cover, and native species.

Materials and Methods

Twelve monitoring study sites were established in hardwood forests in Minnesota. The sites are located between 44°6.600′ and 45°19.356′ N, and 92°3.821′ and 94°56.667′ W. To monitor these plant communities, we used the standardized protocol developed by the Ecology and Management of Invasive Plants Program in 2003 (available at http://www.invasiveplants.net). Sites were selected according to the following criteria: (1) the managers of the site agreed to suspend all management that could impact garlic mustard plants and biological control insects in the area (no herbicide treatments, burns, or pulling of garlic mustard populations), (2) the site had a well-established garlic mustard population of sufficient size to hold four 50-m (164-ft) transects spaced at least 10 m apart, and (3) the site could not be subject to flooding,

Table 1. Garlic mustard monitoring sites in Minnesota, 2005 to 2008. The identification (ID) column lists the abbreviation for that site as found in the figures.

Site no.	ID	Site name	City	County	Habitat type	Latitude, Longitude
1	BP	Baker Park Preserve*	Maple Plain	Hennepin	Upland	45°02.427′, 93°37.195′
2	CR	Coon Rapids Dam Regional Park	Coon Rapids	Anoka	Floodplain	45°07.975′, 93°17.841′
3	CG	Cottage Grove Ravine Regional Park	Cottage Grove	Washington	Upland	44°48.480′, 92°53.960′
4	FS	Fort Snelling State Park*	Saint Paul	Ramsey	Floodplain	44°52.373′, 93°11.634′
5	HP	Hilloway Park	Minnetonka	Hennepin	Upland	44°57.552′, 93°26.098′
6	LL	Luce Line	Long Lake	Hennepin	Upland	44°58.441′, 93°35.137′
7	NE	Nerstrand State Park, Prairie Creek SNA*	Nerstrand	Rice	Upland	44°21.527′, 93°05.809′
8	PB	Pine Bend Bluffs SNA*	Inver Grove Heights	Dakota	Upland	44°47.076′, 93°01.732′
9	PL	Plainview – private land	Plainview	Winona	Upland	44°06.600′, 92°03.821′
10	WN	Warner Nature Center*	Marine on St. Croix	Washington	Upland	45°10.853′, 92°49.641′
11	WH	Westwood Hills Nature Center	St. Louis Park	Hennepin	Upland	44°58.301′, 93°23.692′
12	WI	Willmar - private land	Willmar	Kandiyohi	Upland	45°19.356′, 94°59.667′

* = one of five sites established in time for spring 2005 data collection.

which might drown biological control insects and prevent the establishment of insect populations when released. At each site, 20 permanent 1-m by 0.5-m plots (0.5-m^2 quadrats) were established. The plots were placed along four 50-m transects with each transect containing five plots spaced 10 m from each other. Transects were placed through the center of the infestation, and each transect was at least 10 m from the nearest transect. According to the protocol, all plots must initially contain garlic mustard since the purpose is to monitor the impacts of biological control agents on garlic mustard, rather than monitor spread of garlic mustard populations. If there were no garlic mustard plants in a specific plot location along the transect 10 m from the previous plot, that plot was shifted down the transect to the next garlic mustard plant.

In June 2005, the initial five garlic mustard monitoring sites were established and data were collected. An additional 7 sites were established by the fall monitoring data collection period in October 2005 for a total of 12 sites (Table 1). In 2006 and 2007, data were collected from all 12 sites in June and October. All sites are upland deciduous forests, except for Coon Rapids (CR) and Fort Snelling (FS), which are floodplain forests, although flooding is rare due to management of adjacent rivers. The most common canopy tree species were *Acer negundo* L. (box elder), *Acer saccharum* Marsh. (sugar maple), *Fraxinus pennsylvanica* Marsh. (green ash), *Quercus rubra* L. (northern red oak), *Ulmus rubra* Muhl. (slippery elm), and *Tilia americana* L. (basswood). The most common understory tree species are *A. negundo*, *A. saccharum*, *Celtis occidentalis* L. (hackberry), *Ostrya virginiana* (P. Mill.) K. Koch (ironwood), *Rhamnus cathartica* L. (common buckthorn), and *U. rubra*.

Following the standard protocol, monitoring data were collected in June and October from 2005 to 2008. Garlic mustard is a biennial, and the data collected reflects the various life stages. Seedlings emerge in the spring, and by the fall of that year, develop into basal rosettes. Rosettes overwinter and bolt in the spring of the second year forming adult flowering stalks. Adult plants flower in the spring, set seed in the summer, and senesce by the fall. Spring data include both the first-year seedling and second-year adult stages, while only the first-year rosette stage is present in the fall. The adult plants can be further divided into those with siliques present and those with no siliques present. In each plot, all first-year garlic mustard plants were counted and a visual estimate of their percent cover made. In the spring, each second-year garlic mustard plant in each plot was measured to determine its height. The number of siliques of that individual was counted. The list of each adult plant height and number of siliques also resulted in a count of all adult plants in each plot. Visual estimates of percent cover of second-year garlic mustard plants were also made. Each year, the second-year plants senesced by October, so no fall data were collected on second-year plants.

In each plot, all other species present were identified and visual percent cover estimated for each species. Plants were identified to species when possible, and their percent cover in the plot recorded. For analysis, species were categorized as native, nonnative, or unknown (species that could not be identified to the taxonomic level where native or nonnative status could be determined). The number of native and nonnative species per quadrat was determined, and average native and nonnative species richness per 0.5-m^2 quadrat for each site was calculated. All native or nonnative determinations were based on the Minnesota Department of Natural Resources species list for Minnesota (2009).

Data were also collected to characterize herbivore damage to garlic mustard. Within each plot, a visual estimate was made of the percent of garlic mustard leaf area that was removed due to insect feeding. The following types of damage on garlic mustard plants within the plot were noted when present: leaf miner damage, windowpane feeding, edge feeding, holes, spittle bug presence, scale, browse, or disease.

Litter depth and ground cover at the site were also characterized. In the center of each half of each plot, a ruler was used to measure litter depth to the nearest cm. These two readings were then averaged to give a mean litter depth for each plot. For each plot, visual estimates were made of the percent cover of the ground that was composed of bare soil, wood, leaf litter, or rock. Low litter depths, low percent cover of leaf litter, and high percent cover of bare soil are indicative of sites that have high levels of disturbance by invasive earthworms (Bohlen 2004; Hale et al. 2005).

The amount of photosynthetically active radiation (PAR, 400 to 700 nm) penetrating the canopy was measured to determine if light differed among the sites and plots. Measurements were taken within 2 hr of solar noon, between August 11 and September 9, 2008. Tree leaves had not begun to change color or senesce. A LI-190SA point quantum light sensor with an LI-1000 data logger[1] was used to measure PAR levels in an area of full sun. The data logger sampled PAR levels every 5 s and recorded the average PAR level for 1-min intervals. Concomitantly, a 1-m LI-191SA line quantum light sensor and an LI-189 visual display[2] were used to take PAR measurements in plots under the forest canopy, placing the line sensor along the center of the 1-m-long axis of each plot. The PAR readings and time of each reading were recorded at 1 m above the soil surface to measure PAR transmitted through the forest canopy and available at the top of adult garlic mustard canopies, and at the soil surface to measure PAR available to seedling and rosette garlic mustard plants. The percent of full sun PAR incident at these two levels in the canopy was determined by dividing by the PAR reading under the canopy by the PAR reading in full sun at the time of the plot reading.

Data were summarized by season and site. In all graphs, the error bars are standard errors. A one-way ANOVA was used to determine if the percent of PAR reaching 1 m or the soil surface differed ($P = 0.05$) among the sites (Oehlert and Bingham 2005). Regressions and correlations were used to determine the strength of relationships among variables (Statistix 7 2000).

Results and Discussion

Fluctuations in Garlic Mustard Populations Over Time. Garlic mustard's biennial life cycle added to the complexity of garlic mustard cover and population density over time. At some sites, one life stage clearly dominated in each year, while other sites had populations that were stable, increasing, or decreasing. Figure 1 is a pictorial example of life cycle dominance at Baker Park (BP), a site dominated by adult flowering plants in spring 2005 with few seedlings present that resulted in few rosettes by the fall of 2005. In the spring of 2006, the seedling stage dominated with many seedlings and very few adults. By fall 2006, rosettes were the dominant growth stage. Half of the sites studied (6 of 12) showed this pattern of one life stage dominating in a given year, but at each of these 6 sites, both first- or second-year life stages were present in a given year (Figure 2a). Two sites, Warner Nature Center (WN) and Westwood Hills (WH) showed strong cycling in all 4 yr with rosette densities peaking every other year, while four other sites showed cycling in only 3 of the 4 yr (CR, CG, LL, and NE). Populations were relatively stable at 2 of the 12 sites, FS and Hilloway Park (HP), with little variation in rosette population density from year to year with first- and second-year plants coexisting each year. Population densities increased at Willmar (WI) and decreased at Pine Bend (PB) from 2005 to 2008.

Patterns that were clear in the fall data were less visible in the spring, possibly an artifact of fewer replications included in the spring 2005 data. In most cases, the sites that showed strong year to year population cycling of rosettes in the fall also showed strong cycling of spring population densities of seedlings and adults (Figure 2b, c). For example, the population density of adult plants at WN

Figure 1. Photos of a single plot over time, showing a typical biennial cycle of the dominance of different garlic mustard life stages at Baker Park, MN, 2005 to 2006. The adult flowering plants were dominant in spring 2005 with few seedlings present. By fall 2005, the adults senesced and there was little other vegetation present. In spring 2006, there was a carpet of garlic mustard seedlings. By fall 2006, the surviving seedlings had grown into rosettes.

fluctuated widely, going from an average of 1 plant m^{-2} in 2005 to 85.2 plants m^{-2} in 2006 and then down to 15.4 plants m^{-2} in 2007 (Figure 2c). The low of 1 plant m^{-2} (in 2005) at WN and the high of 133 plants m^{-2} (in 2008) at WN were the lowest and highest adult garlic mustard population densities found across all sites and years. Seedling densities also ranged widely, from a low of 8.2 plants m^{-2} to a high of 301.2 plants m^{-2} on average at CR (Figure 2b).

High mortality occurred as garlic mustard plants progressed through life stages. Many seedlings died before reaching the fall rosette stage. The mean May to October mortality for garlic mustard seedlings averaged across all sites was 47, 52, and 77% in 2006, 2007, and 2008, respectively. Winter survival fluctuated dramatically across years. The mean mortality of rosettes overwintering to form adult plants averaged across sites was 7, 45, and 18% for 2005 to 2006, 2006 to 2007, and 2007 to 2008, respectively. Year to year differences indicate that factors such as precipitation and temperature in a given year can strongly influence garlic mustard survival. For example, the high mortality for first-year garlic mustard plants in 2008 may have been due to low precipitation in that year: 37 cm of precipitation from May to October 2008 vs. the 30-yr (1971 to 2000) average of 52 cm (Minnesota Climatology Working Group 2009).

In addition to monitoring garlic mustard population densities, we also monitored the percent cover of garlic mustard. At some sites, small numbers of plants were large and covered a large percentage of the plot, while at other sites, large numbers of very small plants covered only a small area. The average total percent cover of garlic mustard in the spring (adults plus seedlings) ranged from 20 to 70% among the sites (Figure 3). Garlic mustard cover decreased in the fall because the adult plants had set seed and senesced, so only first-year rosettes were present. Average total garlic mustard cover (seedlings plus adults in the spring, rosettes in the fall) did vary from year to year, although the range of garlic mustard cover was similar from year to year.

When garlic mustard populations are governed by density-dependence, they show a two-point cycle with the adult and seedling/rosette stages alternating in dominance (Pardini et al. 2009). In our study, only half of the sites show this two-point cycle. The population dynamics at the other six sites may not have been governed by density-dependence. Populations of garlic mustard in poor habitats with low population densities do not exhibit the two-point cycle, and high density populations are more likely to cycle (Pardini et al. 2009). However, in our study, the six sites

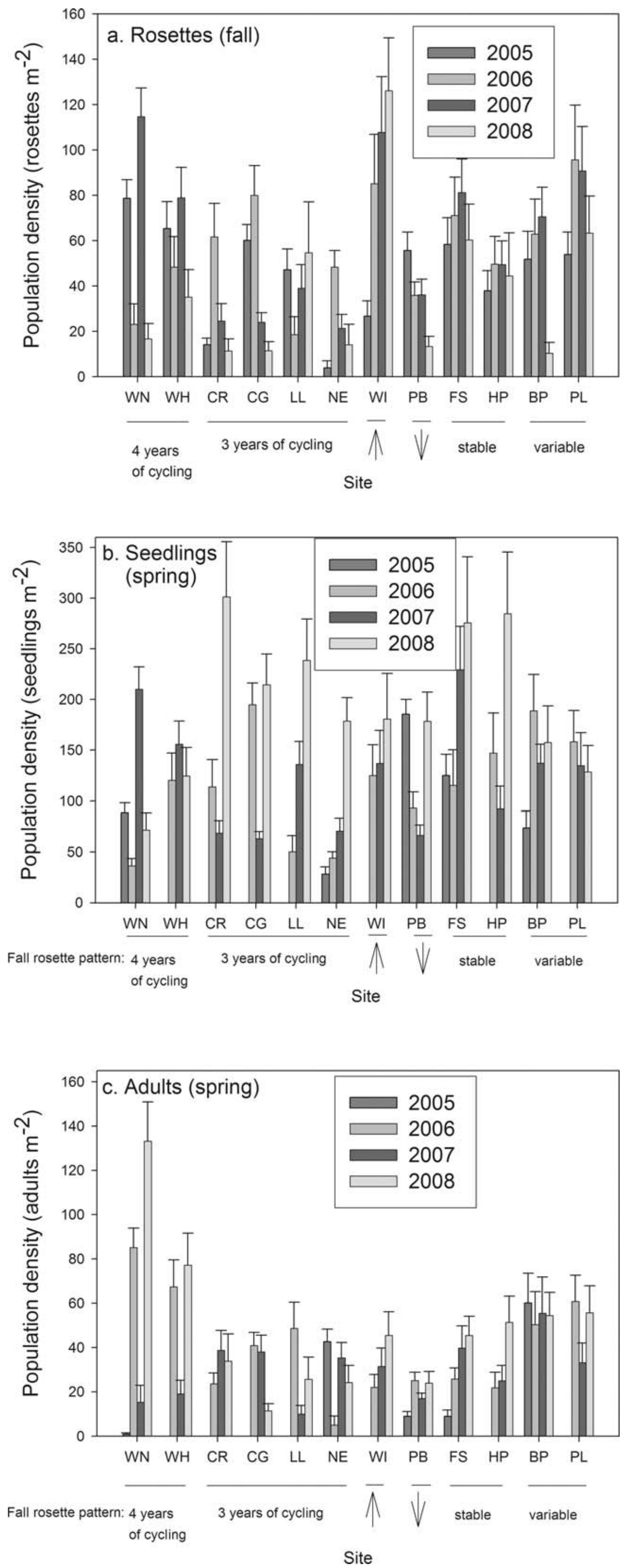

Figure 2. Mean population density (± standard error [SE]) of (a) garlic mustard rosettes, (b) seedlings, and (c) adults over time at 12 monitoring sites in Minnesota, 2005 to 2008. Data were collected on the rosettes in the fall at all 12 sites for 2005 to ← 2008. Data were collected on seedlings and rosettes in the spring at 5 monitoring sites in 2005 (NE, WN, BP, FS, and PB) and at all 12 monitoring sites in 2006 to 2008. Sites are organized according to the rosette density patterns seen in the fall data. Two sites show strong cycling (one life stage is dominant each year) with rosette densities peaking every other year for all 4 yr. Four sites show cycling in the first 3 yr. WI has increasing population density and PB has decreasing population density as indicated by arrows. Two sites are relatively stable with little year to year variation in rosette population density (densities with SE overlap from year to year). Two sites show variation over time and don't clearly fit with any of the previous categories. BP = Baker Park, CR = Coon Rapids, CG = Cottage Grove, FS = Fort Snelling, HP = Hilloway Park, LL = Luce Line, NE = Nerstrand, PB = Pine Bend, PL = Plainview, WN = Warner Nature Center, WH = Westwood Hills, WI = Willmar.

without cycling did not have lower population densities than the sites where cycling occurred. Garlic mustard populations can vary greatly from year to year and with moderate levels of mortality can fall into complex and chaotic population dynamics (Pardini et al. 2009). Intraspecific competition favors the separation of the two age classes (Winterer et al. 2005). Dense garlic mustard itself can suppress its own seedlings, so sites that have a rapid establishment of garlic mustard may show cycling as a legacy of the initial wave of garlic mustard plants (Meekins and McCarthy 2002).

Within a larger population, there can be subpopulations that are established by different colonization events, and these subpopulations may cycle out of synch with one another (Meekins and McCarthy 2002). It is possible that there was subpopulation cycling at the non-cycling monitoring sites but that, if present, occurred at a smaller scale than we analyzed. For example, half the plots could have been dominated by seedlings, while the other half were dominated by adults, and together they even out. To see if individual plots tended to be dominated by one life stage or another, we analyzed data from individual plots from the six non-cycling sites. The total amount of spring garlic mustard cover (seedling cover + adult cover) was determined for the spring evaluations and the portion of that cover that was accounted for by each life stage determined. In 2006, 40% of the individual plots at the six non-cycling sites were dominated by seedling garlic mustard plants (seedlings accounting for 80 to 100% of garlic mustard cover, with the remaining 0 to 20% of garlic mustard cover comprised of adult plants). The reverse occurred in only 27% of the individual plots where adults comprise 80 to 100% of cover. Together, one or the other life stage dominated in 67% of individual plots. These patterns were similar in 2007 (49% of plots with 0 to 20% garlic mustard cover due to adults, and 17% with 80 to

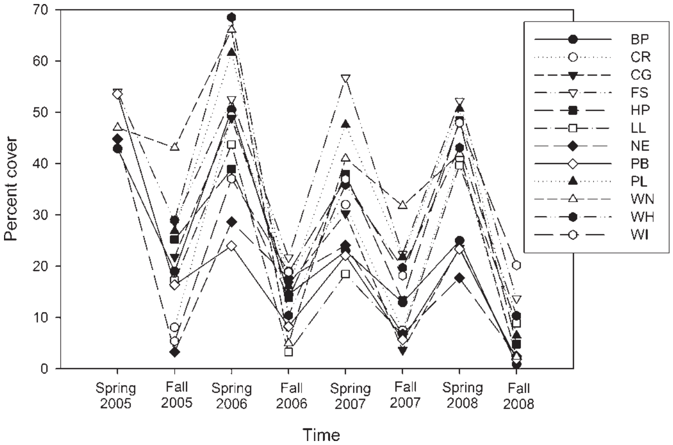

Figure 3. Mean visual percent cover of garlic mustard at each site over time. Spring garlic mustard cover is the total cover of adults and seedlings. Fall cover is cover of the rosettes. Data were collected in Minnesota in the spring at 5 monitoring sites in 2005 (BP, FS, NE, PB, and WN) and at all 12 monitoring sites in 2006 to 2008. BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature Center, WH=Westwood Hills, WI=Willmar.

100% cover due to adults, for a total of 66% of plots dominated by one life stage) and 2008 (37, 26, and 63%, respectively).

Our results indicate that at the individual plot level, garlic mustard populations tended to be dominated by one life stage or the other. Based on our data, half of the 12 sites monitored did not appear to display a cycle of dominance of one life stage over the other on average. However, even at these sites, several individual plots were cycling with either adult or seedling stages of garlic mustard. This phenomenon—if it occurs beyond Minnesota as well—lessens concerns, though still present, that critical life stage synchrony may not be available and may limit successful establishment of biological control insects. Knowledge of the life stage of a particular site, in addition to its importance to successful establishment of biological control agents, is important to determining the impacts of biological control agents post-release.

It will take several years of monitoring data to determine if a particular garlic mustard population is increasing, decreasing, or stable. Applying control methods can release remaining garlic mustard plants from intraspecific competition, and cause garlic mustard populations to no longer be governed by density-dependence and to exhibit complex and unpredictable changes in population density (Pardini et al. 2009). Monitoring garlic mustard populations over time after biological control insects are established will be especially important in determining whether these complex population dynamics occur, or if there is a general decline in garlic mustard populations.

Fluctuations in Garlic Mustard Plant Height and Reproductive Output. Large natural fluctuations in annual garlic mustard reproductive output as determined by plant height and numbers of siliques were detected as height and silique production decreased from 2006 to 2007 with rebounds in 2008 (Figure 4a and 4b). The mean height of adult garlic mustard plants decreased at all 12 sites from 2006 to 2007 (Figure 4a). Mean heights ranged from 48 to 82 cm in 2006, but only 21 to 56 cm in 2007. Shorter garlic mustard plants then produced fewer siliques (Figure 4b). In 2006, silique production was high with 134 to 888 siliques m^{-2}, but by 2007 there were only 86 to 480 siliques m^{-2} (Figure 4b). The number of siliques produced per m^2 varied considerably from year to year depending on whether the silique-producing adult plants or the nonreproductive seedling stage was dominant. The mean number of siliques per garlic mustard stem ranged from 2 to 22 siliques $stem^{-1}$ (Figure 4c). Since plants were generally shorter in 2007 than 2006, they correspondingly produced fewer siliques per plant with 5 to14 siliques $stem^{-1}$ in 2006 vs. 2 to11 siliques $stem^{-1}$ in 2007 (Figure 4c). Environmental factors, such as below normal precipitation in 2007, were the likely cause of decreased growth and production of siliques at all the sites. From April to June 2007 there were only 13 cm of precipitation compared to the 30-yr (1971 to 2000) average April to June precipitation of 25 cm (Minnesota Climatology Working Group 2009). Other studies have found that June precipitation correlates positively with garlic mustard rosette density in October of that year and adult density in June of the next year (Hochstedler and Gorchov 2007; Slaughter et al. 2007).

To further characterize the population, adult stems were categorized as with or without siliques. When biological control is released, we expect that the insects will damage plants and cause a reduction in plant height and number of siliques (Gerber et al. 2007a,b). At most sites, more than 95% of the adult stems produced siliques (Figure 4d). With one exception, the sites had fewer than 10% barren stems. The abnormally high percentage of barren stems (26%) observed at HP in 2006 was due to early season *R. cathartica* control, which resulted in herbicide drift onto garlic mustard plants. This caused reduced and delayed silique development in many plants.

Relationship Between Garlic Mustard and Native Species. Our work supports previous findings that garlic mustard forms dense populations that negatively impact native species (Blossey et al. 2001; Nuzzo 1999; Stinson et al. 2007). There were consistent negative correlations between total garlic mustard cover in the spring (adults + seedlings) and native species richness in the spring (Pearsons correlation P = 0.04, 0.27, 0.24 and R^2 =

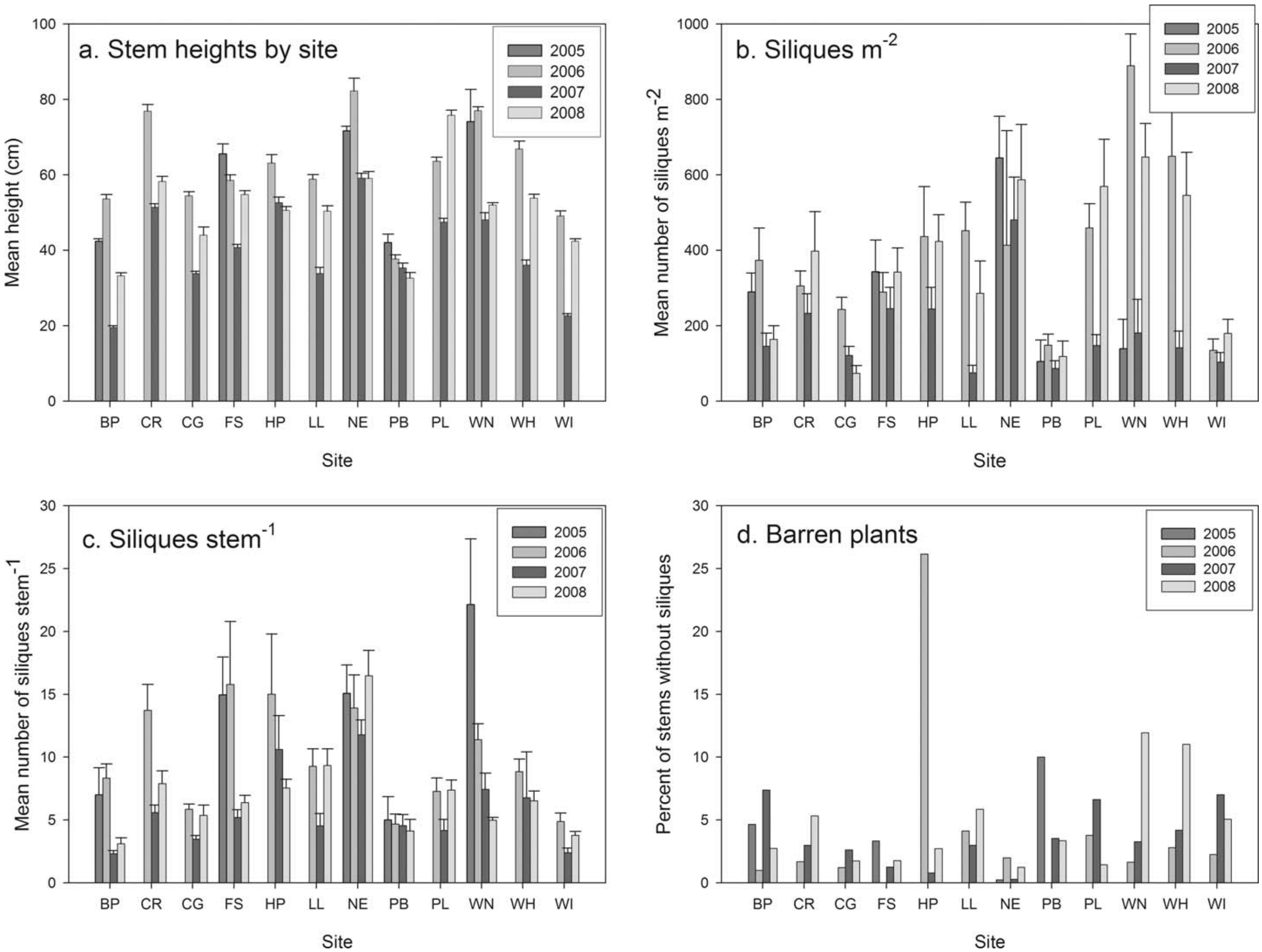

Figure 4. (a) Mean adult garlic mustard plant height (± standard error [SE]) by site, (b) mean number of siliques per m^2 (± SE) (an estimate of seed output at a site), (c) mean number of siliques per adult stem (± SE) (a measure of the fecundity of individual plants at a site), and (d) percent of adult garlic mustard stems without siliques present (the total number of sterile stems recorded at the site / total number of stems at the site × 100%). Data were collected in Minnesota in the spring at 5 monitoring sites in 2005 (BP, FS, NE, PB, and WN) and at all 12 monitoring sites in 2006 to 2008. Note that the 2006 HP percent barren plants was high because many garlic mustard plants were impacted by herbicide drift from adjacent buckthorn treatments. BP = Baker Park, CR = Coon Rapids, CG = Cottage Grove, FS = Fort Snelling, HP = Hilloway Park, LL = Luce Line, NE = Nerstrand, PB = Pine Bend, PL = Plainview, WN = Warner Nature Center, WH = Westwood Hills, WI = Willmar.

−0.59, −0.34, and −0.36 for 2006, 2007, and 2008, respectively). There were also consistent negative correlations between total garlic mustard cover in the spring (adults + seedlings) and native species percent cover in the spring, although P values were nonsignificant (Pearsons correlation P = 0.09, 0.28, 0.13 and $R^2 = -0.51$, −0.34, −0.47 for 2006, 2007, and 2008, respectively). The highest species richness was found in the spring in these habitats. Sites differed strongly in disturbance history, from scientific and natural areas with late-successional, high diversity forests to highly disturbed, second-growth forests in urban parks, which is likely a strong driver of native species cover and richness differences among the sites.

The most common native species found were *Galium aparine* L., *Circaea lutetiana* L., *Fraxinus pennsylvanica* seedlings, *Geum canadense* Jacq., *Ageratina altissima* (L.) King & H.E. Rob. var. *altissima*, *Pilea pumila* (L.) Gray, *Osmorhiza claytonia* (Michx.) C.B. Clarke, and *Laportea canadensis* (L.) Weddell. The most common nonnative species found were *R. cathartica*, *Glechoma hederacea* L., *Hackelia virginiana* (L.) I.M. Johnst., *Taraxacum officinale* G.H. Weber ex Wiggers, and *Solanum dulcamara* L. Spring

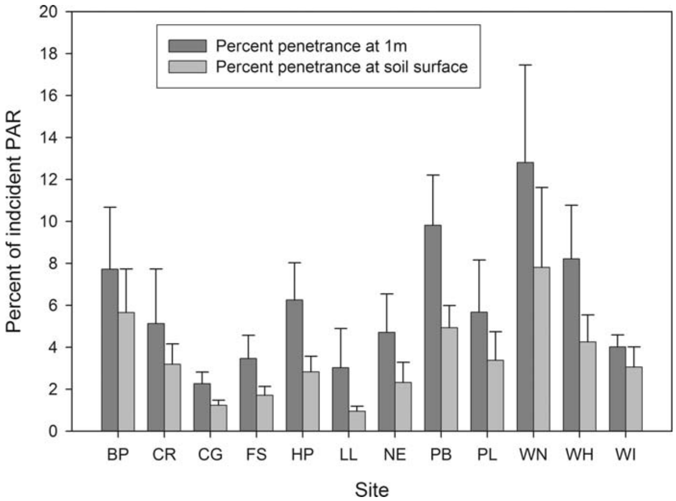

Figure 5. The mean percent of incident photosynthetically active radiation (PAR) penetrating to 1 m above the soil surface and at the soil surface (± standard error [SE]) as measured in August and September 2008 within 2 hr of solar noon at 12 sites in Minnesota. BP = Baker Park, CR = Coon Rapids, CG = Cottage Grove, FS = Fort Snelling, HP = Hilloway Park, LL = Luce Line, NE = Nerstrand, PB = Pine Bend, PL = Plainview, WN = Warner Nature Center, WH = Westwood Hills, WI = Willmar.

native species richness per 0.5-m^2 quadrat ranged from a low of 1.8 at BP in 2005 to a high of 7.1 at WI in 2008. Native species cover ranged from a low of 8.3% cover at Luce Line (LL) in 2008 to a high of 51.4% cover at WI in 2008. Nerstrand (NE) had the lowest nonnative species richness (the number of nonnative species present, not including garlic mustard) and cover with no nonnative species present in the spring from 2005 to 2007, and one nonnative species present in 2008 (*T. officinale*). The highest nonnative species richness per quadrat (1.8 nonnative species) and cover (27.8% cover) were found at CR in 2008 and were typically *G. hederacea* and *R. cathartica*.

The low numbers and cover of native species raise concerns for site restoration following garlic mustard control. If garlic mustard cover and population density are reduced, having a diverse and large native species population increases the chances that the site may move to a more native-species dominated state with minimal active restoration. However, once garlic mustard cover is high and native species richness is low for an extended period of time, it is much more likely that active restoration actions may be necessary to restore native species to the sites. Studies of herbicide treatments of garlic mustard have found that native species, such as spring ephemerals, increase in cover after garlic mustard is reduced (Carlson and Gorchov 2004), although the effect is not always consistent among years (Hochstedler et al. 2007).

Garlic Mustard, Leaf Litter, and Earthworms. Our results showed little evidence for earthworm impacts on garlic mustard populations through reduced litter layer (data not shown) in part due to the fact that the studies were not designed to directly study earthworm impacts. All sites were found to have significantly impacted litter layers, so comparisons with undamaged sites are lacking. It has been shown, however, that garlic mustard invasion can be facilitated by earthworm invasion (Blossey et al. 2005; Nuzzo et al. 2009). We used low depth of the litter layer and high cover of bare soil as indicators of earthworm disturbance. All sites had very low depth of litter with average depths of litter in the spring ranging from < 0.1 to 2.4 cm. These data suggest that earthworms may have been burying leaf litter at all 12 sites; however, more research would be needed to confirm this. Observed depths of litter were consistent with low depths of litter recorded by other researchers in Minnesota (depth of litter layer has been shown to decrease from 10 to 0 cm with the presence of earthworms (Hale et al. 2005)). There was no accumulated litter from previous years. The litter that was measured was recent leaf fall, indicative of earthworm activity. The low variation in depths of litter across sites made it difficult to detect any relationship between increased garlic mustard densities in sites with low depth of litter (data not shown, regression P values > 0.34, $R^2 < 0.09$ in 2006, 2007, and 2008). The percent cover of bare ground did vary widely across sites, ranging from 0 to 84% of the ground cover in the spring. Even with a range of bare ground cover, there was no indication of increasing garlic mustard population density with increasing amounts of bare ground (data not shown, regression P values > 0.54, $R^2 < 0.04$ in 2006, 2007, and 2008). The widespread occurrence of low levels of litter indicate that garlic mustard populations will continue to grow and spread, as low litter sites are ideal for garlic mustard seedling establishment (Bartuszevige et al. 2007).

Influence of Available PAR. We looked at the potential for light availability to explain site to site differences and the tendency for some sites to be dominated by one life stage in a given year. Measurements in August and September of 2008 showed all sites generally had low levels of percent of full sun PAR incident at the top of the garlic mustard canopy (1-m height, mean of 6 ± 0.7%) or at the soil surface (mean of 3 ± 0.4%). Percent incident PAR at either level did not differ among sites due to large variations within these low levels (one-way ANOVA at 1 m $P = 0.08$, $F_{11,228} = 1.69$; and soil surface $P = 0.07$, $F_{11,228} = 1.72$). Mean percent of full sun PAR incident at the 1-m level ranged from 2% at Cottage Grove (CG) to 13% at WN, and at ground level from 1% at LL and CG to 8% at WN (Figure 5). Each site generally had a few plots in an area of a canopy opening, with some openings

Table 2. Garlic mustard presence and types of insect feeding at 12 sites in Minnesota, 2005 to 2008. The percentage of plots with garlic mustard present out of the 20 plots at each of 12 study sites in Minnesota over 3 yr are presented (5 study sites in spring 2005, 12 study sites for all other dates). Of the plots with garlic mustard present, the percentages of those plots with various types of visual leaf damage estimates are listed by the type of feeding damage.

Time	Plots with garlic mustard present	Plots with feeding by this insect type (of plots with garlic mustard present)				Mean leaf removal
		Edge feeding	Holes	Leaf miner	Windowpane feeding	
	%					
Spring 2005	100	96	98	31	4	1.6
Fall 2005	87	99	98	1	1	1.5
Spring 2006	98	96	97	31	9	1.5
Fall 2006	84	97	98	< 1	< 1	2.0
Spring 2007	99	100	100	33	0	1.8
Fall 2007	88	97	96	1	0	2.4
Spring 2008	99	100	98	12	4	2.3
Fall 2008	63	97	91	0	< 1	3.0

allowing 20 to 90% of ambient light to reach the plots, accounting for the large standard errors in the mean percentages of incident PAR.

The light measurements taken in August and September 2008 to characterize the sites were compared with the garlic mustard seedling and adult percent cover measures taken in June 2008 and rosette percent cover measures taken in October 2008. When the garlic mustard cover data for the 240 plots were regressed against the amount of incident PAR, there were no strong relationships. Regressions of garlic mustard cover vs. the amount of incident PAR at the soil surface showed no relationship with seedlings ($P = 0.26$, $R^2 = 0.005$) and rosettes ($P = 0.78$, $R^2 = 0.0003$), and a weak positive relationship with adults ($P = 0.003$, $R^2 = 0.032$). The pattern was similar for regressions vs. PAR at 1 m above the soil surface for seedlings ($P = 0.17$, $R^2 = 0.008$), adults ($P = 0.01$, $R^2 = 0.025$), and rosettes ($P = 0.41$, $R^2 = 0.003$). However, when mean garlic mustard cover and incident PAR levels were calculated for the 12 sites and the data analyzed at the site level, there was a significant relationship between light and seedling cover. The regression of the cover of garlic mustard seedlings against percent of PAR penetrating to the soil surface showed a negative relationship ($P = 0.01$, $R^2 = 0.49$), while the relationships with PAR and adult cover ($P = 0.12$, $R^2 = 0.22$, trending positive) and rosette cover ($P = 0.32$, $R^2 = 0.10$, trending negative) were nonsignificant. Regressions of garlic mustard cover against light at 1 m above soil surface were similar to those at the soil surface for seedlings ($P = 0.01$, $R^2 = 0.48$), adults ($P = 0.13$, $R^2 = 0.21$), and rosettes ($P = 0.25$, $R^2 = 0.13$). The seedling stage appeared to be most sensitive to the amount of available light. Adult garlic mustard plants showed greater percent cover in sites with higher available PAR, but cover of seedlings and rosettes showed the opposite pattern. These PAR measurements were taken in August and September after the adults had died back. At sites with high adult cover, adults likely shaded out seedlings, causing the sites with high adult cover to have low cover of seedlings. The pattern of lower cover of seedlings likely persisted as the seedlings grew into rosettes.

Overall, sites were similar in the amount of light available, indicating that light alone is likely not driving site differences. Adult plants trended toward the expected pattern of increased growth with increased light (Meekins and McCarthy 2000; Myers et al. 2005). The negative relationship of seedlings and rosettes with light supports the density-dependent nature of garlic mustard (Pardini et al. 2009) with the adult plants shading out the younger plants and keeping the cover of younger plants low.

Garlic Mustard Herbivory Levels. While evidence of insect feeding was widespread, the actual amount of leaf damage was low (Table 2). Leaf feeding damage was found in 96 to 100% of plots in which garlic mustard was present. The most common forms of damage were edge or internal hole feeding present on over 91% of the plots that contained garlic mustard. Leaf mining and windowpane feeding also occurred, but at much lower levels. While edge and hole feeding was common in the spring and fall, leaf mining was a much less common occurrence in the fall, decreasing from 31% in the spring to only 1% in the fall, since most leaf mining was on adult plants. Across all sites, seasons, and years, the average amount of leaf area damaged due to insects was 2.0 ± 0.03%. Across sites, mean leaf damage by insect feeding did not vary widely across years or seasons with a range of 1.5 to 3.0%. Among the individual sites, the lowest mean leaf removal was 1.0% at PB in spring 2006, while the highest was 5.5% at FS in fall 2008.

Notably, little insect damage was present on garlic mustard populations in Minnesota. The 2% leaf damage levels in Minnesota were similar to the 3% leaf damage levels reported in Michigan (Evans and Landis 2007). Releasing *C. scrobicollis* weevils for biological control would introduce a significant, new stressor to garlic mustard (Gerber et al. 2007b).

Implications for Biological Control. Garlic mustard plant population densities and dominant growth stage varied considerably from year to year, amplified in part by its biennial life cycle. At some sites, population fluctuations were due the cyclic changes in dominance between the seedling and adult stages. Understanding which cycle a site is in at the time of biological control agent introduction will improve chances for biological control insect establishment, which is most critical in the first releases when numbers of insects available for release will be limiting. Releases should be targeted matching the phenologies of the target plant, insect, and the method of insect release, e.g., releasing egg laying adults whose larvae need to burrow into stems or feed on seeds in a cycle where seedlings will dominate should be avoided. It is also important to take these population cycles into account when analyzing the impacts of management efforts. A decrease in adult plants from 1 yr to the next may simply be a result in this natural oscillation in life stage dominance.

Should biological control insects be released, we expect to see decreases in garlic mustard populations (Davis et al. 2006; Gerber et al. 2007a,b). If biological control insects are approved for release, insects will be released on 6 of the 12 monitoring sites while the other 6 will act as controls. This will allow us to separate changes in plant communities due to biological control insects from changes due to other biotic or abiotic factors. Individual species and functional groups have been found to vary in their responses to experimental removal of garlic mustard (McCarthy 1997; Stinson et al. 2007). Tree seedlings and native grasses are especially susceptible to the presence of garlic mustard and are some of the first species to increase after garlic mustard removal (McCarthy 1997; Stinson et al. 2007).

We found that garlic mustard in Minnesota is currently experiencing very little herbivory. This lack of insect stressors may be one reason why garlic mustard has been such a successful invader. We confirmed that garlic mustard is currently lacking significant insect or disease pressures, and has the resources available to complete its life cycle and produce abundant seed. It is anticipated that the introduction of biological control insects in the United States will stress the plants and result in smaller plants that produce fewer siliques, as reported by Gerber et al. (2007a,b), and the number of stems without siliques will increase. It will likely take several years of reduced garlic mustard populations before impacts on the forest understory can be observed (Hochstedler et al. 2007).

After biological control release, the potential exists for large differences in native plant community recovery among the different sites. Some sites have high levels of disturbance (low litter levels, high nonnative species cover) while others have a more robust native plant community. For example, excluding garlic mustard, NE had no cover of other nonnative species measured in the spring for 3 yr. If garlic mustard decreases, there is a diverse native species community ready to expand. In contrast, BP had the lowest cover of native species and the highest diversity of nonnative species. Monitoring will indicate whether native species are able to reestablish in areas currently dominated by garlic mustard. Our studies encompassed a sufficiently robust range of disturbance levels, light levels, and other abiotic factors to enable us to adequately characterize potential impacts of the biological control agents should they be released, and determine whether those impacts are consistent across sites. Furthermore, this study demonstrates the wide variability in garlic mustard population dynamics, the potential for continued negative impacts of garlic mustard to the remaining native species, and the potential for restoration challenges should garlic mustard be reduced.

Sources of Materials

[1] LI-190SA point quantum light sensor and LI-1000 data logger, LI-COR Biosciences, 4647 Superior St., Lincoln, NE, 68504.

[2] 1-m LI-191SA line quantum light sensor and LI-189 visual display, LI-COR Biosciences, 4647 Superior St., Lincoln, NE, 68504.

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Report 2008-2009

Biological control of backthorns, *Rhamnus catartica* and *Frangula alnus*

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Biological control of buckthorns, *Rhamnus cathartica* and *Frangula alnus*

Report 2008–09

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Table of Contents

Summary

Following a reassessment of the potential for biological control of *Rhamnus cathartica* and *Frangula alnus*, work carried out in 2008–09 concentrated on the biological control of the former species using the leaf-feeding moth *Philereme vetulata*, the leaf-margin gall psyllid *Trichochermes walkeri* and the seed-feeding midge *Wachtiella krumbholzi*.

Fecundity of *P. vetulata* in 2008–09 was much lower than in previous years. A test to see whether the fecundity of adults reared on *R. alnifolia* from North America was lower than that of adults reared on *R. cathartica* therefore yielded inconclusive results. Larval feeding and development tests were conducted with eight plant species, six of which are native to North America. Complete larval development was recorded on *R. cathartica, R. alnifolia* and *R. erythroxylon*, a species native from China. As in previous years, we were unable to obtain oviposition under field cage conditions. This method therefore appears unsuitable for testing the egg-laying behaviour of *P. vetulata.*

In a no-choice test, *T. walkeri* laid the same number of eggs on *R. alaternus* from Europe and on *R. cathartica*. In contrast, only a few eggs were laid on *R. prinoides* from South Africa in a similar test. A single-choice test confirmed that *R. alnifolia* may be used for oviposition. In summary, a few species in the genus *Rhamnus* (*R. alnifolia*, *R. alaternus* and to a lesser extent *R. prinoides*) appear suitable hosts for oviposition by *T. walkeri* in no-choice and/or choice conditions but neither gall nor larval development were recorded on any of the non-target *Rhamnus* species. The North American species *R. ilicifolia* does not seem to support adult survival.

The phytoplasma '*Candidatus* Phytoplasma rhamni' (16SrX-E group) has been detected in two populations of *T. walkeri* in Switzerland. This is the first record of '*Candidatus* Phytoplasma rhamni' in Switzerland and *T. walkeri* is also the first insect host record for this phytoplasma.

The cecidomyiid *W. krumbholzi* is much more common in Europe than previously indicated in the literature since it has been recorded on *R. cathartica* at all sites sampled. Successful oviposition was obtained in the very young developing fruits of *R. cathartica*. In contrast, no oviposition occurred in the well-developed, one-month-older fruits. No midge larvae were found in the fruits of *F. alnus* at two sites where *R. cathartica* and *F. alnus* co-occur and no oviposition was recorded on the latter species in confinement.

A review of successes and failures in biological control of trees and shrubs included in this report shows that beetles, sap suckers, gall wasps and rust fungi are the most successful taxonomic groups for these target plants. In addition, any agents directly or indirectly reducing seed output are expected to facilitate management of the target tree or shrub. Based on this review, further recommendations are made for biological control of *R. cathartica*.

1 Introduction

Rhamnus cathartica (common buckthorn) and *Frangula alnus* (glossy buckthorn) (Rhamnaceae) are both shrubs and small trees of Eurasian origin which have become invasive in North America.

Rhamnus cathartica was introduced to North America as a landscape plant and used as a shelter-belt tree because of its winter hardiness and its ability to grow in multiple soil types and habitats (Archibold et al. 1997). It has spread extensively and is currently found in most Canadian provinces (Nova Scotia to Saskatchewan) and 27 US states predominantly in the north-central and north-eastern portion of the country (Gale 2001; USDA/NRCS 2001). It is one of the most invasive woody perennials in natural ecosystems and has negative impacts on agriculture. Common buckthorn is a suitable overwintering host for soybean aphid, *Aphis glycines*, and the spring host for oat crown rust, *Puccinia coronata* (see Yoder et al. 2008 for references).

Frangula alnus was imported to North America prior to the 1900s as horticultural stock for landscape plantings and has become naturalized in the north-eastern USA and south-eastern Canada (Catling and Porebski 1994; Randall and Marnelli 1996; Haber 1997). Currently, *F. alnus* occurs from Nova Scotia to Manitoba, and south to Minnesota, Illinois, New Jersey and Tennessee, in a range incorporating 23 states in the USA (Converse 2001; USDA/NRCS 2001).

Research to develop biological control for buckthorns was initiated in 1964 and preliminary screening tests were conducted in 1966–1967 (Malicky et al. 1970). A new programme was started in 2001 and has taken into consideration increasing concerns over potential non-target impacts of biological control agents and greater demands for high levels of specificity (Louda et al. 1997; Pemberton 2000).

In 2008, we presented a reassessment of the potential for biological control of *R. cathartica* and *F. alnus* by target species and by the arthropod-feeding guilds (Gassmann et al. 2008a). It was based on work conducted in Europe in 2002–2007 on selected potential biological control agents (Gassmann et al. 2006, 2007). The assumption was that candidate biological control agents should be monospecific to *R. cathartica* or *F. alnus* or their host ranges should be restricted to a few species in either the genus *Rhamnus* or the genus *Frangula*. Following discussions with our counterparts in the USA, it was decided to focus on the biological control of *R. cathartica* and on the leaf-feeding moth *Philereme vetulata*, the leaf-margin gall psyllid *Trichochermes walkeri*, and the seed-feeding midge *Wachtiella krumbholzi*. This report presents work carried out in 2008–09.

The project is presenting a range of difficulties and its feasibility needs to be readdressed. We have reviewed 25 past or current programmes on biological control of invasive trees and shrubs in order (1) to assess the feasibility and likelihood of success of such programmes, and (2) to assess which groups of agents appear to work better than others. This review is presented in section 6.

2 *Philereme vetulata* (Lep., Geometridae)

The leaf-feeding moth *P. vetulata* is exclusively associated with *R. cathartica* in Europe with the exception of one record on *R. alpina* (Malicky et al. 1965). *Philereme vetulata* has one generation per year and overwinters in the egg stage on the bark of its host plant. Larvae feed within folded leaves.

Larval feeding and development tests on potted plants carried out in the past few years indicated that survival to pupal and adult stages was similar on *R. cathartica* EU (= of European origin), *R. alpina* EU and the native North American species *R. alnifolia* (= NA). However, *R. alpina* and *R. alnifolia* NA seem to be slightly less optimal food sources for *P. vetulata* (Gassmann et al. 2006). The pupae reared on *R. alnifolia* NA weighed significantly less than those reared on *R. cathartica* and *R. alpina*, and the time to pupation was significantly shorter on *R. cathartica* than on *R. alnifolia* NA and *R. alpina*. No larval establishment or damage was observed on *Frangula alnus* EU and *F. caroliniana* NA. No oviposition on the field host plant was obtained in confinement.

In 2008–09, larval development and oviposition tests were carried out on a few *Rhamnus* species, three additional species in the family Rhamnaceae, and species in the families Elaeagnaceae and Vitaceae. Tests concentrated on species native to North America.

2.1 Biology and rearing

2.1.1 Collections and adult emergence

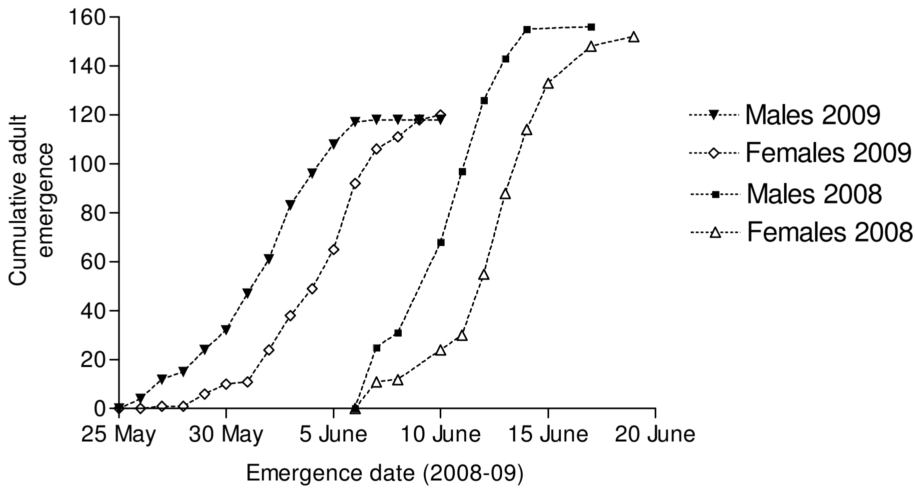

Figure 1 Emergence of *Philereme vetulata* adults reared from field-collected larvae in 2008–09

Following field collection, larvae were reared on leaves of *R. cathartica* in ventilated plastic boxes lined with moist paper to keep leaves fresh. Boxes were stored in an outdoor shelter. Pupae were kept in ventilated plastic cups half-filled with vermiculite to allow adults to emerge. In 2008, a total of 156 males and 152 females (84%) emerged from the 368 larvae collected on 8 and 9 May 2008 in Germany and Switzerland (Figure 1). In 2009, a total of

118 males and 120 females (74%) were obtained from 320 larvae collected at the same sites on 23 April and 5 May.

2.1.2 Rearing and fecundity tests

We tried several rearing methods, varying the number of pairs released:

1. Between 11 May and early July 2008, 64 pairs of *P. vetulata* were kept in groups of two to six pairs (mostly five pairs) in 15 cardboard cylinders (11 × 25 cm) in an outdoor shelter. A total of only 582 eggs were obtained of which 63.9% (372) were fertile.

2. Between 8 May and early July 2008, 12 pairs reared from larvae collected in Germany in spring 2008 were kept individually in cardboard cylinders (11 × 25 cm) in an outdoor shelter. A total of only 91 eggs were obtained of which 81% (74) were fertile, and of these, 59 were obtained from the same female.

3. Between 26 May and early July 2009, 92 pairs were kept in groups of two pairs in ventilated plastic cylinders (11 x 15 cm) in an outdoor shelter. A total of 1,256 eggs were obtained of which about 78% (980) were fertile.

2.1.3 Maternal impact

We initiated this trial to test whether the fecundity of adults reared on *R. alnifolia* NA was lower than that of adults reared on *R. cathartica*.

In 2007, five pairs of *P. vetulata* adults which had been reared throughout the larval stages on *R. alnifolia* NA laid a total of 220 eggs of which 68% (150 eggs) were fertile. Eggs were kept in an outdoor shelter and then transferred to a 1℃ incubator on 4 January 2008 to help synchronize egg hatch with plant availability. On 5 May, eggs were transferred to a 20℃ incubator. Larvae hatched within three days. Successful hatch for eggs laid by *P. vetulata* reared on *R. alnifolia* was 73%, compared to 95% for eggs from *P. vetulata* reared on *R. cathartica*.

Thirty larvae each were reared on potted *R. alnifolia* NA and *R. cathartica* (Table 1). In total, 12 males and five females were obtained from *R. alnifolia* (56.7% successful development) and 13 males and ten females were reared from *R. cathartica* (76.7%) (Table 1). Only four infertile eggs were obtained from five pairs of the '*R. alnifolia* strain'. Seven fertile eggs and 49 infertile eggs were obtained from ten pairs of the '*R. cathartica* strain'. Dead females were in too poor a condition to be dissected for eggs in ovaries to be counted.

2.1.4 Discussion

Mass and individual rearing of *P. vetulata* was not successful in 2008 and only slightly improved in 2009. Such low fecundity and fertility had never been observed in previous years. At this stage, it is difficult to explain why so few females mated and laid eggs over the past two seasons. Regarding mass rearing, it is possible that disturbance arose because too many adults were put in the same container. But this suggestion does not explain the low fecundity recorded from individual rearing in 2008–09; average fecundity in previous years was 62–88 eggs when one or two pairs were reared in similar conditions. Because of the very low fecundity recorded in 2008–09, no conclusions could be drawn from the maternal impact experiment.

A total of 412 eggs were kept in an outdoor shelter in preparation for larval feeding and development tests in 2009. In 2009, 980 eggs are being kept for potential work in 2010.

2.2 Host specificity

2.2.1 Larval feeding and development tests

Methods. In early spring, *P. vetulata* larvae hatching from eggs obtained in the previous year were transferred onto potted plants of *Rhamnus cathartica* and eight test species, including six native to North America.

Results. Complete larval development to the pupal stage was recorded on *R. cathartica* (Table 1). Percent successful development was as high on *R. alnifolia* NA and *R. erythroxylon* from China as on the target plant. Larval feeding damage was negligible on *R. alaternus* EU. No feeding and no larval development were recorded on any of the other species.

Table 1 Results of no-choice larval survival and development tests with *Philereme vetulata* in 2008–09

Test plant[a]	No. of L1 transferred (no. of potted plants)	Percent successful development (pupae, adults)
Rhamnaceae		
Rhamnus cathartica	232 (24)	40.5
R. cathartica	30 (3)[b]	76.7
R. alnifolia NA	30 (3)[b]	56.7
R. erythroxylon	88 (9)	48.9
R. alaternus	178 (15)	0
Frangula caroliniana NA	40 (3)	0
Hovenia dulcis NA	32 (4)	0
Elaeagnaceae		
Elaeagnus commutata NA	40 (4)	0
Hippophae rhamnoides NA	66 (5)	0
Vitaceae		
Parthenocissus quinquefolia NA	31 (2)	0

[a], NA: plant species native to North America; [b], first instar (L1) larvae from an F1 generation reared on *R. alnifolia* in 2007 (see section 2.1.3).

2.2.2 Multiple-choice field cage oviposition tests

Methods. In 2007, no oviposition was recorded in 2 × 2 × 1.6 m field cages in which twelve pairs of *P. vetulata* had been released. In 2008 we reassessed the feasibility of conducting cage oviposition tests in three similar field cages, releasing 15 pairs plus five females into each cage (Plate 1). Each cage contained two potted *R. cathartica*, one potted *R. alpina* and one potted *R. alnifolia* NA (about 50–80 cm high) embedded in sawdust. All cages were protected from excess rain and sun by green gauze covers. Each cage was provided with branches from *Fagus*, *Quercus* or *Corylus* trees as well as with cardboard plates to allow the moths to hide. In 2009, we conducted one last trial exposing two potted *R. cathartica* and three potted *R. alnifolia* NA of about the same size (30–50 cm high) in a cage containing two bushes (*Salix* and *Corylus*) and several herbaceous species, thus creating a more natural environment (Plate 1). Twenty pairs of six- to eight-day-old moths and 12 newly emerged pairs were released into the cage. The tests were established in early June and all plants were removed from cages two months later and searched for eggs.

Results. No eggs were found on any part of the plants. It is concluded that oviposition tests in confinement can definitively be discarded as a method of evaluating the oviposition behaviour of *P. vetulata*.

Plate 1 Field cage oviposition test in 2008 (left) and inside the 'natural' field cage in 2009 (right)

2.2.3 No-choice open-field oviposition test

On 19 June 2008, 25 female and 20 male *P. vetulata* were released on the margin of an orchard in which five large, potted *R. cathartica* had been placed in order to try and assess the oviposition behaviour of the moth in open-field conditions. No naturally growing *R. cathartica* was visible for a distance of at least 300 m from the release point. All plants were removed from the field plot on 18 July and searched for eggs.

No eggs were found on any part of the *R. cathartica* plants although one mating pair was observed on a trunk base just after release (Plate 2).

Plate 2 Potted *Rhamnus cathartica* plants at the margin of an orchard (left) and a mating pair of *Philereme vetulata* just after release (right)

2.3 Conclusions and outlook

The larval feeding and development tests with *P. vetulata* indicated that larval development to the adult stage is restricted to a few *Rhamnus* species. Oviposition tests carried out in 2008–09 confirm the previous finding that egg laying does not occur in confined conditions. Eggs were also not found on *R. cathartica* in the open-field oviposition test established in the vicinity of the CABI Europe – Switzerland (E-CH) Centre. This was probably influenced by the small size of our potted *R. cathartica* and test plant species, making results from any open-field test unreliable. At this point it appears impossible to study the oviposition behaviour of *P. vetulata*.

Currently, host-specificity studies with *P. vetulata* rely on larval feeding and development tests. It is likely that specific requirements for larval establishment related to plant phenology, stage of the developing leaf bud, and leaf shape and toughness, as well as habitat requirements, will restrict host acceptance and host suitability to a few species in the genus *Rhamnus*. Results obtained so far suggest that larvae will not complete development on small tough or thick evergreen leaves such as those of *R. alaternus*. Therefore, the native North American *Rhamnus* species *R. crocea*, *R. ilicifolia*, *R. serrata* and *R. smithii* are unlikely to be suitable for development of *P. vetulata* larvae through to the adult stage. Critical native North American non-target species are *R. alnifolia* and *R. lanceolata* because of their leaf shapes and smoothness and their geographical distributions which partially overlap that of *R. carthartica*.

3 *Trichochermes walkeri* (Hem., Triozidae)

The leaf-margin curl galler *T. walkeri* is known only from *R. cathartica* in Europe. It is also one of the most common insect species on *R. cathartica* and certainly one of the most conspicuous. The galls of *T. walkeri* seem to be aggregated on certain trees, while within a tree they appear to have a more random distribution. The species has one generation per year and overwinters in the egg stage. Females lay small orange eggs during late summer on leaf buds. The nymphs hatch in spring from overwintered eggs. First-instar nymphs migrate to the leaves, feed, and induce rolling of the leaf margin. Egg laying by *T. walkeri* begins about 3–4 weeks after adult emergence and lasts from late August until mid October. Oviposition tests were continued in 2008–09.

3.1 Collections and rearing

Between 28 July and 6 August 2008, 3,600 leaf galls of *T. walkeri* were collected at three sites in western Switzerland. Between 31 July and 18 August, 60 females and 84 males emerged from this material. The last adult emerged on 3 September 2008. A late collection of 550 galls carried out on 19 August 2008 provided only three additional females and ten males. These adults were used in oviposition tests.

On 7 July 2009, a first small collection of leaf galls of *T. walkeri* was made in western Switzerland to assess larval development and larval size. Between 27

July and 6 August 2009, 1,700 leaf galls were collected at the same three sites in western Switzerland as in 2008. Between 28 July and 26 August, 106 females and 150 males emerged from this material. No adults emerged from a late collection of 100 galls carried out on 19 August 2009.

Inspection of the 7 July collection indicated that 23% of the larvae had reached the third larval stage and 77% the fourth larval stage (Figure 2). One month later, one-third of the larvae were in the fourth larval stage and two-thirds in the fifth and last larval stage.

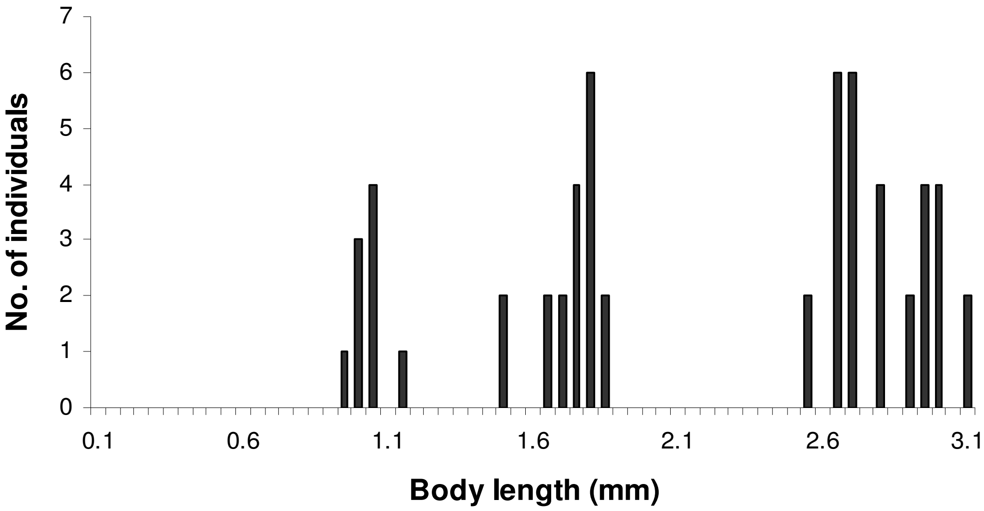

Figure 2 Body lengths of the third, fourth and fifth larval stages of *Trichochermes walkeri*

3.2 Host specificity

3.2.1 Sequential no-choice tests in 2008–09

In 2004, no eggs were laid in no-choice oviposition tests carried out with *R. alnifolia* NA, *R. alpina*, *F. alnus* and *F. caroliniana* NA. These preliminary results also indicated that none of the test plants was suitable for adult feeding and that adults did not survive until oviposition. Therefore, in 2005, no-choice oviposition tests were carried out with females which had previously been exposed to *R. cathartica* for three weeks. Even under these conditions, female longevity was much reduced on all test plants compared to the field host, *R. cathartica*. In 2006, we tested *R. alnifolia* NA and *R. alpina* in sequential no-choice conditions (Gassmann et al. 2006), in 2008 *R. alaternus* and the South African species *R. prinoides*, and in 2009 *R. ilicifolia* NA.

Methods. Females and males were first exposed to *R. cathartica* in pre-oviposition boxes for three weeks in groups of 2–5 pairs in 44 (21 in 2008 and 23 in 2009) ventilated plastic cylinders (diameter 11.0 cm, height 15.0 cm) fixed on branches of potted *R. cathartica.* After this period, i.e. at the start of the oviposition period, each pair of *T. walkeri* was transferred into a small, ventilated plastic cup (diameter 7.0 cm, height 8.5 cm), which was fixed on a branch of a potted test or control plant. Plants were kept outside underneath a suspended tarpaulin to protect them from rain and sun.

Insects were sequentially alternated between the test plant and the target plant, *R. cathartica,* in 'test series'. The assumption was that females would be able to survive the period on the test plants, and would then 'recover' on *R. cathartica*, thus allowing them to oviposit on perhaps less preferred but acceptable plant species. The test series were established in late August – early September and lasted for 3–4 weeks. Because no-choice adult feeding and survival tests carried out during previous years showed that *T. walkeri* usually survives at least 3–4 days on non-target hosts, adult survival and oviposition were recorded every four days.

Branches with eggs were marked with coloured threads. All plants used in tests were protected from natural infestation by *T. walkeri* and other herbivores under a large gauze tent in a greenhouse from July until late October. All attacked plants were overwintered in the same greenhouse and gall and larval development assessed the following spring.

Results. In 2008, 60% of males and females survived the three-week pre-oviposition period during which two late-emerged females laid 101 eggs. In the sequential no-choice oviposition tests, *T. walkeri* laid a similar number of eggs on *R. alaternus* and *R. cathartica* (Table 2) although the leaf buds of *R. alaternus* are smaller and tougher than those of *R. cathartica*. The average fecundity and female longevity were similar to those observed for *R. cathartica* in no-choice tests in previous years. Only a few eggs were laid by *T. walkeri* in the five *R. cathartica* – *R. prinoides* test series suggesting that *R. prinoides* is less suitable than *R. alaternus* for supporting normal adult longevity and egg laying.

In 2009, 90 females and 121 males were put into pre-oviposition boxes. Female mortality was high (87%) and only 12 females could be used in the oviposition trial. Ten sequential no-choice oviposition tests were carried with *R. ilicifolia* NA, starting with six replicates of the control *R. cathartica* and four of *R. ilicifolia* NA. Only 38 eggs were laid on *R. cathartica* and female longevity was much reduced. All eggs were laid by the female with highest longevity (16 days). Only three females survived a four-day period on *R. ilicifolia* NA which appears to be a lethal plant for this insect.

3.2.2 Single-choice tests in 2008–09

In 2005 and 2006, little oviposition occurred on *R. alnifolia* NA in no-choice tests, and no gall and larval development was recorded the following year. To check whether this test species was attacked in the presence of the target weed, single-choice tests were conducted. In 2007, single-choice oviposition tests were evaluated in three 2 × 2 × 1.6 m field cages, but no eggs were found in any of these tests.

Methods. In 2008, single-choice oviposition tests were carried out in five 40 × 40 × 70 cm cages (= replicates) which were kept outdoors underneath a suspended tarpaulin to give protection from rain and sun. Each cage contained one potted *R. cathartica* and one potted *R. alnifolia* NA. Between 21 August and 9 September, three newly emerged pairs of *T. walkeri* were released into each cage. On 3 November, all plants were checked for eggs.

In 2009, one *T. walkeri* pair was added to each of two small cages, each of which contained one potted *R. cathartica* and one potted *R. ilicifolia* NA. The test was set up on 15 September and completed on 6 October.

Results. In 2008, a total of 557 eggs were recorded from four replicates with *R. cathartica* (mean = 111.4 ± 102.9; *n*=5) and 24 eggs from three replicates with *R. alnifolia* NA (mean = 4.8 ± 5.2; *n*=5). Thus egg laying on *R. alnifolia* NA represented 4.1% of the total number of eggs laid in the test. Over 90% of the eggs were laid on the bark of branches and the trunk of *R. alnifolia* NA. In contrast, on *R. cathartica*, over 60% of the eggs were laid on leaf bud axils, thus facilitating gall development in spring.

In 2009, two eggs only were recorded from one replicate with *R. cathartica* and 49 eggs from the second. No eggs were recorded on *R. ilicifolia* NA.

Table 2 Sequential no-choice oviposition tests with *Trichochermes walkeri* in 2008–09 (after a three-week feeding and pre-oviposition period on *Rhamnus cathartica*)

	TEST SERIES (2008)			
	***R. cathartica – R. alaternus* (*n=5*)**		***R. cathartica – R. prinoides* (*n=5*)**	
	R. cathartica	***R. alaternus***	***R. cathartica***	***R. prinoides***
Total no. of ♀ days	107	85	67	41
Total no. of eggs laid	245	302	53	7
Mean no. of eggs/♀ (SD)	49.0 (28.6)	60.4 (40.1)	10.6 (22.6)	1.4 (2.6)
No. of ovipositing females (% of total no. of females)	4 (80)	4 (80)	2 (40)	2 (40)
Mean female longevity in the test series (SD)	21.4 (8.3)		13.4 (3.6)	
Mean total female longevity (SD)	43.4 (8.3)		35.4 (3.6)	
	TEST SERIES (2009)			
	***R. cathartica – R. ilicifolia* (*n=6*)**		***R. ilicifolia – R. cathartica* (*n=4*)**	
	R. cathartica	***R. ilicifolia***	***R. ilicifolia***	***R. cathartica***
Total no. of ♀ days	30	16	10	2
Total no. of eggs laid[a]	38	0	0	0
Mean female longevity in the test series (SD)	7.7 ± 4.8		3.0 ± 2.0	
Mean total female longevity (SD)	27.7 ± 4.8		23.0 ± 2.0	

[a], all eggs laid by one female.

3.2.3 Leaf gall development 2008–09

Potted plants, onto which eggs of *T. walkeri* had been laid in autumn 2008 in no-choice and single-choice oviposition tests, were protected from natural oviposition under a large gauze tent in a greenhouse until the end of November 2008, and then kept outdoors until late May 2009. A total of 179 galls and 261 larvae (mostly second and third larval stages) were obtained from 855 eggs laid on *R. cathartica* in 2008 (Table 3). Thus, 30.5% of the eggs developed successfully to the early larval stages. Sixty-five percent of attacked leaves had one gall and 34% had two galls. One leaf carried three galls.

About 54% of the galls contained one larva, 37% two larvae and 9% three or four larvae. About 70% of all potted plants and branches with eggs developed leaf galls. Ten percent of all branches did not develop leaf galls because they were heavily infested by aphids.

No galls and larval development occurred on *R. alaternus*, *R. alnifolia* NA and *R. prinoides*.

Table 3 Results of gall and larval development with *Trichochermes walkeri* in 2008–09

Test plant[a]	No. of eggs (2008)	No. of galled leaves (2009)	No. of galls (2009)	No. of larvae (2009)
Rhamnus cathartica	855	133	179	261
R. alaternus	302	0	0	0
***R. alnifolia* NA**	24	0	0	0
R. prinoides	7	0	0	0

[a], NA: plant species native to North America.

3.3 Detection of '*Candidatus* Phytoplasma rhamni'

3.3.1 Background

Plant-pathogenic phytoplasma are non-culturable, insect-transmitted wall-less prokaryotes of the class *Mollicutes* that are associated with diseases in several hundred plant species, including many woody shrubs or small trees (Marcone et al. 2004; Weintraub and Beanland 2006). Based on 16S rRNA gene sequences, Lee et al. (1998) describe the 12 main groups of phytoplasmas (designated 16Sr I-XII); their subgroups are designated with a letter suffix.

A lethal witches'-broom disease of *R. cathartica* was observed for the first time in south-western Germany in the 1990's (Mäurer and Seemüller 1996). This disease, known as buckthorn witches'-broom (BWB) phytoplasma, belongs to the 16SrX-E group (i.e, 16Sr ten group, E subgroup). The BWB phytoplasma is phylogenetically more closely related to phytoplasmas of the apple proliferation (AP) group (16SrX) than to other phytoplasma subclades (see Marcone et al. 2004 for references). The 16SrX group of phytoplasmas includes for example the apple proliferation phytoplasma (16SrX-A) and the pear decline phytoplasma (16SrX-C).

For uncultured phytoplasmas, a novel putative species may be described when its 16S rRNA gene sequence (>1200 bp) has ≤ 97.5% similarity to any previously described '*Candidatus* Phytoplasma' species (IRPCM, 2004). The BWB phytoplasma share < 97.5% 16S rDNA sequence similarity with other known phytoplasmas, including the AP group phytoplasmas. This is the reason why Marcone et al. (2004) proposed the BWB phytoplasma as a novel '*Candidatus* Phytoplasma' species, i.e. '*Candidatus* Phytoplasma rhamni'. According to these authors, the BWB phytoplasma has clearly distinct molecular and biological properties, especially a different and unique field host plant, *R. cathartica*.

According to Mäurer and Seemüller (1996), symptoms are brush-like witches' brooms which arise from the stems or major branches. These witches' brooms develop from young, premature shoots that start to grow in January. The leaves of diseased plants were often distorted and the vigour of such plants steadily decreased. Severely affected trees and shrubs did not bear fruits and declined.

The single most successful insect vectors of phytoplasma are the Hemiptera. Phytoplasmas are phloem-limited; therefore, only phloem-feeding insects can potentially acquire and transmit the pathogen. However, within the groups of phloem-feeding insects only a small number, primarily in a very few taxonomic groups, have been confirmed as vectors of phytoplasmas (Weintraub and Beanland 2006). The main group of known vectors is the Cicadeliidae. Another seven families including 15 species are also known as vectors of phytoplasmas (Weintraub and Beanland 2006).

Two genera of Psyllidae are vectors. Six species of *Cacopsylla* transmit AP group (16SrX) phytoplasmas on apple, stonefruit and pear trees. Another genus, *Bactericera*, has one vector species, *B. trigonica*, which transmits a stolbur (16SrXII) phytoplasma to carrots. *Trichochermes walkeri* was not recorded as a potential vector of phytoplasma.

3.3.2 Material and Methods

Six pairs and four pairs of *T. walkeri* were reared from galls collected in early August 2009 at two well separated sites in Switzerland, respectively, and kept in 95% ethanol for further studies. Phytoplasma detection and characterization was carried out by PCR amplification of 16S ribosomal RNA gene with universal and group specific primers. Amplification was performed in nested PCR with P1/P7 (Deng and Hiruki, 1991; Smart *et al.*, 1996) followed by F2n/R2 universal primer pair (Gundersen and Lee, 1996) or R16(X)F1/R1 primers specific for amplification of 16SrX group phytoplasmas (Lee et al., 1995). To obtain longer fragments for sequencing, 16S rRNA amplicons were obtained in nested PCR assay with the universal primers P1A/P7A with reaction conditions according to Lee *et al*. (2004).

3.3.3 Results

The presence of the p*hytoplasma* named '*Candidatus* Phytoplasma rhamni' (16SrX-E group) was detected in all four insect pulls analyzed from the locality along lake Neuchatel while from the second locality, in the Jura hills, only one out of four analyzed pulls was positive. One isolate from each locality was sequenced and an approximately 1500bp long sequence was obtained. Sequences were identical among themselves. Comparison with available sequences from the NCBI database (using BLAST analyses) confirmed the presence of '*Candidatus* Phytoplasma rhamni' in *T. walkeri* samples.

This finding is a first record of '*Candidatus* Phytoplasma rhamni' in Switzerland, and the first record of a phytoplasma detected in *T. walkeri*.

3.4 Conclusions and outlook

Unlike results with other non-target *Rhamnus* species (i.e. *R. alnifolia* NA, *R. alpina* and *R. prinoides*), consistent egg laying occurred in 2008 on *R. alaternus* under sequential no-choice conditions. However, no gall development was recorded on this species in 2009 and there are no records of *T. walkeri* galls on *R. alaternus* in Europe, confirming that this plant is not a suitable host for larval development of *T. walkeri*. The single-choice tests confirmed that *R. alnifolia* NA is a much less suitable host than the target weed for oviposition. As in previous years, no gall development was recorded on *R. alnifolia* NA the following spring. Female longevity was about 20 days in the tests with *R. alnifolia* NA, *R. alaternus* and *R. alpina*, and much reduced in those with *R. prinoides* and *R. ilicifolia* NA (see also Gassmann et al. 2007). Adult longevity was also much reduced on *Frangula* spp.

Trichochermes walkeri overwinters as eggs, which are usually laid on the leaf buds. The difficulties encountered in the manipulation and overwintering of eggs on cut material and the transfer of first-instar or older larvae from young galls onto the leaves of potted plants means this is not a suitable method for assessing the physiological host range of *T. walkeri*. Therefore, host-specificity tests need to rely on oviposition tests and subsequent larval and gall development. Oviposition tests carried out so far indicate that usually only limited oviposition occurs on non-target *Rhamnus* species under no-choice and choice conditions. No gall development was recorded the following spring on any non-target species indicating that *T. walkeri* has a very narrow host range. Because oviposition usually starts 3–4 weeks after adult emergence, it will not occur on non-target hosts in field situations where *R. cathartica* is not present since the longevity of *T. walkeri* females is much reduced on those plants.

Trichochermes walkeri has been recorded exclusively on *R. cathartica* in Europe and no larval and gall development has been observed so far on any other *Rhamnus* species.

The detection of a phytoplasma in *T. walkeri* adults raises several important questions: 1) is the phytoplasma '*Candidatus* Phytoplasma rhamni' common on *R. cathartica* in Europe?; 2) does '*Candidatus* Phytoplasma rhamni' already occur in North America, and if yes, which insect is the vector?; 3) does the phytoplasma occur on other *Rhamnus* species in Europe?; 4) does *T. walkeri* transmit the phytoplasma, and if not, which other insect is the vector, and 5) is '*Candidatus* Phytoplasma rhamni' specific to *R. cathartica* as it is suggested in the literature?

4 *Wachtiella krumbholzi* (Dipt., Cecidomyiidae)

Little is known about this insect, which was identified by Dr M. Skuhrava (Czech Republic). Interestingly, with the exception of a few specimens reared from *R. cathartica* in the Czech Republic, Skuhrava has not found this species during 50 years of investigations of cecidomyiids in 1800 European localities (Simova-Tosic et al. 2000, 2004; Skuhrava et al. 2005). The main characteristics of fruits attacked by *W. krumbholzi* are premature fruit maturation with changes in colour, with the fruits also larger in size than normal and irregularly shaped. Attacked fruits become dark-red/black while healthy fruits remain green (see Plate 3). Casual observations revealed up to nine midge larvae per fruit and three larvae in one seed. The midge larva leaves the fruit and enters the soil to prepare a larval cocoon made of silk and debris.

Work on *W. krumbholzi* started in 2007.

4.1 Collections and rearing in 2008–09

Fruits of *R. cathartica* were collected in Austria (six sites), southern Germany (two sites) and Switzerland (two sites) during late June – early August 2008 (Plate 3). Midge larvae were reared from all sites. In total, about a thousand larvae emerged and were transferred to Petri dishes filled with a mixture of sterilized sifted soil and vermiculite. In late August, the soil was checked and 850 larval cocoons recovered. Batches of larval cocoons were overwintered in an outdoor shelter in a mixture of sifted soil and vermiculite.

Plate 3 Larvae of *Wachtiella krumbholzi* feeding in the fruit and seeds of *Rhamnus cathartica* (left) and a sample of fruits, including many attacked ones with exit holes (right)

Several hundred fruits of *R. cathartica* were collected in southern Germany on 2 July and 20 July 2009. Fruits were kept on a wire grille, allowing the larvae to drop into a container beneath filled with a mixture of vermiculite and sifted soil. In late August, the soil was checked and 213 larval cocoons were recovered. Batches of larval cocoons are being overwintered in an outdoor shelter in a mixture of sifted soil and vermiculite for potential work in 2010.

No midge larvae were reared from the fruits of *Frangula alnus* collected in 2008 at one site in Austria and at one site in Switzerland, where *R. cathartica* and *F. alnus* co-occur.

4.2 Adult emergence in 2009

Methods. In early March 2009, 600 larval cocoons reared in 2008 were transferred from outdoor storage into a 1°C incubator to delay adult emergence according to experimental needs. On 18 May 2009, as the first adults emerged from the outdoor storage boxes, about 50% of this material was transferred into a 10°C incubator to investigate whether adult emergence could be delayed by this means. On 2 June, all cocoons from cold storage were returned to outdoor conditions.

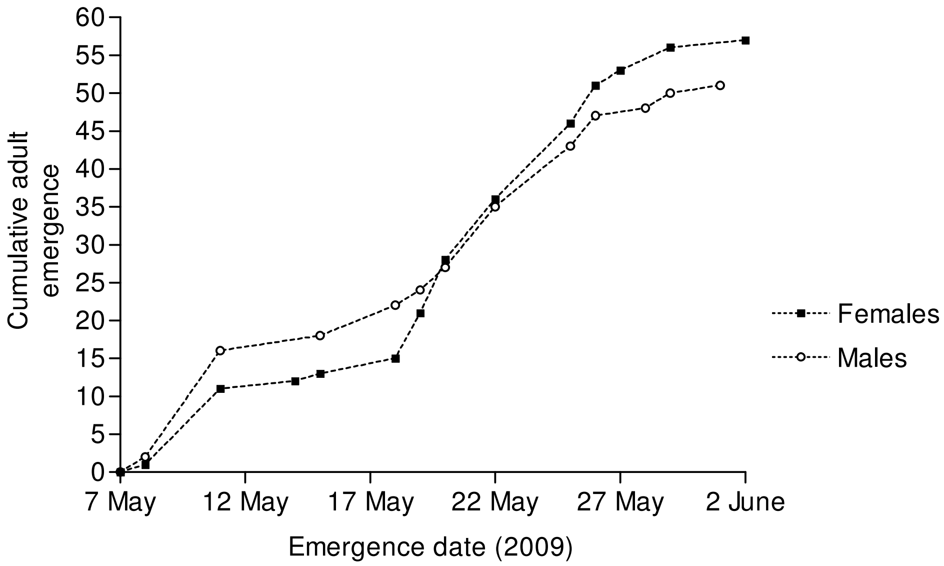

Figure 3 Emergence of *Wachtiella krumbholzi* adults reared from field-collected larvae in 2008

Results. A total of 57 females and 51 males emerged between 8 May and 1 June 2009 from 120 cocoons held permanently in outdoor storage (Figure 3). Larval mortality was quite high for the material which had been kept at 1℃ until 2 June, since only 96 females and 90 males emerged between 24 June and 13 July. No adults emerged from the cocoons held in the 10℃ incubator indicating that the cold treatment was lethal for adults ready to emerge.

4.3 No-choice oviposition tests

4.3.1 Methods

Only a few potted *R. cathartica* yielded flowers and developing fruits, thus limiting the number of oviposition trials. One individual branch of two potted *R. cathartica* and one potted *F. alnus* were each exposed to four pairs of *W. krumbholzi***.** Branches were covered with a gauze bag and the plants kept outdoors. All tests were set up on 22–25 May and the fruits collected on 6 July for dissection. Fruits of an *R. cathartica* tree growing naturally in the vicinity of the Centre were dissected on 24 June to confirm the presence of *W. krumbholzi* in the area.

On 24 June, one branch of potted *R. cathartica* and two branches of potted *F. alnus* with well-developed fruits were each exposed to five pairs of *W. krumbholzi*. Fruits of potted *R. cathartica* and potted *F. alnus* were dissected on 6 July to check whether *W. krumbholzi* oviposited naturally on the test plants in the Centre's garden.

4.3.2 Results

Our preliminary tests indicate successful oviposition by *W. krumbholzi* in the very young developing fruits of *R. cathartica* (Table 4). In contrast, no oviposition occurred in fruits that were one month older and well developed. No midge larvae were found in the unexposed fruits of potted *R. cathartica* used as a control for this experiment. Attack by *W. krumbholzi* on a *R. cathartica* tree growing naturally in the vicinity of the Centre was lower than in the oviposition tests. No midge larvae were found in the fruits of *F. alnus*.

Table 4 Results of no-choice oviposition tests with *Wachtiella krumbholzi* in 2009

	Set-up date	No. of fruits dissected	No. of fruits attacked (%)	Mean no. of larvae/fruit (± SD)	Max. no. of larvae/fruit
Rhamnus cathartica					
Test 1 on potted plant with very young developing fruits	22 May	25	15 (60)	2.4 ± 4.2	18
Test 2 on potted plant with very young developing fruits	22 May	20	19 (95)	5.6 ± 4.1	14
Test 3 on potted plant with well-developed fruits	24 June	4	0	-	-
Test 4 on potted plant with well-developed fruits	24 June	11	0	-	-
Control 1 dissection of unexposed fruits from potted plants	-	16	0	-	-
Control 2 dissection of fruits from a nearby tree	-	30	10 (33)	1.0 ± 2.0	8
Frangula alnus					
Test 1 on potted plant with very young fruits	22 May	4	0	-	-
Test 2 on potted plant with well-developed fruits	24 June	9	0	-	-
Control dissection of unexposed fruits from potted plants	-	21	0	-	-

4.4 Conclusions and outlook

Host-range tests with this fruit-attacking gall midge species will rely entirely on oviposition tests. The main difficulty will be to get test plants at the right phenological stage, i.e. probably in a very early stage of fruit development, to coincide with when *W. krumbholzi* lays eggs. The difficulty is enhanced because, to the best of our knowledge, *Rhamnus* species are mostly dioecious (i.e. male and female flowers are on separate plants) and pollination could be a problem.

Batches of cocoons should be kept at below-ambient temperatures in order to delay adult emergence and to match it with plant phenology even though maintaining larval cocoons at low temperatures seems to induce high mortality.

Work conducted on midges in Europe over several decades suggests that *W. krumbholzi* is specific to *R. cathartica* (Simova-Tosic et al. 2000, 2004; Skuhrava et al. 2005). *Contarinia rhamni* and *Dasyneura frangulae,* recorded in the literature on *F. alnus* (Gassmann et al. 2008b), have not been reared from *R. cathartica* fruits. No adult midges have yet been reared from the fruits of *F. alnus*.

5 Discussion

Despite the fact that some difficulties have been encountered with rearing *Philereme vetulata*, work in 2008 and 2009 has confirmed that the physiological host range of this leaf-feeding moth is restricted to species in the genus *Rhamnus*, most probably to deciduous species with large smooth leaves. No oviposition was obtained in confinement; hence assessing the host specificity of *P. vetulata* will rely on larval feeding and development in no-choice tests.

In contrast, assessing host specificity of the leaf-margin gall psyllid *Trichochermes walkeri* and the seed-feeding midge *Wachtiella krumbholzi* will rely on oviposition and larval development tests. Adult feeding and oviposition by *T. walkeri* are restricted to species in the genus *Rhamnus* and larval development is likely on *R. cathartica* only. The likelihood of *T. walkeri* accepting a non-target species for oviposition in containment that would not be accepted in the field (a false positive) is considered high.

The detection of a phytoplasma in *T. walkeri* adults raises several questions that will need to be answered in parallel with host range studies (see 3.4).

The challenges in working with *W. krumbholzi* will be obtaining pollination of female buckthorn flowers and synchronizing fruit development with midge oviposition and larval development. More generally, one current constraint in developing biological control of buckthorns is the difficulty of obtaining seeds for a number of test plant species and/or growing plants from seeds.

With one exception (*P. vetulata*), the three candidate agents *P. vetulata*., *T. walkeri* and *W. krumbholzi* have been recorded exclusively on *R. cathartica* in Europe where, however, only a few *Rhamnus* species occur.

Likely specific requirements for host acceptance and suitability will be related to plant phenology, stage of the developing leaf bud, and leaf shape and toughness, as well as habitat requirements. There are indications that larvae of *P. vetulata* and *T. walkeri* will not complete development on small tough or thick evergreen leaves such as those of *R. alaternus*. Therefore, the native North American *Rhamnus* species *R. crocea*, *R. ilicifolia*, *R. serrata* and *R. smithii* are unlikely to support development of *P. vetulata* and *T. walkeri* larvae to the adult stage. Critical native non-target North American species are *R. alnifolia* and *R. lanceolata* because of their leaf shapes and smoothness and their geographical distributions which partially overlap that of *R. carthartica*.

A range of difficulties has not been solved over the past two years. Collecting and growing a couple of critical test plant species are still difficult. The success of this programme is complicated by two other factors: the need to work with genus- or species-specific species which considerably limits the number of potential biological control agents and the difficulty of rearing and testing some candidate agents. At this point, and after several years of research, the feasibility of biological control of *R. cathartica* needs to be addressed and considered from another standpoint.

The following review of successes and failures in biological control programmes for trees and shrubs has been carried out in order (1) to assess the feasibility and likelihood of success of such programmes, and (2) to further help prioritize potential biological control agents for buckthorn based on the most successful groups of biological control agents for invasive trees and shrubs.

6 Successes and failures in the biological control of invasive trees and shrubs and implications for the buckthorn project (A. Gassmann)

6.1 Introduction

This review is based on a paper by Moran et al. (2004) and updated from most-recent information extracted from CAB Direct (www.cabdirect.org/) and a search on the internet. It focusses on programmes against invasive trees and shrubs for which biological control agents have already been released.

Since the paper by Moran et al. (2004) was written, insect releases have been made against one other tree genus, *Tamarix* spp., in North America. Of the list of plants analysed by Moran et al. (2004), *Mimosa pigra* is the only species which can be considered as a shrub exclusively and not a tree/shrub. Unlike these authors, I have included in this review other ‘obvious’ shrub species such as *Ulex europaeus*, *Cytisus scoparius*, *Clidemia hirta* and *Mimosa invisa* but have, like them, excluded vines.

Of the 25 tree/shrub species which have been targeted for biological control, seven are invasive in North America (including three exclusively in Hawaii), seven in Australia, New Zealand and the Pacific islands and 14 in South Africa (of which nine are *Acacia* spp.). With the exception of *Tamarix*, *U. europaeus* and *C. scoparius*, the species targeted occur mostly in the dry or humid tropical or subtropical ecoregions according to the definitions proposed by Bailey (1996). With the exception of the Hawaiian programmes of the 1960s, and a few early insect introductions against *U. europaeus* and *C. scoparius*, releases for biological control of trees and shrubs started in the late 1970s, mainly in South Africa.

6.2 Successes and failures in biological control of trees and shrubs

Demonstrating that an agent introduced to a new geographical area is effective against a target weed across its range and over the long term is a difficult task. Almost without exception, early publications on biological control provide definitions of success that refer to reductions in either ‘density’ or ‘abundance’ of the target plant (see Hoffmann and Moran 2008).

The initiation of biological control of trees in the late 1970s in South Africa revealed another aspect of what is meant by success (see Moran et al. 2004) and pleas have been made to develop other performance criteria for the role of biological control in weed management. First, the economic importance of some invasive *Acacia* species in South Africa has limited the choice of biocontrol agents to those that reduce flower and seed production and thus have the potential to limit the spread of cultivated exotic acacias (Dennill et al. 1999). Second, the apparent failure of biological control agents to reduce the distribution or density of, e.g., *Acacia pycnantha*, *A. cyclops* and *Sesbania punicea* in South Africa is hiding the fact that management of the weeds was much faster and therefore cheaper after biological control agents had reduced the levels of seeding, and hence seedling recruitment (Moran et al. 2004). The conclusion is that there is increasing evidence from the studies of biological control of invasive trees in South Africa that any reduction in seed output aids management and that after seed-destroying agents are deployed, agents that attack other parts of the plant should be considered.

A rather similar innovative goal-based approach was used for the *Melaleuca quinquenervia* programme in Florida, USA, showing that this programme could be considered as a success even though vast stands of *M. quinquenervia* still exist that overtly appear unchanged (Center et al. 2008). The hypothesis was that biological control cannot eliminate the huge amounts of woody biomass present in large infestations. The role of biological control is instead to neutralize the reproductive potential of those populations which are reduced to maintenance level by other control methods, or to reduce it in other small isolated stands such as those on private lands.

From the 25 species targeted for biological control, the programmes against *M. quinquenervia* (Center et al. 2008), *Tamarix* spp. (DeLoach et al. 2008), *S. punicea* (Hoffmann and Moran 1999), *Acacia longifolia*, *A. saligna*, *A. pycnantha*, *A. cyclops* (Dennill et al. 1999) and *Mimosa invisa* (Kuniata and Korowi 2004) are considered as successes either in a classical sense of stand and density reduction or in terms of improved management of the weed (see also Julien and Griffiths 1998). Biological control was also effective in preventing the spread of *Clidemia hirta* into open pastures and cultivated land but failed in shaded areas (Nakahara et al. 1992). In summary, biological control programmes against seven of 20 targeted trees (35%) and two of five targeted shrubs (40%), i.e. *C. hirta* and *M. invisa*, have resulted in some level of satisfactory control so far. These numbers are at least as encouraging as those proposed two decades ago for biological control of weeds in general (Crawley 1989; Waage 1992; Bruzzese 1993). In terms of the amount of work done and the number of biological control agents released, the most obvious recalcitrant trees are *Schinus terebinthifolius* in Hawaii in the 1960s, *Prosopis* spp. in South Africa and Australia in the 1990s, *Parkinsonia aculeata* in northern Australia in the 1990s and *Acacia nilotica* ssp. *indica* also in Australia. With regard to shrubs, no control has been achieved so far for *M. pigra*, *Ulex europaeus* and *Cytisus scoparius* in spite of a number of introductions.

6.3 Prioritization of agents for shrub and tree control

Weed biological control projects are not often undertaken on the basis of the likelihood of a successful outcome and biological control of many weed problems would likely never be attempted if target choice was based primarily on maximizing the probability of success. For example, in the recent *Melaleuca quinquenervia* programme, no pre-release studies were carried out to prioritize the potentially most efficient agents and all species cleared for release so far have been selected according to their host specificity exclusively (Center et al. 2008).

There is a vast literature on pre-release modelling and experimental studies to evaluate the effectiveness of biological control agents that could thus has assisted agent selection and prioritization and helped to fine-tune a biological control programme's strategy. These approaches, which have been recently evaluated by Morin et al. (2009), include, e.g., setting performance targets, evaluating agent effectiveness, and performing laboratory and field studies, plant demographic modelling and benefit-cost analyses. However, the ultimate efficacy of an agent will only be demonstrated in the area of release, entailing many more years of research, and a priori predictions of agent efficacy have seldom been explicitly tested by quantifying effectiveness in the field after release (Morin et al. 2009). There are therefore great disincentives to undertaking in-depth pre-release evaluation of agent effectiveness because of the additional time and resources required and the potential likelihood of rejecting agents that could turn out to be effective in the introduced range. Quite obviously, invasive trees and shrubs present even more difficulties in terms of predicting effectiveness of classical biological control. Regardless of the costs of such studies it may take many generations of attack before quantifiable impacts are observed on the target plant. In addition, for seed-feeders, population-level impact is directly related to amount of seed destroyed and the importance of recruitment from seed in the area of introduction.

Given the constraints, only a few authors have tried to analyse which taxonomic groups make the best biological control agents (Crawley 1989; Gassmann 1995; Syrret et al., 1996). These reviews showed that beetles, in particular Chrysomelidae and Curculionidae, are the most effective weed biological control agents in the temperate world. In subtropical and tropical areas, beetles are not of such dominant importance, perhaps because the impact of the prolonged combined feeding period of adult beetles and larvae is counterbalanced by continuous and overlapping breeding of species belonging to other taxa (Gassmann 1995).

In this review I attempt to carry out a similar analysis, predicting which taxonomic group(s) make(s) the best biological control agents of invasive trees and shrubs. Of 72 arthropod species released against invasive trees and shrubs, there are only 16 (22%) that did not become established or whose establishment status is unknown (Table 5). Over 50% of the species that failed to establish were released under two Australian programmes which turned out to be very problematic, i.e. *Acacia nilotica* ssp. *indica* and *Mimosa pigra*. Thus, in general, the establishment rate of arthropod agents in the biological control of woody perennials has been very successful. The figures are quite similar when trees and shrubs are considered separately.

Of the 56 arthropod species that have established, 28 species are Coleoptera (i.e. 82% of all beetles released, including 20 seed feeders), 16 Lepidoptera (67% of all moths released, including three seed feeders), six Hemiptera (86%), two Thysanoptera, two gall-forming Hymenoptera, one Diptera and one Acari. Approximately 40% of these agents directly reduce seed production.

Table 5 Successful biological control agents of invasive trees and shrubs by taxonomic groups

Taxonomic group	No. of species released	No. of species established (%)	No. of species having a substantial impact (% of those established)
Coleoptera	34	28 (82.4)	8 (28.6)
Lepidoptera	24	16 (66.7)	0
Hemiptera	7	6 (85.7)	2 (33.3)
Diptera	2	1 (50.0)	0
Hymenoptera	2	2 (100)	2 (100)
Thysanoptera	2	2 (100)	1 (50.0)
Acari	1	1 (100)	0
Pathogens	4	1 (25.0)	1 (100)
Total	**72**	**56 (78%)**	**14 (25%)**

Of the agents established, 14 species are reported to impact on the target plant and almost two-thirds of these successful agents belong to the Coleoptera; i.e. nearly one-third of all beetles which have become established are contributing to successful control (Table 6). In addition to the four beetle species which directly attack the reproductive parts of the target, four other species have had a major impact on their target weed, e.g. the leaf-feeding chrysomelid *Diorhabda* spp. on *Tamarix*, or the flush feeder *Oxyops vitiosa* on *Melaleuca quinquenervia*.

Gall-forming wasps are also a very successful group, as are the sap-sucking species in the families Phlaeothripidae (Thysanoptera)) and Psyllidae (Hem.). Of four pathogens released, the gall-forming rust fungus, *Uromycladium tepperianum*, turned out to be a very effective agent on *Acacia saligna* in South Africa, two species failed in the *Mimosa pigra* programme in Australia and one did not become established on *Ulex europaeus* in the USA.

The success rate of the beetles drops slightly, from 28.6% to 22.7%, when the nine *Acacia* species targeted for biological control are excluded from the analysis (data not shown) and the pathogens disappear from the list of successful agents.

Interestingly, none of the 16 Lepidoptera species established is considered as having a substantial impact, including three seed-feeding species and two stem borers. It is perhaps surprising that no Lepidoptera seem to impact on invasive trees or shrubs as a number of Lepidoptera are recorded as major forest pests. One explanation could be that these species never reached population densities capable of defoliating plants to a level resulting in a long-term decrease in the fitness of their host plants. It should also be noted that defoliation is generally more detrimental to coniferous trees than to deciduous ones because the regrowth of foliage of coniferous trees takes longer than for deciduous trees and the plants are not able to overcome complete defoliation (Dajoz 1980).

Table 6 Taxonomy and food niche of most effective agents in the biological control of trees and shrubs (for references see Annex 1)

Plant species	Biological control agent	Taxonomy	Food niche	Country of introduction
Melaleuca quinquenervia	*Oxyops vitiosa*	Col., Curculionidae	Flush feeder, shoot tip, foliage	USA (Florida)
	Boreioglycaspis melaleucae	Hem., Psyllidae	Sap sucker, foliage	USA (Florida)
Tamarix spp.	*Diorhabda* spp.	Col., Chrysomelidae	Foliage feeder	Southern USA
Sesbania punicea	*Trichapion lativentre*	Col., Curculionidae	Bud feeder	South Africa
	Rhyssomatus marginatus	Col., Curculionidae	Seed feeder	South Africa
	Neodiplogrammus quadrivittatus	Col., Curculionidae	Stem borer	South Africa
Acacia cyclops	*Melanterius servulus*	Col., Curculionidae	Seed feeder	South Africa
Acacia pycnantha	*Trichilogaster* sp.	Hym., Pteromalidae	Stem galler	South Africa
Acacia longifolia	*Melanterius ventralis*	Col., Curculionidae	Seed feeder	South Africa
	Trichilogaster acaciaelongifoliae	Hym., Pteromalidae	Stem galler	South Africa
Acacia saligna	*Melanterius compactus*	Col., Curculionidae	Seed feeder	South Africa
	Uromycladium tepperianum	Uredinales	Gall former	South Africa
Clidemia hirta	*Liothrips urichi*	Thysanoptera, Phlaeothripidae	Sap sucker, shoot tips	USA (Hawaii), Fiji
Mimosa invisa	*Heteropsylla spinulosa*	Hem., Psyllidae	Sap sucker, young leaves	Australia, Papua New Guinea

In conclusion, the success rate of biological control of invasive trees and shrubs appears to be quite similar to what has been observed in biological control of weeds in general, but how success is defined may considerably differ from that of herbaceous plants. Based on the taxonomic groups of the most efficient agents used in 25 programmes to date against invasive trees or shrubs, beetles, sap suckers, gall wasps and rust fungi should be prioritized. In addition, any agents reducing regeneration, either through reduced seed output or attack of seedlings, are expected to facilitate management of the target tree or shrub. Although these recommendations may be simplistic, in the absence of any pre-release impact efficacy assessment or other models, they could be used as additional criteria for agent prioritization.

7 Recommendations for biological control of *Rhamnus cathartica*

In total, 39 specialized arthropods were recorded from *R. cathartica* and *F. alnus* in Europe (Gassmann et al. 2008b). Lepidoptera (22 species) largely dominate, followed by Hemiptera (eight species), Diptera, (four species) and Acari (four species). There is only one specialized beetle on buckthorn in Europe, the stem-boring longhorned beetle, *Oberea pedemontana* (Col., Cerambycidae), but this species is not specific at the genus level.

Based on the above review, the next best group to consider is the sap suckers. A dozen species have been recorded on buckthorn in Europe including three psyllids, *Trichochermes walkeri* (Hem., Triozidae), *Cacopsylla rhamnicola* (Hem., Psyllidae) and *Trioza rhamni* (Hem., Triozidae). One of them, *T. walkeri*, is currently being studied. One Miridae (Hem.) and three Eriophydidae (Acari) have also been recorded on *R. cathartica* in Europe. With the exception of one species inducing leaf erinea on *R. cathartica*, none of the eriophyid species has been observed on buckthorn in past surveys. We therefore suggest not focussing on these species in the immediate future.

The coccinellid beetle *Harmonia axyridis* was recently found to be abundant on *R. cathartica* in Minnesota (Yoder et al. 2008) and it is possible that predation by *H. axyridis* could pose a particular threat to introduced biocontrol agents. The risk for each species is discussed below:

Trichochermes walkeri: Larval development occurs in leaf galls and thus larvae should be safe from predation. The species overwinters in the egg stage and eggs are laid on leaf bud axils. In Switzerland, *H. axyridis* adults start to look for overwintering sites in early October (M. Kenis, pers. comm.). The presence of *T. walkeri* eggs (October–April) may thus not fully coincide with maximum predation activity in *H. axyridis*. It has also been observed that *H. axyridis* does not feed on all insect species. It is planned to study the predation of *T. walkeri* by *H. axyridis* in collaboration with Marc Kenis who is studying the multitrophic interactions of this coccinellid beetle at CABI E-CH (see www.cabi.org/default.aspx?site=170&page=1017&pid=2319).

Cacopsylla rhamnicola: this species overwinters in the adult stage (Ossiannilsson 1992). The eggs are found in the inflorescences and young folded leaves, in which we have also observed young larvae. In this case, too, the threat from predation should be minimal.

Trioza rhamni: This species overwinters as an adult on conifers (Ossiannilson 1992). Females lay eggs singly on the underside of young leaves of the host plant and before long a pit-gall develops around each egg. The first-instar larvae remain in the gall, but after each moult the larvae move to another site on the leaf. Of the three psyllids associated with buckthorn, *T. rhamni* seems to be the most susceptible to predation and perhaps also the potentially least efficient species.

The detection of '*Candidatus* Phytoplasma rhamni' in *T. walkeri* adults raises several questions that will need to be addressed before further considering sap-suckers for biological control of *R. cathartica*. In addition to the questions raised about *T. walkeri* in section 3.4, it will be necessary to determine whether *C. rhamnicola* is also host of the phytoplasma and able to transmit it.

Based on the preceding review, Lepidoptera were one of the least successful taxonomic groups for the biological control of shrubs or trees. In addition, the Lepidoptera we have investigated so far were either not sufficiently specific or are very difficult to test. They will therefore be given low priority as potential agents.

As far as insects that directly reduce seed output of buckthorn are concerned, two midge species and two Lepidoptera are known from the fruits of *R. cathartica* in Europe. One midge, *Wachtiella krumbholzi* is under evaluation. We have not found the second midge species, *Lasioptera kosarzewskella* or the two Lepidoptera species, *Sorhagenia rhamniella* (Cosmopterigidae) and *Hysterosia sodaliana* (Tortricidae), which also do not appear to be genus specific according to literature.

Wachtiella krumbholzi is the only available potential seed feeder for biological control of *R. cathartica* but the feasibility of host-range testing still needs to be addressed.

8 Proposed work programme 2010–2011

Based on the above, we propose the following work programme for 2010 and 2011:

Trichochermes walkeri and *Cacopsylla rhamnicolla* (Hem., Psylloidae)

- Establish a protocol to determine whether the leaf gall psyllid *Trichochermes walkeri* transmits '*Candidatus* Phytoplasma rhamni';
- Sample additional *T. walkeri* populations for the detection of the phytoplasma;
- Collect samples of *R. cathartica* and other *Rhamnus* spp. from Europe and North America for the detection of the phytoplasma;
- Sample populations of the psyllid *Cacopsylla rhamnicolla* for the detection of '*Candidatus* Phytoplasma rhamni';
- Elaborate a protocol to determine the specificity of '*Candidatus* Phytoplasma rhamni';
- Continue host range studies with *T. walkeri* (no-choice and single-choice oviposition and larval development tests);
- Conduct preliminary studies of the predatory behaviour of *Harmonia axyridis* on *T. walkeri.*

***Wachtiella krumbholzi* (Dipt., Cecidomyiidae)**

- Further assess the feasibility of host-range testing of this seed-feeding midge.

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Annex 1

Deliberate introductions of biological control agents against invasive trees and shrubs (the data are extracted from Julien and Griffiths (1998) and updated by more recent information)[a]

	Plant growth habit / Agent taxonomic group	Introduced range / date	Native range	Food niche	Success status	References
Melaleuca quinquenervia (Myrtaceae)	Tree	Florida, USA	Eastern Australia; New Caledonia			
Oxyops vitiosa (Curculionidae)	Coleoptera	First released in 1997		Foliage, flush feeder	Success	Rayamajhi et al. 2002; Center et al. 2008
Boreioglycaspis melaleucae (Psyllidae)	Hemiptera	First released in 2002		Sap sucker	Success	Rayamajhi et al. 2002; Center et al. 2008
Fergusonina turneri (Fergusoninidae)	Diptera	First released in 2005		Foliage, flush feeder	Not established	Rayamajhi et al. 2002; Center et al. 2008
Schinus terebinthifolius (Anacardiaceae)	Tree	Hawaii, Florida, USA	Argentina, Brazil			
Episimus unguiculus (=*utilis*) (Tortricidae)	Lepidoptera	First released in 1954 in Hawaii		Foliage feeder	Failure	Hight et al. 2002
Lithraeus atronotatus (Bruchidae)	Coleoptera	First released in 1960 in Hawaii		Seed feeder	Failure	Hight et al. 2002
Crasimorpha infuscata (Gelechiidae)	Lepidoptera	First released in 1961 in Hawaii		Stem galler	Not established	Hight et al. 2002
Tamarix spp. (Tamaricaceae)[a]	Tree	Western USA	Western Asia			
Diorhabda spp. (Chrysomelidae)	Coleoptera	First releases of populations from China/Kazakhstan in 2001 and Greece in 2003		Foliage feeder	Success	Hudgeons et al. 2007; DeLoach et al. 2008
Solanum mauritianum (Solanaceae)	Tree	South Africa, New Zealand, India, Pacific islands	South America			
Gargaphia decoris (Tingidae)	Hemiptera	First released in South Africa in 1999		Sap sucker	Failure	Olckers and Borea 2009

Clidemia hirta (Melastomataceae)	Shrub	Hawaii, USA	Central America, Trinidad and Tobago			
Liothrips urichi (Phlaeothripidae)	Thysanoptera	First released in Fiji in the 1930s and in Hawaii in 1953		Sap sucker	Success	Simmonds 1937; Reimer and Beardsley 1989; Conant 2002
Ategumia matutinalis (syn. *ebulealis* ?) (Pyralidae)	Lepidoptera	First released in Hawaii in 1969		Foliage feeder	Failure	Nakahara et al. 1992; Julien and Griffiths 1996; Conant 2002
Antiblemma acclinalis (Noctuidae)	Lepidoptera	First released in Hawaii in 1995		Foliage feeder	Failure	Julien and Griffiths 1998; Conant 2002; Culliney et al. 2003
Carposina bullata (Carposinidae)	Lepidoptera	First released in Hawaii in 1995		Flowerbud feeder	Not established	Julien and Griffiths 1998; Conan 2002; Culliney et al. 2003
Lius poseidon (Buprestidae)	Coleoptera	First released in Hawaii in 1988		Foliage feeder	Failure	Julien and Griffiths 1998; Conant 2002
Mompha trithalama (Momphidae)	Lepidoptera	First released in Hawaii in 1995		Seed feeder	Failure	Julien and Griffiths 1998; Conant 2002; Culliney et al. 2003
Sesbania punicea (Fabaceae)	Tree	South Africa	South America			
Trichapion lativentre (Curculionidae)	Coleoptera	Accidental introduction in South Africa in the 1970s		Foliage, flush feeder	Success	Julien and Griffiths 1998; Hoffmann and Moran 1999
Rhyssomatus marginatus (Curculionidae)	Coleoptera	First released in South Africa in 1984		Seed feeder	Success	Julien and Griffiths 1998; Hoffmann and Moran 1999
Neodiplogrammus quadrivittatus (Curculionidae)	Coleoptera	First released in South Africa in 1984		Stem borer	Success	Julien and Griffiths 1998; Hoffmann and Moran 1999
Hakea sericea (Proteaceae)	Tree	South Africa	Australia			
Erytenna consputa (Curculionidae)	Coleoptera	First released in South Africa in 1972		Seed feeder	Failure	Gordon 1999
Cydmaea binotata (Curculionidae)	Coleoptera	First released in South Africa in 1979		Stem borer	Failure	Gordon 1999
Carposina autologa (Carposinidae)	Lepidoptera	First released in South Africa in 1991		Seed feeder	Failure	Gordon 1999
Prosopis spp. (Mimosaceae)[a]	Tree	South Africa, Australia	North and South America			
Algarobius prosopis (Bruchidae)	Coleoptera	First released in South Africa in 1987 and in Australia in 1996		Seed feeder	Failure	Impson et al. 1999

Algarobius bottimeri (Bruchidae)	Coleoptera	First released in South Africa in 1990		Seed feeder	Failure	Impson et al. 1999
Neltumius arizonensis (Bruchidae)	Coleoptera	First released in South Africa in 1993		Seed feeder	Failure	Impson et al. 1999
Evippe sp. (Gelechiidae)	Lepidoptera	First released in Australia in 1998		Foliage feeder	Failure	van Klinken et al. 2003
Prosopidopsylla flava (Psyllidae)	Hemiptera	First released in Australia in 1998		Sap sucker	Failure	van Klinken et al. 2003
Parkinsonia aculeata (Caesalpiniaceae)	Tree	Northern Australia	America			
Mimosetes ulkei (Bruchidae)	Coleoptera	First released in Australia in 1993		Seed feeder	Failure	Lockett et al. 1999; Grace et al. 2006
Penthobruchus germaini (Bruchidae)	Coleoptera	First released in Australia in 1995		Seed feeder	Failure	Lockett et al. 1999; Grace et al. 2006
Rhinacloa callicrates (Miridae)	Hemiptera	First released in Australia in 1989		Seed feeder	Failure	Lockett et al. 1999; Grace et al. 2006
Leptospermum laevigatum (Myrtaceae)	Tree	South Africa	Australia			
Parectopa thalassias (Gracillariidae)	Lepidoptera	First released in South Africa in 1996		Foliage feeder	Failure	Gordon 1999
Myrica faya (Myricaceae)	Tree	Hawaii	Azores, Canary Islands, Madeira			
Caloptilia nr *schinell* (Gracillariidae)	Lepidoptera	First released in Hawaii in 1991		Foliage feeder	Failure	Leen and Markin 1996; Markin 2001
Acacia nilotica ssp. *indica* (Fabaceae)	Tree	Australia	Pakistan, Kenya and southern Africa			
Bruchidius sahlbergi (Bruchidae)	Coleoptera	First released in Australia in 1982		Seed feeder	Failure	Dhileepan 2009
Cuphodes profluens (Gracillariidae)	Lepidoptera	First released in Australia in 1983		Flush feeder, shoot-tip borer	Not established	Dhileepan 2009
Homicloda barkeri (Chrysomelidae)	Coleoptera	First released in Australia in 1996		Foliage feeder	Establishment unknown	Lockett and Palmer 2003; Dhileepan 2009

Cometaster pyruoctuidae (Noctuidae)	Lepidoptera	First released in Australia in 2004		Foliage feeder	Not established	Dhileepan 2009
Chiasmia inconspicua (Geometridae)	Lepidoptera	First released in Australia in early 2000s		Foliage	Not established	Palmer et al. 2007
Chiasma assimilis (Geometridae)	Lepidoptera	First released in Australia in early 2000s		Foliage	Failure	Palmer et al. 2007
Acacia cyclops (Fabaceae)	Tree	South Africa	Australia			
Dasyneura dielsi (Cecidomyiidae)	Diptera	First released in South Africa in 2001		Seed feeder	Failure	Adair 2005; Dennill et al. 1999; Moseley et al. 2009
Melanterius servulus (Curculionidae)	Coleoptera	First released in South Africa in 1991		Seed feeder	Success	Dennill et al. 1999
Acacia dealbata (Fabaceae)	Tree	South Africa	Australia			
Melanterius maculatus (Curculionidae)	Coleoptera	First released in South Africa in 1991		Seed feeder	Not established	Dennill et al. 1999
Acacia decurrens (Fabaceae)		South Africa	Australia			
Melanterius maculatus (Curculionidae)	Coleoptera	First released in South Africa in 2001		Seed feeder	Not established	Moran et al. 2004
Acacia longifolia (Fabaceae)	Tree	South Africa	Australia			
Melanterius ventralis (Curculionidae)	Coleoptera	First released in South Africa in 1985		Seed feeder	Success	Dennill et al. 1999
Trichilogaster acaciaelongifoliae (Pteromalidae)	Hymenoptera	First released in South Africa in 1982		Stem galler	Success	Dennill 1985; Dennill et al. 1999
Acacia mearnsii	Tree	South Africa	Australia			
Melanterius maculatus (Curculionidae)	Coleoptera	First released in South Africa in 1994		Seed feeder	Failure	Dennill et al. 1999
Acacia melanoxylon	Tree	South Africa	Australia			
Melanterius acaciae (Curculionidae)	Coleoptera	First released in South Africa in 1986		Seed feeder	Failure	Dennill et al. 1999

Acacia pycnantha	Tree	South Africa	Australia			
Trichilogaster sp. (Pteromalidae)	Hymenoptera	First released in South Africa in 1987		Stem galler	Success	Dennill et al. 1999; Hoffmann et al. 2002
Acacia saligna	Tree	South Africa	Australia			
Melanterius compactus (Curculionidae)	Coleoptera	First released in South Africa in 2001		Seed feeder	Success	Impson and Moran 2004
Uromycladium tepperianum (Uredinales)	Pathogen	First released in South Africa in 1987		Galler of any young tissue	Success	Morris 1999; Wood and Morris 2007
Paraserianthes lophanta	Tree	South Africa	Australia			
Melanterius servulus (Curculionidae)	Coleoptera	First released in South Africa in 1989		Seed feeder	Failure	Dennill et al. 1999
Mimosa pigra	Shrub	Northern Australia	Tropical America			
Acanthoscelides puniceus (Bruchidae)	Coleoptera	First released in Australia in 1983		Seed feeder	Failure	Ostermeyer and Grace 2007
Acanthoscelides quadridentatus (Bruchidae)	Coleoptera	First released in Australia in 1983		Seed feeder	Not established	Ostermeyer and Grace 2007
Chlamisus mimosae (Chrysomelidae)	Coleoptera	First released in Australia in 1985		Foliage	Failure	Ostermeyer and Grace 2007
Neurostrota gunniella (Gracillariidae)	Lepidoptera	First released in Australia in 1989		Foliage	Failure	Ostermeyer and Grace 2007
Carmentosa mimosa (Sesiidae)	Lepidoptera	First released in Australia in 1989		Stem borer	Failure	Ostermeyer and Grace 2007
Coelocephalapion aculeatum (Curculionidae)	Coleoptera	First released in Australia in 1992		Seed feeder	Not established	Ostermeyer and Grace 2007
Coelocephalapion pigrae (Curculionidae)	Coleoptera	First released in Australia in 1994		Seed feeder	Failure	Ostermeyer and Grace 2007
Phloeospora mimosae-pigrae (Coelomycetes)	Pathogen	First released in Australia in 1995		Leaves and stems	Not established	Ostermeyer and Grace 2007
Chalcodermus serripes (Curculionidae)	Coleoptera	First released in Australia in 1996		Seed feeder, flush feeder	Not established	Ostermeyer and Grace 2007

Diabole cubensis (Uredinales)	Pathogen	First released in Australia in 1996		Leaves and stems	Not established	Ostermeyer and Grace 2007
Sibina fastigiata (Curculionidae)	Coleoptera	First released in Australia in 1997		Seed feeder, flush feeder	Not established	Ostermeyer and Grace 2007
Malacorhinus irregularis (Chrysomelidae)	Coleoptera	First released in Australia in 2000		Root feeder	Failure	Ostermeyer and Grace 2007
Macaria pallidata (Geometridae)	Lepidoptera	First released in Australia in 2002		Foliage	Failure	Ostermeyer and Grace 2007
Leuciris fimbriaria (Geometridae)	Lepidoptera	First released in Australia in 2005		Foliage	Establishment unknown	Ostermeyer and Grace 2007
Mimosa invisa	Vine shrub	Australia, Pacific islands	Tropical America			
Heteropsylla spinulosa (Psyllidae)	Hemiptera	First released in Australia in 1988		Sap sucker	Success	Kuniata and Korowi 2004
Psigida walkeri (Citheroniidae)	Lepidoptera	First released in Cook Islands in 1994		Flush feeder	Not established	Waterhouse 1994
Scamurius sp. (Coreidae)	Hemiptera	First released in Australia in 1987		Sap sucker	Not established	Waterhouse 1994
Ulex europaeus	Shrub	USA, New Zealand, Australia	Temperate Europe			
Exapion ulicis (Brentidae)	Coleoptera	First released in Hawaii, USA, in 1926		Seed feeder	Failure	Hill et al. 2008
Cydia succedana (Tortricidae)	Lepidoptera	First released in New Zealand in 1992		Seed feeder	Failure	Hill et al. 2008
Tetranychus lintearius (Tetranychidae)	Acari	First released in New Zealand in 1989		Sap sucker	Failure	Hill et al. 2008
Sericothrips staphylinus (Thripidae)	Thysanoptera	First released in New Zealand in 1991		Sap sucker	Failure	Hill et al. 2008
Agonopterix ulicetella (Oecophoridae)	Lepidoptera	First released in Hawaii, USA, in 1988		Foliage	Failure	Hill et al. 2008
Pempelia genistella (Pyralidae)	Lepidoptera	First released in New Zealand and the USA in 1996		Foliage	Failure	Hill et al. 2008
Scytheris grandipennis (Scythrididae)	Lepidoptera	First released in New Zealand in 1990		Foliage	Not established	Hill et al. 2008

Eutrichapion scutellare (Curculionidae)	Coleoptera	First released in Hawaii, USA, in 1961		Stem galler	Not established	Markin et al. 1996
Uromyces pisi (Uredinales)	Pathogen	First released in the USA in 2000		Foliage	Not established	Hill et al. 2008
Cytisus scoparius	Shrub	USA, New Zealand, Australia	Temperate Europe			
Leucoptera spartifoliella (Lyonetiidae)	Lepidoptera	First released in the USA in 1960		Stem borer	Failure	Sheppard et al. 2006
Arytainilla spartiophila (Psyllidae)	Hemiptera	First released in New Zealand in 1993		Sap sucker	Failure	Sheppard et al. 2006
Bruchidius villosus (Bruchidae)	Coleoptera	First released in New Zealand in 1987		Seed feeder	Failure	Sheppard et al. 2006
Exapion fuscirostre (Curculionidae)	Coleoptera	First released in the USA in 1964		Seed feeder	Failure	Coombs et al. 2008

[a], the exact number of *Prosopis* species is not given because the genus has formed hybrid communities in the invaded ranges; the number of *Tamarix* species is not given either since most papers refers to the biological control of *Tamarix* spp.

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KNOWLEDGE FOR LIFE

Monitoring garlic mustard (*Alliaria petiolata*) in anticipation of future biocontrol release (2005-2009)

Report to the Legislative-Citizen Commission on Minnesota Resources

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Table of Contents

Executive Summary

Garlic mustard (*Alliaria petiolata* (Bieb.) Cavara & Grande) is a biennial forb that has become invasive in forests in Minnesota and much of the United States. Garlic mustard has been found to negatively impact native biota in the areas it invades. Three species of *Ceutorhynchus* weevils native to Europe are being studied to determine if they can be safe and effective biological control agents for garlic mustard. In 2005, a garlic mustard monitoring program was initiated in Minnesota. Permanent monitoring plots were established at 12 sites throughout Minnesota. One purpose of the program was to provide baseline data on garlic mustard populations which could then be compared with data collected after biological control agent release to determine the effectiveness of garlic mustard control and the response of the native plant community. Additionally, the monitoring program provides information on year to year changes in garlic mustard, the extent of herbivory on garlic mustard in Minnesota, and the relationship between garlic mustard and other plant species and ground cover. In addition to the standard monitoring protocol, data has been collected to better understand how the sites differ in their levels of shading and tree canopy species composition.

The garlic mustard monitoring data from 2005 to 2009 showed that garlic mustard populations can vary considerably from year to year. Multiple years of monitoring are necessary to characterize garlic mustard populations. About half of the sites demonstrate strong cycling in the dominance of one garlic mustard life stage over another. For example, in year one the site is dominated by the seedling (1st year) stage of the garlic mustard, in the next year the adults (2nd year plants) dominate and prevent the establishment of many seedlings. In the 3rd year the site is dominated by seedlings again. These life stage fluctuations will be important to consider if biological control insects are released so that the insects and plants are matched at the correct life stages. Monitoring data has also shown that garlic mustard plants are occurring at high population densities (up to 133 adult plants m^{-2} and 720 seedlings m^{-2} mean densities). Garlic mustard monitoring sites also appear to be heavily impacted by nonnative earthworms as no site had a layer of leaf litter deeper than 2 cm in June 2009. Monitoring data also showed that garlic mustard is currently experiencing very little herbivory in Minnesota. The mean amount of leaf tissue removed due to insects was never over 3% in the 5 years of the study. Low herbivory indicates that garlic mustard is currently not heavily impacted by insects already present in Minnesota.

Site to site differences in garlic mustard populations may be due to a number of factors, such as light availability, tree species composition, land use history, high deer populations, soil properties, and other environmental factors. The amount of light available to plants in the understory of the forest has been found to be a strong driver of the growth of garlic mustard. Garlic mustard populations may differ across sites due to the amount of light they receive. Light availability in the form of photosynthetically active radiation (PAR) was characterized at each of the 12 sites. In general, the sites differed little in the amount of PAR available. When plant community differences are observed among the sites, it is likely that it is factors other than light availability which cause those differences. Tree species making up the canopy were surveyed at each site. The differences and similarities in tree species composition may aid in interpreting the varying population changes and impacts of garlic mustard among the sites.

Chapter 1

Population Biology of Garlic Mustard (*Alliaria petiolata*) in Minnesota Hardwood Forests

2005-2008

See attached journal article

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Chapter 2

Garlic Mustard (*Alliaria petiolata*) Monitoring in Minnesota: 2009 Update

INTRODUCTION

Garlic mustard (*Alliaria petiolata*) is a non-native, biennial, herbaceous plant that has become abundant in wooded areas in Minnesota and the eastern United States (Meekins et al. 2001; Rodgers et al. 2008). Garlic mustard can form dense cover on the forest floor and negatively impact native species (Nuzzo 1999; Blossey et al. 2001; Stinson et al. 2006). In order to better understand garlic mustard populations in Minnesota and to collect baseline data in the event of biological control insect release (Blossey et al 2001), a garlic mustard monitoring was initiated in Minnesota in 2005. The results of the monitoring data collected from 2005 to 2008 are presented in Van Riper et al. 2010. This chapter provides an update to Van Riper et al. 2010 by presenting the data gathered in 2009.

Garlic mustard and associated plant communities were monitored at deciduous forests sites in Minnesota. Garlic mustard populations can fluctuate dramatically from year to year (Meekins and McCarthy 2002; Winterer et al. 2005; Pardini et al. 2009). Multiple years of monitoring are necessary to produce baseline data on garlic mustard populations and to determine the impacts of biological control agents, should they be released (Blossey 1999). It is expected that releasing biological control agents would decrease the population density and cover of garlic mustard and reduce garlic mustard plant height and silique production (Blossey et al. 2001; Davis et al. 2006; Gerber et al. 2007a, b). In this study data were collected on garlic mustard population density, cover, height, and silique production so the current population could be characterized and comparisons could be made should biocontrol agents be released in the future. Additionally, data were collect on the current levels of insect herbivory garlic mustard experiences in Minnesota.

In addition to collecting data on garlic mustard, data were collected on the other species growing with garlic mustard. The relationship between garlic mustard and other species can then be examined. The species composition of the site also indicates how the site is likely to respond to the reduction of garlic mustard. If the site has few native species present, it may need additional restoration actions after garlic mustard is reduced to restore a native plant community.

The composition of the ground layer can impact garlic mustard and other native species. Invasive, nonnative earthworms have damaged many forests in Minnesota and caused large reductions in the depth of the layer of litter generally found in deciduous forests (Bohlen et al. 2004; Hale et al. 2005). Earthworm impacts can create environments that favor invasive species such as garlic mustard and negatively impact native species (Bartuszevige et al. 2007; Blossey et al. 2009). In this study, data were collected on depth of litter layer and ground cover composition to determine the status of the litter layer at the monitoring sites and its relationship with garlic mustard and other species.

Together, the data on garlic mustard populations, native and invasive species, herbivory, and litter depth provide a strong understanding of the current impact and population of dynamics of garlic mustard in Minnesota. These data can be compared with data collected after the release of biological control agents to determine if the agents are effective at reducing garlic mustard and whether the native plant species are able to increase after garlic mustard cover is reduced.

METHODS

Methods follow the standard protocol of the Ecology and Management of Invasive Plants Program developed in 2003 (available at http://www.invasive plants.net) and described in Van Riper et al. 2010. Data were collected from 12 sites throughout Minnesota (Table 1). Each site consisted of 20 permanent 1-m by 0.5-m monitoring plots. Data were collected on garlic mustard population density, estimated visual percent cover, and adult plant heights and numbers of siliques (seed pods). The presence of any type of insect damage was noted and the average amount of leaf removed due to insects was visually estimated for each plot. All other species in the plots were identified and their percent covers were visually estimated. The depth of the layer of leaf litter was measured for each plot. For each plot, the ground cover was visually estimated for the following categories: leaf litter, bare soil, woody debris, rocks. Statistical analyses were performed using Statistix 7 (2000).

Garlic mustard is a biennial plant and can have complicated population dynamics (Pardini et al. 2009). Data were collected on the various life stages of garlic mustard. A garlic mustard seed germinates early in the spring. By the fall monitoring period (October) the seedlings had grown into basal rosettes of leaves. The rosettes over-winter and in the following spring, they bolt to form adult plants. Adult plants flower in April-May. By June they have formed siliques which are counted in the monitoring protocol. Adult plants fully mature and drop seeds and senesce by late July to August. Therefore, in the June monitoring period both seedling and adult stages of garlic mustard are present, but in October only the rosette stage is present.

A few unexpected events occurred during the course of the study. On May 25, 2008 Warner Nature Center was hit by a tornado. A number of trees were knocked down in the area of the garlic mustard monitoring plots. This opened up the canopy to more light than the site had experienced in previous years. At the Luce Line Trail, garlic mustard plants in plots 1-10 and 16-20 were treated with 2% Roundup (glyphosate) herbicide on May 29-30, 2008. At Pine Bend Bluff SNA, in an effort to reduce the amount of *Rhamnus cathartica* L. (common buckthorn) and *Lonicera spp*. (nonnative honeysuckles), those trees were cut down in April 2009 in the area with garlic mustard monitoring plots 1-10 and 16-20. See chapter “Differences in available photosynthetically active radiation among garlic mustard monitoring sites” in this report for more information. The tree clearing resulted in a dramatic increase in light to the plots and a loss of some plots as they were covered in brush piles. Unforeseen events are to be expected in any long-term monitoring project. Having 12 monitoring sites helps dampen the impact of alterations to any 1 monitoring site. We are also able to continue to follow the monitoring sites after these changes and note the impacts on garlic mustard and other plant species.

RESULTS

Fluctuations in garlic mustard populations over time

Garlic mustard populations in Minnesota are highly variable from year to year (Van Riper et al. 2010). Garlic mustard population density in 2009 followed previous years in showing variability (Fig. 1). Warner Nature Center (WN) and Westwood Hills (WH) continued to show strong population cycling with the sites alternating between being dominated by the seedling/rosette 1st year life stage in one year and then dominated by the adult 2nd year life stage the next (Fig 1). Coon Rapids (CR), Cottage Grove (CG), Luce Line (LL), and Nerstrand (NE) had showed population cycling in the first three years of monitoring, but then the pattern became less pronounced. The 2009 data show CR, CG, and LL returning toward a cycling pattern (Fig. 1a), but at NE the pattern was less clear. At NE, rosette density tended to be decreasing, seedling density increasing, and adult density returning to cycling. Previously, the Willmar (WI) rosette population density was increasing each year, but in 2009 the rosette population density decreased (Fig. 1a). However, seedling and adult population densities increased indicating that the garlic mustard population is still increasing at this site (Fig. 1b, c). Pine Bend (PB) had been trending towards decreasing rosette populations, but 2009 saw an increase rosette population (Fig. 1a). The high seedling density and low adult density may indicate that this site is beginning to cycle (Fig. 1b, c). Fort Snelling (FS) and Hilloway Park (HP) had shown relatively stable rosette population densities, but both saw increases in seedling and rosette densities in 2009 while adult population density remained rather stable (Fig. 1). Baker Park (BP) and Plainview (PL) had shown variable rosette population density over time. In 2009, BP had similar seedling and rosette population densities to 2008, but had a marked decrease in adult population density (Fig 1). PL had similar rosette population densities to previous years, a slight increase in seedling population density, and a decrease in adult population density (Fig. 1).

The mean May 2009 to October 2009 mortality for garlic mustard seedlings to the rosette stage, averaged across all sites, was 80%. The mean October 2008 to May 2009 mortality for garlic mustard rosettes over-wintering to become adults, averaged across all sites, was 34%. In previous years, seedling to rosette mortality ranged from 47-77% and rosette to adult mortality ranged from 7-45% (Van Riper et al. 2010). The 2009 seedling to rosette mortality of 80% was similar to the 77% recorded in previous years. The 2009 rosette to adult mortality of 34% fell within the 7-45% range previously recorded. The total mortality from seedling stage in June to adult stage in June of the next year was 89%, 62%, and 70% for 2008-2009, 2007-2008, and 2006-2007, respectively. There can be high mortality from the seedling to adult stage.

The mean total garlic mustard percent cover (seedling cover + adult cover) in the spring of 2009 ranged from 8% cover at LL to 61% cover at WI (Fig. 2). The rosette percent cover in the fall of 2009 ranged from 1% cover at NE to 21% cover at FS (Fig. 2). In the spring, WI, WN, FS, WH, and HP clustered together with total garlic mustard covers ranging from 42-61% (Fig. 2). PL, CR, BP, NE, CG, PB, and LL clustered together with total garlic mustard cover ranging from 8-22% (Fig. 2). Ranges of garlic mustard percent cover in the spring and fall of 2009 were similar to those observed in 2005-2008.

The spring 2008 herbicide treatment at LL appeared to have an impact on garlic mustard cover, but little impact on garlic mustard population density. Data were collected in June 2008 before the herbicide had killed the plants. All data after June 2008 reflect the aftermath of the herbicide treatment. It would be expected that the herbicide treatment would cause a reduction in the rosettes in 2008 and the adults in 2009. However, the population density for rosettes at LL in 2008 was the highest recorded for LL (55 rosettes m^{-2}, Fig. 1a). Adult garlic mustard population density at LL in 2009 was low (10 adults m^{-2}), but the same as that recorded in 2007 (Fig. 1c). The population density data appeared to be following a population cycling pattern with little impact from the herbicide. However, garlic mustard percent cover at LL did decrease after the herbicide treatment. Total (adult + seedling) garlic mustard percent cover in the spring went from 44% in 2006 to 18% in 2007 to 40% in 2008 to 8% in 2009 (Fig. 2). This follows a pattern of population cycling, although the 8% cover in 2009 is the lowest recorded. Fall rosette percent cover did not cycle so strongly, ranging from 3% in 2006 to 7% in 2007 to 9% in 2008 to 3% in 2009 (Fig. 2). While garlic mustard percent cover was somewhat reduced after the herbicide treatment, the cover of garlic mustard was still similar to values recorded in previous years.

Fluctuations in garlic mustard plant height and reproductive output

It is anticipated that biological control agents, if released, would cause a decrease in mean adult garlic mustard stem height (Gerber et al. 2007a, b). Mean garlic mustard stem heights were determined for each site for 2005-2009 (Fig. 3). Mean stem heights ranged from a low of 17 cm tall at LL and BP to a high of 63 cm tall at NE. Mean stem heights vary considerably from year to year (Fig. 3) and variations do not appear to relate to which life stage is dominant at a given site. For example, WN and WH show strong cycling of life stages, but adult plant heights do not cycle. Abiotic factors may have a strong impact on mean adult stem height.

In plots that had garlic mustard present, the mean number of siliques present per m^2 was determined (Fig. 4a). This gives an indication of the seed rain density experienced in these plots. In 2009, the mean number of siliques per m^2 ranged from 8 siliques m^{-2} at CG to 348 siliques m^{-2} at WI. Studies have consistently shown that garlic mustard plants average been 14 and 16 seeds per silique (Nuzzo 1999; Susko and Lovett-Doust 1999; Evans and Landis 2007). This means that the plots with the highest density of siliques in 2009 could be producing from 4872 to 5568 seeds m^{-2}.

The mean number of siliques per stem indicates the fecundity of individual plants. It is expected that biological control agents will reduce the number of siliques per stem (Gerber et al. 2007a, b). In 2009, the mean number of siliques $stem^{-1}$ ranged from 1 silique $stem^{-1}$ at LL to 14 siliques $stem^{-1}$ at NE (Fig. 4b). While wide year to year variations in siliques $stem^{-1}$ were found at several sites (eg. WN and FS), other sites were more consistent in the number of siliques $stem^{-1}$ from year to year (eg. NE and PB) (Fig. 4b). The most fecund plant in 2009 was found at HP; it measured 112 cm tall and had 52 siliques. The tallest plant measured in 2009 was from WH and was 130 cm tall with 30 siliques.

To further characterize the fecundity of garlic mustard plants at the sites, the percent of stems without siliques present was calculated (the total number of sterile stems recorded at the site / total number of stems at the sites x 100%). It is anticipated that biological control agents, if released, will increase the percentage of garlic mustard plants without siliques. In previous years, at most sites, more than 95% of the adult stems produced siliques (Fig. 4c). A high percentage of stems without siliques were observed at HP in 2006 due to herbicide drift from early season *Rhamnus cathartica* control. In contrast with previous years, in 2009 there were a number of sites with more than 5% barren stems (Fig. 4c). CG, HP, PL, and WH had from 10-16% adult garlic mustard plants with barren stems. At LL 24% of adult stems (22 plants of 98) were barren. The herbicide applied to seedlings in May 2008 likely resulted in stunted adult plants in 2009 causing the increase in barren stems. BP also had a high percentage of barren stems (27%). It is unclear why the number was so high, but it should be noted that there were very few adult plants at BP, so the high percentage is the result of 6 barren plants out of 22 total adults recorded for the site in 2009).

Site species richness and species composition

Sites varied in their species richness. Species richness for each $0.5m^2$ plot was determined and the mean species richness per plot was calculated for each site (Fig. 5). Species richness did not include garlic mustard, but did include native species, nonnative species, species that could not be identified, and moss. PB and WI were the most species rich sites, averaging 8 species per $0.5m^2$ plot. FS and LL were the least species rich with between 1.1 and 2.5 species per $0.5m^2$ plot. For most sites, mean species richness was very similar between June and October (Fig 5). At PL and CG, species richness decreased from June to October (5.1 to 2.6 and 5.1 to 3.5 species per $0.5m^2$ plot, respectively). There was no correlation between total spring garlic mustard cover (adult + seedling) and richness or cover of other (non-garlic mustard) species (Pearson correlations, P=0.91, 0.81).

To characterize the species composition of the sites, lists were made of the 8 most frequent species to occur in the monitoring plots at the 12 sites (Tables 2, 3). Tree seedlings were a common component of the vegetation in the monitoring plots. The invasive tree species *R. cathartica* was one of the 8 most frequent species for 8 of the 12 sites (Table 2). It was the most frequently encountered species at FS, LL, and PB. NE, PL, WN, and WI had no nonnative species among their 8 most frequent species, while BP had 3, CR, FS, LL, and PB had 2, and CG, HP, and WH had 1. CR, FS, LL, and PB all had a nonnative species as their most frequent species. Species such as *Hydrophyllum virginianum, Sanguinaria canadensis*, *Desmodium glutinosum*, *Geranium maculatum*, *Osmorhiza claytonii*, *Ageratina altissimia* var. *altissima*, *Athyrium filix-femina*, and *Amphicarpaea bracteata* are important species that indicate mesic hardwood forest native plant communities (MN DNR 2005). Other common species in mesic hardwood forest and floodplain forest native plant communities include *Phryma leptostachya*, *Parthenocissus sp.*, *Circaea lutetiana*, *Laportea canadensis*, *Impatiens sp.*, and *Galium aparine* (MN DNR 2005). WN and WI each had 3 of the important native species in their top 8 most frequent list, indicating that they are higher quality sites than some of the others. CR, CG, NE, PB, PL, and WH all had one species from the important native species list in their most frequent species list. *G. aparine*, *C. lutetiana*, and

Parthenocissus vitacea were extremely common, occurring in the list of top 8 most frequent species lists for 10, 9, and 6 of the 12 sites, respectively. The species lists indicate that CG, NE, PL, WN, and WI tend to be the highest quality sites while the others are more degraded.

Garlic mustard and leaf litter

All sites had layers of leaf litter that were very low (Fig. 6a). Low depth of litter layer has been associated with invasion of non-native earthworms. In Minnesota, earthworm invasion has caused litter layers to decrease from 10 cm to 0 cm (Hale et al. 2005). In spring 2009, all monitoring sites had layers of leaf litter that were less than 2 cm deep (Fig. 6a). Litter depth was lowest at BP (0.20 cm) and PB (0.36 cm) and highest at CG (1.7cm). The low range of litter depths among the sites makes it difficult to examine the relationship between litter depth and garlic mustard cover and density.

To further characterize ground cover at the sites, the ground cover was visually estimated for each plot into the following categories: leaf litter, bare soil, woody debris, rocks. The ground cover at most sites in spring 2009 was composed mainly of leaf litter (Fig. 6b). With the exceptions of BP and PB, all other sites the ground was at least 60% covered by leaf litter. BP, which had the lowest depth of litter layer, had ground that was 20% covered by leaf litter and 65% composed of exposed bare soil. PB, which is on a steep slope, had ground that was 38% covered by leaf litter and 40% composed of exposed bare soil. High amounts of bare soil indicate disturbed sites which may especially favorable to garlic mustard instead of native species.

Depth of the litter layer and percent of bare soil did not relate to garlic mustard cover or the cover of other species at the site level. Linear regressions showed no significant relationship between spring 2009 depth of litter layer and total cover (adult + seedling) of garlic mustard (P=0.35) or 2009 percent bare soil and total cover of garlic mustard (P=0.15). Depth of litter layer and percent bare soil also did not relate to the percent cover of non-garlic mustard species found at the site (P=0.75, 0.82).

Garlic mustard herbivory levels

Garlic mustard herbivory in 2009 was similar to herbivory levels in 2005-2008 (Table 4). Edge feeding and holes in the leaves were present in almost all (89-97%) of the plots that contained garlic mustard in 2009 (Table 4). Leaf mining and windowpane feeding occurred in the spring, but they occurred in fewer than 8% of the plots with garlic mustard. Across all sites and plots in 2009, the mean amount of leaf removed due to insects was 1.4% in the spring and 2.4% in the fall. All insect herbivory data fell within the range of values seen in 2005-2008.

Plots at three of the sites (FS, NE, and WH) had garlic mustard plants with visible colonies of aphids at their apex (Fig. 6). Additionally, aphids were observed at CG and WN (pers. obs. and pers. comm. Laura Phillips-Mao). Plants with large quantities of aphids showed a twisted morphology in their siliques (Fig. 7). Across all sites, only 3% of plots with garlic mustard had aphids present. Aphids collected in Minnesota by Laura Phillips-Mao were identified by Doris Lagos of the University of Illinois as *Lipaphis brassicae* (pers. comm. Laura Phillips-Mao). Additional information is needed on the potential impacts of this aphid species on garlic mustard.

DISCUSSION

Garlic mustard populations at several of the sites continued to show strong cycling of life stages in 2009. Cycling continued to be strong at WN, WH, CR, CG, and LL. If biological control agents are released, extra care should be taken at the WN, WH, CR, CG, and LL sites to ensure the life stage of the insects match up with the dominant garlic mustard life stage at that time. Garlic mustard population density and percent cover in 2009 were generally similar to the ranges recorded in previous years. In 2009, WN, WH, WI, FS, HP and PL recorded their highest seedling population densities during the 5 year study. The variable nature of garlic mustard populations continues to reinforce the need for multi-year population monitoring (Blossey 1999; Pardini et al. 2009). If biological control agents are released, it will take several years to separate out normal population fluctuations from long-term change in garlic mustard population density and cover.

The year to year variations in garlic mustard height and silique production also indicate that it will take several years to determine if biological control agents are in fact causing a decrease in stem height and seed production. Mean garlic mustard stem heights tended to be shorter with fewer siliques in 2009. Many of the sites were in a year where the seedling stage was more abundant than the adult stage and this may account for the decreases in silique density and the increase in the percentage of plants with no siliques present. Abiotic factors can also play a role in the growth and reproductive success of garlic mustard plants in a given year (Susko and Lovett-Doust 1999; Hochstedler and Gorchov 2007).

Information on species richness, species composition, and litter depth at the sites helps predict which sites may need additional restoration efforts after garlic mustard cover is decreased and which are likely to have a stronger native plant community that may be able to recover on its own. Sites such as Cottage Grove, Nerstrand, Plainview, Warner Nature Center, and Willmar appear to have the strongest native species components of the monitoring sites. These sites may recover more easily than others if garlic mustard is reduced. Sites such as Baker Park, Fort Snelling, Hilloway Park, and Luce Line which have low species richness and few high quality native forest species will likely need additional restoration if garlic mustard cover is reduced. All sites are at risk for continued degradation due to their low depths of the litter layer which indicate that the sites are impacted by nonnative earthworms (Bohlen et al. 2004; Hale et al. 2005; Nuzzo et al. 2009).

Garlic mustard plants in Minnesota are currently experiencing little herbivory from insects already present in Minnesota. This indicates that the release of biological control insects could impact garlic mustard populations. Laboratory testing of potential biological control agents shows promise for these biological control agents to reduce garlic mustard populations (Davis et al. 2006; Gerber et al. 2007a, b).

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TABLES

Table 1. Garlic mustard monitoring sites in Minnesota, USA. The ID column lists the abbreviation for that site as found in the figures (from Van Riper et al. 2010).

Site no.	ID	Site Name	City	County	Habitat type	Latitude Longitude
1	BP	Baker Park Preserve*	Maple Plain	Hennepin	Upland	45° 02.427’ 93° 37.195’
2	CR	Coon Rapids Dam Regional Park	Coon Rapids	Anoka	Floodplain	45° 07.975’ 93° 17.841’
3	CG	Cottage Grove Ravine Regional Park	Cottage Grove	Washington	Upland	44° 48.480’ 92° 53.960’
4	FS	Fort Snelling State Park*	Saint Paul	Ramsey	Floodplain	44° 52.373’ 93° 11.634’
5	HP	Hilloway Park	Minnetonka	Hennepin	Upland	44° 57.552’ 93° 26.098’
6	LL	Luce Line	Long Lake	Hennepin	Upland	44° 58.441’ 93° 35.137’
7	NE	Nerstrand State Park, Prairie Creek SNA*	Nerstrand	Rice	Upland	44° 21.527’ 93° 05.809’
8	PB	Pine Bend Bluffs SNA*	Inver Grove Heights	Dakota	Upland	44° 47.076’ 93° 01.732’
9	PL	Plainview – private land	Plainview	Winona	Upland	44° 06.600’ 92° 03.821’
10	WN	Warner Nature Center*	Marine on St. Croix	Washington	Upland	45° 10.853’ 92° 49.641’
11	WH	Westwood Hills Nature Center	St. Louis Park	Hennepin	Upland	44° 58.301’ 93° 23.692’
12	WI	Willmar - private land	Willmar	Kandiyohi	Upland	45° 19.356’ 94° 59.667’

*= one of five sites established in time for spring 2005 data collection

Table 2. Species composition of garlic mustard monitoring plots by site for June 2009. Species listed are the 8 most frequent species (occur in the most plots) for each site, listed in declining order of frequency, with the most frequent species at the top of the list. Tree species listed occurred as tree seedlings in the plots. Nomenclature follows the Integrated Taxonomic Information System (http://www.itis.gov) accessed 22 February 2010 (see Table 3 for authorities and common names).

Baker Park	**Coon Rapids**	**Cottage Grove**	**Fort Snelling**	**Hilloway Park**	**Luce Line**
Fraxinus pennsylvanica[T]	*Gleochoma hederacea**	*Galium aparine*	*Rhamnus cathartica**[T]	*Pinus strobus*[T]	*Rhamnus cathartica**[T]
Geum canadense	*Galium aparine*	*Circaea lutetiana*	*Circaea lutetiana*	*Galium aparine*	*Circaea lutetiana*
*Taraxacum officinale**	*Rhamnus cathartica**[T]	*Osmorhiza claytonii*	*Partheno-cissus vitacea*	*Arisaema triphyllum*	*Geum canadense*
Galium aparine	*Laportea canadensis*	*Rhamnus cathartica**[T]	*Impatiens sp.*	*Prunus serotina*[T]	*Fraxinus pennsylvanica*[T]
Solidago canadensis var. *scabra*	*Ageratina altissima* var. *altissima*	*Maianthemum canadense*	*Fraxinus pennsylvanica*[T]	*Ulmus sp.* [T]	*Galium aparine*
*Rhamnus cathartica**[T]	*Impatiens sp.*	*Ostrya virginiana*[T]	*Solanum dulcamara**	*Rhamnus cathartica**[T]	*Solanum dulcamara**
*Solanum dulcamara**	*Fraxinus pennsylvanica*[T]	*Rubus sp.*	*Celtis occidentalis*[T]	*Pilea pumila*	*Parthenocissus vitacea*
Partheno-cissus vitacea	*Geum canadense*	*Anemone quinquefolia*	*Teucrium canadense*	*Acer negundo*[T]	*Ribes sp.*

Nerstrand	**Pine Bend**	**Plainview**	**Warner Nature**	**Westwood Hills**	**Willmar**
Galium aparine	*Rhamnus cathartica**[T]	*Circaea lutetiana*	*Prunus serotina*[T]	*Fraxinus pennsylvanica*[T]	*Osmorhiza claytonii*
Laportea canadensis	*Ageratina altissima* var. *altissima*	*Ribes sp.*	*Circaea lutetiana*	*Circaea lutetiana*	*Galium aparine*
Viola sp.	*Circaea lutetiana*	*Parthenocissus vitacea*	*Rubus sp.*	*Amphicarpaea bracteata*	*Circaea lutetiana*
Circaea lutetiana	*Celtis occidentalis*[T]	*Arisaema triphyllum*	*Amphicarpaea bracteata*	*Rhamnus cathartica**[T]	*Hydrophyllum virginianum*
Carya cordiformis[T]	*Prunus sp.* [T]	*Geum canadense*	*Desmodium glutinosum*	*Geum canadense*	*Phryma leptostachya*
Carex sp.	*Partheno-cissus vitacea*	*Athyrium filix-femina*	*Acer rubrum*[T]	*Galium aparine*	*Sanguinaria canadensis*
Geranium maculatum	*Galium aparine*	*Rubus sp.*	*Athyrium filix-femina*	*Acer negundo*[T]	*Uvularia perfoliata*
Geum canadense	*Leonurus cardiaca**	*Vitis riparia*	*Galium aparine*	*Solanum dulcamara*	*Fraxinus pennsylvanica*[T]

* = nonnative (Nativity follows Minnesota Department of Natural Resources Vascular Plants of Minnesota -- September 25, 2002 (http://files.dnr.state.mn.us/eco/plant_list9-25-02.pdf) accessed 22 Feb 2010.)

[T] = tree species

Table 3. List of the species from Table 2 with authority and common name. Nomenclature follows the Integrated Taxonomic Information System (http://www.itis.gov) accessed 22 February 2010.

Scientific name	**Authority**	**Common name**
Acer negundo	L.	box elder
Acer rubrum	L.	red maple
Ageratina altissima var. *altissima*	(L.) King & H.E. Robins.	white snakeroot
Amphicarpaea bracteata	(L.) Fern.	hog peanut
Anemone quinquefolia	L.	wood anemone
Arisaema triphyllum	(L.) Schott	jack-in-the-pulpit
Athyrium filix-femina	(L.) Roth	lady fern
Carex sp.	L.	sedge
Carya cordiformis	(Wangenh.) K. Koch	bitternut hickory
Celtis occidentalis	L.	hackberry
Circaea lutetiana	L.	common enchanter's nightshade
Desmodium glutinosum	(Muhl. ex Willd.) Wood	pointed-leaved tick trefoil
Fraxinus pennsylvanica	Marsh	green ash
Galium aparine	L.	cleavers
Geranium maculatum	L.	wild geranium
Geum canadense	Jacq.	white avens
Gleochoma hederacea	L.	creeping charlie
Hydrophyllum virginianum	L.	Virginia waterleaf
Impatiens sp.	L.	touch-me-not
Laportea canadensis	(L.) Weddell.	wood nettle
Leonurus cardiaca	L.	motherwort
Maianthemum canadense	Desf.	Canada mayflower
Osmorhiza claytonii	(Michx.) C.B. Clarke	Clayton's sweet cicely
Ostrya virginiana	(P. Mill.) K. Koch	ironwood
Parthenocissus vitacea	(Knerr.) A.S. Hitchc.	woodbine
Phryma leptostachya	L.	lopseed
Pilea pumila	(L.) Gray	clearweed
Pinus strobus	L.	white pine
Prunus serotina	Ehrh.	black cherry
Prunus sp.	L.	cherry
Rhamnus cathartica	L.	common buckthorn
Ribes sp.	L.	gooseberry
Rubus sp.	L.	blackberry
Sanguinaria canadensis	L.	bloodroot
Solanum dulcamara	L.	bittersweet nightshade
Solidago canadensis var. *scabra*	Torr. & Gray	Canada goldenrod
Taraxacum officinale	G.H. Weber ex Wiggers	dandelion
Teucrium canadense	L.	germander
Ulmus sp.	L.	elm
Uvularia perfoliata	L.	perfoliate bellwort
Viola sp.	L.	violet
Vitis riparia	Michx.	wild grape

Table 4. Garlic mustard presence and types of insect feeding at 12 sites in Minnesota, USA, 2005 to 2009 (modified from Van Riper et al. 2010). The percentage of plots with garlic mustard present out of the 20 plots at each of 12 study sites in Minnesota over 4 years are presented (5 study sites in spring 2005, 12 study sites for all other dates). Of the plots with garlic mustard present, the percentages of those plots with various types of visual leaf damage estimates are listed by the type of feeding damage.

	Plots with garlic mustard present	Plots with feeding by this insect type (of plots with garlic mustard present)				
Time		Edge feeding	Holes	Leaf miner	Windowpane feeding	Mean leaf removal
	------------------------------------ % ------------------------------------					
Spring 2005	100	96	98	31	4	1.6
Fall 2005	87	99	98	1	1	1.5
Spring 2006	98	96	97	31	9	1.5
Fall 2006	84	97	98	<1	<1	2.0
Spring 2007	99	100	100	33	0	1.8
Fall 2007	88	97	96	1	0	2.4
Spring 2008	99	100	98	12	4	2.3
Fall 2008	63	97	91	0	<1	3.0
Spring 2009	99	97	98	8	<1	1.4
Fall 2009	78	95	89	0	0	2.4

FIGURES

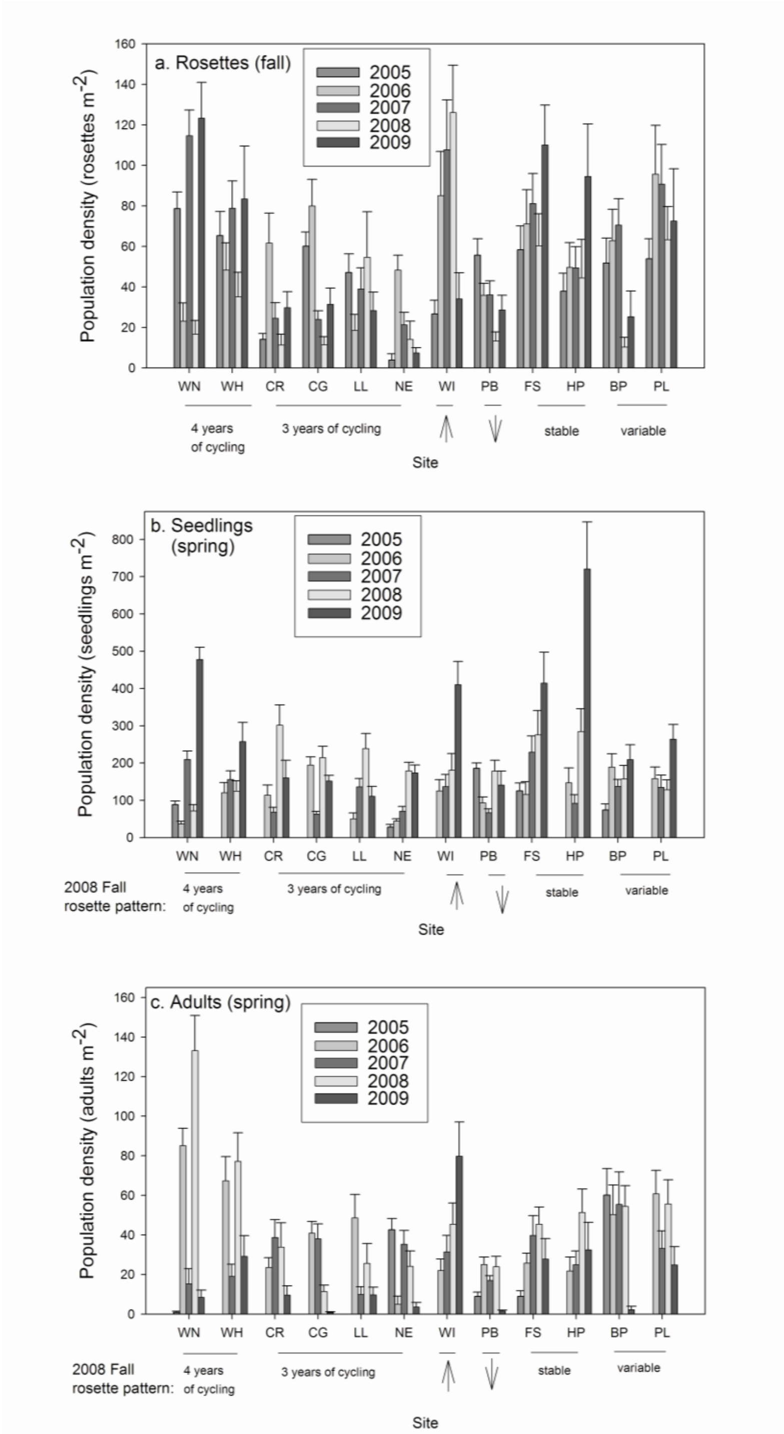

Figure 1. Mean garlic mustard population density (± SE) of rosettes (a), seedlings (b), and adults (c) from 2005-2009 at 12 garlic mustard monitoring sites in Minnesota. Plots are grouped according to the population cycling patterns they exhibited as of fall 2008 (as presented in Van Riper et al. 2010). Note that the y-axes vary.
BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

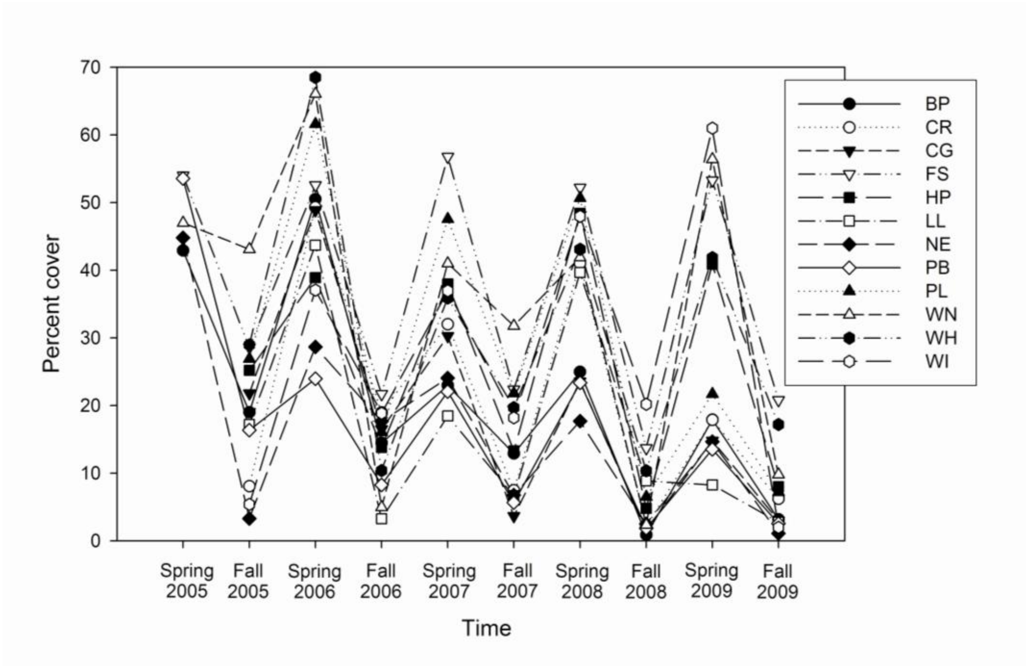

Figure 2. Mean visual percent cover of garlic mustard at each garlic mustard monitoring site from 2005-2009. Spring cover is the total cover of adult + seedling garlic mustard plants in June. Fall cover is the cover of rosettes in October.
BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

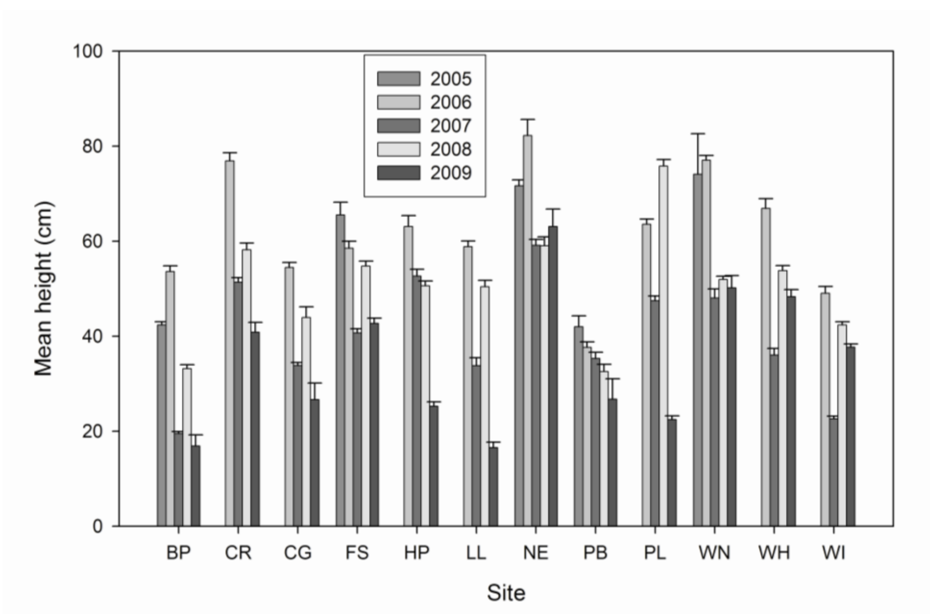

Figure 3. Mean adult garlic mustard stem heights (± SE) by site as measured in June of 2005-2009. BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

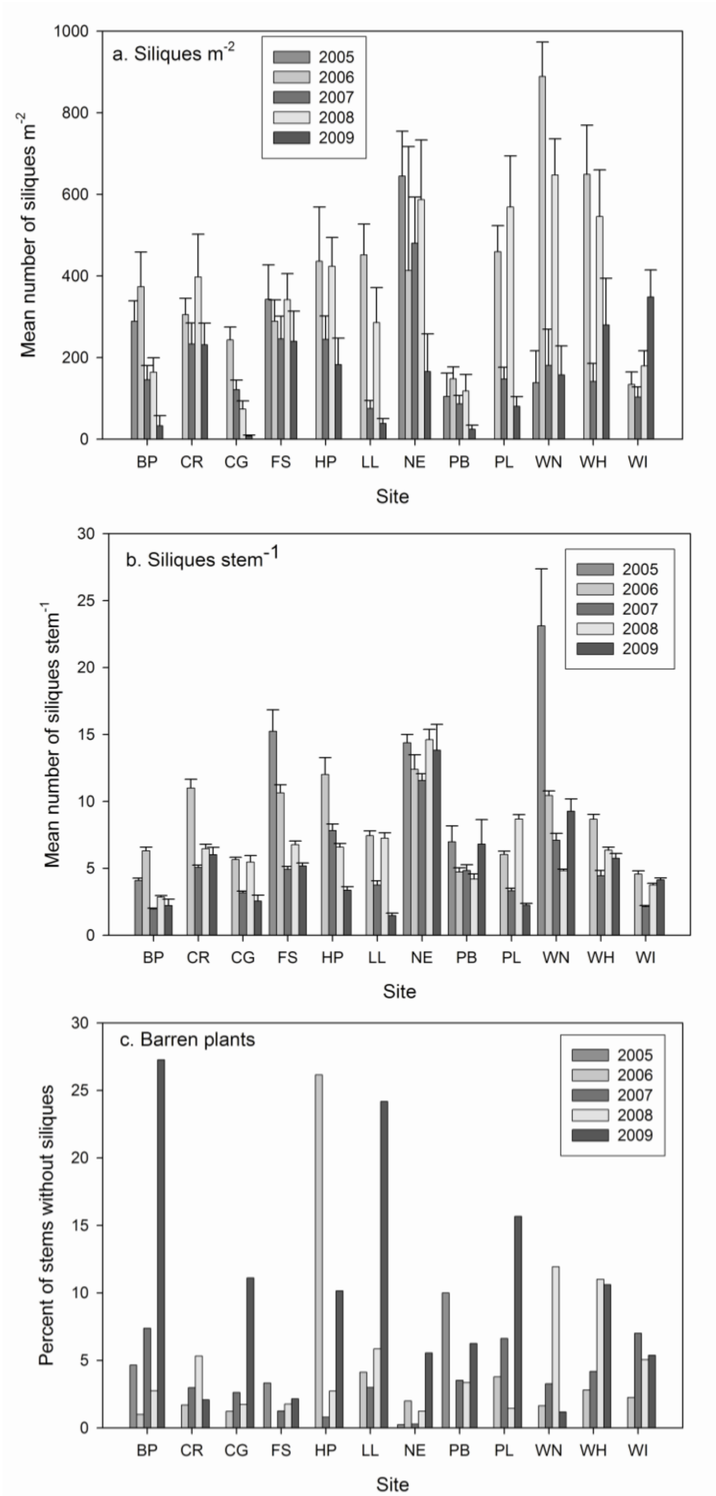

Figure 4. (a) The mean number of siliques per m^2 (± SE) of plots with adult garlic mustard present, (b) mean number of siliques per adult stem, and (c) percent of stems without siliques present (the total number of sterile stems recorded at the site / total number of stems at the sites x 100%). BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

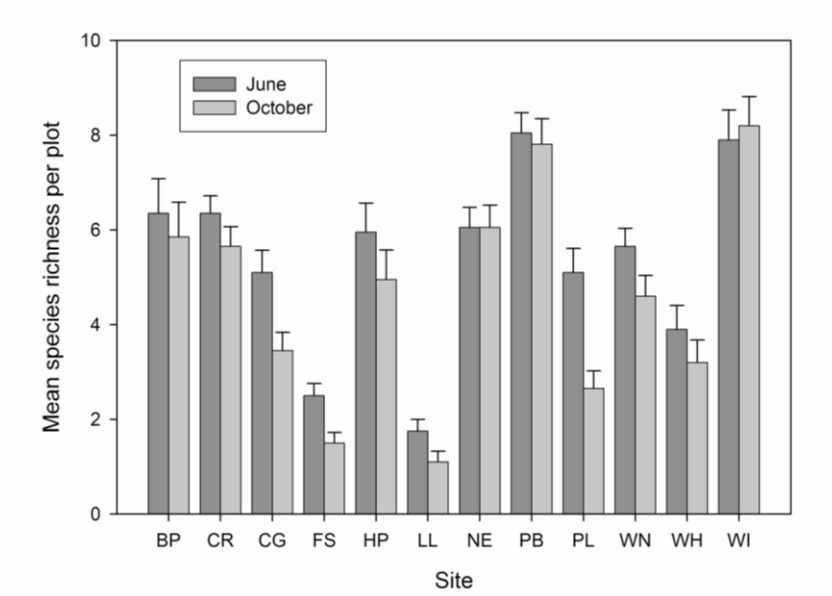

Figure 5. Mean species richness per $0.5m^2$ plot (± SE) in June and October 2009.
BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

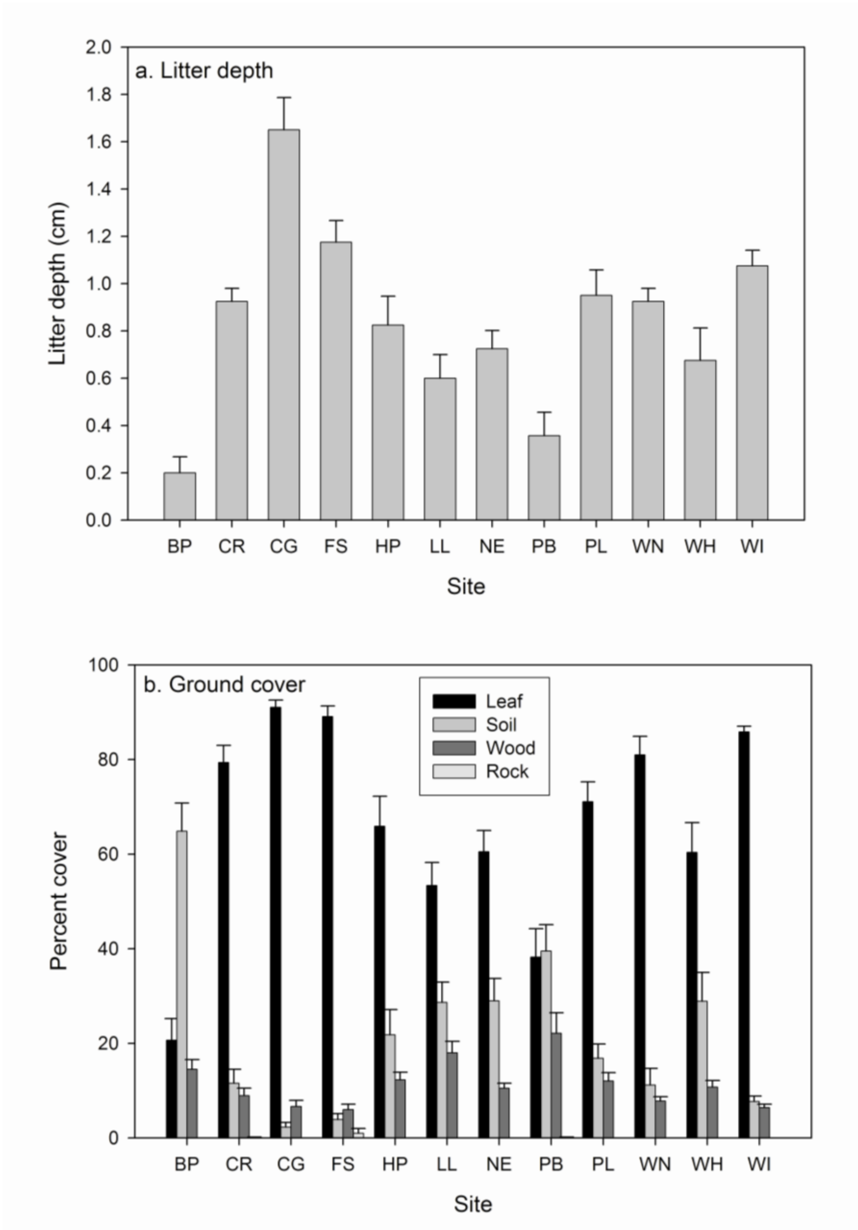

Figure 6. Mean litter depth (cm) (± SE) of each site in June 2009. The mean percent cover (± SE) of various types of ground cover (leaf litter, bare soil, woody debris, or rocks) of each site in June 2009.

BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

Figure 7. Closeup of aphid colony.

Figure 8. Garlic mustard plant with aphid colony present. Note the twisted siliques.

Chapter 3

Differences in Available Photosynthetically Active Radiation among Garlic Mustard (*Alliaria petiolata*) Monitoring Sites

Updated and modified from Van Riper et al. 2010.

INTRODUCTION

Garlic mustard (*Alliaria petiolata*) is a nonnative, herbaceous, biennial plant that is invasive in forests in the United States and can negatively impact native biota (Nuzzo 1999; Blossey et al. 2001; Meekins et al. 2001; Rodgers et al. 2008). In 2005, a monitoring program was initiated in Minnesota to examine the population biology of garlic mustard and its associated species in anticipation of the potential release of biological control insects (Van Riper et al. 2010). Permanent monitoring plots were established at 12 sites throughout Minnesota. Sites vary in aspects such as slope, species composition, latitude and longitude, and potentially light availability.

Garlic mustard populations may be influenced by the amount of light available at a site. Studies have shown that higher light sites can have garlic mustard plants with greater biomass and seed production than lower light sites (Meekins and McCarthy 2000; Myers et al. 2005). The differing amount of light available among sites may drive differences in garlic mustard population density and cover (Eschtruth and Battles 2009). Additionally, when adult garlic mustard plants grow densely they may shade out garlic mustard seedlings germinating under the adult garlic mustard stand. This can contribute to the effect of having populations in which one garlic mustard life stage (adults or rosettes) dominates in any given year (Meekins and McCarthy 2002; Winterer et al. 2005; Pardini et al. 2009; Van Riper et al. 2010).

The purpose of this study was to collect light availability information for the 12 Minnesota garlic mustard monitoring sites. The study attempted to determine whether light availability differs significantly among the 12 sites and if so, which sites tended to have high and low light availability. These data can then be used to determine the relationship between light availability and garlic mustard populations.

METHODS

Twelve garlic mustard monitoring sites, each with 20 permanent 1-m by 0.5-m plots were established in Minnesota in 2005 (Van Riper et al. 2010). To determine light availability we measured the amount of photosynthetically active radiation (PAR, 400 to 700nm) penetrating the forest canopy. Light measurements were taken between August 11 and September 9 in 2008 and between May 12 and June 3 in 2009 (Table 1). Additional measurements were taken at Pine Bend Bluffs on August 27, 2009 since many trees had been cut at the site since the measurements taken in August 2008. All measurements were taken within two hours of solar noon. In August and September

2008 and 2009, tree leaves had not begun to change color or senesce. In May 2009, trees were in early leaf-out, but had not yet reached full leaf-out.

PAR measurement methods follow Van Riper et al. 2010. A LI-190SA point quantum light sensor with a LI-1000 data logger was placed in an area of full sun to measure full sun PAR levels. The data logger sampled PAR levels every 5 seconds and recorded the average PAR level for one minute intervals. While the point sensor recorded full-sun data, a 1-meter LI-191SA line quantum light sensor and a LI-189 visual display were used to take PAR measurements in plots under the forest canopy, placing the line sensor along the center of the 1-m long axis of each plot. PAR readings were taken at 1 meter above the soil surface (equivalent to what an adult garlic mustard plant would receive) and at the soil surface (where seedling and rosette garlic mustard plants would receive light). For each plot, the amount of PAR and the time of each reading were recorded. The percent of full sun PAR incident at 1-m and the soil surface was determined by dividing by the PAR reading under the canopy by the PAR reading in full sun at the time of the plot reading. In 2008, all measurements were taken on days with full sun and no clouds. In 2009, there were not 12 days of full sun in May. Measurements were either taken on days with no clouds or overcast days with an even, full cover of clouds (Table 1).

To determine if sites differed in percent of available PAR, one-way ANOVAs were conducted (Statistix 7 2000). To account for the impact of varying sky conditions and tree leaf-out in spring 2009, a mixed model ANOVA was performed (Oehlert and Bingham 2005). All multiple comparison tests used Tukey's hsd.

RESULTS AND DISCUSSION

Percent of available photosynthetically active radiation in 2008 and 2009

Light has the potential to explain site to site differences in garlic mustard cover and plant species composition. When sites were at full leaf out in August and September of 2008, they showed no significant differences in the percent of available PAR at either the top of the garlic mustard canopy (1 m height) or at the soil surface (one-way ANOVA at 1m P=0.08, $F_{11,228}$=1.69; at soil surface P=0.07, $F_{11,228}$=1.72). The percent of incident PAR was generally low with a mean 6% ±0.7 at the top of the garlic mustard canopy and 3% ±0.4 at the soil surface. Mean percent of full sun PAR incident at 1-m ranged from 2% at Cottage Grove to 13% at Warner Nature Center and from 1% at Luce Line and Cottage Grove to 8% at Warner Nature Center at the soil surface (Fig. 1a). Warner Nature Center was hit by a tornado on May 25, 2008 which caused a number of trees to fall. It is not surprising that Warner would have some of the highest amounts of light availability. Large standard errors were present in the graphs of the mean percent incident PAR because the sites usually had a few plots that occurred in canopy openings which allowed high amounts of light to pass through to the forest floor.

In contrast to the August-September 2008 readings, the sites did show site to site differences in the May-June 2009 readings (one-way ANOVA for percent PAR at 1m P<0.00001, $F_{11,224}$=9.63; at soil surface P<0.00001, $F_{11,224}$=9.7). In May 2009 the sites generally had higher levels of percent of PAR incident at the top of the garlic mustard canopy (1 m height, mean of 15% ±1) or at the soil surface (mean of 12% ±1) than in

Aug-Sep 2008 (Fig. 1b). This difference likely reflects that trees were in full leaf-out in Aug-Sept, but not in May. Mean percent of full sun PAR incident at the 1-meter level ranged from 4% at Luce Line to 30% at Pine Bend, and at ground level ranged from 3% at Willmar to 23% at Pine Bend. Pairwise comparisons (Tukey's hsd) of the sites based on 2009 PAR measures showed that Pine Bend, Warner Nature Center, Coon Rapids, and Westwood Hills tended to have high PAR availability, while Luce Line, Willmar, and Plainview tended to have low PAR availability (Table 2).

The amount (not percent) of available incident PAR penetrating to 1 m and the soil surface is presented in Fig. 2. These data are not directly comparable from site to site to as day to day differences in strength of PAR are not directly comparable. However, these data are included to reinforce the percent PAR data by showing that sites received less PAR in Aug-Sep 2008 than in May-June 2009. The amount of PAR can also be used to compare the results of this study with other studies that examine the impact of available PAR. Note that in 2009, some measurements were taken on overcast days while others were taken on clear days (Table 1).

The May-June 2009 light data are somewhat limited in usefulness as the data are confounded by relationships with date (as time went on sites became more heavily leafed out) and overcast vs. clear sky conditions. The mean percent light reaching 1m above the soil surface was not equal for the group of sites measured on clear sky days versus the group of sites measured on overcast sky days (unequal variances, t=-2.58, df=229.2, P=0.03). Sites measured on clear days had a lower mean percent PAR at 1m (13% ± 1 SE) versus sites measured on overcast days (mean = 17% ± 1 SE). However, this pattern did not hold for the percent PAR reaching the soil surface (unequal variances, t=-1.10, df=216, P=0.27) with sites measured on clear days having similar mean percent available PAR as those measured on overcast days (clear = 11% ± 1 SE, overcast mean = 13% ± 1 SE). The later in the year (the more leaves), the lower the percent PAR at 1m and soil surface (regressions are significant P<0.00001, with low R^2 = 0.08 and 0.12 respectively).

To address the impact of sky conditions and date in 2009 on the PAR measures at 1m, we performed a mixed model ANOVA (Oehlert and Bingham 2005). The dependent variable was the percent of PAR available at 1m and the explanatory variables were date of reading (continuous variable, ordinal date), sky conditions (categorical: overcast or clear), and site. All explanatory variables were significant: date ($F_{1,224}$=27.6, P<0.00001), sky conditions ($F_{1,224}$=6.5, P=0.01), and site ($F_{9,224}$=8.0 P<0.00001). Pairwise comparisons (Tukey's hsd) among sites indicated that Luce Line and Nerstrand differed significantly form Pine Bend. Luce Line and Nerstrand tended to have low levels of PAR while Pine Bend had the highest levels.

Relationship between garlic mustard cover and percent PAR at the site level

Garlic mustard has been shown to have a strong relationship with light. The mean percent available PAR at each of the 12 sites was regressed against the mean garlic mustard cover for the sites to determine if there was a linear relationship (Fig. 3). In August-September 2008, there was a negative relationship between light and garlic mustard as shown in the regression of the cover of garlic mustard seedlings against percent of PAR penetrating to the soil surface (P=0.01, R^2=0.49). Relationships with PAR and adult cover (P=0.12, R^2=0.22, trending positive) and rosette cover (P=0.32, R^2=0.10, trending negative) were non-significant (Fig. 3a). Regressions of garlic mustard cover against PAR at 1 m above soil surface were similar to those at the soil surface for seedlings ($P=0.01$, $R^2=0.48$), adults ($P=0.13$, $R^2=0.21$), and rosettes ($P=0.25$, $R^2=0.13$). There was little evidence for a relationship between garlic mustard cover and light in the May-June 2009 measurements. Regressions of mean garlic mustard percent cover per site against mean percent PAR penetrating to the soil surface were not significant (Fig. 3b, adult: $P=0.92$, $R^2<0.00001$, seedling: $P=0.45$, $R^2=0.06$, rosette: $P=0.23$, $R^2=0.14$) nor were regressions against mean percent PAR penetrating to 1m above the soil surface (adult: $P=0.95$, $R^2=0.0004$, seedling: $P=0.38$, $R^2=0.08$, rosette: $P=0.28$, $R^2=0.12$).

According to the August-September 2008 data, the seedling stage appeared to be most sensitive to the amount of available light (Van Riper et al. 2010). Adult garlic mustard plants showed the expected greater percent cover in sites with higher available PAR (Meekins and McCarthy 2000; Myers et al. 2005), but cover of seedlings and rosettes showed a negative relationship. When adult plants grow tall in relationship with increased light, they may in turn shade out seedlings, causing seedlings to show a negative relationship with light. The pattern of lower cover of seedlings likely persisted as the seedlings grew into rosettes. In the May-June 2009 data there was little evidence of a relationship of percent available PAR and garlic mustard cover. There may truly be no relationship or the analysis of the PAR measurements may be confounded by the effects of increased tree leaf out over the course of the month and the necessity of measuring some sites on clear days and other sites on overcast days.

Relationship between garlic mustard cover and percent PAR at the plot level

In addition to looking at the relationship between garlic mustard cover and percent available PAR at the site level, we also examined the relationship at the plot level. The percent available PAR at each plot was regressed against the garlic mustard cover in that plot. When the garlic mustard cover data for the 240 plots were regressed against the amount of incident PAR there were no strong relationships. Regressions of 2008 garlic mustard cover versus the amount of incident PAR at the soil surface and 1 m in 2008 showed no relationship with seedlings and rosettes (all $P>0.05$). There was a weak positive relationship with adults at the soil surface ($P=0.003$, $R^2=0.03$) and 1 m levels ($P=0.01$, $R^2=0.03$). For the 2009 data, all regressions of garlic mustard percent cover per plot against percent PAR penetrating to the soil surface and 1m were not significant (all $P>0.05$), except for the percent of PAR penetrating to soil surface by the percent cover of adult garlic mustard plants ($P=0.009$), but the R^2 value was very low ($R^2=0.03$). At the plot level, light does not appear to be a strong driver of garlic mustard cover.

Impact of tree clearing at Pine Bend

In April of 2009, in an effort to decrease cover of nonnative common buckthorn (*Rhamnus cathartica*) and nonnative honeysuckles (*Lonicera spp.*) at Pine Bend Bluffs SNA, work was completed to cut and apply herbicide stump treatments to these species in an area that overlapped with some of the garlic mustard monitoring plots. Since there had been a dramatic change in tree canopy from the light measurements taken in August 2008, light measures were retaken in August 2009. Figure 4 shows the percent of incident PAR at Pine Bend at each plot in August 2008 and 2009. Many plots experienced a dramatic increase in available light (ex. 4% to 100% for plot 3 and 14% to

97% for plot 18, Fig. 4a). This large increase in available light will likely change the species composition and cover of plots at this site.

CONCLUSION

In general, sites generally showed little difference in the amount of light available. This indicates that differences between sites in garlic mustard population density, garlic mustard cover, and the cover of other species is likely not determined mainly by differences in light availability. It is likely that density-dependence of garlic mustard (Pardini et al. 2009) and other site differences (land-use history, deer population, earthworm invasion, etc.) are the main drivers of garlic mustard and other species differences among sites.

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TABLES

Table 1. Monitoring sites in order of dates of data collection for May and June 2009 along with sky conditions. All sites are located in Minnesota, USA between 44°6.600' and 45°19.356'N and 92°3.821' and 94°56.667'W.

Site	Site ID	2009 Date	2009 Sky Conditions	2008 Date	2008 Sky Conditions
Westwood Hills Nature Center	WH	5-12	overcast	8-19	clear
Coon Rapids Dam Regional Park	CR	5-13	overcast	8-18	clear
Fort Snelling State Park	FS	5-14	clear	8-15	clear
Warner Nature Center	WN	5-15	clear	8-11	clear
Baker Park Preserve	BP	5-18	clear	8-29	clear
Cottage Grove Ravine Regional Park	CG	5-19	clear	9-05	clear
Hilloway Park	HP	5-26	overcast	8-19	clear
Luce Line Trail	LL	5-26	overcast	9-8	clear
Nerstrand State Park, Prairie Creek SNA	NE	5-27	overcast	9-3	clear
Pine Bend Bluffs SNA	PB	5-27	overcast	8-26	clear
Plainview – private land	PL	6-03	clear	8-28	clear
Willmar – private land	WI	6-08	clear	8-25	clear

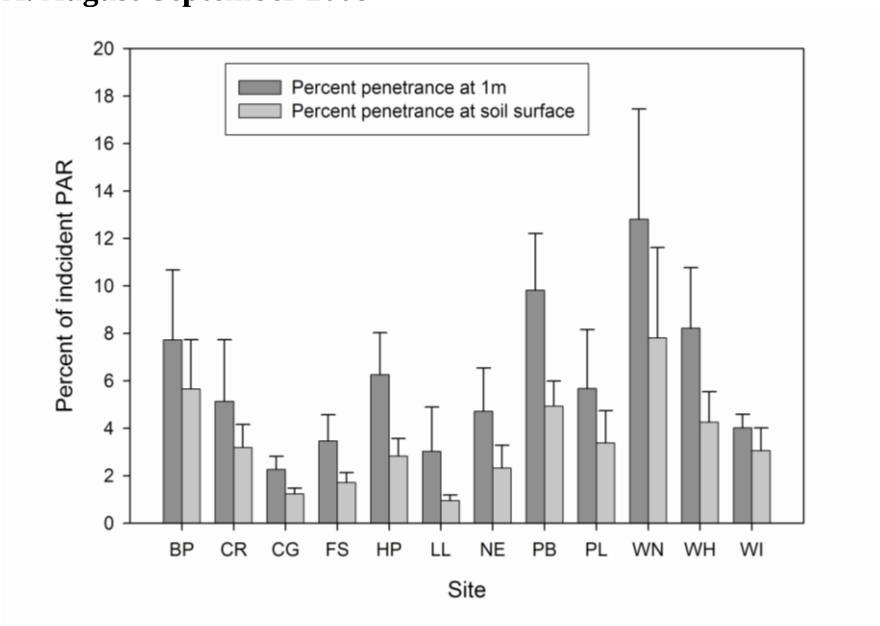
Table 2. Percent PAR reaching the soil surface and 1m above soil surface from highest percent to lowest. Group = sites that are not statistically different from one another according to multiple comparison tests. Date order = order in which data were taken (ex. 1=first site to have data collected, 12=last site). Sky = sky conditions on date of data collection.

Site	**% PAR**	**SE**	**Group**	**Date order**	**Sky**
By percent of PAR reaching soil surface					
PB	22.9	4.3	a	10	overcast
WN	22.2	3.9	a	4	clear
CR	17.5	1.1	ab	2	overcast
WH	16.8	1.6	ab	1	overcast
BP	16.7	3.4	ab	5	clear
HP	16.6	1.5	ab	7	overcast
CG	15.6	3.8	ab	6	clear
FS	7.4	1.8	bc	3	clear
NE	4.0	0.4	c	9	overcast
PL	3.4	2.4	c	11	clear
LL	3.3	0.4	c	8	overcast
WI	2.9	0.9	c	12	Clear
By percent of PAR reaching 1m above soil surface					
PB	29.7	4.4	a	10	overcast
WN	24.2	4.9	ab	4	clear
WH	22.2	1.7	ab	1	overcast
CR	21.2	1.5	abc	2	overcast
HP	21.0	2.4	abc	7	overcast
BP	16.0	3.2	bcd	5	clear
CG	15.6	2.9	bcde	6	clear
NE	9.4	1.3	cde	9	overcast
FS	9.4	1.9	cde	3	clear
WI	6.8	1.8	de	12	clear
PL	5.4	2.7	de	11	clear
LL	3.8	0.5	e	8	overcast

BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

FIGURES

A. August-September 2008



B. May-June 2009

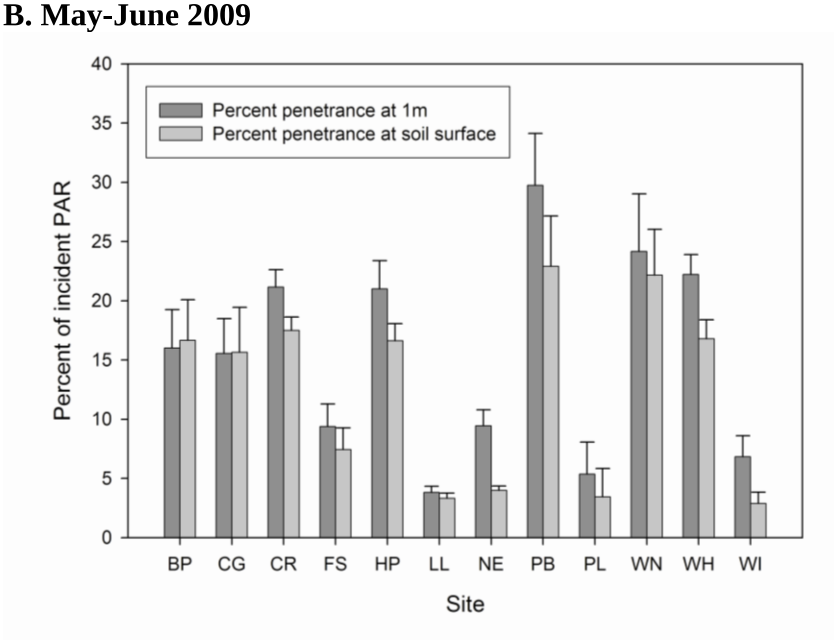
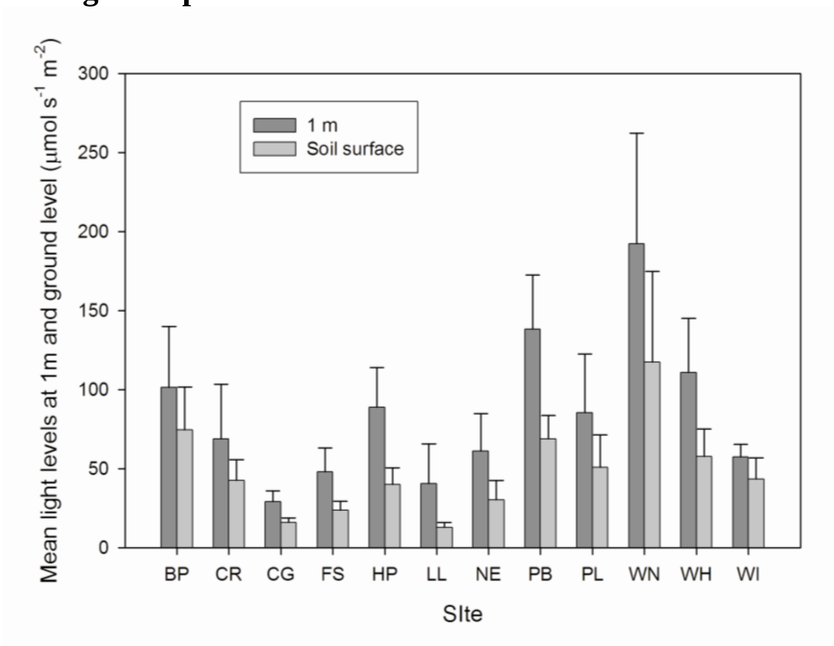


Figure 1. The mean percent of incident photosynthetically active radiation (PAR) penetrating to 1 meter above the soil surface and at the soil surface (± SE) in 2008 (A) and 2009 (B). Measurements were taken in August and September 2008 and May and June 2009 within 2 hours of solar noon at 12 sites in Minnesota, USA. Note that y-axes differ.

BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

A. August-September 2008



B. May-June 2009

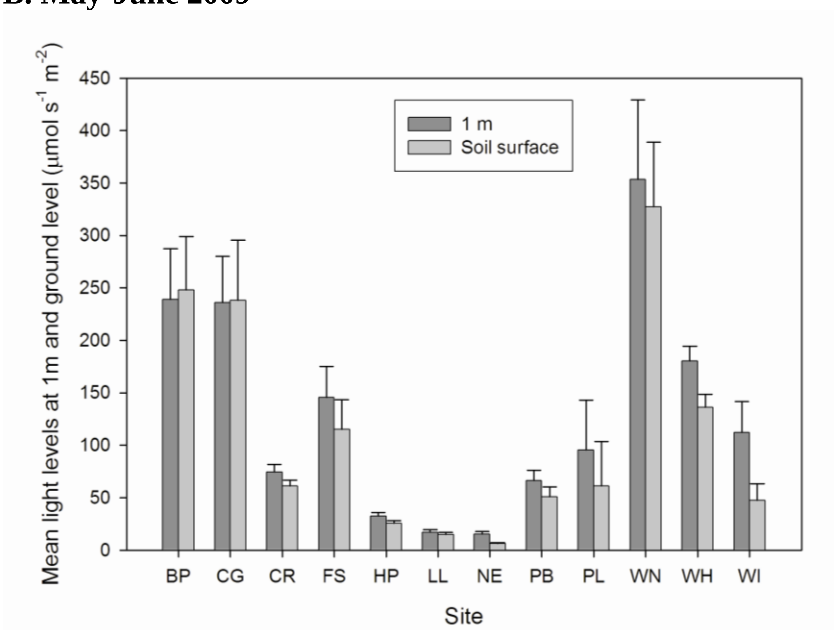
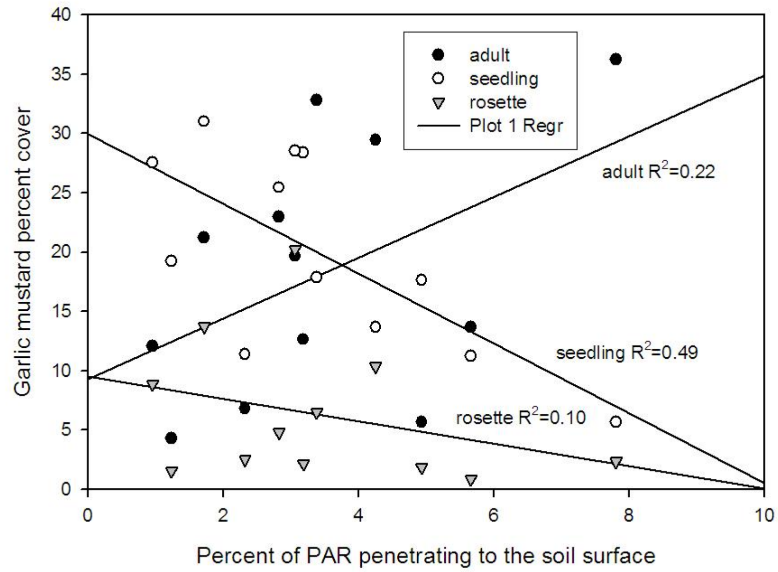


Figure 2. The mean amount of incident photosynthetically active radiation (PAR) penetrating to 1 meter above the soil surface and at the soil surface (± SE) in 2008 (A) and 2009 (B). Measurements were taken in August and September 2008 and May and June 2009 within 2 hours of solar noon at 12 sites in Minnesota, USA. Note that y-axes differ.

BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

A. PAR from August-September 2008



B. PAR from May-June 2009

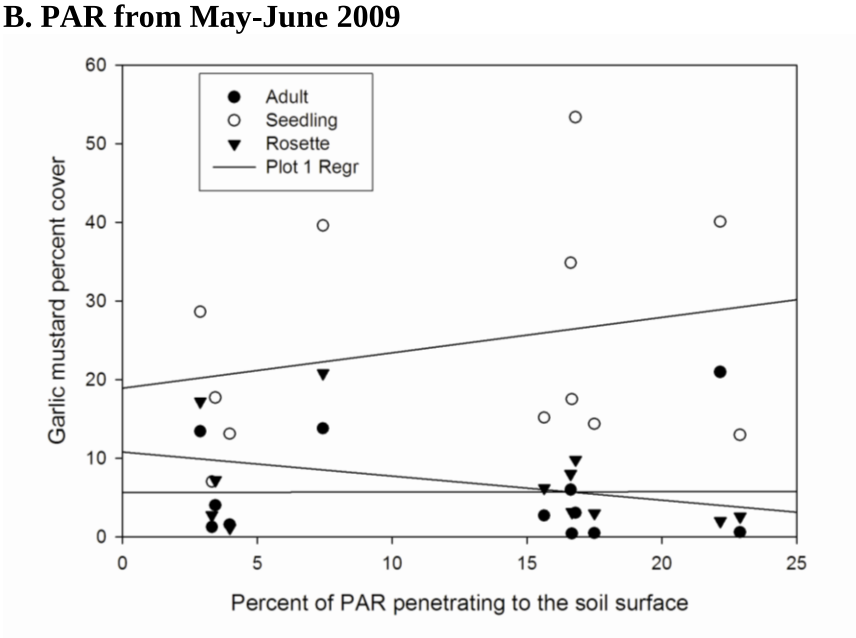


Figure 3. Linear regressions of mean percent cover of garlic mustard and mean percent PAR reaching the soil surface of the 12 monitoring sites, Minnesota, USA in 2008 (A) and 2009 (B). In 2009, all R^2 measures were <0.15. PAR measurements were taken during August and September 2008 and May and June 2009 within 2 hours of solar noon. Adult and seedling garlic mustard covers were measured in June of each year. Rosette cover was measured in October of each year. Note that y-axes differ.

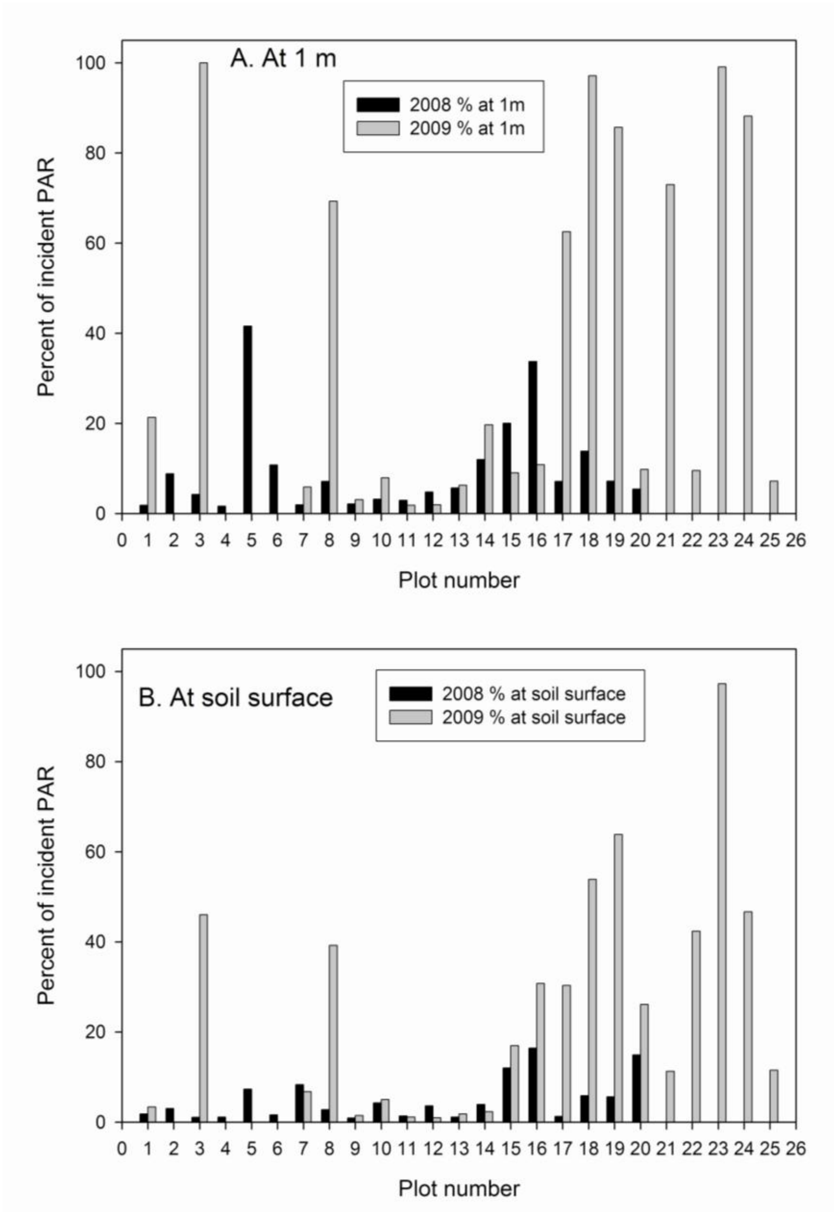


Figure 4. The percent of incident PAR penetrating 1 meter above the soil surface (A) and to the soil surface (B) and as measured in August 2008 and 2009 within 2 hours of solar noon at Pine Bend Bluffs Scientific and Natural Area, Minnesota, USA. In 2008 readings were taken at plots 1-20. In early spring 2009, a large number of trees were removed and piled up. Plots 2, 4, 5, and 6 were covered by brush piles, so there are no measurements for these plots in 2009. Plots 21-25 were established in June 2009 to replace the lost plots (consequently there are no May 2009 readings for plots 21-25). Plots 1-10 and 16-25 are in the area where trees were cleared. No trees were cleared in the area where plots 11-15 were located.

Chapter 4

Tree Canopy Differences among Garlic Mustard (*Alliaria petiolata*) Monitoring Sites

INTRODUCTION

Garlic mustard (*Alliaria petiolata*) in an invasive forb which can have negative ecological impacts on the communities which it invades ((Nuzzo 1999; Blossey et al. 2001; Rodgers et al. 2008). To characterize Minnesota garlic mustard populations and to collect pre-release data in the event of the release of biological control agents, a garlic mustard monitoring program was initiated in Minnesota (Van Riper et al. 2010). The monitoring protocol used is a standard protocol developed by the Ecology and Management of Invasive Plants Program (http://www.invasiveplants.net) to facilitate standardized data collection across states and data collectors. The monitoring protocol focuses on collecting species data on forest floor species and does not address the tree canopy. In order to better describe the 12 garlic mustard monitoring sites, data was collected on the tree species present at the sites. A sample of trees in the understory and canopy were identified and their diameters at breast height (dbh) measured.

METHODS

Each garlic mustard monitoring site has 20 permanent 0.5 m by 1.0 m monitoring plots. In these plots data are recorded on the plant species composition of the forest floor. There is not a standard protocol component for describing the tree canopy. In order to give quantitative descriptions of the tree compositions of the 12 sites, each site was surveyed. The 20 monitoring plots are laid out along four transects, with the plots 10 m apart from one other. In order to survey the tree species, four transects of 40 m each were laid out next to the permanent monitoring plots. Any trees with a dbh greater than 2 cm found within 0.5 m of either side of the transect were recorded. The tree was identified, its position along the transect was recorded, dbh was recorded, and it was noted whether the top of the tree was part of the canopy (no other trees above it) or in the understory (the top of the tree did not reach full sun). For each site, a total area of 160 m^2 was surveyed (40m transect x 1m wide x 4 transects). Sites were surveyed in August and September of 2008. At this time slope and aspect were visually estimated for each site. Tree canopy data was summarized using Statistix 7 (2000). Tree species scientific names, authorities, common names, and native/nonnative status are listed in the Appendix.

RESULTS

Twenty-three different tree species were recorded among the 12 monitoring sites. *Ulmus rubra*, *Acer negundo,* and *Quercus rubra* were the most frequent native species as they were found at 6 or more of the sites (Table 1). The invasive tree, *Rhamnus cathartica* was present in 5 of the sites. However it should be noted that *Rhamnus cathartica* is present at almost all of sites, but several have done work to control adult plants, so there are fewer tree-sized individuals at those sites. The native species *Celtis occidentalis, Franxinus pennsylvanica, Tilia americana, Acer saccharum, Ostrya virginiana,* and *Prunus serotina* were found at 3 or 4 of the sites. The remaining 13 species were only found at 1 or 2 of the sites.

The number of each species of tree present at each site shows some of the variation among sites. *Ostyra virginiana* was only present at 3 sites, but was very frequent at the Cottage Grove and Willmar sites (Table 1). *Ulmus rubra* was the most frequent tree at Coon Rapids, Luce Line, and Plainview while *Acer negundo* was the most frequent tree at Baker Park and Fort Snelling. Hilloway Park showed the legacy of planted *Pinus strobus* with that species slightly more frequent than *Ulmus rubra*. Nerstrand had the largest number of *Acer saccharum*. The invasive tree, *Rhamnus cathartica* was the most frequent tree at Pine Bend Bluffs. At Warner Nature Center, *Prunus serotina* and *Quercus alba* were the most frequent trees. *Fraxinus pennsylvanica* was the most frequent tree at Westwood Hills. The variations in frequencies and species that are unique to individual sites, highlight the differences among sites.

Species diversity and total number of trees further distinguish the sites from one another. The most diverse sites were Plainview (8 species), Nerstrand (7), Cottage Grove (6), Luce Line (6), Pine Bend (6), and Westwood Hills (6) (Table 1). Baker Park was the least diverse with only 3 species found in the survey area. Nerstrand had 4 species that were not present at any of the other sites (Table 1). Cottage Grove, Willmar, Luce Line, and Plainview all had the highest total number of trees present (Table 1). Warner Nature Center had the fewest number of trees present, but it should be noted that the sites was hit by a tornado on May 25, 2008 causing trees to fall. Baker Park, Fort Snelling, and Westwood Hills also had relatively fewer trees than other sites.

To further clarify similarities and differences among the sites, a cluster analysis was run on PC-ORD (McCune and Mefford 1999). Data on the number of each species present in each site was used to perform a cluster analysis using the Sorensen (Bray-Curtis) distance measure and the group average linkage method. The cluster analysis (Fig. 1) showed that Cottage Grove and Willmar were the most similar sites (both had high numbers of *Ostrya virginiana* and had similar numbers of *Acer negundo*). Luce Line, Plainview, and Coon Rapids were very similar in their high numbers of *Ulmus rubra*. Additionally, Luce Line and Plainview had similar numbers of *Quercus rubra* and *Acer saccharum*. Fort Snelling and Westwood Hills were somewhat similar in their abundance of *Acer negundo* and *Fraxinus pennsylvanica* and they were the only sites with *Populus deltoides*. Baker Park's common species and low diversity made it somewhat similar to the cluster of Coon Rapids, Luce Line, Plainview, Fort Snelling, and Westwood Hills. Hilloway Park and Warner Nature Center were somewhat similar to each other in that each had *Ulmus rubra, Acer negundo,* and *Prunus serotina*. Pine Bend with its high number of *Rhamnus cathartica* and 2 unique species and Nerstrand with its high number of *Acer saccharum* and 4 unique species were the two sites that were least similar to any of the sites.

Sites varied in slope from nearly level to extreme slopes (Table 3). Slope and aspect may impact the tree species composition at a site. In the cluster analysis (Fig. 1), Pine Bend and Nerstrand were the most unlike the other sites and those two sites had the steepest slopes. Cottage Grove and Willmar were similar to one another and both were on strong to moderate slopes. Hilloway Park and Warner Nature Center grouped together and both were on very gentle slopes. With the exception of Plainview, all the sites in the Baker Park, Coon Rapids, Luce Line, Plainview, Fort Snelling, and Westwood Hills group had level to very gentle slopes.

The dbh measures give an indication of tree size at the monitoring sites. Canopy trees had very similar dbhs among the sites with the exception of Fort Snelling and Pine Bend Bluffs (Fig. 2a). Fort Snelling had several very large *Populus deltoides* which increased its average dbh. The canopy trees Pine Bend Bluffs tended to be small. Average dbh among the understory trees varied more greatly (Fig. 2b). Understory trees were largest at Hilloway Park and Westwood Hills. Cottage Grove, Luce Line, Pine Bend, and Willmar had the smallest average dbhs of their understory trees. The sum of all the dbh values for the trees at a site indicates which sites have the most tree biomass (Table 2). Willmar, Hilloway Park, and Coon Rapids had the highest amount of tree biomass while Pine Bend Bluffs and Luce Line had the lowest (Table 2). Trees with the highest average dbh were found at Warner Nature Center (26.8 cm) and Hilloway Park (25.8 cm), while Pine Bend Bluffs (8.6 cm) and Luce Line (9.0 cm) had the lowest (Table 2). Warner Nature Center had the fewest trees (12), but they were large (26.8 cm) while Cottage Grove had the highest number of trees (39), but they were small (9.4 cm) (Table 2).

DISCUSSION

The variability in tree species composition, number, and size indicates that the 12 garlic mustard monitoring sites vary in their site history (historic natural community, logging/farming history, other disturbances, etc.) and/or environmental factors (soil pH, soil nutrients, slope (Table 3), latitude, etc.). Garlic mustard, garlic mustard biological control agents, and other plant species may have different impacts among the sites. Understanding site differences will aid in interpreting the impacts of garlic mustard and their biocontrol agents.

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Nuzzo, V. A. 1999. Invasion pattern of the herb garlic mustard (Alliaria petiolata) in high quality forests. Biol. Invasions 1:169-179.

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Van Riper, L. C., R. L. Becker, L. C. Skinner. 2010. Population biology of garlic mustard (*Alliaria petiolata*) in Minnesota hardwood forests. Invasive Plant Sci. Manage. *In press.*

Statistix 7. 2000. Statistix version 7.0. Tallahassee, FL: Analytical Software.

TABLES

Table 1. The tree species present at each site. Tree species are listed in order of frequency, with the species found at the most sites listed first. The table shows the number of individuals of that species found within the 160 m^2 survey area.

Tree species	**BP**	**CR**	**CG**	**FS**	**HP**	**LL**	**NE**	**PB**	**PL**	**WN**	**WH**	**WI**	**Total**	**# of sites**
Ulmus rubra	3	10	1		6	13	1	1	11	1	1		48	**10**
Acer negundo	12	4	2	6	1				6	2	2	3	38	**9**
Quercus rubra			4			1		3	1	2	1		12	**6**
Rhamnus cathartica		2	1	4		4		19					30	**5**
Celtis occidentalis			1	1				5	1				8	**4**
Fraxinus pennsylvanica		7		4		2					12		25	**4**
Tilia americana	2								2		1	5	10	**4**
Acer saccharum						7	12		4				23	**3**
Ostrya virginiana			30				1					21	52	**3**
Prunus serotina					2				1	4			7	**3**
Populus deltoides				2							1		3	**2**
Carya cordiformis							1						1	**1**
Crataegus sp.							1						1	**1**
Fraxinus nigra							2						2	**1**
Juglans cinerea								1					1	**1**
Malus sp.									1				1	**1**
Pinus strobus					7								7	**1**
Populus granidentata							1						1	**1**
Quercus alba										3			3	**1**
Quercus bicolor												3	3	**1**
Quercus macrocarpa								2					2	**1**
Robinia pseudoacacia					3								3	**1**
Zanthoxylum americanum						1							1	**1**
Total # of trees	17	23	39	17	19	28	19	31	27	12	18	32	282	
Total # of species	3	4	6	5	5	6	7	6	8	5	6	4		

BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

Table 2. Summary of diameter at breast height data (cm) for the 12 garlic mustard monitoring sites. "Sum of all the dbhs" sums the dbhs of all the trees at the site to show which sites have the greatest biomass of wood). "Mean dbh" indicates the mean dbh of trees at the site (showing which sites have the largest trees). Sites are listed in descending order of the sum of dbhs.

Site	Total # of trees	Sum of all dbhs (cm)	Mean dbh (cm)	S.E. of Mean
Willmar	32	491.2	15.4	2.4
Hilloway Park	19	489.9	25.8	2.3
Coon Rapids	23	445.7	19.4	3.0
Nerstrand	19	421.1	22.2	3.4
Westwood Hills	18	417.6	23.2	3.5
Baker Park	17	399.2	23.5	4.0
Fort Snelling	17	375.8	22.1	6.8
Cottage Grove	39	365.5	9.4	1.6
Plainview	27	354.6	13.1	1.7
Warner Nature	12	321.3	26.8	4.2
Pine Bend	31	265.8	8.6	1.6
Luce Line	28	251.8	9.0	1.7
For all sites	282	4599.5	16.3	0.9

Table 3. Slope differences among the garlic mustard monitoring sites.

Site	Primary slope at site	Degrees of slope	Direction the slope faces
Coon Rapids	nearly level	0.3-1.1	not applicable
Luce Line	nearly level	0.3-1.1	not applicable
Westwood Hills	nearly level	0.3-1.1	not applicable
Fort Snelling	very gentle	1.1-3	north & south
Hilloway Park	very gentle	1.1-3	east
Warner Nature	very gentle	1.1-3	north & south
Baker Park	gentle	3-5	south
Willmar	moderate	5-8.5	north
Cottage Grove	strong	8.5-16.5	east
Plainview	strong	8.5-16.5	west
Nerstrand	extreme	24-35	south
Pine Bend	extreme	24-35	south-southeast

FIGURES

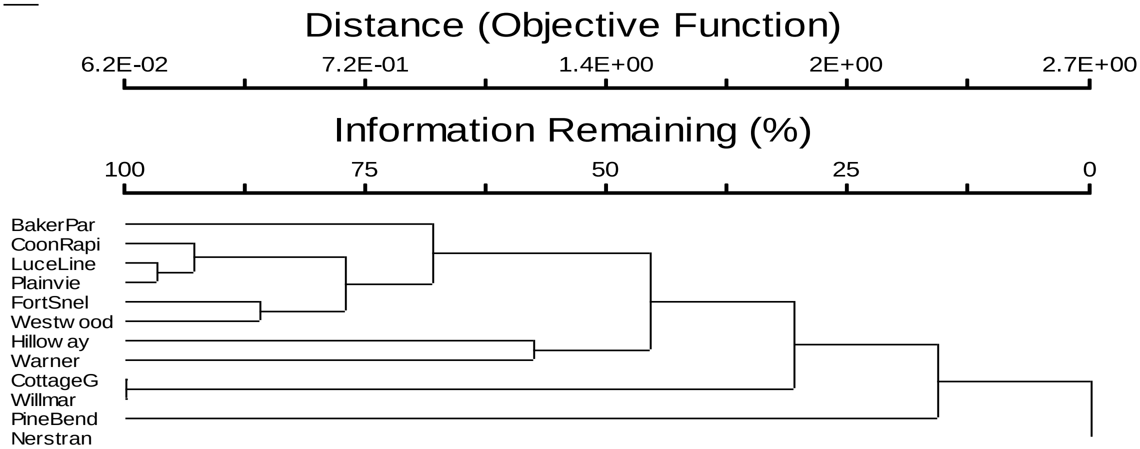

Figure 1. Cluster analysis using the Sorensen (Bray-Curtis) distance measure and the group average linkage method.

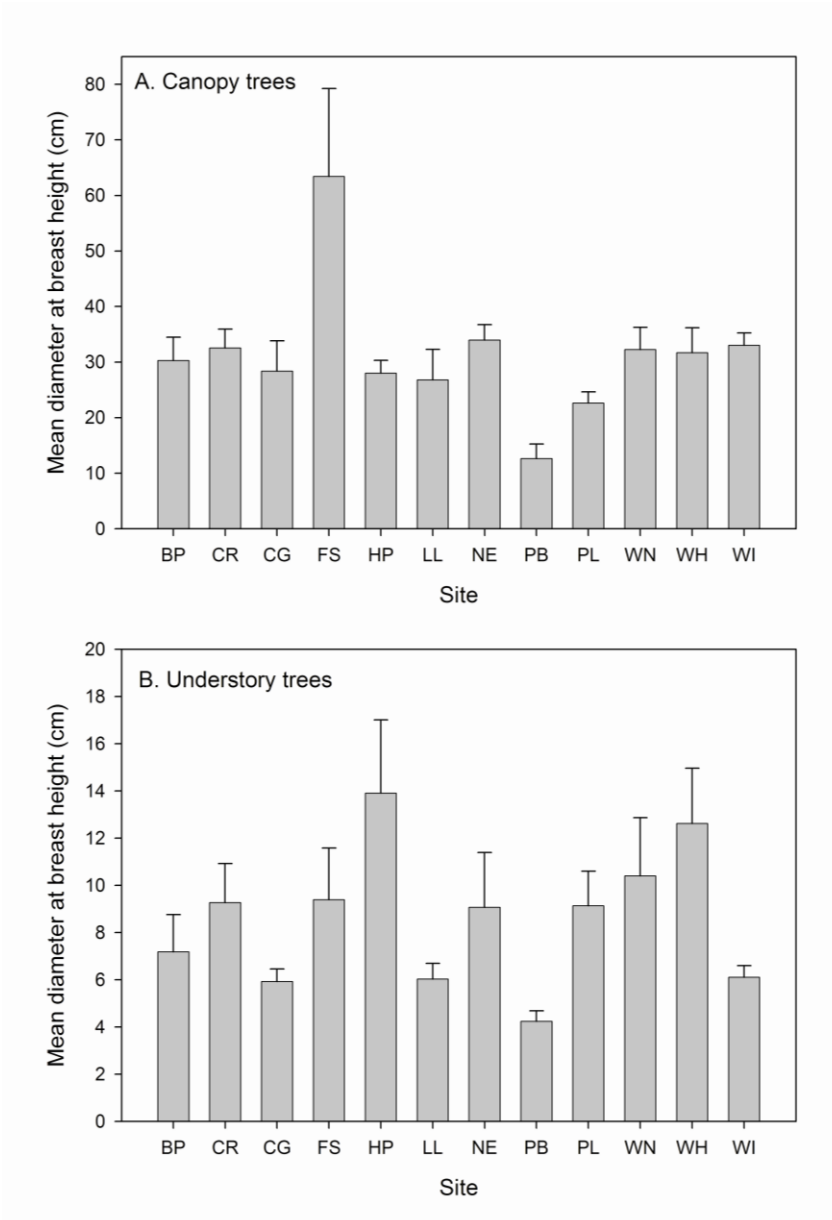

Figure 2. Mean diameter at breast height (dbh) of canopy trees (A) and understory trees (B) at 12 garlic mustard monitoring sites in Minnesota. Note that the y-axes vary.
BP=Baker Park, CR=Coon Rapids, CG=Cottage Grove, FS=Fort Snelling, HP=Hilloway Park, LL=Luce Line, NE=Nerstrand, PB=Pine Bend, PL=Plainview, WN=Warner Nature, WH=Westwood Hills, WI=Willmar

APPENDIX

Appendix 1. Species names, authority, and nativity status in Minnesota. Taxonomy follows the Integrated Taxonomic Information System (http://www.itis.gov/) accessed 4 Feb 2010. Nativity follows Minnesota Department of Natural Resources Vascular Plants of Minnesota -- September 25, 2002 (http://files.dnr.state.mn.us/eco/plant_list9-25-02.pdf) accessed 4 Feb 2010.

Species	**Authority**	**Common name**	**Native/Nonnative**
Acer negundo	L.	box elder	native
Acer saccharum	Marsh.	sugar maple	native
Carya cordiformis	(Wangenh.) K. Koch	bitternut hickory	native
Celtis occidentalis	L.	hackberry	native
Crataegus sp.	L.	hawthorn	native
Fraxinus nigra	Marsh.	black ash	native
Fraxinus pennsylvanica	Marsh.	green ash	native
Juglans cinerea	L.	butternut	native
Malus sp.	P. Mill.	apple	needs to be identified to species
Ostrya virginiana	(P. Mill.) K. Koch	ironwood	native
Pinus strobus	L.	white pine	native
Populus deltoides	Bartr. ex Marsh.	cottonwood	native
Populus granidentata	Michx.	bigtooth aspen	native
Prunus serotina	Ehrh.	black cherry	native
Quercus alba	L.	white oak	native
Quercus bicolor	Willd.	swamp white oak	native
Quercus macrocarpa	Michx.	bur oak	native
Quercus rubra	L.	northern red oak	native
Rhamnus cathartica	L.	common buckthorn	nonnative
Robinia pseudoacacia	L.	black locust	nonnative
Tilia americana	L.	basswood	native
Ulmus rubra	Muhl.	slippery elm	native
Zanthoxylum americanum	P. Mill.	prickly ash	native

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: **Neutralization of Reed Canary Grass Root Exudates**
PROJECT MANAGER: **Bradley J. Cook**
AFFILIATION: **Minnesota State University-Mankato**
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WEBSITE: **NA**

FUNDING SOURCE: **Environment and Natural Resources Trust Fund**
LEGAL CITATION: **ML 2007, [Chap._30_], Sec.[_2_], Subd._4j_.**

APPROPRIATION AMOUNT: $ 115000

<u>Overall Project Outcome and Results</u>

Reed canary grass (*Phalaris arundinaceae*; hereafter Pa) is an aggressive plant invading wetlands in the Midwest. Invasion by Pa leads to a reduction of native plant diversity and loss of wetland functionality. Our ability to control invasion by Pa and reestablish native plant communities has been unsuccessful because of our limited understanding of the mechanisms that allow Pa to become invasive. The study of plant-soil feedbacks as a mechanism for dominance is a two-step process: plants alter their soil microbial community; and the altered soil microbial community has a positive feedback on plant growth or a negative feedback on neighboring plants. Results from three experiments comparing soil microbial communities and plant growth revealed that *Phalaris arundinacea* (Pa) used plant-soil feedbacks to outcompete tussock sedge (*Carex stricta*; hereafter Cs).

In a soil training experiment, Pa and Cs cultured their soil microbial communities in a manner that differed in both magnitude and composition. Soil training had a neutral feedback on Pa growth and a negative feedback on Cs.

In our first reciprocal transplant experiment, growth of Pa and Cs was greater in their corresponding native soils than in the soil of the other species. Thus, both plants receive positive feedback from their native soil microbial communities. Soil microbial communities were similar when cultivated by Pa regardless of soil type, and Cs soil microbial community catabolic activity depended on soil type.

In our second reciprocal transplant experiment, the effects of competition were dependent on soil microbial communities. Pa growth was best in competition with Cs in Cs-native soils and Pa-sterile soils. Competition did not affect the growth of Cs; however, Cs growth was least in native soils from Pa and Cs. In sterile soils, soil microbial communities depended on the type of competition. In native Pa soils, heterospecific competition had a greater effect on soil microbial communities than did conspecific competition.

Denaturing gradient gel electrophoresis (DGGE) analysis indicated that Pa SMCs were stable and of low diversity, but Cs SMCs were dynamic and of comparatively high diversity.

Bioassays and gas chromatography-mass spectrometry (GC-MS) analyses revealed the presence of methyl esters of fatty acids known to have antimicrobial activity.

Our results suggest that Pa does not use alleopathy, but is induced to produce an antimicrobial compound that has a strong, directional effect on soil microbial communities, which promotes its growth and inhibits the growth of neighboring plants.

Project Results Use and Dissemination

Portions of Results 1, 2, and 3 have been written as a manuscript (*A plant-soil feedback as a mechanism for the invasive success of Phalaris arundinacea*) and is being revised for publication. A second manuscript including Results 1-5 is in preparation by the investigators.

Portions of this work were presented:

1) as an invited talk at the University of Bern, Switzerland (8/08)
2) at the 93rd Annual Ecological Society of America Meeting; Milwaukee, WI. (8/08)
3) at the 13rd "Annual Conference of the Wisconsin Wetland Association; Oconomowoc, WI. (2/08)
4) (two papers) at the North American Lake Managers Society (NALMS) International Conference; Hartford, CT. (10/09)
5) (four papers) at the 2008 and 2009 Minnesota State University Undergraduate Research Conference (4/08 and 4/09)

In addition, portions of this work were used for a M.S. thesis project, as class exercises in undergraduate courses, and as several undergraduate independent research projects at Minnesota State University.

Trust Fund 2007 Work Program Final Report

Date of Report: December 18, 2009
Trust Fund 2007 Work Program Final Report
Date of Work program Approval: June 5, 2007
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Neutralization of Reed Canary Grass Root Exudates

Project Manager: Bradley J. Cook
Affiliation: **Minnesota State University-Mankato**
Mailing Address: **Department of Biological Sciences**
242 Trafton Science Center S
City / State / Zip : **Mankato, MN 56001**
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Web Page address:

Location: *Green House A on Minnesota State University-Mankato campus, Trafton Science Center South, Blue Earth County, Mankato, MN 56001*

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	**115000**
	Minus Amount Spent:	**$**	**79,874**
	Equal Balance:	**$**	**35,127**

Legal Citation: ML 2007, [Chap._30_], Sec.[_2_], Subd._4j_.

Appropriation Language:
Neutralization of Reed Canary Grass Root Exudates
$115,000 is from the trust fund to Minnesota State University, Mankato, to assess plant-soil feedback contribution to the invasiveness of reed canary grass through identification and neutralization of inhibitory root exudates.

II. and III. FINAL PROJECT SUMMARY

Reed canary grass (*Phalaris arundinaceae*; hereafter Pa) is an aggressive plant invading wetlands in the Midwest. Invasion by Pa leads to a reduction of native plant diversity and loss of wetland functionality. Our ability to control invasion by Pa and reestablish native plant communities has been unsuccessful because of our limited understanding of the mechanisms that allow Pa to become invasive. The study of plant-soil feedbacks as a mechanism for dominance is a two-step process: plants alter their soil microbial community; and the altered soil microbial community has a positive feedback on plant growth or a negative feedback on neighboring plants. Results from three experiments comparing soil microbial communities and plant growth revealed that *Phalaris arundinacea* (Pa) used plant-soil feedbacks to outcompete tussock sedge (*Carex stricta*; hereafter Cs).

In a soil training experiment, Pa and Cs cultured their soil microbial communities in a manner that differed in both magnitude and composition. Soil training had a neutral feedback on Pa growth and a negative feedback on Cs.

In our first reciprocal transplant experiment, growth of Pa and Cs was greater in their corresponding native soils than in the soil of the other species. Thus, both plants receive positive feedback from their native soil microbial communities. Soil microbial communities were similar when cultivated by Pa regardless of soil type, and Cs soil microbial community catabolic activity depended on soil type.

In our second reciprocal transplant experiment, the effects of competition were dependent on soil microbial communities. Pa growth was best in competition with Cs in Cs-native soils and Pa-sterile soils. Competition did not affect the growth of Cs; however, Cs growth was least in native soils from Pa and Cs. In sterile soils, soil microbial communities depended on the type of competition. In native Pa soils, heterospecific competition had a greater effect on soil microbial communities than did conspecific competition.

Denaturing gradient gel electrophoresis (DGGE) analysis indicated that Pa SMCs were stable and of low diversity, but Cs SMCs were dynamic and of comparatively high diversity.

Bioassays and gas chromatography-mass spectrometry (GC-MS) analyses revealed the presence of methyl esters of fatty acids known to have antimicrobial activity.

Our results suggest that Pa does not use alleopathy, but is induced to produce an antimicrobial compound that has a strong, directional effect on soil microbial communities, which promotes its growth and inhibits the growth of neighboring plants.

OUTLINE OF PROJECT RESULTS*:*

Result 1: Soil preparation and training

Description: Soils will be collected from the rhizospheres of Pa and Tussock sedge (*Carex stricta*; hereafter Cs) communities locally. Each soil type will be sieved with a 2 cm sieve to remove coarse organic matter. Half of both Pa and Cs soils will be triple autoclaved for 20 minutes at 121ºC over the course of 3 successive days to kill all biotic organisms. Newly purchased and washed 40/70 grit silica sand will be autoclaved at 110ºC for 12 hours so that it can be used as a neutral substrate for microbial inoculation. The sterile and non-sterile Pa and Cs soils will then be mixed with the sterile sand in a 9:1 (sand: soil) volumetric proportion to produce four soil treatments, Pa soil; autoclaved Pa soil; Cs soil*;* and autoclaved Cs soil.

Summary Budget Information for Result 1: Trust Fund Budget: $ ~~21000~~
Revised Budget: $ 11000

Amount Spent:	**$**	**9825**
Balance:	**$**	**1175**

Deliverable	Completion Date	Budget	Status
1. Soil collected and sterilized	7/10/07	$2000	completed
	12/23/07	$2000	completed
2. Soil partitioned for treatment/storage	7/10/07	$3000	completed
	12/23/07	$3000	completed
3. Soil trained	10/31/08	$1000	completed

Final Report Summary: All the deliverables for Result 1 were completed below budget despite problems encountered with storm damage to our greenhouse. Soils were collected and sterilized three times rather than the once as proposed. We first collected and sterilized soils prior to receiving funding for this project in hope of facilitating the work if funded. This first set of soils were subsequently partitioned, stored, treated, and trained as proposed. A second set of soils were collected for additional plant-soil feedback experiments but these soils were likely contaminated as a result of a wind storm that damaged our greenhouse. Due to the likely contamination we removed this second set of soils from further study. A third set of soils were collected again for additional plant-soil feedback experiments. The third set of soils was used in three experiments. This set of soils was used for three experiments: 1) A second soil-plant feedback experiment; 2) An experiment to determine if there was an allelopathic effect of Pa on Cs; and 3) An experiment to determine if there was an effect of activated carbon on the soil microbe community.

The substantial balance of $1175 is due to cost savings from our collection and set up of an initial experiment prior to receiving funding from the LCCMR.

Result 2: *CLSU testing*

Description: – Difference in the composition of microbial communities can be revealed by comparing the sources of carbon that can be used by each community. BIOLOG plates contain 95 different carbon substrates. Microbial catabolism of each substrate is detected by a redox indicator, and the use of substrates can be quantitatively evaluated through the use of a microplate photometer. Each inoculated plate will be read twice daily for up to 7 days. Normalization procedures described by others will be used to control for differences in microbial numbers among samples (Garland and Mills, 1991).

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$ 23000**
	Amount Spent:	**$ 17564**
	Balance:	**$ 5436**

Deliverable	Completion Date	Budget	Status

1. CLSU data collected	2/28/08	$9000	completed
	2/28/09	$9500	completed
2. CLSU data analyzed	3/30/08	$2500	completed
	3/30/09	$2000	completed

Final Report Summary: Originally we proposed to conduct two experiments to investigate the ability of Pa to shape microbial communities. We added a third experiment to directly compare the effects of Pa and Cs on native vs. non-native soil communities.

In our reciprocal transplant experiment, we observed that in native soils, Pa cultivated similar microbial communities, regardless of whether the soil originated from Pa or Cs monoculture stands. In contrast, the microbial communities cultivated by Cs were dependent on the original plant community. Pa appeared to actively shape its soil microbial communities into one with common catabolic capability.

For our second experiment, we used sterile soils that were passively inoculated with greenhouse microbes, i.e., non-native communities, in order to investigate the role of soil training by both Pa and Cs. Two sets of soils were left fallow, while a third and fourth set were planted with Pa or Cs for training. Following a four-month training period, the plants were removed. Cs was planted into one fallow soil and the Cs-trained soil, and Pa was planted into the second fallow soil and the Pa-trained soil. At this time, samples for CLSU testing were collected from all four soils. Following a four-month growth period, a final set of samples was collected for CLSU analysis, and plants were harvested. We observed that in the soils that were not pre-trained by either Pa or Cs, soil microbial communities changed little between the start and finish of the experiment. However, CLSU patterns were markedly different between the beginning and the end of the experiment in soils that had been previously trained by either Pa or Cs. Both plants shaped not only native soil communities (as seen with the first reciprocal transplant experiment, above), but also non-native communities. In addition, one plant growth cycle of prior training of the soil appears to have a profound effect on soil microbial community composition.
In our third experiment, we investigated the effect of conspecific (same species) and heterospecific (different species) competition on soil microbial communities by performing reciprocal transplants into native and non-native soils. In non-native soils, we observed that, regardless of soil type, CLSU patterns for microbial communities were different when grown with heterospecific or conspecific neighbors. In native Cs soils, the type of competition appeared to have little effect on soil microbial community composition. However, in native Pa soils, heterospecific competition had a greater effect on soil microbial community competition than did conspecific competition. These results, when combined with those of the second experiment, suggest that the effect of Pa on soil microbial communities is induced in the presence of a heterospecific neighbor.

The substantial balance of $5436 reflects unspent graduate student stipend and tuition waiver due to the departure of a graduate student prior to the completion of their studies and this project. The work was completed by Secott and undergraduate student volunteers.

Result 3: Plant harvest and data analysis

Description: Plant height and biomass will be measured at the end of each training phase.

Summary Budget Information for Result 3:	**Trust Fund Budget:**	**$ 4000**
	Amount Spent:	**$ 2502**
	Balance:	**$ 1498**

1. Plant height and biomass data	11/30/07	$1000	completed
	3/30/08	$1000	completed
	6/30/08	$1000	completed
	11/1/08	$1000	completed

Final Report Summary: Here we summarize the results from 4 experiments: 1) A soil-training experiment; 2) A reciprocal transplant experiment; 3) An experiment that tests for allelopathy between Pa and Cs; and 4) A second reciprocal transplant experiment.

The results from our soil-training experiment revealed that Pa biomass did not differ between sterile soils trained by Pa and untrained soils. However, Cs biomass was negatively affected in Cs trained soil. Therefore, soil training by Pa had a neutral effect on Pa growth but soil trained by Cs had a negative effect on Cs growth.

Our first reciprocal transplant experiment compared growth of Pa and Cs in their own native soil and that of the other species. Our results showed that both Pa and Cs produced 91% and 88% more biomass, respectfully, when grown in soil that had been field-cultured by conspecifics (individuals of its own species) than heterospecifics (individuals of the other species) These results are important because they indicated that both Pa and Cs had positive plant-soil feedback interactions when grown in their own soil with native microbial communities.

The results from our test for allelopathy reveled that Pa did not have an allelopathic effect on Cs, but Pa was a better competitor under our experimental conditions. Additionally, activated carbon did not affect the growth of either Pa or Cs; that is Pa and Cs biomass did not differ between soils with and without activated carbon. These results are important because they provide good evidence that Pa does not use allelopathy as a mechanism to outcompete Cs.

Our second reciprocal transplant experiment compared growth of Pa and Cs in their own native and sterile soils and in those of the other species.

Competition with either a conspecific or heterospecific neighbor did not affect Cs growth. However, growth of Cs was less in native soils of both Pa and Cs than in sterilized Pa and Cs soils.

For Pa, the effect of soil type was influenced by the species of neighboring plant. There was no difference in Pa growth in native Pa soil in the presence of either conspecific or heterospecific competitors. Pa growth was best in sterile Cs soils, regardless of the level of competition. Pa growth was higher in sterile Pa soil and native Cs soil when in competition with Cs. The latter result indicates that enhanced Pa growth may be induced in the presence of heterospecific competition in native Cs soils. This observation is significant, as it is the most likely scenario at the beginning of the invasion of a stand of native plants.

The substantial balance of $1498 is due to cost savings from our collection and set up of the first soil-training experiment and reciprocal transplant experiment prior to receiving funding from the LCCMR and due to cost savings from our decision to use student volunteers rather than graduate students to work on this part of the project.

Result 4: *T-RFLP testing*

Description: DNA will be extracted from soil, and ribosomal RNA genes (rDNA) will be amplified using fluorescently-labeled primers in the Polymerase Chain Reaction (PCR). The PCR products will be digested with restriction enzyme *Msp*I, and fragments will be separated and visualized using a LiCor 4300 DNA Analyzer. Because each taxon has a unique rDNA sequence, each may generate different banding patterns following digestion. Soils containing similar communities will have similar banding patterns; where the community compositions are significantly different, the banding patterns will also differ.

Summary Budget Information for Result 4:	**Trust Fund Budget:**	**$ 26085**
	Revised Budget	**$ 36085**
	Amount Spent:	**$ 23653**
	Balance:	**$ 12432**

Deliverable	**Completion Date**	**Budget**	**Status**
1. Protocol establishment	1/31/08	$7585	completed
2. Analysis of DGGE data	6/30/08	$9750	completed
	3/30/09	$8750	completed

Final Report Summary: We substituted denaturing gradient gel electrophoresis (DGGE) analysis for terminal restriction fragment length polymorphism (T-RFLP) analysis because the former is more commonly employed, and therefore more easily placed in the broader context of microbial community analysis. There was no apparent correlation between CLSU analysis and DGGE analysis for the soil training experiment. However, two general conclusions could be reached. First, the number of taxa present in Cs soils (as indicated by the number of discrete DGGE bands) was greater than that observed for Pa. This indicates that the microbial communities in Cs soils are more diverse than those in Pa soils. Second, the taxa present in Cs soils within and among treatments were variable, whereas the taxa in Pa soils were relatively consistent. These results may indicate that Pa limits soil microbial community diversity more so than does Cs.

The remaining balance of $12432 resulted from using undergraduate student volunteers to conduct the procedures instead of hiring a graduate research assistant.

Result 5: *HPLC analysis*

Description: The original soil extracts and extracts prepared from soils collected periodically from the tanks and from the Pa rhizosphere will be analyzed by Reverse Phase HPLC-UV/VIS. A mixture of solvents (methanol, acetonitrile) and columns (C-18 pre-column, ODS, C-18) coupled with several different wavelengths (280 nm, universal for phenolics, 260 nm catechins, etc) will be used to separate and screen components. Those fractions that show biological activity will be analyzed by HPLC-MS. The MS fingerprint will be used to search existing libraries of compounds to identify the compounds.

Pa rhizomes will also be collected. After collection the rhizomes will be rinsed with deionized water and divided into the root section and stem/leaf section. Both sections will be weighed for biomass determination. Aliquots of roots (approximately 150 grams) will be crushed using a ball grinder. The crushed roots will be extracted with water and methanol. These extracts will be analyzed for compounds using HPLC-UV/Vis. Components will be separated and collected by HPLC. Those fractions showing biological activity will be further analyzed by HPLC-MS. The MS will give a fingerprint of the compound.

Summary Budget Information for Result 5: **Trust Fund Budget: $ 25000**
Amount Spent: $ 15691
Balance: $ 9309

Deliverable	**Completion Date**	**Budget**	**Status**
1. Protocol establishment	1/31/08	$7500	completed
2. Sample preparation/analysis	4/15/08	$12000	completed
	1/31/09	$5500	completed

Final Report Summary: Because the HPLC-MS was not functioning properly, it was decided to begin these analyses using bioassays to identify inhibitory extracts. GS-MS analyses were used to identify potentially inhibitory compounds present in the extracts Extracts of Pa roots were used to test the effect of extracted compounds on the germination of seeds known to be sensitive to bioactive substances commonly used in bioassays. Methanol extracts of Pa roots inhibited the germination of lettuce and radish seeds, as well as those of Reed Manna Grass, a wetland plant. GC-MS analyses of the inhibitory methanol extracts revealed the presence of methyl esters of linoleic acid and linolenic acid. The formation of the methyl esters was due to the methanol solvent. Both of these C18 unsaturated fatty acids are known to inhibit both gram-positive and gram-negative bacteria, and are used as antimicrobial food additives.

The balance of $9309 resulted from using undergraduate student volunteers and undergraduate student class projects instead of hiring a graduate research assistant.

Result 6: Final Report Preparation

Description: Final report preparation, printing, and dissemination.

Summary Budget Information for Result 6:	**Trust Fund Budget:**	**$ 15915**
	Amount Spent:	**$ 10638**
	Balance:	**$ 5277**

Deliverable	**Completion Date**	**Budget**	**Status**
1. Draft report	4/30/09	$4000	completed
2. Final report	6/30/09	$11915	completed

Result Status as of *(December 18, 2009)***:** The final report is completed. Portions of Results 1, 2, and 3 have been written as a manuscript (*A plant-soil feedback as a mechanism for the invasive success of Phalaris arundinacea*) and is being revised for publication. A second manuscript including Results 1-5 is in preparation by the investigators.

Portions of this work were presented:

1) as an invited talk at the University of Bern, Switzerland (8/08)
2) at the 93rd Annual Ecological Society of America Meeting; Milwaukee, WI. (8/08)
3) at the 13rd "Annual Conference of the Wisconsin Wetland Association; Oconomowoc, WI. (2/08)
4) (two papers) at the North American Lake Managers Society (NALMS) International Conference; Hartford, CT. (10/09)
5) (four papers) at the 2008 and 2009 Minnesota State University Undergraduate Research Conference (4/08 and 4/09)

In addition, portions of this work were used for a M.S. thesis project, as class exercises in undergraduate courses, and as several undergraduate independent research projects at Minnesota State University.

Final Report Summary:

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services:

Bradley Cook: $12787 (36 days over 2 years) = 10% of full-time employment over two years. Cook is the principle investigator of the project and is responsible for all project tasks, data collection/analysis, results, deliverables, and reports. Cook is primarily responsible for soil preparation/training, all greenhouse experiments, data analysis, report writing and dissemination. Cook will directly co-supervise the two graduate students with Secott.

Timothy Secott: $24314 (54 days over 2 years) = 15% of full-time employment over two years. Secott is the co-principle investigator of the project and is primarily responsible for CLSU and T-RFLP testing and analysis and will assist with report writing and dissemination. Secott will directly co-supervise the two graduate students with Cook.

Beth Proctor: $12181 (14 days over 2 years) = 4.1% of full-time employment over two years. Proctor is primarily responsible for HPLC/MS analysis.

Graduate Student #1: $13412 (4 of 6 semesters stipend and tuition) = 66% of full-time employment for one year. This student will be under the direct supervision of Cook.

Graduate Student #2: $1600 (4 of 6 semesters stipend and tuition) = 66% of full-time employment for one year. This student will be under the direct supervision of Secott.

Equipment: $9730. Purchase of denaturing gradient gel electrophoresis system, replacement of equipment damaged during move.
Supplies: $15334. Supplies include HPLC columns, solvents, sand, DNA extraction reagents, PCR primers, BIOLOG plates, electrophoresis reagents (buffers, agarose, polyacrylamide, etc.) and laboratory consumables (pipet tips, gloves, etc.).

Travel: $515. This money will be used to collect plant and soils for this project. The remainder will be spent to send the graduate students to a local/regional meeting to present their research.

Development: $ N/A
Restoration: $ N/A
Acquisition, including easements: $ N/A

TOTAL TRUST FUND PROJECT BUDGET: $ 115000

Explanation of Capital Expenditures Greater Than $3,500 (October 6, 2008 Update): In May we purchased an Ingeny PhorU Denaturing Gradient Gel Electrophoresis (DGGE) System for $8,000. We are requesting retroactive approval of this purchase. We offer fiscal and technical explanations for retroactive approval. From a fiscal perspective, we simply did not read the LCCMR guidelines carefully and did not realize that we should have acquired prior approval. Additionally, prior to its purchase, my review of our expenditures indicated that we were under budget and ahead of schedule on several project results. For example, out of hopeful anticipation of receiving LCCMR funding, much of the work for Result 1 was started during the peer review process and completed before funding arrived. This preliminary work was funded by the Department of Biological Sciences at MSU. Similarly, we originally budgeted $15,134 as salary for Cook and, to date, have spent $2,900 on his salary. Much of Cook's time spent on this project to date has been covered by MSU or another grant.

From a technical perspective the DGGE system was recommended by one of the peer review panel members and will provide us with clearer results than will T-RFLP. In addition, the use of the DGGE system will allow us to identify (through DNA sequencing) those organisms that respond to reed canarygrass root exudates, rather than simple functional groups -- more and better information.

We will continue to use the DGGE system for similar analyses for its useful lifetime. If not, we commit to pay back the Environment and Natural Resources Trust Fund an amount equal to either the cash value received or the residual value approved by the LCCMR director if it is sold.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: N/A

B. Other Funds Proposed to be Spent during the Project Period: Minnesota State University-Mankato (MSUM) will contribute ~$15,000 as direct matching funds as teaching assistantships and tuition waivers for the two graduate students. MSUM will provide in-kind matching funds including office space and computer facilities for key personnel and graduate students for the duration of the project. Support services including greenhouse/laboratory, library access and services, statistical expertise, accounting services, copying costs, publication costs, some travel, and office/laboratory/greenhouse maintenance and power will be also be provided by MSUM for the duration of the project.

C. Past Spending: N/A

D. Time: N/A

VII. DISSEMINATION: At appropriate opportunities the investigators of this project will continue to present the results at local, state, regional, and international venues. Portions of Results 1, 2, and 3 have been written as a manuscript (A plant-soil feedback as a mechanism for the invasive *success of Phalaris arundinacea*) and is being revised for publication. A second manuscript including Results 1-5 is in preparation by the investigators.

Portions of this work were presented:

1) as an invited talk at the University of Bern, Switzerland (8/08)
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In addition, portions of this work were used for a M.S. thesis project, as class exercises in undergraduate courses, and as several undergraduate independent research projects at Minnesota State University.

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than January 8, 2008; June 30, 2008; and January 8, 2009. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR

IX. RESEARCH PROJECTS: See attachment B: revised research addendum

Attachment A: Budget Detail for 2007 Projects - **Summary and a Budget page for each partner (if applicable)**

Project Title: Neutralization of Reed Canary Grass Root Exudates - *4(i)*

Project Manager Name: *Bradley J. Cook*

Trust Fund Appropriation: $ *115000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Result 1 Budget: Revised 10/08**	**Amount Spent** *(as of 6/30/09)*	**Balance** *(as of 6/30/09)*	**Result 2 Budget:**	**Amount Spent** *(as of 6/30/09)*	**Balance** *(as of 6/30/09)*	**Result 3 Budget:**	**Amount Spent** *(as of 6/30/09)*	**Balance** *(as of 6/30/09)*
	Soil preparation and training			*21000*	*CLSU testing*		*23000*	*Plant harvest and data analysis*		*4000*
BUDGET ITEM				0			0			0
PERSONNEL: wages and benefits	~~18,500~~	8,500	8,351	149	19,500	13,533	5,967	4,000	2,502	1,498
Printing				0			0			0
Other Supplies *(list specific categories)*				0			0			0
Sand	~~500~~	500	314	187			0			0
Pots	~~1,000~~	1,000	161	839			0			0
BIOLOG plates				0	3,000	3,000	0			0
PCR primers				0			0			0
T-RFLP primers				0			0			0
Molecular biology reagents and kits				0			0			0
HPLC Solvents				0			0			0
HPLC Columns				0			0			0
Disposibles (gloves, tips, etc.)	~~1,000~~	1,000	1,000	0	500	1,031	-531			0
Travel expenses in Minnesota				0			0			0
Travel outside Minnesota *(where?)*				0			0			0
Other *(Describe the activity and cost) be specific*				0			0			0
COLUMN TOTAL	**~~$21,000~~**	**$11,000**	**$9,825**	**$1,175**	**$23,000**	**$17,564**	**$5,436**	**$4,000**	**$2,502**	**$1,498**
	$10,000 was transferred to other for Result 4; DGGE system.									

2007 Trust Fund Budget	**Result 4 Budget:**	**Result 4 Budget: Revised 10/08**	**Amount Spent** *(as of 6/30/09)*	**Balance** *(as of 6/30/09)*	**Result 5 Budget:**	**Amount Spent** *(as of 6/30/09)*	**Balance** *(as of 6/30/09)*	**Result 6 Budget:**	**Amount Spent** *(as of 6/30/09)*	**Balance** *(as of 6/30/09)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	T-RFLP testing			*36,085*	*HPLC analysis*		*25000*	*Final report preparation*		*15915*		
BUDGET ITEM				0			0			0	0	0
PERSONNEL: wages and benefits	~~22,816~~	22,816	9,012	13,804	20,000	10,747	9,253	15,000	10,149	4,851	89,816	35,522
Printing				0			0	400	323	77	400	77
Other Supplies *(list specific categories)*				0			0			0	0	0
Sand				0			0				500	187
Pots				0			0				1,000	839
BIOLOG plates				0			0				3,000	0
PCR primers	~~400~~	400	1,246	-846			0				400	-846
T-RFLP primers	~~769~~	769	1,369	-600			0				769	-600
Molecular biology reagents and kits	~~1,600~~	1,600	1,796	-196			0				1,600	-196
HPLC Solvents				0	2,000	1,944	56				2,000	56
HPLC Columns				0	3,000	3,000	0				3,000	0
Disposibles (gloves, tips, etc.)	~~500~~	500	500	0			0				2,000	-531
Travel expenses in Minnesota				0			0	515	166	349	515	349
Travel outside Minnesota *(where?)*				0			0			0	0	0
Other *(Describe the activity and cost) be specific*		10,000	9,730	270			0			0	10,000	270
COLUMN TOTAL	**~~$26,085~~**	$36,085	**$23,653**	**$12,432**	**$25,000**	**$15,691**	**$9,309**	**$15,915**	**$10,638**	**$5,277**	**$115,000**	**$35,127**
		Other = DGGE system										

Minnesota's Habitat Conservation Partnership

Final Phase IV Report – August 31, 2009
ML 2007, Chapter 30, Sec. 2 Subd 4b

The mission of the Minnesota Habitat Corridors Partnership is to restore, enhance and conserve habitat corridors for the purpose of sustaining fish, wildlife and native plant communities for all generations.

This unique Partnership is funded in part by the Minnesota Legislature, as recommended by the Legislative Commission on Minnesota Resources. Funding is provided by the Environment & Natural Resources Trust Fund and the participating partners. The Partnership provides for statewide coordination of existing federal, state, and private land and water conservation programs and focuses resources on identified habitat corridors.

<u>Partner Organizations</u>

Ducks Unlimited ☼ Fond du Lac Reservation ☼ Leech Lake Band of Ojibwe ☼ Minnesota Board of Water and Soil Resources ☼ Minnesota Deer Hunters Association
Minnesota Department of Natural Resources ☼ Minnesota Land Trust ☼ Minnesota Valley National Wildlife Refuge Trust, Inc. ☼ National Wild Turkey Federation
Pheasants Forever ☼ Friends of the Detroit Lakes Wetland Management District☼ The Nature Conservancy ☼ Trust for Public Land ☼ U.S. Fish and Wildlife Service
U.S. Natural Resources Conservation Service

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Restoring Minnesota's Fish and Wildlife Habitat Corridors

A Brief History

The general concept of focusing conservation efforts in geographic areas with the greatest need and opportunity is intuitively attractive. Applying this approach to the problem of habitat fragmentation makes sense to most conservationists. It was this approach that formed the basis for the project proposal Restoring Minnesota's Fish and Wildlife Habitat Corridors submitted to LCMR in 2000. It was heralded as a fresh approach to bringing together conservation partners, differing restoration and protection strategies, and consolidated funding to a new level of coordination. Even before the project was officially approved, members of LCMR wanted to know more about where the corridors would be and what kinds of activities would be funded.

In response, a group of partners led by the Minnesota Waterfowl Association and in consult with the Citizens Advisory Committee to the LCMR was convened to identify target areas, or "corridors", to form the backbone of the proposal. The complexity of the issue became immediately apparent. The state of Minnesota is highly variable in terms of natural resources, threats to these resources, loss of the resources, potential for protection and restoration, and the agencies and nongovernmental organizations committed to sound resource management.
The first step was to apply a geographic information system to map important aspects of the existing resource base. The basic elements were forests, grasslands, water, and land use. Data layers included mapped information from state and federal agencies. Examples included: Wildlife Management Areas, RIM easements, the Minnesota Natural Heritage Database, rivers, and shallow lakes.

More information about important resources areas was gathered through regional meetings with Department of Natural Resources and U. S. Fish and Wildlife Service field staff throughout the state. The information was further refined through meetings with individual partners. The meetings with partners also served to identify information related to partner specific priorities and restrictions.

The three basic geographic concepts created through these meetings were: Spatial Corridors, Linear Corridors and Project Areas.

Project Areas: These areas were the actual areas identified for focusing projects within the LCMR proposal and work plans. Project areas included spatial and linear corridors but were modified by political, cultural, and practical considerations. While the two types of corridors were driven primarily by natural resource considerations, the project areas were driven by organization resource considerations. There were spirited discussions concerning the appropriate size and configuration of the project areas as they were identified on maps. Some partners wanted to limit the size of the areas in order to concentrate project dollars in specific areas of high priority to their organization. Others favored larger areas toallow flexibility in identification of projects for funding and completion. Meetings were held with the 14 Restoring Minnesota's Fish and Wildlife Corridors Project Partners to determine which spatial or linear corridors in the State projects will be performed for the LCMR grant. Each Project Partner selected a combination of 3 linear and/or 3 spatial corridors throughout the State where they will perform restoration & management programs, conservation easement programs, or habitat acquisition programs for the grant. Those corridors that were selected became the boundaries for the Corridor Project Areas theme. Community GIS Services then on-screen digitized the polygons.

In the end, eleven project areas were identified that sought to balance opportunities for all the partners while focusing the habitat protection and restoration efforts on key areas of Minnesota. Phase I of the Minnesota Habitat Corridors Partnership completed work within the eleven identified project areas. In Phase II & III, only minor changes were made to the some project areas. Future Phases may change the project area boundaries when justified, but it has been agreed that the total project area acreage would not increase.

Spatial corridors: Spatial corridors are broad areas that include resources of interest to the partners. An example is the headwaters of the Minnesota River valley. This area includes a relative abundance of wetlands and native prairie as well as major state and federal management areas. Meetings were held at Community GIS Services offices with resource managers from MN DNR wildlife and the Minnesota Waterfowl Association Staff. At these meetings, corridor delineations were on-screen digitized based upon the spatial corridor criteria including: 1) Clusters of shallow lakes that provide important production and migration benefits to waterfowl, 2) Concentrations of 500 acre of larger shallow lakes that provide greater security and resources , areas of historical significance to waterfowl, other migratory birds, and wetland wildlife, 3) Relationships to high density waterfowl production areas 4) Recommendations of resource managers and project partners. The associated data and spatial corridors were printed on large format paper and brought to project partner meetings and resource manager meetings with USFWS and MN DNR wildlife staff where corrections and additions were made. The spatial corridors were then clipped to project areas.

Linear Corridors: Linear corridors are relatively narrow bands of resources that generally follow distinct geologic features or river corridors and often occurred within one or more spatial corridors. An example is the riparian area along the Cannon River in southeastern Minnesota. Meetings were held at each MN DNR Regional Office throughout the state where approximately 35-40 maps with mylar overlays containing the information listed below was presented to resource managers from MN DNR wildlife, forestry and fisheries staff. At these meetings corridor delineations were made on mylar overlays that contained important habitat and protected land linkages by the resource managers. The maps and mylar overlays were brought back to the Community GIS Services offices. There, with the oversight of Corridors Partners, linear corridors were delineated either based upon ArcView Shapefile buffers of rivers/streams or by selecting groups of sections from the MN DNR Section Level Public Land Survey and creating ArcView Shapefiles. These ArcView Shapefiles of linear corridors ere merged in ArcView and clipped to the 11 project area polygons.

LCCMR FINAL REPORT
Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase IV
Habitat Conservation Partnership

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Fund: Environment and Natural Resources Trust Fund
Legal Citation: ML 2007, Ch. 30, Sec. 2, Subd. 4b

Appropriation Language: Minnesota Habitat Corridors Partnership – Phase IV

$4,200,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with Pheasants Forever; Minnesota Deer Hunters Association; Ducks Unlimited, Inc.; National Wild Turkey Federation; The Nature Conservancy; Minnesota Land Trust; The Trust for Public Land; Minnesota Valley National Wildlife Refuge Trust; United States Fish and Wildlife Service; Red Lake Band of Chippewa; Leech Lake Band of Chippewa; Fond du Lac Band of Chippewa; USDA-Natural Resources Conservation Service; and the Board of Water and Soil Resources to plan, restore, and acquire fragmented landscape corridors that connect areas of quality habitat to sustain fish, wildlife, and plants. Expenditures are limited to the project corridor areas as defined in the work program. Land acquired with this appropriation must be sufficiently improved to meet at least minimum habitat and facility management standards as determined by the commissioner. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner with money from this appropriation must be designated (1) as an outdoor recreation unit under Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 797 A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

Total Project Budget

Result	Env. Trust Fund Allocation	Env. Trust Funds Spent	Env. Trust Balance	Other Funds Spent
Coordination/Mappin	$181,000	$147,383	$7,317	$8,000
Restoration	$1,204,000	$1,180,184	$23,816	$2,280,711
Easement	$920,000	$910,784	$9,216	$8,537,453
Acquisition	$1,895,000	$1,857,078	$37,922	$1,063,800
Grand Total:	**$4,200,000**	**$4,121,730**	**$78,270**	**$11,889,963**

*The above table reflects Habitat Corridors Partnership expenditures by result. Please note that the expenditures for restoration, easement acquisition and fee-title acquisition reflected here will not exactly match the subtotals for those categories reflected in Table 2. Also note that the total expenditures are identical. The reason for this is that some work programs expend dollars on both acquisition and restoration. Also, some partners expend funds on both easement and fee title acquisition, depending on the wishes of the landowner they are working with. For example, a partner working under the 4a work program to acquire a state wildlife management area (acquisition) is also responsible to ensure that the initial habitat is developed (restoration) on that acquired parcel.

Overall Work Program Summary

Between 7/1/07 and 6/30/09, Minnesota's Habitat Conservation Partnership (HCP) restored, enhanced or protected 32,334 acres (17,650 ENTF) in defined project areas expending $16,011,693 ($4,121,730 ENTF). Go to http://www.mnhabitatcorridors.org for complete information.

Partners restored/enhanced 27,556-acres, exceeding the 6.398-acre goal due to increased non-state funding being spent upon easement restoration projects during the grant period. Work included 14,610-acres of grassland restoration/enhancement, 7,547-acres of wetland restoration, 91-acres of woodland restoration, and 1,040-acres of wetland enhancement, 496-acres of dam modification, 115 acres of shoreline restoration, & 29-acres of wild rice restoration. Other accomplishments included shallow lake surveys, lake aeration, site access/development & lakescaping demonstration projects/workshops. A total of $3,460,895 ($1,180,184 ENTF, $2,280,711 Other Funds) was expended to restore/enhance habitat.

Partners acquired 3,926 acres of perpetual conservation easements. HCP fell shy of the 4,320-acre goal due to increased non-state funds being used for habitat restoration activities on easements. Shoreline habitats continued to be a priority for HCP partners working on easement, with over 8.6 shoreline miles protected. Habitats protected were grasslands, wetlands, and woodlands. A total of $9,448,237 ($910,784 ENTF, $8,537,453 Other Funds) was expended to acquire perpetual conservation easements.

Partners acquired 852-acres in fee-title, which fell short of the proposal goal of 1,254 acres. This was due to land prices being high, the focus on shoreline (higher priced lands) and other fund projects falling through. HCP achieved 408-acres of new WMA's, 136 acres of AMA's, 78-acres of WPA's, and 230-acres of private/local government lands. A total of $2,931,662 ($1,857,8078 ENTF, $1,063,800 Other Funds) was expended on fee-title acquisition projects.

HCP Partners include: Ducks Unlimited, Fond du Lac Reservation, Leech Lake Band of Ojibwe, MN Board of Water and Soil Resources, MN Deer Hunters Association, MN Department of Natural Resources, MN Land Trust, MN Valley National Wildlife Refuge Trust, Inc, National Wild Turkey Federation, Pheasants Forever, The Nature Conservancy, Trust for Public Land, U.S. Fish and Wildlife Service, U.S. Natural Resources Conservation Service

Table 2 - Accomplishments by Work Program - Phase 4 — Minnesota Habitat Conservation Partnership — Sheet 1 of 2

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS			STATE FUNDS			PARTNERS STATE LEVERGED FUNDS			OTHER		
Activity(Results)	ENTF Allocation	ENTF Expenditure	Balance	Acres	Shoreline /Riparian (feet)	Expenditure	Acres	Shoreline /Riparian (feet)	Expenditure	Acres	Shoreline /Riparian (feet)	Expenditure	Acres	Shoreline /Riparian (feet)	Expenditure	Acres	Shoreline /Riparian (feet)
1. Project Coordination and Mapping																	
1A - Project Coordination and Mapping - Pheasants Forever	$100,000	$92,683	$7,317	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0
1B - Restorable Wetlands Inventory - Ducks Unlimited	$48,000	$48,000	$0	0	0	$8,000	0	0	$0	0	0	$0	0	0	$0	0	0
* 1C - DNR Contract Admnistration - MN-DNR	$33,000	$33,000	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0
SubTotal:	$181,000	$173,683	$7,317	0	0	$8,000	0	0	$0	0	0	$0	0	0	$0	0	0
2. Restoration & Management																	
2A - Hides for Habitat Restoration - MDHA	$75,000	$75,000	$0	35	0	$24,379	9	0	$0	0	0	$0	0	0	$0	0	0
2B - Partners for Fish and Wildlife - U.S. Fish & Wildlife Service	$30,000	$30,000	$0	80	0	$42,718	200	0	$0	0	0	$0	0	0	$58,596	187	0
2C - Living Lakes Enhancement - Ducks Unlimited	$300,000	$300,000	$0	415	0	$446,839	531	0	$46,389	177	0	$0	0	0	$0	0	0
2D - Shallow Lakes Assessment and Management - MN DNR - Division of Wildlife	$98,000	$98,000	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0
2E2 - Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe	$30,000	$30,000	$0	780	6,490	$41,036	2,126	0	$0	0	0	$0	0	0	$2,300	0	0
2E3 - Wild Rice Habitat Restoration - Fond du Lac Band of Chippewa Indians	$21,000	$0	$21,000	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0
2G - Wildlife Areas Management - DNR-Division of Fish & Wildlife	$50,000	$47,185	$2,816	237	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0
2H - Fish Habitat Restoration - MN DNR - Division of Fisheries	$280,000	$280,000	$0	3,847	50,567	$19,945	313	132	$65,219	1,330	1,026	$0	0	0	$44,983	3	2,318
2I - Set out Seedlings - National Wild Turkey Federation	$20,000	$20,000	$0	91	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0
2J - Lakescaping - MN DNR - Division of Ecological Services	$100,000	$100,000	$0	5	1,685	$0	0	0	$20,830	0	0	$7,000	0	0	$0	0	0
2K - Prairie Management - MN DNR - Scientific and Natural Areas Program	$100,000	$100,000	$0	1,311	0	$53,300	0	0	$0	0	0	$0	0	0	$0	0	0
2N - Campagin for Conservation - Restoration - The Nature Conservancy	$80,000	$80,000	$0	9,976	0	$22,549	10	0	$0	0	0	$0	0	0	$0	0	0
2O - Working Lands Initiative Partnership - FWS	$20,000	$20,000	$0	13	0	$5,000	0	0	$0	0	0	$0	0	0	$0	0	0
SubTotal:	$1,204,000	$1,180,184	$23,816	16,788	58,742	$655,765	3,189	132	$132,439	1,507	1,026	$7,000	0	0	$105,879	190	1,159

Table 2 - Accomplishments by Work Program - Phase 4 | Minnesota Habitat Conservation Partnership | Sheet 2 of 2

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS			STATE FUNDS			PARTNERS STATE LEVERGED FUNDS			OTHER		
Activity(Results)	ENTF Allocation	ENTF Expenditure	Balance	Acres	Shoreline /Riparian (feet)	Expenditure	Acres	Shoreline /Riparian (feet)	Expenditure	Acres	Shoreline /Riparian (feet)	Expenditure	Acres	Shoreline /Riparian (feet)	Expenditure	Acres	Shoreline /Riparian (feet)
3. Conservation Easement Programs																	
3A - Shorelands Protection Program - Minnesota Land Trust	$300,000	$300,000	$0	248	2,505	$5,239,400	1,024	32,695	$0	0	0	$0	0	0	$0	0	12,437
3C - Shallow Lakes Easements - Ducks Unlimited	$200,000	$200,000	$0	101	4,476	$261,341	83	3,987	$128,000	50	2,130	$0	0	0	$0	0	0
3D - Wetlands Reserve Program - DU and NRCS	$350,000	$350,000	$0	0	0	$4,661,433	10,022	0	$0	0	0	$0	0	0	$0	0	0
3F - Habitat Encroachment Buffers - Pheasants Forever	$20,000	$0	$20,000	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0
3G - Campagin for Conservation - Easements - The Nature Conservancy	$50,000	$50,000	$0	23	2,091	$225	0	0	$116,439	53	4,868	$0	0	0	$33,746	15	8,370
SubTotal:	$920,000	$900,000	$20,000	372	9,072	$10,162,399	11,130	36,681	$244,439	103	6,999	$0	0	0	$33,746	15	1,411
4. Habitat Acquisition Programs																	
4A - Critical Lands Conservation Initiative IV - Pheasants Forever	$450,000	$450,000	$0	198	1,095	$361,150	210	105	$109,200	60	0	$59,800	33	0	$0	0	0
4B - Fisheries Acquisition - MN DNR - Division of Fisheries	$500,000	$500,000	$0	32	2,935	$131,700	11	386	$646,580	75	2,544	$0	0	0	$436,500	59	10,135
4C - Critical Lands Protection Program - The Trust for Public Land	$480,000	$480,000	$0	95	1,392	$0	0	0	$175,000	35	508	$175,000	35	508	$0	0	0
4F - Minnesota NWTF Super Fund - National Wild Turkey Federation	$15,000	$0	$15,000	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0
4G - Campaign for Conservation - Acquisition - The Nature Conservancy	$300,000	$300,000	$0	141	0	$337,974	89	0	$0	0	0	$0	0	0	$0	0	0
4H - MN Valley Refuge Expansion - MN Valley Trust	$100,000	$100,000	$0	23	0	$232,976	55	0	$0	0	0	$0	0	0	$0	0	0
4I - Habitat Acquisition - Professional Services - MN DNR - Division of Fish & Wildlife	$50,000	$37,862	$12,138	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0
SubTotal:	$1,895,000	$1,867,862	$27,138	490	5,423	$1,063,800	365	490	$930,780	170	3,051	$234,800	67	508	$436,500	75	9,275
Grand Total:	$4,200,000	$4,121,730	$78,270	17,650	73,237	$11,889,963	14,684	14,684	$1,307,657	1,779	1,779	$241,800	264	67	$576,124	264	67

*Please note that the 2E2 Work Program that was previously unalloted has now been moved to the DNR Contract Administration. This is shown as the 1C Work Program on Sheet 1.

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Table 3 - Accomplishments by Project Area - Phase 4 | **Minnesota Habitat Conservation Partnership** | Sheet 1 of 6

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS					STATE FUNDS					PARTNERS STATE LEVERGED FUNDS					OTHER				
Activity(Results)	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian
1 - Aspen Parklands																									
Restoration																									
2A -Hides for Habitat Restoration	$50,621	0	0	25	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2B -Partners for Fish and Wildlife	$1,526	0	0	14	0	$2,474	0	0	22	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2C -Living Lakes Enhancement	$64,374	0	0	49	0	$195,897	0	0	21	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2G -Wildlife Areas Management	$15,140	0	0	123	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2J -Lakescaping	$45,665	0	0	5	880	$0	0	0	0	0	$8,825	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2K -Prairie Management	$6,080	0	0	113	0	$53,300	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2N -Campagin for Conservation - Restoration	$60,000	0	0	176	0	$22,549	0	0	10	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2O -Working Lands Initiative Partnership	$20,000	0	0	13	0	$5,000	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3D -Wetlands Reserve Program	$0	0	0	0	0	$1,261,996	0	0	6,300	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$263,405	0	0	518	880	$1,114,970	0	0	6,352	0	$8,825	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement																									
3D -Wetlands Reserve Program	$0	0	0	0	0	$1,397,226	0	1,010	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement Subtotal	$0	0	0	0	0	$1,139,571	0	1,010	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
1 - Aspen Parklands Subtotal	$263,405	0	0	518	880	$2,254,541	0	1,010	6,352	0	$8,825	0	0	518	0	$0	0	0	0	0	$0	0	0	0	0
2 - Mississippi Headwaters																									
Restoration																									
2E2 -Shallow Lake and Impoundment Management	$30,000	0	0	780	6,490	$41,036	0	0	2,126	0	$0	0	0	0	0	$0	0	0	0	0	$2,300	0	0	0	0
2H -Fish Habitat Restoration	$47,493	0	0	3,379	26,380	$6,000	0	0	0	132	$8,276	0	0	1,102	21	$0	0	0	0	0	$15,000	0	0	0	331
Restoration Subtotal	$77,493	0	0	4,159	32,870	$47,036	0	0	2,126	132	$8,276	0	0	1,102	21	$0	0	0	0	0	$17,300	0	0	0	331
Easement																									
3A -Shorelands Protection Program	$0	0	0	0	0	$10,000	0	43	0	3,144	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement Subtotal	$0	0	0	0	0	$10,000	0	43	0	3,144	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition																									
4B -Fisheries Acquisition	$44,100	0	0	0	300	$0	0	0	0	0	$64,000	28	0	0	800	$0	0	0	0	0	$0	0	0	0	0
4C -Critical Lands Protection Program	$480,000	0	0	0	1,392	$0	0	0	0	0	$175,000	35	0	0	508	$175,000	35	0	0	508	$0	0	0	0	0
Acquisition Subtotal	$524,100	106	0	0	1,692	$0	0	0	0	0	$239,000	63	0	0	1,308	$175,000	0	0	0	508	$0	0	0	0	0
2 - Mississippi Headwaters Subtotal	$601,593	106	0	4,159	34,562	$57,036	0	43	2,126	3,276	$247,276	63	0	4,159	1,328	$175,000	63	0	0	508	$17,300	0	0	0	331

Table 3 - Accomplishments by Project Area - Phase 4 — **Minnesota Habitat Conservation Partnership** — Sheet 2 of 6

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS					STATE FUNDS					PARTNERS STATE LEVERGED FUNDS					OTHER				
Activity(Results)	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian
3 - Border Prairie																									
Restoration																									
2A -Hides for Habitat Restoration	$606	0	0	0	0	$606	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2H -Fish Habitat Restoration	$5,244	0	0	57	21,120	$0	0	0	0	0	$11,607	0	0	206	0	$0	0	0	0	0	$0	0	0	0	0
2N -Campagin for Conservation - Restoration	$20,000	0	0	9,800	0	$19,176	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3D -Wetlands Reserve Program	$0	0	0	0	0	$638,806	0	0	1,033	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$25,850	0	0	9,857	21,120	$381,757	0	0	1,033	0	$11,607	0	0	206	0	$0	0	0	0	0	$0	0	0	0	0
Easement																									
3D -Wetlands Reserve Program	$0	0	0	0	0	$644,566	0	541	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement Subtotal	$0	0	0	0	0	$386,911	0	541	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition																									
4A -Critical Lands Conservation Initiative IV	$85,139	0	0	0	0	$2,600	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
4B -Fisheries Acquisition	$323,926	0	0	0	1,489	$3,500	0	0	0	18	$51,500	1	0	0	248	$0	0	0	0	0	$121,500	37	0	0	7,545
Acquisition Subtotal	$409,065	38	0	0	1,489	$3,500	0	0	0	18	$51,500	1	0	0	248	$0	37	0	0	0	$121,500	37	0	0	7,545
3 - Border Prairie Subtotal	$434,916	38	0	9,857	22,609	$772,168	0	541	1,033	18	$63,107	1	0	9,857	248	$0	1	0	0	0	$121,500	37	0	0	7,545
4 - Central Lakes																									
Restoration																									
2B -Partners for Fish and Wildlife	$5,534	0	0	19	0	$323	0	0	1	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2H -Fish Habitat Restoration	$7,900	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2J -Lakescaping	$27,470	0	0	0	410	$0	0	0	0	0	$5,145	0	0	0	0	$3,000	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$40,904	0	0	19	410	$323	0	0	1	0	$5,145	0	0	0	0	$3,000	0	0	0	0	$0	0	0	0	0
Easement																									
4B -Fisheries Acquisition	$1,691	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement Subtotal	$1,691	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition																									
4B -Fisheries Acquisition	$11,631	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition Subtotal	$11,631	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
4 - Central Lakes Subtotal	$54,227	0	0	19	410	$323	0	0	1	0	$5,145	0	0	19	0	$3,000	0	0	0	0	$0	0	0	0	0

Table 3 - Accomplishments by Project Area - Phase 4 | **Minnesota Habitat Conservation Partnership** | Sheet 3 of 6

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS					STATE FUNDS					PARTNERS STATE LEVERGED FUNDS					OTHER				
Activity(Results)	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian
5 - Lower St. Louis River																									
Restoration																									
2H -Fish Habitat Restoration	$7,239	0	0	0	100	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$7,239	0	0	0	100	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement																									
3A -Shorelands Protection Program	$0	0	0	0	0	$41,000	0	8	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
4B -Fisheries Acquisition	$9,093	0	3	0	860	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement Subtotal	$9,093	0	3	0	860	$41,000	0	8	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
5 - Lower St. Louis River Subtotal	$16,332	0	3	0	100	$41,000	0	8	0	0	$0	0	3	0	0	$0	0	0	0	0	$0	0	0	0	0
6 - Upper Minnesota River																									
Restoration																									
2K -Prairie Management	$11,135	0	0	134	0	$53,300	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3D -Wetlands Reserve Program	$0	0	0	0	0	$306,508	0	0	75	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$11,135	0	0	134	0	$48,853	0	0	75	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement																									
3D -Wetlands Reserve Program	$0	0	0	0	0	$308,165	0	78	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement Subtotal	$0	0	0	0	0	$50,510	0	78	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
6 - Upper Minnesota River Subtotal	$11,135	0	0	134	0	$99,363	0	78	75	0	$0	0	0	134	0	$0	0	0	0	0	$0	0	0	0	0
7 - Alexandria Moraine																									
Restoration																									
2H -Fish Habitat Restoration	$19,776	0	0	0	300	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3D -Wetlands Reserve Program	$0	0	0	0	0	$363,815	0	0	55	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$19,776	0	0	0	300	$106,160	0	0	55	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition																									
4G -Campaign for Conservation - Acquisition	$300,000	0	0	0	0	$337,974	89	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition Subtotal	$300,000	141	0	0	0	$337,974	89	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
7 - Alexandria Moraine Subtotal	$319,776	141	0	0	300	$444,134	89	0	55	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
8 - Big Woods North																									
Restoration																									
2C -Living Lakes Enhancement	$7,150	0	0	0	0	$108,415	0	0	0	0	$10,000	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2H -Fish Habitat Restoration	$2,509	0	0	17	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$9,659	0	0	17	0	$12,299	0	0	0	0	$10,000	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
8 - Big Woods North Subtotal	$9,659	0	0	17	0	$12,299	0	0	0	0	$10,000	0	0	17	0	$0	0	0	0	0	$0	0	0	0	0

Table 3 - Accomplishments by Project Area - Phase 4 | **Minnesota Habitat Conservation Partnership** | Sheet 4 of 6

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS					STATE FUNDS					PARTNERS STATE LEVERGED FUNDS					OTHER				
Activity(Results)	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian
9 - Des Moines River Valley																									
Restoration																									
2B -Partners for Fish and Wildlife	$8,000	0	0	11	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2C -Living Lakes Enhancement	$119,733	0	0	214	0	$236,951	0	0	445	0	$36,389	0	0	177	0	$0	0	0	0	0	$0	0	0	0	0
2G -Wildlife Areas Management	$12,352	0	0	31	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2H -Fish Habitat Restoration	$41,450	0	0	382	0	$13,945	0	0	313	0	$5,000	0	0	17	0	$0	0	0	0	0	$0	0	0	0	0
2K -Prairie Management	$29,755	0	0	307	0	$53,300	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$211,291	0	0	946	0	$154,780	0	0	757	0	$41,389	0	0	194	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition																									
4A -Critical Lands Conservation Initiative IV	$88,299	0	0	0	0	$85,100	40	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
4B -Fisheries Acquisition	$2,280	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition Subtotal	$90,579	40	0	0	0	$82,500	40	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
9 - Des Moines River Valley Subtotal	$301,870	40	0	946	0	$237,280	40	0	757	0	$41,389	0	0	946	0	$0	0	0	0	0	$0	0	0	0	0
10 - Southern Lakes																									
Restoration																									
2B -Partners for Fish and Wildlife	$11,501	0	0	18	0	$24,146	0	0	66	0	$0	0	0	0	0	$0	0	0	0	0	$39,546	0	0	48	0
2C -Living Lakes Enhancement	$36,971	0	0	115	0	$112,560	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2I -Set out Seedlings	$20,000	0	0	91	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2K -Prairie Management	$13,675	0	0	48	0	$53,300	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3D -Wetlands Reserve Program	$0	0	0	0	0	$342,096	0	0	117	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$82,147	0	0	272	0	$125,031	0	0	183	0	$0	0	0	0	0	$0	0	0	0	0	$39,546	0	0	48	0
Easement																									
3A -Shorelands Protection Program	$44,000	0	5	0	243	$616,000	0	67	0	3,407	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3C -Shallow Lakes Easements	$58,073	0	12	0	1,403	$36,861	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3D -Wetlands Reserve Program	$0	0	0	0	0	$1,459,495	0	815	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Easement Subtotal	$102,073	0	17	0	1,646	$1,824,316	0	882	0	3,407	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition																									
4A -Critical Lands Conservation Initiative IV	$2,500	0	0	0	0	$2,600	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
4B -Fisheries Acquisition	$107,278	0	0	0	287	$128,200	11	0	0	367	$531,080	46	0	0	1,495	$0	0	0	0	0	$315,000	22	0	0	1,731
4H -MN Valley Refuge Expansion	$100,000	0	0	0	0	$232,976	55	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Acquisition Subtotal	$209,778	32	0	0	287	$361,176	66	0	0	367	$531,080	46	0	0	1,495	$0	22	0	0	0	$315,000	22	0	0	1,731
10 - Southern Lakes Subtotal	$393,998	32	17	272	1,933	$2,310,523	66	882	183	3,774	$531,080	46	17	272	1,495	$0	46	0	0	0	$354,546	22	0	48	1,731

Table 3 - Accomplishments by Project Area - Phase 4 | **Minnesota Habitat Conservation Partnership** | Sheet 5 of 6

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS					STATE FUNDS					PARTNERS STATE LEVERGED FUNDS					OTHER				
Activity(Results)	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian
11 - Mississippi Bluff Lands																									
Restoration																									
2H -Fish Habitat Restoration	$113,742	0	0	11	2,666	$0	0	0	0	0	$37,251	0	0	4	1,005	$0	0	0	0	0	$29,983	0	0	3	828
2K -Prairie Management	$6,470	0	0	137	0	$53,300	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$120,212	0	0	148	2,666	$0	0	0	0	0	$37,251	0	0	4	1,005	$0	0	0	0	0	$29,983	0	0	3	828
Easement																									
3G -Campagin for Conservation - Easements	$50,000	0	23	0	2,091	$225	0	0	0	0	$116,439	0	53	0	4,868	$0	0	0	0	0	$33,746	0	15	0	1,411
Easement Subtotal	$50,000	0	23	0	2,091	$225	0	0	0	0	$116,439	0	53	0	4,868	$0	0	0	0	0	$33,746	0	15	0	1,411
11 - Mississippi Bluff Lands Subtotal	$170,212	0	23	148	2,666	$225	0	0	0	0	$153,690	0	23	148	1,005	$0	0	0	0	0	$63,729	0	15	3	828
3-7-8 - Border Prairie Transition Zone																									
Restoration																									
2A -Hides for Habitat Restoration	$23,773	0	0	9	0	$23,773	0	0	9	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2B -Partners for Fish and Wildlife	$3,439	0	0	18	0	$15,774	0	0	110	0	$0	0	0	0	0	$0	0	0	0	0	$19,050	0	0	139	0
2C -Living Lakes Enhancement	$33,197	0	0	37	0	$177,479	0	0	65	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2G -Wildlife Areas Management	$19,692	0	0	83	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2H -Fish Habitat Restoration	$3,379	0	0	0	0	$0	0	0	0	0	$3,086	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2J -Lakescaping	$26,865	0	0	0	395	$0	0	0	0	0	$6,860	0	0	0	0	$4,000	0	0	0	0	$0	0	0	0	0
2K -Prairie Management	$32,885	0	0	572	0	$53,300	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration Subtotal	$143,231	0	0	718	395	$120,910	0	0	185	0	$9,946	0	0	0	0	$4,000	0	0	0	0	$19,050	0	0	139	0
Easement																									
3A -Shorelands Protection Program	$155,000	0	243	0	2,262	$4,572,400	0	906	0	26,144	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3C -Shallow Lakes Easements	$130,939	0	89	0	3,073	$254,865	0	83	0	3,987	$128,000	0	50	0	2,130	$0	0	0	0	0	$0	0	0	0	0
Easement Subtotal	$285,939	0	332	0	5,335	$4,796,880	0	989	0	30,131	$128,000	0	50	0	2,130	$0	0	0	0	0	$0	0	0	0	0
Acquisition																									
4A -Critical Lands Conservation Initiative IV	$262,363	0	0	0	1,095	$278,650	171	0	0	105	$109,200	60	0	0	0	$59,800	33	0	0	0	$0	0	0	0	0
Acquisition Subtotal	$262,363	130	0	0	1,095	$276,050	171	0	0	105	$109,200	60	0	0	0	$59,800	0	0	0	0	$0	0	0	0	0
3-7-8 - Border Prairie Transition Zone Subtotal	$691,533	130	332	718	6,723	$5,193,841	171	989	185	17,901	$247,146	60	332	718	2,130	$63,800	60	0	0	0	$19,050	0	0	139	0

Table 3 - Accomplishments by Project Area - Phase 4 | Minnesota Habitat Conservation Partnership | Sheet 6 of 6

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS					STATE FUNDS					PARTNERS STATE LEVERGED FUNDS					OTHER				
Activity(Results)	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian
Expenditures not Attributable to Specific Projects	$853,077	-	-	-	-	$467,231	-	-	-	-	$0	-	-	-	-	$0	-	-	-	-	$0	-	-	-	-
Grand Total:	$4,121,730	487	375	10,768	73,237	$11,889,963	365	3,551	10,768	37,304	$1,307,657	170	103	1,507	11,076	$241,800	67	0	0	508	$576,124	59	15	190	10,434

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Table 4 - Accomplishments by Result - Phase 4 — **Minnesota Habitat Conservation Partnership** — Sheet 1 of 2

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS					STATE FUNDS					PARTNERS STATE LEVERGED FUNDS					OTHER				
Activity(Results)	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Ease ment Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acq. Acres	Easement Acres	Rest. Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian
Project Coordination/Mapping																									
1A -Project Coordination and Mapping	$92,683	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
1B -Restorable Wetlands Inventory	$48,000	0	0	0	0	$8,000	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
1C -DNR Contract Admnistration	$33,000	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
SubTotal:	$173,683	0	0	0	0	$8,000	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
Restoration																									
2A -Hides for Habitat Restoration	$75,000	0	0	35	0	$24,379	0	0	9	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2B -Partners for Fish and Wildlife	$30,000	0	0	80	0	$42,718	0	0	200	0	$0	0	0	0	0	$0	0	0	0	0	$58,596	0	0	187	0
2C -Living Lakes Enhancement	$300,000	0	0	415	0	$446,839	0	0	531	0	$46,389	0	0	177	0	$0	0	0	0	0	$0	0	0	0	0
2D -Shallow Lakes Assessment and Management	$98,000	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2E2 -Shallow Lake and Impoundment Management	$30,000	0	0	780	6,490	$41,036	0	0	2,126	0	$0	0	0	0	0	$0	0	0	0	0	$2,300	0	0	0	0
2E3 -Wild Rice Habitat Restoration	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2G -Wildlife Areas Management	$47,185	0	0	237	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2H -Fish Habitat Restoration	$280,000	0	0	3,847	50,567	$19,945	0	0	313	132	$65,219	0	0	1,330	1,026	$0	0	0	0	0	$44,983	0	0	3	1,159
2I -Set out Seedlings	$20,000	0	0	91	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2J -Lakescaping	$100,000	0	0	5	1,685	$0	0	0	0	0	$20,830	0	0	0	0	$7,000	0	0	0	0	$0	0	0	0	0
2K -Prairie Management	$100,000	0	0	1,311	0	$53,300	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2N -Campagin for Conservation - Restoration	$80,000	0	0	9,976	0	$22,549	0	0	10	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
2O -Working Lands Initiative Partnership	$20,000	0	0	13	0	$5,000	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3D -Wetlands Reserve Program	$350,000	0	0	0	0	$1,882,601	0	0	7,579	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
SubTotal:	$1,180,184	0	0	16,788	58,742	$2,280,711	0	0	10,768	132	$132,439	0	0	1,507	1,026	$7,000	0	0	0	0	$105,879	0	0	190	1,159
Easement																									
3A -Shorelands Protection Program	$300,000	0	248	0	2,505	$5,239,400	0	1,024	0	32,695	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3C -Shallow Lakes Easements	$200,000	0	101	0	4,476	$261,341	0	83	0	3,987	$128,000	0	50	0	2,130	$0	0	0	0	0	$0	0	0	0	0
3D -Wetlands Reserve Program	$350,000	0	0	0	0	$3,036,487	0	2,444	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3F -Habitat Encroachment Buffers	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
3G -Campagin for Conservation - Easements	$50,000	0	23	0	2,091	$225	0	0	0	0	$116,439	0	53	0	4,868	$0	0	0	0	0	$33,746	0	15	0	1,411
4B -Fisheries Acquisition	$10,784	0	3	0	860	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
SubTotal:	$910,784	0	375	0	9,932	$8,537,453	0	3,551	0	36,681	$244,439	0	103	0	6,999	$0	0	0	0	0	$33,746	0	15	0	1,411

Table 4 - Accomplishments by Result - Phase 4 — **Minnesota Habitat Conservation Partnership** — Sheet 2 of 2

	ENVIRONMENTAL AND NATURAL RESOURCES TRUST FUNDS					OTHER FUNDS					STATE FUNDS					PARTNERS STATE LEVERGED FUNDS					OTHER				
Activity(Results)	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Ease ment Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian	Expenditure	Acq. Acres	Easement Acres	Rest. Acres	Shoreline/ Riparian	Expenditure	Acquisition Acres	Easement Acres	Restoration Acres	Shoreline/ Riparian
Acquisition																									
4A -Critical Lands Conservation Initiative IV	$450,000	198	0	0	1,095	$361,150	210	0	0	105	$109,200	60	0	0	0	$59,800	33	0	0	0	$0	0	0	0	0
4B -Fisheries Acquisition	$489,216	29	0	0	2,075	$131,700	11	0	0	386	$646,580	75	0	0	2,544	$0	0	0	0	0	$436,500	59	0	0	9,275
4C -Critical Lands Protection Program	$480,000	95	0	0	1,392	$0	0	0	0	0	$175,000	35	0	0	508	$175,000	35	0	0	508	$0	0	0	0	0
4F -Minnesota NWTF Super Fund	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
4G -Campaign for Conservation - Acquisition	$300,000	141	0	0	0	$337,974	89	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
4H -MN Valley Refuge Expansion	$100,000	23	0	0	0	$232,976	55	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
4I -Habitat Acquisition - Professional Services	$37,862	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0	$0	0	0	0	0
SubTotal:	$1,857,078	487	0	0	4,563	$1,063,800	365	0	0	490	$930,780	170	0	0	3,051	$234,800	59	0	0	508	$436,500	59	0	0	9,275
Grand Total:	$4,121,730	487	375	16,788	73,237	$11,889,963	365	3,551	16,788	37,304	$1,307,657	170	103	1,507	11,076	$241,800	67	0	0	508	$576,124	59	15	190	10,434

*Table 4 reflects Habitat Conservation Partnership expenditures by result. Please note that the expenditures for restoration, easement acquisition and fee-title acquisition reflected here will not exactly match the subtotals for those categories reflected in Table 2. Also note that the total expenditures are identical. The reason for this is that some work programs expend dollars on both acquisition and restoration. For example, a partner working under the 4a work program to acquire a state wildlife management area (acquisition) is also responsible to ensure that the initial habitat is developed (restoration) on that acquired parcel.

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Restoration Expenditures and Accomplishments by Funding Type, Activity, Land Type, and Owner

Minnesota's Habitat Conservation Partnership - Phase 4

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			ENTF			Other Funds			Partners State Leveraged Funds			State Funds			Other			Total		
			Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline
Dam Modification	Public	Lake	$48,294	182	0	$10,500	36	0	$0	0	0	$16,607	224	0	$0	0	0	$75,400	442	0
		River	$56,328	1,314	47,165	$0	0	0	$0	0	0	$12,342	1,102	219	$15,000	0	0	$83,670	2,417	47,384
		Total	**$104,622**	**1,496**	**47,165**	**$10,500**	**36**	**0**	**$0**	**0**	**0**	**$28,949**	**1,326**	**219**	**$15,000**	**0**	**0**	**$159,070**	**2,859**	**47,384**
	Total		**$104,622**	**1,496**	**47,165**	**$10,500**	**36**	**0**	**$0**	**0**	**0**	**$28,949**	**1,326**	**219**	**$15,000**	**0**	**0**	**$159,070**	**2,859**	**47,384**
Grassland Enhancement	Private	Land	$63,260	829	0	$11,950	90	0	$0	0	0	$0	0	0	$18,450	137	0	$93,660	1,057	0
		Total	**$63,260**	**829**	**0**	**$11,950**	**90**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$18,450**	**137**	**0**	**$93,660**	**1,057**	**0**
	Public	SNA	$39,105	498	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$39,105	498	0
		WMA	$50,621	25	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$50,621	25	0
		Total	**$89,726**	**523**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$89,726**	**523**	**0**
	Total		**$152,986**	**1,353**	**0**	**$11,950**	**90**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$18,450**	**137**	**0**	**$183,386**	**1,580**	**0**
Grassland	Private	Land	$86,645	9,984	0	$333,840	3,021	0	$0	0	0	$0	0	0	$19,773	8	0	$440,258	13,014	0

Restoration Expenditures and Accomplishments by Funding Type, Activity, Land Type, and Owner

Minnesota's Habitat Conservation Partnership - Phase 4

The table below reflects expenditures attributable to specific restoration projects. Please note that the expenditures here will not match the subtotals for those categories reflected in Table 2 and Table 4. Also note that the total accomplishments(acres an is that some work programs expend dollars not attributable to a specific projects. For example Ducks Unlimited expends funds on technical assistance by DU biologists to DNR, US Fish & Wildlife Service, local units of goverment, and private landowners and managment. These personal expenditures are not reflected in the table below.

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Other:	Any other expenditures (e.g. grant income funds)

			ENTF			Other Funds			Partners State Leveraged Funds			State Funds			Other			Total		
			Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline
Grassland Restoration	Private	**Total**	**$86,645**	**9,984**	**0**	**$333,840**	**3,021**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$19,773**	**8**	**0**	**$440,258**	**13,014**	**0**
	Public	Lake	$2,450	17	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$2,450	17	0
		WMA	$20,549	235	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$20,549	235	0
		Total	**$23,000**	**252**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$23,000**	**252**	**0**
	Total		**$109,645**	**10,236**	**0**	**$333,840**	**3,021**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$19,773**	**8**	**0**	**$463,258**	**13,265**	**0**
Lake Aeration	Public	Lake	$3,000	241	0	$3,445	276	0	$0	0	0	$0	0	0	$0	0	0	$6,445	517	0
		Total	**$3,000**	**241**	**0**	**$3,445**	**276**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$6,445**	**517**	**0**
	Total		**$3,000**	**241**	**0**	**$3,445**	**276**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$6,445**	**517**	**0**
Outreach	Private	Lake	$500	0	0	$0	0	0	$0	0	0	$250	0	0	$0	0	0	$750	0	0
		Total	**$500**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$250**	**0**	**0**	**$0**	**0**	**0**	**$750**	**0**	**0**
	Total		**$500**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$250**	**0**	**0**	**$0**	**0**	**0**	**$750**	**0**	**0**

Restoration Expenditures and Accomplishments by Funding Type, Activity, Land Type, and Owner

Minnesota's Habitat Conservation Partnership - Phase 4

The table below reflects expenditures attributable to specific restoration projects. Please note that the expenditures here will not match the subtotals for those categories reflected in Table 2 and Table 4. Also note that the total accomplishments(acres an is that some work programs expend dollars not attributable to a specific projects. For example Ducks Unlimited expends funds on technical assistance by DU biologists to DNR, US Fish & Wildlife Service, local units of goverment, and private landowners and managment. These personal expenditures are not reflected in the table below.

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Other:	Any other expenditures (e.g. grant income funds)

			ENTF			Other Funds			Partners State Leveraged Funds			State Funds			Other			Total		
			Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline
Shallow Lake Survey / Design /	Public	Lake	$7,150	0	0	$12,299	0	0	$0	0	0	$10,000	0	0	$0	0	0	$29,449	0	0
		Total	**$7,150**	**0**	**0**	**$12,299**	**0**	**0**	**$0**	**0**	**0**	**$10,000**	**0**	**0**	**$0**	**0**	**0**	**$29,449**	**0**	**0**
	Total		**$7,150**	**0**	**0**	**$12,299**	**0**	**0**	**$0**	**0**	**0**	**$10,000**	**0**	**0**	**$0**	**0**	**0**	**$29,449**	**0**	**0**
Shoreline Habitat Restoration /	Private	Lake	$99,500	5	1,685	$0	0	0	$7,000	0	0	$20,580	0	0	$0	0	0	$127,080	5	1,685
		Total	**$99,500**	**5**	**1,685**	**$0**	**0**	**0**	**$7,000**	**0**	**0**	**$20,580**	**0**	**0**	**$0**	**0**	**0**	**$127,080**	**5**	**1,685**
	Public	Lake	$41,529	2,083	816	$6,000	0	132	$0	0	0	$934	0	21	$15,000	0	331	$63,463	2,083	1,300
		River	$84,800	10	2,586	$0	0	0	$0	0	0	$32,251	4	786	$14,983	3	828	$132,034	16	4,200
		Total	**$126,329**	**2,093**	**3,402**	**$6,000**	**0**	**132**	**$0**	**0**	**0**	**$33,185**	**4**	**807**	**$29,983**	**3**	**1,159**	**$195,497**	**2,100**	**5,499**
	Total		**$225,829**	**2,098**	**5,087**	**$6,000**	**0**	**132**	**$7,000**	**0**	**0**	**$53,765**	**4**	**807**	**$29,983**	**3**	**1,159**	**$322,577**	**2,105**	**7,184**
Site / Access Developme	Private	Lake	$2,951	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$2,951	0	0
		Total	**$2,951**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$2,951**	**0**	**0**

Restoration Expenditures and Accomplishments by Funding Type, Activity, Land Type, and Owner

Minnesota's Habitat Conservation Partnership - Phase 4

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			ENTF			Other Funds			Partners State Leveraged Funds			State Funds			Other			Total		
			Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline
Site / Access Development	Public	Lake	$6,000	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$6,000	0	0
		River	$3,379	0	0	$0	0	0	$0	0	0	$3,086	0	0	$0	0	0	$6,465	0	0
		WMA	$24,111	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$24,111	0	0
		Total	**$33,490**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$3,086**	**0**	**0**	**$0**	**0**	**0**	**$36,575**	**0**	**0**
	Total		**$36,440**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$3,086**	**0**	**0**	**$0**	**0**	**0**	**$39,526**	**0**	**0**
Wetland Enhancement	Private	Lake	$31,464	93	0	$22,031	0	0	$0	0	0	$5,177	0	0	$0	0	0	$58,671	93	0
		Total	**$31,464**	**93**	**0**	**$22,031**	**0**	**0**	**$0**	**0**	**0**	**$5,177**	**0**	**0**	**$0**	**0**	**0**	**$58,671**	**93**	**0**
	Public	Lake	$14,617	58	0	$84,391	445	0	$0	0	0	$21,213	177	0	$0	0	0	$120,221	680	0
		NWR	$64,374	49	0	$99,781	21	0	$0	0	0	$0	0	0	$0	0	0	$164,155	70	0
		WMA	$110,748	178	0	$50,857	0	0	$0	0	0	$10,000	0	0	$0	0	0	$171,605	178	0
		WPA	$33,197	37	0	$81,363	65	0	$0	0	0	$0	0	0	$0	0	0	$114,560	102	0

Restoration Expenditures and Accomplishments by Funding Type, Activity, Land Type, and Owner

Minnesota's Habitat Conservation Partnership - Phase 4

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			ENTF			Other Funds			Partners State Leveraged Funds			State Funds			Other			Total		
			Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline
Wetland Enhancement	Public	**Total**	**$222,935**	**322**	**0**	**$316,393**	**531**	**0**	**$0**	**0**	**0**	**$31,213**	**177**	**0**	**$0**	**0**	**0**	**$570,541**	**1,030**	**0**
	Tribal	Lake	$4,000	94	0	$500	0	0	$0	0	0	$0	0	0	$2,300	0	0	$6,800	94	0
		Total	**$4,000**	**94**	**0**	**$500**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$2,300**	**0**	**0**	**$6,800**	**94**	**0**
	Total		**$258,399**	**509**	**0**	**$338,924**	**531**	**0**	**$0**	**0**	**0**	**$36,389**	**177**	**0**	**$2,300**	**0**	**0**	**$636,012**	**1,217**	**0**
Wetland Restoration	Private	Lake	$1,116	0	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$1,116	0	0
		Land	$20,990	55	0	$1,319,002	4,659	0	$0	0	0	$0	0	0	$20,373	41	0	$1,360,365	4,755	0
		Total	**$22,106**	**55**	**0**	**$1,319,002**	**4,659**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$20,373**	**41**	**0**	**$1,361,481**	**4,755**	**0**
	Public	AMA	$0	0	0	$6,244	18	0	$0	0	0	$0	0	0	$0	0	0	$6,244	18	0
		WMA	$2,525	2	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$2,525	2	0
		WPA	$44,379	22	0	$29,379	9	0	$0	0	0	$0	0	0	$0	0	0	$73,758	31	0
		Total	**$46,904**	**24**	**0**	**$35,623**	**27**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$82,527**	**51**	**0**

Restoration Expenditures and Accomplishments by Funding Type, Activity, Land Type, and Owner

Minnesota's Habitat Conservation Partnership - Phase 4

The table below reflects expenditures attributable to specific restoration projects. Please note that the expenditures here will not match the subtotals for those categories reflected in Table 2 and Table 4. Also note that the total accomplishments(acres an is that some work programs expend dollars not attributable to a specific projects. For example Ducks Unlimited expends funds on technical assistance by DU biologists to DNR, US Fish & Wildlife Service, local units of goverment, and private landowners and managment. These personal expenditures are not reflected in the table below.

Funding Type Definitions

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Other Funds:	Non-state, non-state leveraged dollars (If partner funds are leveraging state funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as other funds commitment)
Partners State Levereged Funds:	Non state funds that have leveraged state funds as part of an HCP project (not eligible for use as other funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

			ENTF			Other Funds			Partners State Leveraged Funds			State Funds			Other			Total		
			Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline	Expenditures	Acres	Shoreline
Wetland Restoration	Tribal	Lake	$18,760	14	6,490	$32,986	29	0	$0	0	0	$0	0	0	$0	0	0	$51,746	43	6,490
		Land	$2,500	643	0	$6,000	2,097	0	$0	0	0	$0	0	0	$0	0	0	$8,500	2,740	0
		Total	**$21,260**	**656**	**6,490**	**$38,986**	**2,126**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$60,246**	**2,783**	**6,490**
	Total		**$90,270**	**735**	**6,490**	**$1,393,612**	**6,812**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$20,373**	**41**	**0**	**$1,504,254**	**7,589**	**6,490**
Wild Rice Restoration	Tribal	Lake	$3,500	29	0	$1,550	0	0	$0	0	0	$0	0	0	$0	0	0	$5,050	29	0
		Total	**$3,500**	**29**	**0**	**$1,550**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$5,050**	**29**	**0**
	Total		**$3,500**	**29**	**0**	**$1,550**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$5,050**	**29**	**0**
Woodland Restoration	Private	Land	$20,000	91	0	$0	0	0	$0	0	0	$0	0	0	$0	0	0	$20,000	91	0
		Total	**$20,000**	**91**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$20,000**	**91**	**0**
	Total		**$20,000**	**91**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**0**	**$20,000**	**91**	**0**
Total			**$1,012,341**	**16,788**	**58,742**	**$2,112,120**	**10,767**	**132**	**$7,000**	**0**	**0**	**$132,439**	**1,507**	**1,026**	**$105,879**	**190**	**1,159**	**$3,369,778**	**29,252**	**61,058**

Easement Expenditures and Accomplishments by Funding Type and Easement Holder

Minnesota's Habitat Conservation Partnership - Phase 4

The table below reflects expenditures attributable to specific easement projects. Please note that the expenditures here may not match the subtotals for those categories reflected in Table 2 and Table 4. Also note that the total accomplishments(acres and shoreline) are identical. The reason for this is that some work programs expend dollars not attributable to a specific project or a project that was not completed. For example Pheasants Forever expended funds on a appraisal fee for the desired acquisition of Hands Marsh WMA in which the offer was made and rejected by the potential seller. Therefore, this expenditure is not reflected in the table below.

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Other:	Any other expenditures (e.g. grant income funds)

		ENTF	Other Funds	State Funds	Other	Total
Board of Water and Soil Resources	Expenditures	$50,000	$225	$116,439	$33,746	$200,409
	Shoreline	0.0	0.0	0.0	0.0	0.0
	Riparian	2,090.0	0.0	4,868.0	1,410.0	8,368.3
	Grassland Acres	11.3	0.0	26.3	7.6	45.2
	Woodland Acres	5.0	0.0	11.6	3.4	20.0
	Wetland Acres	6.5	0.0	15.1	4.4	26.0
	Acres	22.8	0.0	53.0	15.4	91.2
DNR Fisheries	Expenditures	$10,784	$0	$0	$0	$10,784
	Shoreline	0.0	0.0	0.0	0.0	0.0
	Riparian	860.0	0.0	0.0	0.0	860.0
	Grassland Acres	0.0	0.0	0.0	0.0	0.0
	Woodland Acres	2.0	0.0	0.0	0.0	2.0
	Wetland Acres	0.8	0.0	0.0	0.0	0.8
	Acres	2.8	0.0	0.0	0.0	2.8
Ducks Unlimited	Expenditures	$189,012	$230,956	$128,000	$0	$547,968
	Shoreline	4,476.0	3,986.0	2,130.0	0.0	10,592.0
	Riparian	0.0	0.0	0.0	0.0	0.0
	Grassland Acres	64.5	44.9	23.5	0.0	132.8
	Woodland Acres	1.0	4.5	9.5	0.0	15.0
	Wetland Acres	6.4	9.4	3.8	0.0	19.6
	Acres	101.2	83.3	49.6	0.0	234.1

Easement Expenditures and Accomplishments by Funding Type and Easement Holder

Minnesota's Habitat Conservation Partnership - Phase 4

The table below reflects expenditures attributable to specific easement projects. Please note that the expenditures here may not match the subtotals for those categories reflected in Table 2 and Table 4. Also note that the total accomplishments(acres and shoreline) are identical. The reason for this is that some work programs expend dollars not attributable to a specific project or a project that was not completed. For example Pheasants Forever expended funds on a appraisal fee for the desired acquisition of Hands Marsh WMA in which the offer was made and rejected by the potential seller. Therefore, this expenditure is not reflected in the table below.

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State Funds:	State Funds expended on HCP projects (not eligible for use as other funds commitment)
Partners State Levereged Funds:	Non state funds that have leveraged state funds as part of an HCP project (not eligible for use as other funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

		ENTF	Other Funds	State Funds	Other	Total
Minnesota Land Trust	Expenditures	$199,000	$5,239,400	$0	$0	$5,438,400
	Shoreline	2,402.0	20,359.0	0.0	0.0	22,761.0
	Riparian	102.0	12,333.0	0.0	0.0	12,434.5
	Grassland Acres	6.3	176.0	0.0	0.0	182.3
	Woodland Acres	165.0	308.4	0.0	0.0	473.3
	Wetland Acres	54.1	106.0	0.0	0.0	160.1
	Acres	248.1	1,023.8	0.0	0.0	1,271.9
USDA - Natural Resource Conservation Service	Expenditures	$0	$2,778,832	$0	$0	$2,778,832
	Shoreline	0.0	0.0	0.0	0.0	0.0
	Riparian	0.0	0.0	0.0	0.0	0.0
	Grassland Acres	0.0	1,551.2	0.0	0.0	1,551.2
	Woodland Acres	0.0	61.0	0.0	0.0	61.0
	Wetland Acres	0.0	831.5	0.0	0.0	831.5
	Acres	0.0	2,443.7	0.0	0.0	2,443.7

Easement Expenditures and Accomplishments by Funding Type and Easement Holder

Minnesota's Habitat Conservation Partnership - Phase 4

The table below reflects expenditures attributable to specific easement projects. Please note that the expenditures here may not match the subtotals for those categories reflected in Table 2 and Table 4. Also note that the total accomplishments(acres and shoreline) are identical. The reason for this is that some work programs expend dollars not attributable to a specific project or a project that was not completed. For example Pheasants Forever expended funds on a appraisal fee for the desired acquisition of Hands Marsh WMA in which the offer was made and rejected by the potential seller. Therefore, this expenditure is not reflected in the table below.

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Other:	Any other expenditures (e.g. grant income funds)

		ENTF	Other Funds	State Funds	Other	Total
Total	Expenditures	$448,796	$8,249,413	$244,439	$33,746	$8,976,394
	Shoreline	6,877.8	24,345.2	2,130.0	0.0	33,352.9
	Riparian	3,052.0	12,332.5	4,868.0	1,410.3	21,662.8
	Grassland Acres	82.0	1,772.1	49.8	7.6	1,911.5
	Woodland Acres	172.9	373.9	21.2	3.4	571.3
	Wetland Acres	67.8	946.9	18.9	4.4	1,038.0
	Acres	374.8	3,550.8	102.6	15.4	4,043.6

Acquisition Expenditures and Accomplishments by Funding Type and Acquisition Holder

Minnesota's Habitat Conservation Partnership - Phase 4

The table below reflects expenditures attributable to acquisition projects. Please note that the expenditures here will not match the subtotals for those categories reflected in Table 2 and Table 4. Also note that the total accomplishments(acres and shoreline) are identical. The reason for this is that some work programs expend dollars not attributable to a specific project. For example the Minnesota Land Trust works on a large number of potential conservation projects and because many projects initiated or worked on under the grant are not actually completed in this phase of the project, the Land Trust does not allocate salaries to specific conservation easement projects. Therefore, salaries and benefits for staff working on contacing lanowners, negotiating conservation easements and completing all aspects of easement projects are not reported on a per

Funding Type Definitions

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Other:	Any other expenditures (e.g. grant income funds)

		ENTF	Other	Other Funds	Partners State Lever	State Funds	Total
DNR-AMA	Expenditures	$969,216	$436,500	$131,700	$175,000	$821,580	$2,533,996
	Shoreline	3,467.2	9,275.1	385.4	507.4	3,050.4	16,685.5
	Riparian	0.0	0.0	0.0	0.0	0.0	0.0
	Grassland Acres	9.0	15.0	9.0	0.0	35.0	67.0
	Woodland Acres	55.0	11.0	1.0	17.0	28.0	112.0
	Wetland Acres	60.3	33.6	1.4	17.9	47.3	160.6
	Acres	124.4	59.2	11.3	34.7	109.9	339.6
DNR-WMA	Expenditures	$438,300	$0	$358,550	$59,800	$109,200	$965,850
	Shoreline	1,095.4	0.0	104.5	0.0	0.0	1,199.9
	Riparian	0.0	0.0	0.0	0.0	0.0	0.0
	Grassland Acres	90.0	0.0	129.0	0.0	0.0	218.5
	Woodland Acres	3.0	0.0	2.0	0.0	0.0	5.0
	Wetland Acres	106.0	0.0	78.9	32.7	59.8	277.4
	Acres	198.2	0.0	210.3	32.7	59.8	501.1
TNC-Preserve	Expenditures	$300,000	$0	$337,974	$0	$0	$637,974
	Shoreline	0.0	0.0	0.0	0.0	0.0	0.0
	Riparian	0.0	0.0	0.0	0.0	0.0	0.0
	Grassland Acres	50.0	0.0	32.0	0.0	0.0	82.2
	Woodland Acres	0.0	0.0	0.0	0.0	0.0	0.0
	Wetland Acres	90.8	0.0	57.2	0.0	0.0	147.9
	Acres	141.2	0.0	88.9	0.0	0.0	230.1

Acquisition Expenditures and Accomplishments by Funding Type and Acquisition Holder

Minnesota's Habitat Conservation Partnership - Phase 4

The table below reflects expenditures attributable to acquisition projects. Please note that the expenditures here will not match the subtotals for those categories reflected in Table 2 and Table 4. Also note that the total accomplishments(acres and shoreline) are identical. The reason for this is that some work programs expend dollars not attributable to a specific project. For example the Minnesota Land Trust works on a large number of potential conservation projects and because many projects initiated or worked on under the grant are not actually completed in this phase of the project, the Land Trust does not allocate salaries to specific conservation easement projects. Therefore, salaries and benefits for staff working on contacing lanowners, negotiating conservation easements and completing all aspects of easement projects are not reported on a per

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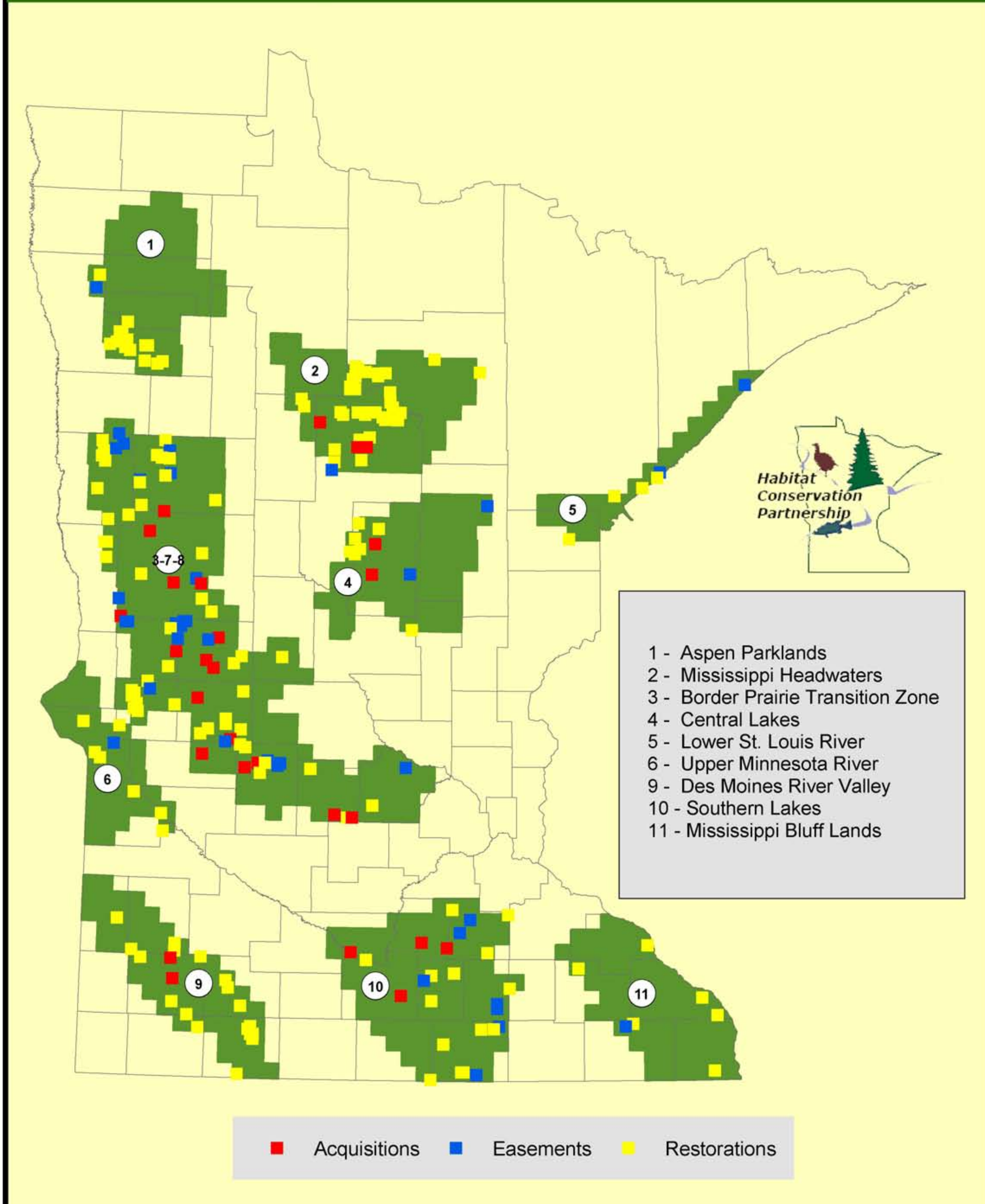
Other:	Any other expenditures (e.g. grant income funds)

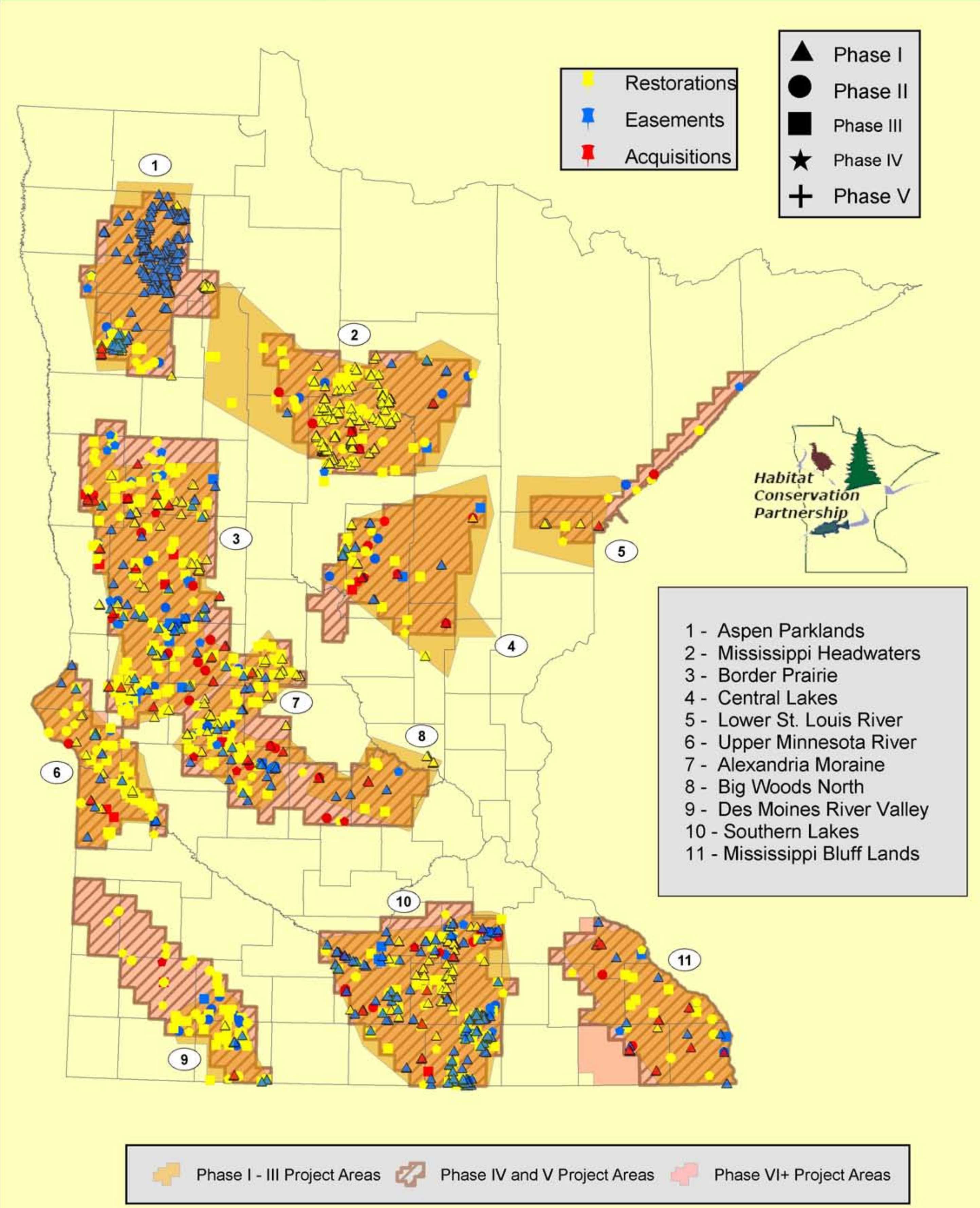
		ENTF	Other	Other Funds	Partners State Lever	State Funds	Total
USFWS-WPA	Expenditures	$100,000	$0	$232,976	$0	$0	$332,976
	Shoreline	0.0	0.0	0.0	0.0	0.0	0.0
	Riparian	0.0	0.0	0.0	0.0	0.0	0.0
	Grassland Acres	20.0	0.0	48.0	0.0	0.0	67.9
	Woodland Acres	0.0	0.0	0.0	0.0	0.0	0.0
	Wetland Acres	3.0	0.0	7.0	0.0	0.0	10.0
	Acres	23.4	0.0	54.5	0.0	0.0	77.9
Total	Expenditures	$1,807,516	$436,500	$1,061,200	$234,800	$930,780	$4,470,796
	Shoreline	4,562.5	9,275.1	489.9	507.4	3,050.4	17,885.4
	Riparian	0.0	0.0	0.0	0.0	0.0	0.0
	Grassland Acres	169.1	14.7	216.8	0.0	35.0	435.6
	Woodland Acres	57.9	10.8	3.9	16.8	27.7	117.0
	Wetland Acres	260.1	33.6	144.4	50.7	107.1	595.9
	Acres	487.2	59.2	365.1	67.4	169.8	1,148.7

Habitat Conservation Partnership
Phase IV Accomplishments
Restoring Minnesota' Fish and Wildlife Habitat Corridors



Habitat Conservation Partnership Accomplishments

Restoring Minnesota' Fish and Wildlife Habitat Corridors



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

1A: Project Coordination and Mapping - Pheasants Forever

Project Manager: Matt Holland
Affiliation: Pheasants Forever
Address: 679 W. River Dr.
New London, MN 56,273
Phone: (320) 354-4377
Fax: (320) 354-4377
E-mail: mholland@pheasantsforever.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Work Program Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Project Coord./ Mapping	$100,000	$ 92,683	$7,317	$0	$0
Total	$100,000	$ 92,683	$7,317	$0	$0

Work Program Summary

Overall Project Outcome and Results

Duties assigned to the project coordinator under this work program and as outlined and approved by the Habitat Conservation Partnership on April 23, 2003 were to:

1. Coordinate partners, projects and cultivate partnerships.
2. Manage project data and contract/coordinate mapping services
3. Solicit & compile partner information & provide reports to LCCMR and partners.
4. Schedule, coordinate, and chair meetings & provide meeting minutes.
5. Coordinate public relations outreach to media.
6. Serve as primary contact for LCCMR.
7. Facilitate executive & full committee meetings & coordinate subcommittee meetings.
8. Manage contract for administration and mapping components of the Partnership.

Pheasants Forever, Inc. completed the above tasks; expending a total of $92,683 of ENTF funds. ENTF expenditures for personnel (Project Coordinator and accounting staff) and project coordinator travel totaled $35,401. In addition, $57,282 of ENTF funds were expended to manage data, operate the online reporting system (from which this report was generated), & develop a website and map projects. Pheasants Forever, Inc. contracted the mapping and data management services for the Phase IV Habitat Conservation Partnership with Community GIS Services of Duluth, Minnesota.

A fully operational online reporting system and website has been created and improved upon with the input of LCCMR staff, partners, and Community GIS Services. Data is accessible and available to query. The Partnership website also allows partners to evaluate projects using available map products. All HCP project accomplishments and expenditures are accounted for and fully described within the online reporting system and report generation. Minnesotans now have access to all Phase IV data electronically. Please contact the program coordinator (currently Matt Holland (320)354-4377) or Community GIS Services (218)279-5925 should access the online reporting system or mapping products be desired.

Project Results Use and Dissemination

The Partnership acknowledges funding from the Minnesota Environment & Natural Resources Trust Fund. Accomplishment report Information, mapping products, & project information can be found at www.mnhabitatcorridors.org .

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

1A: Project Coordination and Mapping - Pheasants Forever

Work Program Expenditures

FundingType	*Funding Category*	*Amount*	*Description*
ENTF	Supplies and Misc	$329.44	Expenses related to printing and postage for Phase IV update reports.
ENTF	Travel	$1,039.10	Travel expenses for Habitat Conservation Partnership meetings. Expenses include mileage reimbursement and meals.
ENTF	Personnel Expenditures	$34,032.37	Documented personnel expenditures for Project Coordinator and Grant Coordinator.
ENTF	Professional Services	$57,282.50	Contract mapping & data management services for the Habitat Conservation Partnership which includes the online reporting system and data management, report generation, mapping, and website.
	Total:	**$92,683.41**	

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Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects
FINAL
Project Title: Minnesota Habitat Corridors Partnership - Phase IV - Project Coordination and Mapping (1a)

Project Manager Name: Matt Holland
As amended 8/24/09
Trust Fund Appropriation: $ 100,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(May 1, 2008)*	**Balance** *(May 1, 2008)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Project Coordination				
BUDGET ITEM					
PERSONNEL: wages and benefits for 0.5 FTE Partnership Coordinator, 0.15 FTE Grant Coordinator, 0.15 Admin Asst.	41,349	34,032	7,317	41,349	7,317
Contracts					
Contract with Community GIS Services to provide mapping, data management, website support to LCCMR members, staff, partners and the public. This includes purchasing a server & software, and contracting the development of a web portal to link geographic information and project data and moving it to a web server that may be used by all.	57,283	57,283	0	57,283	0
Other direct operating costs: Coordinator Expenses (Travel, supplies, postage, etc.)	1,369	1,369	0	1,369	0
COLUMN TOTAL	**$100,000**	**$92,683**	**$7,317**	100,000	7,317

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

1B: Restorable Wetlands Inventory - Ducks Unlimited

Project Manager: Darin R. Blunck
Affiliation: Ducks Unlimited
Address: 2525 River Road
Bismarck, ND 58,503
Phone: 701-355-3500
Fax: 701-355-3575
E-mail: dblunck@ducks.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Work Program Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Project Coord./ Mapping	$48,000	$ 48,000	$0	$8,000	$8,000
Total	$48,000	$ 48,000	$0	$8,000	$8,000

Work Program Summary

Overall Project Outcome and Results
This project was a continuation of on-going efforts of the U.S. Fish & Wildlife Service, Ducks Unlimited, Inc., and the Restorable Wetlands Working Group partnership. Twenty-five counties within Minnesota have been mapped. In HCP Phase IV, areas within Lincoln, Lyon, Murray, Todd, and Otter Tail Counties were mapped. These counties fell within the Des Moines River Valley, Alexandria Moraine, and Border Prairie Habitat Corridors.

Project Results Use and Dissemination
Photo-Interpretation and Digitization is complete for areas within Lincoln, Lyon, Murray, Todd, and Otter Tail Counties.

All data is available on-line for download at http://prairie.ducks.org and on the Minnesota GIS Data Deli

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

1B: Restorable Wetlands Inventory - Ducks Unlimited

Work Program Expenditures

FundingType	*Funding Category*	*Amount*	*Description*
ENTF	Personnel Expenditures	$42,000.00	Photo-interpretation of Otter Tail, Todd, Lincoln, Lyon, and Murray Counties.
ENTF	Personnel Expenditures	$2,000.00	Digitization of Lyon County
ENTF	Personnel Expenditures	$4,000.00	Digitization of of Otter-Tail, Todd, Lincoln, Lyon, and Murray Counties.
Other Funds	Supplies and Misc	$5,000.00	USFWS - Acquisition costs for color-infrared imagery
Other Funds	Personnel Expenditures	$3,000.00	DU - In-Kind Contribution for distribution of data and project management.
	Total:	**$56,000.00**	

Work Program Expenditures By Funding Type

Funding Type	**Amount**
ENTF	$48,000.00
Other Funds	$8,000.00
Total	**$56,000.00**

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State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

Project Title: *Drained Wetland Inventory 1(b)*

Project Manager Name: *Darin R. Blunck - Ducks Unlimited, Inc.*

Trust Fund Appropriation: $48,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	**TOTAL BUDGET**	**TOTAL BALANCE**
	Photo-Interpretation and Digitization				
BUDGET ITEM					
Contracts					
Professional/technical: GIS Laboratory, Department of Fish and Wildlife Sciences, South Dakota State University	$48,000	$48,000	$0	$48,000	$0
COLUMN TOTAL	**$48,000**	**$48,000**	**$0**	**$48,000**	**$0**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2A:Hides for Habitat Restoration - MDHA

Project Manager: Kim Hanson
Affiliation: MDHA
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Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Restoration	$75,000	$75,000	$0	$75,000	$24,379
Total	$75,000	$75,000	$0	$75,000	$24,379

Work Program Summary

Overall Project Outcome and Results

MDHA funding restored a total of 32 wetland basins consisting of 18.5 acres on the Buchl, Kruger, and Donley/Tillman waterfowl production areas (WPA'S). Also, 25.3 acres of oak savannah habitats were enhanced on the Winger WPA bringing the work completed under this project to 43.8 –acres. Federal WPA's are managed for waterfowl production and are open to public hunting and other recreation consistent with the National Wildlife Refuge System.

Specifically, on Kruger WPA (Becker County Callaway Township Section's 15, 16, 21, 22) we restored 20 basins for 12.5 acres, on Buchl WPA (Becker County-Riceville Township Section 10) we restored 1 basin for 0.5 acres, and on Donley Tillman WPA (Becker County- Riceville Township Section's 13 & 14) we restored 11 basins for 5.5 acres. In addition, we enhanced 25.31-acres of oak savannah (grassland enhancement) on Winger WPA (Polk County-Winger Township, Section 2) by shearing and piling undesirable trees and opening the landscape to promote savannah habitat. All work was done in partnership with the USFWS Detroit Lakes Wetland Management District and other funds were secured and provided for through North American Wetlands Conservation Act grants and are federal in origin.

Project Results Use and Dissemination

MDHA has restored a total of 32 wetland basins (18.5 acres total) and 25.31 acres of oak savannah on public land that is permanently protected and open to public hunting. These restored wetlands and oak savannahs provide wetland and upland habitat for a variety of wildlife with a large scale benefit to hundreds of acres on four separate WPA's as well as the surrounding private land habitats. Future management of wetlands and grasslands will be conducted by the USFWS Detroit Lakes Wetland Management District.

Since this initial project was submitted, MDHA changed project managers and has received further guidance on "other funds" as it relates to our work plans. In phase IV, our matching dollars have been limited to mainly to NAWCA grants on the WPA's which is why there are less "other funds" contributed to this Phase IV work plan than originally proposed. MDHA strives to identify projects that capitalize on our chapter system and will improve on this into the future.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2A:Hides for Habitat Restoration - MDHA

Restoration Activities

Project Area - 1 - Aspen Parklands

Project Name: Winger WPA
Township: 147, Range: 42, Section: 2

Activity: Grassland Enhancement
Landtype: Public - WMA
Description: Tree Removal - Shear & Pile All boxelder, cottonwood, willow, aspen, etc to restore scattered oak savannas. All smaller oaks flagged to prevent accidental damage.

$50,620.76 in the phase IV (2007 Appropriation) project was spent on the restoration of these areas. Being that the phase V (2008 Appropriation) work plan was accepted, we continued into the phase V (2008) funds in fall of 2008. We are going to utilize the remaining $621 from the phase V (2008) project funds for a Winger WPA work day. With the help of local Minnesota Deer Hunters Association Chapter volunteers in fall 2009, we will select natural growth oak seedlings and then mat and tube them for release. The funds would be used to purchase supplies(matting & tubing) for the work day.

			Acres	**Shoreline**
		Non Prorated Totals	40.00	0.00
Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$50,620.76	25.31	0.00

Project Area - 3 - Border Prairie

Project Name: Buchl WPA
Township: 141, Range: 42, Section: 10

Activity: Wetland Restoration
Landtype: Public - WPA
Description: Project included the restoration of 1 small wetland basin to complete an 89 basin restoration begun in Phase III on the Buchl WPA. Restoration included the rebuilding of the wetland by clearing and excavation, and allowing it to refill naturally. Location of basin was determined by early conservation service photo's prior to ditching.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$606.33	0.25	0.00
Other Funds	Restoration	$606.33	0.25	0.00
Buchl WPA Total		**$1,212.66**	**0.50**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2A:Hides for Habitat Restoration - MDHA

Project Area - 3-7-8 - Border Prairie Transition Zone

Project Name: Donley/Tillman WPA
Township: 141, Range: 42, Section: 13

Activity: Wetland Restoration
Landtype: Public - WPA
Description: Project included the restoration of 11 wetland basin on the Donley/Tillman WPA. Each basin was located based on early conservation service photo's and was then cleared and excavated to replicate the earlier identified basins. Basins are allowed to refill naturally.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$5,570.80	2.75	0.00
Other Funds	Restoration	$5,570.80	2.75	0.00
Donley/Tillman WPA Total		**$11,141.60**	**5.50**	**0.00**

Project Name: Kruger WPA
Township: 141, Range: 41, Section: 16

Activity: Wetland Restoration
Landtype: Public - WPA
Description: This project included the restoration of 20 wetland basins on the Kruger WPA. Wetland basins were located based on early conservation photo's and were then cleared and excavated. Basins are allowed to fill naturally with some native grass seeding along edges of basins.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$18,202.11	6.25	0.00
Other Funds	Restoration	$18,202.11	6.25	0.00
Kruger WPA Total		**$36,404.22**	**12.50**	**0.00**

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet
ENTF:	$75,000.00	34.56	0.00
Other Funds:	$24,379.24	9.25	0.00
Total:	**$99,379.24**	**43.81**	**0.00**

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

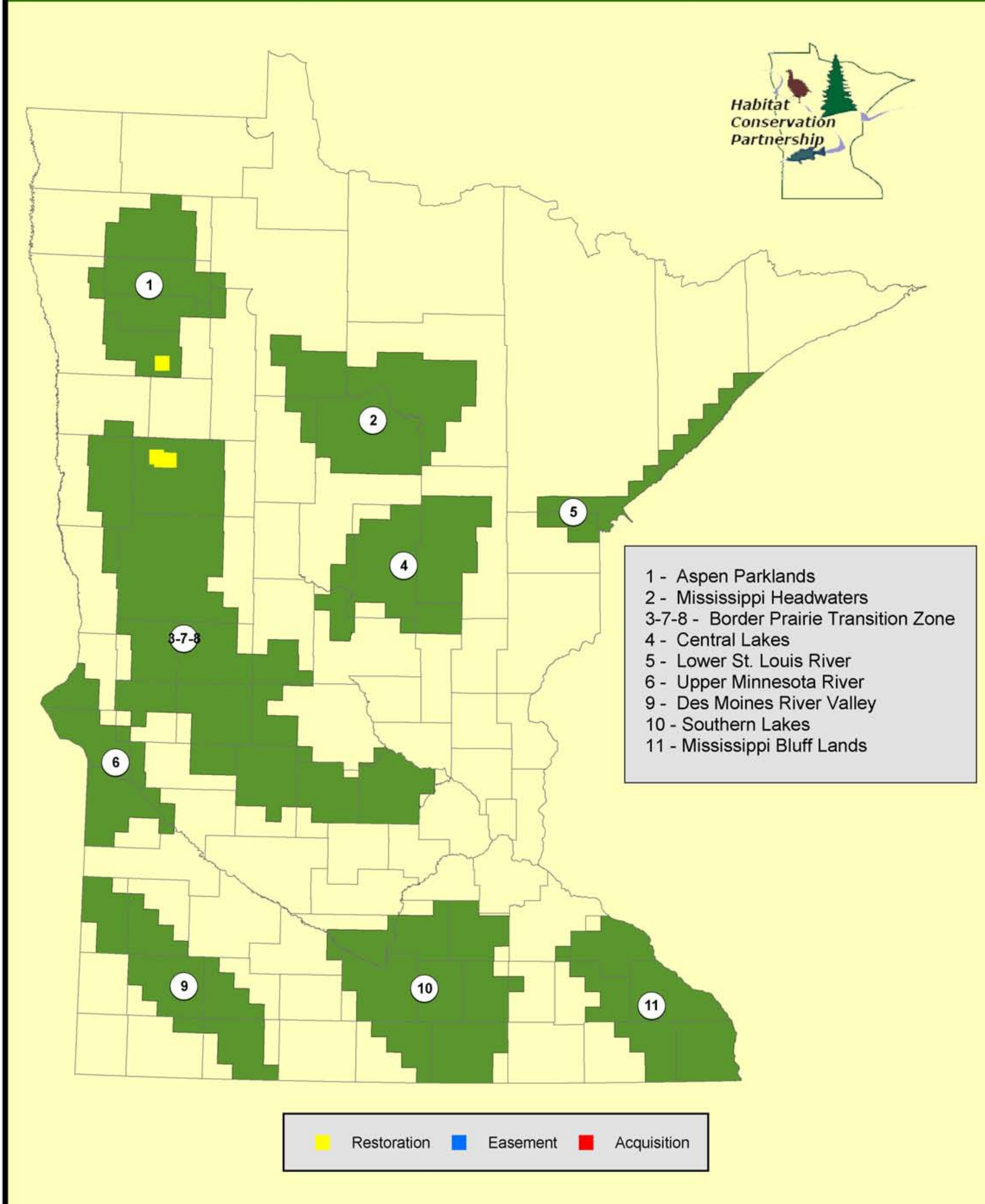
Project Title: *Hides for Habitat Restoration 2A - Phase IV*

Project Manager Name: Kim Hanson

Trust Fund Appropriation: $75,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	**TOTAL BUDGET**	**TOTAL BALANCE**
	Restoration				
BUDGET ITEM					
Other land improvement - Restoration	75,000	0	75,000	75,000	75,000
COLUMN TOTAL	**$75,000**	**$0**	**$75,000**	**$75,000**	**$75,000**

Habitat Conservation Partnership
Phase 4 - Accomplishments
2J - Lakescaping - MN DNR - Division of Ecological Services



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2B:Partners for Fish and Wildlife - U.S. Fish & Wildlife Service

Project Manager: Sheldon Myerchin
Affiliation: U.S. Fish & Wildlife Service
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Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds * Proposed	Other Funds * Spent
Restoration	$30,000	$30,000	$0	$30,000	$42,718
Total	$30,000	$30,000	$0	$30,000	$42,718

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:

Other: $58,595.86

See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results

Since 1987, the USFWS' Partners for Fish and Wildlife (Partners) Program has restored more than 16,000 drained wetlands (67,000 acres) and restored more than 1,000 upland sites (35,000 acres) to native grasses and forbs, on private lands in Minnesota. Since fiscal year 1999, the USFWS has expended in excess of $1.2 million annually to deliver the Partners Program in Minnesota; such expenditures are represented by technical assistance (personnel, administrative support) and habitat restoration or enhancement (project construction) funding. Through its Partners Program, the USFWS works with other federal and state agencies, local units of government, tribal entities, conservation organizations, and individual landowners to restore or enhance fish and wildlife habitats on private land. This program emphasizes restoring habitats and native vegetation for fish and wildlife in concert with the goals of individual private landowners. These projects benefit both Minnesota landowners and the general public by providing habitat for fish, wildlife and plants, improving water quality and watershed health, reducing non-point source pollution, and creating opportunities for outdoor recreation and education. Most projects completed through the Partners Program will utilize cost-share assistance from multiple sources including the landowners to accomplish the habitat restoration.

The $30,000.00 of Minnesota Environment and Natural Resources Trust Fund (Trust Fund) funding that was obtained through this work program, accelerated the USFWS' existing Partners Program with an additional voluntary restoration or enhancement of eleven wetland basins covering 159.1 acres of wetland habitat and three native prairie upland sites covering 136.5 acres of upland habitat. With this funding, a total of eight projects were completed on private land within HCP Project Areas 1,3-7-8, 4, 9, and 10. These Trust Funds were expended from November 2007 through June 30, 2009.

USFWS personnel provided technical assistance (approximately $30,000 in-kind value not reported in budget) to these private landowners who voluntarily restored wetland and upland habitat on their land. Once these habitats were restored, they are protected for no less than 10 years through agreements between the USFWS and the respective landowners. Some of the restored or enhanced project areas are protected in perpetuity by fee title acquisition or easements obtained by partnering agencies, organizations, or the USFWS (easements only). The USFWS also committed $30,000.00 in matching funds to support this overall project. These funds were used to provide cost-share on some of the projects funded with Trust Fund dollars and also to make payments on additional eligible wetland restoration or enhancement projects and native prairie restoration or enhancement

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2B:Partners for Fish and Wildlife - U.S. Fish & Wildlife Service

projects.

Although $30,000.00 USFWS match funding was committed to this work program, a total of $42,718.00 match funding was spent. Of these funds, $25,054.00 was expended towards six of the projects identified above that were cost-share funded by Trust Fund dollars. In addition, four more projects were funded by USFWS match funding, expending $17,663.50, to restore two wetlands (30 acres) and three native prairie upland sites (140.5 acres). These habitat restoration projects were completed from November 2007 through September 2, 2008, and were completed on private land within HCP Project Areas 3-7-8, and 10.

Some projects involved funding contributions from the landowners or other partnering agencies or organizations. These funds are identified as “Other” in the project table as their accountability as leveraged funds is unknown.

*Please note: This Final Report has been ammended from previous reports as Project PLSkaC has been deleted and Project PLSchS has been added which resulted in a change of acres restored and Other Funds spent.

Project Results Use and Dissemination
These habitat restoration projects were completed with private landowners on their properties within the nine HCP Project Areas across the state of Minnesota through the USFWS’ Partners for Fish and Wildlife Program. Without the willingness of the landowners involved, and the variety of other partners, this important wetland, upland and river/riparian wildlife habitat would not be restored.

Numerous presentations including the Trust Fund habitat restoration information have been made over the past seven years at various meetings i.e. Minnesota State Private Lands Meeting, the Wetland Summit, the Shallow Lakes Forum, and at Kiwanis, Rotary, and Lion’s Club presentations. One project completed with Trust Fund dollars was also featured on the Minnesota Bound television program hosted by Ron Schara.

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2B:Partners for Fish and Wildlife - U.S. Fish & Wildlife Service

Restoration Activities

Project Area - 1 - Aspen Parklands

Project Name: PLSchS
Township: 147, Range: 42, Section: 9

Activity: Wetland Restoration
Landtype: Private - Land
Description: One wetland basin was restored on private land totaling 36 acres. A ditch plug with a fish barrier was installed to prevent invasive fish from entering the wetland. This project is protected by a 10-year agreement. The landowner and FWS are responsible for future maintenance and management of the project.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,525.60	13.62	0.00
Other Funds	Restoration	$2,474.40	22.08	0.00
PLSchS Total		**$4,000.00**	**35.70**	**0.00**

Project Area - 4 - Central Lakes

Project Name: PLBorT
Township: 42, Range: 28, Section: 35

Activity: Wetland Restoration
Landtype: Private - Land
Description: One wetland basin was restored on private property, totaling 20 acres.
Project is covered under a 10-year agreement. Landowner and FWS are responsible for future maintenance and management.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$5,534.00	18.90	0.00
Other Funds	Restoration	$323.00	1.10	0.00
PLBorT Total		**$5,857.00**	**20.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2B:Partners for Fish and Wildlife - U.S. Fish & Wildlife Service

Project Area - 9 - Des Moines River Valley

Project Name: PLVerM
Township: 104, Range: 39, Section: 27

Activity: Grassland Restoration
Landtype: Private - Land
Description: One 6.5 acre native prairie tract restored on private land. A total of $8,000 ETF was spent on the entire project, which was diveded 3 ways to cover the 2 wetland restorations and one grassland restoration. Project has perpetual protection through CREP and RIM program.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,666.67	6.50	0.00
Grassland Restoration Total		$2,666.67	6.50	0.00

Activity: Wetland Restoration
Landtype: Private - Land
Description: Two wetlands were restored covering 4.7 acres. A total of $8,000 ETF was spent on this project, which was divided by 3 to cover the 2 wetland restorations and one grassland restoration. Project has perpetual protection through the CREP and RIM program.

Two wetlands were restored, totaling 4.7 acres, on private land.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$5,333.33	4.70	0.00
Wetland Restoration Total		$5,333.33	4.70	0.00
PLVerM Total		**$8,000.00**	**11.20**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2B:Partners for Fish and Wildlife - U.S. Fish & Wildlife Service

Project Area - 10 - Southern Lakes

Project Name: PLPetD
Township: 103, Range: 23, Section: 23

Activity: Grassland Restoration
Landtype: Private - Land
Description: One retired crop field totaling 10 acres was restored to prairie by seeding native grasses and forbs. Project has perpetual protection through CREP and RIM program. Adjacent wetlands were also restored.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$3,978.50	1.68	0.00
Other	Restoration	$19,772.93	8.32	0.00
Grassland Restoration Total		$23,751.43	10.00	0.00

Activity: Wetland Restoration
Landtype: Private - Land
Description: Two wetland basins were restored on private land, totaling 47.3 acres. Project has perpetual protection through the CREP and RIM program. Adjacent grassland was also restored.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$3,978.50	7.92	0.00
Other	Restoration	$19,772.93	39.38	0.00
Wetland Restoration Total		$23,751.43	47.30	0.00
PLPetD Total		**$47,502.86**	**57.30**	**0.00**

Project Name: PLBerR
Township: 112, Range: 22, Section: 29

Activity: Wetland Restoration
Landtype: Private - Land
Description: Two wetland basins were restored on private land, totaling 25 acres. Project is covered under a 10-year agreement. Landowner and FWS are responsible for future maintenance and management.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,687.54	5.12	0.00
Other Funds	Restoration	$6,553.00	19.88	0.00
PLBerR Total		**$8,240.54**	**25.00**	**0.00**

Project Name: PLJamM
Township: 109, Range: 20, Section: 22

Activity: Wetland Restoration
Landtype: Private - Land
Description: One wetland basin was restored on private land, totaling 25 acres. Project is protected by a 10-year agreement. Landowner and FWS are responsible for future maintenance and management.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,856.46	3.74	0.00
Other Funds	Restoration	$10,569.54	21.26	0.00
PLJamM Total		**$12,426.00**	**25.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2B:Partners for Fish and Wildlife - U.S. Fish & Wildlife Service

Project Name: PLLowK
Township: 108, Range: 22, Section: 33

Activity: Wetland Restoration
Landtype: Private - Land
Description: One wetland basin was restored on private land, totaling 25 acres. Project is protected by a 10-year agreement. Landowner and FWS are responsible for future maintenance and management.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
Other Funds	Restoration	$7,023.50	25.00	0.00

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2B:Partners for Fish and Wildlife - U.S. Fish & Wildlife Service

Project Area - 3-7-8 - Border Prairie Transition Zone

Project Name: PLHttL
Township: 128, Range: 34, Section: 12

Activity: Wetland Restoration
Landtype: Private - Land
Description: One wetland basin was restored on private land, totaling 5 acres. Project is protected by 10-year agreement. Landowner and FWS are responsible for future maintenance and management.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
Other	Restoration	$600.00	1.82	0.00
Other Funds	Restoration	$1,050.00	3.18	0.00
PLHttL Total		**$1,650.00**	**5.00**	**0.00**

Project Name: PLEIlL
Township: 122, Range: 36, Section: 5

Activity: Grassland Enhancement
Landtype: Private - Land
Description: One native prairie upland tract of 120 acres was enhanced by removing invasive woody species on private land. Project is protected by a 10-year agreement. Landowner and the FWS are responsible for future management.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,365.00	16.34	0.00
Other	Restoration	$10,000.00	69.10	0.00
Other Funds	Restoration	$5,000.00	34.55	0.00
PLEIlL Total		**$17,365.00**	**120.00**	**0.00**

Project Name: PLBigB
Township: 139, Range: 43, Section: 4

Activity: Wetland Restoration
Landtype: Private - Land
Description: Two wetlands basins were restored on private land, totaling 1.39 acres. Project is covered under a 10-year agreement. Landowner and FWS are responsible for future maintenance and management.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,074.40	1.24	0.00
Other Funds	Restoration	$134.30	0.15	0.00
PLBigB Total		**$1,208.70**	**1.39**	**0.00**

Project Name: PLForP
Township: 122, Range: 36, Section: 10

Activity: Grassland Enhancement
Landtype: Private - Land
Description: One native prairie upland tract on private land totaling 124 acres was enhanced by removing woody invasive species. Project is protected by a 10-year agreement. Landowner and FWS are responsible for future mangement.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
Other	Restoration	$8,450.00	68.04	0.00
Other Funds	Restoration	$6,950.00	55.96	0.00
PLForP Total		**$15,400.00**	**124.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2B:Partners for Fish and Wildlife - U.S. Fish & Wildlife Service

Project Name: PLPFSpring Creek Tract
Township: 142, Range: 41, Section: 7

Activity: Grassland Restoration
Landtype: Private - Land
Description: Two former crop fields were restored to native prairie grasses and forbs on private land, totaling 16.5 acres. Project will be protected in perpituity as PF will turn tract over to DNR for WMA.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
Other Funds	Restoration	$2,640.00	16.50	0.00

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet
ENTF:	$30,000.00	79.74	0.00
Other Funds:	$42,717.74	199.68	0.00
Other:	$58,595.86	186.66	0.00
Total:	**$131,313.60**	**466.09**	**0.00**

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

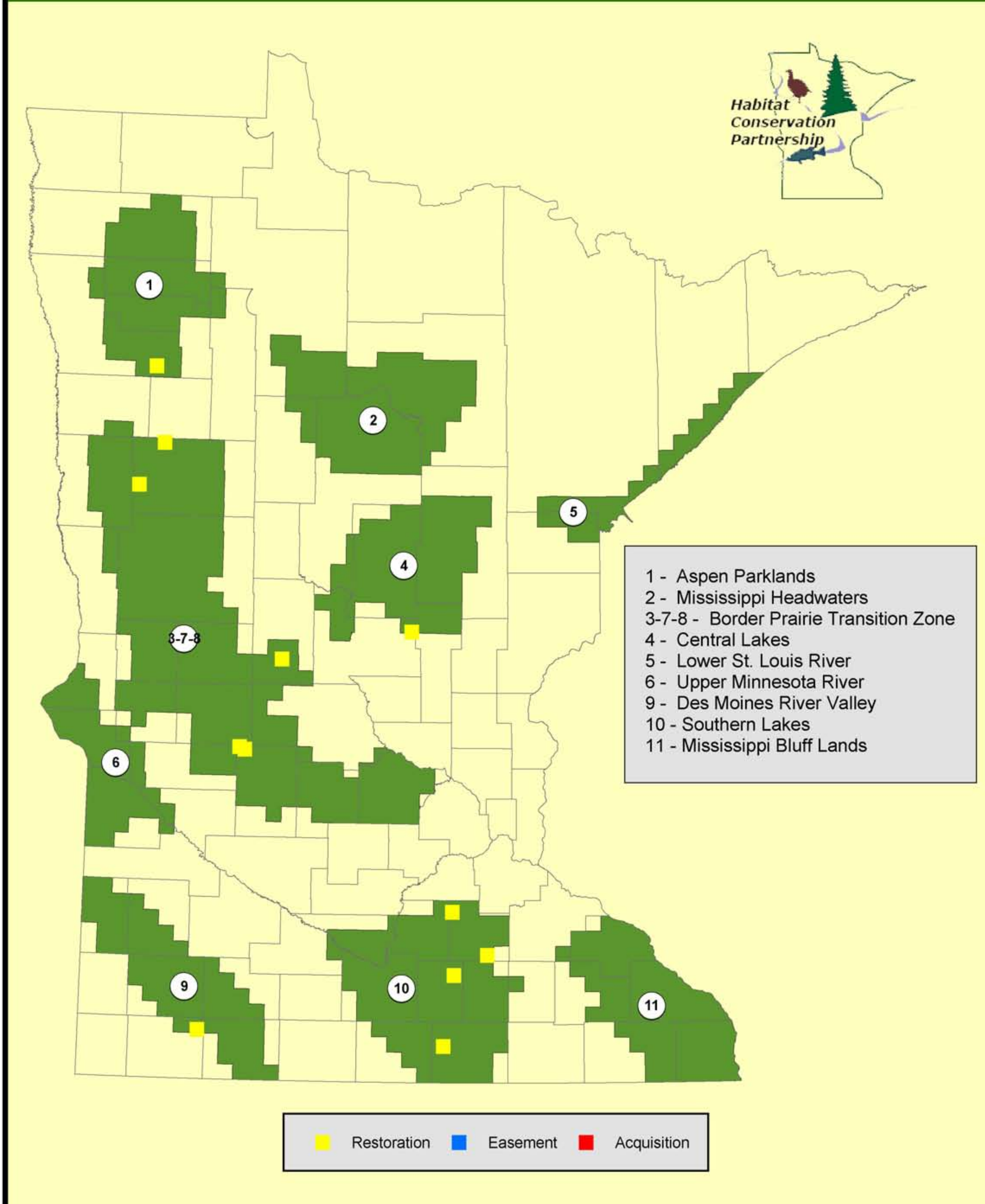
Attachment A: Budget Detail for 2007 - Projects

Project Title: ***Minnesota Habitat Corridors Partnership - Phase V Partners for Fish and Wildlife (2b)***

Project Manager Name: ***Sheldon Myerchin***

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**
	Restoration or Enhancement Acres		
BUDGET ITEM			
Restoration/Enhancement (project details entered below under individual project ares)	$30,000		$30,000
Restoration/Enhancement Acres			
Project Area 1 Aspen Parklands		$1,526	-$1,526
Project Area 2 Mississippi Headwaters			$0
Project Area 3-7-8 Prairie Forest Transition Zone		$3,439	-$3,439
Project Area 4 Central Lakes		$5,534	-$5,534
Project Area 5 Lower St. Louis River			$0
Project Area 6 Upper Minnesota River			$0
Project Area 9 Des Moines River Valley		$8,000	-$8,000
Project Area 10 Southern lakes		$11,501	-$11,501
Project Area 11 Mississippi Bluff Lands			$0
			$0
COLUMN TOTAL	**$30,000**	**$30,000**	**$0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
2B - Partners for Fish and Wildlife - U.S. Fish & Wildlife Service



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2C:Living Lakes Enhancement - Ducks Unlimited

Project Manager: Jon Schneider
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Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds * Proposed	Other Funds * Spent
Restoration	$300,000	$300,000	$0	$50,000	$446,839
Total	$300,000	$300,000	$0	$50,000	$446,839

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:
State Funds: $46,389.32

See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results
The objective of this project was to accelerate Ducks Unlimited (DU) bio-engineering assistance to help agencies enhance shallow lakes for waterfowl through our Living Lakes Initiative. DU biologists and engineers provided technical assistance to Minnesota DNR, U.S. Fish & Wildlife Service, and private landowners around shallow lakes with a goal of enhancing at least one shallow lake totaling 350 wetland acres with a new water control structure and/or fish barrier, engineering at least five shallow lakes projects, and providing technical assistance to agency field staff on at least 10 other shallow lake projects.

Through this grant project, DU biologists and engineers designed 8 new water control structures and fish barriers for the Minnesota DNR and US Fish & Wildlife Service, and constructed 7 of them including Hjermstad Lake in Murray County, Mott Lake on Mueller WMA in Waseca County, South Twin Lake in Lyon County, Augusta Lake in Cottonwood County, Hanson WPA in Grant County, and Sunset Lake and Golden Pond on the Rydell NWR in Polk County. The construction of these 7 shallow lake structures enhanced 1,123 wetland acres. The eighth water control structure engineered for Smith Lake in Wright County will be constructed in the future after DNR secures an easement for the structure and legally designates the lake for wildlife management purposes. Finally, DU shallow lakes field biologist provided technical assistance to MNDNR and USFWS on 44 shallow lake projects in HCP Project Areas to help assess lake condition and develop new enhancement projects for future implementation.

DU's total cost to provide this service to the state was $793,228, including $300,000 from the Environment & Natural Resources Trust Fund, $46,389 in other state funds (DNR) and $446,839 in Other Funds (DU and federal funds) that far exceeds the $50,000 of Other Funds proposed.

Project Results Use and Dissemination
This grant helped DU, DNR, and the Service accelerate the assessment and enhancement of shallow lakes throughout southern, central and western Minnesota. DU provided 8 detailed engineering design plans to state and federal agency staff, and informed the public of shallow lake improvement projects through public meetings, news releases sent to the media, and in articles in DU publications. Shallow lake assessment data collected by DU biologists was provided to DNR's shallow lake program and area wildlife managers, and shared with MPCA to aid in their impaired waters assessment.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2C:Living Lakes Enhancement - Ducks Unlimited

Restoration Activities

Project Area - 1 - Aspen Parklands

Project Name: Rydell National Wildlife Refuge
Tract: Sunset Lake
Township: 148, Range: 43, Section: 3

Activity: Wetland Enhancement
Landtype: Public - NWR
Description: DU engineered and installed a variable crest water control structure on the outlet of the 50-acre "Sunset Lake" wetland on the Rydell NWR in Polk County near Erskine for the US Fish & Wildlife Service. The Service will use the structure to conduct temporary draw-downs of the basin to eliminate invasive fish and rejuvenate the aquatic ecology of the wetland. Both DU and the Service provided non-state cost-share funding for the project.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$35,841.07	35.09	0.00
Other Funds	Personnel Expenditures	$37,494.35	0.00	0.00
Other Funds	Restoration	$15,223.08	14.91	0.00
Rydell National Wildlife Refuge Sunset Lake Total		**$88,558.50**	**50.00**	**0.00**

Project Name: Rydell National Wildlife Refuge
Tract: Golden Pond
Township: 148, Range: 43, Section: 2

Activity: Wetland Enhancement
Landtype: Public - NWR
Description: DU engineered and installed a variable crest water control structure on the outlet of the 20-acre "Golden Pond" wetland on the Rydell NWR in Polk County near Erskine for the US Fish & Wildlife Service. The Service will use the structure to conduct temporary draw-downs of the basin to eliminate invasive fish and rejuvenate the aquatic ecology of the wetland. Both DU and the Service provided non-state cost-share funding for the project.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$28,532.50	14.16	0.00
Other Funds	Personnel Expenditures	$35,297.40	0.00	0.00
Other Funds	Restoration	$11,766.24	5.84	0.00
Rydell National Wildlife Refuge Golden Pond Total		**$75,596.14**	**20.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2C:Living Lakes Enhancement - Ducks Unlimited

Project Area - 8 - Big Woods North

Project Name: Smith Lake, Wright County
Township: 119, Range: 28, Section: 36

Activity: Shallow Lake Survey / Design / Wetland Mapping
Landtype: Public - Lake
Description: DU engineers surveyed and designed a water control structure for the outlet of Smith Lake in Wright County, a shallow lake of importance to migratory birds. DU has previously engineered a velocity tube fish barrier for the downstream outlet channel of Smith Lake. However, this shallow lake has not winterkilled in many years due to landscape drainage, above average precipitation patterns, and an outlet choked with hybrid cattails and sediment. The new outlet structure designed by DU engineers will be implemented in the future. DNR legally designated Smith Lake for active wildlife management in May 2009 with help from DU, and is obtaining a legal easement to place, operate, and maintain the structure. DU plans to construct this new structure for DNR in 2009 or 2010 with funds granted through the LSOHC.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Personnel Expenditures	$7,150.35	0.00	0.00
Other Funds	Personnel Expenditures	$12,298.97	0.00	0.00
State Funds	Personnel Expenditures	$10,000.00	0.00	0.00
Smith Lake, Wright County Total		**$29,449.32**	**0.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2C:Living Lakes Enhancement - Ducks Unlimited

Project Area - 9 - Des Moines River Valley

Project Name: Augusta Lake
Township: 106, Range: 37, Section: 3

Activity: Wetland Enhancement
Landtype: Public - Lake
Description: DU engineers designed and installed a velocity tube fish barrier structure on the outlet channel of Augusta Lake in Cottonwood County near Storden for the Minnesota DNR to prevent carp and other invasive fish from entering Augusta Lake and other wetlands from Highwater Creek. DNR obtained a permanent easement on the site that allows for placement and maintenance of the structure, and DNR will monitor and manage it in perpetuity. DU awarded an $80,000 construction contract for the project in September 2008, the work began in October 2008, and was completed by early December 2008. Funding for this project included a combination of DU, DNR, LCCMR, and NAWCA small grant funds.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Personnel Expenditures	$7,623.91	0.00	0.00
ENTF	Restoration	$6,992.59	58.36	0.00
Other Funds	Personnel Expenditures	$29,413.66	0.00	0.00
Other Funds	Professional Services	$1,701.98	0.00	0.00
Other Funds	Restoration	$53,275.84	444.61	0.00
State Funds	Restoration	$21,212.70	177.03	0.00
Augusta Lake Total		**$120,220.68**	**680.00**	**0.00**

Project Name: Hjermstad Lake
Township: 108, Range: 43, Section: 11

Activity: Wetland Enhancement
Landtype: Public - WMA
Description: DU engineered and constructed a new water control structure on the outlet of 63-acre Hjermstad Lake on Hjermstad WMA in Murray County. DU used a combination of LCCMR, DNR, DU, and federal NAWCA funds to complete this shallow lake enhancement work, and DNR will now use the structure to actively manage the lake in perpetuity to improve it and keep it productive for wildlife.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Personnel Expenditures	$4,448.75	0.00	0.00
ENTF	Restoration	$69,328.21	63.00	0.00
Other Funds	Personnel Expenditures	$34,412.87	0.00	0.00
State Funds	Personnel Expenditures	$10,000.00	0.00	0.00
Hjermstad Lake Total		**$118,189.83**	**63.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2C:Living Lakes Enhancement - Ducks Unlimited

Project Name: South Twin Lake
Township: 109, Range: 40, Section: 30

Activity: Wetland Enhancement
Landtype: Private - Lake
Description: DU engineers designed and installed a water control structure on the outlet of South Twin Lake in Lyon County (just 3 miles west of Tracy, MN) for the Minnesota DNR and US Fish & Wildlife Service to allow DNR to conduct temporary draw-downs to rejuvenate aquatic ecology and enhance water quality in the basin. The Minnesota DNR obtained flowage easements from each of three riparian landowners and an easement for the structure in spring 2008. The Service provided a $15,000 challenge cost-share grant for construction of the project. DU awarded a construction contract for the project in September 2008, and the project was completed in November 2008.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$31,340.00	93.00	0.00
Other Funds	Personnel Expenditures	$22,030.86	0.00	0.00
State Funds	Personnel Expenditures	$5,176.62	0.00	0.00
South Twin Lake Total		**$58,547.48**	**93.00**	**0.00**

Project Area - 10 - Southern Lakes

Project Name: Mott Lake Fish Barrier
Township: 106, Range: 24, Section: 25

Activity: Wetland Enhancement
Landtype: Public - WMA
Description: DU engineered and installed a velocity tube fish barrier in the outlet ditch downstream of Mott Lake on the Mueller WMA in Waseca County to prevent carp and other fish from entering this shallow lake. Mott Lake routinely winterkills, and this fish barrier will ensure the basin becomes fish free and is maintained in the clear water state. The Minnesota DNR annually monitors and manages Mott Lake as part of its work on Mueller WMA, and is working to minimize fish and encourage natural winterkill events in the lake.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Personnel Expenditures	$12,035.40	0.00	0.00
ENTF	Restoration	$24,935.76	115.00	0.00
Other Funds	Personnel Expenditures	$16,444.50	0.00	0.00
Mott Lake Fish Barrier Total		**$53,415.66**	**115.00**	**0.00**

Project Area - 3-7-8 - Border Prairie Transition Zone

Project Name: Hanson WPA
Township: 127, Range: 41, Section: 4

Activity: Wetland Enhancement
Landtype: Public - WPA
Description: DU engineered and installed a variable crest water control structure on the outlet of a 102-acre wetland on the Hanson WPA in Grant County near Hoffman for the US Fish & Wildlife Service. The Service will use the structure to conduct temporary draw-downs of the basin to eliminate invasive fish and rejuvenate the aquatic ecology of the wetland.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Personnel Expenditures	$3,196.96	0.00	0.00
ENTF	Restoration	$30,000.00	36.51	0.00
Other Funds	Personnel Expenditures	$27,557.63	0.00	0.00
Other Funds	Restoration	$53,805.60	65.49	0.00
Hanson WPA Total		**$114,560.19**	**102.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2C:Living Lakes Enhancement - Ducks Unlimited

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet
ENTF:	$261,425.50	415.12	0.00
Other Funds:	$350,722.98	530.85	0.00
State Funds:	$46,389.32	177.03	0.00
Total:	**$658,537.80**	**1,123.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2C:Living Lakes Enhancement - Ducks Unlimited

Work Program Expenditures - Not Attributable to Specific Projects

FundingType	*Category*	*Amount*	*Description*
ENTF	Personnel Expenditures	$21,844.16	Technical Assistance provided in the Prairie Transition HCP Project Area (#3-7-8) by DU biolgists to DNR, US Fish & Wildlife Service, local units of government, and private landowners regarding shallow lake assessment, improvement and management.
ENTF	Personnel Expenditures	$5,495.49	Technical Assistance provided in the Prairie Coteau HCP Project Area #9 by DU biolgists to DNR, US Fish & Wildlife Service, local units of government, and private landowners regarding shallow lake assessment, improvement and management.
ENTF	Personnel Expenditures	$3,420.51	Technical Assistance provided in the Upper Minnesota River HCP Project Area #6 by DU biolgists to DNR, US Fish & Wildlife Service, local units of government, and private landowners regarding shallow lake assessment, improvement and management.
ENTF	Personnel Expenditures	$7,814.34	Technical Assistance provided in the Southern Lakes HCP Project Area #10 by DU biolgists to DNR, US Fish & Wildlife Service, local units of government, and private landowners regarding shallow lake assessment, improvement and management.
Other Funds	Personnel Expenditures	$49,403.36	DU staff time spent on HCP part 2c Phase 4 grant administration and coordination of DU bio-engineering field work to assess, enhance, and manage shallow lakes in partnership with DNR's Shallow Lakes Program and with U.S. Fish & Wildlife Service's Wetland Management Districts.
Other Funds	Personnel Expenditures	$27,245.08	Technical Assistance provided in the Prairie Transition HCP Project Area (#3-7-8) by DU biolgists to DNR, US Fish & Wildlife Service, local units of government, and private landowners regarding shallow lake assessment, improvement and management.
Other Funds	Personnel Expenditures	$6,229.51	Technical Assistance provided in the Prairie Coteau HCP Project Area #9 by DU biolgists to DNR, US Fish & Wildlife Service, local units of government, and private landowners regarding shallow lake assessment, improvement and management.
Other Funds	Personnel Expenditures	$3,907.73	Technical Assistance provided in the Upper Minnesota River HCP Project Area #6 by DU biolgists to DNR, US Fish & Wildlife Service, local units of government, and private landowners regarding shallow lake assessment, improvement and management.
Other Funds	Personnel Expenditures	$9,330.05	Technical Assistance provided in the Southern Lakes HCP Project Area #10 by DU biolgists to DNR, US Fish & Wildlife Service, local units of government, and private landowners regarding shallow lake assessment, improvement and management.
	Total:	**$134,690.23**	

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2C:Living Lakes Enhancement - Ducks Unlimited

Work Program Expenditures (Not Attributable to Specific Projects) By Funding Type

Funding Type	Amount
ENTF	$38,574.50
Other Funds	$96,115.73
Total	**$134,690.23**

Work Program Expenditures Breakdown

Funding Type:	Restoration Projects	Not Attributable to Specific Projects	Total
ENTF	$261,425.50	$38,574.50	$300,000.00
Other Funds	$350,722.98	$96,115.73	$446,838.71
State Funds	$0.00	$0.00	$46,389.32
Total	$658,537.80	$134,690.23	$793,228.03

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

Project Title: Living Lakes Enhancements 2c & Easements 3c

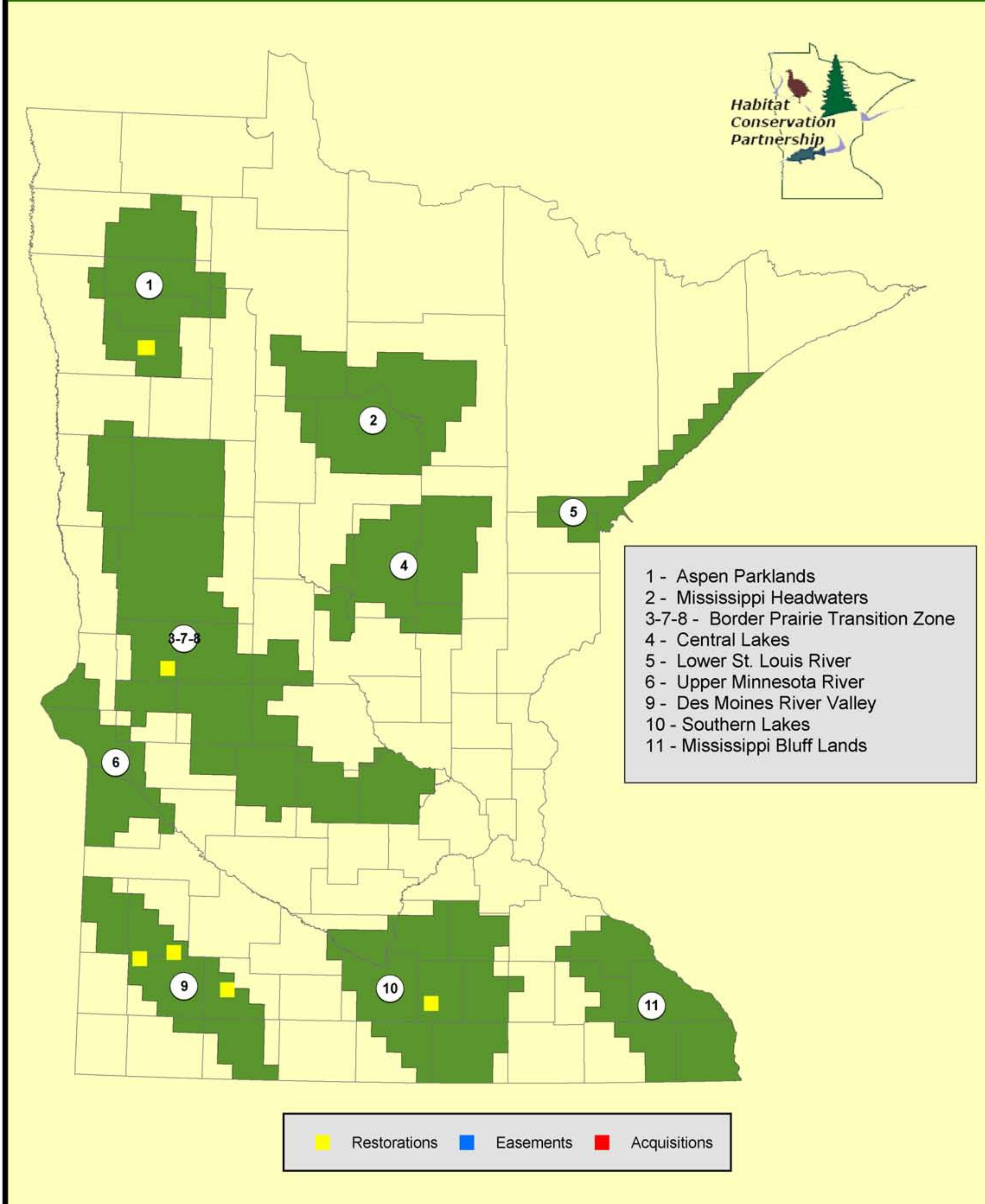
Project Manager Name: Jon Schneider, DU

Trust Fund Appropriation: $500,000

Date: Final Report July 2009

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	**Result 2 Budget:**	**Amount Spent**	**Balance**	**TOTAL BUDGET**	**TOTAL SPENT**	**TOTAL BALANCE**
	Living Lakes Enhancements			*Living Lakes Easements*					
BUDGET ITEM									
PERSONNEL: (wages and benefits for DU staff professional biologists and engineers to deliver habitat projects)	$73,030	$73,030	$0	$23,411	$23,411	$0	$96,441	$96,441	$0
Contracts	$226,970		$0	$24,770		$0	$251,740	$251,740	$0
Professional/technical (soils investigations, appraisals, legal, and baseline documentation reports)					$24,770				
Other contracts (construction of water control structures and fish barriers)		$226,970							
Equipment / Tools									
Land rights acquisition (easements, not fee)				$98,050	$98,050	$0	$98,050	$98,050	$0
Professional Services for Acqusitions									
Other (Easement Stewardship to DU WAT)				$53,769	$53,769	$0	$53,769	$53,769	$0
COLUMN TOTAL	**$300,000**	**$300,000**	**$0**	**$200,000**	**$200,000**	**0**	**$500,000**	**$500,000**	**0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
2C - Living Lakes Enhancement - Ducks Unlimited



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2D: Shallow Lakes Assessment and Management - MN DNR - Division of Wildlife

Project Manager: Ray Norrgard
Affiliation: MN DNR - Division of Wildlife
Address: 500 Lafayette Rd.
St. Paul, MN 55,155
Phone: (651) 259-5227
Fax: (651) 297-4961
E-mail: ray.norrgard@dnr.state.mn.us

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Work Program Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Restoration	$98,000	$ 98,000	$0	$0	$0
Total	$98,000	$ 98,000	$0	$0	$0

Work Program Summary

Overall Project Outcome and Results

The Trust Fund monies were used to support 1 full time temporary Natural Resource Specialist (wildlife) position and up to 6 seasonal interns to identify shallow lake and watershed habitat occurrence and quality, design restoration projects, and implement management strategies to improve shallow lake and wetland habitat. A target was established to conduct at least 50 shallow lake surveys in project areas 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 to help identify and prioritize restoration strategies conducted through HCP 2c and 3c. These strategies include shore land protection, reducing undesirable fish, managing water levels, constructing fish barriers, and establishing beneficial vegetation. These strategies are consistent with the DNR – Wildlife's Long Range Duck Recovery Plan.

Work began in mid-September, 2007. Data entry from habitat surveys conducted during the 2007 field season were completed. Weekly dissolved oxygen surveys were conducted on six lakes during the winter of 2007-2008. Reverse aeration to winterkill carp was conducted on Weaver and Hubbard Lakes in Kandiyohi County. Carp barriers were constructed. Public input was taken on management options for Wakanda Lake in Kandiyohi County. 100 shallow lake habitat surveys were conducted during the 2008 field season covering 58,138 acres: Area 1 – 2 lakes (90 acres); Area 2 – 2 lakes (2518 acres); Area 3 – 62 lakes (2236 acres); Area 4 – 3 lakes (2902 acres); Area 5 – 5 lakes (1804 acres); Area 6 – 2 lakes (2367 acres); Area 9 – 12 lakes (1633 acres); Area 10 – 12 lakes (4463 acres).

Project Results Use and Dissemination

The habitat and oxygen survey information was used to support DNR's shallow lake management efforts identified in the 2006 Duck Recovery Plan and Ducks Unlimited's efforts under Restoring Minnesota's Fish and Wildlife Habitat Corridors IV – Wildlife Shallow Lakes Enhancement 2(c). Dissemination of project accomplishments will be through the LCCMR reporting process and normal DNR budgeting and accomplishment reporting. Data collected on the habitat quality of shallow lakes will be available as part of the DNR shallow lakes database managed by Division of Fish and Wildlife staff in Brainerd.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2D: Shallow Lakes Assessment and Management - MN DNR - Division of Wildlife

Work Program Expenditures

FundingType	*Funding Category*	*Amount*	*Description*
ENTF	Personnel Expenditures	$84,105.12	Wages and Benefits
ENTF	Equipment Costs	$328.34	Boats and Lake Survey Tools
ENTF	Supplies and Misc	$205.80	Printing
ENTF	Supplies and Misc	$45.00	Office Supplies
ENTF	Supplies and Misc	$123.92	Communications
ENTF	Supplies and Misc	$483.09	Material for Carp Barrier
ENTF	Travel	$1,711.82	Travel Expenses in Minnesota
ENTF	Equipment Costs	$10,365.87	Vehicle Fleet Costs
ENTF	Supplies and Misc	$631.00	Other Supplies
	Total:	**$97,999.96**	

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects Final Report

Project Title: Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase IV – Shallow Lakes (2d)

Project Manager Name: Ray Norrgard

Trust Fund Appropriation: $ *98,000.00*

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent	Balance	TOTAL BUDGET	TOTAL BALANCE
	Fill in your result title here.				
BUDGET ITEM					
PERSONNEL: wages and benefits	$78,000	$84,105	-$6,105	$78,000	-$6,105
Equipment *(boats and lake survey tools)*	$6,000	$328	$5,672	$6,000	$5,672
Printing		$206	-$206	$0	-$206
Other Supplies *(list specific categories)*	$0	$631	-$631	$0	-$631
office supplies		$45	-$45		-$45
communications		$124	-$124		-$124
material for carp barrier		$483	-$483		-$483
Travel expenses in Minnesota	$4,000	$1,712	$2,288	$4,000	$2,288
Other: Vehicle Fleet Costs	$10,000	$10,366	-$366	$10,000	-$366
COLUMN TOTAL	**$98,000**	**$98,000**	**$0**	**$98,000**	**$0**

Explanation: Personnel costs were slightly higher (7%) than forecasted. Printing, office supplies, and communications (mailing) costs were for landowner contacts to gain access to public waters for habitat surveys. Fleet costs were 4% higher than anticipated. Other supplies included replacement lake survey materials. Materials were also purchased for constructon of a carp barrier to facilitate management of one of the shallow lakes. On the other hand equipment and travel costs were substantially lower than the amounts budgeted.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2E2:Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe

Project Manager: John Ringle

Affiliation: Leech Lake Band of Ojibwe

Address: 6530 HWY 2 NW
Cass Lake, MN 56633

Phone: (218)335-7400

Fax: (218)335-7430

E-mail: llfish@paulbunyan.net

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed *	Other Funds Spent *
Restoration	$30,000	$30,000	$0	$145,000	$41,036
Total	$30,000	$30,000	$0	$145,000	$41,036

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:

Other: $2,300.00

See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results

The goal of our portion of the Habitat Corridors Partnership was to improve habitat for nesting and foraging waterfowl within the boundaries of the Leech Lake Reservation. Enhancements on sedge meadow wetlands were conducted by utilizing prescribed burns on 80 acres of tribal management area and 2700 acres of National Forest Lands along the Leech Lake River. We maintained water levels on 18 managed forested impoundments for wildlife enhancement benefits including a summer drawdown on two of them to enhance productivity. Additionally, water level on three natural lakes was managed for the benefit of wild rice production and to reduce timber flooding issues. On nearly every water body we managed under this project, beaver dams and debris were cleared either by hand or by blasting. We checked, maintained and numbered 217 mapped waterfowl nesting boxes. Because the cost of wild rice seed stock doubled this year, we were only able to re-seed 106 high quality acres, but feel confident these acres will produce a viable rice stand next season.

We were able to complete 2.23 miles of forest road decommissioning work, restoring natural hydrology to the site which is in the Leech Lake watershed. Reduction of forest fragmentation and site re-vegetation will help the status of many interior forest species including the grey wolf, bald eagle, and improve impaired habitat of several important native plants including ferns of the genus Botrychium. Water quality improvement in the watershed should also be a result of wetland road decommissioning.

Project Results Use and Dissemination

In August of 2008, the LCCMR members and staff took a field tour of Leech Lake and viewed firsthand and discussed our Habitat Corridors Partnership projects. We were able to utilize our HCP project funding to leverage a $120,000 Tribal Landowner Incentive Program grant from the US Fish and Wildlife Service and will be able to continue our road decommissioning work into the future. Again as in previous years, the projects have been presented at the 21st Annual Great Lakes Regional meeting of the Native American Fish and Wildlife Society, held on our Reservation this year.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2E2:Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe

Restoration Activities

Project Area - 2 - Mississippi Headwaters

Project Name: Rice Lake
Township: 142, Range: 30, Section: 20

Activity: Wetland Enhancement
Landtype: Tribal - Lake
Description: Additional wild rice as seeded in Rice Lake.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,000.00	77.00	0.00
Other	Site Development	$2,300.00	0.00	0.00
Rice Lake Total		**$4,300.00**	**77.00**	**0.00**

Project Name: Cub Lake Impoundment
Township: 146, Range: 29, Section: 20

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Beaver material revoval from water control and general maintenance were conducted on Cub Impoundment to enhance its value for waterfowl.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$500.00	0.00	0.00
ENTF	Restoration	$224.00	0.00	0.00
ENTF	Site Development	$500.00	0.00	0.00
Other Funds	Restoration	$1,000.00	0.00	0.00
Other Funds	Site Development	$498.00	0.00	0.00
Wetland Restoration Total		$2,722.00	0.00	0.00
Cub Lake Impoundment Total		**$2,722.00**	**0.00**	**0.00**

Project Name: Bag Impoundment
Township: 141, Range: 30, Section: 17

Activity: Wetland Enhancement
Landtype: Tribal - Lake
Description: A drawn down of Bag Lake Impoundment was initiated to premote revegetation and to reduce competing fish species.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,000.00	17.00	0.00
Wetland Enhancement Total		$2,000.00	17.00	0.00

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: General maintenance was conducted on Bag Lake Impoundment to enchance its value for waterfowl.
Thirteen nest boxes were also maintained and monitored.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$180.00	0.00	0.00
ENTF	Restoration	$500.00	0.00	0.00
Other Funds	Restoration	$1,000.00	0.00	0.00
Other Funds	Site Development	$2,480.00	0.00	0.00
Wetland Restoration Total		$4,160.00	0.00	0.00
Bag Impoundment Total		**$6,160.00**	**17.00**	**0.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2E2:Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe

Project Name: Bear Brook Impoundment
Township: 144, Range: 27, Section: 15

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Beaver material removal and general maintenance were concucted on Bear Brook Impoundment to enhance its value for waterfowl.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$500.00	0.00	0.00

Project Name: Snake Brook Impoundment
Township: 144, Range: 26, Section: 21

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest boxes were monitored and maintained on Snake Brook Impoundment

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$154.00	0.00	0.00

Project Name: West Banks 2 Impoundment
Township: 145, Range: 27, Section: 13

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: A drawdown and general maintenance were conducted on this impoundment to enhance its value for waterfowl.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,000.00	0.00	0.00
Other Funds	Restoration	$2,000.00	0.00	0.00
West Banks 2 Impoundment Total		**$3,000.00**	**0.00**	**0.00**

Project Name: West Banks I Impoundment
Township: 145, Range: 26, Section: 30

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Impoundment drawdown and maintenance were conducted on this impoundment to improve its value for waterfowl. The seven nest boxes located on the impoundment were also monitored and maintained.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$500.00	0.00	0.00
ENTF	Restoration	$97.00	0.00	0.00
ENTF	Restoration	$500.00	0.00	0.00
Other Funds	Restoration	$2,000.00	0.00	0.00
Other Funds	Site Development	$475.00	0.00	0.00
West Banks I Impoundment Total		**$3,572.00**	**0.00**	**0.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2E2:Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe

Project Name: Brush Lake Impoundment
Township: 144, Range: 30, Section: 3

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: General maintenance and beaver material removal was conducted on Brush Lake Impoundment to maintain its value for waterfowl.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$318.00	2.27	0.00
ENTF	Restoration	$500.00	3.58	0.00
Other Funds	Restoration	$1,000.00	7.15	0.00
Other Funds	Site Development	$533.00	0.00	0.00
Brush Lake Impoundment Total		**$2,351.00**	**13.00**	**0.00**

Project Name: Boy River meadows
Township: 143, Range: 28, Section: 27

Activity: Wetland Restoration
Landtype: Tribal - Land
Description: A multi agency prescribed burn was conducted on sections of the Boy River Meadows to enhnace habitat for wildlife.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,500.00	623.08	0.00
Other Funds	Restoration	$5,000.00	2,076.92	0.00
Boy River meadows Total		**$6,500.00**	**2,700.00**	**0.00**

Project Name: Battle Point Prescribed Burn
Township: 143, Range: 29, Section: 36

Activity: Wetland Restoration
Landtype: Tribal - Land
Description: A prescribed burn was conducted on a grass sedge wetland on Battle Point to enhance this habitat for waterfowl and other wildlife that utilize this habitat.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,000.00	20.00	0.00
Other Funds	Restoration	$1,000.00	20.00	0.00
Battle Point Prescribed Burn Total		**$2,000.00**	**40.00**	**0.00**

Project Name: Winnie Ponds
Township: 146, Range: 27, Section: 25

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: A prescribed burn was conducted on part of the impoundment complex to enhance habitat for waterfowl and other wildlife species that utilize this type of habitat. Maintenance and monitoring was also conducted on 14 nest boxes located on the project area.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$500.00	5.57	0.00
ENTF	Restoration	$193.50	2.16	0.00
Other Funds	Restoration	$2,000.00	22.28	0.00
Winnie Ponds Total		**$2,693.50**	**30.00**	**0.00**

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2E2:Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe

Project Name: Black Smith Ponds nestboxes
Township: 144, Range: 28, Section: 1

Activity: Wetland Enhancement
Landtype: Private - Lake
Description: Nine nest boxes were monitored and maintained.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$124.00	0.00	0.00

Project Name: Kenogama backwater nestboxes
Township: 147, Range: 29, Section: 33

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest boxes were monitored and maintained on Kenogama Lake.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$98.00	0.00	0.00

Project Name: Mettler Road Pond
Township: 144, Range: 27, Section: 22

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest boxes were maintained and monitored on Mettler Road Pond.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$168.00	0.00	0.00

Project Name: Pigeon River flowage beaver dam removal
Township: 147, Range: 27, Section: 19

Activity: Wetland Enhancement
Landtype: Tribal - Lake
Description: A beaver dam was removed from the Pigeon River Flowage above Pigeon Dam Lake to enhance wild rice throughout the flowage.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
Other Funds	Restoration	$500.00	0.00	0.00

Project Name: Six Mile Creek beaver dam removal
Township: 144, Range: 27, Section: 16

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Beaver dams were removed from Six Mile Creek to enhnace wild rice and restore fish passage.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$500.00	0.00	0.00

Project Name: Sugar Lake Impoundment
Township: 146, Range: 29, Section: 22

Activity: Wetland Restoration
Landtype: Private - Lake
Description: Nest boxes were monitored and maintained on Sugar Lake Impoundment.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$140.00	0.00	0.00

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2E2:Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe

Project Name: Raven Lake Nest Boxes
Township: 147, Range: 29, Section: 11

Activity: Wetland Restoration
Landtype: Private - Lake
Description: Nest boxes were monitored and maintained on Raven's Lake Flowage.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$112.00	0.00	0.00

Project Name: Minisogama Lake
Township: 147, Range: 29, Section: 27

Activity: Wetland Restoration
Landtype: Private - Lake
Description: Nest boxes were monitored and maintained on Minisogama Lake.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$182.00	0.00	0.00
ENTF	Restoration	$98.00	0.00	0.00
Wetland Restoration Total		$280.00	0.00	0.00
Minisogama Lake Total		**$280.00**	**0.00**	**0.00**

Project Name: Hair Pin Pond
Township: 144, Range: 26, Section: 21

Activity: Wetland Restoration
Landtype: Private - Lake
Description: Nest Boxes were monitored and maintained on Hair Pin Pond

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$182.00	0.00	0.00

Project Name: Third River Pond 2
Township: 147, Range: 29, Section: 10

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest Boxes were monitored and maintained on Third River Pond 2.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$84.00	0.00	0.00

Project Name: Third River Pond 1
Township: 146, Range: 29, Section: 17

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest Boxes were monitored and installed on Third River Pond 1.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$182.00	0.00	0.00

Project Name: Third River Pond 3
Township: 147, Range: 29, Section: 3

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest boxes were monitored and maintained on Third River Pond 3.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$196.00	0.00	0.00

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2E2:Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe

Project Name: Third River Pond 5
Township: 147, Range: 28, Section: 17

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Next boxes were monitored and maintained on Third River Pond 5.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$112.00	0.00	0.00

Project Name: Nason Meadow Road Pond
Township: 144, Range: 27, Section: 23

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest boxes were monitored and maintained on Nason Meadow Road Pond.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$224.00	0.00	0.00

Project Name: Wally's Pond nest boxes
Township: 144, Range: 29, Section: 2

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest box maintenance and monitoring was conducted on Wally's Pond.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$154.00	0.00	0.00

Project Name: Soo Line Trail Pond nest boxes
Township: 144, Range: 28, Section: 5

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest box maintenance and monitoring was conducted on Soo Line Trail Pond.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$112.00	0.00	0.00

Project Name: Buelah Pond Nest Boxes
Township: 144, Range: 28, Section: 8

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest box maintenance and monitoring was conducted on Buelash Pond.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$196.00	0.00	0.00
ENTF	Restoration	$112.00	0.00	0.00
ENTF	Restoration	$182.00	0.00	0.00
Wetland Restoration Total		$490.00	0.00	0.00
Buelah Pond Nest Boxes Total		**$490.00**	**0.00**	**0.00**

Project Name: Bird Blind Pond Nest Boxes
Township: 144, Range: 26, Section: 3

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: Nest Box maintenance and monitoring was conducted on Bird Blind Pond.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$175.50	0.00	0.00

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2E2:Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe

Project Name: Portage road decommissioning
Township: 144, Range: 28, Section: 6

Activity: Wetland Restoration
Landtype: Tribal - Lake
Description: An old road was decommissioned and the portion in a wetland removed. This project was done to restore wetlands and protect a rare plant site and eagle nest that are located along the upland portion of the road. It also reduced forest fragementation.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$10,000.00	0.00	6,490.00
Other Funds	Site Development	$20,000.00	0.00	0.00
Portage road decommissioning Total		**$30,000.00**	**0.00**	**6,490.00**

Project Name: Amik Impounement
Township: 147, Range: 27, Section: 15

Activity: Wild Rice Restoration
Landtype: Tribal - Lake
Description: Wild rice was seeded into Amik Impounement. General impoundment operation and maintenance was also conducted.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,000.00	16.80	0.00
ENTF	Restoration	$500.00	4.20	0.00
Other Funds	Site Development	$525.00	0.00	0.00
Amik Impounement Total		**$3,025.00**	**21.00**	**0.00**

Project Name: Pigeon River wild rice planting
Township: 147, Range: 27, Section: 18

Activity: Wild Rice Restoration
Landtype: Tribal - Lake
Description: Wild rice was planted into the Pigeon River Flowage.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,000.00	8.00	0.00
Other Funds	Site Development	$1,025.00	0.00	0.00
Pigeon River wild rice planting Total		**$2,025.00**	**8.00**	**0.00**

Project Name: Sucker Creek beaver dam removal
Township: 144, Range: 30, Section: 11

Activity: Wetland Restoration
Landtype: Private - Lake
Description: Beaver dams were removed from Sucker Creek to enhance wildrice and restore fish passage.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$500.00	0.00	0.00

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet
ENTF:	$30,000.00	779.65	6,490.00
Other Funds:	$41,036.00	2,126.35	0.00
Other:	$2,300.00	0.00	0.00
Total:	**$73,336.00**	**2,906.00**	**6,490.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2E2:Shallow Lake and Impoundment Management - Leech Lake Band of Ojibwe

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

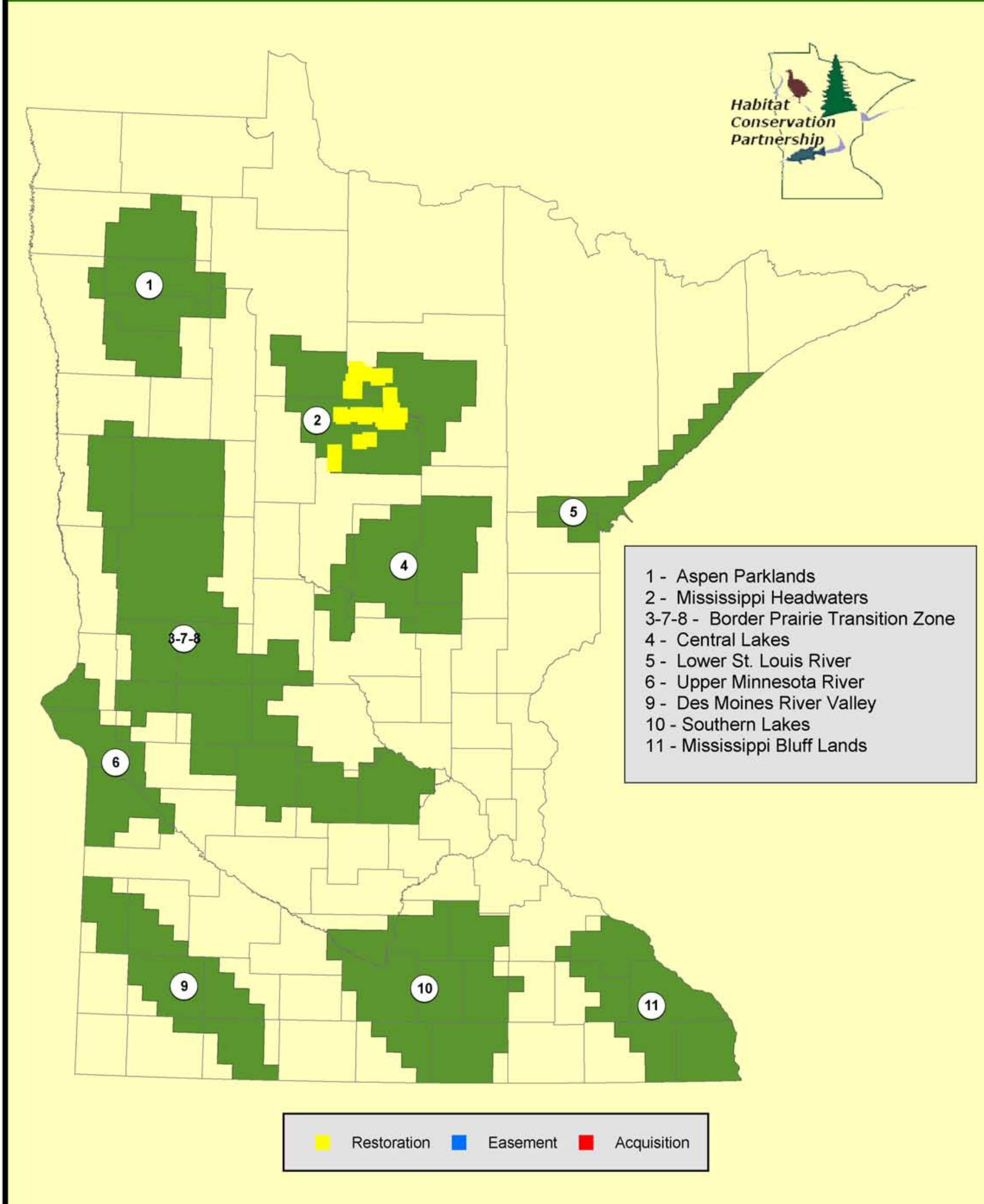
Project Title: *Minnesota Habitat Corridors Partnership - Phase IV, Subd. 5(b)*

Project Manager Name: *John P. Ringle*

Trust Fund Appropriation: $ *30,000*

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent	Balance	Result 2 Budget:	Amount Spent	Balance	TOTAL BUDGET	TOTAL BALANCE
	Shallow Lake and Wetland Management			*Forest Road Decommissioning and Wetland Restoration*				
BUDGET ITEM								
PERSONNEL: Wages and Benefits	$20,000	$20,000	$0	$0	$0	$0	$20,000	$0
Contracts								
Professional/technical *Contract with Leech Lake Heavy Equipment Program for earthwork*	$0	$0	$0	$10,000	$10,000	$0	$10,000	$0
COLUMN TOTAL	**$20,000**	**$20,000**	**$0**	**$10,000**	**$10,000**	**$0**	**$30,000**	**$0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
2E2 - Shallow Lake and Impoundment Managment - Leech Lake Band of Ojibwe



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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2E3: Wild Rice Habitat Restoration - Fond du Lac Band of Chippewa Indians

Project Manager: Tom Howes
Affiliation: Fond du Lac Band of Chippewa Indians
Address: 1720 Big Lake Road
Cloquet, MN 55,720
Phone: 218-878-8088
Fax:
E-mail: Tomhowes@fdlrez.com

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Restoration	$21,000.00	$0.00	$21,000.00	$45,000.00	$0.00
Total	$21,000.00	$0.00	$21,000.00	$45,000.00	$0.00

Work Program Summary

Overall Project Outcome and Results
The Fond du Lac Reservation Natural Resources Program was awarded $21,000 in the 2007 LCCMR appropriations to conduct 20 acres of wild rice habitat restoration. This grant specifically targeted Rice Portage Lake for restoration. In 2008, we were able to complete 9.1 acres of restoration on Rice Portage, but major mechanical problems prohibited us from completing our goal of 20 acres as proposed in our work program. This delay also has led to an overabundance of available funds for this project. The Fond du Lac Natural Resources Program has elected to not request reimbursement for Phase 4.

Project Results Use and Dissemination
Since the The Fond du Lac Natural Resources Program has elected to not request reimbursement for Phase 4, this Work Program has no project results.

Attachment A: Budget Detail

Project Title: Wild Rice Habitat Restoration 2e3

Project Manager Name: Thomas Howes

Trust Fund Appropriation: $ 21,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent 8/1/09**	**Balance 8/1/09**	**Result 2 Budget:**	**Amount Spent 8/1/09**	**Balance 8/1/09**	**TOTAL BUDGET**	**TOTAL BALANCE**
	Wild Rice Habitat Restoration			**Wild Rice Reseeding**				
BUDGET ITEM								
PERSONNEL: wages and benefits for FDL Natural Resources Technicians to operate restoration equipment	$15,000	$0	$15,000	$0	$0	$0	$15,000	$15,000
Other direct operating cost: Gasoline, diesel fuel, and hydraulic fluid for restoration equipment	$2,000	$0	$2,000	$0	$0	$0	$2,000	$2,000
Other Supplies: Wild rice seed for restored areas			$0	$4,000	$0	$4,000	$4,000	$4,000
COLUMN TOTAL	**$17,000**	**$0**	**$17,000**	**$4,000**	**$0**	**$4,000**	**$21,000**	**$21,000**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2G:Wildlife Areas Management - DNR-Division of Fish & Wildlife

Project Manager: Suzann Willhite
Affiliation: DNR-Division of Fish & Wildlife
Address: 500 Lafayette Road
St. Paul, MN 55155
Phone: 6512595235
Fax: 6512974961
E-mail: suzann.willhite@dnr.state.mn.us

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Restoration/Site Development	$50,000	$47,185	$2,816	$0	$0
Total	$50,000	$47,185	$2,816	$0	$0

Work Program Summary

Overall Project Outcome and Results

The Minnesota DNR-Section of Wildlife provided oversight for infrastructure management and habitat restoration on land acquired by partners, transferred to DNR, and designated as State Wildlife Management Areas (WMAs). Infrastructure and habitat work was completed on 237 acres. Infrastructure management included boundary surveys, boundary signing, professional services, public access, parking lots and user facilities, and clean up of old buildings or wells. Habitat restoration included grassland development or improvement, wetland restoration or impoundment development, forest or woody cover development or improvement, brush land management, professional services, and food plot development. Contract vendors and temporary project staff implemented development on WMA lands. Digital boundary, habitat inventory and facilities files were developed as part of the management plans.

Completed Initial Development Project Plans for Phase IV projects include:
Caraway WMA - Site / Access development, Boundary survey.
Maple Meadows WMA - Site cleanup and building disposal.
Sangl WMA - Site cleanup and wetland restoration.
Spring Creek WMA - Habitat restoration and site cleanup.
Thorson Prairie WMA - Habitat restoration.

Project Results Use and Dissemination

Information on new tracts is available on the DNR's website at www.dnr.state.mn, or by contacting the local Area Wildlife Manager.

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2G:Wildlife Areas Management - DNR-Division of Fish & Wildlife

Restoration Activities

Project Area - 1 - Aspen Parklands

Project Name: Thorson Prarie
Township: 148, Range: 45, Section: 5

Activity: Grassland Restoration
Landtype: Public - WMA
Description: Mowed to control Canada thistle and provide prairie chicken habitat. Trees removed. Prescribed burn. Native prairie seeding.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$7,978.23	123.00	0.00
ENTF	Site Development	$508.77	0.00	0.00
Thorson Prarie Total		**$8,487.00**	**123.00**	**0.00**

Project Name: Maple Meadows WMA
Tract: Martinson
Township: 148, Range: 44, Section: 15

Activity: Site / Access Development
Landtype: Public - WMA
Description: Site cleanup and building disposal.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Professional Services	$803.00	0.00	0.00
ENTF	Site Development	$5,850.00	0.00	0.00
Maple Meadows WMA Martinson Total		**$6,653.00**	**0.00**	**0.00**

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Habitat Conservation Partnership

2G:Wildlife Areas Management - DNR-Division of Fish & Wildlife

Project Area - 9 - Des Moines River Valley

Project Name: Caraway WMA
Tract: 3
Township: 104, Range: 36, Section: 25

Activity: Site / Access Development
Landtype: Public - WMA
Description: Boundary survey completed.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Professional Services	$2,160.00	0.00	0.00

Project Name: Sangl WMA
Tract: 7
Township: 101, Range: 36, Section: 29

Activity: Grassland Restoration
Landtype: Public - WMA
Description: Prairie grass seeding, converting 12 acres of CRP to native grass/flowers, prescribed burn, tree removal.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,632.34	31.00	0.00
Grassland Restoration Total		$2,632.34	31.00	0.00

Activity: Site / Access Development
Landtype: Public - WMA
Description: Site clean up. Seal 2 wells. Building and debris removal.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Personnel Expenditures	$1,998.00	0.00	0.00
ENTF	Professional Services	$1,998.15	0.00	0.00
ENTF	Site Development	$3,438.77	0.00	0.00
Site / Access Development Total		$7,434.92	0.00	0.00

Activity: Wetland Restoration
Landtype: Public - WMA
Description: Supplies for wetland restoration in progress.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$124.76	0.00	0.00
Wetland Restoration Total		$124.76	0.00	0.00
Sangl WMA 7 Total		**$10,192.02**	**31.00**	**0.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2G:Wildlife Areas Management - DNR-Division of Fish & Wildlife

Project Area - 3-7-8 - Border Prairie Transition Zone

Project Name: Spring Creek WMA
Township: 142, Range: 41, Section: 7

Activity: Grassland Restoration
Landtype: Public - WMA
Description: Purchased native prairie seed. Leveled site in preparation for native seeding. Purchased herbicide chemical to control invasives.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Personnel Expenditures	$1,964.96	0.00	0.00
ENTF	Restoration	$7,464.78	81.00	0.00
Grassland Restoration Total		$9,429.74	81.00	0.00

Activity: Site / Access Development
Landtype: Public - WMA
Description: Removed and disposed of old farm buildings. Purchased and installed boundary sign posts and signs. Purchased gravel, culvert and steel access gates.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Professional Services	$2,000.00	0.00	0.00
ENTF	Site Development	$3,865.86	0.00	0.00
ENTF	Site Development	$1,996.88	0.00	0.00
Site / Access Development Total		$7,862.74	0.00	0.00

Activity: Wetland Restoration
Landtype: Public - WMA
Description: Wetland restoration to be completed summer 2009.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,400.00	2.00	0.00
Wetland Restoration Total		$2,400.00	2.00	0.00
Spring Creek WMA Total		**$19,692.48**	**83.00**	**0.00**

Restoration Project Totals (By Funding Type)

Funding Type	**Funding Amount**	**Acres**	**Shoreline Feet**
ENTF:	$47,184.50	237.00	0.00
Total:	**$47,184.50**	**237.00**	**0.00**

Attachment A. Budget Detail for 2008/2009 Projects

Date of Report: Aug 6, 2009

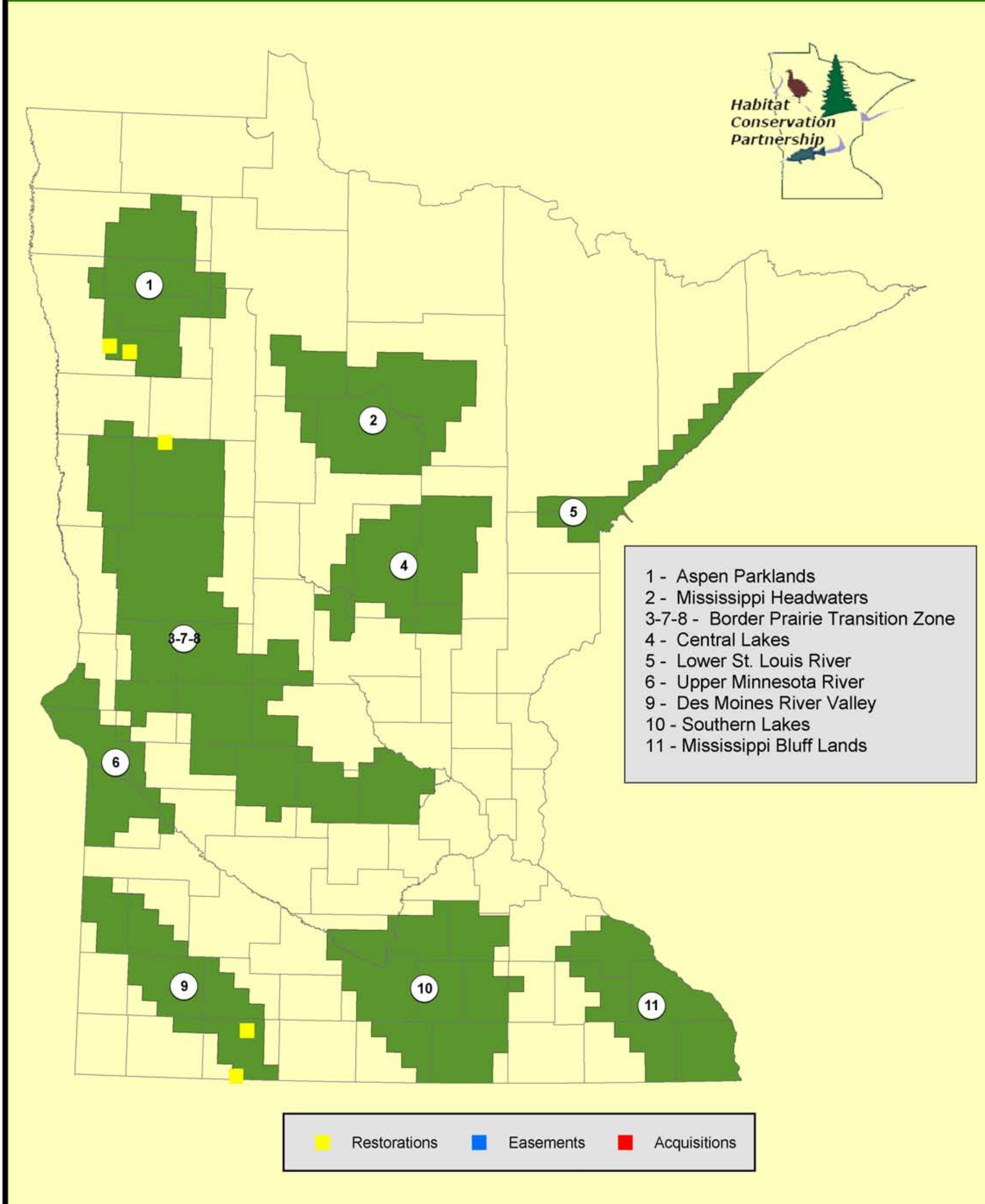
Project Title: Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase IV: Wildlife Area Management (2g)

Project Manager Name: Suzann Willhite

LCCMR Requested Dollars: $ 50,000

2007 LCCMR Proposal Budget	DESCRIPTION	BUDGET	EXPENDITURE	BALANCE
Wages, salaries & benefits	Temporary and seasonal staff	$2,000	$3,962.96	-$1,963
Professional technical contracts	engineering vendors for boundary surveys on new acquisitions	$13,000	$4,961	$8,039
Habitat development and restoration	Prairie, wetland, forest, and openland/brushland mangement, and woody cover development	$23,500	$20,611	$2,889
Vehicle expenses	fleet and equipment costs and fuel	$2,000	$2,649	-$649
Other land improvement	boundary management, site/building cleanup/well sealing, user facility development and improvement, access development and improvement	$9,500	$15,001	-$5,501
Total LCCMR Budget		**$50,000**	**$47,185**	**$2,816**

Habitat Conservation Partnership
Phase 4 - Accomplishments
2G - Wildlife Areas Managment - DNR - Division of Fish & Wildlife



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2H:Fish Habitat Restoration - MN DNR - Division of Fisheries

Project Manager: Linda Erickson-Eastwood
Affiliation: MN DNR - Division of Fisheries
Address: 500 Lafayette Rd.
St. Paul, MN 55155
Phone: (651) 259-5206
Fax: (651) 297-4916
E-mail: linda.erickson-eastwood@dnr.state.mn.us

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed *	Other Funds Spent *
Restoration	$280,000	$280,000	$0	$0	$19,945
Total	$280,000	$280,000	$0	$0	$19,945

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:

State Funds: $65,219.28
Other: $44,983.01

See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results

This project resulted in a grand total of approximately 5,492 acres and 52,800 feet of shoreline of lake and stream habitat being restored, maintained, or opened up to fish movement. Environmental and Natural Resources Trust dollars ($248,731) directly acquired all materials or contracted services for these projects. Donations of staff time and other value and cash (“other funds” $19,944) and other state monies ($65,219 state and $44,983 other) leveraged with trust dollars provided a grand total of $378,878. These contributions helped acquire the materials and labor needed to complete and design these habitat projects.

Project Results Use and Dissemination

This project complemented habitat efforts funded in the past with capital bonding, Trout Stamp, and Environmental Trust Fund dollars. The habitat work done in areas adjacent to lakes and streams ensured that critical riparian habitat areas within sensitive watersheds and headwater areas will be present. Many of the projects also resulted in providing access or restoring critical habitats by opening up or modifying dams or channels. Habit efforts under this segment concentrated in the following project areas: 2) Mississippi Headwaters, 3) Border Prairie 4) Central Lakes, 5) St. Louis River 8) Big Woods, 9) Des Monies River Valley, and 11) Mississippi Blufflands. Work done will be added to DNR GIS layers being developed or maintained

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2H:Fish Habitat Restoration - MN DNR - Division of Fisheries

Restoration Activities

Project Area - 2 - Mississippi Headwaters

Project Name: Battle Point Prescribed Burn
Township: 143, Range: 29, Section: 36

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Public - Lake
Description: Using native plants restored spawning and rearing habitat for bass, crappie, bluegill, and northern pike. Also corrected erosion problem to improve water quality and clarity. Worked with Sauk River Watershed, City of Osakis, Audubon Society, and MN Pollution Control Agency.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$23,421.00	0.29	516.39
Other	Restoration	$15,000.00	0.19	330.72
Other Funds	Restoration	$6,000.00	0.08	132.29
State Funds	Restoration	$934.00	0.01	20.59
Battle Point Prescribed Burn Total		**$45,355.00**	**0.57**	**1,000.00**

Project Name: Turtle Lake
Tract: Frahm
Township: 59, Range: 26, Section: 5

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Public - Lake
Description: In cooperation with the Turtle Lake Association, Itasca County Land Department, and US Forest Service, we surveyed areas for the identification of invasive species. We then treated the areas, primarily purple loosestrife, by hand pulling, chemical treatment, and biological control (released beetles).

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$4,921.64	2,066.00	0.00

Project Name: Three Island Lake
Township: 141, Range: 28, Section: 7

Activity: Dam Modification
Landtype: Public - River
Description: Installed four rock wier/step pools to allow fish passage. Passage was restored between Turtle River and Three Island Lake.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$8,750.00	1,313.14	0.00
State Funds	Restoration	$7,342.17	1,101.86	0.00
Three Island Lake Total		**$16,092.17**	**2,415.00**	**0.00**

Project Name: Hartley Lake Outlet
Township: 59, Range: 23, Section: 32

Activity: Site / Access Development
Landtype: Public - Lake
Description: This is a two phase project. This phase was used to contract out the survey and design work to improve the site for fish passage. Phase 5 monies will be used to implement the project.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$6,000.00	0.00	0.00

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2H:Fish Habitat Restoration - MN DNR - Division of Fisheries

Project Name: Necktie River
Township: 145, Range: 32, Section: 7

Activity: Dam Modification
Landtype: Public - River
Description: Contracted local person to remove beaver and their dams so that flow and fish passage were restored.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,400.00	0.00	20,064.00

Project Name: Bungoshing Creek
Township: 145, Range: 32, Section: 29

Activity: Dam Modification
Landtype: Public - River
Description: Contracted with USDA-APHIS to remove beaver and their dams to maintain fish passage on 1.1 miles of stream for trout.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,000.00	0.00	5,800.00

Project Area - 3 - Border Prairie

Project Name: Block Lake
Township: 131, Range: 38, Section: 17

Activity: Dam Modification
Landtype: Public - Lake
Description: A failing dam was repaired so that the Block Lake impoundment would be maintained.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$3,196.07	56.79	0.00
State Funds	Restoration	$11,606.50	206.21	0.00
Block Lake Total		**$14,802.57**	**263.00**	**0.00**

Project Name: Deadhorse Creek
Township: 138, Range: 38, Section: 4

Activity: Dam Modification
Landtype: Public - River
Description: Contracted with USDA- APHIs to remove dams and beavers from the easement and river to maintain fish passage on four miles of trout stream.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,048.00	0.00	21,120.00

Project Area - 4 - Central Lakes

Project Name: Stoney Brook
Township: 135, Range: 29, Section: 8

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Public - River
Description: An MCC crew was contracted for three weeks to work on 52 different sites. Work was completed on stablizing eroding banks, removing rebar and wire fencing, refurbishing overhead bank cover, and removing nonfunctional habitat structures.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$7,900.00	0.00	0.00

Project Area - 5 - Lower St. Louis River

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2H:Fish Habitat Restoration - MN DNR - Division of Fisheries

Project Name: Blackhoof River
Township: 48, Range: 17, Section: 31

Activity: Dam Modification
Landtype: Public - River
Description: This was a contract to remove beaver dams on coldwater streams. 19.5 miles of stream were surveyed and dams removed to allow access to spawning and rearing habitat for rainbow and brown trout.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$1,038.45	0.00	0.00

Project Name: Little Knife
Township: 52, Range: 12, Section: 36

Activity: Dam Modification
Landtype: Public - River
Description: The old footings and retaining wall from the fish trap were removed. The stream bank was sloped and planted with native plants and the natural stream bed was restored.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$2,630.00	0.00	100.00

Project Name: Miller Creek
Township: 50, Range: 14, Section: 6

Activity: Dam Modification
Landtype: Public - River
Description: Contract with USDA Wildlife Services to remove beaver dams on trout waters. 9.5 miles were surveyed and dams removed to improve water temperture and to provide access for brook trout to spawning and rearing habitat.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$619.49	0.00	0.00

Project Name: Talmadge River
Township: 51, Range: 13, Section: 24

Activity: Site / Access Development
Landtype: Private - Lake
Description: This is a two phase project to provide better fish passage along the river. Currently Ellen River Patners has been contracted to develop the plans for the needed fish passage project. Phase 5 monies will be used to install the passage.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$2,950.70	0.00	0.00

Project Area - 7 - Alexandria Moraine

Project Name: Middle Fork, Crow River, Kandiyohi County
Township: 0, Range: 0, Section: 0

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Public - Lake
Description: Contracted with Reiner Contracting to stabalize shoreline with riprap to prevent it from washing out.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$10,678.00	0.00	300.00

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2H:Fish Habitat Restoration - MN DNR - Division of Fisheries

Project Name: Lake Florida
Township: 121, Range: 35, Section: 34

Activity: Dam Modification
Landtype: Public - Lake
Description: Made modifications to the trap to prevent unwanted fish entering the system.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$9,097.67	0.00	0.00

Project Area - 8 - Big Woods North

Project Name: North Fork of the Crow
Township: 121, Range: 32, Section: 24

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Public - Lake
Description: Contracted labor with Centra Sota to spray weeds and prep the site for planting. Contracted Habitat Forever to seed the area with native prairie mixture.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,508.51	16.70	0.00

Project Area - 9 - Des Moines River Valley

Project Name: Fulda Lake
Township: 105, Range: 40, Section: 36

Activity: Dam Modification
Landtype: Public - Lake
Description: Worked with Murray County, city of Fulda, North Heron Lake Game Producers, Fulda Fish and Game Club, Heron Lake Watershed, Duck Unlimited, and the Peterson family on this project. The project included a drawdown and installation of fish barrier to keep unwanted fish from migrating up the Hwy 59 culvert into the lake.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$36,000.00	125.13	0.00
Other Funds	Restoration	$10,500.00	36.50	0.00
State Funds	Restoration	$5,000.00	17.38	0.00
Fulda Lake Total		**$51,500.00**	**179.00**	**0.00**

Project Name: E & W Twin Lake
Township: 109, Range: 43, Section: 29

Activity: Lake Aeration
Landtype: Public - Lake
Description: Worked with the Balaton Sportsman Club to pay for and install an aeration system to prevent winter kill. The sports group will maintain and operate the system under a state agreement.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$3,000.00	240.66	0.00
Other Funds	Restoration	$3,444.69	276.34	0.00
E & W Twin Lake Total		**$6,444.69**	**517.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2H:Fish Habitat Restoration - MN DNR - Division of Fisheries

Project Name: Stay Lake AMA
Township: 111, Range: 44, Section: 29

Activity: Grassland Restoration
Landtype: Public - Lake
Description: Contracted labor to plant a diverse local mixture of native prarie grasses

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,450.48	16.70	0.00

Project Area - 11 - Mississippi Bluff Lands

Project Name: Trout Run
Township: 104, Range: 10, Section: 8

Activity: Dam Modification
Landtype: Public - River
Description: This is the installation of a rock wier to act as a brown trout fish barrier. This is part of the Coolridge Creek project to limit movement of brown trout into an area where native brook trout are found. Recovery of the brook trout will be studied.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$35,000.00	0.70	0.00
Other	Restoration	$15,000.00	0.30	0.00
Dam Modification Total		$50,000.00	1.00	0.00

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Public - River
Description: This project was done in cooperation with Trout Unlimited Dare; Hiawatha, Twin cities, and Win-cres local chapters of trout unlimited. and MN Trout Association. Trout habitat and stream modifications were done on Trout Run creek.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$23,007.00	3.94	1,271.77
Other	Restoration	$14,983.00	2.56	828.23
Shoreline Habitat Restoration / Stabilization Total		$37,990.00	6.50	2,100.00
Trout Run Total		**$87,990.00**	**7.50**	**2,100.00**

Project Name: Pickwick Creek
Township: 106, Range: 6, Section: 23

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Public - River
Description: This project was done in cooperation with WinCres Trout Unlimited Chapter and Winona County NRCS. The project stabilized a severely eroded bank with re-seeding with native vegetation cover type. Trout habitat structures were also installed.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$53,893.00	6.26	1,313.79
State Funds	Restoration	$32,251.00	3.74	786.21
Pickwick Creek Total		**$86,144.00**	**10.00**	**2,100.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2H:Fish Habitat Restoration - MN DNR - Division of Fisheries

Project Name: Coolridge Creek
Township: 105, Range: 5, Section: 26

Activity: Dam Modification
Landtype: Public - River
Description: This project is to install a rock wier as a barrier to brown trout fish movement into the upper portion of Coolridge Creek. Brown trout appear to be outcompeting the native brook trout for critical habiat. By eliminating the movement of brown trout, we will then study how the brook trout population responds.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,842.06	0.27	80.77
State Funds	Restoration	$5,000.00	0.73	219.23
Coolridge Creek Total		**$6,842.06**	**1.00**	**300.00**

Project Name: Winnebago Cree
Township: 101, Range: 5, Section: 15

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Public - River
Description: A channel restoration and trout habitat installation project was to be done. Due to the 2008 floods, this project will not be able to be done until fiscal year 2010. Consequently, the funding for this project was shifted to the Pickwick Creek project.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
Other	Restoration	$0.01	0.00	0.00

Project Area - 3-7-8 - Border Prairie Transition Zone

Project Name: Lawndale Creek
Township: 135, Range: 45, Section: 6

Activity: Site / Access Development
Landtype: Public - River
Description: Constructed rock weirs near cluvert to ensure fish passage. Opened up 2.5 miles of stream to the fish.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$3,378.93	0.00	0.00
State Funds	Restoration	$3,085.61	0.00	0.00
Lawndale Creek Total		**$6,464.54**	**0.00**	**0.00**

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet
ENTF:	$248,731.00	3,846.57	50,566.73
Other Funds:	$19,944.69	312.91	132.29
State Funds:	$65,219.28	1,329.94	1,026.03
Other:	$44,983.01	3.05	1,158.95
Total:	**$378,877.98**	**5,492.47**	**52,884.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2H:Fish Habitat Restoration - MN DNR - Division of Fisheries

Work Program Expenditures - Not Attributable to Specific Projects

FundingType	*Category*	*Amount*	*Description*
ENTF	Professional Services	$31,269.00	For engineering and design work.
	Total:	**$31,269.00**	

Work Program Expenditures (Not Attributable to Specific Projects) By Funding Type

Funding Type	Amount
ENTF	$31,269.00
Total	**$31,269.00**

Work Program Expenditures Breakdown

Funding Type:	Restoration Projects	Not Attributable to Specific Projects	Total
ENTF	$248,731.00	$31,269.00	$280,000.00
Other Funds	$19,944.69	$0.00	$19,944.69
State Funds	$0.00	$0.00	$65,219.28
Other	$44,983.01	$0.00	$44,983.01
Total	$378,877.98	$31,269.00	$410,146.98

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

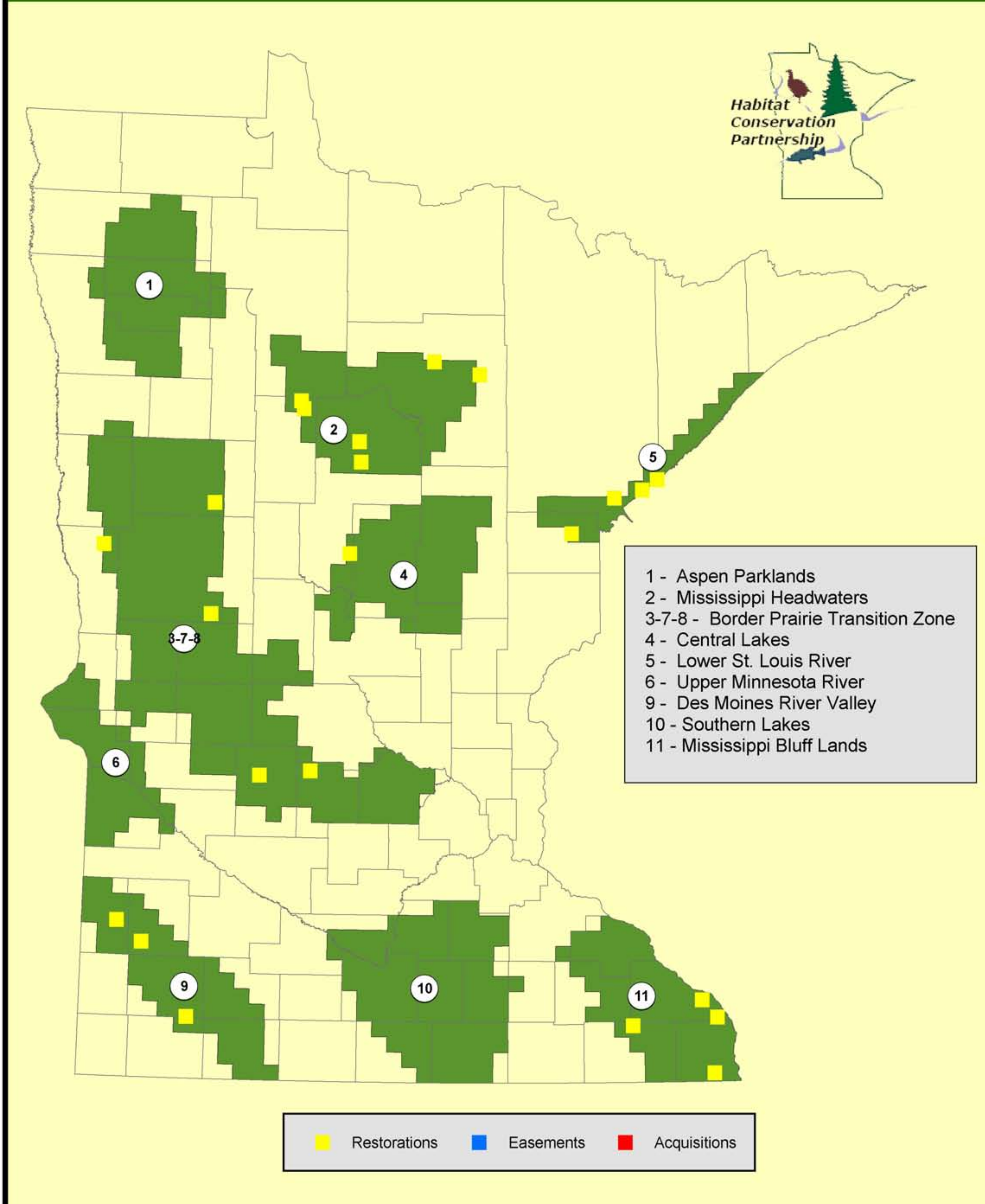
Proposal Title: Fish and Wildlife Habitat Restoration 2h

Project Manager Name: Linda Erickson-Eastwood

LCMR Requested Dollars: $ *280,000*

2007 LCCMR Proposal Budget (8/04 version)	**Result 1 Budget:**	**Amount Spent**	**Balance**	
BUDGET ITEM	*Habitat Projects*			**TOTAL FOR BUDGET ITEM**
Contracts				
Professional/technical				
Other contracts: For materials, equipment and other project implementation costs.	$205,000.00	**$248,280.00**	**$0.00**	**$248,280.00**
Other land improvement *(for what?) Signage of parcel, clean-up, building removal, etc.*	$25,000.00	**$0.00**	**$0.00**	**$0.00**
Other *(Describe the activity and cost) Costs include those incurred by the state for staff time for the Division of Lands and Minerals and the Attorney General's Office, survey costs and engineering design costs.*	$50,000.00	**$31,720.00**	**$0.00**	**$31,720.00**
COLUMN TOTAL	**$280,000.00**	**$280,000.00**	**$0.00**	**$280,000.00**

Habitat Conservation Partnership
Phase 4 - Accomplishments
2H - Fish Habitat Restoration - MN DNR - Division of Fisheries



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2I:Set out Seedlings - National Wild Turkey Federation

Project Manager: Dave Neu

Affiliation: National Wild Turkey Federation

Address: 265 Lorrie Way
De Pere, WI 54115

Phone: (920)347-0312

Fax: (920)427-2335

E-mail: neunwtf@sbcglobal.net

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Restoration	$20,000	$20,000	$0	$20,000	$0
Total	$20,000	$20,000	$0	$20,000	$0

Work Program Summary

Overall Project Outcome and Results

The Wilton River Longspurs chapter of the NWT purchased approximately 35,000 mast-producing native trees and shrubs which were planted on 70+ acres of private land in Waseca County in spring 2009, with the assistance of the NWTF Regional Wildlife Biologist. They also purchased hardwood tree seeds to be direct seeded on 21 acres of private land in the same area. This project will provide a permanent food source for wild turkeys and other wildlife.

Project Results Use and Dissemination

Once planted, photos will be taken and a press release will be developed and distributed by the NWTF Communications Department.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2I:Set out Seedlings - National Wild Turkey Federation

Restoration Activities

Project Area - 10 - Southern Lakes

Project Name: WIlton River Longspurs

Tract: 1

Township: 107, Range: 24, Section: 1

Activity: Woodland Restoration

Landtype: Private - Land

Description: The Wilton River Longspurs Chapter of the NWTF purchased 35,000 native tree and shrub seedlings which will be planted on private land in Waseca County in the spring of 2009. They also purchased tree seeds which will be planted on 21 acres in the same area.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*	*ProratedTrees Planted*
ENTF	Restoration	$20,000.00	91.00	0.00	

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet	# Trees Planted
ENTF:	$20,000.00	91.00	0.00	
Total:	**$20,000.00**	**91.00**	**0.00**	

Attachment A: Budget Detail for 2007 Projects

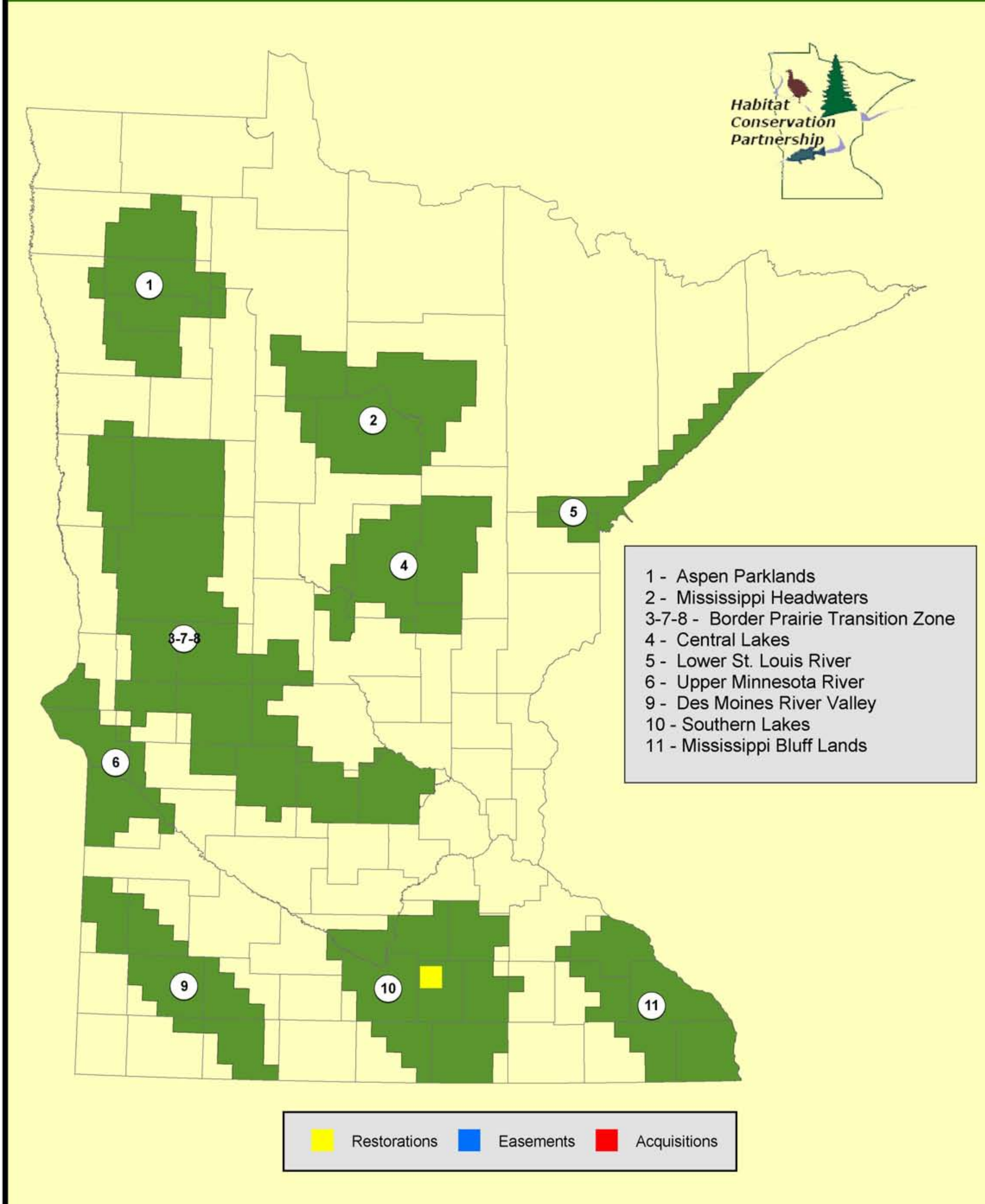
Project Title: Minnesota *NWTF Land Acquisition (4f) and SOS (2i)*

Project Manager Name: *Dave Neu*

Trust Fund Appropriation: $3*5,000*

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	**Result 2 Budget:**	**Amount Spent**	**Balance**	**TOTAL BUDGET**	**TOTAL BALANCE**
	4F - Land Acquisition			*2I - Set Out Seedlings*				
BUDGET ITEM								
Contracts								
Land acquisition	$15,000		$15,000			$0	$15,000	$15,000
Other Supplies *(trees, tubes, mats, stakes)*			$0	$20,000	$20,000	$0	$20,000	$0
COLUMN TOTAL	**$15,000**	**$0**	**$15,000**	**$20,000**	**$20,000**	**$0**	**$35,000**	**$15,000**

Habitat Conservation Partnership
Phase 4 - Accomplishments
2I - Set Out Seedlings - National Wild Turkey Federation



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2J:Lakescaping - MN DNR - Division of Ecological Services

Project Manager: Carrol Henderson
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Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds * Proposed	Other Funds * Spent
Restoration	$100,000	$100,000	$0	$5,000	$0
Total	$100,000	$100,000	$0	$5,000	$0

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:

State Funds: $20,830.00
Partners State Levereged Funds: $7,000.00

See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results

Please Input a Overall Project Outcome and Results: A total of 12 lakescaping demonstration site buffer zones were selected on private lands, and DNR staff worked with the homeowners on a cost-sharing basis to develop a plan for their property that would stabilize the shoreline, improve wildlife habitat, enhance associated water quality and reduce runoff. Plantings were installed in 2007, 2008, and spring and early summer of 2009. These 12 plantings included a total of 1675 feet of shoreline and are serving as a model for adjacent lake owners and lake association members who can see that this is a cost-effective, ecologically sound, and and desirable landscaping treatment for shoreline property. Two field trips were also carried out for local citizens to view demonstration sites in the Brainerd and Detroit Lakes areas.

Project Results Use and Dissemination

Please Input a Project Results Use and Dissemination: The key to the success of the lakescaping demonstration areas is that they serve as a catalyst to stimulate discussion and involvement with lakeshore management to improve water quality at the homeowner's level. There are concurrent benefits for fisheries and wildlife habitat and educational opportunities to show homeowners that there are economical, ecologically sound, and esthetically pleasing strategies for managing lakeshore property that are in stark contrast to the "lawn all the way to the lawn" vision that lakeshore owners have often adopted in the past. The creation of the lakescaping demonstration areas are used to promote lake health and water quality in conjunction with companion support materials like the DNR book "Lakescaping for Wildlife and Water Quality" and the "Restore Your Shore" CD. A total of 24,514 copies of the Lakescaping book have been sold since it came out in 1997, so the public acceptance of the lakescaping buffer zone concept is increasing. By providing actual sites where these buffer zones have been installed as demonstration sites, it helps reassure homeowners that such landscaping does not look like a messy patch of weeds and that it will not cause an increase in mosquito problems.

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
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2J:Lakescaping - MN DNR - Division of Ecological Services

Restoration Activities

Project Area - 1 - Aspen Parklands

Project Name: Lakescaping field trip
Township: 135, Range: 29, Section: 15

Activity: Outreach
Landtype: Private - Lake
Description: A field trip for the public and interested members of the DNR and PCA was conducted on October 30, 2008, in the Brainerd area at Gilbert Lake, Perch Lake, and Nisswa Lake to visit the lakescaping demonstration sites that had been installed on those lakes. A total of 20 people attended. A field trip was also held on June 16 at Detroit Lakes for a total of 22 people to view four different lakescaping sites.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$500.00	0.00	0.00
State Funds	Personnel Expenditures	$250.00	0.00	0.00
Lakescaping field trip Total		**$750.00**	**0.00**	**0.00**

Project Name: Middle Cormorant
Township: 138, Range: 43, Section: 22

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: This lakescaping buffer zone site has been planned and the plants and bioengineering materials acquired. Installation planned for Jun3 1-5, 2009.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$13,400.00	1.00	480.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Middle Cormorant Total		**$15,115.00**	**1.00**	**480.00**

Project Name: Lower Cullen
Tract: 1
Township: 135, Range: 29, Section: 1

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: This restoration will take place along 100 feet of shoreline and will be adjacent to another property that is also undergoing a lakescaping restoration. All site planning and design is completed, and native plants and bioengineering materials have been acquired. Installation will occur the week of June 10, 2009.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$9,045.00	1.00	100.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Lower Cullen 1 Total		**$10,760.00**	**1.00**	**100.00**

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2J:Lakescaping - MN DNR - Division of Ecological Services

Project Name: Lower Cullen
Tract: 2
Township: 135, Range: 29, Section: 1

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: This property is adjacent to site 1 which is also being restored. All planning, design, acquisition of native plants and bioengineering supplies have been purchases. Installation will occur on June 10-11.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$9,445.00	1.00	100.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Lower Cullen 2 Total		**$11,160.00**	**1.00**	**100.00**

Project Name: Lake Andrew
Tract: 2
Township: 121, Range: 35, Section: 12

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: This site has been planned and designed. The native plants and bioengineering materials have already been purchased. The site will be installed during the week of May 20, 2009.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$6,775.00	1.00	100.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Lake Andrew 2 Total		**$8,490.00**	**1.00**	**100.00**

Project Name: Pelican Lake
Township: 130, Range: 41, Section: 22

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: Lakeshore restoration on this site planned and designed; native plants have been purchased and bioengineering material are purchased. Site installation on June 11-13, 2009.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$6,500.00	1.00	100.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Pelican Lake Total		**$8,215.00**	**1.00**	**100.00**

Project Area - 4 - Central Lakes

Project Name: Nisswa Lake, Crow Wing County
Township: 135, Range: 29, Section: 15

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: A total of 135 feet of shoreline was restored on this site with native plants.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$9,045.00	0.00	135.00
Partners State Leveraged Funds	Site Development	$1,000.00	0.00	0.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Nisswa Lake, Crow Wing County Total		**$11,760.00**	**0.00**	**135.00**

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2J:Lakescaping - MN DNR - Division of Ecological Services

Project Name: Lower Whitefish Lake
Tract: 1
Township: 137, Range: 27, Section: 29

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: A total of 200 feet of shoreline was restored on this site with native plants.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$13,400.00	0.00	200.00
Partners State Leveraged Funds	Site Development	$1,000.00	0.00	0.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Lower Whitefish Lake 1 Total		**$16,115.00**	**0.00**	**200.00**

Project Name: Sibley Lake
Tract: 1
Township: 136, Range: 29, Section: 15

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: A total of 75 feet of shoreline was restored using native plants.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$5,025.00	0.00	75.00
Partners State Leveraged Funds	Site Development	$1,000.00	0.00	0.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Sibley Lake 1 Total		**$7,740.00**	**0.00**	**75.00**

Project Area - 3-7-8 - Border Prairie Transition Zone

Project Name: Charlotte Lake
Tract: 1
Township: 125, Range: 41, Section: 24

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: A total of 80 feet of shoreline was planted with native plants to create a buffer zone.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$5,360.00	0.00	80.00
Partners State Leveraged Funds	Site Development	$1,000.00	0.00	0.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Charlotte Lake 1 Total		**$8,075.00**	**0.00**	**80.00**

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2J:Lakescaping - MN DNR - Division of Ecological Services

Project Name: Round Lake
Tract: 1
Township: 135, Range: 39, Section: 22

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: A total of 120 feet of shoreline was restored with native plants.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$8,040.00	0.00	120.00
Partners State Leveraged Funds	Site Development	$1,000.00	0.00	0.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Round Lake 1 Total		**$10,755.00**	**0.00**	**120.00**

Project Name: Lake Jennie
Tract: 1
Township: 118, Range: 29, Section: 29

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: A total of 120 feet of shoreline was restored using local origin native plants.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$8,440.00	0.00	120.00
Partners State Leveraged Funds	Site Development	$1,000.00	0.00	0.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Lake Jennie 1 Total		**$11,155.00**	**0.00**	**120.00**

Project Name: Lower Hay Lake
Tract: 1
Township: 137, Range: 29, Section: 13

Activity: Shoreline Habitat Restoration / Stabilization
Landtype: Private - Lake
Description: A total of 75 feet of shoreline was planted with local origin native plants to create a buffer zone.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$5,025.00	0.00	75.00
Partners State Leveraged Funds	Site Development	$1,000.00	0.00	0.00
State Funds	Personnel Expenditures	$1,715.00	0.00	0.00
Lower Hay Lake 1 Total		**$7,740.00**	**0.00**	**75.00**

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet
ENTF:	$100,000.00	5.00	1,685.00
Partner's State Leveraged Funds	$7,000.00	0.00	0.00
State Funds:	$20,830.00	0.00	0.00
Total:	**$127,830.00**	**5.00**	**1,685.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
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2J:Lakescaping - MN DNR - Division of Ecological Services

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

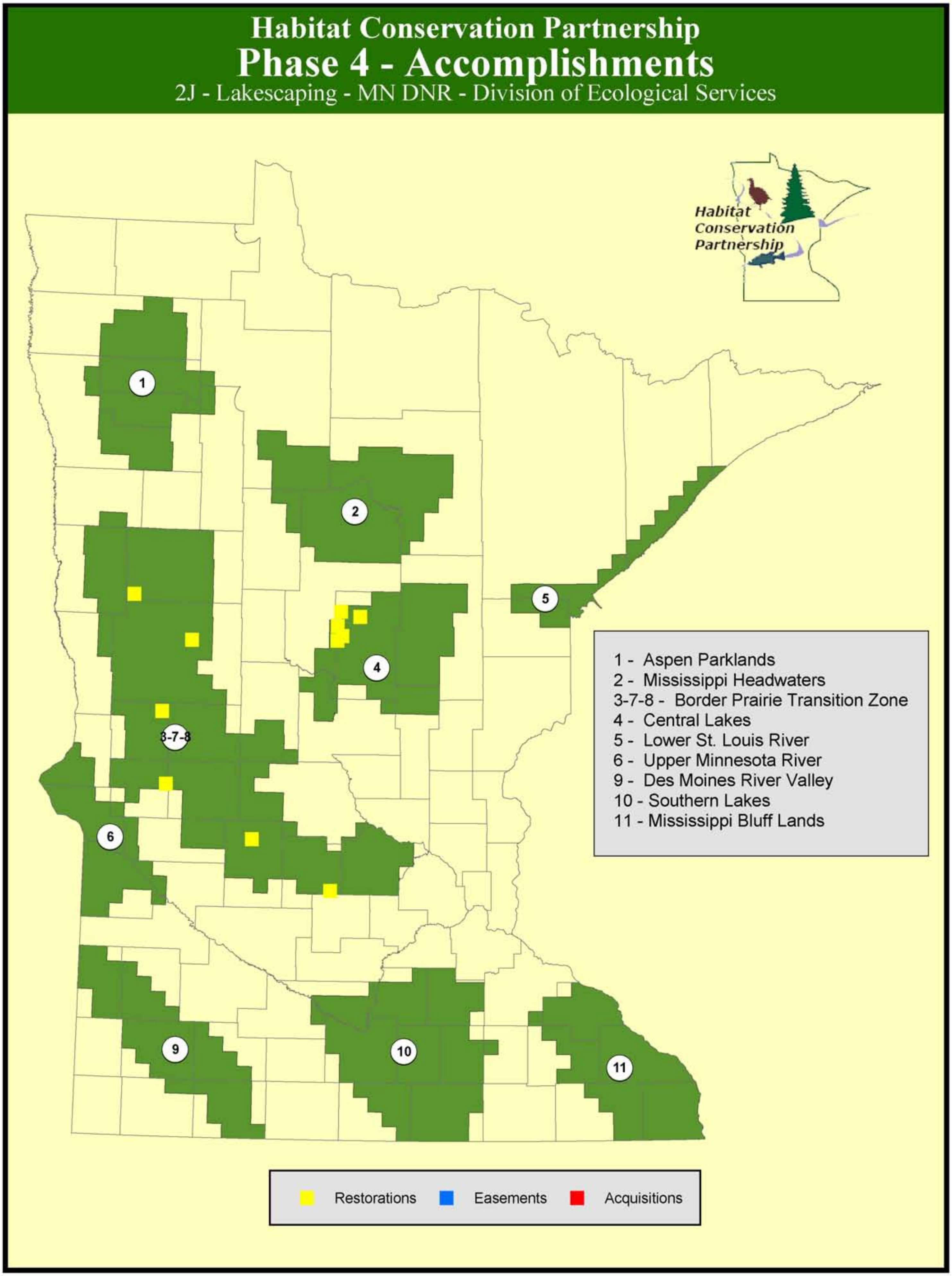
Attachment A: Budget Detail for 2007 Projects

Project Title: Lakescaping for Wildlife and Water Quality, 2(j)

Project Manager: Carrol L. Henderson

Trust Fund Appropriation: $100,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	**Result 2 Budget:**	**Amount Spent**	**Balance**	**TOTAL BUDGET**	**Amount spent**	**TOTAL BALANCE**
BUDGET ITEM	Demo sites			Field Trip					
PERSONNEL: Fisheries tech, at $59,000; 2 nongame wildlife techs at $5,500 each.	$50,000	$50,700	-$700	$0	$0	$0	$50,000	$50,700	-$700
Equipment / Tools								$0	
Supplies: (Plants/bioengineering/food for volunteers)	$36,500	$36,500	$0	$500	$500	$0	$37,000	$37,000	$0
Travel expenses in Minnesota	$13,000	$12,300	$700	$0	$0	$0	$13,000	$12,300	$700
COLUMN TOTAL	**$99,500**	**$99,500**	**$0**	**$500**	**$500**	**$0**	**$100,000**	**$100,000**	**$0**


Habitat Conservation Partnership
Phase 4 - Accomplishments
2J - Lakescaping - MN DNR - Division of Ecological Services
Habitat Conservation Partnership
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3-7-8
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11
1 - Aspen Parklands
2 - Mississippi Headwaters
3-7-8 - Border Prairie Transition Zone
4 - Central Lakes
5 - Lower St. Louis River
6 - Upper Minnesota River
9 - Des Moines River Valley
10 - Southern Lakes
11 - Mississippi Bluff Lands
Restorations
Easements
Acquisitions

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2K:Prairie Management - MN DNR - Scientific and Natural Areas Program

Project Manager: Jason Garms

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Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Restoration	$100,000	$100,000	$0	$50,000	$53,300
Total	$100,000	$100,000	$0	$50,000	$53,300

Work Program Summary

Overall Project Outcome and Results

This project continues an initiative to tackle the 'backlog' of prairie and grassland management needs in priority prairie landscapes. It focuses primarily on woody encroachment removal and prescribed burning, although some restoration and other prairie management projects will be implemented, Prairie management crews and contracts will be used to accelerate current levels of effort. Existing grasslands are impaired by the encroachment of woody vegetation. A lone tree, for example, can affect nesting grassland birds over a radius of 200 yards around that tree (6.5 ac.). A 1/4 mile long tree line on the edge of a field influences approximately 40 acres. The cost of tree removal has ranged between $5.22 and $8.00 per tree, or $25 per acre impacted. Tree and brush removal funded by this project will improve an estimated 2,000 acres native prairie and other grassland habitat. Prescribed burns on native prairie every four to five years is the most effective means to accomplish management goals. This project will accelerate existing efforts and result in an estimated additional 1000 acres burned.

This effort will focus primarily on woody removal and prescribed burning, although some restoration and other prairie management projects will be implemented as well.

Description

Woody encroachment - A significant amount of woody encroachment has occurred on native prairie tracts over the past 50 years and is accelerating. Cutting scattered trees, fencerows, or small groves in prairies and grasslands can improve substantial areas of habitat. For example, removing trees along a 5 mile long fencerow (-1/2 acre of trees) can benefit up to 60 acres of habitat for grassland nesting birds.

Prescribed burning - The importance of fire for keeping prairies healthy is widely recognized. However, a limited spring and fall burn season makes it impossible to accomplish prescribed burning needs given current resources. This activity builds on the success of past LCMR accelerated prairie burning projects.

Project Results Use and Dissemination

Outline of Final Project Results

Woody Encroachment - A total of 134 acres of invading trees and brush have been removed from native prairie, which provides a benefit to all surrounding prairies and other grasslands. Two were completed on Native Prairie Bank easements (Blue Earth and Kandiyohi Counties), and one project completed on an Scientific & Natural Area (Prairie Bush Clover SNA - Jackson County).

Prescribed Burning - A total of 1177 acres of native prairie and surrounding grasslands have been a prescribed burn treatment

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Habitat Conservation Partnership

2K:Prairie Management - MN DNR - Scientific and Natural Areas Program

with these project funds. Prescribed burn plans were written for 26 sites and 23 burns were completed. 10 of these burns where on Scientific and Natural Areas, 13 of them where on perpetual Native Prairie Bank easements.

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Habitat Conservation Partnership

2K:Prairie Management - MN DNR - Scientific and Natural Areas Program

Restoration Activities

Project Area - 1 - Aspen Parklands

Project Name: Pembina Trail SNA
Township: 149, Range: 45, Section: 36

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 89 acres of native prairie.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$3,480.00	89.00	0.00

Project Name: Lake Pleasant 22 Prairie Bank
Township: 150, Range: 44, Section: 22

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 24 acres of native prairie.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$2,600.00	24.00	0.00

Project Area - 6 - Upper Minnesota River

Project Name: Camp Release 30 Prairie Bank
Township: 118, Range: 41, Section: 30

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 12 acres of native prairie.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$2,450.00	12.00	0.00

Project Name: Camp Release 32 Prairie Bank
Township: 117, Range: 41, Section: 32

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 37 acres of native prairie.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$2,975.00	37.00	0.00

Project Name: Hantho 17 Prairie Bank
Township: 119, Range: 43, Section: 17

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 32 acres of native prairie.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$2,760.00	32.00	0.00

Project Name: Schellberg Prairie Bank
Township: 122, Range: 46, Section: 35

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 53 acres of native prairie.

Funding Type	Funds Use	Funding Amount	Prorated Acres	Prorated Shoreline
ENTF	Restoration	$2,950.00	53.00	0.00

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2K:Prairie Management - MN DNR - Scientific and Natural Areas Program

Project Area - 9 - Des Moines River Valley

Project Name: Storden 21 Prairie Bank
Township: 107, Range: 37, Section: 21

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 20 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,775.00	20.00	0.00

Project Name: Belmont 5 Prairie Bank
Township: 103, Range: 35, Section: 5

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 49 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,950.00	49.00	0.00

Project Name: Holly 2 Prairie Bank
Township: 108, Range: 39, Section: 2

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 50 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,850.00	50.00	0.00

Project Name: Purrington Prairie
Township: 105, Range: 36, Section: 9

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 16 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,550.00	16.00	0.00

Project Name: Staples property
Township: 103, Range: 35, Section: 6

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 4 acres of restored prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,490.00	4.00	0.00

Project Name: Des Moines River Prairie SNA
Township: 104, Range: 35, Section: 19

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 86 acres of native and restored prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,990.00	86.00	0.00

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2K:Prairie Management - MN DNR - Scientific and Natural Areas Program

Project Name: Gylnn Prairie SNA
Township: 109, Range: 40, Section: 7

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 32 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$3,430.00	32.00	0.00

Project Name: Lundblad Prairie SNA
Township: 105, Range: 41, Section: 1

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 30 acres of native and restored prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,720.00	30.00	0.00

Project Name: Prairie Bush Clover SNA
Township: 103, Range: 35, Section: 17

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Woody encroachment was removed from 20 acres of native prairie. Encroachment had been threatening a Prairie Bush Clover population (Federally listed sps).

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$8,000.00	20.00	0.00

Project Area - 10 - Southern Lakes

Project Name: Angell Prairie
Township: 111, Range: 19, Section: 1

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Invasive woody species removed from a remnant native prairie. The site has Prairie Bush-Clover and many other rare species.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$6,500.00	8.00	0.00

Project Name: Judson 3 Prairie Bank
Township: 108, Range: 28, Section: 3

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Woody encroachment was removed from 16 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,760.00	16.00	0.00

Project Name: Hythecker Prairie SNA
Township: 107, Range: 18, Section: 31

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 21 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$3,525.00	21.00	0.00

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2K:Prairie Management - MN DNR - Scientific and Natural Areas Program

Project Name: Osmundson Prairie
Township: 101, Range: 24, Section: 36

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 3 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$1,890.00	3.00	0.00

Project Area - 11 - Mississippi Bluff Lands

Project Name: Kellog-Weaver Dunes SNA
Township: 109, Range: 9, Section: 6

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 100 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,825.00	100.00	0.00

Project Name: Oronoco Prairie SNA
Township: 108, Range: 14, Section: 22

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 4 different units for a total of 37 acres of native prairie burned.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$3,645.00	37.00	0.00

Project Area - 3-7-8 - Border Prairie Transition Zone

Project Name: B-B Prairie Bank
Township: 141, Range: 46, Section: 13

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 215 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$4,600.00	215.00	0.00

Project Name: Clay County Prairie
Township: 141, Range: 45, Section: 6

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 167 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$4,550.00	167.00	0.00

Project Name: Nidaros 21 Prairie Bank
Township: 132, Range: 39, Section: 22

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Firebreak installed and a prescribed burn was conducted on 20 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,630.00	20.00	0.00

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2K:Prairie Management - MN DNR - Scientific and Natural Areas Program

Project Name: Blanket Flower Prairie SNA
Township: 137, Range: 44, Section: 11

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 64 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$3,840.00	64.00	0.00

Project Name: Veryln Marth SNA
Township: 126, Range: 42, Section: 6

Activity: Grassland Enhancement
Landtype: Public - SNA
Description: Firebreak installed and a prescribed burn was conducted on 16 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$2,760.00	16.00	0.00

Project Name: Norway Lake 5 Prairie Bank
Township: 123, Range: 36, Section: 5

Activity: Grassland Enhancement
Landtype: Private - Land
Description: Woody encraochment was removed from 90 acres of native prairie.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$14,505.00	90.00	0.00

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet
ENTF:	$100,000.00	1,311.00	0.00
Total:	**$100,000.00**	**1,311.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2K:Prairie Management - MN DNR - Scientific and Natural Areas Program

Work Program Expenditures - Not Attributable to Specific Projects

FundingType	*Category*	*Amount*	*Description*
Other Funds	Personnel Expenditures	$17,000.00	Salary expenditures resulting from technical and cost-share assistance provided to native prairie landowners (Landowner Incentive Program - LIP funds)
Other Funds	Equipment Costs	$8,900.00	Equipment costs resulting from technical and cost-share assistance activities provided to native prairie landowners (Landowner Incentive Program - LIP funds)
Other Funds	Technical Assistance	$23,300.00	Cost-share assistance provided to native prairie landowners for stewardship activities(Landowner Incentive Program - LIP funds)
Other Funds	Admin	$2,000.00	Costs associated with administering the Landowner Incentive Program - LIP
Other Funds	Supplies and Misc	$2,100.00	Supply costs associated with implementation of prairie stewardhip activities funded by the Landowner Incentive Program funds (LIP)
	Total:	**$53,300.00**	

Work Program Expenditures (Not Attributable to Specific Projects) By Funding Type

Funding Type	**Amount**
Other Funds	$53,300.00
Total	**$53,300.00**

Work Program Expenditures Breakdown

Funding Type:	**Restoration Projects**	**Not Attributable to Specific Projects**	**Total**
ENTF	$100,000.00	$0.00	$100,000.00
Other Funds	$0.00	$53,300.00	$53,300.00
Total	$100,000.00	$53,300.00	$153,300.00

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

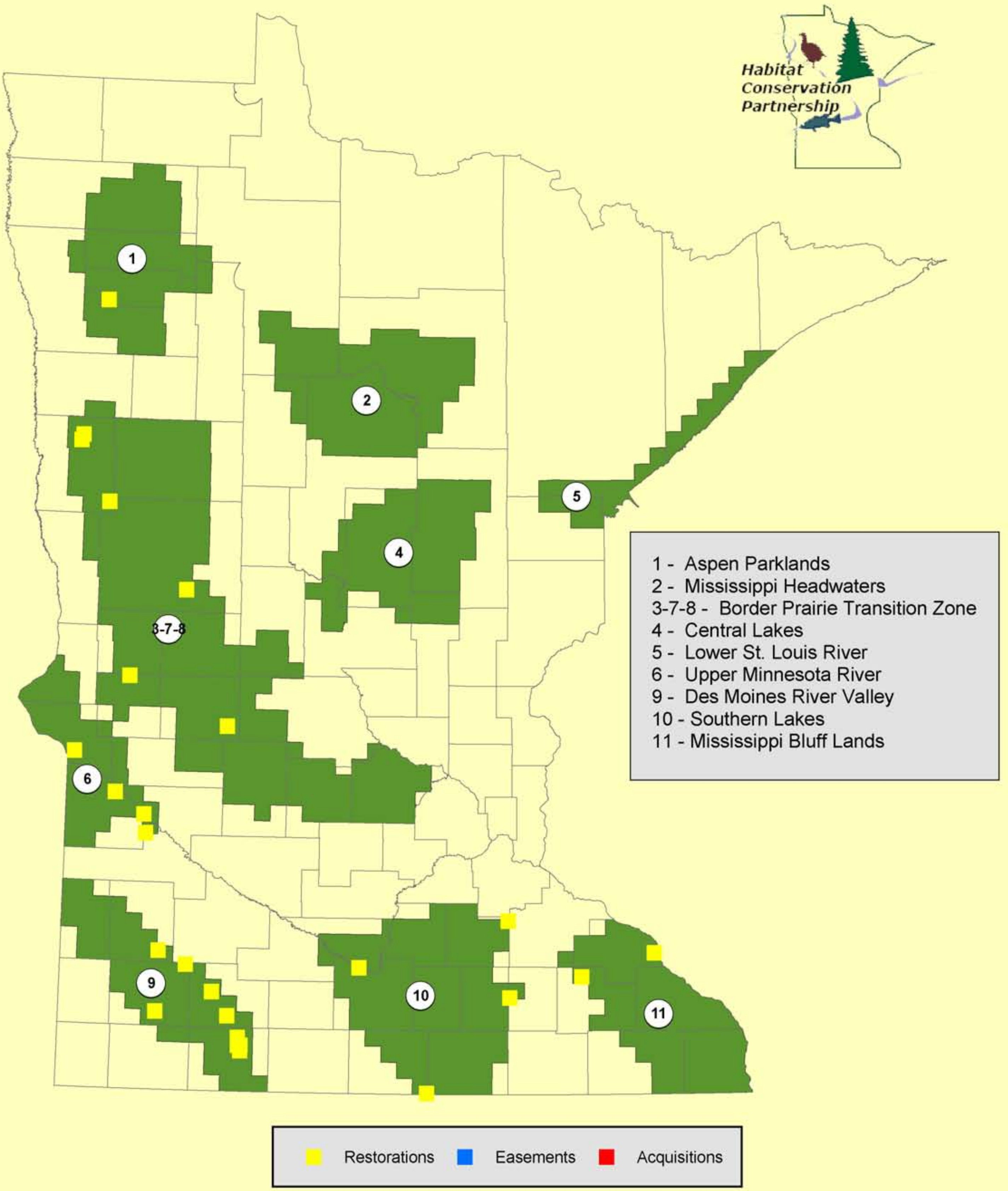
Project Title: Habitat Conservation Partnership Phase IV, Habitat Restoration and Management 2K - Prairie Management. Subd.4b2k

Project Manager Name: Jason Garms

Trust Fund Appropriation: $ 100,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	**TOTAL BUDGET**	**TOTAL BALANCE**
	Habitat Restoration and Management				
BUDGET ITEM					
PERSONNEL: wages and benefits	$60,000	$61,200	-$1,200	$60,000	-$1,200
Contracts					
Other contracts: prescribed burning and woody encroachment contracts	$15,000	$13,500	$1,500	$15,000	$1,500
Equipment / Tools (project supplies, vehicle fleet costs (e.g. ATV, Pick-up, ASV tracked vehicle)	$25,000	$25,300	-$300	$25,000	-$300
COLUMN TOTAL	**$100,000**	**$100,000**	**$0**	$100,000	$0

Habitat Conservation Partnership
Phase 4 - Accomplishments
2K - Prairie Managment - MN DNR - Scientific and Natural Areas Program



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2N:Campaign for Conservation - Restoration - The Nature Conservancy

Project Manager: Michael Pressman

Affiliation: The Nature Conservancy

Address: 1101 West River Parkway
Minneapolis, MN 55415

Phone: 612-331-0706

Fax: 612-331-0770

E-mail: mpressman@tnc.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Restoration	$80,000	$80,000	$0	$80,000	$22,549
Total	$80,000	$80,000	$0	$80,000	$22,549

Work Program Summary

Overall Project Outcome and Results

The Nature Conservancy uses a rigorous planning process to preserve key properties for biological diversity called "Conservation by Design." This method provides for the identification of sites of high biodiversity significance on which to concentrates its financial resources for acquisition and restoration. The Conservancy prefers to acquire large tracts of land but will also assemble smaller properties to form larger blocks of habitat. To accomplish this goal on the landscape level, the Minnesota Chapter of The Nature Conservancy partners with public agencies and other NGO's to locate and acquire such properties that achieve results at the large-scale and across multiple location targets. For its "Campaign for Conservation," the Conservancy proposes to acquire and retain in fee title up to 125 acres (with ETF funds; Conservancy will provide the remaining funds as needed) in one or several blocks to re-connect fragmented landscapes; acquire conservation easements on up to 200 acres of riparian lands; and restore 350 acres of wetlands and existing protected prairie and savanna habitat.

The Conservancy received $80,000 for restoration of 350 acres of wetlands and existing protected prairie and savanna habitat in Project Areas 1 and 3. By the end of this grant period, TNC restored 186 acres of wetlands at the Conservancy's Glacial Ridge Project in Project Area 1, burned over 1,311 acres of native and restored grasslands, and surveyed and treated over 9,800 acres on TNC preserves in Project Area 3.

In this time period, the Conservancy spent an additional $22,548.79 of its private funds on restoration in Project Areas 1 and 3.

Project Results Use and Dissemination

The Conservancy publicizes its work on these projects via press releases, membership publications, presentations and/or the Conservancy's website. The Conservancy has also participated in publicizing the overall accomplishments of the Habitat Corridors Partnership project as it has reached significant mile marks.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2N:Campaign for Conservation - Restoration - The Nature Conservancy

Restoration Activities

Project Area - 1 - Aspen Parklands

Project Name: Glacial Ridge
Tract: Glacial Ridge
Township: 149, Range: 44, Section: 8

Activity: Grassland Restoration
Landtype: Private - Land
Description: The Nature Conservancy restored 186 acres of wetlands at TNC's Glacial Ridge Project in Polk County. This is 136 acres more than the planned 50 acres. Glacial Ridge is the largest prairie and wetland restoration project in America and is a collaboration of more than 30 non-profit, government, and university partners. Eventually, Glacial Ridge will support more than 16,000 acres of native and restored tallgrass prairie and more than 8,000 acres of restored wetlands. Because of its size and location, Glacial Ridge will ultimately serve as a hub connecting other natural areas including 11 state wildlife management areas, two scientific and natural areas, three waterfowl production areas, and the Conservancy's existing Pembina Trail Preserve.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$60,000.00	176.10	0.00
Other Funds	Restoration	$3,373.00	9.90	0.00
Glacial Ridge Glacial Ridge Total		**$63,373.00**	**186.00**	**0.00**

Project Area - 3 - Border Prairie

Project Name: Aggasiz Beach Ridges
Tract: multiple
Township: 139, Range: 46, Section: 22

Activity: Grassland Restoration
Landtype: Private - Land
Description: Prescribed fire on more than 1,311 acres and invasive species survey and control on approximately 9,800 acres on multiple TNC preserves in the Aggassiz Beach Ridges Landscape. This is more than the 300 acres of prairie restoration and management called for in the workprogram.

$20,000 in 12/08 report are for personnel expenditures. They were listed as restoration to facilitate proper acres proration in the online reporting system.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$20,000.00	9,800.00	0.00

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet
ENTF:	$80,000.00	9,976.10	0.00
Other Funds:	$3,373.00	9.90	0.00
Total:	**$83,373.00**	**9,986.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2N:Campaign for Conservation - Restoration - The Nature Conservancy

Work Program Expenditures - Not Attributable to Specific Projects

FundingType	*Category*	*Amount*	*Description*
Other Funds	Admin	$19,175.79	The $19,175.79 in Other Funds listed represents indirect costs (calculated at 23% of allowable costs) on the $80,000 of reimbursable expenses incurred through the restoration portion of the grant and the allowable match expenses ($3,373) already incurred. The Conservancy's federally approved indirect cost recovery rate of 23% (at the time of Phase IV contract) has been applied. This rate is approved by the Conservancy's federal cognizant agency, the US Department of the Interior. A copy of the of the official negotiated indirect rate agreement can be provided upon request.
	Total:	**$19,175.79**	

Work Program Expenditures (Not Attributable to Specific Projects) By Funding Type

Funding Type	Amount
Other Funds	$19,175.79
Total	**$19,175.79**

Work Program Expenditures Breakdown

Funding Type:	Restoration Projects	Not Attributable to Specific Projects	Total
ENTF	$80,000.00	$0.00	$80,000.00
Other Funds	$3,373.00	$19,175.79	$22,548.79
Total	$83,373.00	$19,175.79	$102,548.79

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

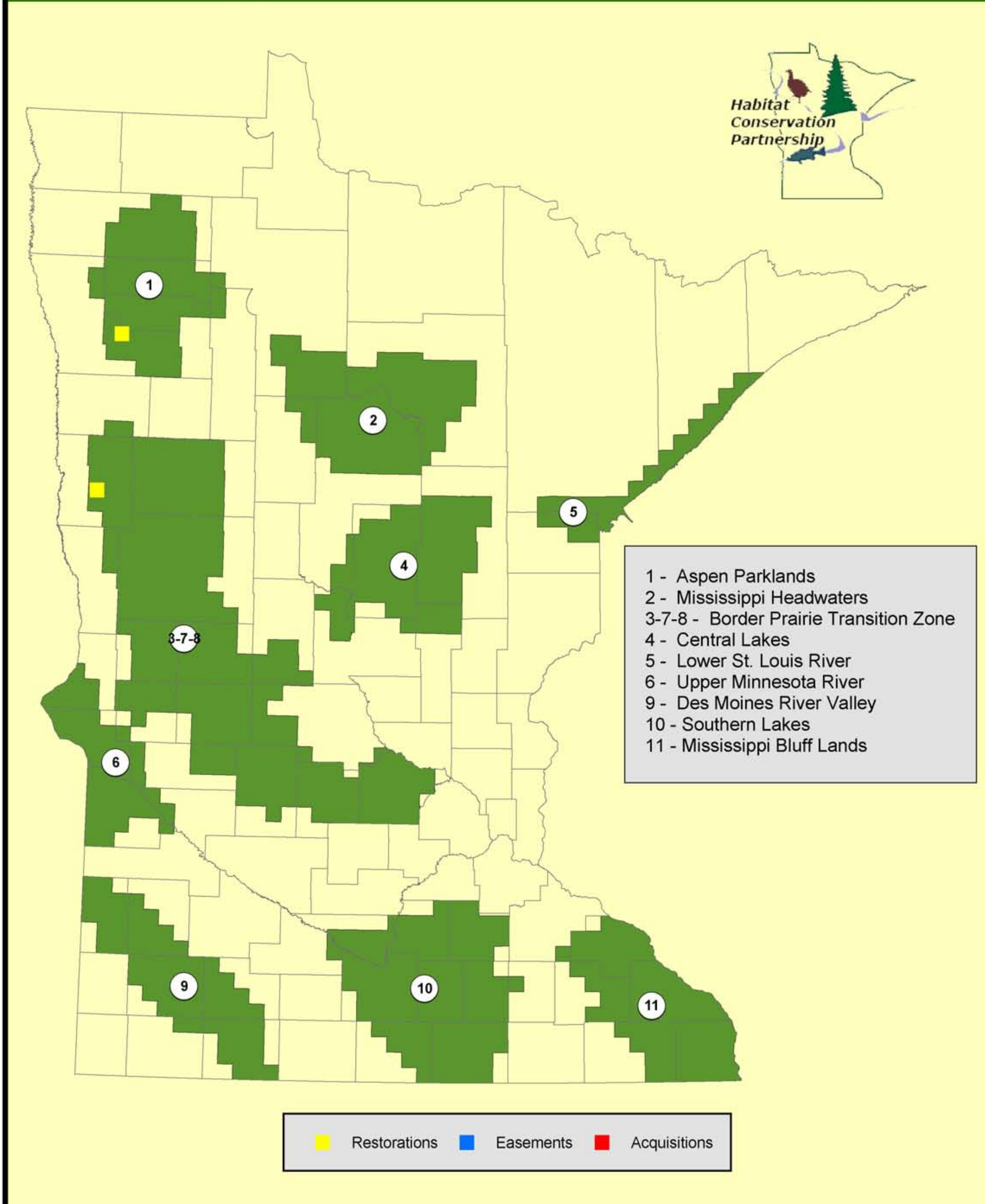
Project Title: TNC's 'Campaign for Conservation' – 2(n), 3(g), 4(g)

Project Manager Name: Michael Pressman

Trust Fund Appropriation: $430,000

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent	Balance	Result 2 Budget:	Amount Spent	Balance	Result 3 Budget:	Amount Spent	Balance	TOTAL BUDGET	TOTAL BALANCE
	Land acquisition			Conservation easements or land acquisition			Restoration				
BUDGET ITEM											
Personnel							20,000	20,000	0	20,000	0
Contracts											
Prescribed burning crews, tree removal and/or seeding services							60,000	60,000	0	60,000	0
Land acquisition	300,000	300,000	0							300,000	0
Land rights acquisition				50,000	50,000	0				50,000	0
Professional Services											
Appraisals, surveys, title work, closing costs, environmental review											
COLUMN TOTAL	**$300,000**	**$300,000**	**$0**	**$50,000**	**$50,000**	**$0**	**$80,000**	**$0**	**$0**	**$430,000**	**$0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
2N - Campaign for Conservation - Restoration - The Nature Conservancy



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

2O:Working Lands Initiative Partnership - FWS

Project Manager: Scott Kahan
Affiliation: FWS
Address: 26624 North Tower Road
Detroit Lakes, MN 56501
Phone: 218-844-3403
Fax: 218-847-4165
E-mail: Scott_Kahan@fws.gov

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Restoration	$20,000	$20,000	$0	$4,000	$5,000
Total	$20,000	$20,000	$0	$4,000	$5,000

Work Program Summary

Overall Project Outcome and Results
Grant completed- All funds (ENTF and Partner) expended:

Location: Union Lake WPA

Project Area: 1 - Aspen Parklands

Project Results Use and Dissemination
In 2007, 15 small "prairie pothole" wetlands (totalling 12.5 acres) were restored on Union Lake WPA (Polk County). These wetlands had been previously ditched/filled when the land was in private ownership. Restoration consisted of removing all the fill from the from the wetlands, and completely filling in all the ditches. Restoration of these small "prairie pothole" wetlands greatly improves the value of the WPA and nearby lands to breeding waterfowl.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

2O:Working Lands Initiative Partnership - FWS

Restoration Activities

Project Area - 1 - Aspen Parklands

Project Name: Union Lake
Township: 147, Range: 43, Section: 3

Activity: Wetland Restoration
Landtype: Public - WPA
Description: In 2007, 15 small "prairie pothole" wetlands were restored on Union Lake WPA (Polk County).

These wetlands had been previously ditched/filled when the land was in private ownership. Restoration consisted of removing all the fill from the from the wetlands, and completely filling in all the ditches.

Restoration of these small "prairie pothole" wetlands greatly improves the value of the WPA and nearby lands to breeding waterfowl.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Prorated Shoreline*
ENTF	Restoration	$20,000.00	12.50	0.00
Other Funds	Personnel Expenditures	$5,000.00	0.00	0.00
Union Lake Total		**$25,000.00**	**12.50**	**0.00**

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Acres	Shoreline Feet
ENTF:	$20,000.00	12.50	0.00
Other Funds:	$5,000.00	0.00	0.00
Total:	**$25,000.00**	**12.50**	**0.00**

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
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Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

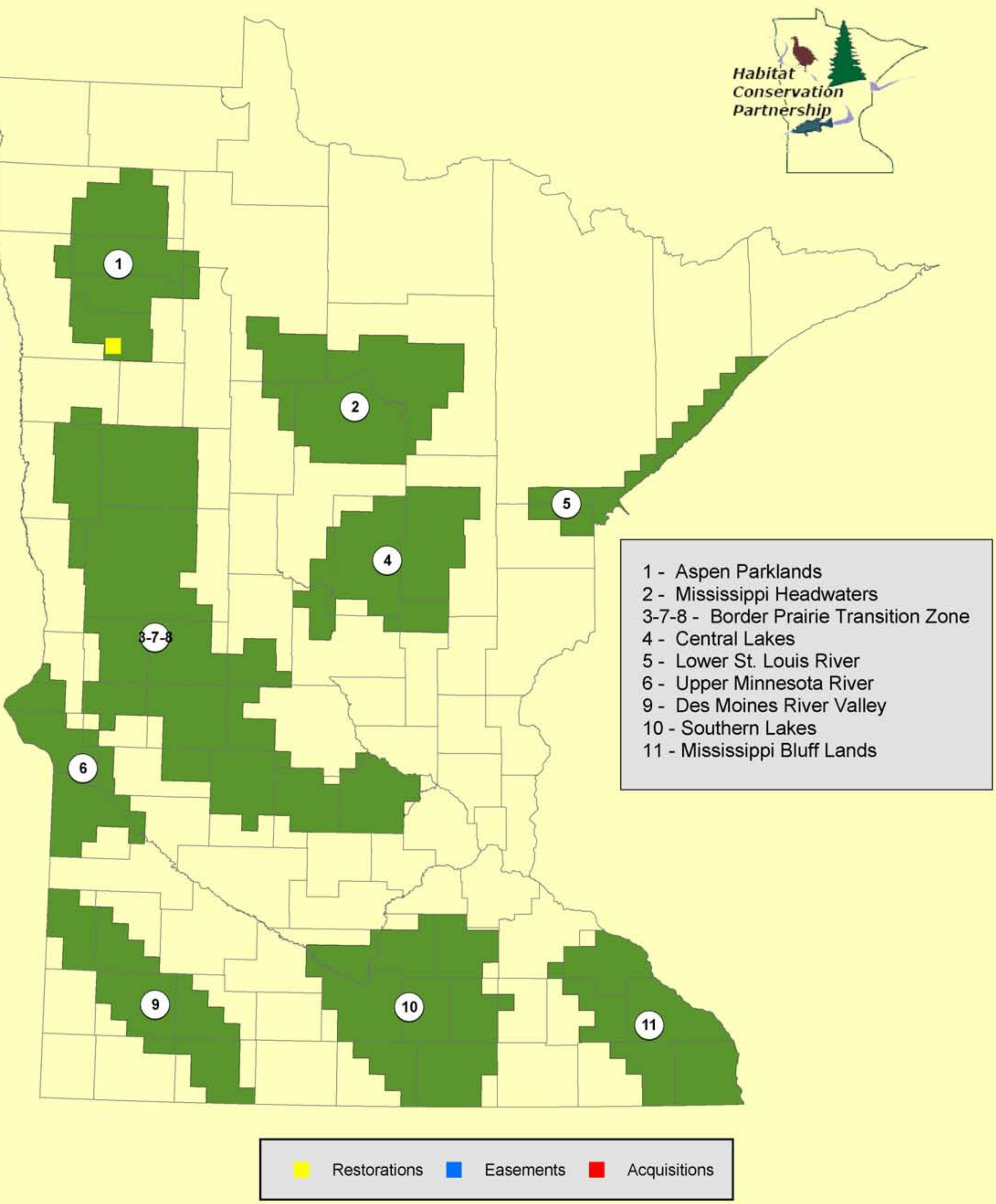
Project Title: *Minnesota Habitat Corridors Partnership - Phase IV 4b, Partners for Fish and Wildlife (2o)*

Project Manager Name: *Scott Kahan*

Trust Fund Appropriation: $20,000

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent	Balance	TOTAL BUDGET	TOTAL BALANCE
	restoration acres				
BUDGET ITEM					
Contracted Wetland Restorations					
20 Restoration Acres					
Project Area 1	$20,000	$20,000	$0	$20,000	$0
			$0	$0	$0
COLUMN TOTAL	**$20,000**	**$20,000**	**$0**	**$20,000**	**$0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
2O - Working Lands Initiative Partnership - FWS



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3A: Shorelands Protection Program - Minnesota Land Trust

Project Manager: Jane Prohaska
Affiliation: Minnesota Land Trust
Address: 2356 University Ave W
St. Paul, MN 55114
Phone: (651) 647-9590
Fax: (651) 647-9769
E-mail: jprohaska@mnland.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Balance	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Easement	$300,000	$300,000	$0	$0	$5,239,400
Total	$300,000	$300,000	$0	$0	$5,239,400

Work Program Summary

Overall Project Outcome and Results
In the fourth phase of our Shorelands Protection project, the Minnesota Land Trust continued to work with landowners to secure permanent conservation easements on quality habitat that borders or contains critical riparian lands. We initiated or continued contact with 67 landowners, completing 10 conservation easements. 7 of these easements directly complement or enhance projects completed under previous stages of this grant.

Collectively, these easements preserve 1,270 acres of land—almost tripling our goal of 300 to 500 acres—and protect more than 32,000 feet of fragile shoreline. Our individual projects are detailed below.

8 of the 10 conservation easements were donated. 2 were purchased, one at well below fair market value. These easements have a known value that exceeds $5,325,000 with landowners generously donating more than $5,160,000 in value. The cost to the State to protect this land was barely $236 per acre—well below the cost to purchase land along our increasingly threatened shorelines.

Additionally, the Land Trust prepared baseline reports for each easement, documenting the status of the property for future monitoring and enforcement.

To fund our required perpetual easement management, monitoring and enforcement obligations, the Land Trust also received and dedicated funds to its segregated Stewardship and Enforcement Fund for several of the completed projects. For these projects, we estimated the anticipated annual expenses for each project and the investment needed in order to generate annual income sufficient to cover these expenses in perpetuity—all in accordance with our internal policies and procedures as approved by LCCMR. We have also provided LCCMR with a letter documenting our commitment to protect the conservation values of these projects in perpetuity and will report to LCCMR annually on the status of the Stewardship and Enforcement Fund and the easements acquired with funds from this grant.

We are extremely pleased with our results under this grant. We will continue to work with many landowners initially contacted here during the next phase of this project, demonstrating the importance of ongoing funding. Enhanced federal income tax benefits available during this stage of the project to landowners donating easements certainly enabled us to exceed our project goals. However, our experience also leads us to continue to believe it will be necessary to purchase more easements if we wish to be increasingly more targeted and selective.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3A: Shorelands Protection Program - Minnesota Land Trust

Project Results Use and Dissemination
Through each individual project and through managing our growing portfolio of easements, the Minnesota Land Trust continually learns more about using and managing conservation easements effectively and efficiently. We remain convinced in the value of conservation easements as important land protection tools in appropriate circumstances. We continue to work with other easement holders--and potential holders--to share what we our learning from our extensive experience.

We also disseminated information about the specific land protection projects completed under this grant through our newsletter, annual report, website and press releases.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3A: Shorelands Protection Program - Minnesota Land Trust

Easement Activities

Project Name: Ten Mile Lake
Project Area: 2 - Mississippi Headwaters
Township: 141, Range: 30, Section: 31

Description: This 43-acre project in Cass County consists of seven parcels of land around the shore of Ten Mile Lake and includes more than 3,100 feet of shoreline. The protected parcels are located in four areas on the lake, and the parcels were selected from properties thought to be highly vulnerable to future development.

The protected property includes approximately wetlands, forest and grasslands. The property is located in close proximity to large expanses of the Chippewa National Forest as well as State and County-administered lands. Ten Mile Lake is one of the cleanest and deepest lakes in the state. Plant life has been documented as deep as 29 feet. The property provides needed habitat for wildlife species including bald eagles, gray wolves, red-necked grebes, loons and trumpeter swans.

The value of the easement is unknown.

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
Other Funds	Stewardship	$10,000.00	43.00	1.59	26.02	15.83	3,144.00	0.00

Project Name: Manitou River
Project Area: 5 - Lower St. Louis River
Township: 58, Range: 6, Section: 35

Description: This property in Lake County consists of approximately 8 acres of mature birch forest located northwest of a 9-acre conservation easement owned by the same landowner that is also held by the Land Trust. The original 9-acre easement also protects approximately 1,300 feet of shoreline along Lake Superior. The northern boundary of the 8-acre easement fronts Highway 61, a scenic byway. The property is adjacent to the Caribou Falls WMA and is located between the Little Manitou and Caribou Rivers. Caribou Falls State Park is less than 1/2 mile away. This area is a critical wintering habitat for whitetail deer and other native wildlife species that winter along the lake in the birch, cedar and pine forests, taking advantage of the lake-effect temperatures. The property is also a component of an identified migratory corridor for waterfowl, shorebirds and neo-tropical songbirds.

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
Other Funds	Donated Easement Value	$36,000.00	7.02	0.27	6.82	0.00	0.00	0.00
Other Funds	Stewardship	$5,000.00	0.98	0.04	0.95	0.00	0.00	0.00
	Total:	**$41,000.00**	**8.00**	**0.31**	**15.54**	**0.00**	**0.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3A: Shorelands Protection Program - Minnesota Land Trust

Project Name: Circle Lake
Project Area: 10 - Southern Lakes
Township: 111, Range: 21, Section: 16

Description: This 72-acre property in Rice County is located approximately 10 miles west of Northfield on Circle Lake. About 20 acres of the property were cultivated at one time and have since been planted in trees or allowed to grow wild. Extensive wetlands are located along the shoreline of Circle Lake. The property is located in a rapidly developing region of Rice County. Several new large lot developments are being constructed across Circle Lake from the property. Directly west of the property is an undeveloped tract of land with a USFWS conservation easement. Directly north across the lake is a portion of DNR-owned land with a fishing access pier and boat launch.

The extensive forest and grasslands of the property provide habitat for migratory and resident wildlife common to the area, and the extensive wetlands of the property and the shoreline along Circle Lake provide excellent aquatic near-shore and wetland habitat for a variety of wetland obligate wildlife and aquatic wildlife dependent on undeveloped shorelines

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Easement Acquisition Costs	$30,000.00	3.27	0.86	1.23	1.18	165.91	0.00
ENTF	Stewardship	$14,000.00	1.53	0.40	0.57	0.55	77.42	0.00
Other Funds	Donated Easement Value	$616,000.00	67.20	17.73	25.20	24.27	3,406.67	0.00
	Total:	**$660,000.00**	**72.00**	**19.00**	**81.00**	**26.00**	**3,650.00**	**0.00**

Project Name: Chippewa Lake
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 129, Range: 38, Section: 7

Description: This 195-acre property in Douglas County is a mix of lakeshore, woodlands, and fallow fields. The landowner has planted hybrid poplar trees for harvest in portions of the property. The protected land includes 1,696 feet of undeveloped shoreline along Chippewa Lake and two ponds. The undeveloped, wooded, rolling hills of the property provide scenic views prominently visible to the public from Chippewa Lake and from County Road 12, and the property provides habitat for a variety of terrestrial and aquatic wildlife species.

Easement Recorded in LCCMR office: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Stewardship	$5,000.00	2.11	0.47	0.48	0.10	92.87	0.00
Other Funds	Donated Easement Value	$452,000.00	190.78	42.43	43.82	8.76	8,395.26	0.00
Other Funds	Stewardship	$5,000.00	2.11	0.47	0.48	0.10	92.87	0.00
	Total:	**$462,000.00**	**195.00**	**43.37**	**134.37**	**8.95**	**8,581.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3A: Shorelands Protection Program - Minnesota Land Trust

Project Name: Glacial Ridge
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 121, Range: 34, Section: 14

Description: This 305-acre property in Kandiyohi County is situated along the Glacial Ridge Scenic Byway (a state scenic byway) and consists of rolling forested terrain with some agricultural land used for cattle grazing and haying. The property also has an open-water pond on its western edge, which is visible from Highway 23. Strawberry Lake lies just to the east of the property and is connected to the property by wetlands. This property is the fourth project in the Glacial Ridge site that that the Minnesota Land Trust has helped to protect with conservation easements. The property lies within the New London Hills portion of Kandiyohi County, which is the most heavily forested and steepest portion of the county.

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Stewardship	$13,000.00	1.67	0.35	0.78	0.02	8.09	0.00
Other Funds	Donated Easement Value	$2,359,000.00	303.33	63.30	141.61	3.54	1,467.91	0.00
ENTF	Stewardship	$13,000.00	158.00	0.00	133.34	21.45	1,206.00	0.00
	Total:	**$2,385,000.00**	**463.00**	**63.65**	**418.12**	**25.01**	**2,682.00**	**0.00**

Project Name: High Hope Farm
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 121, Range: 25, Section: 18

Description: This project adds 35 acres to an existing 80-acre conservation easement held by the Land Trust in Wright County. The additional land consists primarily of rolling grasslands. Protection of the property preserves additional shoreline along a pond partially protected in the original easement and helps maintain the rural character of the area.

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Stewardship	$6,000.00	0.47	0.28	0.00	0.10	15.28	0.00
Other Funds	Donated Easement Value	$435,000.00	34.14	20.31	0.27	7.12	1,107.98	0.00
Other Funds	Stewardship	$5,000.00	0.39	0.23	0.00	0.08	12.74	0.00
	Total:	**$446,000.00**	**35.00**	**20.82**	**0.84**	**7.30**	**1,136.00**	**0.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3A: Shorelands Protection Program - Minnesota Land Trust

Project Name: Lake Emma
Tract: Green
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 133, Range: 39, Section: 8

Description: This 103-acre project in Otter Tail County is adjacent to Glendalough State Park. The property is a mix of forest, wetland, and grassland and features extensive shoreline on Lake Emma, a shallow waterfowl lake. The forest is a high-quality oak forest that is part of a much larger expanse of forest protected by Glendalough State Park and two other conservation easements held by the Land Trust at the Lake Emma site. Protection of this tract of land completes the protection of all of the shoreline of Lake Emma in private ownership.

The property also has significant scenic value as viewed by the public from two observation platforms on Lake Emma in Glendalough State Park. As a component of a migratory corridor, it provides feeding and nesting habitat for migrating ducks, geese, and other waterfowl, as well as Neotropical migratory forest birds.

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Easement Acquisition Costs	$100,000.00	69.88	3.39	25.10	27.14	740.84	0.00
ENTF	Stewardship	$13,000.00	9.08	0.44	3.26	3.53	96.31	0.00
Other Funds	Easement Acquisition Costs	$34,400.00	24.04	1.17	8.64	9.34	254.85	0.00
	Total:	**$147,400.00**	**103.00**	**5.00**	**111.00**	**40.00**	**1,092.00**	**0.00**

Project Name: Otter Tail River
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 132, Range: 44, Section: 30

Description: This 257-acre property in Otter Tail County consists of cultivated farmland along the Otter Tail River. There are low rolling hills in the fields and trees along part of the river bank. The Land Trust holds an easement over another 140 acres about two miles to the east owned by the same landowner. Also, the Orwell Wildlife Management Area lies a few miles to the east. There is public access to the Otter Tail River, which is a designated canoe route.

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Stewardship	$5,000.00	2.12	0.07	0.20	0.07	0.00	102.45
Other Funds	Donated Easement Value	$594,000.00	251.50	8.57	24.02	7.84	0.00	12,170.64
Other Funds	Stewardship	$8,000.00	3.39	0.12	0.32	0.11	0.00	163.91
	Total:	**$607,000.00**	**257.00**	**8.76**	**73.65**	**8.01**	**0.00**	**12,437.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3A: Shorelands Protection Program - Minnesota Land Trust

Project Name: Stoney Ridge

Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 121, Range: 34, Section: 6

Description: This 96-acre property is located near New London in Kandiyohi County. It is adjacent to two other conservation easements held by the Land Trust in the Stoney Ridge site. Sibley State Park lies further to the west across Highway 71. Additionally, the Glacial Ridge site, where the Land Trust holds several other conservation easements, is located to the southeast on the other side of New London. The property is primarily forested with a mixed hardwood forest consisting of oak, elm, birch, green ash, ironwood and red cedar. There is quite a bit of buckthorn, and the landowner hopes to more actively control it in the future. There also are two food plots (corn and clover) and some grassland areas, which are enrolled in CRP. The natural and restored ponds and wetlands on the property provide habitat for a variety of aquatic plants and animals and contribute to the ecological viability of the larger complex of wetlands and small glacial lakes in which they are located.

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
Other Funds	Donated Easement Value	$670,000.00	94.59	19.50	29.79	28.60	2,441.56	0.00
Other Funds	Stewardship	$10,000.00	1.41	0.29	0.44	0.43	36.44	0.00
	Total:	**$680,000.00**	**96.00**	**19.79**	**60.46**	**29.03**	**2,478.00**	**0.00**

Easement Totals (By Funding Type)

Funding Type:	**Funding Amount**	**Prorated Acres**	**Grassland Acres**	**Woodland Acres**	**Wetland Acres**	**Shoreline Feet**	**Riparian Feet**
ENTF	$199,000.00	248.13	6.27	473.35	54.13	2,402.72	102.45
Other Funds	$5,239,400.00	1,023.87	176.02	308.39	106.00	20,360.28	12,334.55
Total	**$5,438,400.00**	**1,272.00**	**182.29**	**473.37**	**160.13**	**22,763.00**	**12,437.00**

Work Program Expenditures (Not Attributable to Specific Projects)

FundingType	*Category*	*Amount*	*Description*
ENTF	Personnel Expenditures	$74,750.00	Salaries and related benefits for staff working on contacting landowners, negotiating conservation easements and completing all aspect of easement projects. Because of the large number of potential conservation projects involved in this grant and because many projects initiated or worked on under the grant are not actually completed in this phase of the project,the Land Trust does not allocate salaries to specific conservation easement projects.
ENTF	Supplies and Misc	$26,250.00	Title work, surveys, appraisals, mapping, film, recording fees and other miscellaneous acquisition expenses related to projects pursued under this grant. Because of the large number of conservation projects involved, the Land Trust does not allocate these expenses to specfic easement projects.
	Total:	**$101,000.00**	

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3A: Shorelands Protection Program - Minnesota Land Trust

Work Program Expenditures (Not Attributable to Specific Projects) By Funding Type

Funding Type	Amount
ENTF:	$101,000.00
Total:	**$101,000.00**

Work Program Expenditures Breakdown

Funding Type:	Easement Projects	Not Attributable to Specific Projects	Total
ENTF	$199,000.00	$101,000.00	$300,000.00
Other Funds	$5,239,400.00	$0.00	$5,239,400.00
Total	**$5,438,400.00**	**$101,000.00**	**$5,539,400.00**

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail

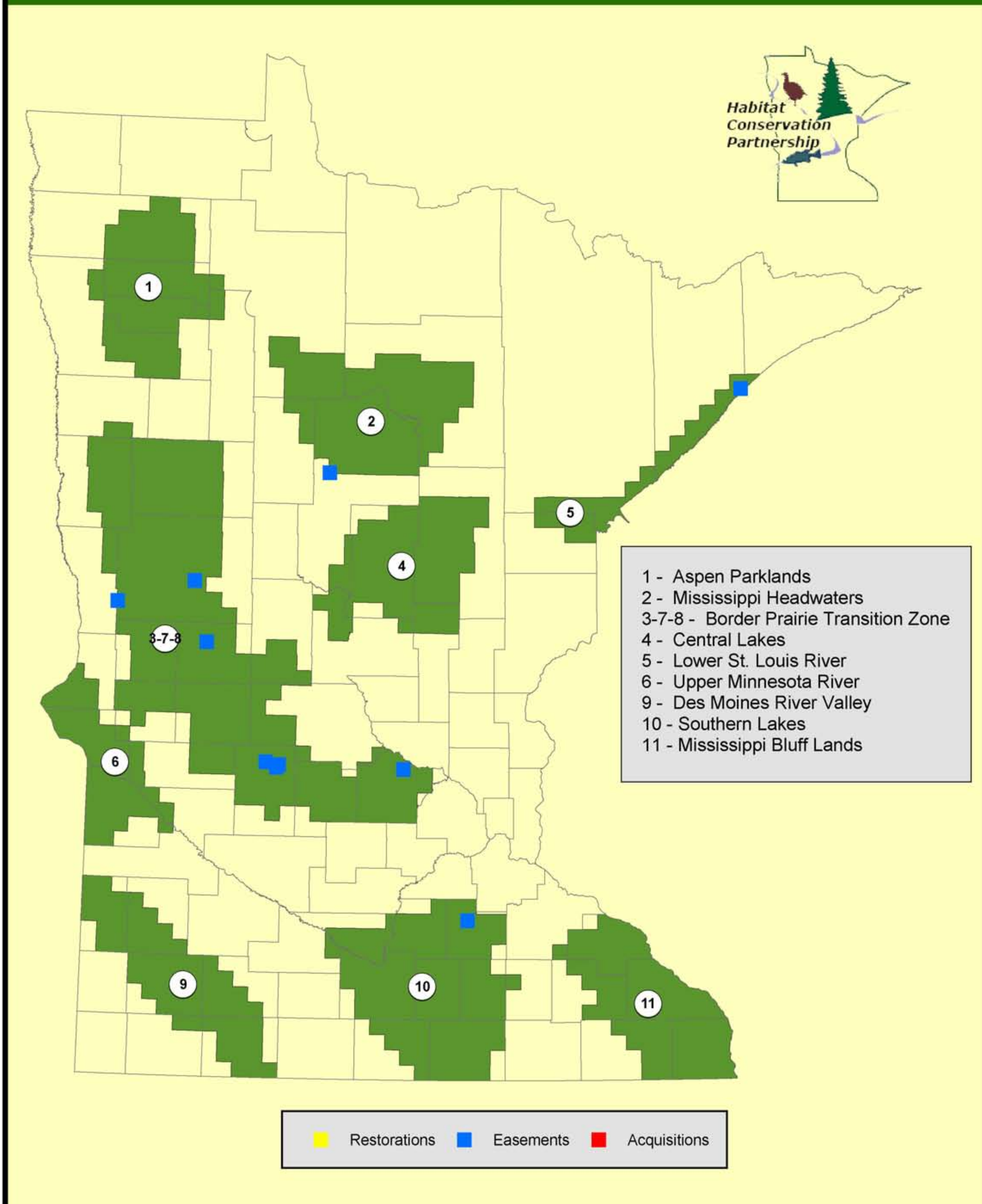
Project Title:
Habitat Corridors Partnership
Minnesota Land Trust - Shoreland Protection Program -3(a)

Project Manager: Jane Prohaska

LCCMR Requested Dollars: $300,000

	Result 1 -- Acquiring CEs - Shoreland Protection Program 3(a): BUDGET	Result 1 -- Acquiring CEs - Shoreland Protection Program 3(a): AMENDED BUDGET	AMOUNT SPENT
BUDGET ITEM			
Personnel: Staff expenses including salaries, benefits (FICA,FUTA. SUI, worker's comp health insurance, 401 (k), etc.) and related costs for approximately .75 FTE for one years as follows:	$50,000.00	$74,750.00	$74,750.00
Conservation directors or other land protection staff (aproximately .50 FTE)			
Staff attorney and other support staff (approximately .25 FTE)			
Easement acquisition costs	$200,000.00	$156,250.00	$156,250.00
Purchase price of conservtion easement(s)			
Title work, title insurance, recording and closing fees, etc.			
Maps, GIS (including project mapping by Community GIS)			
Film			
Other (including appraisals, surveys, etc.)			
Easement stewardship	$50,000.00	$69,000.00	$69,000.00
TOTAL	$300,000.00	$300,000.00	$300,000.00

Habitat Conservation Partnership
Phase 4 - Accomplishments
3A - Shorelands Protection Program - Minnesota Land Trust



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3C: Shallow Lakes Easements - Ducks Unlimited

Project Manager: Jon Schneider
Affiliation: Ducks Unlimited
Address: 311 East Lake Geneva Road
Alexandria, MN 56308
Phone: (320)762-9916
Fax: (320)759-1567
E-mail: jschneider@ducks.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Balance	ENTF Funds Spent	ENTF Balance	Other Funds * Proposed	Other Funds * Spent
Easement	$200,000	$200,000	$0	$50,000	$261,341
Total	$200,000	$200,000	$0	$50,000	$261,341

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:

State Funds: $128,000.00

See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results

The objective of this grant project was to help accelerate Ducks Unlimited's (DU) efforts to protect shoreland on key shallow lakes of import to waterfowl by securing conservation easements through our Living Lakes Initiative. DU's goal was to secure at least one easement protecting at least 200 acres of land on key shallow lakes through donated or purchased permanent conservation easements, and the expenditure of $50,000 in Other Funds.

Through this grant, DU secured six permanent conservation easements protecting 234 acres of land on four shallow lakes (exceeding grant goal of 200 acres), including 10,593 feet of shallow lake shoreline. Lakes protected included lakes Christina and Bah in Douglas County, Buffalo Lake in Waseca County, and Denton Slough in Grant County. DU land protection staff also negotiated with four other landowners on Lake Christina regarding potential easements that may develop into easement deals in the future as itemized in this report, and also provided general outreach and promotion about conservation easement concepts and options to 15 other landowners on other shallow lakes in HCP Project Areas throughout the state. The cost of all this conservation easement work was $589,341, of which $200,000 was reimbursed from the Environment & Natural Resources Trust Fund, $261,341 from non-state Other Funds that greatly exceeds our goal of $50,000 non-state funds, and $128,000 in state "Working Lands Initiative" funds from DNR.

Project Results Use and Dissemination

This grant helped DU accelerate land protection work under our Living Lakes Initiative and promote conservation easement concepts to many individual landowners. Conservation easements with private landowners are sensitive land deals that don't lend themselves to widespread publicity, however, DU has recognized individual landowners and has publicized our land protection work on Lake Christina locally through local conservation groups, including through the Christina-Ina-Anka Lake Association. DU also informed the foundations supporting our Living Lakes Initiative of our conservation accomplishments, including the Bush Foundation and Flint Hills Resources. The accomplishment of securing six new permanent conservation easements through this grant has helped encourage other private landowners around key shallow lakes (especially Christina) to consider working with DU to protect their shorelines, and news of our progress will be further disseminated through a DU news releases and articles DU publications in the future.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

3C: Shallow Lakes Easements - Ducks Unlimited

Easement Activities

Project Name: Britton Farm on Buffalo Lake
Tract: 1
Project Area: 10 - Southern Lakes
Township: 107, Range: 24, Section: 16

Description: DU purchased a permanent conservation easement on the outlet of Buffalo Lake in Waseca County from the Britton Farm family in June 2008. This easement is an extension of DU's work in HCP Phase 3 part 3C. The easement will protect some 1,200 feet of Buffalo Lake's shoreline, as well as allow DU to legally access the lake's outlet to place and maintain a new variable crest outlet structure for DNR to use to manage the lake under DU's 2008 LCCMR grant (HCP Phase 5).

Easement Recorded in LCCMR office: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Easement Acquisition Costs	$28,026.80	6.52	6.52	0.00	0.00	737.54	0.00
ENTF	Personnel Expenditures	$4,757.72	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Stewardship	$25,288.00	5.88	5.88	0.00	0.00	665.46	0.00
Other Funds	Personnel Expenditures	$4,970.54	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Professional Services	$1,505.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total:	**$64,548.06**	**12.40**	**12.40**	**0.00**	**0.00**	**1,403.00**	**0.00**

Project Name: Carlson-Cunz on Lake Christina
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 130, Range: 40, Section: 17

Description: DU is working with the Carlson-Cunz family to secure a permanent donated or bargain sale conservation easement on 180 acres on the shore of Lake Christina in Douglas County. The easement will be closed in spring 2009 under our 2008 grant for HCP Phase 5 part 3c.

Easement Recorded in LCCMR office: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Personnel Expenditures	$1,635.04	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$7,750.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Personnel Expenditures	$4,244.98	0.00	0.00	0.00	0.00	0.00	0.00
	Total:	**$13,630.02**	**0.00**	**0.00**	**87.00**	**0.00**	**0.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

3C: Shallow Lakes Easements - Ducks Unlimited

Project Name: Huselid Farm on Denton Slough

Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 130, Range: 44, Section: 11

Description: DU purchased a permanent conservation easement on 18 acres from the Huselid Farm bordering Denton Slough in Grant County in July 2008. The easement includes 16 acres of native grass buffer on Denton Slough, and will both help protect and buffer the lake from surrounding agricultural operations. DU will annually monitor and steward the property and landowners to ensure compliance with easement terms and long-term protection of Denton Slough.

Easement Recorded in LCCMR office: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Personnel Expenditures	$1,050.94	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$2,380.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Stewardship	$9,250.00	4.53	4.04	0.00	0.49	637.09	0.00
Other Funds	Easement Acquisition Costs	$28,500.00	13.97	12.46	0.00	1.51	1,962.91	0.00
Other Funds	Personnel Expenditures	$7,459.17	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Professional Services	$5,783.75	0.00	0.00	0.00	0.00	0.00	0.00
	Total:	**$54,423.86**	**18.50**	**16.50**	**0.00**	**2.00**	**2,600.00**	**0.00**

Project Name: Johnson Farm on Lake Christina

Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 130, Range: 41, Section: 12

Description: DU purchased a permanent conservation easement from the Johnson Farm family in June 2008 to protect 78 acres of oak savanna land along the north shore of Lake Christina in Grant County near Ashby. The easement will be permanently held and annually monitored by DU.

Easement Recorded in LCCMR office: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Easement Acquisition Costs	$12,895.00	5.00	2.37	0.96	0.38	214.59	0.00
Other Funds	Easement Acquisition Costs	$45,625.00	17.68	8.39	3.40	1.36	759.26	0.00
Other Funds	Personnel Expenditures	$7,132.47	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Professional Services	$12,687.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Stewardship	$14,725.00	5.71	2.71	1.10	0.44	245.04	0.00
State Funds	Easement Acquisition Costs	$128,000.00	49.61	23.53	9.54	3.82	2,130.10	0.00
	Total:	**$221,064.47**	**78.00**	**37.00**	**90.00**	**6.00**	**3,349.00**	**0.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

3C: Shallow Lakes Easements - Ducks Unlimited

Project Name: Lang Farm on Bah Lake

Tract: 1

Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 129, Range: 40, Section: 7

Description: DU purchased a permanent conservation easement from the Lang family on 111 acres along Bah Lake in Douglas County. This easement project was begun in DU's 2006 LCCMR grant (HCP Phase III) and partially funded under that grant, but funds from this 2007 HCP Phase IV grant were also used to complete the easement purchase in Nov 2007. On June 16, 2009, LCCMR approved a conveyance to Grant County for road impacts that reduced the size of this easement by 3 acres, so final the non-prorated total easement size is now 108 acres.

Of the $95,308 needed for Easement Acquisiton Costs and Stewardship, DU used $38,126 of Phase III ENTF Funds,$26,871 Phase IV ENTF Funds, and $11,308 in Other Funds . Therefore of the 108 acres protected with this conservation easement, Phase III ENTF, Phase IV ENTF, and Phase III Other Funds accomplishments are 64.74, 30.45, and 12.81 acres. Please note that Personel Expenditures are not used indetermining the prorated accomplishment credits.

	Phase III Other Funds	Phase III ENTF	Phase IV ENTF	Total
Expenditures	$11,308	$38,126	$57,182	$95,308
Prorated %	11.8%	40%	48.1%	100%
Acres	7.71	30.45	43.26	108

Easement Recorded in LCCMR office: Yes

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	108.00	65.00	0.00	6.00	3,170.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Easement Acquisition Costs	$57,128.42	64.74	38.96	0.00	3.60	1,900.12	0.00
Other Funds	Personnel Expenditures	$1,830.37	0.00	0.00	0.00	0.00	0.00	0.00
	Total:	**$58,958.79**	**64.74**	**38.96**	**0.00**	**3.60**	**1,900.12**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

3C: Shallow Lakes Easements - Ducks Unlimited

Project Name: Lillemon Farm #1 on Lake Christina

Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 130, Range: 40, Section: 3

Description: DU is working with the Lillemon Family to purchase a bargain sale conservation easement to protect land on the east shore of Lake Christina in Douglas County. The easement will be closed in spring 2009 under our 2008 grant for HCP Phase 5 part 3c.

Easement Recorded in LCCMR office: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Personnel Expenditures	$2,067.12	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$3,000.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Personnel Expenditures	$2,444.30	0.00	0.00	0.00	0.00	0.00	0.00
	Total:	**$7,511.42**	**0.00**	**0.00**	**42.00**	**0.00**	**0.00**	**0.00**

Project Name: Lillemon Farm #2 on Lake Christina

Tract: 2

Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 130, Range: 40, Section: 3

Description: DU is working with the Lillemon family to permanently protect a second tract they own on Lake Christina totaling about 132 acres in Douglas County through a purchased conservation easement. The easement will be closed in spring 2009 under our 2008 grant for HCP Phase 5 part 3c.

Easement Recorded in LCCMR office: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Personnel Expenditures	$2,854.90	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$4,400.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Personnel Expenditures	$5,692.04	0.00	0.00	0.00	0.00	0.00	0.00
	Total:	**$12,946.94**	**0.00**	**0.00**	**39.00**	**0.00**	**0.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

3C: Shallow Lakes Easements - Ducks Unlimited

Project Name: Papenheim on Lake Christina
Tract: 1
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 130, Range: 40, Section: 4

Description: DU is continuing to work with the Papenheim's regarding a bargain sale purchased easement on their land along Lake Christina as an extension of DU's work in HCP Phase 3 part 3C. High prices for tillable land and appraisals below landowner expectation are prolonging the negotiations, but DU staff is hopeful that a deal can be reached in the future to purchase this easement with the current or future landowner.

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Personnel Expenditures	$297.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$5,000.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Personnel Expenditures	$830.68	0.00	0.00	0.00	0.00	0.00	0.00
	Total:	**$6,127.68**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: Thiel Trust Farm on Denton Slough
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 130, Range: 44, Section: 10

Description: DU purchased a permanent conservation easement on 28.5 acres from the Thiel Trust Farm bordering Denton Slough in Grant County in July 2008. The easement includes 21 acres of native grass buffer on Denton Slough, and will both help protect and buffer the lake from surrounding agricultural operations. DU will annually monitor and steward the property and landowners to ensure compliance with easement terms and long-term protection of Denton Slough.

Easement Recorded in LCCMR office: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$1,000.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Stewardship	$9,981.00	6.78	5.23	0.00	1.43	157.15	0.00
Other Funds	Easement Acquisition Costs	$32,000.00	21.72	16.77	0.00	4.57	503.85	0.00
Other Funds	Personnel Expenditures	$5,687.27	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Professional Services	$7,205.72	0.00	0.00	0.00	0.00	0.00	0.00
	Total:	**$55,873.99**	**28.50**	**22.00**	**0.00**	**6.00**	**661.00**	**0.00**

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Habitat Conservation Partnership

3C: Shallow Lakes Easements - Ducks Unlimited

Project Name: Weigand Farm on Denton Slough

Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 130, Range: 44, Section: 11

Description: DU purchased a permanent conservation easement on 32 acres from the Weigand Farm bordering Denton Slough in Grant County in July 2008. The easement includes 6 acres of native grass buffer on Denton Slough, and will both help protect the lake from surrounding agricultural operations. DU will annually monitor and steward the property and landowners to ensure compliance with easement terms and long-term protection of Denton Slough.

Easement Recorded in LCCMR office: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$1,000.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Stewardship	$9,250.00	7.74	1.45	0.00	0.48	164.44	0.00
Other Funds	Easement Acquisition Costs	$29,000.00	24.26	4.55	0.00	1.52	515.56	0.00
Other Funds	Personnel Expenditures	$6,696.88	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Professional Services	$6,935.72	0.00	0.00	0.00	0.00	0.00	0.00
	Total:	**$52,882.60**	**32.00**	**6.00**	**0.00**	**2.00**	**680.00**	**0.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

3C: Shallow Lakes Easements - Ducks Unlimited

Easement Totals (By Funding Type)

Funding Type:	Funding Amount	Prorated Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
ENTF	$189,011.94	101.18	64.46	127.00	6.38	4,476.40	0.00
Other Funds	$230,955.89	83.34	44.87	4.50	9.40	3,986.63	0.00
State Funds	$128,000.00	49.61	23.53	9.54	3.82	2,130.10	0.00
Total	**$547,967.83**	**234.14**	**132.86**	**15.00**	**19.60**	**10,593.12**	**0.00**

Work Program Expenditures (Not Attributable to Specific Projects)

FundingType	*Category*	*Amount*	*Description*
ENTF	Personnel Expenditures	$10,748.06	DU biologists perform conservation easement outreach and promotion to private landowners around shallow lakes within HCP Project Areas to initiate new conservation easement projects.
ENTF	Professional Services	$240.00	Consultant technical assistance charges to assist DU with conservation easement outreach and promotion efforts on specific shallow lakes.
Other Funds	Personnel Expenditures	$30,385.11	DU biologists perform conservation easement outreach and promotion to private landowners around shallow lakes within HCP Project Areas to initiate new conservation easement projects.
	Total:	**$41,373.17**	

Work Program Expenditures (Not Attributable to Specific Projects) By Funding Type

Funding Type	Amount
ENTF:	$10,988.06
Other Funds:	$30,385.11
Total:	**$41,373.17**

Work Program Expenditures Breakdown

Funding Type:	Easement Projects	Not Attributable to Specific Projects	Total
ENTF	$189,011.94	$10,988.06	$200,000.00
Other Funds	$230,955.89	$30,385.11	$261,341.00
Partner's State Leveraged Funds	$128,000.00	$0.00	$0.00
Total	**$547,967.83**	**$41,373.17**	**$589,341.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

3C: Shallow Lakes Easements - Ducks Unlimited

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

Project Title: Living Lakes Enhancements 2c & Easements 3c

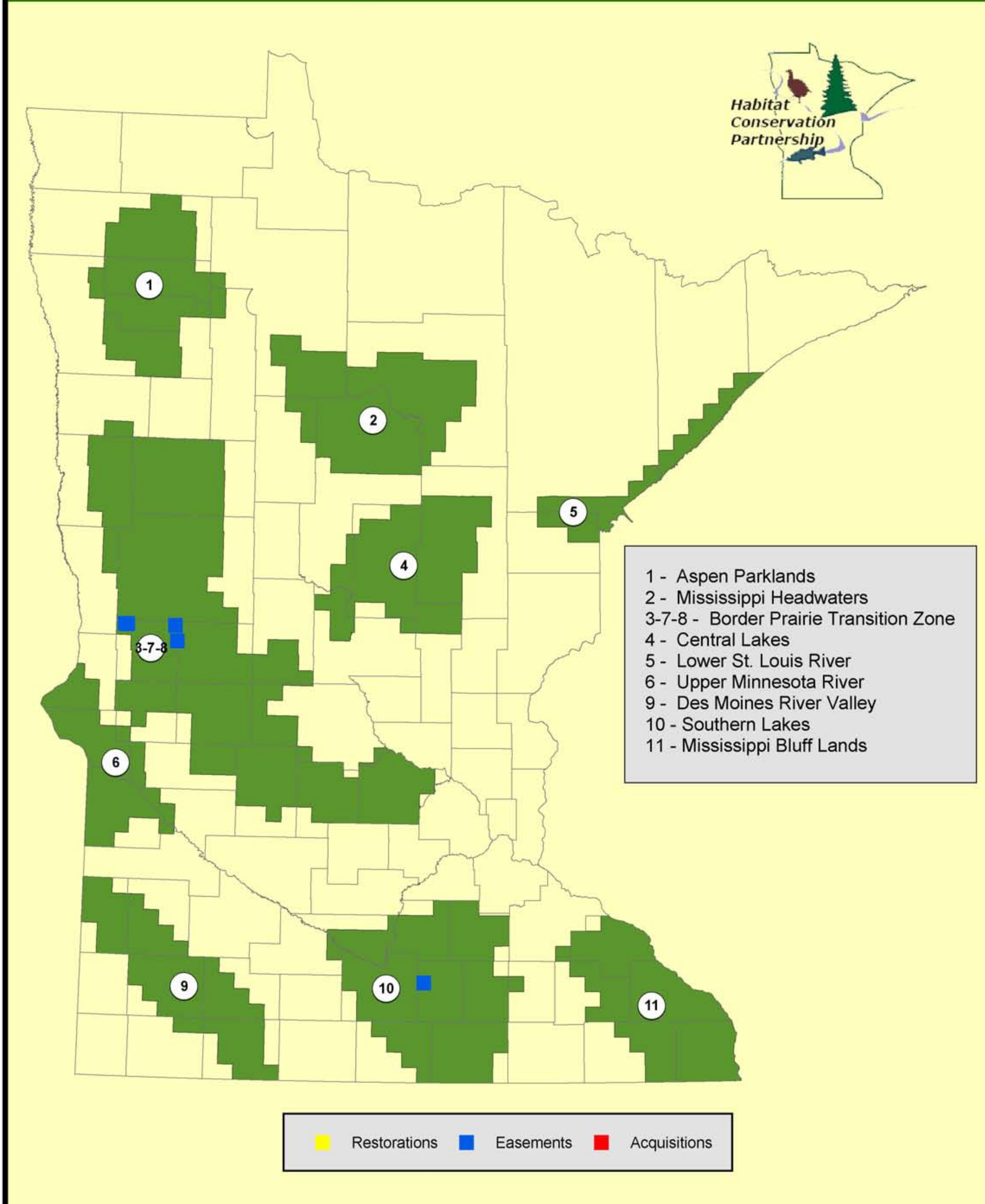
Project Manager Name: Jon Schneider, DU

Trust Fund Appropriation: $500,000

Date: Final Report July 2009

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	**Result 2 Budget:**	**Amount Spent**	**Balance**	**TOTAL BUDGET**	**TOTAL SPENT**	**TOTAL BALANCE**
	Living Lakes Enhancements			*Living Lakes Easements*					
BUDGET ITEM									
PERSONNEL: (wages and benefits for DU staff professional biologists and engineers to deliver habitat projects)	$73,030	$73,030	$0	$23,411	$23,411	$0	$96,441	$96,441	$0
Contracts	$226,970		$0	$24,770		$0	$251,740	$251,740	$0
Professional/technical (soils investigations, appraisals, legal, and baseline documentation reports)					$24,770				
Other contracts (construction of water control structures and fish barriers)		$226,970							
Equipment / Tools									
Land rights acquisition (easements, not fee)				$98,050	$98,050	$0	$98,050	$98,050	$0
Professional Services for Acqusitions									
Other (Easement Stewardship to DU WAT)				$53,769	$53,769	$0	$53,769	$53,769	$0
COLUMN TOTAL	**$300,000**	**$300,000**	**$0**	**$200,000**	**$200,000**	**0**	**$500,000**	**$500,000**	**0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
3C - Living Lakes Easements - Ducks Unlimited



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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

This project has 2 parts. Part 1(3d1) includes the expenditure of Environmental and Natural Resources Trust Fund dollars to contract with WRP technicians and is administered by Ducks Unlimited (DU). Part 2(3d2) is the accomplishment component of this project, administered by the Natural Resources Conservation Service (NRCS) and includes reporting on matching dollars and total acres enrolled.

Project Manager: Jon Schneider
Affiliation: Ducks Unlimited
Address: 311 East Lake Geneva Road
Alexandria, MN 56308
Phone: (320)762-9916
Fax: (320)759-1567
E-mail: jschneider@ducks.org

Project Manager: Tim Koehler
Affiliation: USDA - Natural Resources Conservation Service
Address: 375 Jackson Street, Suite 600
St. Paul, MN 55101
Phone: (651) 602-7857
Fax: (651) 602-7926
E-mail: tim.koehler@mn.usda.gov

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	Environmental Trust Allocation	Environmental Trust Funds Spent	Environmental Trust Balance	Other Funds* Proposed	Other Funds* Spent
Restoration	-	$0	-	-	$1,624,946
Easement	-	$0	-	-	$2,778,832
Work Program Expenditures (Not Attributable to Specific Projects)	-	$350,000	-	-	$257,655
Total	$350,000.00	$350,000.00	$0.00	$3,500,000.00	$4,661,432.69

* Please note that most other funds reported here are federal in origin but do include some Ducks Unlimited Costs.

Work Program Summary

Overall Project Outcome and Results

This project was part 3d of the Habitat Conservation Partnership (HCP) whereby Ducks Unlimited (DU) contracted with wetland restoration specialists to help the USDA's Natural Resources Conservation Service (NRCS) deliver the federal Wetlands Reserve Program (WRP) in Minnesota, a federal Farm Bill conservation easement program funded by the USDA. DU contract wetland restoration specialists assisted landowners in enrolling in the WRP to assisted NRCS in restoring lands enrolled in to the WRP. Specific deliverable goals of the WRP specialists included landowner contacts, WRP applications submitted, restoration plans submitted, wetland restoration designs, and restoration project oversight. USDA's NRCS provided federal cost-share funding for the WRP specialists and funded the cost of all WRP easement purchases and restorations, with a combined goal of 3,500 acres. This phase of the WRP partnership began in October 2007 with nine contract technicians and ended with seven in November 2008 after one contract expired and another terminated after a specialist found permanent employment elsewhere.

During the project performance period October 1, 2007 through November 10, 2008, DU spent the $350,000 Trust Fund grant plus

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Habitat Conservation Partnership

3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

$257,654 in non-state Other Funds on contracted wetland restoration specialists and grant administration. DU contract specialists made 548 landowner contacts, submitted 138 WRP applications, developed 46 WRP conservation plans and 46 WRP wetland restoration designs, and managed construction on 35 WRP wetland restoration projects. This helped USDA's NRCS secure 17 new WRP easements totaling 2,444 acres at a federal Other Fund cost of $2,778,832, and restore 19 grassland and 37 wetland sites totaling 7,579 acres at a federal Other Fund cost of $1,624,946 in HCP Project Areas 1, 3, 6, 7 and 10. Total project Other Fund expense was $4,661,432.69. Contracts for these specialists continued through 2008 into 2009 through a 2008 LCCMR grant for HCP Phase 5 Part 3d WRP.

Project Results Use and Dissemination
Information on the WRP signups has been publicized through news releases from the USDA's NRCS and local Soil and Water Conservation Districts, and through 548 individual landowner contacts made by DU wetland restoration specialists. Additional announcements and landowner contacts continue to be made and publicized by DU and USDA's NRCS. Additionally, the WRP partnership was nominated for a 2009 Minnesota Environmental Institute (MEI) award which was widely distributed. Finally, DU is actively working to increase public awareness and support for the WRP as an important Farm Bill wetland conservation program, including public and congressional support for future funding appropriations.

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Habitat Conservation Partnership

3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

Restoration Activities

Project Area	Project Name:	Description	Township	Range	Section	Activity	Funding Amount	Acres
1								
	66632220088	Polk County restoration	149	44	27	Grassland Restoration	$31,138.34	1,961.50
	66632220088	Polk County restoration	149	44	27	Wetland Restoration	$494,697.95	3,100.80
	66632230097	Douglas County restoration	128	36	8	Wetland Restoration	$6,161.33	10.00
	66632230121	Stevens County restoration	126	43	31	Wetland Restoration	$18,426.26	27.80
	66632230122	Stevens County restoration	125	43	6	Wetland Restoration	$31,152.30	47.00
	66632230138	Stevens County restoration	126	43	32	Wetland Restoration	$2,187.29	3.30
	66632240055	Polk County restoration	153	46	23	Wetland Restoration	$1,057.50	4.80
	66632250011	Polk County restoration	148	44	8	Grassland Restoration	$168,943.25	296.30
	66632250011	Polk County restoration	148	44	8	Wetland Restoration	$234,287.07	809.20
	66632250054	Polk County restoration	149	44	7	Grassland Restoration	$16,290.00	38.90
Project Area 1 Total:							$1,004,341.29	6,299.60
3								
	66632220059	Douglas County restoration	128	37	26	Wetland Restoration	$4,075.00	10.50
	66632230011	Clay County	142	46	13	Wetland Restoration	$1,700.00	13.70
	66632230014	Wilkin County	134	45	5	Wetland Restoration	$13,087.20	59.40
	66632230088	Clay County restoration	137	45	21	Wetland Restoration	$66,248.14	73.40
	66632230115	Otter Tail County restoration	133	43	3	Grassland Restoration	$6,942.00	48.50
	66632230115	Otter Tail County restoration	133	43	3	Wetland Restoration	$8,784.00	29.40

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

	66632230139	Stevens County restoration	125	43	6	Wetland Restoration	$35,460.60	53.50
	66632230139	Douglas County restoration	125	43	6	Wetland Restoration	$9,412.00	16.80
	66632240010	Becker County	138	38	4	Grassland Restoration	$31,125.48	157.10
	66632240010	Becker County	138	38	4	Wetland Restoration	$476.82	2.40
	66632240011	Pope County	123	39	15	Wetland Restoration	$4,845.00	6.60
	66632240023	Pope County	126	36	21	Grassland Restoration	$8,291.30	72.10
	66632240036	Stevens County restoration	125	43	5	Wetland Restoration	$22,734.55	34.30
	66632240062	Big Stone County	121	45	7	Wetland Restoration	$5,447.62	13.50
	66632240070	Stevens County restoration	124	43	4	Wetland Restoration	$15,447.50	9.90
	66632250005	Stevens County restoration	126	43	31	Wetland Restoration	$10,885.60	13.20
	66632250006	Stevens County restoration	126	43	31	Wetland Restoration	$26,165.90	31.40
	66632250010	Stevens County restoration	126	43	30	Grassland Restoration	$1,450.00	1.40
	66632250010	Stevens County restoration	126	43	30	Wetland Restoration	$35,076.10	28.30
	66632250014	Wilkin County	135	45	5	Grassland Restoration	$17,922.23	10.50
	66632250014	Wilkin County	135	45	5	Wetland Restoration	$5,120.64	3.00
	66632250019	Clay County	141	45	29	Grassland Restoration	$5,250.00	1.40
	66632250019	Clay County	141	45	29	Wetland Restoration	$3,000.00	3.10
	66632250039	Stevens County	125	43	32	Grassland Restoration	$471.99	4.90
	66632250039	Stevens County	125	43	32	Wetland Restoration	$16,790.03	4.60

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3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

	66632250049	Pope County	123	38	6	Grassland Restoration	$15,762.47	102.90
	66632250049	Pope County	123	38	6	Wetland Restoration	$505.49	3.30
	66632266007	Stevens Co.	125	43	21	Grassland Restoration	$5,403.58	109.20
	66632266007	Stevens Co.	125	43	21	Wetland Restoration	$329.51	9.40
	66632266016	Becker County restoration	140	41	19	Grassland Restoration	$2,612.40	93.30
	66632266016	Becker County restoration	140	41	19	Grassland Restoration	$327.60	11.70
Project Area 3 Total:							$381,150.75	1,032.70
6								
	66632230081	Big Stone County restoration	124	47	36	Grassland Restoration	$10,194.34	31.00
	66632230081	Big Stone County restoration	124	47	36	Wetland Restoration	$36,800.00	14.50
	66632240053	Stevens County restoration	123	44	5	Grassland Restoration	$931.00	24.50
	66632240053	Stevens County restoration	123	44	5	Wetland Restoration	$927.80	4.90
Project Area 6 Total:							$48,853.14	74.90
7								
	66632230093	Pope County restoration	124	37	17	Wetland Restoration	$43,790.00	18.90
	66632230093	Pope County	124	37	17	Wetland Restoration	$6,244.00	17.90
	66632230094	Pope County restoration	124	37	29	Wetland Restoration	$56,126.00	18.00
Project Area 7 Total:							$106,160.00	54.80
10								
	66632220091	Freeborn County restoration	101	21	18	Wetland Restoration	$22,144.75	4.20
	66632240050	Freeborn County restoration	101	22	13	Wetland Restoration	$19,044.00	28.80
	66632240052	Freeborn County	104	20	20	Wetland Restoration	$29,268.75	34.30

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3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

	66632266055	Freeborn County	104	19	19	Grassland Restoration	$4,771.34	29.60
	66632266055	Freeborn County	104	19	19	Wetland Restoration	$9,211.90	19.70
Project Area 10 Total:							$84,440.74	116.60

Restoration Project Totals (By Funding Type)

Funding Type	Funding Amount	Prorated Acres	Shoreline Feet
Other Funds:	$1,624,945.92	7,578.60	0.00
Total:	**$1,624,945.92**	**7,578.60**	**0.00**

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3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

Easement Activities

Project Area	Project Name	Description	Funding Amount	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline	Riparian
1									
	66632266036	Stevens County	$146,547.00	97.00	71.80	0.00	25.20	0.00	0.00
	66632266042	Steele County	$213,576.00	100.50	20.30	0.00	80.20	0.00	0.00
	66632266057	Polk Co. WRP easement	$24,660.00	51.90	36.40	0.00	15.50	0.00	0.00
	66632266064	Pope County	$119,355.00	145.70	111.70	7.00	27.00	0.00	0.00
	66632266068	Clay County	$86,543.00	145.70	107.10	0.00	38.60	0.00	0.00
	66632270037	Becker County	$160,349.00	183.30	119.40	12.00	51.90	0.00	0.00
	66632270075	Clay County	$191,174.00	216.30	154.30	40.00	22.00	0.00	0.00
	66632270076	Rice County	$197,367.00	69.70	45.60	2.00	22.10	0.00	0.00
Project Area 1 Total			$1,139,571.00	1,010.10	45.60	61.00	282.50	0.00	0.00
3									
	66632250019	Clay Co. WRP Easement.	$158,452.00	158.30	82.70	0.00	75.60	0.00	0.00
	66632266004	Clay Co. WRP easement.	$152,484.00	296.50	226.30	0.00	70.20	0.00	0.00
	66632266008	Becker Co. WRP easement	$21,867.00	19.10	12.00	0.00	7.10	0.00	0.00
	66632266033	Becker Co. WRP easement	$54,108.00	66.80	40.60	0.00	26.20	0.00	0.00
Project Area 3 Total			$386,911.00	540.70	40.60	0.00	179.10	0.00	0.00
6									
	66632266059	Big Stone Co. WRP easement	$50,510.00	78.40	59.70	0.00	18.70	0.00	0.00
Project Area 6 Total			$50,510.00	78.40	59.70	0.00	18.70	0.00	0.00
10									
	66632250055	Steele Co. WRP Easement	$329,053.00	119.20	78.40	0.00	40.80	0.00	0.00
	66632266055	Freeborn Co. WRP easement	$152,297.00	70.10	50.40	0.00	19.70	0.00	0.00

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3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

	66632266056	Freeborn Co. WRP easement	$89,626.00	77.90	32.30	0.00	45.60	0.00	0.00
	66632266058	Freeborn Co. WRP easement	$630,864.00	547.30	302.20	0.00	245.10	0.00	0.00
Project Area 10 Total			$1,201,840.00	814.50	302.20	0.00	351.20	0.00	0.00

Easement Totals (By Funding Type)

Funding Type:	Funding Amount	Prorated Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Other Funds	$2,778,832.00	2,443.70	1,551.20	61.00	831.50	0.00	0.00
Total	**$2,778,832.00**	**2,443.70**	**1,551.20**	**61.00**	**831.50**	**0.00**	**0.00**

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Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

Work Program Expenditures (Not Attributable to Specific Projects)

FundingType	*Category*	*Amount*	*Description*
ENTF	Professional Services	$338,178.02	Expense for contracted field technicians to promote the USDA NRCS' Wetlands Reserve Program (WRP) and help landowners and NRCS restore wetlands and native prairie grasslands enrolled into this permanent conservation easement program within HCP Project Areas 1-10.
ENTF	Personnel Expenditures	$11,821.98	Program management and contracted technician coordination expense to hire and supervise technicians, manage their activities and performance within HCP Project Areas 1-10, and administer the LCCMR HCP grant funding this work.
Other Funds	Professional Services	$239,907.84	Expense for contracted field technicians to promote the USDA NRCS' Wetlands Reserve Program (WRP) and help landowners and NRCS restore wetlands and native prairie grasslands enrolled into this permanent conservation easement program within HCP Project Areas 1-10.
Other Funds	Personnel Expenditures	$17,746.93	Program management and contracted technician coordination expense to hire and supervise technicians, manage their activities and performance within HCP Project Areas 1-10, and administer the LCCMR HCP grant funding this work.
	Total:	**$607,654.77**	

Work Program Expenditures (Not Attributable to Specific Projects) By Funding Type

Funding Type	Amount
ENTF	$350,000.00
Other Funds	$257,654.77
Total	**$607,654.77**

Work Program Expenditures Breakdown

Funding Type	Restoration Projects	Easement Projects	Not Attributable To Specific Projects	Total
ENTF	$0.00	$0.00	$350,000.00	$350,000.00
Other Funds	$1,624,945.92	$2,778,832.00	$257,654.77	$4,661,432.69
Total	**$1,624,945.92**	**$2,778,832.00**	**$607,654.77**	**$5,011,432.69**

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Habitat Conservation Partnership

3D: Wetlands Reserve Program - Ducks Unlimited (DU) & Natural Resources Conservation Services (NRCS)

Funding Type Definitions

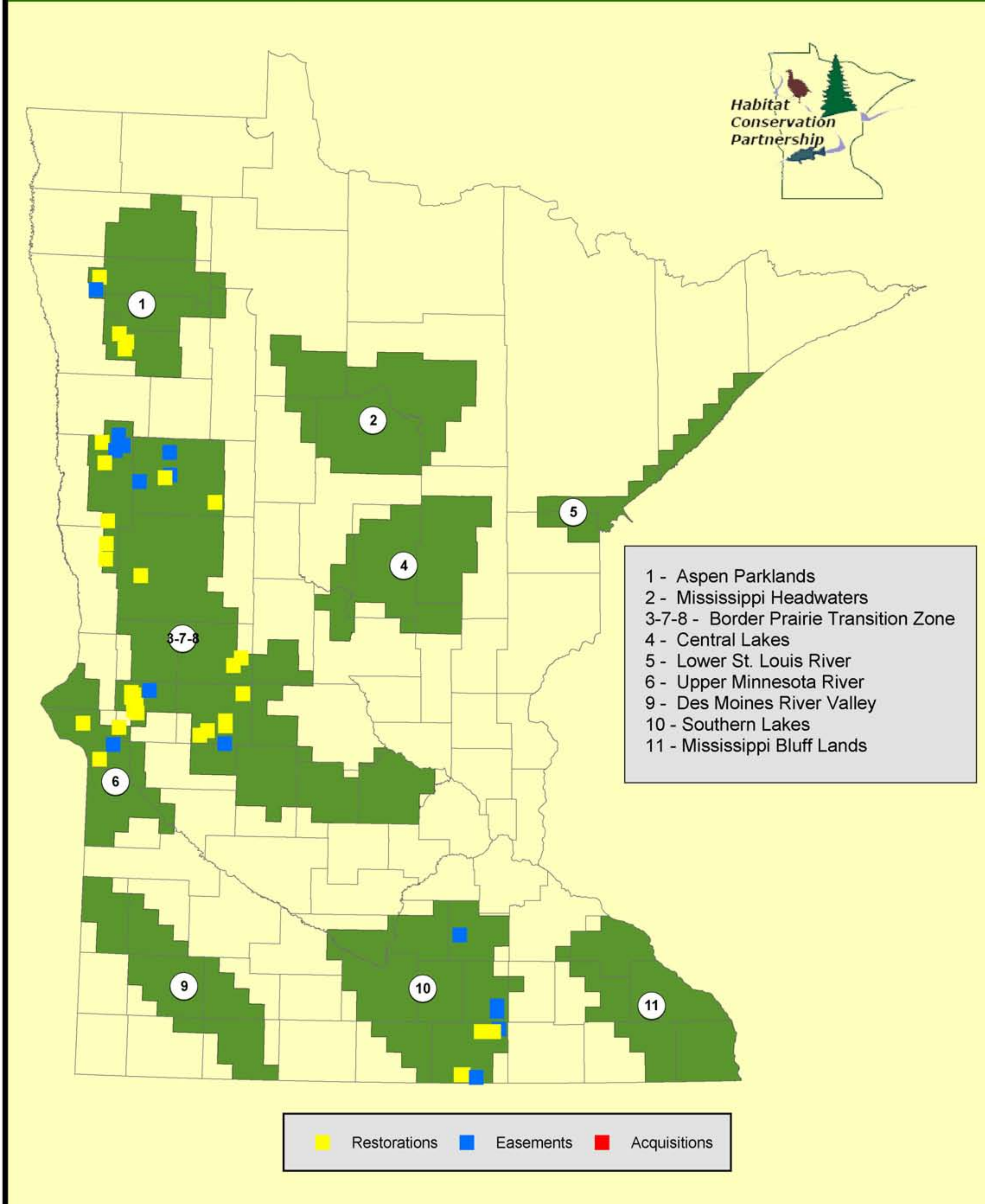
ETF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects
ML 2007, Chapter [30], Section [4], Subdivision [b]. Minnesota's Habitat Conservation Partnership - Phase IV
3D Wetlands Reserve Program
Project Manager Name: Jon Schneider, DU
Project Co-Manager: Tim Koehler, NRCS
Trust Fund Appropriation: $350,000

FINAL REPORT

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent	Balance	TOTAL BUDGET	TOTAL SPENT	TOTAL BALANCE
	TA for WRP Easements					
BUDGET ITEM						
PERSONNEL: wages and benefits (DU staff for project administration)	$11,822	$11,822	$0	$11,822	$11,822	$0
Contracts						
Professional/technical (contract biotechnicians to deliver WRP)	$337,558	$337,558	$0	$337,558	$337,558	$0
Other Supplies (field supplies including items such as hip boots, survey batteries, tapes, lath, clip boards, etc.)	$87	$87	$0	$87	$87	$0
Travel expenses in Minnesota	$533	$533	$0	$533	$533	$0
COLUMN TOTAL	**$350,000**	**$350,000**	**$0**	**$350,000**	**$350,000**	**$0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
3D - Wetlands Reserve Program - Ducks Unlimited & Natural Resources Conservation Service



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3F: Habitat Encroachment Buffers - Pheasants Forever

Project Manager: Matt Holland
Affiliation: Pheasants Forever
Address: 679 W. River Dr.
New London, MN 56,273
Phone: (320) 354-4377
Fax: (320) 354-4377
E-mail: mholland@pheasantsforever.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Easement	$20,000.00	$0.00	$20,000.00	$2,500.00	$0.00
Total	$20,000.00	$0.00	$20,000.00	$2,500.00	$0.00

Work Program Summary

Overall Project Outcome and Results

The work originally proposed here was not completed, and there was never an approved work program for activities under this work plan. In addition to having a fledgling easement program at the time of proposal, the program manager for this work plan transitioned to a different position and we did not get the work plan approved. Thus, there are no accomplishments or expenditures to report. We continue to believe that the concept of protecting our fee-title investments with easements has merit.

Project Results Use and Dissemination

NA

Attachment A: Budget Detail for 2007 Projects

Project Title: Minnesota Habitat Corridors Partnership - Phase IV - Habitat Encroachment Buffers (3f)

Project Manager Name: Matt Holland

Trust Fund Appropriation: $ 20,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(November 1, 2008)*	**Balance** *(November 1, 2008)*	**TOTAL BUDGET**	**TOTAL BALANCE**
BUDGET ITEM					
PERSONNEL: wages and benefits	750		750	750	750
Contracts					
Stewardship Workshop	250		250	250	250
Land Rights Acquisition	19,000		19,000	19,000	19,000
COLUMN TOTAL	**$20,000**	**$0**	**$20,000**	20,000	20,000

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3G: Campaign for Conservation - Easements - The Nature Conservancy

Project Manager: Michael Pressman
Affiliation: The Nature Conservancy
Address: 1101 West River Parkway
Minneapolis, MN 55415
Phone: 612-331-0706
Fax: 612-331-0770
E-mail: mpressman@tnc.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Balance	ENTF Funds Spent	ENTF Balance	Other Funds * Proposed	Other Funds * Spent
Easement	$50,000	$50,000	$0	$50,000	$225
Total	$50,000	$50,000	$0	$50,000	$225

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:

State Funds: $116,438.82
Other: $33,745.60
See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results

The Nature Conservancy uses a rigorous planning process to preserve key properties for biological diversity called "Conservation by Design." This method provides for the identification of sites of high biodiversity significance on which to concentrates its financial resources for acquisition and restoration. The Conservancy prefers to acquire large tracts of land but will also assemble smaller properties to form larger blocks of habitat. To accomplish this goal on the landscape level, the Minnesota Chapter of The Nature Conservancy partners with public agencies and other NGO's to locate and acquire such properties that achieve results at the large-scale and across multiple location targets. For its "Campaign for Conservation," the Conservancy proposes to acquire and retain in fee title up to 125 acres (with ETF funds; Conservancy will provide the remaining funds as needed) in one or several blocks to re-connect fragmented landscapes; acquire conservation easements on up to 200 acres of riparian lands; and restore 350 acres of wetlands, and existing protected prairie and savanna habitat.

The Conservancy initially received $100,000 for conservation easement acquisition on an estimated 200 acres of riparian habitat in Project Areas 5 and 11. On January 18, 2008, TNC received permission to spend $50,000 of these funds on either conservation easement acquisition or fee title acquisition under Work Program 4(g). After receiving approval, TNC re-allocated $50,000 of these funds to a fee title acquisition project under Work Program 4(g) in Project Area 7. For the remaining $50,000, TNC assisted the Board of Water and Soil Resources in acquiring a perpetual RIM Reserve conservation easement on 91.2 acres of riparian and upland habitat in Project Area 11.

In this time period, the Conservancy spent an additional $225 of its private funds in transaction-related expenses for this conservation easement acquisition project. An additional $33,745.60, the value of a donated easement on an additional 13.1 acres, was contributed toward this conservation easement acquisition project as "Other."

Project Results Use and Dissemination

The Conservancy publicizes its work on these projects via press releases, membership publications, presentations and/or the Conservancy's website. The Conservancy has also participated in publicizing the overall accomplishments of the Habitat Corridors Partnership project as it has reached significant mile marks.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3G: Campaign for Conservation - Easements - The Nature Conservancy

Easement Activities

Project Name: Root River
Tract: Christopherson
Project Area: 11 - Mississippi Bluff Lands
Township: 104, Range: 11, Section: 14

Description:

The property is located in Fillmore County at the confluence of the Root River and Rice Creek. The landowners granted a perpetual conservation easement over 91.2 acres of their larger ownership to the Board of Water and Soil Resources under the RIM Reserve Program. 45.2 acres of this easement property were eligible under the RIM Reserve Program as they were considered floodprone cropland. The remaining 46 acres included under the same RIM Reserve easement consists of riparian and upland forest habitat.

On December 8, 2008, the Conservancy granted $50,000 of its Phase IV funding to BWSR to allow the agency to acquire an easement on an additional 32.9 acres. The landowners donated the balance of 13.1 acres, for a donated value of $33,745.60.

Important conservation values of this property include a coldwater trout stream (Rice Creek) and steep bluff habitat that supports a maple-basswood, dry oak, and white pine hardwood forest community.

The Conservancy contributed $225 in Other Funds for a government records report, required for an environmental assessment.

Easement Recorded in LCCMR office: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Easement Acquisition Costs	$50,000.00	22.78	11.29	5.00	6.49	0.00	2,090.57
Other	Donated Easement Value	$33,745.60	15.37	7.62	3.37	4.38	0.00	1,410.95
Other Funds	Professional Services	$225.00	0.00	0.00	0.00	0.00	0.00	0.00
State Funds	Easement Acquisition Costs	$116,438.82	53.05	26.29	11.63	15.12	0.00	4,868.48
	Total:	**$200,409.42**	**91.20**	**45.20**	**80.00**	**26.00**	**0.00**	**8,370.00**

Easement Totals (By Funding Type)

Funding Type:	**Funding Amount**	**Prorated Acres**	**Grassland Acres**	**Woodland Acres**	**Wetland Acres**	**Shoreline Feet**	**Riparian Feet**
ENTF	$50,000.00	22.78	11.29	20.00	6.49	0.00	2,090.57
Other Funds	$225.00	0.00	0.00	0.00	0.00	0.00	0.00
State Funds	$116,438.82	53.05	26.29	11.63	15.12	0.00	4,868.48
Other	$33,745.60	15.37	45.20	3.37	4.38	0.00	1,410.95
Total	**$200,409.42**	**91.20**	**45.20**	**20.00**	**26.00**	**0.00**	**8,370.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

3G: Campaign for Conservation - Easements - The Nature Conservancy

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

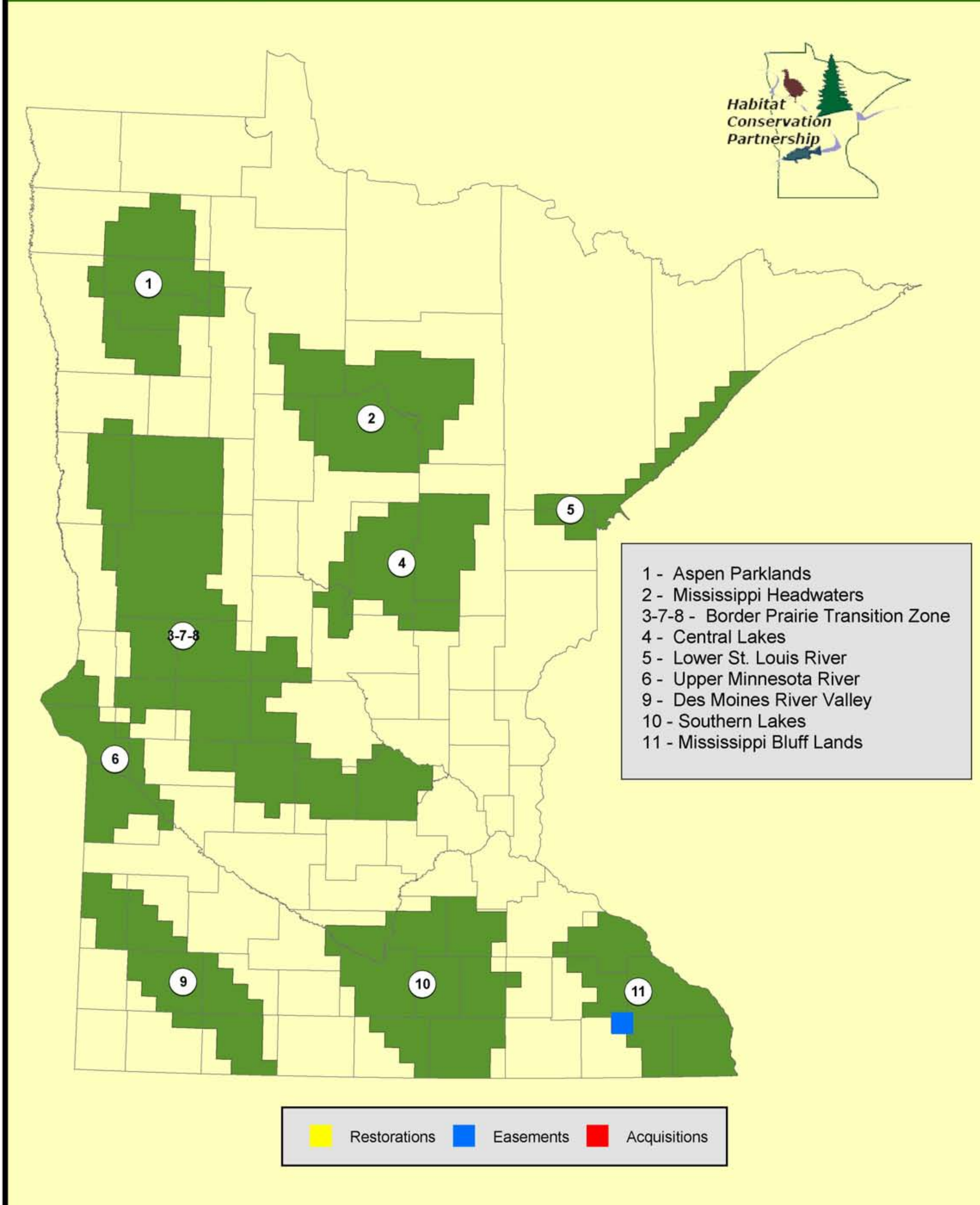
Project Title: TNC's 'Campaign for Conservation' – 2(n), 3(g), 4(g)

Project Manager Name: Michael Pressman

Trust Fund Appropriation: $430,000

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent	Balance	Result 2 Budget:	Amount Spent	Balance	Result 3 Budget:	Amount Spent	Balance	TOTAL BUDGET	TOTAL BALANCE
	Land acquisition			Conservation easements or land acquisition			Restoration				
BUDGET ITEM											
Personnel							20,000	20,000	0	20,000	0
Contracts											
Prescribed burning crews, tree removal and/or seeding services							60,000	60,000	0	60,000	0
Land acquisition	300,000	300,000	0							300,000	0
Land rights acquisition				50,000	50,000	0				50,000	0
Professional Services											
Appraisals, surveys, title work, closing costs, environmental review											
COLUMN TOTAL	**$300,000**	**$300,000**	**$0**	**$50,000**	**$50,000**	**$0**	**$80,000**	**$0**	**$0**	**$430,000**	**$0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
3G - Campaign for Conservation - Easements - The Nature Conservancy



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4A: Critical Lands Conservation Initiative IV - Pheasants Forever

Project Manager: Matt Holland
Affiliation: Pheasants Forever
Address: 679 W. River Dr.
New London, MN 56273
Phone: (320) 354-4377
Fax: (320) 354-4377
E-mail: mholland@pheasantsforever.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds * Proposed	Other Funds * Spent
Acquisition	$450,000	$450,000	$0	$205,000	$361,150
Total	$450,000	$450,000	$0	$205,000	$361,150

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:

State Funds:	$109,200.00
Partners State Levereged Funds:	$59,800.00

See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results

This project completed seven projects totaling 412 acres (203 ENRTF, 209 Other Funds). Six projects are additions to existing state wildlife management areas (WMA) and one project is an addition to a federal waterfowl production area (WPA). PF expended $450,000 of ENRTF funds and $361,150 of other funds directly on this project. PF is pleased to report that we exceeded both our acre goals and other fund commitments made to this proposal

A project by project accounting and supporting context can be found in the final work program report and all accomplishment reports are available at www.mnhabitatcorridors.org . Habitat breakdown of acres acquired shows 220 acres of grasslands, 185 acres of wetlands, 6.8 acres of woodlands and 1,200 feet of shoreline. Lands enrolled in the state WMA System or National Wildlife Refuge System (WPA's) and will be open to public hunting, trapping, bird watching and other activities consistent with the respective systems. All projects are additions to existing units of public land habitat and build upon past investments in wildlife habitat conservation. In addition, we have worked with many local, state and federal partners to achieve results. By doing so, we continue to enhance these areas for wildlife and provide recreation benefits to all Minnesotans.

Completed acquisition projects are listed in the table below. Point locations along with township-range-section information can be found in the completed final report at the website listed above.

Project Name	County	HCP Project Area	Total Acreage
Spring Creek WMA Addition	Becker	3-7-8	201
Henjum Lake WPA Addition	Kandiyohi	3-7-8	35
Bench WMA Addition*	Swift	3-7-8	27
Copeland WMA Addition	Otter Tail	3-7-8	32

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

4A: Critical Lands Conservation Initiative IV - Pheasants Forever

Alvstad WMA Addition	Grant	3-7-8	10
Sangl WMA Addition	Jackson	9	80
White Bear WMA Addition	Pope	3-7-8	56

*This project included state funds and private funds (not match)

Project Results Use and Dissemination

All projects acquired through the Habitat Conservation Partnership acknowledge the funding from the Minnesota Environment & Natural Resources Trust Fund. These new public land additions will be incorporated into the DNR Wildlife Management Area System and National Wildlife Refuge System and will be added to appropriate maps, websites, and other WMA information dissemination outlets. Also, detailed accomplishment report information is available at www.mnhabitatcorridors.org.

Acquisition Activities

Project Name: White Bear WMA

Project Area: 3 - Border Prairie
Township: 125, Range: 39, Section: 4

Acquisition Holder: DNR-WMA

Description: This 50.3-acre addition includes wetland and grass with approximatley 10 acres of farmland adjacent to the White Bear WMA in White Bear Lake Township, Pope County. This parcel helps to square up the existing unit and includes several wetlands that straddle the WMA boundary onto this property. Acquisition also will protect the creek drainage that flows from the WMA until the road. Acquisiton will enable better WMA grassland and wetland management. Since this project straddles phases IV and V, prorated acre totals do not equal total project acres in this report. Professional services were for appraisal, appraisal addenda, closing costs, document shipping, and survey.

Acquisition reported via LCCMR website: Yes

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	50.30	33.00	0.00	17.00	0.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$79,211.00	28.53	18.72	0.00	9.64	0.00	0.00
ENTF	Personnel Expenditures	$1,485.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$1,500.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$2,007.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$100.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$818.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$18.00	0.00	0.00	0.00	0.00	0.00	0.00
White Bear WMA Total		**$85,139.00**	**28.53**	**18.72**	**0.00**	**9.64**	**0.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

4A: Critical Lands Conservation Initiative IV - Pheasants Forever

Project Name: Beaver Creek WMA
Project Area: 9 - Des Moines River Valley
Township: 107, Range: 41, Section: 24
Acquisition Holder: DNR-WMA
Description: PF completed the boundary survey for a the Beaver Creek WMA addition which was completed in Phase III by PF, the National Wild Turkey Federation and Minnesota DNR. The boundary survey was needed to clarify legal description so that MN DNR could accept the property into the WMA system. Since this project spans two phases, the prorated acre totals do not equal the total acres for the project in this report.
Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	119.00	34.74	84.26	0.00	0.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$6,500.00	0.00	0.00	0.00	0.00	0.00	0.00
	Beaver Creek WMA Total	**$6,500.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: Sangl WMA
Tract: 7
Project Area: 9 - Des Moines River Valley
Township: 101, Range: 36, Section: 29
Acquisition Holder: DNR-WMA
Description: This builds upon the 260-acre Sangl WMA and is part of the original Sangl WMA project proposal. At the time of acquisition, this parcel consisted of 14-acres CRP, 5-acres trees, 30-acres wetlands, and 30-acres of cropland. This parcel is in a developing 4-9 square mile wetland complex and is located in the heart of the Little Sioux Worlking Lands Initiative focus area. Wetland and grassland restoration will take place in concert with DNR wildlife managers to restore the habitat. Professional services include appraisal and closing costs. Fees were for property taxes due to close and transfer property to MN DNR.
Acquisition reported via LCCMR website: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fees	$468.00	0.23	0.13	0.01	0.09	0.00	0.00
ENTF	Fee-Title Acquisition Costs	$80,000.00	39.88	22.43	2.49	14.96	0.00	0.00
ENTF	Personnel Expenditures	$172.14	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$1,158.53	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Fee-Title Acquisition Costs	$80,000.00	39.88	22.43	2.49	14.96	0.00	0.00
Other Funds	Professional Services	$2,500.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sangl WMA Total	**$164,298.67**	**80.00**	**45.00**	**5.00**	**30.00**	**0.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4A: Critical Lands Conservation Initiative IV - Pheasants Forever

Project Name: Cambria WMA
Tract: 1
Project Area: 10 - Southern Lakes
Township: 109, Range: 29, Section: 22
Acquisition Holder: DNR-WMA
Description: This new WMA contains 50-acres of hardwood, primarily bur oak, forest adjacent to an oxbow of the Minnesota River and 30 acres of grassland. According to the MN Biological Survey, about 9.6-acres of the grassland caontained a moderately diverse remnant prairie in 1999. Since that time, the site has been managed by fire and the diversity has increased significantly. Adjacent grasslands are to be reseeded from local harvest of the remnant site.
Acquisition reported via LCCMR website: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$2,500.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cambria WMA Total	**$2,500.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: Alvstad WMA
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 128, Range: 41, Section: 1
Acquisition Holder: DNR-WMA
Description: This acquisition squares off the existing Alvstad WMA unit. It will improve nesting cover for grassland birds along with providing improved parking and access to the exisitng Alvstad Wildlife Management Area. Since this project straddles phase IV and V, the prorated acres totals do not equal the total project totals in this report. Professional services include closing costs, appraisal, appraisal addenda and survey.
Acquisition reported via LCCMR website: Yes

	Acres	**Grassland Acres**	**Woodland Acres**	**Wetland Acres**	**Shoreline Feet**	**Riparian Feet**
Non Prorated Totals:	10.00	10.00	0.00	0.00	0.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$29,000.00	4.73	4.73	0.00	0.00	0.00	0.00
ENTF	Professional Services	$870.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$300.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$1,009.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Professional Services	$1,200.00	0.00	0.00	0.00	0.00	0.00	0.00
	Alvstad WMA Total	**$32,379.00**	**4.73**	**4.73**	**0.00**	**0.00**	**0.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

4A: Critical Lands Conservation Initiative IV - Pheasants Forever

Project Name: Bench WMA
Tract: 3
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 122, Range: 39, Section: 26
Acquisition Holder: DNR-WMA
Description: This 120-acre addition to the Bench WMA (217-acres adjacent, 477-acres total) builds upon the Chippewa River habitat complex and provides quality restoration and management potential for grassland, wetland and riparian species. PF participated in this acquisition as a partner, and DNR completed the acquisition. It contains floodplain wetlands (approximately 97 acres) and type 3-4 wetlands (approximately 23 acres) and includes a significant portion of a drained wetland, of which the long-term plan is to acquire rights to restore. Partners include Swift County PF, MN Deer Hunters Association, PF's Minnesota Habitat Fund, and Minnesota DNR (RIM & Surcharge).
Acquisition reported via LCCMR website: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$50,000.00	27.40	0.00	0.00	27.40	0.00	0.00
Partners State Leveraged Funds	Donated Fee Value	$39,000.00	21.37	0.00	0.00	21.37	0.00	0.00
Partners State Leveraged Funds	Fee-Title Acquisition Costs	$20,800.00	11.40	0.00	0.00	11.40	0.00	0.00
State Funds	Fee-Title Acquisition Costs	$109,200.00	59.84	0.00	0.00	59.84	0.00	0.00
	Bench WMA Total	**$219,000.00**	**120.00**	**0.00**	**0.00**	**120.00**	**0.00**	**0.00**

Project Name: Copeland WMA
Tract: 3
Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 131, Range: 44, Section: 32
Acquisition Holder: DNR-WMA
Description: Marsh and upland habitat adjacent to Copeland WMA located in the Southwest Otter Tail County beach ridge habitat corridor. In addition to adding and preserving habitat in this important corridor, acquisition of this tract will enable additional public use and access to the unit from the south. Professional services included appraisal, appraisal addenda, closing costs and survey.
Acquisition reported via LCCMR website: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$62,720.00	32.00	7.00	0.00	25.00	0.00	0.00
ENTF	Personnel Expenditures	$486.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$1,098.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$25.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$1,800.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$1,830.00	0.00	0.00	0.00	0.00	0.00	0.00
	Copeland WMA Total	**$67,959.00**	**32.00**	**7.00**	**0.00**	**25.00**	**0.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

4A: Critical Lands Conservation Initiative IV - Pheasants Forever

Project Name: Henjum Lake WPA

Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 121, Range: 36, Section: 22

Acquisition Holder: DNR-WMA

Description: This addition to the Henjum Lake WPA provides access to significant lakeshore on Henjum lake, including two points for waterfowl hunting. It will also provide for the USFWS to conduct management to the existing and new parcel within the WPA. Expenses include $182 in property taxes, $855.92 in closing costs, $46 to record notice of grant restrictions, $2,300 for an appraisal, $18.72 in UPS shipping charges, and $258.22 in personnel time to complete the transaction. The transfer of title for this parcel to the USFWS was approved by LCCMR at their June 24, 2009 meeting. Professional services were for appraisal, closing costs and UPS document shipping.

Acquisition reported via LCCMR website: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$52,400.00	31.64	15.34	0.00	16.30	1,095.47	0.00
ENTF	Personnel Expenditures	$14.35	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Personnel Expenditures	$243.87	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$855.92	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$2,300.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$18.72	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Donated Fee Value	$5,000.00	3.02	1.46	0.00	1.56	104.53	0.00
Henjum Lake WPA Total		**$60,832.86**	**34.66**	**16.80**	**0.00**	**17.86**	**1,200.00**	**0.00**

4A: Critical Lands Conservation Initiative IV - Pheasants Forever

Project Name: Spring Creek WMA

Project Area: 3-7-8 - Border Prairie Transition Zone
Township: 142, Range: 41, Section: 7

Acquisition Holder: DNR-WMA

Description: This addition to the 757-acre Spring Creek WMA lies adjacent to US HWY 59 and provides a much needed buffer to high quality, rare fen habitats that exist on the Spring Creek WMA. According to Jeannette Leete, MNDNR - Waters, "The calcareous fens that remain within and near the Spring Creek WMA are, in my opinion, and in the opinion of other wetland scientists, among the best examples of short sedge calcareous fens in the world." Additionally, 40-acres of native remnant mesic & wet prairie are also protected along with 75 acres of wetland and 83-acres of marginal cropland sites to be restored. Professional services were for appraisal and closing costs. Fees were real estate taxes due to close and transfer property to Minnesota DNR.

Acquisition reported via LCCMR website: Yes

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fees	$774.68	0.48	0.30	0.00	0.18	0.00	0.00
ENTF	Fee-Title Acquisition Costs	$53,450.00	33.32	20.91	0.00	12.42	0.00	0.00
ENTF	Personnel Expenditures	$187.52	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$2,979.55	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Donated Fee Value	$42,100.00	26.25	16.47	0.00	9.78	0.00	0.00
Other Funds	Fee-Title Acquisition Costs	$98,700.00	61.53	38.61	0.00	22.93	0.00	0.00
Other Funds	Fee-Title Acquisition Costs	$123,850.00	77.21	48.44	0.00	28.77	0.00	0.00
Other Funds	Fee-Title Acquisition Costs	$4,000.00	2.49	1.56	0.00	0.93	0.00	0.00
Other Funds	Professional Services	$1,200.00	0.00	0.00	0.00	0.00	0.00	0.00
Spring Creek WMA Total		**$327,241.75**	**201.29**	**126.29**	**0.00**	**75.00**	**0.00**	**0.00**

Acquisition Totals (By Funding Type)

Funding Type:	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF:	$438,300.28	198.22	89.56	2.51	105.98	1,095.47	0.00
Other Funds:	$358,550.00	210.39	128.98	2.49	78.92	104.53	0.00
Partner's State Leverage Funds:	$59,800.00	32.77	0.00	0.00	32.77	0.00	0.00
State Funds:	$109,200.00	59.84	0.00	0.00	59.84	0.00	0.00
Total:	**$965,850.28**	**501.21**	**218.54**	**5.00**	**277.50**	**1,200.00**	**0.00**

4A: Critical Lands Conservation Initiative IV - Pheasants Forever

Work Program Expenditures (Not Attributable to Specific Projects)

FundingType	Category	Amount	Description
ENTF	Professional Services	$1,000.00	Appraisal fee for the desired acquisition of an addiiton to the Diamond Lake WMA in LeSueur County. The offer was rejected by the potential seller.
ENTF	Professional Services	$1,700.00	Appraisal fees for the desired acquisition of an addiiton to the Cambria WMA in Blue Earth County. The offer was rejected by the potential seller. A second appraisal was completed under this phase and the project will be completed in July of 2009 using Phase V (2008) funding.
ENTF	Professional Services	$1,500.00	Appraisal fees for the desired acquisition of an 80-acre addiiton to the Panicum Prairie WMA in Freeborn County. The project remains active.
ENTF	Professional Services	$1,200.00	Appraisal fees for the desired acquisition of a 200-acre addiiton to the Panicum Prairie WMA in Freeborn County. The project remains active.
ENTF	Professional Services	$2,000.00	Appraisal fees for the desired acquisition of a 15-acre addiiton to the Florida Slough WPA in Kandiyohi County. The project remains active.
ENTF	Professional Services	$2,500.00	Appraisal fees for the desired acquisition of a 80-acre addiiton to the Prairie Storm WPA in Stearns County. The project remains active.
ENTF	Professional Services	$1,800.00	Appraisal fee for the desired 65-acre addition to the Prairie Ridge WMA in Otter Tail County. The offer was rejected by the potential seller.
Other Funds	Professional Services	$2,600.00	Appraisal fee for the desired acquisition of Hands Marsh WMA in Rice County which is within Project Area 10. The offer was made and rejected by the potential seller.
	Total:	**$14,300.00**	

Work Program Expenditures (Not Attributable to Specific Projects) By Funding Type

Funding Type	Amount
ENTF:	$11,700.00
Other Funds:	$2,600.00
Total:	**$14,300.00**

Work Program Expenditures Breakdown

Funding Type:	Acquistion Projects	Not Attributable to Specific Projects	Total
ENTF:	$438,300.28	$11,700.00	$450,000.28

4A: Critical Lands Conservation Initiative IV - Pheasants Forever

Other Funds:	$358,550.00	$2,600.00	$361,150.00
Partner's State Leveraged Funds:	$109,200.00	$0.00	$59,800.00
State Funds:	$59,800.00	$0.00	$109,200.00
Total:	**$965,850.28**	**$14,300.00**	**$980,150.28**

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

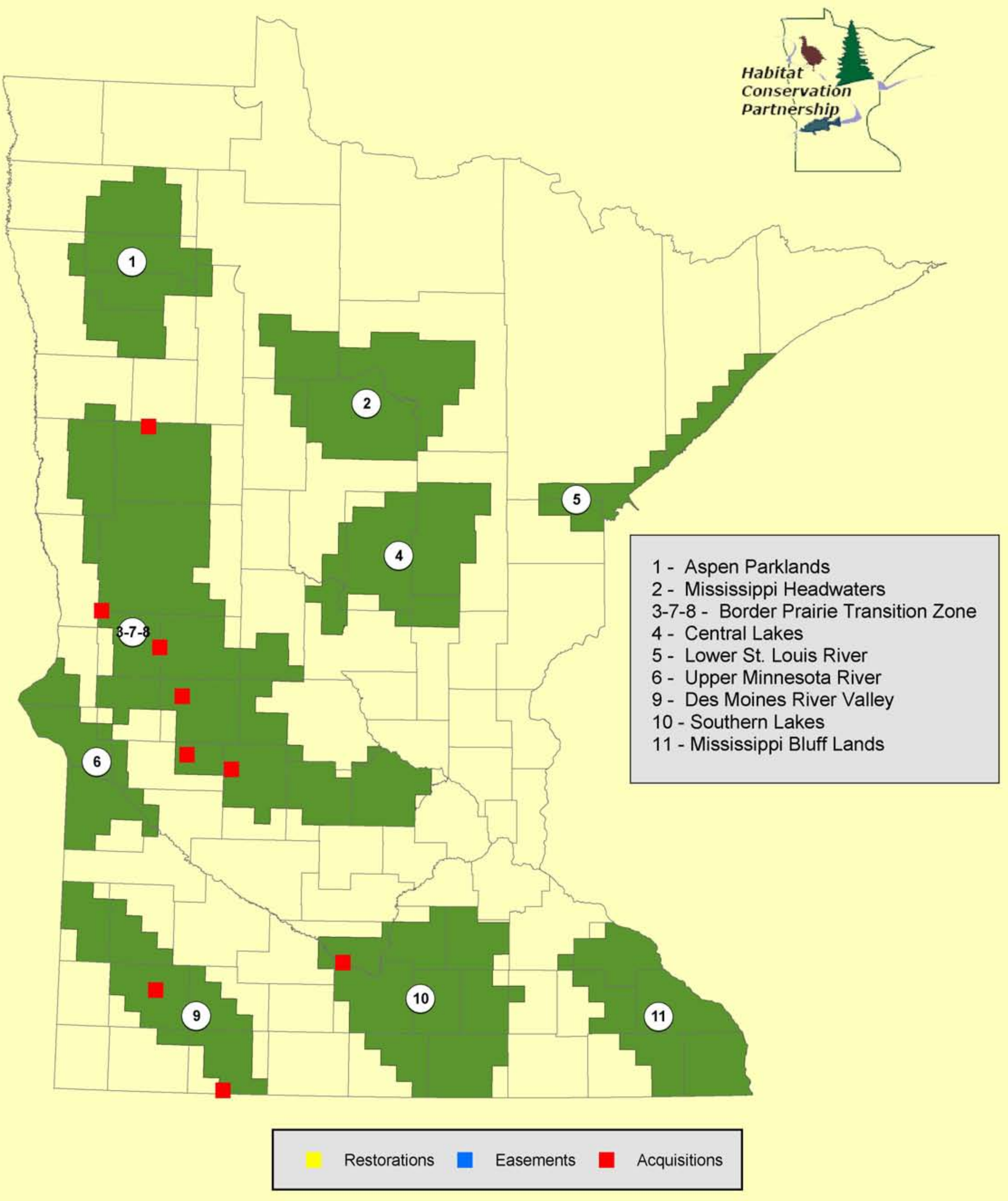
Project Title: Critical Land Conservation Initiative - Phase IV, 4(a)

Project Manager Name: *Matt Holland*

Trust Fund Appropriation: $ *450,000*
Final Report - June 30, 2009

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent	Balance	Result 2 Budget:	Amount Spent	Balance	TOTAL BUDGET	TOTAL BALANCE
	Land Acquisition - CLCI V			*Personnel*				
PERSONNEL: wages and benefits direct to the project	$0	$0	$0	$2,589	$2,589	$0	$2,589	$0
Land acquisition	$447,411	$447,411	$0	$0	$0	$0	$447,411	$0
COLUMN TOTAL	**$447,411**	**$447,411**	**$0**	**$2,589**	**$2,589**	**$0**	**$450,000**	**$0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
4A - Critical Lands Conservation Initiative IV - Pheasants Forever



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Manager: Linda Erickson-Eastwood

Affiliation: MN DNR - Division of Fisheries

Address: 500 Lafayette Rd.
St. Paul, MN 55155

Phone: (651) 259-5206

Fax: (651) 297-4916

E-mail: linda.erickson-eastwood@dnr.state.mn.us

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed *	Other Funds Spent *
Easement	-	$10,784	-	-	$0
Acquisition	-	$489,216	-	-	$131,700
Total	**$500,000**	**$500,000**	**$0**	**$0**	**$131,700**

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:

State Funds: $646,580.00

Other: $436,500.00

See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results

This project resulted in a grand total of approximately 177.8 acres and 2.9 miles of lake and stream shoreline being acquired as either easement or fee title. Environmental and Natural Resources Trust dollars directly acquired approximately 41.1 acres of the total, including 0.8 miles of lake and stream shoreline. Donations of land value and cash ("other funds" $597,700) and other state monies ($633,300) leveraged with trust dollars totaled $1,231,000. These contributions helped acquire the remaining acres of the grand total, including 72.2 acres and 0.5 shoreline miles using state dollars and 64.5 acres and 1.6 shoreline miles from donations of land value and cash.

Project Results Use and Dissemination

This project complemented parcel acquisitions funded in the past with capital bonding, Trout Stamp, and Environmental Trust Fund dollars. The acquisition of aquatic management areas adjacent to lakes and streams ensured the protection of critical riparian habitat areas within sensitive watersheds and headwater areas, as well as, angler and management access. Acquisition under this segment concentrated in the following project areas: 2) Mississippi Headwaters, 3) Border Prairie, 4) Central Lakes, 5) Lower St, Louis River, and 10) Southern Lakes. AMA parcels will be added to PRIM maps.

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Acquisition Activities

Project Name: Bear Island
Tract: 1
Project Area: 2 - Mississippi Headwaters
Township: 142, Range: 29, Section: 14
Acquisition Holder: DNR-AMA
Description: Property includes 79 acres of land, with 3,740 feet of shoreline on Bear Island of Leech Lake in Cass County. The owners expectations were much higher than the appraised value and the acquisition failed, even though the owners had originally indicated a willingness to donate a portion of the value.
Acquisition reported via LCCMR website: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$7,580.00	0.00	0.00	0.00	0.00	0.00	0.00
Bear Island Total		**$7,580.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: Buetow AMA
Tract: 1
Project Area: 2 - Mississippi Headwaters
Township: 142, Range: 28, Section: 16
Acquisition Holder: DNR-AMA
Description: Property includes 238 acres of land, with over 2 miles of shoreline on Headquarters Bay of Leech Lake in Cass County. The project will both protect the natural integrity of the shoreline habitat, and provide non-motorized public acces, including fishing, hunting, trapping, and other light use activities. This is a partnership project with TPL. This project will be completed in Phase V.
Acquisition reported via LCCMR website: Yes

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	238.00	0.00	115.00	123.00	3,480.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$3,020.00	0.00	0.00	0.00	0.00	0.00	0.00
Buetow AMA Total		**$3,020.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: Steamboat Lake AMA
Tract: 2
Project Area: 2 - Mississippi Headwaters
Township: 144, Range: 31, Section: 29
Acquisition Holder: DNR-AMA
Description: Property includes 39 acres of land, with 1,100 feet of shoreline on Steamboat Lake in Cass County. This parcel doubles the shoreline protected as AMA on Steamboat Lake. Acquisition of this site permanently protects habitat important to a variety of fish and wildlife species, as well as protect vital surface and groundwater resources.
Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	38.70	0.00	6.00	32.70	1,100.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$24,000.00	10.55	0.00	1.64	8.92	300.00	0.00
ENTF	Professional Services	$9,500.00	0.00	0.00	0.00	0.00	0.00	0.00
State Funds	Fee-Title Acquisition Costs	$64,000.00	28.15	0.00	4.36	23.78	800.00	0.00
Steamboat Lake AMA Total		**$97,500.00**	**38.70**	**0.00**	**6.00**	**32.70**	**1,100.00**	**0.00**

Project Name: Bennewitz Pond AMA
Tract: 1
Project Area: 3 - Border Prairie
Township: 128, Range: 39, Section: 24
Acquisition Holder: DNR-AMA
Description: This parcel is a donation from the Vikings Sportsmens Club in Douglas County. They acquired this property to provide permanent access to the DNR for the purposes of rearing walleye for stocking in area lakes. The property includes 27.5 acres with 1.13 miles of shoreline on Bennewitz Pond in Douglas County . The project provides permanent state access to rear walleye, public access to fish during years when walleye survive the winter, and permanently protects the natural integrity of the shoreline habitat.
Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	27.50	0.00	2.50	25.00	5,950.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$6,568.15	0.00	0.00	0.00	0.00	0.00	0.00
Other	Donated Fee Value	$27,500.00	27.50	0.00	2.50	25.00	5,950.00	0.00
Bennewitz Pond AMA Total		**$34,068.15**	**27.50**	**0.00**	**2.50**	**25.00**	**5,950.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: Bucks Mill AMA
Tract: 2
Project Area: 3 - Border Prairie
Township: 138, Range: 41, Section: 31
Acquisition Holder: DNR-AMA
Description: Property includes 45 acres of land, with 3,725 feet of shoreline on Buck Lake in Becker County. The parcel along with the existing AMA, protects 3/4s of the shoreline on this important link between Melissa and Little Pelican Lakes. The owners decided not to sell at the last minute. There still is a chance that they will change their mind.
Acquisition reported via LCCMR website: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$5,750.00	0.00	0.00	0.00	0.00	0.00	0.00
Bucks Mill AMA Total		**$5,750.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: Greenleaf AMA
Tract: 1
Project Area: 3 - Border Prairie
Township: 118, Range: 30, Section: 21
Acquisition Holder: DNR-AMA
Description: Property includes 28 acres of land, with 0.5 miles of shoreline on Souix Lake in Meeker County. This is part of a larger project called the Greenleaf Recreation Area. This AMA parcel will both protect the natural integrity of the shoreline habitat, and provide light use public access, including shorefishing. This project is being carried forward into Phase V.
Acquisition reported via LCCMR website: No

	Acres	**Grassland Acres**	**Woodland Acres**	**Wetland Acres**	**Shoreline Feet**	**Riparian Feet**
Non Prorated Totals:	28.00	8.00	10.00	10.00	1,700.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$40.00	0.00	0.00	0.00	0.00	0.00	0.00
Greenleaf AMA Total		**$40.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: Ida Lake AMA
Tract: 7
Project Area: 3 - Border Prairie
Township: 129, Range: 38, Section: 2
Acquisition Holder: DNR-AMA
Description: This parcel is a donation from the Vikings Sportsmens Club in Douglas County. They acquired this property to permanently protect important spawning habitat. The property includes 21.8 acres with 0.66 miles of shoreline on Ida Lake in Douglas County. The project provides permanent protection to an important gamefish spawning area, protects the natural integrity of the shoreline habitat and provides walk-in public access. This acquisition will be carried forward into phase V.
Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	21.80	0.00	5.00	16.80	1,350.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$4,544.00	0.00	0.00	0.00	0.00	0.00	0.00
ENTF	Professional Services	$3,430.80	0.00	0.00	0.00	0.00	0.00	0.00
Other	Donated Fee Value	$50,000.00	8.80	0.00	3.00	5.80	1,365.00	0.00
Ida Lake AMA Total		**$57,974.80**	**8.80**	**0.00**	**3.00**	**5.80**	**1,365.00**	**0.00**

Project Name: Little Wolf AMA
Tract: 1
Project Area: 3 - Border Prairie
Township: 118, Range: 29, Section: 27
Acquisition Holder: DNR-AMA
Description: This is a joint project with the Division of Trails and Waterways. Property includes 7.2 acres of land, with 610 feet of shoreline on Little Wolf Lake in Meeker County. The project will both protect the natural integrity of the shoreline habitat, and provide public access.
Acquisition reported via LCCMR website: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$37,500.00	3.60	2.00	1.00	0.60	270.00	0.00
ENTF	Professional Services	$201.50	0.00	0.00	0.00	0.00	0.00	0.00
State Funds	Professional Services	$4,000.00	0.00	0.00	0.00	0.00	0.00	0.00
Little Wolf AMA Total		**$41,701.50**	**3.60**	**2.00**	**1.00**	**0.60**	**270.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: Lizzie Lake AMA
Tract: 1
Project Area: 3 - Border Prairie
Township: 136, Range: 42, Section: 7
Acquisition Holder: DNR-AMA
Description: This is a joint project with the Division of Trails and Waterways. Property includes 3 acres of land, with 900 feet of shoreline where the Pelican River enters Lizzie Lake in Becker County. The project will both protect the natural integrity of the shoreline habitat, and provide public access. This project will be completed in Phase V.
Acquisition reported via LCCMR website: No

			Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
		Non Prorated Totals:	3.00	2.00	0.00	1.00	900.00	0.00
Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$1,480.00	0.00	0.00	0.00	0.00	0.00	0.00
Lizzie Lake AMA Total		**$1,480.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: Mary Lake AMA
Tract: 1
Project Area: 3 - Border Prairie
Township: 127, Range: 38, Section: 4
Acquisition Holder: DNR-AMA
Description: This parcel is a donation from the Vikings Sportsmens Club in Douglas County. They acquired this property in 1964 to provide access to an inlet area that served as state carp trap. The property includes 1.4 acres with 715 feet of shoreline on Mary Lake in Douglas County. The project provides permanent protection to an important wetland connection to Mary Lake, protects the natural integrity of the shoreline habitat and provides walk-in public access. This project is being carried forward into Phase V.
Acquisition reported via LCCMR website: No

			Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
		Non Prorated Totals:	1.40	0.00	1.00	0.40	715.00	0.00
Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$6,022.90	0.00	0.00	0.00	0.00	0.00	0.00
Mary Lake AMA Total		**$6,022.90**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: Mason Lake Pass
Tract: 1
Project Area: 3 - Border Prairie
Township: 133, Range: 39, Section: 22
Acquisition Holder: DNR-AMA
Description: This parcel is a donation by the last survivors of an old shooting club. They acquired this property in 1965 to use as a duck hunting property for pass shooting ducks between East And West Mason Lakes. The property includes 3.4 acres with 1,070 feet of shoreline. The project provides permanent protection to an important wetland, and public access to both lakes. This project will carry forward into Phase V.
Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	3.40	0.00	2.00	3.40	1,070.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$10,800.70	0.00	0.00	0.00	0.00	0.00	0.00
Mason Lake Pass Total		**$10,800.70**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: Middle Lake AMA
Tract: 1
Project Area: 3 - Border Prairie
Township: 121, Range: 35, Section: 9
Acquisition Holder: DNR-AMA
Description: Property includes 14 acres of land, with 3,010 feet of shoreline on Middle Lake in Kandiyohi County. This is a cooperative project with MN DNR Trails and Waterways, who will develop a public boat access on their portion. The Fisheries administered portion will both protect the natural integrity of the shoreline habitat, and provide light use public access, including shorefishing.
Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	8.80	0.00	8.00	0.80	1,715.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$233,383.00	6.25	0.00	5.69	0.57	1,218.86	0.00
ENTF	Professional Services	$13,509.60	0.00	0.00	0.00	0.00	0.00	0.00
Other	Donated Fee Value	$44,000.00	1.18	0.00	1.07	0.11	229.79	0.00
Other Funds	Fee-Title Acquisition Costs	$3,500.00	0.09	0.00	0.09	0.01	18.28	0.00
State Funds	Fee-Title Acquisition Costs	$47,500.00	1.27	0.00	1.16	0.12	248.07	0.00
Middle Lake AMA Total		**$341,892.60**	**8.80**	**0.00**	**8.00**	**0.80**	**1,715.00**	**0.00**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: North Turtle Lake AMA
Tract: 1
Project Area: 3 - Border Prairie
Township: 133, Range: 41, Section: 23
Acquisition Holder: DNR-AMA
Description: This project is a continuation from an acquisition during Phase III. Property includes 5.1 acres of land, with 0.3 mile of shoreline on North Turtle Lake in Otter Tail County. This was a cooperative acquisition with MN-DNR Trails and Waterways, who simultaneously acquired a public access immediately adjacent to the North Turtle Lake AMA. The project will both protect the natural integrity of the shoreline habitat, and provide public shorefishing access.
Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	5.10	0.50	3.60	1.00	1,565.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$695.80	0.00	0.00	0.00	0.00	0.00	0.00
North Turtle Lake AMA Total		**$695.80**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: Glacier Lake AMA
Tract: 1
Project Area: 4 - Central Lakes
Township: 50, Range: 23, Section: 26
Acquisition Holder: DNR-AMA
Description: This a continuation of a project acquired in Phase III. The property includes 19.5 acres of land, with 0.25 mile of shoreline on Glacier Lake in Aitkin County. This property was willed to the DNR with a 30 year life estate. In order to complete fee title, the life estate is being acquired. This will provide shore angling opportunities on a lake that has no other public access, as well as protecting the untouched shoreline habitat.
Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	19.50	0.00	19.00	0.50	1,335.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$4,453.01	0.00	0.00	0.00	0.00	0.00	0.00
Glacier Lake AMA Total		**$4,453.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: Pelican Lake AMA
Tract: 1
Project Area: 4 - Central Lakes
Township: 136, Range: 28, Section: 25
Acquisition Holder: DNR-AMA
Description: Property includes 78 acres of land, with 2,815 feet of shoreline on Pelican Lake in Crow Wing County. The land is already encumbered with a Conservation Easement held by the Minnesota Land Trust. The fee title portion is being donated to the DNR and will provide light use public access, including shorefishing. This project will be completed in Phase V.
Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	78.30	0.00	38.30	40.00	2,815.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$5,578.29	0.00	0.00	0.00	0.00	0.00	0.00
Pelican Lake AMA Total		**$5,578.29**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: Savageau AMA
Tract: 1
Project Area: 4 - Central Lakes
Township: 134, Range: 28, Section: 26
Acquisition Holder: DNR-AMA
Description: This parcel was a donation by the owner, who wanted to make sure that his property remained in a natural state. He had been ill and passed away before deeding the property to us. His intentions were not clear in writing and his heirs do not intend to complete his wish. The property included 3.2 acres with 410 feet of shoreline on the Mississippi River just north of Brainerd. The project would have provided permanent protection and angler access to this stretch of river.
Acquisition reported via LCCMR website: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$1,600.00	0.00	0.00	0.00	0.00	0.00	0.00
Savageau AMA Total		**$1,600.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: Shetek AMA
Tract: 1A
Project Area: 9 - Des Moines River Valley
Township: 108, Range: 41, Section: 11
Acquisition Holder: DNR-AMA
Description: Property includes 9 acres of land, with 2,200 feet of shoreline at the inlet to Shetek Lake in Murray County. The land is immediately adjacent to a parcel already administered by DNR Fisheries. It will not only protect the natural integrity of the shoreline habitat, but will provide safe walk-in access to an important spring fishery. Owner has decided not to sell, but we hope to revisit.
Acquisition reported via LCCMR website: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$2,280.00	0.00	0.00	0.00	0.00	0.00	0.00
	Shetek AMA Total	**$2,280.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Project Name: German Lake
Tract: 1
Project Area: 10 - Southern Lakes
Township: 110, Range: 24, Section: 32
Acquisition Holder: DNR-AMA
Description: This parcel is a donation from the landowner. The property includes 2.4 acres with 0.21 miles of shoreline on German Lake in LeSueur County. The project provides permanent protection to critical shoreline habitat and provides walk-in public access to German Lake.
Acquisition reported via LCCMR website: No

	Acres	**Grassland Acres**	**Woodland Acres**	**Wetland Acres**	**Shoreline Feet**	**Riparian Feet**
Non Prorated Totals:	2.40	0.00	2.00	0.40	1,100.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$2,232.62	0.00	0.00	0.00	0.00	0.00	0.00
Other	Donated Fee Value	$95,000.00	2.40	0.00	2.00	0.40	1,100.00	0.00
	German Lake Total	**$97,232.62**	**2.40**	**0.00**	**2.00**	**0.40**	**1,100.00**	**0.00**

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: Horseshoe Lake AMA
Tract: 2
Project Area: 10 - Southern Lakes
Township: 109, Range: 23, Section: 12
Acquisition Holder: DNR-AMA
Description: This is an addition to an existing AMA. The property includes 85 acres with 0.53 miles of shoreline on Horseshoe Lake in LeSueur County. The project provides permanent protection to critical shoreline habitat and provides additional walk-in public access to Horseshoe Lake. The area will be open to angling, hunting, trapping, and other light use, non-motorized activity.
Acquisition reported via LCCMR website: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$100,000.00	8.78	6.70	1.03	1.05	286.60	0.00
ENTF	Professional Services	$5,045.30	0.00	0.00	0.00	0.00	0.00	0.00
Other	Donated Fee Value	$220,000.00	19.32	14.74	2.27	2.31	630.52	0.00
Other Funds	Fee-Title Acquisition Costs	$128,200.00	11.26	8.59	1.32	1.35	367.42	0.00
State Funds	Fee-Title Acquisition Costs	$201,800.00	17.73	13.52	2.08	2.12	578.35	0.00
State Funds	Fee-Title Acquisition Costs	$320,000.00	28.11	21.44	3.30	3.36	917.11	0.00
State Funds	Professional Services	$9,280.00	0.00	0.00	0.00	0.00	0.00	0.00
Horseshoe Lake AMA Total		**$984,325.30**	**85.20**	**65.00**	**10.00**	**10.20**	**2,780.00**	**0.00**

Acquisition Totals (By Funding Type)

Funding Type:	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF:	$489,215.67	29.19	8.70	9.35	11.14	2,075.45	0.00
Other Funds:	$131,700.00	11.35	8.59	1.41	1.36	385.70	0.00
State Funds:	$646,580.00	75.25	34.97	10.90	29.38	2,543.54	0.00
Other:	$436,500.00	59.20	14.74	10.84	33.62	9,275.31	0.00
Total:	**$1,703,995.67**	**175.00**	**67.00**	**32.50**	**75.50**	**14,280.00**	**0.00**

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Easement Activities

Project Name: Bay Lake-Church Island
Tract: First Lutheran Church
Project Area: 4 - Central Lakes
Township: 45, Range: 28, Section: 10
Description: This project is a continuation from an acquistion during Phase III. Fisheries worked with the Minnesota Land Trust to protect this 59 acre island in Bay Lake. The island is currently owned by First Lutheran Church and used as a summer youth camp. About 12 acres of the property is used as the camp-site. The remaining land is undeveloped, comprising one of the last large undeveloped tracts on land on Bay Lake. The island is protected by a conservation easement held by DNR, which will allow the camp to continue in operation. No buildings or structures will be allowed outside of the current camp area. Outside of the area used by the camp, the island will be open to the public for angling and other light use. If the camp ever ceases operation, one single-family dwelling will be allowed on the property.

	Acres	**Grassland Acres**	**Woodland Acres**	**Wetland Acres**	**Shoreline Feet**	**Riparian Feet**
Non Prorated Totals:	59.00	0.00	50.00	0.00	8,976.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$386.50	0.00	0.00	0.00	0.00	0.00	0.00

Project Name: Glacier Lake AMA
Tract: 2
Project Area: 4 - Central Lakes
Township: 50, Range: 23, Section: 26
Description: This is a continuation from Phase III. The project completes access to Glacier Lake AMA, Parcel 1. The easement is being donated by Camp New Hope which is immediately adjacent to the AMA.

	Acres	**Grassland Acres**	**Woodland Acres**	**Wetland Acres**	**Shoreline Feet**	**Riparian Feet**
Non Prorated Totals:	0.10	0.00	0.10	0.00	0.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Professional Services	$1,304.80	0.00	0.00	0.00	0.00	0.00	0.00

4B: Fisheries Acquisition - MN DNR - Division of Fisheries

Project Name: Knife River
Tract: 27
Project Area: 5 - Lower St. Louis River
Township: 52, Range: 11, Section: 19
Description: This is a permanent AMA angling and management easement that provides angler access on 860 feet of the Knife River, a designated trout stream. The easement is immediately adjacent to another permanent easement. The easement also provides protection to the shoreline habitat.

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Easement Acquisition Costs	$6,970.03	2.80	0.00	2.00	0.80	0.00	860.00
ENTF	Professional Services	$2,123.00	0.00	0.00	0.00	0.00	0.00	0.00
	Knife River Total	**$9,093.03**	**2.80**	**0.00**	**4.00**	**0.80**	**0.00**	**860.00**

Easement Totals (By Funding Type)

Funding Type:	Funding Amount	Prorated Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
ETF	$10,784.33	2.80	0.00	54.10	0.80	0.00	860.00
Total	**$10,784.33**	**2.80**	**0.00**	**2.00**	**0.80**	**0.00**	**860.00**

Work Program Expenditures Breakdown

Funding Type:	Acquistion Projects	Easement Projects	Not Attributable to Specific Projects	Total
ENTF:	$489,215.67	$10,784.33	$0.00	$500,000.00
Other Funds:	$131,700.00	$0.00	$0.00	$131,700.00
Partner's State Leveraged Funds:	$646,580.00	$0.00	$0.00	$0.00
Other:	$436,500.00	$0.00	$0.00	$436,500.00
Total:	**$1,703,995.67**	**$10,784.33**	**$0.00**	**$1,714,780.00**

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail Phase IV Projects

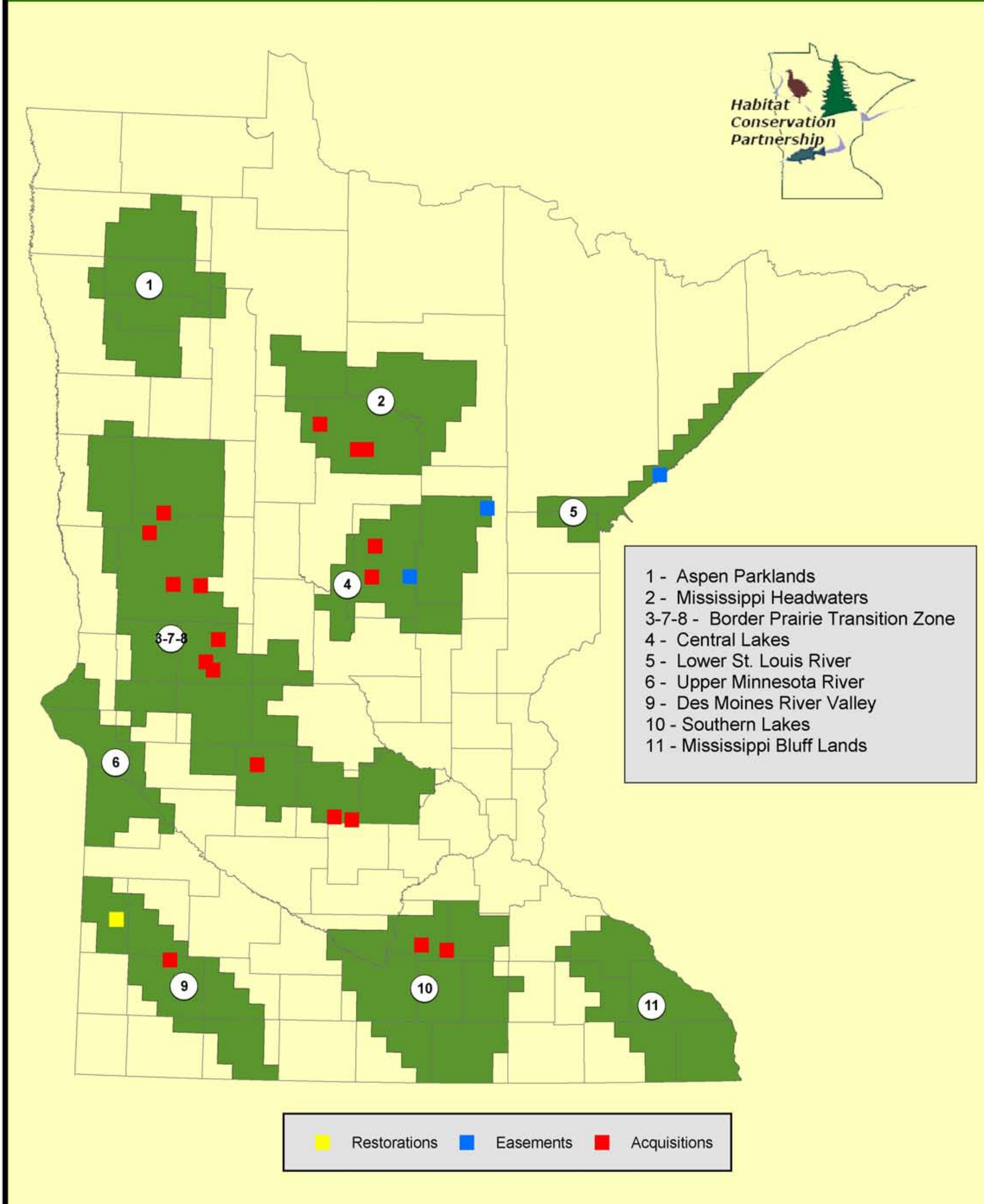
Proposal Title: Habitat Corridors Partnership Phase IV - Fish and Wildlife Land Acquisition (4b)

Project Manager Name: *Linda Erickson-Eastwood.*

LCMR Requested Dollars: $ *500,000*

2007 LCMR Proposal Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	
	Land Acquistion			
BUDGET ITEM				**TOTAL FOR BUDGET ITEM**
Land acquisition *(177.8 Acres)*	**$500,000**	**$500,000**	**$0**	**$500,000**
COLUMN TOTAL	**$500,000**	**$500,000**	**$0**	**$500,000**

Habitat Conservation Partnership
Phase 4 - Accomplishments
4B - Fisheries Acquisition - MN DNR - Division of Fisheries



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

4C: Critical Lands Protection Program - The Trust for Public Land

Project Manager: Robert McGillivray

Affiliation: The Trust for Public Land

Address: 2610 University Ave
St. Paul, MN 55114

Phone: 651-999-5307

Fax: 651-917-2248

E-mail: Bob.McGillivray@tpl.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds * Proposed	Other Funds * Spent
Acquisition	$480,000	$480,000	$0	$135,000	$0
Total	$480,000	$480,000	$0	$135,000	$0

*Other Funds are classified as non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds). Please note, however, that this work program has spent the following amounts not shown in the above table:

State Funds: $175,000.00

Partners State Levereged Funds: $175,000.00

See the tables and funding type definitions at the end of this report for further explanation.

Work Program Summary

Overall Project Outcome and Results

On February 27, 2009, The Trust for Public Land (TPL) acquired 238 acres on Leech Lake in Cass County, Minnesota from members of the Beutow Family for $1,025,000 and sold it to the Minnesota Department of Natural Resources (DNR) for $545,000. TPL used $480,000 of 2007 Environment and Natural Resources Trust Fund (ENRTF) (HCP Phase 4) money and DNR Fisheries used $190,000 of 2008 ENRTF (HCP Phase 5) money towards this purchase. TPL negotiated the purchase of the property for $175,000 less than its appraised fair market value of $1,200,000, and thus $175,000 of RIM funding could also be used. DNR Fisheries used $180,000 of bonding money to fund the balance of the acquisition.

The Buetow AMA acquisition creates a new DNR Aquatic Management Area providing outstanding opportunities for public fishing, hunting and nature observation. The 238 acre parcel contains thousands of feet of shoreline on a shallow bay with a floating bog and extensive stands of wild rice and submerged vegetation. This diverse forest and wetland habitat also links a number of parcels of land already in public ownership (see attached map) ensuring a large landscape for wildlife to roam.

The multiple owners of this land had decided to sell the property and preliminary plans for a development with over 20 houses had been drafted. This threat of development to the important natural resources described above made this acquisition a priority for the DNR, the U. S. Forest Service, the Leech Lake Band of Ojibwe, and the Leech Lake Area Watershed Foundation. Although the property was listed for sale, TPL was able to quickly secure the property for less than its appraised fair market value, complete the due diligence process and work together with DNR Fisheries to assemble a funding package to protect this important water resource for fish, wildlife and future generations.

Project Results Use and Dissemination

4C: Critical Lands Protection Program - The Trust for Public Land

The Leech Lake Area Watershed encompasses nearly 800,000 acres of land and water critical to the water quality of Minnesota's lakes and rivers. It is under intense development pressure as more and more people seek to have second homes in the heart of Minnesota's Northwoods. TPL is working with the Minnesota DNR and interested stakeholders, such as the Leech Lake Area Watershed Foundation, the U. S. Forest Service and the Leech Lake Band of Ojibwe, to protect the most sensitive lands in this area. In the near future, we hope to disseminate a press release describing these efforts including the Buetow AMA project and two other pending acquisitions.

4C: Critical Lands Protection Program - The Trust for Public Land

Acquisition Activities

Project Name: Buetow AMA
Tract: 1
Project Area: 2 - Mississippi Headwaters
Township: 142, Range: 28, Section: 16
Acquisition Holder: DNR-AMA
Description: The Buetow AMA acquisition creates a new DNR Aquatic Management Area providing outstanding opportunities for public fishing, hunting and nature observation. The 238 acre parcel contains thousands of feet of shoreline on a shallow bay with a floating bog and extensive stands of wild rice and submerged vegetation. This diverse forest and wetland habitat also links multiple parcels of land already in public ownership ensuring a large landscape for wildlife to roam. Although the property was listed for sale, TPL was able to quickly secure the property for less than its appraised fair market value and work together with DNR Fisheries to assemble a funding package to protect this important water resource for fish, wildlife and future generations.

Of the $1,200,000 needed to purchase this property, DNR used $370,000(30.83%) and TPL used $830,000(69.17%). Therefore, of the 238 acres and 11,000 feet of shoreline protected with this project, DNR and TPL's prorated accomplishments are 73.4(acres)\3,480(shoreline feet) and 164.6(acres)\7,520(shoreline feet). See below. Please note that Professional Services are not used in determining the prorated accomplishment credits.

	DNR	TPL	Total
Expenditures	$370,000	$830,000	$1,2000,000
Prorated %	30.83%	69.7%	100%
Acres	73.4	164.6	238
Shoreline(feet)	3,480	7,520	11,000

TPL used $480,000 of 2007 Environment and Natural Resources Trust Fund (ENRTF) (HCP Phase 4) money and DNR Fisheries used $190,000 of 2008 ENRTF (HCP Phase 5) money towards this purchase. TPL negotiated the purchase of the property for $175,000 less than its appraised fair market value of $1,200,000, and thus $175,000 of RIM funding could also be used. DNR Fisheries used $180,000 of bonding money to fund the balance of the acquisition.

Acquisition reported via LCCMR website: Yes

			Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
		Non Prorated Totals:	238.00	0.00	115.00	123.00	3,480.00	0.00
Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$480,000.00	95.20	0.00	46.00	49.20	1,392.00	0.00
Partners State Leveraged Funds	Donated Fee Value	$175,000.00	34.71	0.00	16.77	17.94	507.50	0.00
State Funds	Fee-Title Acquisition Costs	$175,000.00	34.71	0.00	16.77	17.94	507.50	0.00
	Buetow AMA Total	**$830,000.00**	**164.62**	**0.00**	**79.54**	**85.08**	**2,407.00**	**0.00**

LCCMR Work Program Final Report
Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4C: Critical Lands Protection Program - The Trust for Public Land

Acquisition Totals (By Funding Type)

Funding Type:	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF:	$480,000.00	95.20	0.00	46.00	49.20	1,392.00	0.00
Partner's State Leverage Funds:	$175,000.00	34.71	0.00	16.77	17.94	507.50	0.00
State Funds:	$175,000.00	34.71	0.00	16.77	17.94	507.50	0.00
Total:	**$830,000.00**	**164.62**	**0.00**	**79.54**	**85.08**	**2,407.00**	**0.00**

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

FINAL Attachment A: Budget Detail for 2007 Projects

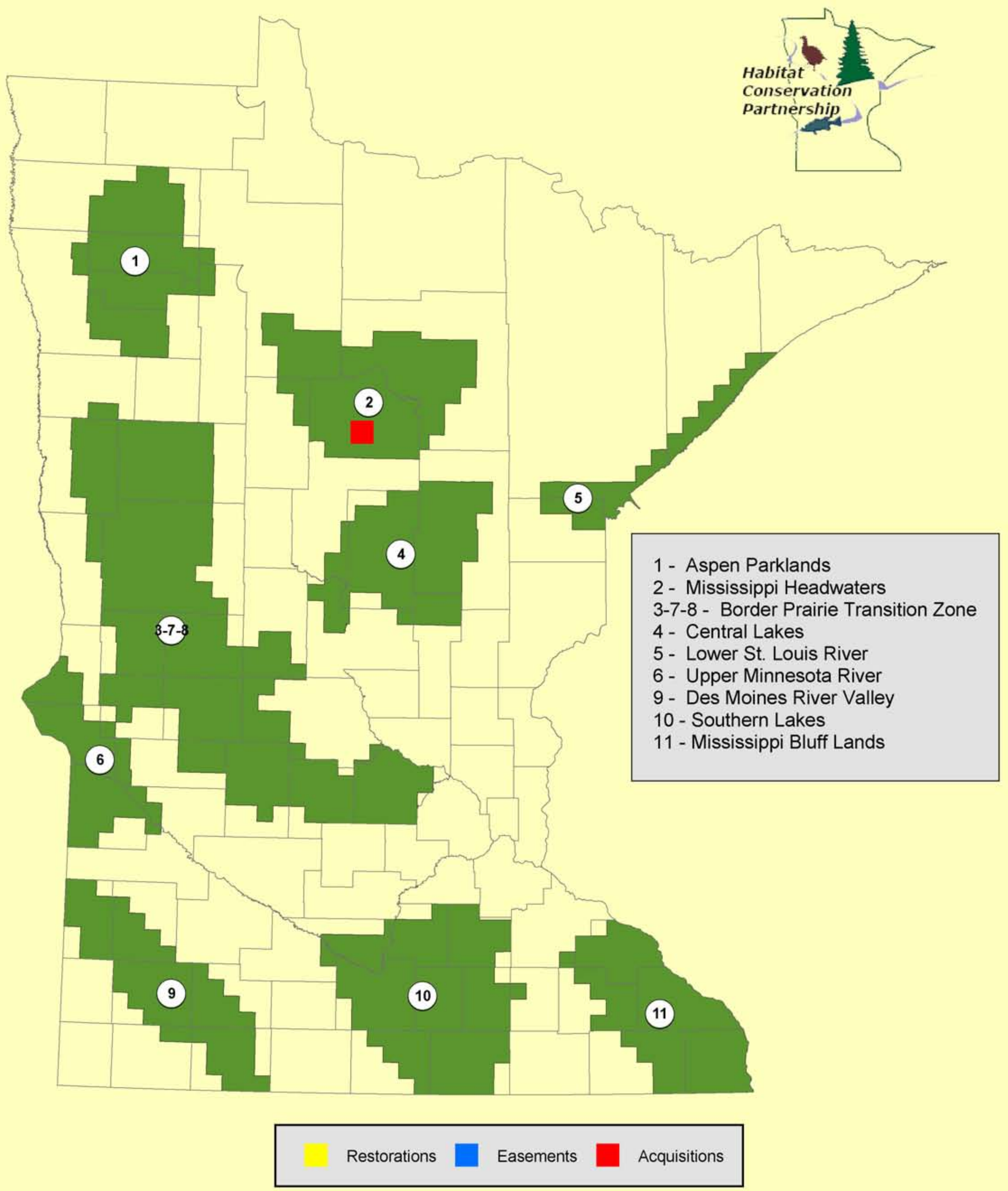
Project Title: Minnesota Habitat Corridors Partnership—Phase IV—TPL's Critical Lands Protection Program (4C)

Project Manager Name: Robert McGillivray

Trust Fund Appropriation: $480,000

2007 Trust Fund Budget	**Result 1 Budget: Habitat Acquisition programs**	**Amount Spent 2-27-09**	**Balance 2-27-09**	**TOTAL BUDGET**	**TOTAL BALANCE**
BUDGET ITEM	Acquisition				
Land acquisition	**$480,000**	**$480,000**	**$0**	**$480,000**	**$0**
COLUMN TOTAL	**$480,000**	**$480,000**	**$0**	**$480,000**	**$0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
4C- Critical Lands Protection Program - The Trust for Public Land



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

4F: Minnesota NWTF Super Fund - National Wild Turkey Federation

Project Manager: Dave Neu
Affiliation: National Wild Turkey Federation
Address: 265 Lorrie Way
De Pere, WI 54,115
Phone: (920)347-0312
Fax: (920)427-2335
E-mail: neunwtf@sbcglobal.net

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Acquisition	$15,000.00	$0.00	$15,000.00	$0.00	$0.00
Total	$15,000.00	$0.00	$15,000.00	$0.00	$0.00

Work Program Summary

Overall Project Outcome and Results
Several parcels were under consideration for purchase, but they either dropped out or were available too late to close by June 30, 2009.

Project Results Use and Dissemination
No results for this project.

Attachment A: Budget Detail for 2007 Projects

Project Title: Minnesota *NWTF Land Acquisition (4f) and SOS (2i)*

Project Manager Name: *Dave Neu*

Trust Fund Appropriation: $3*5,000*

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	**Result 2 Budget:**	**Amount Spent**	**Balance**	**TOTAL BUDGET**	**TOTAL BALANCE**
	4F - Land Acquisition			*2I - Set Out Seedlings*				
BUDGET ITEM								
Contracts								
Land acquisition	$15,000		$15,000			$0	$15,000	$15,000
Other Supplies *(trees, tubes, mats, stakes)*			$0	$20,000	$20,000	$0	$20,000	$0
COLUMN TOTAL	**$15,000**	**$0**	**$15,000**	**$20,000**	**$20,000**	**$0**	**$35,000**	**$15,000**

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

4G: Campaign for Conservation - Acquisition - The Nature Conservancy

Project Manager: Michael Pressman

Affiliation: The Nature Conservancy

Address: 1101 West River Parkway
Minneapolis, MN 55415

Phone: 612-331-0706

Fax: 612-331-0770

E-mail: mpressman@tnc.org

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Acquisition	$300,000	$300,000	$0	$500,000	$337,974
Total	$300,000	$300,000	$0	$500,000	$337,974

Work Program Summary

Overall Project Outcome and Results

The Nature Conservancy uses a rigorous planning process to preserve key properties for biological diversity called "Conservation by Design." This method provides for the identification of sites of high biodiversity significance on which to concentrates its financial resources for acquisition and restoration. The Conservancy prefers to acquire large tracts of land but will also assemble smaller properties to form larger blocks of habitat. To accomplish this goal on the landscape level, the Minnesota Chapter of The Nature Conservancy partners with public agencies and other NGO's to locate and acquire such properties that achieve results at the large-scale and across multiple location targets. For its "Campaign for Conservation," the Conservancy proposes to acquire and retain in fee title up to 125 acres (with ETF funds; Conservancy will provide the remaining funds as needed) in one or several blocks to re-connect fragmented landscapes; acquire conservation easements on up to 200 acres of riparian lands; and restore 350 acres of wetlands, and existing protected prairie and savanna habitat.

The Conservancy initially received $250,000 for fee title acquisition to acquire an estimated 125 acres in Project Areas 6, 3-7-8 or 9. On January 18, 2008, TNC received permission to spend $50,000 of the initial $100,000 approved for conservation easement acquisition under Work Program 3(g) on either fee title or conservation easement acquisition. After receiving approval, TNC re-allocated $50,000 of those funds to fee title acquisition to have a total of $300,000 to spend on fee title acquisition. On February 25, 2008, TNC closed on a 280-acre acquisition in Pope County adjacent to other property owned and managed by The Nature Conservancy.

In this time period, the Conservancy spent an additional $337,973.55 of its private funds in transaction-related expenses for this fee title acquisition project.

Project Results Use and Dissemination

The Conservancy publicizes its work on these projects via press releases, membership publications, presentations and /or the Conservancy's website. The Conservancy has also participated in publicizing the overall accomplishments of the Habitat Corridors Partnership project as it has reached significant mile marks.

4G: Campaign for Conservation - Acquisition - The Nature Conservancy

Acquisition Activities

Project Name: Sheepberry Fen
Tract: Nugent
Project Area: 7 - Alexandria Moraine
Township: 123, Range: 37, Section: 27
Acquisition Holder: TNC-Preserve
Description: The Nature Conservancy purchased 280 acres of high quality native prairie and wetland habitat in Pope County for $594,666, using its LCCMR Phase III and Phase IV land acquisition funding and privately-raised funds for the balance. The Conservancy will retain ownership and manage this property as an addition to its Sheepberry Fen Preserve.

On January 18, 2008 TNC submitted a workprogram ammendment which was approved by the LCCMR. That ammendment gave TNC discretion to use the $100,000 allocated to conservation easements in Result 2 for conservation easements and/or fee title acquisition. $50,000 of those funds were used for the Sheepberry Fen acquisition.

Other Funds contributed to this project total to $337,973.55. This amount includes TNC's privately-raised acquisition funds; a stewardship endowment and start-up funds for site development; an environmental assessment document; an appraisal update; recording fee; and a NICRA-approved indirect cost recovery rate of 23% on project-related costs other than acquisition or endowments.

Acquisition reported via LCCMR website: No

	Acres	Grassland Acres	Woodland Acres	Wetland Acres	Shoreline Feet	Riparian Feet
Non Prorated Totals:	280.00	100.00	0.00	180.00	0.00	0.00

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fee-Title Acquisition Costs	$300,000.00	141.26	50.45	0.00	90.81	0.00	0.00
Other Funds	Fee-Title Acquisition Costs	$188,826.12	88.91	31.75	0.00	57.16	0.00	0.00
Other Funds	Professional Services	$391.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Professional Services	$89.93	0.00	0.00	0.00	0.00	0.00	0.00
Other Funds	Site Development	$148,666.50	0.00	0.00	0.00	0.00	0.00	0.00
Sheepberry Fen Total		**$637,973.55**	**230.17**	**82.20**	**0.00**	**147.96**	**0.00**	**0.00**

Acquisition Totals (By Funding Type)

Funding Type:	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF:	$300,000.00	141.26	50.45	0.00	90.81	0.00	0.00
Other Funds:	$337,973.55	88.91	31.75	0.00	57.16	0.00	0.00
Total:	**$637,973.55**	**230.17**	**82.20**	**0.00**	**147.96**	**0.00**	**0.00**

4G: Campaign for Conservation - Acquisition - The Nature Conservancy

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

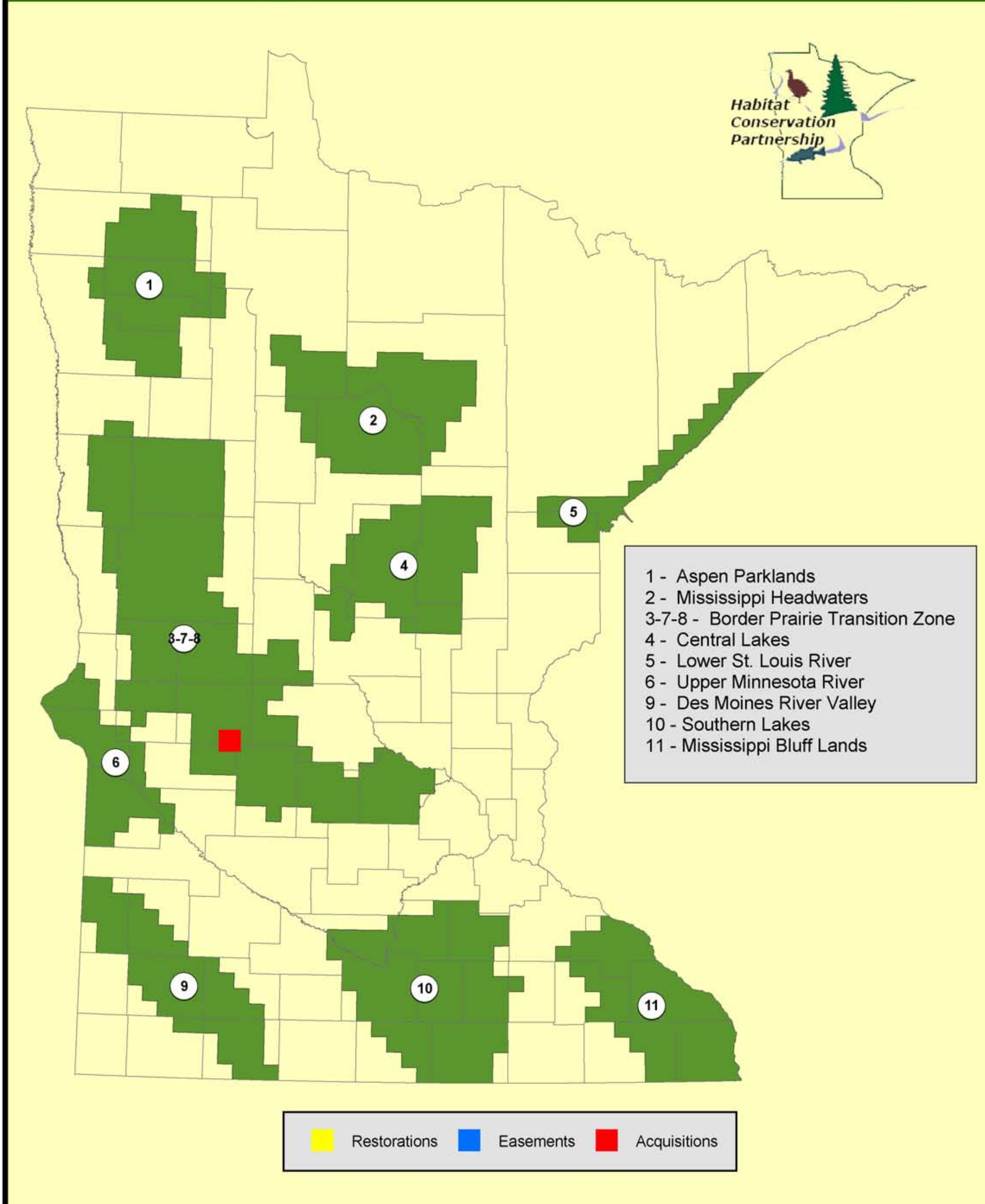
Project Title: TNC's 'Campaign for Conservation' – 2(n), 3(g), 4(g)

Project Manager Name: Michael Pressman

Trust Fund Appropriation: $430,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	**Result 2 Budget:**	**Amount Spent**	**Balance**	**Result 3 Budget:**	**Amount Spent**	**Balance**	**TOTAL BUDGET**	**TOTAL BALANCE**
	Land acquisition			Conservation easements or land acquisition			Restoration				
BUDGET ITEM											
Personnel							20,000	20,000	0	20,000	0
Contracts											
Prescribed burning crews, tree removal and/or seeding services							60,000	60,000	0	60,000	0
Land acquisition	300,000	300,000	0							300,000	0
Land rights acquisition				50,000	50,000	0				50,000	0
Professional Services											
Appraisals, surveys, title work, closing costs, environmental review											
COLUMN TOTAL	**$300,000**	**$300,000**	**$0**	**$50,000**	**$50,000**	**$0**	**$80,000**	**$0**	**$0**	**$430,000**	**$0**

Habitat Conservation Partnership
Phase 4 - Accomplishments
4G - Campaign for Conservattion - Acquisition - The Nature Conservancy



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4

Habitat Conservation Partnership

4H: MN Valley Refuge Expansion - MN Valley Trust

Project Manager: Deborah Loon

Affiliation: MN Valley Trust

Address: 2312 Seabury Avenue
Minneapolis, MN 55406

Phone: (612)728-3772

Fax: (612)728-0700

E-mail: DebLoon@comcast.net

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Biennial Project Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Acquisition	$100,000	$100,000	$0	$100,000	$232,976
Total	$100,000	$100,000	$0	$100,000	$232,976

Work Program Summary

Overall Project Outcome and Results

The Minnesota Valley National Wildife Refuge Trust, Inc. acquired 77.94 acres of significant habitat in Beauford Township of Blue Earth County (HCP Project Area 10) on August 2, 2007. Of the 77.94 acres, 23.41 acres were purchased with Environment and Natural Resources Trust grant funds and the balance of 54.53 acres were purchased with Minnesota Valley Trust funds.

This tract sits just east of the existing Cobb Waterfowl Production Area (WPA) and adjacent to Perch Lake, an important migratory waterfowl resting lake. This 480 acre lake hosts more than 10,000 migrating waterfowl each year and is designated as an important resting area for Lesser Scaup. It is designated by the DNR for wildlife management, one of only 40 such lakes in Minnesota with that designation.

The MN Valley Trust will acquire another 72.37 acres from the same landowner in the near future. That land is immediately east of this parcel and has approximately 2,000 feet of shoreline on the south end of Perch Lake.

Project Results Use and Dissemination

The Minnesota Valley Trust will publicize the completion of this acquisition and plans for the lands through its newsletter and news releases to the local media. After restoration is completed, the land will be donated to the Minnesota Valley National Wildlife Refuge and Wetland Management District. All funding partners will be acknowledged on Refuge kiosks, including the Environment and Natural Resources Trust Fund, as recommended by the Legislative Commission on Minnesota Resources.

4H: MN Valley Refuge Expansion - MN Valley Trust

Acquisition Activities

Project Name: Perch Lake WPA
Tract: 1
Project Area: 10 - Southern Lakes
Township: 106, Range: 26, Section: 13
Acquisition Holder: USFWS-WPA
Description: The Minnesota Valley National Wildife Refuge Trust, Inc. acquired 77.94 acres of significant habitat in Beauford Township of Blue Earth County (HCP Project Area 10) on August 2, 2007. Of the 77.94 acres, 23.41 acres were purchased with Environment and Natural Resources Trust grant funds and the balance of 54.53 acres were purchased with Minnesota Valley Trust funds.

This tract sits just east of the existing Cobb Waterfowl Production Area (WPA) and adjacent to Perch Lake, an important migratory waterfowl resting lake. This 480 acre lake hosts more than 10,000 migrating waterfowl each year and is designated as an important resting area for Lesser Scaup. It is designated by the DNR for wildlife management, one of only 40 such lakes in Minnesota with that designation.

The MN Valley Trust will acquire another 72.37 acres from the same landowner in the near future. That land is immediately east of this parcel and has approximately 2,000 feet of shoreline on the south end of Perch Lake.

Once the additional land is acquired, the MN Valley Trust will conduct restoration activities, working cooperatively with other partners. Restoration plans include tile breaks, earthen berms, and pump abandonment to restore approximately six wetlands totaling 20 acres. Another 130 acres will be seeded to native grass and will provide nesting habitat for a host of grassland species.

This acquisition and restoration will provide a critical link from Perch Lake to the Cobb River WPA complex located just west of this tract.

Acquisition reported via LCCMR website: No

Funding Type	*Funds Use*	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF	Fees	$100,000.00	23.41	20.40	0.00	3.00	0.00	0.00
Other Funds	Fees	$232,976.00	54.53	47.54	0.00	7.00	0.00	0.00
Perch Lake WPA Total		**$332,976.00**	**77.94**	**67.94**	**0.00**	**10.00**	**0.00**	**0.00**

Acquisition Totals (By Funding Type)

Funding Type:	*Funding Amount*	*Prorated Acres*	*Grassland Acres*	*Woodland Acres*	*Wetland Acres*	*Shoreline Feet*	*Riparian Feet*
ENTF:	$100,000.00	23.41	20.40	0.00	3.00	0.00	0.00
Other Funds:	$232,976.00	54.53	47.54	0.00	7.00	0.00	0.00
Total:	**$332,976.00**	**77.94**	**67.94**	**0.00**	**10.00**	**0.00**	**0.00**

4H: MN Valley Refuge Expansion - MN Valley Trust

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail for 2007 Projects

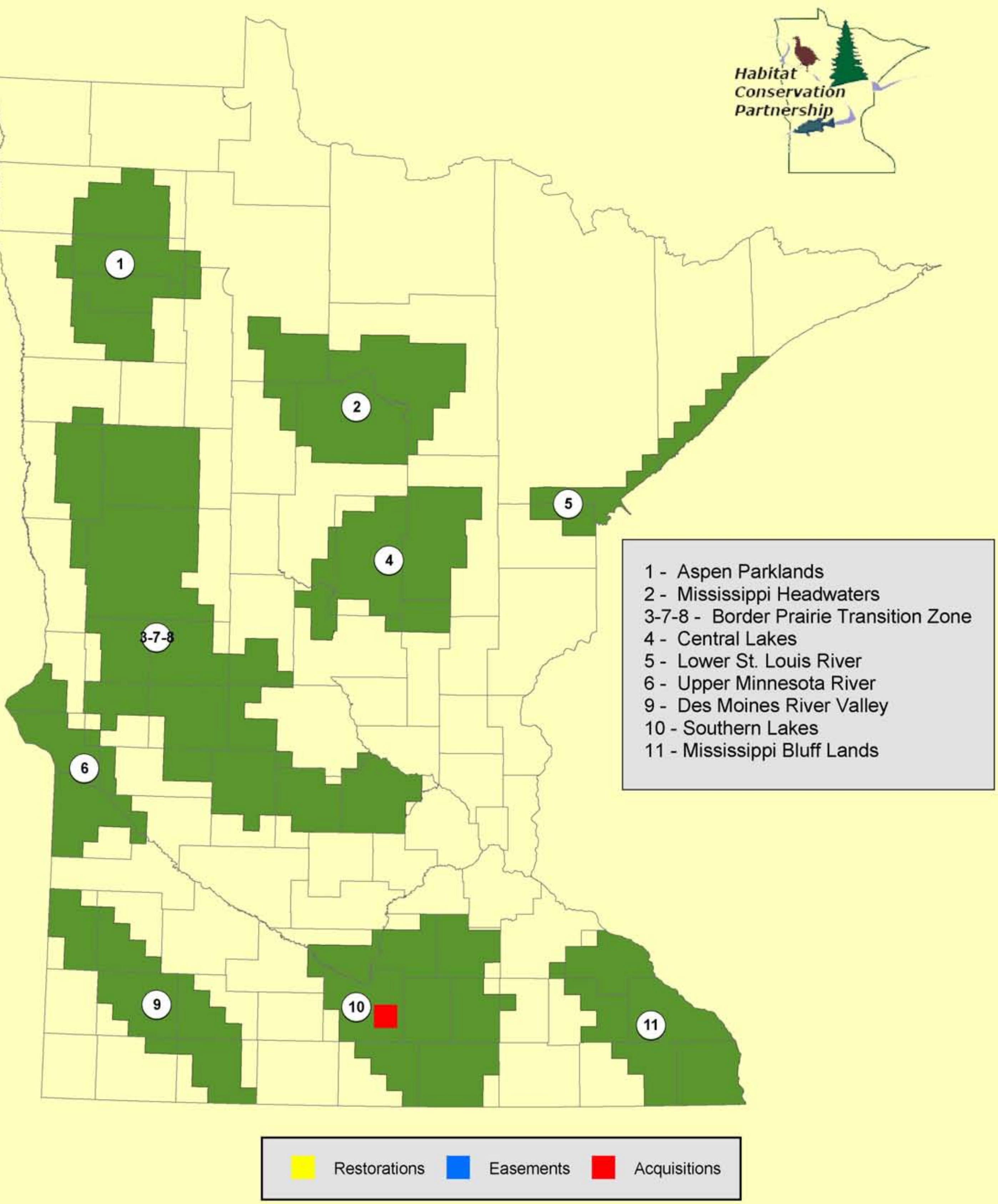
Project Title: Habitat Acquisition for Minnesota Valley Wetland Management District, USFWS - 4(h)

Project Manager Name: Deborah Loon, Minnesota Valley National Wildlife Refuge Trust, Inc.

LCMR Requested Dollars: $ 100,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance**	
	Acquired 23.41 acres of priority habitat in focus area 10 for Minnesota Valley Wetland Management District, USFWS			
BUDGET ITEM				**TOTAL FOR BUDGET ITEM**
Land acquisition	**$ 100,000.00**	**$ 100,000.00**	**0**	**$ 100,000.00**
COLUMN TOTAL	**$ 100,000.00**	**$ 100,000.00**	**$ -**	**$ 100,000.00**

Habitat Conservation Partnership
Phase 4 - Accomplishments
4H - MN Valley Refuge Expansion - MN Valley Trust



LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4I: Habitat Acquisition - Professional Services - MN DNR - Division of Fish & Wildlife

Project Manager: Kim Hennings

Affiliation: MN DNR - Division of Fish & Wildlife

Address: 500 Lafayette Rd.
St. Paul, MN 55,155

Phone: (651) 259-5210

Fax: (651) 297-4961

E-mail: kim.hennings@dnr.state.mn.us

Fund: Environment and Natural Resources Trust Fund

Legal Citation: ML 2007, Ch. 30, Sec. 2, Sub 4(b)

Total Work Program Budget

Result	ENTF Allocation	ENTF Funds Spent	ENTF Balance	Other Funds Proposed	Other Funds Spent
Acquisition	$50,000	$ 37,862	$12,138	$0	$0
Total	$50,000	$ 37,862	$12,138	$0	$0

Work Program Summary

Overall Project Outcome and Results

This project allowed DNR to pay professional services and processing costs related to land acquisition transfers to the DNR from HCP partners. Costs include the following: staff time for Division of Lands and Minerals ($80/hour) and the Attorney General's Office ($101/hour), survey costs, recording and abstracting fees, deed tax, and any property taxes due the subsequent year following conveyance to the DNR. The total cost to process and complete the estimated land conveyances to the DNR under this program is approximately 10% of the total value of these acquisitions.

Project Results Use and Dissemination

As of June 30, 2009 a total of $37,861.95 of ETF have been expended related to abstracting, recording, appraisals, property taxes and real estate transactions for Phase IV HCP. Expenses did not reach the expected needs of $50,000 for this work program. In an effort to better match future needs, requests for Phase V and VI Professional Services have been reduced to $30,000 and $25,000 respectively.

LCCMR Work Program Final Report

Restoring Minnesota's Fish and Wildlife Habitat Corridors Phase 4
Habitat Conservation Partnership

4I: Habitat Acquisition - Professional Services - MN DNR - Division of Fish & Wildlife

Work Program Expenditures

FundingType	*Funding Category*	*Amount*	*Description*
ENTF	Professional Services	$26,941.70	Real estate/Attorney General's fees
ENTF	Professional Services	$2,806.25	Abstracting
ENTF	Professional Services	$8,114.00	Property taxes
	Total:	**$37,861.95**	

Funding Type Definitions

ENTF:	Grant dollars provided through the Minnesota Environment and Natural Resources Trust Fund
Other Funds:	Non-state, non-state leveraged dollars (if partner funds are leveraging State Funds (e.g. RIM) they are not eligible to be considered Other Funds)
State Funds:	State Funds expended on HCP projects (not eligible for use as Other Funds commitment)
Partner's State Leveraged Funds:	Non State Funds that have leveraged State Funds as part of an HCP project (not eligible for use as Other Funds commitment)
Other:	Any other expenditures (e.g. grant income funds)

Attachment A: Budget Detail Phase IV Projects - FINAL

Project Title: Habitat Corridors Partnership Phase IV – Habitat Acquisition Professional Services

Project Manager Name: *Kim Hennings*

Trust Fund Appropriation: $50,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(6/30,09)*	**Balance** *(6,30,09)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Conveyance of corridor lands to DNR				
BUDGET ITEM					
Contracts			0		
Professional/technical (professional service costs - appraisals, abstracting, recording/deed tax, property taxes, Attorney General and Division of Lands & Minerals costs)	$50,000	$37,862	$12,138	$50,000	$12,138
COLUMN TOTAL	**$50,000**	**$37,862**	**$12,138**	**$50,000**	**$12,138**

2007 Project Abstract
For the Period Ending June 30, 2009

TITLE:	Metro Conservation Corridors – Phase III Overall Summary
PROJECT MANAGER:	Bill Becker (Wayne Sames – temporary)
ORGANIZATION:	MN Department of Natural Resources
ADDRESS:	500 Lafayette Road St. Paul, MN 55155-4010
WEB SITE ADDRESS:	www.dnr.state.mn.us/metroconservationcorridors
FUND:	Environmental and Natural Resources Trust Fund
LEGAL CITATION:	Minnesota Laws 2007, Chapter 30, Section 2, Subdivision 4(c)

APPROPRIATION AMOUNT: $2,500,000

OVERALL PROJECT OUTCOME AND RESULTS

During the third phase of the Metro Corridors project, the Metro Conservation Corridors Partners continued their work to accelerate protection and restoration of remaining high-quality natural lands in the greater Twin Cities Metropolitan Area by strategically coordinating and focusing conservation efforts within a connected and scientifically-identified network of critical lands. This corridor network stretches from the area's urban core to its rural perimeter, including portions of 16 counties.

The Partners employed a multi-faceted approach, which included accomplishments in four specific result areas:

1. *Coordinate Metro Conservation Corridors and Metro Greenways Programs*: Partners met quarterly to review project accomplishments and coordinate activity. With DNR support, the partners also launched development of an online database to facilitate tracking and reporting of MeCC projects over time.

2. *Restore and Enhance Significant Habitat*: Collectively, the partners restored 770 acres of land, including 1.26 miles of shoreline. Restoration of an additional 259 acres was completed using other funds.

3. *Acquire Significant Habitat*: Collectively, the partners protected 721 acres of land, including more than one-half mile of shoreline through acquisition of fee title and conservation easements and leveraged an additional 232 acres of land and ¼-mile of shoreline using other funds.

4. *Provide Community Conservation Assistance*: The Metro Greenways Program assisted four cities and two counties with the integration of natural resources information into local development and conservation planning and policy decisions.

Accomplishments during this phase also helped address a number of recommendations of the Statewide Conservation and Preservation Plan, including: protecting priority land habitats; protecting critical shorelands of streams and lakes; restoring land, wetlands, and wetland-associated watersheds; and improving connectivity and access to outdoor recreation.

PROJECT RESULTS USE AND DISSEMINATION

As projects were completed, the individual partners were encouraged to publicize accomplishments through press releases, organization newsletters, and websites. These efforts resulted in information being distributed to the public through websites, email lists, daily and weekly newspapers, newsletters, and other print materials. Additionally, once the MeCC database development is complete, the partnership hopes to be able to better disseminate information on its accomplishments through a public web portal.

Trust Fund 2007 Work Program Final Report

Date of Report: March 1, 2010
Date of Work program Approval:
Project Completion Date: 6/30/09

I. PROJECT TITLE: Metro Conservation Corridors (MeCC) Phase lll: Overall Summary

Project Manager: Wayne Sames
Affiliation: MN Dept of Natural Resources
Mailing Address: 500 Lafayette Road
City / State / Zip : St. Paul, MN 55155-4010
Telephone Number: 651-259-5559
E-mail Address: wayne.sames@dnr.state.mn.us
FAX Number: 651-296-6047
Web Page address: www.dnr.state.mn.us/metroconservationcorridors

Location: Within mapped Focus Area in the counties of Anoka, Carver, Chisago, Dakota, Goodhue, Hennepin, Isanti, LeSueur, Nicollet, Ramsey, Rice, Scott, Sherburne, Sibley, Washington and Wright. See Figure 1.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	2,500,000
	Minus Amount Spent:	**$**	2,465,225
	Equal Balance:	**$**	34,775

Legal Citation: ML 2007, Chapter 30, Section 2, Subdivision 4c

Appropriation Language: *(c)* Metro Conservation Corridors- Phase III

$2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated:(1) as an outdoor recreation unit under

Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II. AND III. FINAL PROJECT SUMMARY:

During the third phase of the Metro Corridors project, the Metro Conservation Corridors Partners continued their work to accelerate protection and restoration of remaining high-quality natural lands in the greater Twin Cities Metropolitan Area by strategically coordinating and focusing conservation efforts within a connected and scientifically-identified network of critical lands. This corridor network stretches from the area's urban core to its rural perimeter, including portions of 16 counties.

The Partners employed a multi-faceted approach, which included accomplishments in four specific result areas.

1. *Coordinate Metro Conservation Corridors and Metro Greenways Programs*: Partners met quarterly to review project accomplishments and coordinate activity. With DNR support, the partners also launched development of an online database to facilitate tracking and reporting of MeCC projects over time.

2. *Restore and Enhance Significant Habitat*: Collectively, the partners restored 770 acres of land, including 1.26 miles of shoreline. Restoration of an additional 259 acres was completed using other funds.

3. *Acquire Significant Habitat*: Collectively the partners protected 721 acres of land, including more than one-half mile of shoreline through acquisition of fee title and conservation easements and leveraged an additional 232 acres of land and ¼-mile of shoreline using other funds.

4. *Provide Community Conservation Assistance*: The Metro Greenways Program assisted four cities and two counties with the integration of natural resources information into local development and conservation planning and policy decisions.

Accomplishments during this phase also helped address a number of recommendations of the Statewide Conservation and Preservation Plan, including, protecting priority land habitats, protecting critical shorelands of streams and lakes, restoring land, wetlands, and wetland-associated watersheds, and improving connectivity and access to outdoor recreation.

IV. OUTLINE OF PROJECT RESULTS:

Result 1: Coordinate Metro Conservation Corridors and Metro Greenways Programs

The work of the partners to conserve habitat and natural areas threatened by development was coordinated and prioritized to increase cost-effectiveness and efficiently leverage private and public resources. This project component represented 2 years of implementation support for the management and coordination of the overall program and the Metro Greenways component within it.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$** 165,000
	Amount Spent:	**$** 150,572
	Balance:	**$** 14,428

Deliverable
Bi -annual progress reports on overall results

Final Completion Date: 6/30/2009

Final Report Summary:
MeCC Partners met quarterly to discuss progress on accomplishments and coordinate protection, restoration, and community assistance efforts. Partners also launched development of a project database that will help track and report progress of the partnership over time.

Result 2: Restore & Enhance Significant Habitat

Description: Partner organizations restored approximately 770 acres of significant upland, shore land and/or wetland habitat within the corridors. This includes Metro Greenways providing grants for restoration work to a local unit of government and a non-profit organization. These two grants were selected through a request for proposal process (RFP) that included broad eligibility and outreach.

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$** 279,416
	Amount Spent:	**$** 265,069
	Balance:	**$** 14,347

Deliverable
1. 203 acres restored

Final Completion Date: 6/30/2009

Final Report Summary:
Collectively, six partners restored 770 acres of land, including 1.26 miles of shoreline at 32 sites. Restoration of an additional 259 acres was completed using other funds.

Restoration activities were focused, and often coordinated, on improving habitat within SNA's and on other important public lands, restoring wetlands, and restoring habitat along trout streams.

A summary of each sub-result is provided below. For additional information and details on projects and expenditures, please see Table A and the individual work program final reports.

2.1: Restore/Enhance Significant Watershed Habitat – Friends of the Mississippi River

Friends of the Mississippi restored a total of 238 acres of significant habitat, including 79 acres using LCCMR funding, 95 acres using non-state funding, and 64 acres with other state funding.

Activities were focused on the following natural areas:

- Sand Coulee Prairie - City of Hastings
- Pine Bend Bluffs Scientific and Natural Area
- Rosemount Wildlife Preserve
- City of St. Paul Parks
- Hastings Wildlife Management Area
- Hastings River Flats Park
- Hastings Sand Coulee Scientific and Natural Area

2.2: Lower Minnesota River Watershed Restoration and Enhancement Project – Friends of the Minnesota Valley

Friends of the Minnesota Valley restored and enhanced a total of 234 acres of wetland within the Lower Minnesota River Watershed, including 165 acres using LCCMR funds and 69 acres using other funds. An additional 28 acres were restored using 2008 LCCMR funds and will be reported in the 2008 work program accomplishments.

Activities were focused on the following areas:

- Porter Creek, Scott County
- Rapids Lake, Carver County

2.3: Restore/Enhance Significant Habitat – Great River Greening

Great River Greening restored a total of 116.5 acres of ecologically significant land, including 86 acres using LCCMR funds and 30.5 acres using other funds.

Activities were focused in the following areas:

- St. Croix River Corridor (Arcola Mills, Afton State Park, Wind in the Pines Park, Tanglewood Nature Preserve, and Camp Waub-O-Jeeg)
- Eagle Creek AMA
- Credit River

2.4: Habitat Restoration/Enhancement Grants – DNR Metro Greenways

DNR Metro Greenways awarded two grants to restore a total of 11 acres of public lands and the project sponsors matched those dollars with $100,000. At the Bruce Vento Nature Sanctuary in St. Paul neighborhood groups worked with volunteers and the City to remove invasive plant and plant oak woodland and prairie on the bluffs. Elk River removed invasive species and planted a prairie/savanna in an old pasture that was acquired in 2005 to expand Top of the World City Park.

<u>2.5: Scientific & Natural Area Restoration and Enhancement – DNR Ecological Services</u>
The SNA Program and its partners (including MeCC partner Friends of the Mississippi River) restored and enhanced native habitat on over 429 acres at 12 SNAs within the Metro Conservation Corridors. Specific accomplishments are: 13 acres of prairie restoration work at two sites in Washington and Dakota Counties; 197 acres of prescribed burns (and associated burn break development) at 6 SNAs in Goodhue and Washington Counties; and 219 acres of exotics species removal at 9 sites in Carver, Hennepin, Goodhue, and Washington Counties. This work was necessary to prevent the loss of important species, plant communities and features.

<u>2.6: Stream Habitat Restoration – Trout Unlimited</u>
Trout Unlimited restored 1.26 miles of streams in the Metro area by stabilizing streambanks and incorporating habitat for trout. Trout Unlimited also promoted stream restoration in the Metro area by providing 100 hours of technical assistance to local units of government and non-profit organizations, by creating and presenting a stream restoration display at the Great Waters Expo and the Healthy Waters & Heritage Fair as well as other local conservation venues, by the development of two news releases on key projects, by conducting three workshops, and by distributing handouts and newsletters.

Activities were focused in the following areas:
- Hay Creek, Goodhue County
- Vermillion River, Dakota County
- Brown’s Creek, Washington County

Result 3: Acquire Significant Habitat

Description: Partner organizations protected through conservation easements and/or fee title approximately 721 acres of significant habitat within the identified corridors. This includes Metro Greenways providing funding to two locally nominated projects. Metro Greenways grants were selected through a request for proposal process (RFP) that includes broad eligibility and outreach.

Summary Budget Information for Result 3:	**Trust Fund Budget:**	**$** 1,955,584
	Amount Spent:	**$** 1,955,584
	Balance:	**$** 0

Deliverable
1. 630 acres acquired

Final Completion Date: 6/30/2009

Final Report Summary:
Collectively, six partners acquired fee title or conservation easements on 18 sites, protecting a total of 721 acres. Acquisition of an additional 232 acres was completed using other funds.

Acquisition activities were focused on building on past projects, such as the Vermillion River, Rum River, and Minnesota Valley National Wildlife Refuge sites. Efforts also focused on acquiring new SNA lands.

A summary of each sub-result is provided below. For additional information and details on projects and expenditures, please see Table A and the individual work program final reports.

<u>3.1: Critical Land Protection Program fee title & conservation easement acquisition – The Trust for Public Land</u>
The Trust for Public Land secured fee title on 118 acres of significant habitat, including 8 acres using LCCMR funding, 59 acres using non-state funding, and 51 acres with other state funding. The properties were then conveyed to public agencies for permanent protection.

Specific acquisitions include the following:
- Franconia St. Croix Bluffs SNA, Chisago County
- Ojiketa Regional Park, Chisago County

<u>3.2: Protecting significant habitat by acquiring conservation easements - Minnesota Land Trust</u>
The Minnesota Land Trust acquired conservation easements to protect 519 acres of land and more than 15,000 feet of shoreline. Contact was initiated with approximately 39 landowners, and 9 perpetual conservation easements were completed. Two easements were purchased, both at a bargain price. The remaining 7 easements were donated.

Projects were focused in the following areas:
- Rum River Watershed, four projects in Isanti County
- Hennepin County Corridors, four projects in Hennepin County
- Wild River State Park, Chisago County

<u>3.3: Fee acquisition for the MN Valley National Wildlife Refuge - Minnesota Valley National Wildlife Refuge Trust, Inc.</u>
The Minnesota Valley National Wildlife Refuge Trust, Inc. acquired fee title on 69 acres of significant habitat in the Minnesota River Valley in Jessenland Township of Sibley County, including 49 acres using LCCMR funding and 100 acres using non-state funding. Additionally, the MN Valley Trust acquired fee title to another 80 acres of significant habitat in the Minnesota River Valley in Faxon Township. After restoration of these parcels, they will be donated to the US Fish and Wildlife Service for perpetual management as part of the Jessenland Unit of the Minnesota Valley National Wildlife Refuge.

3.4: Grants & acquisition of fee title & conservation easements - Minnesota Department of Natural Resources - Metro Greenways

The DNR Metro Greenways program provided funding to protect significant habitat by acquiring fee title or conservation easements on 104 acres, including 96 acres using LCCMR funding and 8 acres using non-state funding. An additional 152 acres were protected through conservation easements held by the Minnesota Land Trust using two Metro Greenways grants provided through 2007 LCCMR funding, but have been excluded here to avoid double-counting.

Individual protection successes include the following:

- Wilmar - Dakota County
- Pilot Knob, Phase II – Mendota Heights (Dakota County)
- St. Catherine's Bluff – Scott County

3.5: DNR Fish & Wildlife Acquisition - Minnesota Department of Natural Resources – Fisheries & Wildlife

DNR Fisheries & Wildlife acquired two parcels on the Vermillion River in Dakota County, protecting nearly 47 acres of significant habitat, including 33 acres using LCCMR funding and 14 acres with other state funding. One of the parcels was also paid for with 2005 acquisition dollars, resulting in both acres and miles being divided proportionately between the two phases.

3.6: Scientific & Natural Area (SNA) Acquisition - Minnesota Department of Natural Resources – Ecological Services

The DNR SNA program, in cooperation with the Trust for Public Land, acquired two parcels of land totaling 85 acres of high priority native habitat which was designated as Franconia Bluffs SNA. Transaction costs for the acquisition and the boundary survey for Parcel 1 were covered using 2007 LCCMR funding, while the funds to purchase the parcel were covered using 2005 LCCMR funding. The LCCMR accomplishment acres for the acquisition of Parcel 1 are all counted as 2005 funding by the Trust for Public Land.

Parcel 2 consists of 37 acres, 16 acres of which were purchased using 2007 DNR SNA program LCCMR funds. An additional 20 acres were acquired using 2008 LCCMR funds and will be reported in the 2008 work program accomplishments.

Result 4: Provide Community Conservation Assistance

Description: Metro Greenways Program assisted four cities and two counties with the integration of natural resources information into local development and conservation planning and policy decisions. Grants were made to assist communities with a wide range of local conservation planning and implementation activities, such as:

- Obtaining a land cover inventory;
- Collecting and analyzing natural resources information;

- Integrating natural resources information and/or analysis into local plans, practices, and policies;
- Educate local government staff and elected and appointed officials on conservation and development approaches;
- Developing a process or approach to encourage inter-jurisdictional cooperation for management around a share, vital natural resource.

Projects were selected through a request for proposal process (RFP) that included broad eligibility and outreach. Selection criteria addressed the project and community's potential to: preserve ecological value, protect sensitive habitat from impairment, address growth pressures, integrate natural resource data and information into local plans, ordinances and policies. Project sponsors provided a 1:1 match (non-state dollars or in-kind support.)

Summary Budget Information for Result 4:	**Trust Fund Budget:**	**$** 100,000
	Amount Spent:	**$** 94,000
	Balance:	**$** 6,000

Deliverable
1. 4-6 Communities Assisted

Final Completion Date: 6/30/2009

Final Report Summary:
DNR Metro Greenways awarded Community Conservation Assistance matching grants to four cities and two counties within the metropolitan area. Priority was given to projects that sought to resolve challenges associated with the conservation of remaining natural habitats in rapidly changing communities.

Metro Greenways provided grants that used a variety of tools in order to integrate natural resources information into local government planning, including the identification of natural areas, the development of ordinances and policies that protect natural resources and the creation of a GIS model to track natural resources.

Grant recipients included the following:

- City of Andover – Natural Resource Inventory
- City of Dayton – Ordinances
- Goodhue County – Policy & Planning
- City of Maplewood – Natural Resource Inventory
- City of Monticello – Natural Resource Inventory
- Scott County – Policy & Planning

V. TOTAL TRUST FUND PROJECT BUDGET:

Please also see the attached Table B and individual work programs for additional detail.

Staff or Contract Services: $345,901
Community Assistance Grants: $94,000
Equipment: $5,292
Development: $368
Restoration: $107,330
Acquisition, including easements: $ 1,851,809
Other: $ 60,525

TOTAL TRUST FUND PROJECT BUDGET: $2,500,000 ($2,465,225 Spent)

Explanation of Capital Expenditures Greater Than $3,500: N/A

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: Metro Conservation Corridor partners (see Table A) and private landowners, local governments, regional, state and federal agencies, nonprofit organizations and citizen groups.

B. Other Funds Proposed to be Spent during the Project Period: Approximately $6,800,000 were proposed to be spent during the project period. Actual funds spent or leveraged were: $2,527,545 of other state funds and $7,159,563 of other non-state funds (see Table A).

C. Past Spending:
Phase I (2003) - $4,850,000 ETF
Phase II (2005) - $3,530,000 ETF
Phase III (2007) - $2,500,000 ETF

VII. DISSEMINATION: As projects were completed, the individual partners were encouraged to publicize accomplishments through press releases, organization newsletters and websites. These efforts resulted in information being distributed to the public through websites, email lists, daily and weekly newspapers, newsletters, and other print materials. Additionally, once the MeCC database development is complete, the partnership hopes to be able to better disseminate information on its accomplishments through a public web portal.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports were submitted February 1st and August 1st of each year, starting with February 1, 2008. This is the final work program report.

Metro Conservation Corridors - Phase III date: 1/12/2010

Table A: Summary of Funding & Accomplishments **LCCMR Recommended Dollars:** **$2,500,000**

Result / Activity	Partner	Project Funding: ENRTF 2007 Funds: ENRTF 2007 Funds Allocated	ENRTF 2007 Funds Spent	ENRTF 2007 Funds Balance	Other Funds: Other State Funding Spent	Other Non-State Funding Spent	Total Project Funds Spent *(ENRTF, Other State Funds & Non-State Funds combined)*	Accomplishments: ENRTF: ENRTF 2007 Acres/Miles Completed: ACRES	MILES	Other Funds: Other Funds Acres/Miles Completed: ACRES	MILES	Total Project Acres Completed *(ENRTF & Other Funds combined)*
1. Coordinate MeCC Program												
1.1. Coordination of MeCC program, local outreach and conservation implementation assistance for two year project term	All partners below - led by DNR Metro Greenways	$165,000	$150,572	$14,428	$0	$0	$150,572					
2. Restore & Enhancement Significant Habitat												
2.1. Restore/enhance significant watershed habitat.	Friends of the Mississippi River	$53,000	$52,630	$370	$68,370	$45,330	$166,330	79		159		238
2.2. Lower Minnesota River Watershed Restoration & Enhancement Project.	Friends of MN Valley	$34,000	$34,000	$0	$0	$13,087	$47,087	165		69		234
2.3. Restore/enhance significant habitat.	Great River Greening	$60,000	$60,000	$0	$31,000	$90,000	$181,000	86		30.5		116.5
2.4. Habitat restoration/enhance grants.	DNR - Metro Greenways	$32,528	$30,870	$1,658		$89,038	$119,908	11				11
2.5 Scientific & Natural Area (SNA) restoration & enhancement.	DNR - Ecological Services	$34,888	$34,888	$0			$34,888	429				429
2.6. Stream habitat restoration	Trout Unlimited	$65,000	$52,681	$12,319	$0	$93,058	$145,739		1.26			0.0
SUBTOTAL		$279,416	$265,069	$14,347	$99,370	$330,513	$694,952	770	1.26	259	0.00	1,029
3. Acquire Significant Habitat												
3.1 Critical Land Protection Program fee title & conservation easement acquisition.	The Trust for Public Land	$420,000	$420,000	$0	$1,995,000	$2,320,000	$4,735,000	8		110		118
3.2. Protecting significant habitat by acquiring conservation easements.	Minnesota Land Trust	$134,000	$134,000	$0	$372,925	$2,399,500	$2,906,425	519		0		519
3.3. Fee acquisition for Mn Valley National Wildlife Refuge.	MN Valley NWR Trust, Inc.	$210,000	$210,000	$0	$0	$375,719	$585,719	49		100		149
3.4. Grants & acquisition of fee title & conservation easements.	DNR - Metro Greenways	$811,472	$811,472	$0		$1,662,625	$2,474,097	96		8		104
3.5. DNR Fish & Wildlife Acquisition.	DNR - Fisheries & Wildlife	$172,000	$172,000	$0	$60,250	$0	$232,250	33	0.62	14	0.27	47
3.6. Scientific & Natural Area (SNA) Acquisition.	DNR - Ecological Services	$208,112	$208,112	$0			$208,112	16				16
SUBTOTAL		$1,955,584	$1,955,584	$0	$2,428,175	$6,757,844	$11,141,603	721	0.62	232	0.27	953
4. Community Conservation Assistance												
4.1 Assist local governments to promote the conservation of natural habitats.	DNR - Metro Greenways	$100,000	$94,000	$6,000		$71,206	$165,206					70
TOTAL		**$2,500,000**	**$2,465,225**	**$34,775**	**$2,527,545**	**$7,159,563**	**$12,152,333**	**1,491**	**1.88**	**490**	**0.27**	**2,051**

MLT Non-State Funding represents *known* donated value of conservation easements. Value is not known for every project completed.

Metro Conservation Corridors - Phase III

Table B: LCCMR Funding Request - Budget Detail

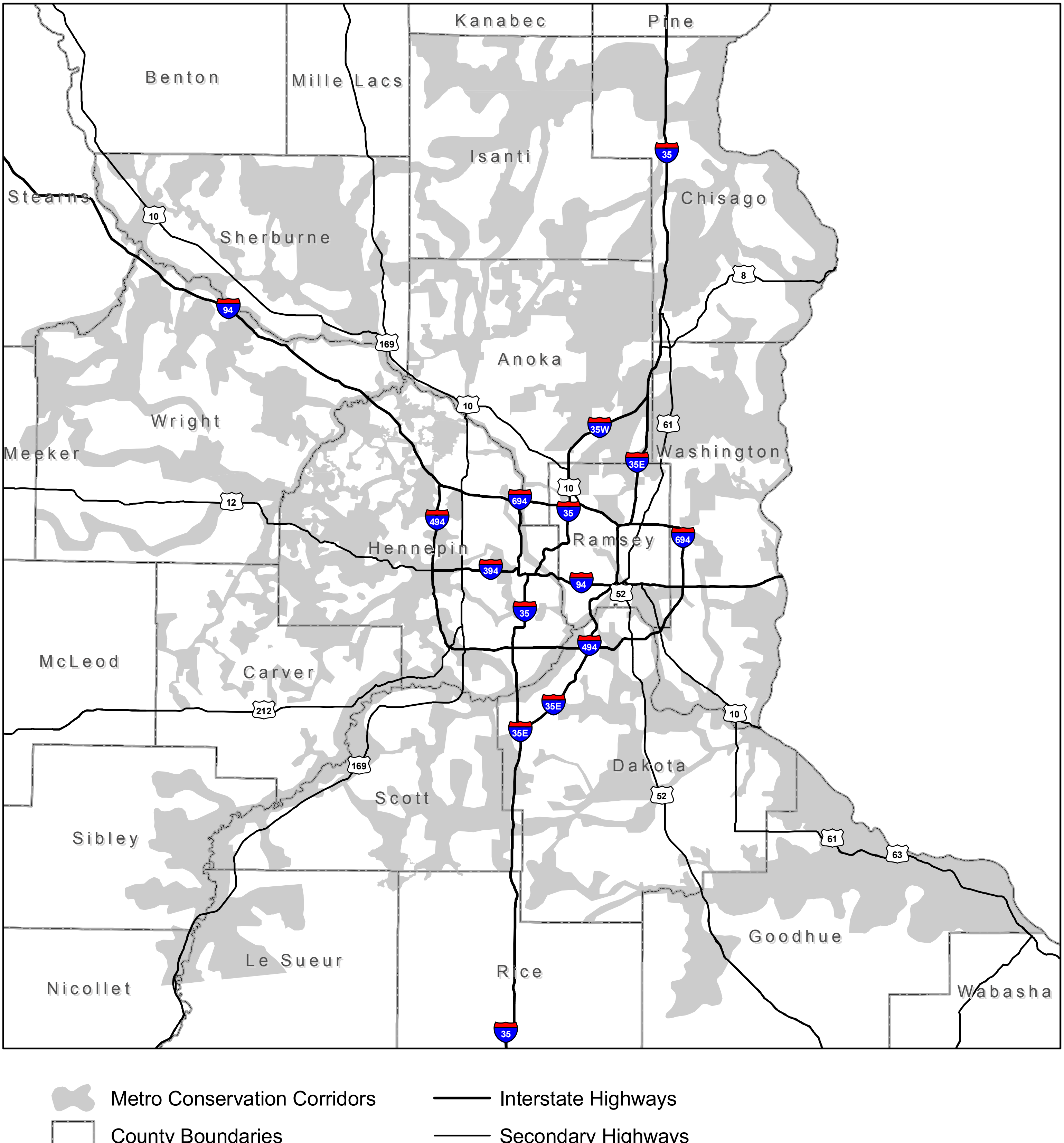
date: 1/6/10

LCCMR Recommended Dollars: $2,500,000

Activity	Partners	Staff/contract services	Equipm't	Developm't	Restoration	Acquisition	Other	Total	Budget Explanation (staff/contractservices, development, equipment, other)
		LCCMR Funding Spent							
1. Coordinate MeCC Program									
1.1. Coordination of MeCC program & local outreach and implementation assistance for two year project term	DNR Metro Greenways/DNR OMBS	$ 150,572						$ 150,572	Staff to manage and coordinate the program for two years
2. Restore & Enhance Significant Habitat									
2.1. Restore/enhance significant watershed habitat	Friends of the Mississippi River	$ 52,360			$ 271			$ 52,631	Includes hiring contractors to conduct restoration and enhancement activities and purchasing supplies and materials.
2.2. Lower Minnesota River Watershed restoration & enhancement project	Friends of Minnesota Valley	$ 23,000			$ 11,000			$ 34,000	Staff/Contracts: Director of Conservation Programs for project coordination and implementation; Contracts for earth work, installing water control structures, breaking drain tile, etc.; Restoration:native plants and seed, trees, water control structures
2.3. Restore/enhance significant habitat	Great River Greening	$ 44,535	$ 1,859		$ 12,851		$ 754	$ 59,999	Staff: Ecologists and Conservation Director; Field Manager; Volunteer Manager; Restorations Technicians; Project Administration. Restoration: Contracts for site prep, prairie seeding; plant, mulch, and seed purchase; travel within Minnesota. Equipment: Seed drill, mower, harrow, roller, sprayers, Rx burn eq't, saws, loppers, etc. Other: Volunteer event supplies (approved food and bevg, port. toilets, tent rentals etc.)
2.4 Habitat restoration/enhance. Grants	DNR - Metro Greenways				$ 30,870			$ 30,870	Grants to LGU's and NGO's for restoration and enhancement
2.5 Scientific & Natural Area (SNA) restoration & enhancement	DNR - Ecological Services	$ 27,959	$ 3,433	$ 368	$ 3,128			$ 34,888	DNR SNA crew; fleet charges & incidental parts; supplies (e.g. fencing & signs); seeds & seedlings & other supplies.
2.6 Stream habitat restoration	Trout Unlimited	$ 2,700			$ 49,210		$ 771	$ 52,681	Staff: Project Manager for promotion of stream restoration in the Metro area; Restoration: hourly rate for bulldozers, excavators, and dump trucks; rock and materials; Other: Display to promote stream restoration projects
SUBTOTAL		$ 150,554	$ 5,292	$ 368	$ 107,330	$ -	$ 1,525	$ 265,069	
3. Acquire Significant Habitat									
3.1 Critical Land Protection Program fee title & conservation easement acquisition	The Trust for Public Land					$ 420,000		$ 420,000	To protect 48 acres at Franconia St. Croix Bluffs/Franconia Bluffs SNA, a project that also used the balance of TPL's Phase II 2005 MeCC funding; and to protect 70 acres on Green Lake/ Camp Ojiketa, a project that also used the balance of TPL's Phase IV 2008 MeCC funding.
3.2. Protecting significant habitat by acquiring conservation easements	Minnesota Land Trust	44,589				30,411	59,000	$ 134,000	Staff: Includes conservation director or land protection staff; staff attorney; and support staff. Acquisition: $28,657 for costs associated with acquiring donated or purchased CE's, $1,754 for mileage and related travel expenses Other: $59,000 for easement stewardship .
3.3. Fee acquisition for Mn Valley National Wildlife Refuge	MN Valley NWR Trust, Inc.					$ 210,000		$ 210,000	Fee title acquisition of significant habitat in Minnesota River Valley
3.4. Grants & acquisition of fee title & conservation easements	DNR - Metro Greenways					$ 811,472		$ 811,472	Grants to LGUs and NGOs for direct acquisition of fee title & conservation easements.
3.5. DNR Fish & Wildlife Acquisition	DNR - Fisheries & Wildlife					$ 172,000		$ 172,000	DNR fee acquisition of lands for AMA and/or WMA, including related real estate transaction costs
3.6. Scientific & Natural Area (SNA) Acquisition	DNR - Ecological Services	$ 186				$ 207,926		$ 208,112	Acquisition: fee title acquisition, including related real estate transaction costs.
SUBTOTAL		$ 44,775				$ 1,851,809	$ 59,000	$ 1,955,584	
4. Community Conservation Assistance									
4.1 Assist local governments to promote the conservation of natural habitats	DNR - Metro Greenways						$ 94,000	$ 94,000	Grants to assist local governments with gathering and integrating natural resources information into local development and conservation planning and policy decisions
SUBTOTAL							$ 94,000	$ 94,000	
TOTAL		**$ 345,901**	**$ 5,292**	**$ 368**	**$ 107,330**	**$ 1,851,809**	**$ 60,525**	**$ 2,465,225**	

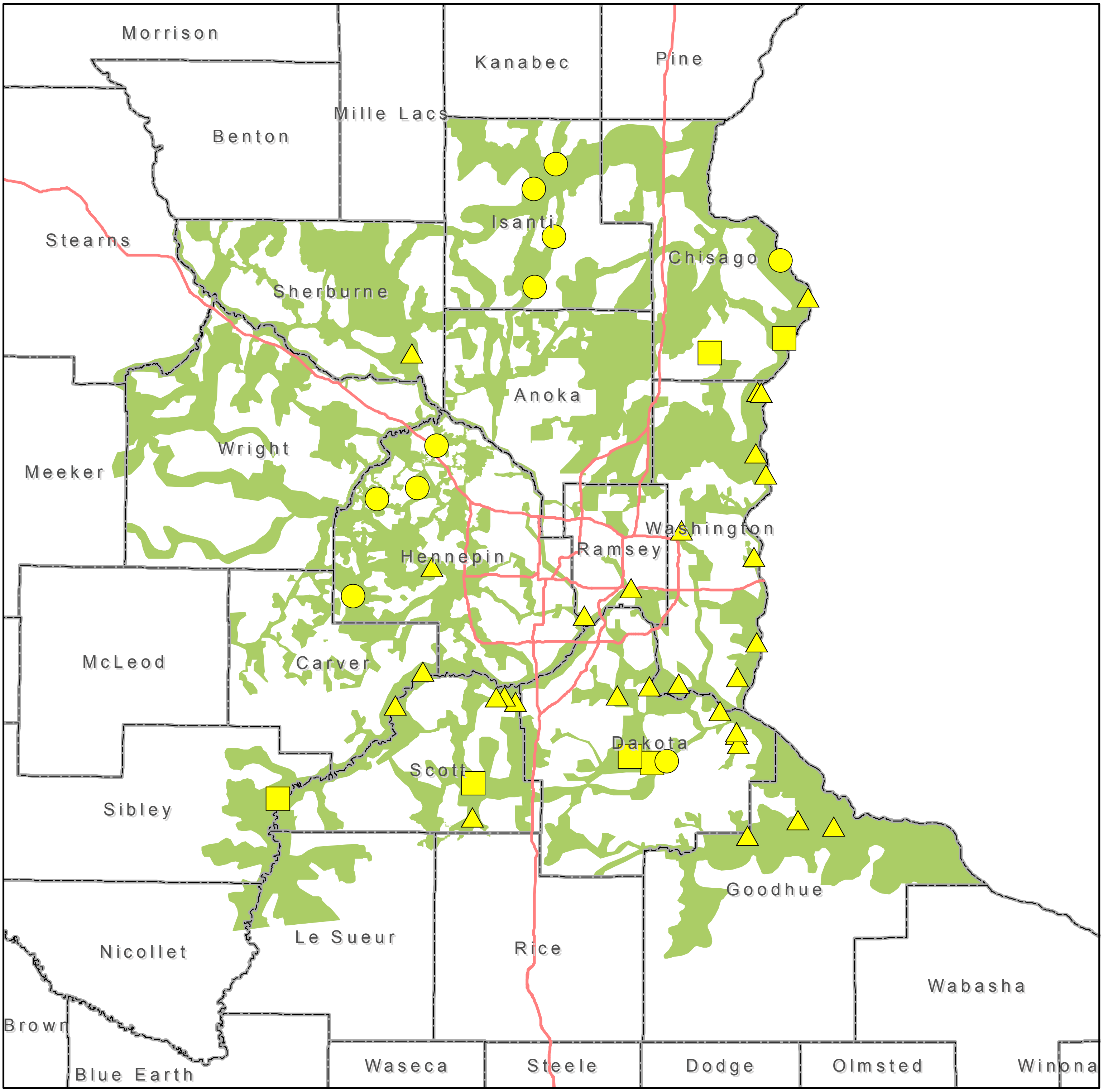
Figure 1

Metro Conservation Corridors
2007 Focus Areas



DNR Central Region
March 6, 2007

Metro Conservation Corridors Projects



MeCC projects - 2007

- Restoration
- Conservation Easement
- Fee

DNR Central Region
2010

LEGISLATIVE-CITIZEN COMMISSION ON MINNESOTA RESOURCES

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: (4c.2.1) Metro Conservation Corridors (MeCC) Phase lll-Friends of the Mississippi River - Restore/enhance significant watershed habitat.
Project Manager: Tom Lewanski
Affiliation: Friends of the Mississippi River
Mailing Address: 360 North Robert Street, Suite 400
City / State / Zip : St. Paul, MN 55101
Telephone Number: 651 222-2193 Ext. 12
E-mail Address: tlewanski@fmr.org
FAX Number: 651 222-6005
Web Page address: www.fmr.org
Funding Source: Environment and Natural Resources Trust Fund\
Legal Citation: ML 2007, [Chap.30], Sec.[2], Subd.4c (2.1).

Appropriation Amount: $53,000.

OVERALL PROJECT OUTCOME AND RESULTS

FMR committed to working with both public and private landowners to restore and/or enhance 18 acres of significant habitat using MeCC Phase III funding and an additional 7 acres of significant habitat using other funding for a total of 25 acres. We also committed to leveraging $20,000 in non-state funding for the project.

In the final analysis of our achievements for this project (MeCC Phase III – 2007 appropriation) FMR was able to conduct restoration activities on 79-acres using Environment and Natural Resources Trust Fund (ENRTF) dollars. We were able to use the ENRTF funding to leverage an additional $45,330 in non-state funding with which we were able to conduct restoration/enhancement activities on 95-acres. Furthermore, we were able to leverage additional state funding ($68,370) to do restoration and enhancement activities on 64-acres.

Specifically, FMR conducted restoration and enhancement activities on the following sites:

- **Sand Coulee Prairie - City of Hastings' property**. We cut and treated shrubs and trees (9-acres), controlled knapweed (3-acres), conducted a prescribed burn (20-acres) and worked with a biology class from the Hastings High School to collect seed and ultimately install the plants germinated from this seed, back in the prairie (1-acre).
- **Pine Bend Bluffs Scientific and Natural Area.** Two prescribed burns took place on prairie (27-acres). We removed brush from bluff prairies

and other areas (30-acres) and mowed installed prairie (42-acres). We also cut and treated buckthorn and herbaceous weeds (42-acres).

- **Rosemount Wildlife Preserve.** We conducted a prescribed burn on an installed prairie (8-acres) and cut and treated buckthorn in the woodland (14-acres).
- **City of St. Paul Parks.** Exotic brush removal (14-acres).
- **Hastings Wildlife Management Area.** Cut and treated buckthorn (20-acres).
- **Hastings River Flats Park.** Mowed an installed prairie (1-acre).
- **Hastings Sand Coulee Scientific and Natural Area.** Treated herbaceous weeds (6.5-acres).

PROJECT RESULTS USE AND DISSEMINATION

Website description of St. Paul Parks restoration project:

http://www.fmr.org/news/current/crosby_farm_restoration-2008-01

Trust Fund 2007 Work Program Final Report

Date of Report: 08/17/09
Trust Fund 2007 Work Program Final Report
Date of Next Status Report: 08/01/09
Date of Work program Approval: June 5, 2007
Project Completion Date: 6/30/09

I. PROJECT TITLE: (4c.2.1) Metro Conservation Corridors (MeCC) Phase lll- Friends of the Mississippi River - Restore/enhance significant watershed habitat.
Project Manager: Tom Lewanski
Affiliation: Friends of the Mississippi River
Mailing Address: 360 North Robert Street, Suite 400
City / State / Zip : St. Paul, MN 55101
Telephone Number: 651 222-2193 Ext. 12
E-mail Address: tlewanski@fmr.org
FAX Number: 651 222-6005
Web Page address: www.fmr.org

Location: Within mapped focus area in the counties of Dakota, Goodhue, Hennepin, Ramsey, and Washington .

Total Trust Fund Project Budget:	**~~T~~Tr~~r~~ust Fund Appropriation:**	**$**	53,000.
	Minus Amount Spent:	**$**	**50,890.**
	Equal Balance:	**$**	**2,110.**

Legal Citation: ML 2007, [Chap.30], Sec.[2], Subd.4c (2.1).

Appropriation Language:
(c) Metro Conservation Corridors - Phase III
$2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the

purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated:
1) as an outdoor recreation unit under Minnesota Statutes, section 86A.07; or
2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a);97A.101; 97A.125; 97C.001; and 97C.011.
The commissioner may similarly designate any lands acquired in less than fee title.

II & III FINAL PROJECT SUMMARY:

FMR committed to working with both public and private landowners to restore and/or enhance 18 acres of significant habitat using MWC III funding and an additional 7 acres of significant habitat using other funding for a total of 25 acres. We also committed to leveraging $20,000 in non-state funding for the project.

In the final analysis of our achievements for this project (MeCC Phase III – 2007 appropriation) FMR was able to conduct restoration activities on 79-acres using LCCMR funding. We were able to use the LCCMR funding to leverage an additional $45,330 in non-state funding with which we were able to conduct restoration/enhancement activities on 95-acres. Furthermore, we were able to leverage additional state funding ($68,370) to do restoration and enhancement activities on 64-acres.

Specifically, FMR conducted restoration and enhancement activities on the following seven sites:

- **Sand Coulee Prairie - City of Hastings' property**. We cut and treated shrubs and trees (9-acres), controlled knapweed (3-acres), conducted a prescribed burn (20-acres) and worked with a biology class from the Hastings High School to collect seed and ultimately install the plants germinated from this seed, back in the prairie (1-acre).
- **Pine Bend Bluffs Scientific and Natural Area.** Two prescribed burns took place on prairie (27-acres). We removed brush from bluff prairies and other areas (30-acres) and mowed installed prairie (42-acres). We also cut and treated buckthorn and herbaceous weeds (42-acres).
- **Rosemount Wildlife Preserve.** We conducted a prescribed burn on an installed prairie (8-acres) and cut and treated buckthorn in the woodland (14-acres).
- **City of St. Paul Parks.** Exotic brush removal (14-acres).
- **Hastings Wildlife Management Area.** Cut and treat buckthorn (20-acres).
- **Hastings River Flats Park.** Mowed an installed prairie (1-acre).
- **Hastings Sand Coulee Scientific and Natural Area.** Treated herbaceous weeds (6.5-acres).

IV. OUTLINE OF PROJECT RESULTS*:*
Result 1: N/A (see Overall Work Program Summary)

Result 2: Restore & Enhance Significant Habitat:

Final Report Summary 6/30/2009:

Description: During the timeframe of this project (MeCC Phase III – 2007 appropriation) FMR was able to conduct restoration activities on 79-acres using LCCMR funding. We were able to use the LCCMR funding to leverage an additional $45,330 in non-state funding with which we were able to conduct restoration/enhancement activities on 95-acres. Furthermore, we were able to leverage additional state funding ($68,370) to do restoration and enhancement activities on 64-acres. The total number of acres upon which we conducted restoration and enhancement activities was 238.

Specifically, FMR conducted restoration and enhancement activities on the following sites:

- **Sand Coulee Prairie -City of Hastings' property**. We cut and treated shrubs and trees (9-acres), controlled knapweed (3-acres), conducted a prescribed burn (20-acres) and worked with a biology class from the Hastings High School to collect seed and ultimately install the plants germinated from this seed, back in the prairie (1-acre).
  The Sand Coulee Prairie is the largest remaining native prairie in Dakota County and one of the highest quality prairies remaining in the metro area. There have been thirteen rare species documented on this prairie. Over the last several years, we have partnered with a field biology class from the Hastings High School to improve the ecological health of the City's portion of the prairie. We work with the students to collect prairie seed from the site. During this phase of the project, a local nursery, The Vagary, donated their expertise, materials, and greenhouse space to germinate the seed and to grow the young plants. The high school students then returned to install the plants back to the site.
- **Hastings Sand Coulee Scientific and Natural Area.** Treated herbaceous weeds (6.5-acres).
- **Pine Bend Bluffs Scientific and Natural Area.** Two prescribed burns took place on prairie (27-acres). We removed brush from bluff prairies and other areas (30-acres) and mowed installed prairie (42-acres). We also cut and treated buckthorn and herbaceous weeds (42-acres).
- **Rosemount Wildlife Preserve.** We conducted a prescribed burn on an installed prairie (8-acres) and cut and treated buckthorn in the woodland (14-acres).
- **City of St. Paul Parks.** Exotic brush removal (14-acres).
- **Hastings Wildlife Management Area.** Cut and treat buckthorn (20-acres).
- **Hastings River Flats Park.** Mow an installed prairie (1-acre).

With this final report, we are asking for a change to the budget. We are seeking to move some funding between budget categories. Attachment A has been modified to reflect this budget change. In the final analysis, we did not use the $2000 allocated to plant material in the Other direct operating cost line item.

Summary Budget Information for Result 2: **Trust Fund Budget:** **$** 53,000.
Amount Spent: **$ 50,890.**
Balance: **$** 2,110.

Deliverable	**Completion Date**	**Budget**	**Status**
1. 25 acres restored	6/30/2009	$53,000	Completed

Final Completion Date: 6/30/2009

V. TOTAL TRUST FUND PROJECT BUDGET (FINAL REVISED):

Staff or Contract Services: $52,734
Equipment:
Development: $
Restoration: $
Other: travel: $266
Acquisition, including easements: $

TOTAL TRUST FUND PROJECT BUDGET: $ 53,000*

(*Staff or contract services include both staff expenses and contractor fees for restoration activities. Restoration category includes plant material expenses.)

Explanation of Capital Expenditures Greater Than $3,500: N/A

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: FMR partnered with the following entities to conduct the restoration & enhancement activities presented in this report:

Partner funds	**Site**	**amount**
nonstate		
FMR/Malcolm Trust account	Pine Bend Bluffs SNA	$7,074.18
Hastings High School	Sand Coulee-City of Hastings	$11,000.00
St. Paul Parks	Crosby Park	(in-kind) $16,056.00
The Vagary	Sand Coulee-City of Hastings	(in-kind) $1,200.0

Capital Region Watershed District	Crosby Park	$10,000.00
Subtotal -nonstate	-	$45,330.18
other state funds used		
DNR Remediation Grant	Hastings Sand Coulee SNA & Pine Bend Blulffs SNA	$68,370.65
Total leveraged funds		$113,700.83

C. Past Spending: Metro Wildlife Corridors I & II - $182,000

D. Time: 2 years

VII. DISSEMINATION: Metro Corridors will periodically distribute information about the program through the widely broadcasted emails to people on the Embrace Open Space (EOS) database, through the EOS quarterly meetings and jointly held county meetings, and on the MeCC website. FMR will also highlight projects on its website, through local media, through its monthly electronic newsletter, and through its periodic print newsletter.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than February 1st and August 1st each year, starting with February 1, 2008. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR.

Attachment A: Budget Detail for 2007 Projects

Project Title: Metro Conservation Corridors (MeCC) Phase III-Friends of the Mississippi River (2.1)

Project Manager Name: Tom Lewanski

Trust Fund Appropriation: $ 53,000

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 2 Budget:**	**Amount Spent** *(6/30/08)*	**Amount Spent** *(12/31/08)*	**Amount Spent** *(6/30/09)*	**Balance** *(12/31/08)*
BUDGET ITEM	Restoration				
PERSONNEL: wages and benefits	$ 8,859	$ -	$ 4,057	$ 4,693	$ 110
Contracts					$ -
Professional/technical *(with whom?, for what?)*	$ 41,875	$ 15,260	$ 7,931	$ 18,684	$ 0
Other direct operating costs *(plant material)*	$ 2,000	$ -			$ 2,000
Travel expenses in Minnesota	$ 266	$ -	$ 68	$ 198	$ 0
COLUMN TOTAL	**$ 53,000**	**$ 15,260**	**$ 12,055**	**$ 23,575**	$ 2,110

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Metropolitan Area Wildlife Corridors – Phase III: 2.4. Lower Minnesota River Watershed Restoration & Enhancement Project - Friends of the MN Valley
PROJECT MANAGER: Joe Pavelko
AFFILIATION: Friends of the Minnesota Valley
MAILING ADDRESS: 10800 Lyndale Ave. South, Suite 120
CITY/STATE/ZIP: Bloomington, MN 55420
PHONE: 952-881-9075
FAX: 952-881-3174
E-MAIL: jpavelko@friendsofmnvalley.org
WEBSITE: www.friendsofmnvalley.org
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chp. 30, Sec. 2, Subd. 4(c).

APPROPRIATION AMOUNT: $34,000

Overall Project Outcome and Results

Friends of the Minnesota Valley, in conjunction with numerous partners, restored and enhanced 165 acres of wetland within the Lower Minnesota River Watershed (plus an additional 97 acres from matching funds for a total of 262 acres) exceeding the projected restored acreage total of 25 acres. We restored two wetlands, a 2 acre wetland adjacent to the impaired Porter Creek in Scott County and a 260 acre wetland near the City of Carver within the Rapids Lake Unit of the Minnesota Valley National Wildlife Refuge. Both wetlands will provide quality habitat for migratory birds and other wetland-dependent species, especially the 260 acre wetland known as Rapids Lake.

Rapids Lake, a large wetland in the floodplain of the Minnesota River between the Cities of Carver and Jordan, is located within the Rapids Lake Unit, an expanding unit of the national wildlife refuge. The structure will restore the hydrology of the wetland and enable the USFWS to manage water levels to maximize benefits to wetland dependant plant and animal species. The USFWS will protect and manage the restoration in perpetuity.

The restoration of the lake was a key part in the overall development and restoration plan of the Rapids Lake Unit spearheaded by the Refuge and the Minnesota Valley National Wildlife Refuge Trust, Inc. The Rapids Lake restoration enabled the completion of seven miles of newly-constructed visitor trails open to the public for wildlife-dependent recreation and is only a short walk from the newly-constructed Rapids Lake Education and Visitor Center located on the bluff of the Minnesota River.

Trust Fund 2007 Work Program Final Report

Date of Report: 7/2/2009
Trust Fund 2007 Work Program Final Report
Date of Work program Approval: 6/5/2007
Project Completion Date: 6/30/2009

I. PROJECT TITLE: Metropolitan Area Wildlife Corridors – Phase III: 2.4. Lower Minnesota River Watershed Restoration & Enhancement Project - Friends of the MN Valley

Project Manager: Joe Pavelko
Affiliation: Friends of the Minnesota Valley
Mailing Address: 10800 Lyndale Ave. South, Suite 120
City / State / Zip: Bloomington, MN 55420
Telephone Number: 952-881-9075
E-mail Address: jpavelko@friendsofmnvalley.org
FAX Number: 952-881-3174
Web Page address: www.friendsofmnvalley.org
http://www.dnr.state.mn.us/metroconservationcorridors/index.html

Location: Within mapped Focus Area and within the counties of Carver, Dakota, Hennepin, Le Sueur, Nicollet, Rice, Scott, and Sibley. See Figure 1.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	34,000
	Minus Amount Spent:	**$**	34,000
	Equal Balance:	**$**	0

Legal Citation: ML 2007, Chp. 30, Sec. 2, Subd. 4(c).

Appropriation Language: (c) Metro Conservation Corridors- Phase III $2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated: (1) as an outdoor recreation unit under

Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II. and III. Final Project Summary:

Friends of the Minnesota Valley, in conjunction with numerous partners, restored and enhanced 165 acres of wetland within the Lower Minnesota River Watershed (plus an additional 97 acres from matching funds for a total of 262 acres) exceeding the projected restored acreage total of 25 acres. We restored two wetlands, a 2 acre wetland adjacent to the impaired Porter Creek in Scott County and a 260 acre wetland near the City of Carver within the Rapids Lake Unit of the Minnesota Valley National Wildlife Refuge. Both wetlands will provide quality habitat for migratory birds and other wetland-dependent species, especially the 260 acre wetland known as Rapids Lake.

Rapids Lake, a large wetland in the floodplain of the Minnesota River between the Cities of Carver and Jordan, is located within the Rapids Lake Unit, an expanding unit of the national wildlife refuge. The structure will restore the hydrology of the wetland and enable the USFWS to manage water levels to maximize benefits to wetland dependant plant and animal species. The USFWS will protect and manage the restoration in perpetuity.

The restoration of the lake was a key part in the overall development and restoration plan of the Rapids Lake Unit spearheaded by the Refuge and the Minnesota Valley National Wildlife Refuge Trust, Inc. The Rapids Lake restoration enabled the completion of seven miles of newly-constructed visitor trails open to the public for wildlife-dependent recreation and is only a short walk from the newly-constructed Rapids Lake Education and Visitor Center located on the bluff of the Minnesota River.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Restore & Enhance Significant Habitat

Description: Within the Expanded Minnesota River Focus Area, Friends of the Minnesota Valley restored and enhanced 164 acres of regionally significant habitat (prorated of the 262 total restored project acres).

Summary Budget Information for Result 1:

Trust Fund Budget:	**$** 34,000
Amount Spent:	**$** 34,000
Balance:	**$** 0

Deliverable	Completion Date	Budget	Status
1. 164 acres restored	6/30/2009	$34,000	Complete

Source	Cost	Acres
Trust Fund Dollars (2007)	34,000.00	165
Trust Fund Dollars (2008)	5,019.50	28
Matching Dollars (Non-State)	13,086.62	69
Totals	**52,106.12**	**262**

A total of 262 acres were restored with the help of matching dollars. Acres were prorated based on percent of funding for the project.

In order to complete the Rapids Lake restoration, Friends of the MN Valley needed to use the remaining 2007 appropriation funding and a small amount of the 2008 appropriation funding. The number of acres restored with the 2008 appropriation (28 acres prorated) will be counted toward the 2008 appropriation funding.

Final Completion Date: 6/30/2009

Final Report Summary 6/30/2009:
Friends of the Minnesota Valley, along with the USFWS and Scott County SWCD, restored a 2 acre wetland adjacent to Porter Creek within Cedar Lake Township of Scott County. The wetland will provide quality habitat and help increase the water quality of Porter Creek.

Friends of the Minnesota Valley along with the USFWS, MN DNR, and Carver County SWCD, successfully designed and installed a water control structure on the outlet to Rapids Lake, a large 260 acre Type IV riverine wetland within the Minnesota Valley National Wildlife Refuge near the City of Carver, MN. The water control structure will restore the hydrology of the wetland and will enable the USFWS to manage water levels to maximize benefits to wetland-dependent plant and animal species. The water control structure is specifically designed to prevent beaver damage and to withstand flooding from the Minnesota River. It will also help prevent rough fish from entering the wetland. In addition, the structure acts as a trail crossing. In order to get heavy equipment into the site, a new trail had to be constructed. This new trail was the critical link in completing over seven miles of recreational trails.

Currently Rapids Lake water levels are being drawn down to expose mudflats to stimulate vegetation growth. Until recently, the lake had not successfully been drawn down for over 15 years. Restoration work is protected and managed in perpetuity by the USFWS.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $ 5,000 (for staff salaries)
Equipment: **$** 0
Development: $ 0
Restoration: $ 29,000

Acquisition, including easements: $ 0

TOTAL TRUST FUND PROJECT BUDGET: $ 34,000

Explanation of Capital Expenditures Greater Than $3,500: N/A

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: Metro Conservation Corridor partners (see Table A), private landowners, local governments, regional, state and federal agencies, nonprofit organizations and citizen groups.

B. Other Funds Proposed to be Spent during the Project Period: Friends of the Minnesota Valley along with other partners spent an additional $13,086.62 of matching funds.

C. Past Spending: The Friends of the MN Valley received $40,000 in appropriations from the 2005 LCMR/Phase2 MWC. LCMR appropriation during the 2002-2003 biennium of $18,000 to help implement the successful Big Rivers Partnership.

D. Time: 2 years

VII. DISSEMINATION: Metro Corridors periodically distributed information about the program through the widely broadcasted emails to people on the Regional Greenways Collaborative (RGC) database, through the RGC quarterly meetings, and jointly held county meetings. As projects were completed, Friends of the Minnesota Valley publicized project accomplishments through press releases, the Friends' quarterly newsletter, and posted projects on our website.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports were submitted not later than February 1st and August 1st each year, starting with February 1, 2008. This is the final work program submitted July 2nd, 2009.

Attachment A: Budget Detail for 2007 Projects

Project Title: Metro Conservation Corridors (MeCC) Phase III: Friends of the MN Valley (2.4)

Project Manager Name: Joe Pavelko

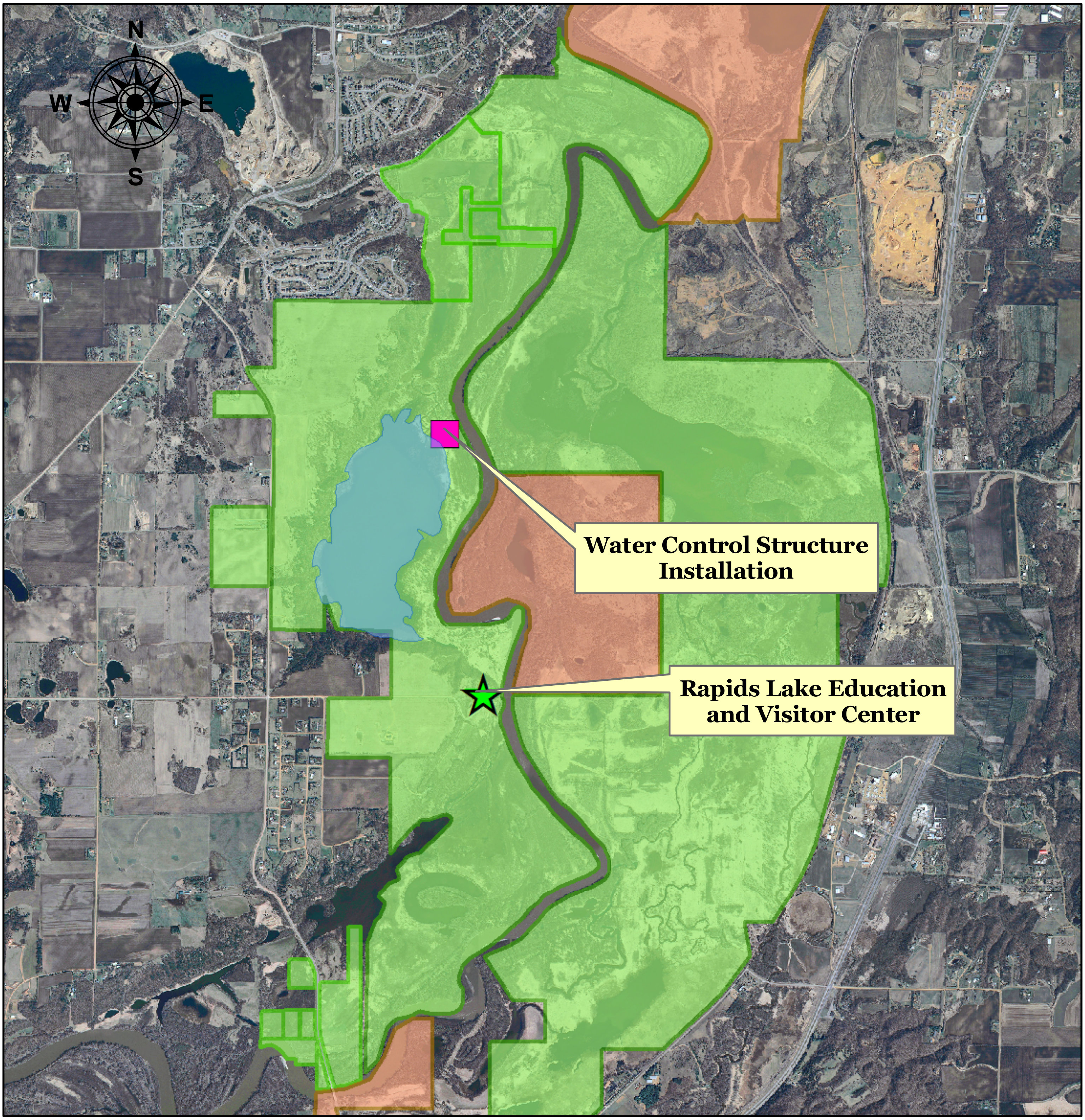
Trust Fund Appropriation: $ 34,000

1) **See list of non-eligible expenses, do not include any of these items in your budget sheet**
2) **Remove any budget item lines not applicable**

2007 Trust Fund Budget	Result 2 Budget:	Amount Spent *(date)*	Balance *(date)*	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	Restoration				
PERSONNEL: wages and benefits	$ 5,000	$ 5,000	$ -	$ 5,000	$ -
Contracts			$ -	$ -	$ -
Professional/technical *(Construction companies for earth work such as building dikes, installing water control structures, breaking drain tile, and other activities that require heavy equipment)*	$ 18,000	$ 18,000	$ -	$ 18,000	$ -
Other land improvement *(native prairie seed, trees, water control structures)*	$ 11,000	$ 11,000	$ -	$ 11,000	$ -
COLUMN TOTAL	**$ 34,000**	**$ 34,000**	**$ -**	**$ 34,000**	**$ -**

Rapids Lake Restoration

MN Valley National Wildlife Refuge - Rapids Lake Unit
Carver County, MN



- Rapids Lake - 260 Acres
- State Recreation Area - MN DNR
- MN Valley National Wildlife Refuge - USFWS

MINNESOTA VALLEY TRUST
Minnesota Valley National Wildlife Refuge Trust, Inc.

Miles
0 0.25 0.5 1

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Restore/Enhance Significant Habitat. Metro Conservation Corridors (MeCC) Phase lll: Great River Greening (2.3)
PROJECT MANAGER: Wiley Buck
AFFILIATION: Great River Greening
MAILING ADDRESS: 35 W. Water St.
CITY/STATE/ZIP: St. Paul, MN 55107
PHONE: 651 665.9500 x15
FAX: 651 665.9409
E-MAIL: wbuck@greatrivergreening.org
WEBSITE: www.greatrivergreening.org
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 4c2.3.

APPROPRIATION AMOUNT: $ 60,000

Overall Project Outcome and Results

This project restored a total of 86 ecologically significant acres, and an additional 30.5 acres using other state funds. Primary criteria for project selection were ecological significance, importance to the community, and partner commitment.

Several distinguished projects were part of our St. Croix Healthy Waters Initiative. These include:

- Forest reconstruction at Afton State Park using the direct hardwood seeding method (56 acres plus 29 using other state funds)
- Oak savanna restoration at Tanglewood Nature Preserve in the protected St. Croix Greenway, Marine (5 acres).
- Garlic mustard control and ravine erosion control for prime Louisiana Waterthrush habitat, at Arcola Mills Historic Foundation, a protected site with forest of Minnesota County Biological Survey (MCBS) statewide significance (12 acres).
- Erosion control and invasive shrub control at Wind in the Pines Park, a Scandia park adjacent to Falls Creek SNA (.5 acres plus .5 acres using other state funds)
- Award-winning erosion control for ravines traversing three communities of MCBS statewide significance at Camp Waub-O-Jeeg, Taylor’s Falls. (4.5 acres)

Other project activities include:

- Continued prairie reconstruction establishment, maintenance, and supplemental plug planting at OH Anderson Elementary School, Mahtomedi, while using it as a living classroom (3 acres)
- Maintained the planted oak trees and controlled invasive species at Eagle Creek AMA, Savage, as part of the savanna reconstruction (4 acres plus 1 acre using other state funds)
- Installed a raingarden to protect the Credit River (recently listed as impaired) and continued invasive species control at the dry hill prairie of MCBS statewide significance, both at Hidden Valley City Park, Savage (1 acre).

We leveraged over $90,000 of non-state cash match (1.5 to 1) and garnered over $31,000 of other state support; 327 volunteers contributed 760 hours to these projects; and at Afton State Park, 2.8 million hardwood seeds, including 1.7 million acorns, were planted.

Project Results Use and Dissemination

Great River Greening listed community volunteer events on its website, www.greatrivergreening.org (350 hits/month), distributed 1,000 flyers at various community events like Hands on Twin Cities Day at the Mall of America and the Living Green Expo, mailed 3,200 hard copies of its event listings to its community volunteers, and e-mailed over 4,000 of the volunteer workday lists. From these and other recruitment efforts, 327 volunteers contributed 760 hours to Greening's Restore/Enhance Significant Habitat: MeCC Phase III projects. Our volunteer opportunities offer community members transformative experiences – including service learning, camaraderie, ownership and stewardship of the project, and face-to-face contact with ecologists – that can create a life-long dialogue about the importance of preserving Minnesota's native habitats.

Projects are typically collaborations with partners that foster exchange of information on techniques, strategies, and priorities. Jon and Neu Gamble, the owners of Camp Waub-O-Jeeb, were awarded Chisago SWCD's Outstanding Conservationist Award for 2009 http://www.chisagoswcd.org/Conservationists.htm for their support and willingness to have work done at the camp to help mitigate sedimentation to the St. Croix River. Greening identified problem areas and provided design solutions to control run-off from their property to the ravines and eventually the St. Croix River. They are now being put forward by the county for the regional SWCD award.

At Afton State Park, Greening and DNR Parks recruited volunteers from the birding community, through both Audubon Minnesota and DNR birding volunteers, to conduct bird monitoring at the project site. Through this process, the birding community will be directly learning about the project.

Trust Fund 2007 Work Program Final Report

Date of Report: 8/15/09
Trust Fund 2007 Work Program Final Report
Date of Next Status Report: n/a
Date of Work program Approval: 22 March 2007
Project Completion Date: 6/30/09

I. PROJECT TITLE: Metro Conservation Corridors (MeCC) Phase lll: Great River Greening (2.3)

Project Manager: Wiley Buck
Affiliation: Great River Greening
Mailing Address: 35 W. Water St.
City / State / Zip : St. Paul, MN 55107
Telephone Number: 651 665.9500 x15
E-mail Address: wbuck@greatrivergreening.org
FAX Number: 651 665.9409
Web Page address: www.greatrivergreening.org

Location: Within mapped Focus Area in the counties of Anoka, Carver, Chisago, Dakota, Goodhue, Hennepin, Isanti, LeSueur, Nicollet, Ramsey, Rice, Scott, Sherburne, Sibley, Washington and Wright. See attached MCC_2007_bw.pdf.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	60,000
	Minus Amount Spent:	**$**	60,000
	Equal Balance:	**$**	-0-

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 4c2.3.

Appropriation Language:
(c) Metro Conservation Corridors- Phase III $2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated: (1) as an

outdoor recreation unit under Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II. and III. FINAL PROJECT SUMMARY

This project restored a total of 86 ecologically significant acres, and an additional 30.5 acres using other state funds. Primary criteria for project selection were ecological significance, importance to the community, and partner commitment.

Several distinguished projects were part of our St. Croix Healthy Waters Initiative. These include:

- Forest reconstruction at Afton State Park using the direct hardwood seeding method (56 acres plus 29 using other state funds)
- Oak savanna restoration at Tanglewood Nature Preserve in the protected St. Croix Greenway, Marine (5 acres).
- Garlic mustard control and ravine erosion control for prime Louisiana Waterthrush habitat, at Arcola Mills Historic Foundation, a protected site with forest of Minnesota County Biological Survey (MCBS) statewide significance (12 acres).
- Erosion control and invasive shrub control at Wind in the Pines Park, a Scandia park adjacent to Falls Creek SNA (.5 acres plus .5 acres using other state funds)
- Award-winning erosion control for ravines traversing three communities of MCBS statewide significance at Camp Waub-O-Jeeg, Taylor's Falls. (4.5 acres)

Other project activities include:

- Continued prairie reconstruction establishment, maintenance, and supplemental plug planting at OH Anderson Elementary School, Mahtomedi, while using it as a living classroom (3 acres)
- Maintained the planted oak trees and controlled invasive species at Eagle Creek AMA, Savage, as part of the savanna reconstruction (4 acres plus 1 acre using other state funds)
- Installed a raingarden to protect the Credit River (recently listed as impaired) and continued invasive species control at the dry hill prairie of MCBS statewide significance, both at Hidden Valley City Park, Savage (1 acre).

We leveraged over $90,000 of non-state cash match (1.5 to 1) and garnered over $31,000 of other state support; 327 volunteers contributed 760 hours to these projects; and at Afton State Park, 2.8 million hardwood seeds, including 1.7 million acorns, were planted.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: N/A

Result 2: Restore & Enhance Significant Habitat:

Description: Within the mapped Focus Areas, Great River Greening anticipates restoring 61 acres and 0.10 miles of shoreline of ecologically significant natural areas, including prairie, oak communities, and streambanks. Primary criteria for project selection are ecological significance, importance to the community, and partner commitment.

Final Report Summary 6/30/2009:
Greening restored 86 ecologically significant acres, and an additional 30.5 acres using other state funds. Primary criteria for project selection were ecological significance, importance to the community, and partner commitment. Greening exceeded our anticipated restoration of 60 acres with and 0.1 mile of shoreline.

While all acres were ecologically significant, many of these acres were concentrated into our St. Croix Healthy Waters Initiative and our Million Acorn Campaign, providing an additional focus to the restoration work. In addition, we employed the direct hardwood seeding technique for a large forest reconstruction project at Afton State Park, and in the process built capacity to undertake these projects in the metro area.

We leveraged over $90,000 of non-state match (1.5 to 1), exceeding our non-state match goals of 1:1, and garnered over $31,000 of other state support; 327 volunteers contributed 760 hours to these projects; and at Afton State Park, 2.8 million hardwood seeds, including 1.7 million acorns, were planted.

V. TOTAL TRUST FUND PROJECT BUDGET: $60,000

Staff or Contract Services: **$**44,535
Equipment: **$**1,859
Development: $ -0-
Restoration: $ 11,936+ Other: $1,670
Acquisition, including easements: $ -0-

TOTAL TRUST FUND PROJECT BUDGET: $ 60,000

Explanation of Capital Expenditures Greater Than $3,500: N/A

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: Metro Conservation Corridor partners (see Table A) and anticipated project partners include NFWF, Bush Foundation, Washington Co., Chisago Co., DNR Parks, Anoka County, and Target Corp.

B. Other Funds Proposed to be Spent during the Project Period: We anticipate $45,000 in non-state matching funds will be leveraged with the LCCMR funds, and $10,000 of other state funds.

C. Past Spending: 2005: $100,000 for Metro Corridors II; 2003: $124,000 for Metro Corridors I, and $255,000 for Bucks and Buckthorn: Engaging Young Hunters in Restoration; 2001: $910,000 for Big Rivers Partnership; 1999: $800,000 for Big Rivers Partnership. $300,000 RIM Critical Habitat Match. These funds leveraged over $4.5 million in non-state funds.

D. Time: 2 years

VII. DISSEMINATION

Great River Greening listed community volunteer events on its website, www.greatrivergreening.org, (350 hits/month) distributed 1,000 flyers at various community events like Hands on Twin Cities Day at the Mall of America and the Living Green Expo, mailed 3,200 hard copies of its event listings to its community volunteers, and e-mailed over 4,000 of the volunteer workday lists. From these and other recruitment efforts, 327 volunteers contributed 760 hours to Greening's Restore/Enhance Significant Habitat: MeCC III projects. Our volunteer opportunities offer community members transformative experiences - including service learning, camaraderie, ownership and stewardship of the project, and face-to-face contact with ecologists - that can create a life-long dialogue about the importance of preserving Minnesota's native habitats.

Projects are typically collaborations with partners that foster exchange of information on techniques, strategies, and priorities. Jon and Neu Gamble, the owners of Camp Waub-O-Jeeb, were awarded Chisago SWCD's Outstanding Conservationist Award for 2009 http://www.chisagoswcd.org/Conservationists.htm for their support and willingness to have work done at the camp to help mitigate sedimentation to the St. Croix River; Greening identified problem areas and provided design solutions to control run-off from their property to the ravines and eventually the St. Croix River. They are now being put forward by the county for the regional SWCD award.

At Afton State Park, Greening and DNR Parks recruited from the birding community, both Audubon Minnesota and DNR birding volunteers, to conduct bird monitoring at the project site. Through this process, the birding community will be directly learning about the project.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than February 1st and August 1st each year, starting with February 1, 2008. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR

Attachment A: Budget Detail for 2007 Projects

Project Title: Metro Conservation Corridors (MeCC) Phase III: Great River Greening (2.3)

Project Manager Name: Wiley Buck

Trust Fund Appropriation: $ 60,000

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	Result 2 Budget: *approved 3/2/09*	Result 2 Budget: *revised 6/30/09*	Amount Spent *6/30/09*	Balance *6/30/09*	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	Restore and Enhance					
PERSONNEL: wages and benefits	~~$ 24,217~~	$ 25,963	$ 25,963	$ -	$ 25,963	$ -
Contracts				$ -	$ -	$ -
Professional/technical *(site prep, prairie seeding)*	~~$ 19,697~~	$ 18,572	$ 18,572	$ -	$ 18,572	$ -
Grants to LGUs and NGOs for restoration projects				$ -	$ -	$ -
Other direct operating costs *(for what? – be specific)*				$ -	$ -	$ -
Equipment / Tools (*Seed drill, mower, harrow, roller, sprayers, Rx burn eq't, saws, loppers,)*	~~$ 1,836~~	$ 1,859	$ 1,859	$ -	$ 1,859	$ -
Office equipment & computers - NOT ALLOWED unless unique to the project				$ -	$ -	$ -
Other Capital equipment *(list specific items)*				$ -	$ -	$ -
Land acquisition				$ -	$ -	$ -
Land rights acquisition *(less than fee)*				$ -	$ -	$ -
Professional Services for Acq.				$ -	$ -	$ -
Printing				$ -	$ -	$ -
Other Supplies *(list specific categories)*				$ -	$ -	$ -
Travel expenses in Minnesota	~~$ 1,000~~	$ 915	$ 915	$ -	$ 915	$ -
Travel outside Minnesota *(where?)*				$ -	$ -	$ -
Construction *(for what?)*				$ -	$ -	$ -
Other land improvement *(plant, mulch, and seed purchase)*	~~$ 13,230~~	$ 11,936	$ 11,936	$ -	$ 11,936	$ -
Other (*Volunteer event supplies (approved food and bevg, port. toilets, tent rentals etc.))*	~~$ 20~~	$ 754	$ 754	$ -	$ 754	$ -
COLUMN TOTAL	**$ 60,000**	**$ 60,000**	**$ 60,000**	**$ -**	**$ 60,000**	**$ -**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Metro Conservation Corridors (MeCC) Phase lll: Metro Greenways
PROJECT MANAGER: Marybeth Block (Sharon Pfeifer 06/07 through 12/07)
AFFILIATION: MN Dept of Natural Resources - Central Regional Operations
MAILING ADDRESS: 1200 Warner Road
CITY/STATE/ZIP: St. Paul, MN 55106
PHONE: 651-259-5835
FAX: 651-772-7997
E-MAIL: Marybeth.block@state.mn.us
WEBSITE: http://www.dnr.state.mn.us/greenways/index.html
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, [Chap. 30], Sec.[2], Subd.4c.

APPROPRIATION AMOUNT: $944,000

Overall Project Outcome and Results:

The DNR Metro Greenways mission is to ***protect, connect and restore*** a regional network of natural areas in the growth corridor of the state. This mission is accomplished by supporting local conservation efforts with matching grants, while insuring each individual effort contributes to the regional network concept. During Phase 3 of this program:

Two projects received a total of $30,870 to implement restoration activities on 11 acres of public land and the project sponsors matched those dollars with $100,000. At the Bruce Vento Nature Sanctuary in St. Paul neighborhood groups worked with volunteers and the City of St. Paul to remove invasive plant and plant oak woodland and prairie on the bluffs. The city of Elk River removed invasive species and planted a prairie/savanna in an old pasture that was acquired in 2005 to expand Top of the World City Park.

Five projects received a total of $1,029,349 that, when combined with over $3 million dollars from other funding partners, protected 248 acres of open space and high-value ecological areas. Three projects acquired conservation easements to protect: 44 acres along the Vermillion River in Dakota County, 12 acres in the St. Croix Basin's Valley Branch watershed, and 140 acres in Isanti County. The program assisted two local governments to purchase land: the City of Mendota Heights acquired 15 acres at the Pilot Knob Natural Area and Scott County acquired 41 acres that will become part of the future planned 900+ acre Doyle-Kennefick Regional Park.

Six projects received Community Assistance grants to develop tools and policies that local governments will use to protect high quality natural areas. Three of the projects conducted natural resource inventories using the MN Land Cover Classification System. One project developed a model to predict a parcel's sensitivity to development. One project drafted a conservation ordinance. One project developed a Stewardship Guide to provide crucial information to a county wanting to develop a sound conservation easement program.

Project Results Use and Dissemination

Press releases were sent to local newspapers where projects were funded. The DNR intends to post Community Assistance Project Profiles on their website and restoration and protection project information will be available through the public map generated from the MeCC database. All DNR Metro Greenways-generated news releases cited the required MN Environment and Natural Resources Trust Fund attribution language.

Trust Fund 2007 Work Program Final Report

Date of Report: September 14, 2009
Date of Next Status Report: Trust Fund 2007 Work Program Final Report
Date of Work program Approval: 6/5/2007
Project Completion Date: 6/30/09

I. PROJECT TITLE: Metro Conservation Corridors (MeCC) Phase lll: Metro Greenways
Project Manager: Marybeth Block (Sharon Pfeifer 06/07 through 12/07)
Affiliation: MN Dept of Natural Resources - Central Regional Operations
Mailing Address: 1200 Warner Road
City / State / Zip : St. Paul, MN 55106
Telephone Number: 651 259-5835
E-mail Address: Marybeth.block@dnr.state.mn.us
FAX Number: 651 772 7997
Web Page address: http://www.dnr.state.mn.us/greenways/index.html

Location: Within mapped Focus Area in the counties of Anoka, Carver, Chisago, Dakota, Goodhue, Hennepin, Isanti, LeSueur, Nicollet, Ramsey, Rice, Scott, Sherburne, Sibley, Washington and Wright. See Figure 1.

Total Trust Fund Project Budget:

Trust Fund Appropriation:	**$** 944,000
Minus Amount Expended:	$ 936,342
Balance:	**$** 7,658

Legal Citation: ML 2007, [Chap. 30], Sec.[2], Subd.4c.

Appropriation Language: *(c)* Metro Conservation Corridors- Phase III $2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated:(1) as an outdoor recreation unit under Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II. and III. FINAL PROJECT SUMMARY:

The DNR Metro Greenways mission is to ***protect, connect and restore*** a regional network of natural areas in the growth corridor of the state. This mission is accomplished by supporting local conservation efforts with matching grants, while insuring each individual effort contributes to the regional network concept. During Phase 3 of this program:

Two projects received $30,870 to implement restoration activities on 11 acres public land and the project sponsors matched those dollars with $100,000. At the Bruce Vento Nature Sanctuary in St. Paul neighborhood groups worked with volunteers and the City to remove invasive plant and plant oak woodland

and prairie on the bluffs. Elk River removed invasive species and planted a prairie/savanna in an old pasture that was acquired in 2005 to expand Top of the World City Park.

Five projects received $1,029,349 that, when combined with over $3 million dollars from other funding partners, protected 248 acres of open space and high-value ecological areas. Three conservation easements acquired 44 acres along the Vermillion River in Dakota County, 12 acres in the St. Croix Basin's Valley Branch watershed and 140 acres in Isanti County. The program assisted two local governments to purchase land: 15 acres at the Pilot Knob Natural Area in Mendota Heights and 41 acres that will become part of a future 900+ acre regional park.

Six project received Community Assistance grants to develop tools and policies that local governments will use to protect high quality natural areas. Three of the projects conducted a natural resource inventories using the MN Land Cover Classification System. One developed a model predict a parcel's sensitivity to development and another drafted a conservation ordinance. A Stewardship Guide was written to provide crucial information to a county wanting to develop a sound conservation easement program.

IV. OUTLINE OF PROJECT RESULTS:

Result 1 (restoration): The original project proposal stated a goal of treating 45 acres with restoration practices with over $44,000 budgeted for grants.   The request for proposal process yielded 2 projects applications to carry out restoration activities on 11 acres.

In April of 2008 the LCCMR approved an amendment to transfer the balance of $13,885 from this result to result 2 (protection). In February of 2009 the work program was again amended to transfer the remaining balance of $2,413 in result 2 (protection) was back to result 1 to increase the grant to the City of Elk River so they could carry out all of the restoration activities they had planned.

<u>The East Side Neighborhood Development Association</u> was awarded a $20,000 grant to continue carrying out restoration activities at the Bruce Vento Nature Sanctuary at St. Paul, MN. This site, once sacred to the Dakota, was contaminated with asbestos when owned by the BNSF Railroad. The Metro Greenways program assisted the City of St. Paul to purchase the property by acquiring a conservation easement on this parcel in 2002 (with bonding funds.) After extensive clean up of the site, Metro Greenways awarded a $50,000 grant (appropriated from Minnesota Environment and Natural Resources Trust Fund funds "Trust Funds") in 2005 to begin landscape restoration activities at the Nature Center. The activities carried out with money awarded under this work program include:

- Removed 11 invasive species from 1.75 acres: Canada Thistle, Burdock, Spotted Knapweed, Buckthorn, Garlic Mustard, Birdsfoot Trefoil, Artemisia, Canada Goldenrod, biennial Thistle, Curly dock and Reed Canary Grass.
- Conducted a prescribed burn.
- In April, 2008, 300 volunteers planted, caged and mulched 700 oaks woodland trees and shrubs on 1.5 acres. This site was selected for HGTVs "Change the World Week."
- In April of 2009 the City of St. Paul and Lower Phalen Creek Group planted, caged and mulched 220 oaks woodland trees and shrubs on .75 acres.

  *note: the City of St. Paul has been watering the trees during drought conditions.
- 7 warm season native grass species and 7 native forbs species where planted on the bluff.

The oak woodland tree and shrub plantings are doing well with the extra steps taken to establish them. Establishing the native species on the bluff is challenging due to the step slops, poor quality soil and invasive species.

The total cost of the project was $97,254 up substantially from the original budget amount of $50,500. The match of $77,711 was provided by various entities (refer to the chart on the next page.)

The City of Elk River carried out restoration activities on 7 acres at the Top of the World Park Addition. This project was carried out on land acquired in Phase 3 (2005) in part with Trust Funds through a Metro Greenways Grant. This restoration project, carried out with Phase 4 (2007) Trust Fund money, focused on native prairie/savanna restoration activities:

- Site preparation
- Treatment to remove & control invasive trees and shrubs: cut and treat the stumps.
- Selectively cut small oaks that occurred under the canopy of healthy, more mature oaks.
- Conducted a prescribed burn
- Seeded the prairie and savanna area

This project included a collaborative approach with the City of Elk River parks staff, volunteers, and a private contractor (Bonestroo). This team worked well together and was able to successfully complete a number of site preparation activities in close sequence, thanks to good communication. With the economic downturn the city experienced some budgetary challenges during the course of this project that required some adjustment in the work plan for this grant project. The MN DNR staff worked with the city and the contractor to make appropriate adjustments to the work plan and schedule, allowing this project to be successfully completed. The City has (and will continue to)spot mow and apply herbicide as needed to establish the seeding. The City is also responsible for installing an interpretive sign.

Summary Budget Information for Result 2:

Grant Recipient	Project Name	Deliverable	Acres	Total Cost	Metro Greenways $	Other Funds $
Eastside Neighbor-hood	Bruce Vento Nature Center	Continued restoration of this urban site that was severely degraded when purchased from Burlington Northern Railroad in 2002.	4	$97,254	$19,543	McNeely Foundation: $13,000; McKnight Foundation: 2,000; HGTV funds: 6,405 St. Paul: $15,945; St. Paul & East Side Youth Consv Corps & HGTV Volunteers $40,361
Elk River	Top of the World Savanna	Invasive control, prairie/savanna restoration activities and signage. .	7	$22,664	$11,327	City in-kind/cash match: ~$11,000
			11	$119,908	30,870	

Deliverable **Completion Date**

1. 11 acres treated with restoration efforts 6/30/2009

Original Budget:	$44,000
Amended Budget:	$32,528
Amount Expended:	$30,870
Balance:	$ 1,658

Result 2 (acquisition): The Metro Greenways Advisory Committee recommended 7 projects, but one withdrew and two were funding with bonding dollars. Five projects protecting 248 acres were funded with trust fund dollars.

- 3 projects protect 194 acres by acquiring a conservation easement on privately owned land. The Minnesota Land Trust holds easements on 2 properties (12 acres in Washington County and 140 acres in Isanti County.) Dakota County holds one conservation easement on 44 acres (and along 1,310 linear feet of the Vermillion River) near Hastings.
- 2 projects protect 52 acres by acquiring land that will be owned by local units of government and protected by deed restrictions. The City of Mendota Heights expanded the Pilot Knob Natural Area by 15 acres. Scott County purchased a parcel that, in the future, will be part of a regional park.

Grantee	Project Name	Location	Deliverable	Acres	Total Cost	Metro Greenway Grant	Other Funds $
Result 2: Acquire Significant Habitat							
Dakota County	Wilmar	Dakota County, Vermillion Township	**The County acquired a conservation easement** from the landowner. The protected area includes cropland, floodplain trees and other vegetation that straddles 1,310 linear feet Vermillion River.	44	$225,000	$40,000	Dakota County FNAP
Mendota Heights	Pilot Knob, Phase II	Dakota County, Mendota Heights	**The City acquired** a parcel that abuts Pilot Knob parcel acquired in 2005. The MG grant included 2 appropriations: 72% acquired from Phase 3 funds and 28% from Phase 2 funds (acreage has been prorated by the % paid in this phase.)	11	$1,689,911	$144,513	City $400K; Dak. Co. $400K; DNR $1.2 M; TPL-ETF $200K
MN Land Trust	Beckman Farm	Isanti County, Stanchfield Township	**MLT acquired a Conservation easement** from the landowner. The protected area includes restored cropland including a 40 acre wetland, 40 acre mature red/white pine forest, and 800 feet of shoreline.	140	$475,000	$315,000	none
MN Land Trust	Steltzner	Washington County, Afton	**MLT acquired a Conservation easement** from the landowner. This project was originally submitted by Washington Co. but MLT took over because the landowner is an employee of the County. The protected area is largely oak woodland-brushland. Valley Creek flows by property and it abuts Belwin.	12	$150,000	$75,000	landowner donation
Scott County	St. Catherine's Bluff	Scott County, Cedar Lake Township	**The County acquired** land comprised of a high-quality bluff-top maple-basswood forest (25 acres) and 3500' of undisturbed shoreline. The parcel will be part of the planned Doyle-Kennefick Regional Park, which will encompass about 900 acres. The MG grant included 2 appropriations - 85% acquired with Phase 3 and 15% with Phase 4 Metro Greenways funds. (acreage has been prorated by the % paid in this phase.)	41	$1,210K	$236,959	$41,740 from Metro Greenways Phase 3, $769,680 from Met Council and $170,044 from ENT fund
TOTAL				248	$3,812K	$811,472	

Deliverable	**Completion Date**
1. 256 acres acquired	6/30/2009

Original Budget:	*$800,000*
Amended Budget:	$811,472
Amount Expended:	$811,472
Balance:	**$ 0**

Result 3: Community Conservation Assistance

Four cities and two counties within the metropolitan area were awarded Community Conservation Assistance matching grants. The purpose of this grant is to assist local governments with gathering and integrating natural resources information into local development and conservation planning and policy decisions. The DNR is especially interested in projects that seek to resolve challenges associated with the conservation of remaining natural habitats in rapidly changing communities.

Final Report Project Summary:

Grant Recipient	Project Type	Deliverable	Area	Total Cost $	Metro Greenway $	Other Funds
Result 3: Provide Community Conservation Assistance						
Andover	Natural Resource Inventory (Targeted)	NRI/MLCCS to identify natural and semi-natural areas and assess the overall quality to aid staff and commission members efforts to protect, restore and encourage private land stewardship.	740 acres	$14,000	$9,476	City
Dayton	Ordinances	Developed a Conservation Subdivision Ordinance aimed at protection of natural resources within the designated Greenway Corridor.	Greenway	$35,000	$10,000	City
Goodhue County	Policy & Planning	Developed a GIS model that combines data and assigns a numerical score to a parcel indicating the quantity and quality of natural resources, and other relevant characteristics of the property.	entire county	$70,000	$35,000	County
Maple-wood	Natural Resource Inventory (Targeted)	NRI/MLCCS to 1) Develop a Greenways policy statement and 2) Develop a conservation-based zoning district	Greenway	$40,000	$10,000	City
Monti-cello	Natural Resource Inventory (Targeted)	NRI/MLCCS to identify high quality natural resources based on scientific review and concurrent process where the public identified priority natural resource areas. Protection strategies were also identified.	10,000 acres	$30,000	$9,984	City
Scott	Policy & Planning	Developed a Stewardship Guide to provide crucial information specific to land management for the purpose of informing the decisions and process Scott County is undertaking to develop a sound conservation easement program.	entire county	$66,000	$19,540	Co. Parks& Trails McKnight Scott WMO
				$165,206	$94,000	

Deliverable: Local land protection tools, policies and inventories. **Completion Date** **06/30/2009**

Summary Budget Information for Result 3:

Original Budget:	$ 100,000
Amount Expended:	$ 94,000
Balance:	$ 6,000

TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $0
Equipment:$0
Development: $ 0
Restoration: $ $30,870 for restoration activities on 11 acres
Acquisition, including easements: $ 811,472 protected 248 acres
Community Assistance: $94,000 for 6 projects developing tools to assist local governments in managing and protecting natural resources.

TOTAL TRUST FUND PROJECT BUDGET: $ 936,342

Explanation of Capital Expenditures Greater Than $3,500: N/A

V. OTHER FUNDS & PARTNERS:

A. Project Partners: Metro Conservation Corridor partners (see Table A) and private landowners, local governments, regional, state and federal agencies, nonprofit organizations and citizen groups.

B. Other Funds Spent during the Project Period: $3,161,154

C. Past Spending: In the past 8 years, Metro Greenways has received the following direct appropriations: 1998 bonding: $4,000,000, 2000 Bonding: $1,500,000, 2001 LCMR: $2,730,000 2003 LCMR/Phase1 MWC: $1,089,000 appropriation, 2005 LCMR/Phase2 MWC: $1,200,000. In addition, since inception of the program, over $3 of non-state funds for every LCMR dollar has been directly leveraged towards the projects funded by Metro Greenways.

D. Time: 2 years

VI. DISSEMINATION: Metro Corridors will periodically distribute information about the program through the widely broadcasted emails to people on the Embrace Open Space (EOS) database, through the EOS quarterly meetings and jointly held county meetings, and on the MeCC website. As projects are completed, the partners involved will publicize accomplishments through press releases and organization newsletters and websites.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than February 1st and August 1st each year, starting with February 1, 2008. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR.

Attachment A: Final Budget Detail 2007 (Phase 3) MeCC- DNR Metro Greenways

Project Title: Metro Greenways (Results 1,2 and 3)

Project Manager Name: Marybeth Block

Trust Fund Appropriation: $ 944,000

2007 Trust Fund Budget	Result 1 Budget: Restoration	Amount Spent	Balance	Result 2 Budget: Protection	Amount Spent	Balance	Result 3 Budget: CCA	Amount Spent	Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM											
Grants to LGUs and NGOs	32,528	$ 30,870	$ 1,658	$ 811,472	$811,472	0	$100,000	94,000.00	$6,000	$944,000	7,658
COLUMN TOTAL	**$ 32,528**	**$ 30,870**	**$ 1,658**	**$ 811,472**	**$811,472**	**$ -**	**$100,000**	**$94,000**	**$6,000**	**$ 944,000**	**$7,658**

2007 Work Project Abstract
For the Period Ending June 30, 2007

PROJECT TITLE: Metro Conservation Corridors Phase lll: Scientific and Natural Areas (2.5 & 3.6)
Project Manager: Margaret (Peggy) Booth
Affiliation: MN Dept of Natural Resources – Div. of Ecological Resources
Mailing Address: 500 Lafayette Rd, Box 25
City / State / Zip : St. Paul, MN 55155-4025
Telephone Number: 651-259-5088
E-mail Address: peggy.booth@dnr.state.mn.us
FAX Number: 651-296-1811
Web Page Address: **http://www.dnr.state.mn.us/snas/index.html**
Funding Source: Environment & Natural Resources Trust Fund

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 4(c)
Appropriation Language: (c) Metro Conservation Corridors - Phase III
$2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated: (1) as an outdoor recreation unit under Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

APPROPRIATION AMOUNT: $243,000

Overall Project Outcome & Results
The Minnesota Department of Natural Resources (DNR) Scientific and Natural Area (SNA) Program worked with the Trust for Public Land (Metro Conservation Corridors partner) to acquire a 16 acre portion of a larger acquisition of 85.2 acres of high priority native habitat designated as the new Franconia Bluffs SNA. The sites acquired contain native plant communities, such as mesic oak and maple-basswood forests and habitat for rare plant and animal species including red-shouldered hawk, Cerulean warbler, Acadian flycatcher, Louisiana waterthrush, bald eagle, and wood turtle; and adjoins the St. Croix National Scenic Riverway which contains four state-listed fish species documented near the SNA and a total of 40 native mussel species, two of which are federally- and state-endangered;

The SNA Program and its partners (including Metro Corridor partners Friends of the Mississippi River) restored and enhanced native habitat on over 429 acres at 12 SNAs within the Metro Corridors Focus Area. Specific accomplishments are: 13 acres of prairie restoration work (local ecotype seed collection from onsite or within 20 miles and seeding) at two sites in Washington and Dakota Counties; 197 acres of prescribed burns (and associated burn break development) at 6 SNAs in Goodhue and Washington Counties; and 219 acres of exotics species removal at 9 sites in Carver, Hennepin, Goodhue, and Washington Counties. This work is necessary to prevent the loss of important species, plant communities and features.

The SNA goal is to preserve and perpetuate the ecological diversity of Minnesota's heritage for scientific study, education, and nature observation. Over 3000 acres in 24 SNAs have been designated within Metro Conservation Corridors Focus Area. These SNAs are managed to protect elements of natural diversity such as rare and endangered plant and animal species, undisturbed plant communities, and geological features.

Project Results Use & Dissemination

SNA's partner – the Trust for Public Land – issued a press release for each acquisition completed through this project.

Trust Fund 2007 Work Program Final Report

Date of Report: 11/13/09
Trust Fund 2007 Work Program Final Report

Project Completion Date: 6/30/09

I. PROJECT TITLE: Metro Conservation Corridors Phase lll:
Scientific and Natural Areas (2.5 and 3.6)
Project Manager: Margaret (Peggy) Booth
Affiliation: MN Dept of Natural Resources – Div. of Ecological Resources
Mailing Address: 500 Lafayette Rd, Box 25
City / State / Zip : St. Paul, MN 55155-4025
Telephone Number: 651-259-5088
E-mail Address: peggy.booth@dnr.state.mn.us
FAX Number: 651-296-1811
Web Page address: **http://www.dnr.state.mn.us/snas/index.html**

Location: Current and proposed Scientific and Natural Areas within mapped Focus Area in the counties of Anoka, Carver, Chisago, Dakota, Goodhue, Hennepin, Isanti, LeSueur, Nicollet, Ramsey, Rice, Scott, Sherburne, Sibley, Washington and Wright. See Figure 1.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$243,000**
	Minus Amount Spent:	**$243,000**
	Equal Balance:	**$0**

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 4(c)

Appropriation Language:
Appropriation Language: (c) Metro Conservation Corridors - Phase III
$2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated: (1) as an outdoor recreation unit under

Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II & III. FINAL PROJECT SUMMARY

The Minnesota Department of Natural Resources (DNR) Scientific and Natural Area (SNA) Program worked with the Trust for Public Land (Metro Conservation Corridors partner) to acquire 85.2 acres (16 acres directly through these funds) of high priority native habitat which were designated as the new Franconia Bluffs SNA. The sites acquired contain native plant communities, such as mesic oak and maple-basswood forests and habitat for rare plant and animal species including red-shouldered hawk, Cerulean warbler, Acadian flycatcher, Louisiana waterthrush, bald eagle, and wood turtle; and adjoins the St. Croix National Scenic Riverway which contains four state-listed fish species documented near the SNA and a total of 40 native mussel species, two of which are federally- and state-endangered;

The SNA Program and its partners (including Metro Corridor partners Friends of the Mississippi River) restored and enhanced native habitat on over 429 acres at 12 SNAs within the Metro Corridors Focus Area. Specific accomplishments are: 13 acres of prairie restoration work (local ecotype seed collection from onsite or within 20 miles and seeding) at two sites in Washington and Dakota Counties; 197 acres of prescribed burns (and associated burn break development) at 6 SNAs in Goodhue and Washington Counties; and 219 acres of exotics species removal at 9 sites in Carver, Hennepin, Goodhue, and Washington Counties. This work is necessary to prevent the loss of important species, plant communities and features.

The SNA goal is to preserve and perpetuate the ecological diversity of Minnesota's heritage for scientific study, education, and nature observation. Over 3000 acres in 24 SNAs have been designated within Metro Conservation Corridors Focus Area. These SNAs are managed to protect elements of natural diversity such as rare and endangered plant and animal species, undisturbed plant communities, and geological features.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: N/A

Result 2: Scientific & Natural Area (SNA) Restoration & Enhancement
The SNA Program and its partners (including Metro Corridor partners Friends of the Mississippi River) restored and enhanced native habitat on over 429 acres (not counting accomplishment acres done through other partners or funding). Work was targeted at prairie restoration and enhancement and exotics species removal. This work is necessary to prevent the loss of important species, plant communities and features from past land use practices (prior to SNA designation), lack of natural disturbance regimes, and encroachment by invasives species. Project crew and partner activities included seed collection (local ecotype from onsite or within 20

miles), planting, removal of exotics, control of woody encroachment, and prescribed burns.

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$ 34,888**
	Amount Spent:	**$ 34,888**
	Balance:	**$ 0**

Final Report Summary 6/30/2009:
The SNA goal is to preserve and perpetuate the ecological diversity of Minnesota's heritage for scientific study, education, and nature observation. To date, 24 SNAs encompassing over 3000 acres have been designated within Metro Conservation Corridors Focus Area. These SNAs are managed to protect elements of natural diversity such as rare and endangered plant and animal species, undisturbed plant communities, and geological features.

Restoration and enhancement activities on 429 acres at 12 SNAs were completed with this appropriation as follows:

- 197 acres of prescribed burns (and associated burn break development) at River Terrace Prairie (17 ac), Spring Creek Prairie (42 ac), and Cannon River Turtle Preserve (17.5 ac) SNAs (Goodhue Co); Grey Cloud Dunes (71 ac), St. Croix Savanna (31.5 ac), and Lost Valley Prairie (18 ac) SNAs (Washington Co);
- 219 acres of exotics species removal at Seminary Fen** SNA (4 ac – Carver Co); Spring Creek Prairie** SNA (Goodhue Co); Wood-Rill SNA (200 ac – Hennepin Co); Hastings Sand Coulee (1 ac – Dakota Co); Savage Fen (Scott Co); Falls Creek SNA, Lost Valley Prairie** (2 ac), St. Croix Savanna** (11 ac), and Grey Cloud Dunes** (1 ac) SNAs (Washington Co); and
- 13 acres of prairie restoration work (seeding only) at Pine Bend Bluffs (3 ac – Dakota Co); and Lost Valley Prairie (10 ac – Washington Co; supplemented by donated time by SNA volunteers).

Note: ** additional exotics control activities (acres not counted here) were also completed on these sites during this timeframe using 2005 and 2006 bonding funds. Also, prairie restoration work above was supplemented by Friends of the Mississippi River work funded by Remediation Grant projects at Pine Bend Bluffs.

Result 3: Scientific & Natural Area (SNA) Acquisition.
The SNA program in cooperation with the Trust for Public Land acquired 85.2 acres (16 acres directly through this funding) of high priority native habitat which was designated as Franconia Bluffs SNA. Priority was given to fee acquisition both protecting the resources and providing for public access. Acquisition was initially targeted at four primary locations: a) the largest remaining unprotected parcel of Mississippi River frontage within the Pine Bend Bluffs Natural Area (a MCBS-mapped natural area of bluffs, remnant white pines and other forests, as well as prairies with listed species in Dakota County), b) an addition of MCBS mapped native prairie and ravines adjoining the Lost Valley SNA (Washington County), c) additional lands supporting rare animal and plant species at Hastings Sand Coulee (Dakota County); and d) a proposed new Franconia Bluffs SNA in Chisago County overlooking the St Croix River (Chisago County).

The DNR has a long-range plan for SNA acquisition and designation based upon the Natural Heritage data system, Minnesota County Biological Survey (MCBS), the Ecological Classification, and the Minnesota Comprehensive Wildlife Conservation Strategy. All lands acquired as an SNA must have an ecological evaluation approved by the Commissioner's Advisory Committee.

Summary Budget Information for Result 3:	**Trust Fund Budget:**	**$208,112**
	Amount Spent:	**$208,112**
	Balance:	**$ 0**

Final Report Summary 6/30/2009: Two parcels totaling 85.2 acres in Franconia Township in Chisago County were acquired in part through funding through collaboration with Metro Corridors partner – the Trust for Public Land – and designated as the new Franconia Bluffs SNA. These acquisitions were approved by the township and county boards and are both open to public hunting.

The new Franconia Bluffs SNA is within the northern end of 6-mile long Franconia St. Croix Corridor project area that was evaluated by the DNR's Natural Heritage Program (November 2005) and approved by the Commissioner's Advisory Committee (December 2005) for potential protection through Scientific and Natural Area designation. The St Croix valley and adjoining lands are a resource of national significance. This part of the St Croix River is home to 4 species of state-listed fish species and 40 species of native mussels, two of which are federal and state endangered species. Furthermore, the wooded bluffs of Franconia Township are habitat for many birds and rare plants, including wood turtles. Much of the bottomlands along this 6-mile stretch of river are protected through the St Croix National Scenic Riverway. But, the adjoining bluffs and creek valleys (such as acquired here) are incredibly important wildlife habitat that is very vulnerable to impacts by development.

The new Franconia Bluffs SNA contains native plant communities such as Southern Dry-Mesic Oak Forest, Southern Dry-Mesic Oak (Maple) Woodland, and Maple-Basswood Forest (East Central) and habitat for rare plant and animal species including red-shouldered hawk (Buteo lineatus), Cerulean warbler (Dendroica cerulea), Acadian flycatcher (Empidonax virescens), Louisiana waterthrush (Seiurus motacilla), bald eagle (Haliaeetus leucocephalus), and wood turtle (Gl~~e~~yptemys insculpta).

Transaction costs totaling $26,597 (including boundary survey costs of $16.6K) from this appropriation to the SNA program was expended towards acquisition of the 48-acre Franconia Bluffs – Parcel 1 by the Trust for Public Land (TPL) and conveyed to the DNR on June 2, 2008. TPL used its 2005 Metro Corridors LCCMR funds to pay the landowner. This site was designated as the Franconia Bluffs SNA on June 19, 2008. The boundary survey for the new Franconia Bluffs SNA was completed in September 2008 with this funding (and boundary signs installed using 2008 bonding). The LCCMR accomplishment acres for this acquisition are all counted as 2005 funding by TPL.

The 37.2-acre Franconia Bluffs – Parcel 2 was acquired by the Trust for Public Land and conveyed to the DNR on June 4, 2009 and designated as SNA on June 29, 2009. The landowner donated $8,105 of its value and DNR paid all the direct landowner costs ($385,000) using a combination of this fund (42.3% - 15.7 acres) and the 2008 LCCMR SNA Statewide funding (55.7% - 20.7 acres) – with costs summarized in the table below. The LCCMR members and staff visited this site on June 17, 2009. The map of both parcels is attached which also shows areas of the site for restoration and enhancement through other funding.

Franconia Bluffs SNA – Parcel 2 Funding Sources	$s Spent	Pro-rated %	Pro-rated Acres
2007 LCCMR Metro Corridors/SNA appropriation – Direct Cost	$166,251	42.29%	15.73
2008 LCCMR SNA Statewide – Direct Cost	$218,749	55.65%	20.70
Landowner Donation	$8,105	2.06%	0.77
SUBTOTAL – Direct Fee Acquisition	**$393,105**	**100.00%**	**37.20**
2007 LCCMR – SNA Real Estate Transaction $s *(other transaction costs to be reported as part of 2008 report)*	$5,803		
TPL Real Estate Transaction $s (donated)	$23,953		

Work was also initiated through using $9,461 of this funding to acquire several other parcels which could not be completed under this appropriation: a proposed addition to the Lost Valley Prairie SNA (with the offer turned down by the landowner, but was acquired later in 2009 with state bonding); a proposed addition to Hastings Sand Coulee (with the offer turned down by the landowner); a proposed addition to Pine Bend Bluffs SNA (which was moved to other funding because of delays in the project).

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $28,145 (for 0.7 FTE of SNA project crew, paid almost exclusively with special project funds, to carry out restoration & development work; and less than .001 FTE unclassified acquisition specialist)
Equipment: $3,433 (truck, tractor & equipment fleet charges & incidental parts for chainsaws, tractor, & vehicles needed for restoration & development work)
Development: $0 (signs, fencing, and other supplies needed to bring sites up to minimum standards) – costs were or will be paid through bonding.
Restoration: $3,496 (towards work on 429 acres – various supplies & direct expenses for restoration field work, including travel expenses)
Acquisition, including easements: $207,926 (for 85 acres acquired in fee and designated as SNA – 16 acres fully paid with these funds; including transaction costs and some travel expenses)

TOTAL TRUST FUND PROJECT BUDGET: $ 243,000

Explanation of Capital Expenditures Greater Than $3,500: N/A

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: SNA developed and implemented its projects in cooperation with Friends of the Mississippi River and The Trust for Public Land. SNA also involved the Minnesota Conservation Corps, Sentence to Serve, local groups, and volunteers in project implementation.

B. Other Funds Proposed to be Spent during the Project Period: Restoration/enhancement projects include DNR general funding support and bonding and involved NGO partners using other state or non-state funds (not counted in accomplishment acres). Because landowners declined acquisition offers on two projects and a third project was delayed past the timeframe of this appropriation, this project did not generate any county match and landowner donations, nor was Metro Greenways LCCMR or bonding funds used.

C. Past Spending: SNA acquisition and development appropriations received July 2005-June 2007: LCMR SNA Metro Corridors Phase II: $300,000; 2005 Bonding (primarily non-Metro): $2,000,000. SNA general fund for Central Region is approximately $110,000 annually for region staff, operations and crew.

D. Time: Restoration work was completed by June 2008; acquisition projects were completed in June 2009.

VII. DISSEMINATION: SNA's partner – the Trust for Public Land – issued a press release for each acquisition completed through this project.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports were completed by around February 1st and August 1st each year, starting with February 1, 2008. This is the final work program report and associated products.

Attachment A: Budget Detail for 2007 Projects **FINAL**

Project Title: Metro Conservation Corridors Phase III: Scientific and Natural Areas (2.5 and 3.6)

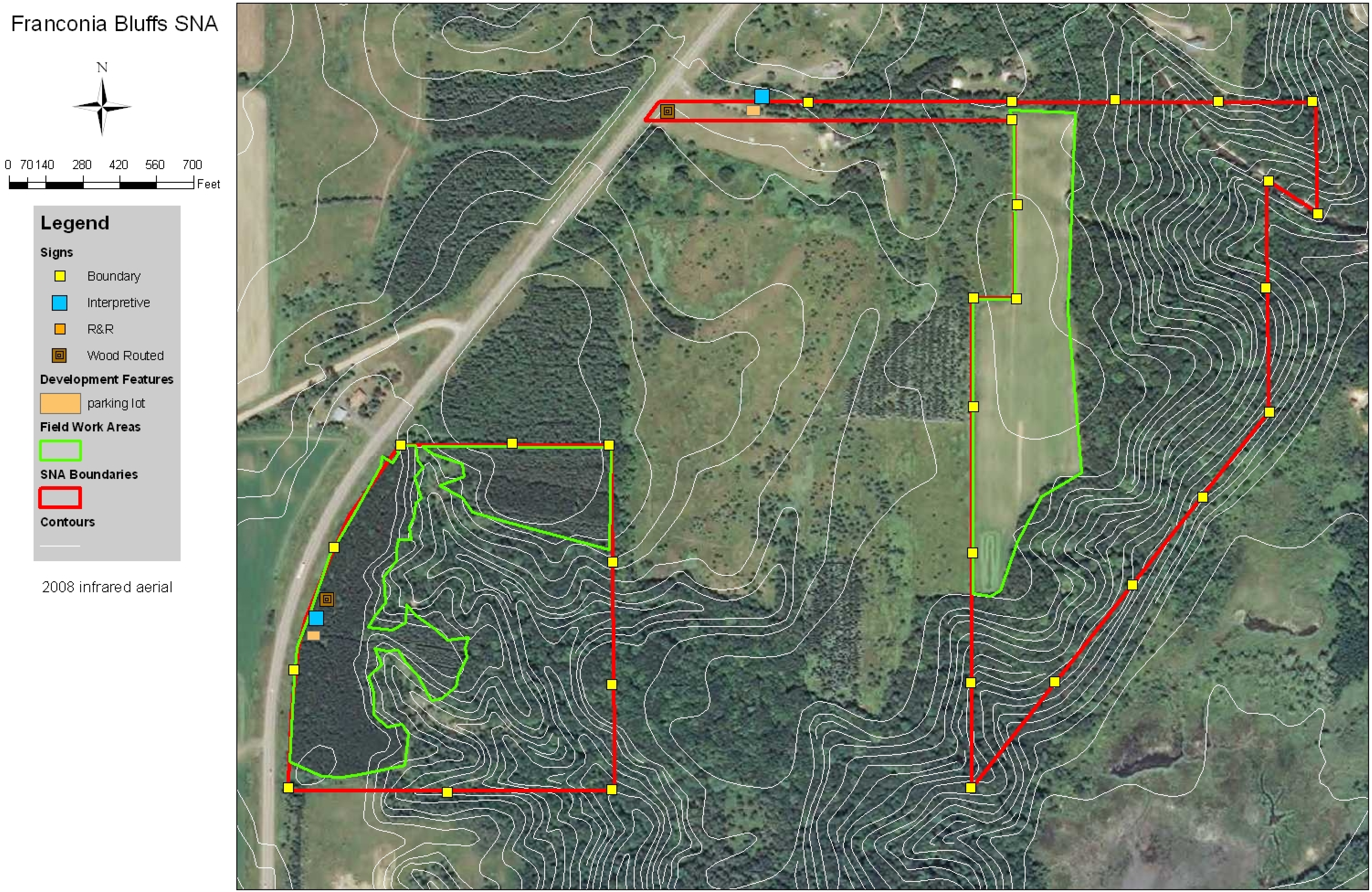
Project Manager Name: Margaret (Peggy) Booth

Trust Fund Appropriation: **$ 243,000**

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 2 Budget:**	**Amount Spent** *(FINAL)*	**Balance** *(FINAL)*	**Result 3 Budget:**	**Amount Spent** *(FINAL)*	**Balance** *(FINAL)*	**TOTAL BUDGET**	**TOTAL BALANCE**
BUDGET ITEM	**Restoration**			**Protection**				
PERSONNEL: wages and benefits: Project crews (paid almost exclusively with special project funds) to carry out restoration and enhancement, amounting to .6 FTE over the life of the project. Fringe varies from 14.8 -18%	$ 27,959	$ 27,959	$ -	$ 186	$ 186	$ -	$ 28,145	$ -
Equipment / Tools: truck, tractor & equipment fleet charges & incidental parts for chainsaws, tractor, vehicles, etc.	$ 3,433	$ 3,433	$ -			$ -	$ 3,433	$ -
Land acquisition			$ -	$ 166,251	$ 166,251	$ -	$ 166,251	$ -
Land rights acquisition *(less than fee)*			$ -			$ -	$ -	$ -
Professional Services for Acq. - including attorney general & closing company costs			$ -	$ 41,648	$ 41,648	$ -	$ 41,648	$ -
Other Supplies: e.g. fencing, exclosure matls, signs, seeds, gloves, chemical, etc	$ 2,460	$ 2,460	$ -			$ -	$ 2,460	$ -
Travel expenses in Minnesota	$ 668	$ 668	$ -	$ 27	$ 27	$ -	$ 695	$ -
Other land improvement: direct expenses not included above for purposes of meeting min. standards & restoration	$ 368	$ 368	$ -			$ -	$ 368	$ -
COLUMN TOTAL	**$ 34,888**	**$ 34,888**	**$ -**	**$ 208,112**	**$ 208,112**	**$ -**	**$ 243,000**	**$ -**


Franconia Bluffs SNA
N
0 70 140 280 420 560 700
Feet
Legend
Signs
Boundary
Interpretive
R&R
Wood Routed
Development Features
parking lot
Field Work Areas
SNA Boundaries
Contours
2008 infrared aerial

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Metro Conservation Corridors (MeCC) – Phase III – (Trout Unlimited)
PROJECT MANAGER: Jeff Hastings
AFFILIATION: Trout Unlimited
MAILING ADDRESS: E7740 Hastings Lane
CITY/STATE/ZIP: Westby, Wisconsin 54667
PHONE: 608-606-4158
FAX: N/A
E-MAIL: jhastings@tu.org
WEBSITE: www.tu.org/driftless
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec.2, Subd. 4c (2.6).

APPROPRIATION AMOUNT: $65,000

Overall Project Outcome and Results
Stream restoration projects that stabilize eroding banks and incorporate habitat for adult trout are common projects in the southeast part of Minnesota; however, few such projects have been undertaken in the Metro area. This project was initiated to ramp up the number of projects in the Metro area and build the capacity of various groups to do them. Funding from the Minnesota Environment and Natural Resources Trust Fund helped sponsor educational workshops, field days, symposiums, displays and eventually two major restoration projects organized by the Twin Cities TU on Hay Creek.

In terms of capacity building, there was significant progress made in working with the Twin Cities Trout Unlimited Chapter, with over 3000 members, which had never taken the lead on a major stream restoration project. Over the course of this grant several of their members attended workshops, symposiums, and other projects so that they too could do a project.

One of the goals of this project was to restore over 1.5 miles of stream corridor over a two year period. Unfortunately time ran out and two projects were not completed – permits, funding, weather, contractors and rock availability, and other factors all have to be timed perfectly to complete a project on time. However, over 1.25 miles were completed involving a number of federal, state, county and private groups and over 2000 hours of volunteer labor.

The project was successful in that: (1) a number of groups completed successful projects; (2) several groups obtained the skills to complete stream projects; (3) the public was better informed on what is involved in a stream restoration project; (4) and four projects totaling over 1.25 miles were completed in the Metro area.

Project Results Use and Dissemination
Project results were disseminated both locally and nationally. Project updates were emailed quarterly to all the partners and anyone that requested to be informed of current happenings. To help facilitate an email newsletter Trout Unlimited created a signup sheet on their website allowing easy access to anyone interested in finding out more about projects. Local and state media were also used to raise awareness of the importance of stream resources and benefits of local restoration projects in the Metro Area. Partnership signs will be posted in the fall of 2010 on both the Hay Creek and Brown Creek projects. Project Manger gave numerous presentations to Trout Unlimited chapters, Great Waters Fly Fishing Expo, and County and

Federal Conservationists. Finally, each fall a display was developed and exhibited at the Great Waters Fly Fishing Expo in Minneapolis. For more detail see final report under “Promote Stream restoration in the Metro Area”.

Trust Fund 2007 Work Program Final Report

Date of Report: August 5, 2009
Trust Fund 2007 Work Program Final Report
Date of Work program Approval:
Project Completion Date: June 30, 2009

I. PROJECT TITLE: **Metro Conservation Corridors (MeCC)– Phase Ill – (Trout Unlimited)**

Project Manager: **Jeff Hastings**
Affiliation: Trout Unlimited
Mailing Address: E7740 Hastings LN,
City / State / Zip : Westby, WI 54667
Telephone Number: 608-606-4158
E-mail Address: jhastings@tu.org
FAX Number: n/a
Web Page address: www.tu.org/driftless

Location: Within mapped Focus Area in the counties of Anoka, Carver, Chisago, Dakota, Goodhue, Hennepin, Isanti, LeSueur, Nicollet, Ramsey, Rice, Scott, Sherburne, Sibley, Washington and Wright.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$65,000**
	Minus Amount Spent:	**$52,681**
	Equal Balance:	**$12,319**

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 4c (2.6).

Appropriation Language: (c) Metro Conservation Corridors- Phase III $2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated: (1) as an outdoor recreation unit under Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II & III. FINAL PROJECT SUMMARY: Although stream restoration projects that stabilize eroding banks and incorporate habitat for adult trout are common projects in the southeast part of the state few projects have been undertaken in the Metro area; this project was initiated to ramp up the number of projects in the Metro area and build the capacity of various groups to do them. One successful example was the Twin Cities Trout Unlimited Chapter, with over 3000 members, had never taken the lead on a major stream restoration project. Over the course of this grant several of their members attended workshops, symposiums and other projects so that they too could do a project. Funding from the Minnesota Environment and Natural Resources Trust Fund helped sponsor educational workshops, field days, symposiums, displays and eventually two major projects organized by the Twin Cities TU on Hay Creek.

The goal of this project was to restore over 1.5 miles of stream corridor over a two year period, unfortunately time ran out and two projects were not completed; permits, funding, weather, contractor and rock availability, and other factors all have to been timed perfectly to complete a project on time. However, over 1.25 miles were completed involving a number of federal, state, county and private groups and over 2000 hours of volunteer labor.

The project was successful in that: (1) a number of groups completed successful projects; (2) several groups obtained the skills to complete a stream project; (3) the public was better informed on what is involved in a stream restoration project; (4) and four projects totaling over 1.25 miles were completed in the Metro area.

IV. OUTLINE OF PROJECT RESULTS*:*

- Restore over 1.5 miles of stream corridor
- Display stream restoration display at Great Waters Fly Fishing Expo in Minneapolis.
- Meet with conservation field offices in Metro area to develop skills for implementing stream restoration projects.
- Develop various Media (radio, newspaper & web) on Metro area stream restoration projects.
- Develop display on stream restoration projects completed in Metro Area
- Contact partners (Trout Unlimited Chapters, Minnesota Soil and Water Conservation Districts, Natural Resources Conservation Service and MN Department of Natural Resources) to develop joint projects.

Final Result 1: 1.26 miles of stream restoration (on several different sections of stream)

Description: Improved 1.26 miles of streams in the Metro area by stabilizing streambanks and incorporating habitat for trout. First, the banks of the incised channels were reshaped to reconnect the stream to their floodplains, usually to a 3:1 slope or better. Future streambank erosion is prevented by using a combination of rock riprap and vegetation. In some areas the steep gradient and the highly erosive glacial loess soils require us of riprap at the stream toe to maintain bank stability. Structures are installed to provide overhead bank cover, help restore pool depth or recreate the natural meaner patters. Deflectors were also used to redirect flow along stable stream banks or to protect steep banks from erosion.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$61,000**
	Amount Spent:	**$48,710**
	Balance:	**$12,290**

Deliverable	Completion Date	Budget	Status
1. 1.26 miles restored	**June 30, 2009**	**$61,000**	**$48,710**
		Matching Contributions	**$76,058**

Final Completion Date: 6/30/2009

Progress Summary: 6650 of streams restored (1.26 miles)

- **Hay Creek, Goodhue County** –
  Twin Cities Trout Unlimited, TU completed two projects on Hay Creek, one in 2008 and one in 2009.
  - The project in 2009 was Twin Cities TU Chapters first major project. Hiawatha TU and MN DNR also assisted with the project to restore 3,000 feet on Hay Creek. Over 945 hours of volunteer work for seeding, mulching, constructing and installing 22 habitat structures for trout. Volunteers were from the following Trout Unlimited Chapters – Hiawatha, Twin Cities, Wisconsin Clear Waters, and Kiap-TU-Wish. We also had volunteers from the surrounding area. Stabilizing streambanks and incorporating deep pools and overhead cover has been shown to increase the carrying capacity of the stream for trout by as much as 900 percent. (LCCMR cost $8,428 – Match $32,010 from a grant from the National Fish Habitat Action Plan $15,000 and volunteer labor)
  - In 2009 Twin Cities TU completed another 2200 feet with the assistance of the Hiawatha chapter and MN DNR. All banks were stabilized, 32 habitat structures for adult trout were installed and 1 vortex weir (create permanent deep pool). The chapter and its members worked four days building structures, seeding, mulching and installing structures; over the course of four days they volunteered over 680 hours. (LCCMR cost $22,651 – Match $30,263)

- **Vermillion River, Dakota County** – This was a great collaborative effort between Twin Cities TU, MN DNR, Dakota Soil & Water Conservation District & the City of Farmington. Project was to stabilize approx. 40 of eroding bank and at the same time installed overhead cover for trout. Over 100 hours in volunteer time to build the trout habitat structures, seed and mulch exposed areas, and donated equipment time – (LCCMR costs $1,745 match/contribution approx. $4,200)

- **Brown's Creek, Washington County –** This was another joint project between the City of Stillwater, DNR Fisheries, Trout Unlimited, Brown's Creek Watershed District & Resident Volunteers, Washington Conservation District and Critical Connections Ecological Services, Inc. Brown Creek has been listed as impaired for biota. The main stressors have been identified as high total suspended solids, high temperatures and high copper concentrations. To projects were conducted to address both the total suspended solids loading and high temperatures. Fisheries Biologist Brian Nerbonne developed a course of action with the Brown's Creek Watershed District:
    - The first project was to remove the invasive Reed Canary Grasses from 3.5 acres of adjacent land. This non-native grass has a shallow root system and allows the banks to erode easily causing erosion into Brown's Creek. The native vegetation that was seeded with its deep roots will stabilize the banks, reduce the potential for reintroduction of the Reed Canary Grass and the tall native grasses adjacent to the stream will provide additional overhead cover.
    - The second part of the project was the addition of 55 native floodplain trees to the south side of Brown's Creek to increase shading and additional bank stabilization. (LCCMR dollars spent $5,551 – Match $11,585)

Final Report Summary: 6/30/2009

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Result 2: Promote Stream restoration in the Metro Area.

Description: The streams and riparian areas of the Metro Area suffer from a history of erosion as a result of agricultural land use and runoff off of urban areas. Across the region, hundreds of miles of spring creeks have been inundated with soils and fine sediment, which has degraded water quality, increased stream temperatures, damaged aquatic habitat, and altered watershed hydrology. Trout Unlimited's initiative with this proposal was to address these impacts and restore the waters and riparian habitat of this area by developing partnerships. By educating our partners and providing technical assistance we were successful in stabilizing eroding streambanks, decreasing stream temperatures and overall improving the fisheries and wildlife. Our trained project manager, with over 25 years experience in watershed and stream restoration worked one-on-one with a host of partners to restore over 1.26 miles in the Metro area, creating showcase projects to demonstrate integrated conservation projects, focus resources for maximum conservation benefit, and raise public awareness and support.

Summary Budget Information for Result 2: **Trust Fund Budget: $4,000**
Amount Spent: $3,971
Balance: $ 29

Deliverable	Completion Date	Budget	Status
1. 100 hrs. Technical assistance	**6/30/09**	**$2,700**	**$2,700**
2. Stream Restoration Display	**1/30/08**	**$800**	**$ 771**
3. 3 news releases on showcase projects	**6/30/09**	**$0**	
4. Display at Great Waters Expo	**4/30/08**	**$0**	
5. Meet with 1 NGO, 3 County, State DNR	**6/30/08**	**$500 (mi.)**	**$ 500**

Final Completion Date: 6/30/2009

Progress Summary

- **Contacts:** Since the beginning of the project in the summer of 2007 I have made numerous contacts to promote stream restoration in the Metro Area,
  - I have been in contact with Area Resource Conservationist, staff from Chisago, Dakota, Goodhue, Rice, Scott, and Washington;
  - NRCS Area Engineers, Regional Fish Biologists,
  - Hiawatha and the Twin Cities Trout Unlimited Chapters.
  - Washington and Brown Creek Watershed project managers.
  - Parks & Recreation Director Farmington

- **Newsletters**: 4 newsletters were electronically sent out to our partners in the Metro Area.

- **Presentations**:
  - Two stream restoration presentations at the Great Waters Fly Fishing Expo at the Renaissance Schaumburg Hotel and Convention Center, Minneapolis.
  - Presentation to the Southeastern District Conservationists (includes Goodhue and Dakota Counties), and another presentation to the County Administrators.
  - Presentations to both the Twin Cities and Hiawatha T.U. Chapters.
  - Presentation to Basin Alliance for the Lower Mississippi in Minnesota and the Blufflands Alliance (includes Minnesota Land Trust).
  - Finally, I lead the third Partnership for River Restoration and Science in the Upper Midwest (PRRSUM) monthly forum, at the St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, MN. The April forum topic was Stream restoration of incised channels in the Driftless Area. I presented a historical overview of the long record of restoration in the Driftless area, beginning with 1930s era Civilian Conservation Corps efforts. I also covered the impacts of agricultural land-use on both the geomorphology and riparian vegetation of the incised channels. Viewers online were able to view photographs and diagrams.

- **Displays:** Displays were created (with partial funding from the LCCMR) and displayed at the Great River Fly-Fishing Expos and the Healthy Waters & Heritage Fair at the William O'Brian state park in Washington Co.

- **Workshops:**
    - At the 2008 stream restoration project on Hay Creek I organized a "hands-on" stream restoration training. Close to 40 participants attended one or both days of this workshop. The workshop was developed to attract conservationists that have not done stream restoration in the past and create additional interest for local citizens and future Trout Unlimited members. All participants received a 3-ring binder packed with standard designs, graphs, pictures and tables of materials I have gathered over the past 15 years of working with streams.
    - I also organized a Stream Restoration Project Planning Workshop in 2008 & 2009 that was attended by members of both Hiawatha and Twin Cities TU.

- **Handouts**:
    - Trout Unlimited Driftless Area Restoration Effort – tri-fold with information about the project & contact information.
    - Trout Unlimited completed "The Economic Impact of Recreational Trout Angling in the Driftless Area", and there was a press conference and news releases sent out. The publication had broad coverage and several newspapers, TV and radio aired the results in Minnesota.
    - The Driftless Area – map/fold out with information on who to contact to help manage your land.
    - Driftless Riparian Habitat Guide – information on both game and non-game species, plus standard designs on 12 habitat practices.

- **Symposium:** Driftless Area Restoration Effort Symposium. *A forum for sharing results of management and research experiments related to stream habitat and fishery restoration in the Driftless region.* Organized and coordinated Driftless Symposium near Lanesboro Minnesota. Approximately 20 presentations were delivered by Professors, Fish Biologists and conservationists to participants from throughout the Driftless Area. The two day event attracted university staff, biologists, conservationist, nonprofit groups, and private restoration specialists from the Metro area. (No funding from the Metro Conservation Corridors (MeCC)– Phase III was used to fund this symposium; however there was partial funding utilized from the "Southeast Minnesota Showcase Stream Restoration Projects" grant)

- **News Releases:**
    - News Release on the 2008 Hay Creek project.

        - The Red Wing Republican Eagle
    - News Release on the 2009 Hay Creek project
        - Hmong Times, KSTP-TV 6 p.m. newscast.

- **Signage:** Signs will be constructed by the end of the summer on both the Hay Creek and Browns Creek project, acknowledging the Minnesota Environment and Natural Resources Trust Fund contributions.

Final Report Summary:

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $3,200
Equipment: n/a
Development: $ n/a
Restoration: $61,000
Other: $800
Acquisition, including easements: $ n/a
TOTAL TRUST FUND PROJECT BUDGET: $65,000

Explanation of Capital Expenditures Greater Than $3,500: n/a

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: Minnesota Department of Natural Resources, Hiawatha, Twin Cities, Wisconsin Clear Waters, Kiap-tu-Wish Trout Unlimited Chapters, Greater Metro Area Soil and Water Conservation Districts and Natural Resources Conservation Service Offices. Washington Conservation District and Brown Creek Watershed Districts, staff University of Minnesota, National Fish and Wildlife Foundation, U.S. Fish and Wildlife Service, City of Farmington, Tom Helgeson – Great Waters Fly fishing Expo, St. Anthony's Lab, Critical Connections Ecological Services, Inc., Volunteers,

B. Other Funds Proposed to be Spent during the Project Period: Trout Unlimited Chapter Dollars, U.S. Fish and Wildlife Service, Volunteer hours, Conservation Districts, Watershed Districts,

C. Past Spending: This was a new initiative for the Metro Conservation Corridor. However, similar restoration projects have been completed throughout the Driftless area**.**

D. Time: 2 years

VII. DISSEMINATION: Project results were disseminated both locally and nationally. Project updates were emailed quarterly to all the partners and anyone that has requested to be informed of current happenings. To help facilitate an email newsletter Trout Unlimited created a signup sheet on their website allowing easy access to anyone interested in finding out more about projects. Local and state media were also used to raise awareness of the importance of stream resources and benefits of local restoration projects in the Metro Area. Signs will be posted later this summer at both the Hay Creek and Brown Creek projects. Finally, each fall a display was developed and exhibited at the Great Waters Fly Fishing Expo in Minneapolis.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports were submitted not later than February 1st and August 1st each year starting with February 1, 2008. A final work program report and associated products was submitted August 17th, 2009 as requested by the LCCMR

IX. RESEARCH PROJECTS: *n/a*

Attachment A: Budget Detail for 2009 Projects

Project Title:Metro Conservation Corridors - Phase III - (Trout Unlimited)

Project Manager Name: Jeff Hastings

Trust Fund Appropriation: $ *65,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent June 30, 09	Unspent Allocation	Result 2 Budget:	Amount Spent June 30, 09	Unspent Allocation	TOTAL BUDGET	TOTAL BALANCE
	Restore & Enhance 1.5 miles of stream			*Promote Stream Restoration in the Metro Area*				
PERSONNEL: wages and benefits				2,700	2,700	0	2,700	0
Equipment / Tools Hourly rate for bulldozers, excavators and dump trucks	35,000	31,079	3,921			0	35,000	3,921
Other Supplies limestone rock for stabilizing banks	26,000	17,631	8,369			0	26,000	8,369
Travel expenses in Minnesota				500	500	0	500	0
Other Display to promote stream restoration projects				800	771	29	800	29
COLUMN TOTAL	**$61,000**	**$48,710**	**$12,290**	**$4,000**	**$3,971**	**$29**	**$65,000**	**$12,319**

2007 Project Abstract- amended 12/16/09
For the Period Ending June 30, 2009

PROJECT TITLE: Metro Conservation Corridors (MeCC) Phase lll – The Trust for Public Land Critical Lands Protection Program (3.1)

Project Manager: Becca Nash
Affiliation: The Trust for Public Land
Mailing Address: 2610 University Avenue West, Suite 300
City / State / Zip: Saint Paul, MN 55114
Telephone Number: 651-999-5325 **FAX:** 651-917-2248
E-MAIL: Becca.Nash@tpl.org **WEBSITE:** www.tpl.org
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, [Chap.30], Sec.[2], Subd.4c 3.1.

APPROPRIATION AMOUNT: $420,000

Overall Project Outcome and Results*

In its Critical Lands Protection Program, the Trust for Public Land (TPL) secured fee title on a total of **118 acres** worth $4,735,000 and conveyed them to public agencies for permanent protection**.** Individual protection successes include the following:

- TPL purchased 48 acres of land adjacent to the St. Croix National Scenic Riverway (Chisago County), containing sensitive slopes and native maple basswood forest known to support numerous rare species in Minnesota, and conveyed them to the Minnesota Department of Natural Resources to create a new Scientific and Natural Area (**Franconia Bluffs SNA)**. TPL spent $10,000 2007 ENRTF on this effort to protect 0.9 (pro-rated) acres of land.

- TPL purchased 70 acres of one of the highest quality natural resources sites in Chisago County, including 1/2 mile of shoreline on Green Lake and oak forests, meadows, and wetlands. TPL conveyed the property to Chisago City for protection and creation of a new regional park (**Ojiketa Regional Park**). TPL spent $410,000 2007 ENRTF on this effort to protect 6.8 (pro-rated) acres of land.

TPL leveraged $420,000 in TPL Metro Conservation Corridor (MeCC) 2007 funding on these projects with **$2,320,000** in non-state funding to protect 46.4 (pro-rated) acres of land. $1,510,000 of this was non-state public funds and $810,000 of this was private ($650,000 in land and $160,00 in cash donated). Additionally, $1,000,000 in state bonding funds were used to protect 16.7 (pro-rated) acres and $995,000 in other ENRTF funds were used to protect 47.3 (pro-rated) acres out of 118 total acres.

*Please note, since two years of ENRTF funding was used for both projects, a portion of these results was also reflected in TPL's 2005 MeCC Phase II Final Report and will be reflected in TPL's 2008 MeCC Phase IV reports.

Project Results Use and Dissemination

TPL posted project information on the TPL website, www.tpl.org, in addition to DNR's posting at its web site, and the Camp Ojiketa Preservation Society posting on its website. TPL included project descriptions in its newsletters, which are mailed to about 6,600 people, and worked with project partners to create and disseminate press releases for each of the projects. Articles were published in the *South Washington County Bulletin*, *North Branch Post Review*, the *Pioneer Press*, the *Star Tribune*, the *Wall Street Journal* and *USA Today*. TPL also sent an e-mail announcement to the Minnesota "TPL Near You" mailing list of approximately 1,200 email addresses, and provided information to Embrace Open Space for inclusion in its monthly e-newsletter (approximately 800 recipients). TPL worked with a nationally recognized photographer to take photographs at Franconia. Land acquired has been or will be posted. Sample media materials are attached.

Trust Fund 2007 Work Program Final Report

Date of Report: 9/11/09- amended 12/16/09
Trust Fund 2007 Work Program Final Report

Date of Work Program Approval: 6/20/07
Project Completion Date: 6/30/09

I. PROJECT TITLE: Metro Conservation Corridors (MeCC) Phase lll – The Trust for Public Land Critical Lands Protection Program (3.1)

Project Manager: Becca Nash
Affiliation: The Trust for Public Land
Mailing Address: 2610 University Avenue West, Suite 300
City / State / Zip: Saint Paul, MN 55114
Telephone Number: 651-999-5325
E-mail Address: Becca.Nash@tpl.org
FAX Number: 651-917-2248
Web Page address: www.tpl.org

Location: Within mapped Focus Area in the counties of Anoka, Carver, Chisago, Dakota, Goodhue, Hennepin, Isanti, LeSueur, Nicollet, Ramsey, Rice, Scott, Sherburne, Sibley, Washington and Wright. See Figure 1.

Total Biennial Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$ 420,000**
	Minus Amount Spent:	**$ 420,000**
	Equal Balance:	**$ 0**

Legal Citation: ML 2007, [Chap.30], Sec.[2], Subd.4c 3.1.

Appropriation Language:
Subd. 4(c) Metro Conservation Corridors- Phase III
$2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated: (1) as an outdoor recreation unit under Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II. and III. FINAL PROJECT SUMMARY*:

In its Critical Lands Protection Program, the Trust for Public Land (TPL) secured fee title on a total of **118 acres** worth $4,735,000 and conveyed them to public agencies for permanent protection**.** Individual protection successes include the following:

- TPL purchased 48 acres of land adjacent to the St. Croix National Scenic Riverway (Chisago County), containing sensitive slopes and native maple basswood forest known to support numerous rare species in Minnesota, and conveyed them to the Minnesota Department of Natural Resources to create a new Scientific and Natural Area. (**Franconia Bluffs SNA)**. TPL spent $10,000 2007 ENRTF on this effort to protect 0.9 (pro-rated) acres of land.

- TPL purchased 70 acres of another of the highest quality natural resources sites in Chisago County, including 1/2 mile of shoreline on Green Lake and oak forests, meadows, and wetlands. TPL conveyed the property to Chisago City for protection and creation of a new regional park. (**Ojiketa Regional Park**). TPL spent $410,000 2007 ENRTF on this effort to protect 6.8 (pro-rated) acres of land.

TPL leveraged $420,000 in TPL Metro Conservation Corridor (MeCC) 2007 funding on these projects with **$2,320,000** in non-state funding to protect 46.4 (pro-rated) acres of land. $1,510,000 of this was non-state public funds and $810,000 of this was private ($650,000 in land and $160,00 in cash donated). Additionally, $1,000,000 in state bonding funds were used to protect 16.7 (pro-rated) acres and $995,000 in other ENRTF funds were used to protect 47.3 (pro-rated) acres out of 118 total acres.

*Please note, since two years of ENRTF funding was used for both projects, a portion of these results was also reflected in TPL's 2005 MeCC Phase II Final Report and will be reflected in TPL's 2008 MeCC Phase IV reports.

IV. OUTLINE OF PROJECT RESULTS*:*

<u>Result 1: Acquire Significant Habitat</u>

Description: TPL secured fee title on 118 acres of high quality habitat in the Metro Conservation Corridors areas, which included 7.7 acres (pro-rated) protected with 2007 ENRTF funds. Both projects resulted from outreach and prioritizing based on resource mapping, stakeholder suggestions, and joint recommendations concerning the appropriate lead organization made by the coalition of groups involved in this overall effort. These projects also represent instances in which TPL's help was solicited because of challenges to the public agency in accomplishing the conservation acquisition alone. Some of these challenges included: large acreages; difficult and/or complex ownerships; a need for multiple funding sources; a high risk of development, and/or a short timeframe in which to work. TPL only worked with willing sellers, and it transferred fee to the appropriate, qualified public steward—in this case, the DNR (Franconia Bluffs SNA) and Chisago City (Ojiketa Regional Park). TPL donated to the land steward the land value of the MeCC-ENRTF funds.

FRANCONIA ST. CROIX BLUFFS SCIENTIFIC AND NATURAL AREA (SNA):

TPL acquired +/- 48 acres above the St. Croix River in Chisago County, and conveyed it to the DNR for management as an SNA. The land adjoins St. Croix National Scenic Riverway lands on the St. Croix River owned by the National Park Service.

This property falls within a six-mile corridor of land that was formally evaluated by the DNR's Natural Heritage Program in November, 2005 and approved for SNA status by the DNR's Commissioner's Advisory Committee in December, 2005. The area, known as Franconia-Scandia project area, contains a rich diversity of native plant communities, from cliffs and seepage swamps, to prairies and pine forests. Half of the corridor, primarily floodplain next to the river, is owned by the National Park Service as part of the St. Croix National Scenic Riverway. The approximate "other half" of the corridor is a high priority for protection by the SNA Program. The corridor supports numerous rare species in Minnesota, such as the Coopers Hawk and cerulean warbler. Located at the edge of a rapidly growing metropolitan region, the area is becoming increasingly vulnerable to over-development, habitat fragmentation, erosion, and invasive species.

In March 2007, The DNR requested assistance from TPL to conduct landowner outreach in the Franconia-Scandia Corridor. Additionally, TPL had been meeting with the National Park Service to understand their priorities for protection along the St. Croix Scenic Riverway. TPL has been interested in conservation along the nationally significant St. Croix River and has been eager to help implement conservation objectives articulated and supported by both the DNR and the National Park Service.

Near the time of a public meeting DNR hosted in Franconia last spring, at which TPL was a speaker, TPL was contacted by a Franconia resident, who was seeking help in conserving a neighboring property that he knew was for sale. After a number of conversations with the Franconia resident, the National Park Service, and DNR's SNA program, including a number of site visits, TPL understood protection of this property was a high priority of both public agencies. At that point, TPL pursued purchase of the property with the intent that we would make it available to the DNR for purchase from us.

The project involved working through a number of complicated issues including the participation of a number of neighbors of the property with various interests in the outcome, securing access to the property from a third party living in Alaska, and convincing interested parties to forego a subdivision of the property into 4 parcels with 3 housing sites.

The property was eventually purchased by TPL for $105,000 less than the property's fair market value of $535,000, and then donated in full to the DNR. The following summarizes the full funding package for the project:

Partner on Franconia St. Croix Bluffs SNA project	Funding Source	Funding for land acquisition costs	Allocated Acreage	Notes
TPL	Metro Wildlife Corridors Phase II 2005	$420,000	37.7	Lead
TPL	Metro Wildlife Corridors Phase III 2007	$10,000	.9	
	Land Value	$105,000	9.4	

	Donation			
TOTAL		**$535,000**	**48**	

GREEN LAKE – CAMP OJIKETA

Located in a recognized corridor of significance for wildlife, Camp Ojiketa features over 1/2 mile of shoreline on Green Lake and is one of the highest quality natural resources sites in Chisago County because of its oak forests, meadows, wetlands, and lakeshore.

Protection of Camp Ojiketa now ensures that critical habitat remains intact for a variety of wildlife & fish, including a number of Species of Greatest Conservation Need such as Bald Eagles, Canada Warblers, and Common Loons, as well as Barred Owls, Downy Woodpeckers, and Red Fox. The property's shoreline can continue to provide important spawning habitat for walleye, northern pike, black crappie and other fish species found in Green Lake.

The site's location in a high growth area less than 30 miles from downtown St. Paul makes it an excellent place for people to enjoy nature through hiking, biking, fishing, canoeing, and environmental education close to home. (See two maps attached.)

For over 80 years, thousands of young people learned about nature and stewardship at Camp Ojiketa on the beautiful shores of Green Lake in Chisago County. There they truly experienced the "sweetness of life" as the name means in Ojibwa. However, to meet financial obligations and reflect changing priorities, Camp Fire USA announced in 2006 that it was putting the property up for sale.

This news, and subsequent news of a proposed commercial or residential development, caused a group of Camp Fire alumni to organize to save the land. Chisago City and the alumni initially attempted to make the land a park, but were unsuccessful. They then turned to TPL for help structuring and funding a deal that would preserve the land for the benefit of the public.

After many months of negotiations, in early 2008, TPL secured an option good through December 31, 2008 to purchase the land.

During the one-year option period, TPL performed all of the necessary due diligence on the property including having the property appraised, having several environmental assessments conducted, causing Camp Fire to clean up a number of items at the site, conducting title investigation, and working with Camp Fire to cure a number of title issues. TPL led efforts to identify and secure the funds for the purchase of this property, which included applying for public grants, applying for private grants, working with local legislators to seek funding from the legislature, and private fundraising from individuals. TPL also worked with the City to help develop its vision and commitment to the preservation of this site. TPL further worked with the City, camp alumni and local legislators to inform the public about this project, including organizing the support needed for grant-making purposes.

The project received wide publicity in the *Pioneer Press*, the *Star Tribune*, local papers and even the *Wall Street Journal* and *USA Today*. Formal supporters included Wild River Audubon, Chisago Soil and Water Conservation District, Green Lake Association, Chisago City, Chisago County, Ojiketa Preservation Society, DNR Fisheries Division, Sen. Rick Olseen, and Rep. Jeremy Kalin. Ultimately, funding came from a variety of sources as is detailed below.

Camp Ojiketa Acquisition, Chisago City MN

Funding Source**	Partner on Camp Ojiketa project	Amount of funding for land acquisition costs	Allocated Acreage	Recipient of Grant Funds (if applicable)
State Funds				
State Bonding - DNR Non-Metro Regional Park Grant Program	DNR	$1,000,000	16.7	Chisago City
ENTF - Metro Wildlife Corridors Phase IV 2008 (TPL)	TPL	$475,000	7.9	TPL
ENTF Metro Wildlife Corridors Phase III 2007 (TPL)	TPL	$410,000	6.8	TPL
ENTF - Metro Greenways (DNR)	DNR	$100,000	1.7	Chisago City
	Sub Total	**$1,985,000**		
Local Government Funds				
City Bonding	Chisago City	$1,500,000	25.0	
Chisago Lakes Lake Improvement District	TPL	$10,000	0.2	Chisago City
	Sub Total	**$1,510,000**		
Private Funds				
Private Fundraised, received directly by TPL*	TPL	$94,800	1.6	TPL
Private Fundraised, received directly by Chisago City*	TPL & Ojiketa Preservation Society	$65,200	1.1	Chisago City
Camp Fire USA- Negotiated reduction in sales price from appraised value	TPL	$545,000	9.1	NA
	Sub Total	**$705,000**		
	TOTAL	**$4,200,000**	**70.0**	

*Donors were given the option to send donations to either the City or TPL

** Please note that total Environment and Natural Resources Trust Fund funding equals $985,000, total other state (bond) funding is $1M, total non-state public funding is $1.510M, total private funding is $705K

V. TOTAL TRUST FUND PROJECT BUDGET:

All Results: Staff or Contract Services: $0
All Results: Equipment: $0
All Results: Development: $0
All Results: Acquisition, including easements: $ 420,000 (capital costs)
TOTAL TRUST FUND PROJECT BUDGET: $ 420,000

Explanation of Capital Expenditures Greater Than $3,500: N/A

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: TPL coordinates its work with other Metro Conservation Corridor partners (See Table A). In addition, project partners & cooperators included private landowners, local governments, regional agencies, state agencies, water-related agencies, federal agencies, and private nonprofit organizations and citizen groups (such as the Ojiketa Preservation Society). The Trust for Public Land transferred fee title to Chisago City and to the DNR. TPL contracted with entities providing real estate transaction services such as environmental consultants, appraisers and title companies.

B. Other Funds Spent during the Project Period: Local, regional, federal, and state units of government; non-profit organizations; and private donations were secured and spent. Please see funding charts in Section IV for specific sources and amounts. The Trust for Public Land leveraged **$2,320,000** in non-state funding (including $1,510,000 in non-state public funds and $810,000 in private land or cash donated) for the acquisitions included in this project period. $1,000,000 in state bonding dollars and $995,000 in other ENRTF funds were also used toward these land acquisitions.

C. Past Spending: From 2002 until Phase 1 initiation in July 2003, TPL provided a significant in-kind contribution to development of the project, including shaping the initial proposal, facilitating partner and stakeholder communications, arranging stakeholder meetings held in October 2002, printing maps and producing project descriptions for stakeholder participation, organizing proposed focus area meetings held in March 2003, soliciting land acquisition project proposals, and laying the groundwork for project initiation in July 2003. Total in-kind contribution by July 2003 is equivalent to ¼ FTE. TPL also invested land acquisition capital of $50,000 to help the DNR purchase land in Dec. 2002 in the Lower Mississippi focus area for the new Pine Bend Bluffs Scientific and Natural Area, where restoration funds from other partners for this project are being invested.

For Phases 1 – 3, the Trust for Public Land provided a significant in-kind contribution to development of the project, including serving on the Executive Committee, helping shape the initial proposals, contributing to partner and stakeholder communications, participating in stakeholder meetings held in June 2004 and September - October 2004, helping organize stakeholder meetings in November 2006 in Wright and Sherburne counties, soliciting land acquisition project proposals, and helping lay the groundwork for project initiation in July 2007. Total in-kind contribution from July 2003 to date is equivalent to 1/8 FTE.

During the Phase 1 project term (July 2003 – June 2006), the Trust for Public Land (TPL) protected and linked 40 acres of valuable, high quality habitat in the Twin Cities Metropolitan Region to meet habitat connectivity goals in Focus Areas 2 (Carlos Avery) – 144 acres at Gordie Mikkelson WMA; 6 (Lower Mississippi) – 30 acres at Eagan Core Greenway and Patrick Eagan Park – Caponi Art Park, and 7 (Vermillion) – 475 acres at Vermillion River AMA/WMA. The Trust for Public Land leveraged approximately $3,845,000 from local, federal and private funds for habitat protection work, compared to a target total of $168,000. These funds would not have been available for use in Minnesota but for this Metropolitan Area Wildlife Corridors Phase I project. In addition, TPL covered and did not seek reimbursement for transaction costs and the substantial staff, phone, travel and office expenses associated with the land transaction work as well as all costs associated with Metropolitan Area Wildlife Corridors Phase I project partnership.

The Trust for Public Land provided technical assistance and private funding to add 17 acres to the Pine Bend Bluffs Scientific and Natural Area in the Lower Mississippi focus area, in partnership with DNR Scientific and Natural Area Program, Metro Greenways, and Friends of the Mississippi River.

In Phase 2 to February 2007, the Trust for Public Land leveraged $303,000 in Wildlife Management Area bond funds to protect +/- 670 acres on East Rush Lake in Chisago County, to be conveyed to the Department of Natural Resources Division of Fisheries and Wildlife for protection as a Wildlife Management Area and Aquatic Management Area.

D. Time: 2 years, until June 30, 2009.

VII. DISSEMINATION:

TPL posted project information on the TPL website, www.tpl.org, in addition to DNR's posting at its web site, and the Camp Ojiketa Preservation Society posting on its website. TPL included project descriptions in its newsletters, which are mailed to about 6,600 people, and worked with project partners to create and disseminate press releases for each of the projects. Articles were published in the *South Washington County Bulletin*, *North Branch Post Review*, the *Pioneer Press*, the *Star Tribune*, the *Wall Street Journal* and *USA Today*. TPL also sent an e-mail announcement to the Minnesota "TPL Near You" mailing list of approximately 1,200 email addresses, and provided information to Embrace Open Space for inclusion in its monthly e-newsletter (approximately 800 recipients). TPL worked with a nationally recognized photographer to take photographs at Franconia. Land acquired has been or will be posted. Sample media materials are attached.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports were submitted twice a year, with an additional amendment request in November 2008, and with this report serving as the final work program report.

Attachment A: Budget Detail for 2007 Metro Corridors Project **Date: September 11, 2009**
Title: Metropolitan Area Wildlife Corridors Phase III – The Trust for Public Land Critical Lands Protection Program (3.1)

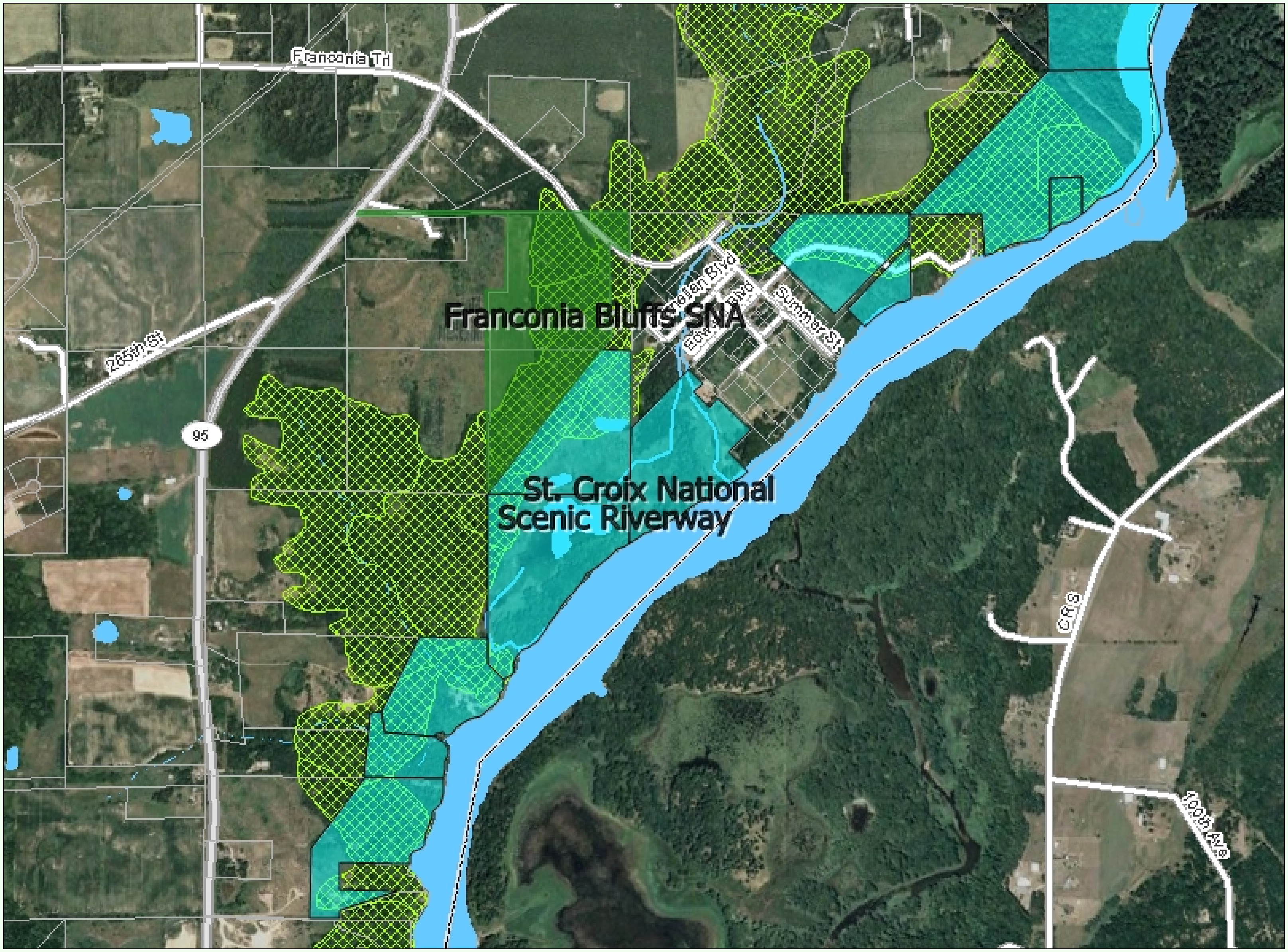
Partner Project Manager Name: **Becca Nash**

LCMR Dollars: **$420,000**

BUDGET ITEM	Amount Budgeted ($)	Amount Spent ($)	Balance ($)	Comments
ACQUISITION				
Land acquisition *(fee title & conservation easement)*	**$420,000**	**$420,000**	**$0**	**To protect 48 acres at Franconia St. Croix Bluffs/Franconia Bluffs SNA, a project that also used the balance of TPL's Phase II 2005 MeCC funding; and to protect 70 acres on Green Lake/ Camp Ojiketa, a project that also used the balance of TPL's Phase IV 2008 MeCC funding.**
TOTAL LCMR Funding	**$420,000**	**$420,000**	**$0**	

Franconia Bluffs Scientific and Natural Area

THE TRUST for PUBLIC LAND
CONSERVING LAND FOR PEOPLE



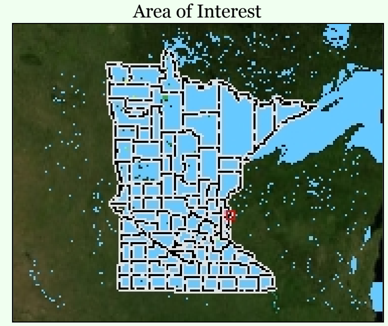
Legend

- County Boundary
- Chisago County Parcels
- Transportation (18k to 0)
  - Interstate
  - Highway
  - Major Road
  - Local Road
  - Ramp
- Major Rivers
- Streams
- Intermittent Streams
- Major Waterbodies
- All Waterbodies
- MCBS Native Plant Communiti
- State Forests
- Wildlife Management Areas
- Scientific and Natural Areas
- NWR-NFWS
- USA Prime Imagery

0 0.30 0.6 Miles

Map Notes: Showing MCBS Native Plant Communities

Area of Interest

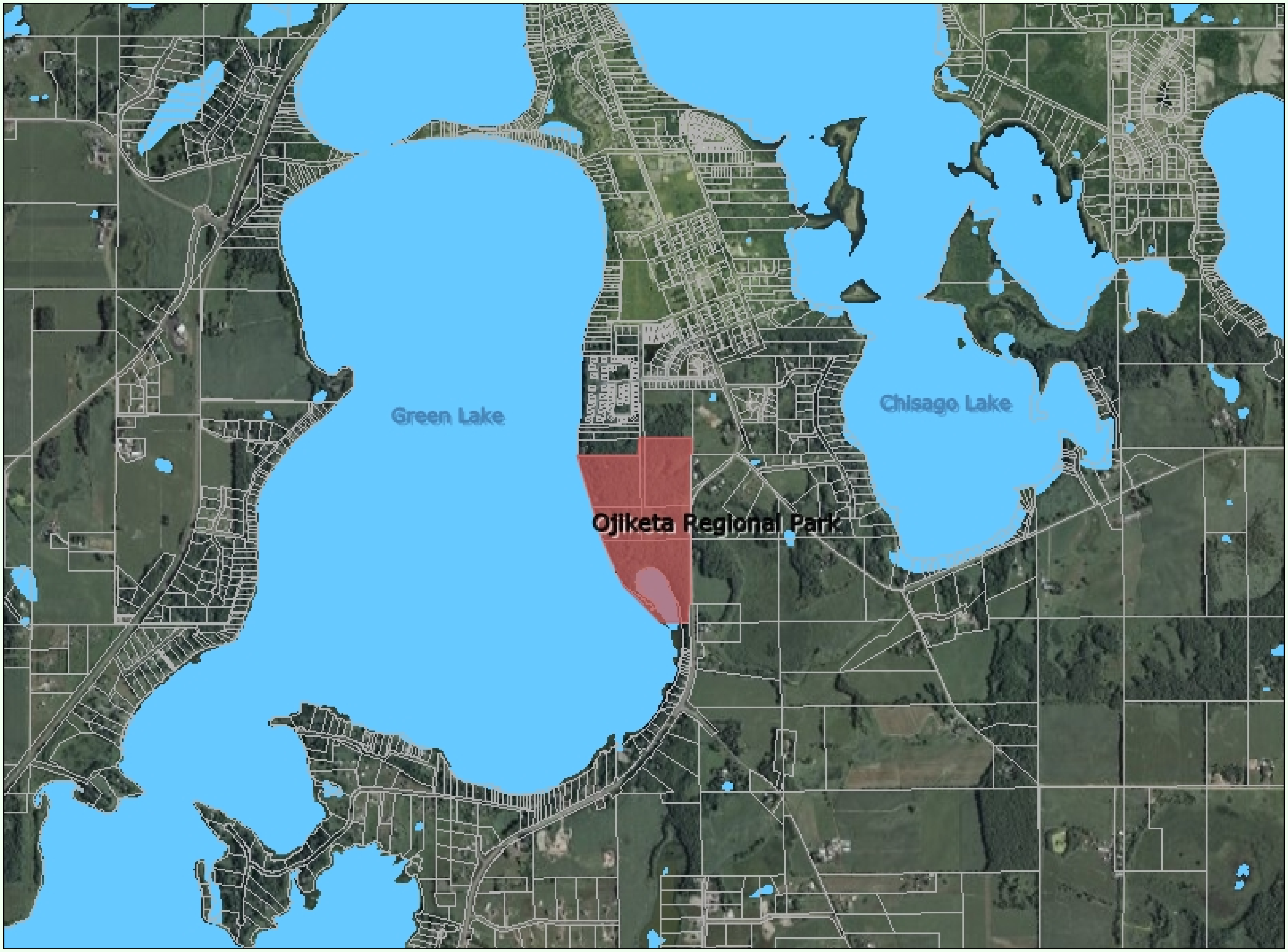


Information on this map is provided for purposes of discussion and visualization only.

This map was created on: December 16, 2009

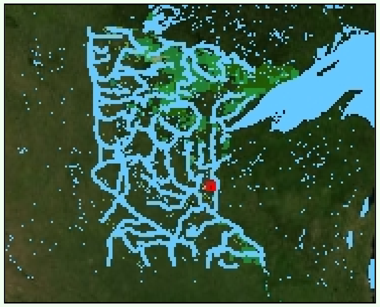
Ojiketa Regional Park

THE TRUST for PUBLIC LAND
CONSERVING LAND FOR PEOPLE



Legend
- Chisago County Parcels
- Major Rivers
- Major Waterbodies
- All Waterbodies
- Metro Parks
- State Forests
- Wildlife Management Areas
- Scientific and Natural Areas
- NWR-NFWS
- National Forests

Area of Interest



0 0.50 1.0 Miles

Map Notes: Est. December 17, 2008

This map was created on: August 3, 2009

Information on this map is provided for purposes of discussion and visualization only.

2007 Project Abstract
For the Period Ending June 30, 2009

TITLE:	Metro Conservation Corridors – Phase III Protecting Significant Habitat by Acquiring Conservation Easements - 3.2
PROJECT MANAGER:	Jane Prohaska, President
ORGANIZATION:	Minnesota Land Trust
ADDRESS:	2356 University Avenue West, Suite 240 St. Paul, MN 55114
WEB SITE ADDRESS:	www.mnland.org
FUND:	Environmental and Natural Resources Trust Fund
LEGAL CITATION:	Minnesota Laws 2007, Chapter 30, Section 2, Subdivision 4(c)

APPROPRIATION AMOUNT: $134,000

OVERALL PROJECT OUTCOME AND RESULTS

During the third phase of the Metro Corridors project, the Minnesota Land Trust continued to work with landowners throughout the greater metropolitan area to permanently protect lands that are key components of Minnesota's remaining natural areas in the region. Contact was initiated with approximately 39 landowners, and 9 perpetual conservation easements were completed. Collectively, these conservation easements protect 519 acres of land and more than 15,000 feet of shoreline. Two easements were purchased, both at a bargain price. The remaining 7 easements were donated. The general locations of our completed projects are identified on the attached map.

These conservation easements have a known value of $2,768,500, with a known donated value of $2,399,500. The cost to the State of Minnesota under this grant to complete these projects was just over $976 per acre (other State funds came from the Metro Greenways program to purchase two easements).

Additionally, the Land Trust prepared baseline property reports for each easement, detailing the condition of the property for future monitoring and enforcement. To fund this required perpetual obligation, the Land Trust dedicated funds to its segregated Stewardship and Enforcement Fund for several completed projects. For these projects, we estimated the anticipated annual expenses of each project and the investment needed in order to generate annual income sufficient to cover these expenses in perpetuity – all in accordance with our internal policies and procedures as approved by LCCMR. We also have provided LCCMR with a letter documenting our commitment to protect the conservation values of these projects in perpetuity and will report to LCCMR annually on the status of the Stewardship and Enforcement Fund and the easements acquired with funds from this grant.

The Land Trust's work on this project demonstrates the cost effectiveness of working with conservation easements to protect natural and scenic resources within developed and developing areas, as the cost to the State was well below the cost to purchase land in the Twin Cities region. This grant continued to generate interest among landowners, and therefore, ongoing funding will be important to sustained success. Additionally, our experiences during this phase of the grant continue to indicate that funds to purchase easements will be necessary in the future if work becomes more targeted, selective, and focused on building complexes of protected land.

PROJECT RESULTS USE AND DISSEMINATION

The Land Trust continued to gain more experience with conservation easements, easement management, and issues unique to protecting land in a metropolitan area. This experience and information was shared with our partner organizations, other easement holders, local communities, as well as policy makers. The Land Trust also disseminated information about the specific land protection projects completed under this grant though our newsletter, annual report, web site, and press releases.

Trust Fund 2007 Work Program Final Report

Date of Report: June 15, 2009
Trust Fund 2007 Work Program Final Report

I. PROJECT TITLE: Metro Conservation Corridors - Phase lll
Acquire Significant Habitat by Acquiring Conservation Easements (3.2)

Project Manager: Jane Prohaska, President and Executive Director
Affiliation: Minnesota Land Trust
Mailing Address: 2356 University Avenue West, Suite 240
City / State / Zip : St. Paul, MN 55114
Telephone Number: 651-647-9590
E-mail Address: jprohaska@mnland.org
FAX Number: 651-647-9769
Web Page address: www.mnland.org

Location: Within mapped corridors (shown on the attached map) in the counties of Anoka, Carver, Chisago, Dakota, Goodhue, Hennepin, Isanti, LeSueur, Nicollet, Ramsey, Rice, Scott, Sherburne, Sibley, Washington and Wright.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	134,000
	Minus Amount Spent:	**$**	134,000
	Equal Balance:	**$**	0

Legal Citation: ML 2007, Chapter 30, Section 2, Subd. 4(c)

Appropriation Language: 4 (c) Metro Conservation Corridors- Phase III $2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated: (1) as an outdoor recreation unit under

Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II. and III. FINAL PROJECT SUMMARY:
During the third phase of the Metro Corridors project, the Minnesota Land Trust continued to work with landowners throughout the greater metropolitan area to permanently protect lands that are key components of Minnesota's remaining natural areas in the region. Contact was initiated with approximately 39 landowners, and 9 perpetual conservation easements were completed. Collectively, these conservation easements protect 519 acres of land and more than 15,000 feet of shoreline. Two easements were purchased, both at a bargain price. The remaining 7 easements were donated. The general locations of our completed projects are identified on the attached map.

These conservation easements have a known value of $2,768,500, with a known donated value of $2,399,500. The cost to the State of Minnesota under this grant to complete these projects was just over $976 per acre (other State funds came from the Metro Greenways program to purchase two easements).

Additionally, the Land Trust prepared baseline property reports for each easement, detailing the condition of the property for future monitoring and enforcement. To fund this required perpetual obligation, the Land Trust dedicated funds to its segregated Stewardship and Enforcement Fund for several completed projects. For these projects, we estimated the anticipated annual expenses of each project and the investment needed in order to generate annual income sufficient to cover these expenses in perpetuity – all in accordance with our internal policies and procedures as approved by LCCMR. We also have provided LCCMR with a letter documenting our commitment to protect the conservation values of these projects in perpetuity and will report to LCCMR annually on the status of the Stewardship and Enforcement Fund and the easements acquired with funds from this grant.

The Land Trust's work on this project demonstrates the cost effectiveness of working with conservation easements to protect natural and scenic resources within developed and developing areas, as the cost to the State was well below the cost to purchase land in the Twin Cities region. This grant continued to generate interest among landowners, and therefore, ongoing funding will be important to sustained success. Additionally, our experiences during this phase of the grant continue to indicate that funds to purchase easements will be necessary in the future if work becomes more targeted, selective, and focused on building complexes of protected land.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Protect Significant Habitat by Acquiring Conservation Easements – 3.2

Description:
The Minnesota Land Trust protected critical habitat in several of the focus areas by 1) identifying and contacting interested landowners; 2) negotiating and completing 3-5 permanent conservation easements on up to 125 acres of land; and 3) dedicating funds for the perpetual monitoring, management and enforcement of the easements.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$** 134,000
	Amount Spent:	**$** 134,000
	Balance:	**$** 0

Deliverable

1. Identify and contact landowners

2. Negotiate, draft, and complete 3-5 easements, including completion of baseline documentation

3. Dedicate funds for easement stewardship

Final Completion Date: June 30, 2009

Final Report Summary:
The Land Trust is pleased that we were able to far exceed our project goals by completing 9 conservation easements protecting 519 acres of land and more than 15,000 feet of shoreline. Four of the projects were located in the Northwest Area, four in the Central Area, and one in the East Area. No projects were completed in the Southwest or Southeast areas.

Our average parcel size was approximately 57 acres for parcels completed under this phase of this grant, which tracks similar to our accomplishments under the previous phase. It is important to note, however, that this average size of Metro projects is still half the size of average Minnesota Land Trust projects, meaning that it continues to be more expensive to protect land in the Metro area.

As noted in our Phase II Final Report, we continue to encounter a greater number of landowners who cannot afford to donate the value of the development rights they are willing to give up. Under this phase of the grant, two of our projects were bargain purchases, bringing up the cost to the State of Minnesota to just over $976 per acre (compared to $800 in the prior phase).

This means that while conservation easements remain an incredibly cost effective land protection tool, it also is increasingly important to have acquisition funding available to protect select and targeted sites.

All of the projects completed by the Land Trust under this project are discussed in detail below and also are summarized on the attached map.

Descriptions and Results by Areas:

Northwest Area: Wright, Sherburne, Isanti and Anoka Counties

Acres protected: 245
Easements completed: 4

Project: Rum River
Description: This 53-acre property is located along the Rum River in Isanti County. The property is relatively flat to gently rolling, with the exception of some steeper slopes near the Rum River. The property primarily contains a mixed hardwood forest, with white oak and maple as the two dominant tree types. This forested area on the property is contiguous with DNR-owned land to the south. There are several wetlands and some natural springs on the property. Additionally, the Marget Lake Wildlife Management Area is located about 1/10 of a mile north of the Hassel property.

The value of this easement is unknown. $12,000 of LCCMR funds were used to cover stewardship on this project.

Project: Rum River
Description: This 32-acre project is located on the Rum River in Isanti County. The property is primarily forested with oaks, some mixed hardwoods, and a conifer planting. The Rum River flows along the eastern boundary of the property for about 1,500 feet, and there is a large pond on the property. A DNR Stewardship Plan identifies this property as a major link in a riparian buffer strip that borders the Rum River and serves as a wildlife corridor. The Minnesota Land Trust currently holds several easements on the Rum River.

The value of this easement is unknown. $9,500 of LCCMR funds were used to cover stewardship on this project.

Project: Stanchfield Creek
Description: This project in Isanti County adds 20 acres of land to previously protected parcels and consolidates the easements into one easement covering all 467 acres of land. The 20-acre addition is composed of rolling terrain primarily covered with forest and wetlands. Stanchfield Creek runs through the middle of the property for nearly ¼ mile, and there are some natural springs in the vicinity of the creek. The Minnesota County Biological Survey has identified the property as a site of moderate biodiversity significance due to its large expanse of wetland, including floodplain forest, hardwood swamp, and emergent marsh. The amendment to the easement also prohibits any division of the property and eliminates a building right reserved in one of the original easements.

The value of this easement is unknown. $9,500 of LCCMR funds were used to cover stewardship on this project.

Project: Beckman Farm
Description: This 140-acre property in Isanti County consists of restored prairie, upland coniferous forest, wetland, and an unnamed pond. The prairie and forest are key habitats for a variety of species in greatest conservation need, and the wetlands and pond provide wildlife habitat as well as water filtration benefits. The Beckman farm plays a key role in connecting two extensive sites of biodiversity significance in this part of Isanti County, as noted by the Minnesota County Biological Survey. The property is located near several other conservation easements held by the Minnesota Land Trust.

The value of this easement is $475,000. The Land Trust purchased the easement for $315,000 using Metro Greenways grant dollars. $15,000 of LCCMR funds were used to cover stewardship on this project. Additional detail is provided in the attached Summary of Purchased Easements.

Central Area: Hennepin and Ramsey Counties
Acres protected: 134
Easements completed: 4

Project: Gale Woods
Description: This project in Hennepin County consists of a 39-acre peninsula on the south shore of Whale Tail Lake. It lies directly west and across the lake from Gale Woods Park, which was protected by the same landowners in 2000 and is now a unit of the Three Rivers Park District. The protected property is primarily forested with maple-basswood and includes a large wetland area on the tip of the peninsula. The property also has over 6,500 feet of shoreline on Whale Tail Lake.

The donated value of this easement is $1,500,000.

Project: Henry’s Woods
Description: This 39-acre property in the Town of Hassan consists mostly of maple-basswood forest. The parcel has been identified by the Minnesota County Biological Survey as one of the highest quality remants of the "Big Woods" in the state. The property provides habitat for a variety of animals and plants, including American ginseng, a state species of special concern. The property also features a creek and wetlands scattered throughout the woods. Henry's Woods is an important piece of the Township's park and open space network. A future trail is planned to connect the Henry's Woods property with nearby Elm Creek Park Reserve.

The value of this easement is unknown.

Project: Schendel Lake

Description: This 43-acre property in Hennepin County is a mix of wetlands, grasslands and forest with some small wildlife food plots. The protected land includes 1,368 feet of undeveloped shoreline along an intermittent stream that flows through the property. The wetlands on the property adjacent to Schendel Lake help to maintain the water quality and ecological integrity of the lake.

The value of this easement is unknown. $8,000 of LCCMR funds were used to cover stewardship on this project.

Project: Rabe Woods
Description: This 13-acre property in Hennepin County is located in a generally rural residential/agricultural setting near the town of Corcoran. This property has been mapped and identified by Hennepin County as part of an important county-wide open space and habitat corridor. The wooded, undeveloped, and natural character of the property provides habitat to a variety of plants and animals common to maple-basswood forests and provides continuity with other forested land to the east.

The donated value of this easement is $204,500. $6,000 of LCCMR funds were used to cover stewardship on this project.

East Area: Chisago and Washington Counties
Acres protected: 140
Easements completed: 1

Project: Wild River State Park
Description: This 140-acre property in Chisago County borders Wild River State Park. The protected property features hardwood forested bluffs overlooking the St. Croix River Valley. The high quality forest, seeps, and springs on the protected property provide excellent habitat for resident and migratory wildlife. The property is also a component of the Chisago County Green Corridor, a locally significant natural habitat corridor project area as identified by Chisago County. The property represents the seventh project completed at the Wild River State Park site.

The value of this easement is $589,000. The Land Trust purchased the easement for $54,000 using Metro Greenways grant dollars. Additional detail is provided in the attached Summary of Purchased Easements.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $44,589 to cover a portion of the salaries and benefits of staff working on projects funded under this grant, including approximately .50 FTE conservation program staff and .15 FTE conservation, legal and other support staff.

Acquisition, including easements: $ 30,411 to acquire 9 conservation easements held by the Minnesota Land Trust. This includes transaction costs such as travel, appraisals, surveys, title work, and mapping to acquire donated easements or for easements purchased with funds provided by another partner or through another source.

Stewardship: $59,000 to be dedicated to the Stewardship and Enforcement Fund. Actual amounts committed for stewardship were calculated on a project-by-project basis depending on the number and nature of specific projects and the availability of other funds. We did not need to use this grant to cover all stewardship costs for completed projects due to landowner and other contributions.

TOTAL TRUST FUND PROJECT BUDGET: $ 134,000

Explanation of Capital Expenditures Greater Than $3,500: N/A

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: Metro Conservation Corridor partners (please see overall report for list of project partners) and private landowners, local governments, regional, state and federal agencies, nonprofit organizations and citizen groups.

B. Other Funds Spent during the Project Period: By working to acquire donated conservation easements, the Minnesota Land Trust was be able to protect lands at a fraction of what it would cost to purchase comparable lands in fee. This funding leveraged millions of dollars of value in easements on lands protected through this grant. The known donated value of easements completed this phase is $2,399,500. The DNR Metro Greenways program provided $372,925 to purchase two easements, both at bargain prices. Additional funds were spent by the Minnesota Land Trust to cover costs associated with the project not covered by the grant.

C. Past Spending: The Minnesota Land Trust has received the following from past Metro Corridors grants: $ 230,000 in 2003 and $ 230,000 in 2005.

D. Time: July 1, 2007 - June 30, 2009. This is a continuation of the Minnesota Land Trust's exisiting Metro Conservation Corridors Partnership project. Components were designed to be overlapping so that activities could continue seamlessly. Some of the projects closed under this phase were initiated under previous phases. Similarly, landowner contacts made under this Phase III will not result in completed projects until a future phase.

VII. DISSEMINATION: The Land Trust continued to gain more experience with conservation easements, easement management, and issues unique to protecting land in a metropolitan area. This experience and information was shared with our partner organizations, other easement holders, local communities, as well as policy makers. The Land Trust also disseminated information about the specific land protection projects completed under this grant though our newsletter, annual report, web site, and press releases.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports were submitted February 1st and August 1st of each year, starting with February 1, 2008. This is the final work program report.

IX. RESEARCH PROJECTS: N/A

Attachment A: Budget Detail for 2007 Projects

Project Title: Metro Conservation Corridors Phase III: Acquire Significant Habitat by Acquiring Conservation Easements (3.2)

Project Manager Name: Jane Prohaska

Trust Fund Appropriation: $ 134,000

	Result 1 Final Adjusted Budget:	**Amount Spent** *as of 6/1/09*	**Balance** *as of 6/1/09*
BUDGET ITEM			
PERSONNEL: wages and benefits (Includes approximately 0.5 FTE conservation director or land protection staff; 0.05	$ 44,589	$ 44,589	$ -
Land rights acquisition *(less than fee)*			
Land transaction costs (Costs associated with acquiring donated or purchased conservation easements including mapping, surveys, title work, appraisals, environmental assessments, recording fees, etc.)	$28,657	$ 28,657	$ -
Travel expenses in Minnesota (Mileage and related travel expenses)	$1,754	$ 1,754	$ -
Easement Stewardship (Funds dedicated to perpetually monitoring, managing and enforcing acquired easments.)	$59,000	$ 59,000	$ -
COLUMN TOTAL	$134,000	$ 134,000	$ -

Minnesota Land Trust: Metro Conservation Corridors – 2007 (Phase 3)
Summary of Purchased Easements

Project	**Acres**	**Funding Type**	**Funds Use**	**Funding Amount**
Wild River State Park Chisago County	140	ENTF – 2005 Metro Greenways	Purchase price of conservation easement	$54,000
		Landowner donation	Donation of easement value	$535,000
		Landowner donation	Stewardship	$10,000
Beckman Farm Isanti County	140	ENTF - 2007 Metro Greenways	Purchase price of conservation easement	$315,000
		Landowner donation	Donation of easement value	$160,000
		ENTF – 2007 Minnesota Land Trust	Stewardship	$15,000

In addition to the expenses listed above, staff time and professional services expenses covering closing costs, title review, etc. were incurred and covered by the Land Trust's 2007 Metro Conservation Corridors allocation. The Land Trust does not allocate staff time or professional services expenses to specific conservation projects.

Minnesota Land Trust Completed Projects
LCCMR Metro Corridors Phase III

Beckman Farm: This 140-acre property in Isanti County consists of restored prairie, upland coniferous forest, wetland, and an unnamed pond. The prairie and forest are key habitats for a variety of species in greatest conservation need, and the wetlands and pond provide wildlife habitat and water filtration benefits.

Gale Woods: This project in Hennepin County consists of a 39-acre peninsula on the south shore of Whale Tail Lake, encompassing more than 6,500 feet of shoreline along the lake. The property lies directly across the lake from Gale Woods Park.

Henry's Woods: This 39-acre property in the Town of Hassan consists primarily of maple-basswood forest and has been identified by the Minnesota County Biological Survey as a high quality remnant of Big Woods. The property provides habitat for a variety of animals and plants, including American ginseng, a state species of special concern. Henry's Woods also is an important piece of the Township's park and open space network.

Rabe Woods: This 13-acre property in Hennepin County is a component of a larger county-wide open-space and habitat corridor. The property consists of mature maple-basswood forest and a small area of wetland. It also includes approximately 1,016 feet of shoreline along an unnamed creek.

Rum River: This 53-acre property in Isanti County is situated along the Rum River and feature approximately 1,800 feet of river shoreline. The property primarily contains a mixed hardwood forest, with white oak and maple the two dominant tree types. This forested area on the property is contiguous with DNR-owned land to the south. Additionally, there are several wetlands and some natural springs on the property.

Rum River: This 32-acre property in Isanti County is primarily forested with oaks, some mixed hardwoods, and conifers. The Rum River flows along the eastern boundary of the property for approximately 1,500 feet. This project builds upon prior work done by the Minnesota Land Trust at the Rum River site.

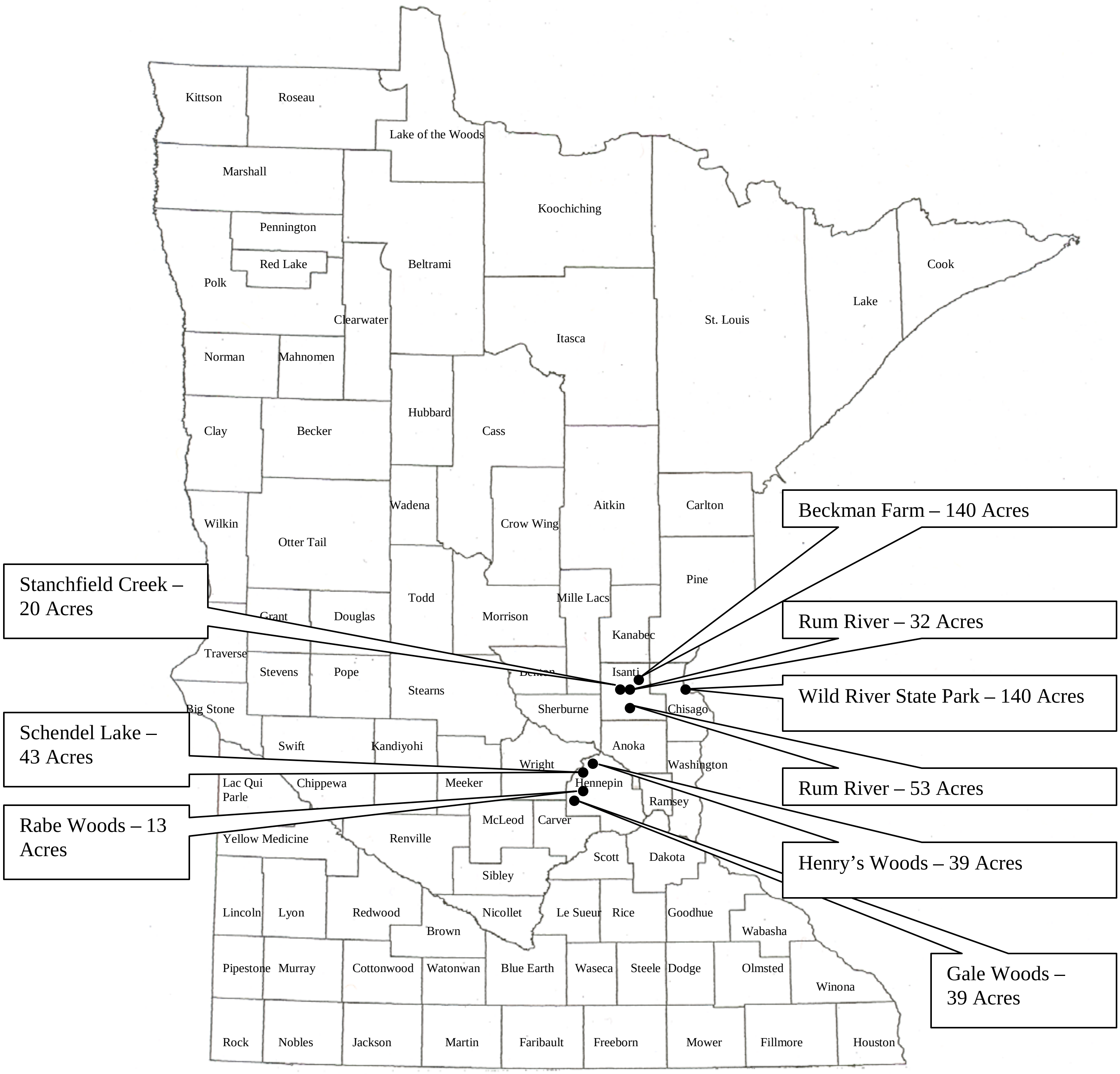
Schendel Lake: This 43-acre property in Hennepin County is a mix of wetlands, grasslands, and forest. The property protects 1,368 feet of shoreline along an intermittent stream that flows through the property as well as wetlands adjacent to Schendel Lake that provide important habitat and help maintain the ecological quality of the lake. This property also lies within a corridor that Hennepin County has prioritized for protection.

Stanchfield Creek: This project in Isanti County adds 20 acres of rolling forest and wetlands to two existing easements, protecting in total, 467 acres of land. Stanchfield Creek runs through the middle of the property for nearly ¼ mile, and there are some natural springs in the vicinity of the creek.

Wild River State Park: This 140-acre property in Chisago County features forested bluffs overlooking the St. Croix River Valley. The property's high quality forest, seeps, and springs provide important habitat for resident and migratory wildlife. The property also lies adjacent to Wild River State Park, thereby adding to a larger continuous block of habitat and helping to buffer the park from surrounding development.

Minnesota Land Trust

Completed Projects
LCCMR Metro Corridors Phase III



MINNESOTA LAND TRUST

June 2009

2007 Project Abstract
For the Period Ending June 30, 2009

TITLE: Metro Conservation Corridors Phase III (3.3) – Fee Acquisition for Minnesota Valley National Wildlife Refuge
PROJECT MANAGER: Deborah Loon
ORGANIZATION: Minnesota Valley National Wildlife Refuge Trust, Inc.
ADDRESS: 2312 Seabury Avenue, Minneapolis, MN 55406
WEB SITE ADDRESS: www.mnvalleytrust.org
FUND: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Ch. 30, Sec. 2, Subd. 4c (3.3)

APPROPRIATION AMOUNT: $210,000

Overall Project Outcome and Results

The Minnesota Valley Trust acquired fee title to 69.13 acres of significant habitat in the Minnesota River Valley in Jessenland Township of Sibley County. Of that acreage, the grant from the Environment and Natural Resources Trust Fund covered 49.1 acres and MN Valley Trust (other non-state funds) covered 20 acres.

In addition, the Minnesota Valley Trust acquired fee title to 80 acres of significant habitat in the Minnesota River Valley in Faxon Township of Sibley County, completing and exceeding the match commitment of this work program.

After restoration of these parcels, they will be donated to the US Fish and Wildlife Service for perpetual management as part of the Jessenland Unit of the Minnesota Valley National Wildlife Refuge.

Project Results Use and Dissemination

The Minnesota Valley Trust will publicize the completion of this acquisition and plans for the lands through its website and news releases to the local media. After restoration is completed, the land will be donated to the Minnesota Valley National Wildlife Refuge and Wetland Management District. All funding partners will be acknowledged on Refuge kiosks, including the Environment and Natural Resources Trust Fund, as recommended by the Legislative Commission on Minnesota Resources.

Trust Fund 2007 Work Program Final Report

Date of Report: June 19, 2008
Trust Fund 2007 Work Program Final Report
Project Completion Date: May 21, 2008

I. PROJECT TITLE: Metro Conservation Corridors Phase lll - Minnesota Valley National Wildlife Refuge Trust – 3.3

Project Manager: Deborah Loon
Affiliation: Minnesota Valley National Wildlife Refuge Trust, Inc.
Mailing Address: 2312 Seabury Avenue
City / State / Zip: Minneapolis, MN 55406
Telephone Number: 612-801-1935 (mobile)
E-mail Address: DebLoon@comcast.net
FAX Number: 612-728-0700
Web Page address: www.mnvalleytrust.org

Location: Within project area 10 of the Metro Conservation Corridors, specifically Carver, LeSueur, Scott and/or Sibley Counties.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$ 210,000**
	Minus Amount Spent:	**$ 210,000**
	Equal Balance:	**$ 0**

Legal Citation: ML 2007, Chapter 30, Section 2, Subdivision 4c (3.3).

Appropriation Language: (c) Metro Conservation Corridors- Phase III $2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated: (1) as an outdoor recreation unit under Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II. and III. FINAL PROJECT SUMMARY: The Minnesota Valley Trust acquired fee title to 69.13 acres of significant habitat in the Minnesota River Valley in Jessenland Township of Sibley County. Of that acreage, the grant from the Environment and Natural Resources Trust Fund covered 49.1 acres and MN Valley Trust (other non-state funds) covered 20 acres.

In addition, the Minnesota Valley Trust acquired fee title to 80 acres of significant habitat in the Minnesota River Valley in Faxon Township of Sibley County, completing and exceeding the match commitment of this work program.

After restoration of these parcels, they will be donated to the US Fish and Wildlife Service for perpetual management as part of the Jessenland Unit of the Minnesota Valley National Wildlife Refuge.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Acquire significant habitat.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$ 210,000**
	Amount Spent:	**$ 210,000**
	Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. Acquire 42 acres	**June 30, 2009**	**$ 210,000**	**Complete**

Final Completion Date: 5/21/2008

Final Report Status: The Minnesota Valley Trust acquired fee title to 69.13 acres of significant habitat in the Minnesota River Valley in Jessenland Township of Sibley County. Of that acreage, the Trust Fund grant covered 49.1 acres and MN Valley Trust (other non-state funds) covered 20 acres.

In addition, the Minnesota Valley Tust acquired fee title to 80 acres of significant habitat in the Minnesota River Valley in Faxon Township of Sibley County, completing and exceeding the match commitment of this work program.

After restoration of these parcels, they will be donated to the US Fish and Wildlife Service for perpetual management as part of the Jessenland Unit of the Minnesota Valley National Wildlife Refuge.

V. TOTAL TRUST FUND PROJECT BUDGET: $ 210,000

Staff or Contract Services: $ 0
Equipment: $ 0
Development: $ 0 (improvement to land or building)
Restoration: $ 0 (how many acres)
Acquisition, including easements: $ 210,000 – 49.1 acres were acquired with Trust Fund grant by the Minnesota Valley National Wildlife Refuge Trust, Inc. Another 20 acres of this parcel and 80 acres of another parcel were acquired by the MN Valley Trust to complete the match commitment (total nonprofit, non-state funds of $375,519).

TOTAL TRUST FUND PROJECT BUDGET: $ 210,000

Explanation of Capital Expenditures Greater Than $3,500:

VI. OTHER FUNDS & PARTNERS: The Minnesota Valley National Wildlife Refuge Trust, Inc. spent $375,719 to complete this acquisition and the additional acquisition of 80 acres for the match.

A. Project Partners: US Fish and Wildlife Service, Metro Conservation Corridors partners

B. Other Funds Spent during the Project Period: $375,719

C. Past Spending: None on this specific project.

D. Time: 2 years. No additional time beyond June 30, 2009 will be needed.

VII. DISSEMINATION: As projects are completed, the Minnesota Valley Trust will announce its accomplishments through press releases and the Trust's newsletter.

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than February 8, 2008, October 10, 2008 and February 1, 2009. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR.

IX. RESEARCH PROJECTS: na

Attachment A: Budget Detail for 2007 Projects

Project Title: Metro Conservation Corridors Phase lll - Minnesota Valley National Wildlife Refuge Trust - 3.3

Project Manager Name: Deborah Loon, Minnesota Valley National Wildlife Refuge Trust.

Trust Fund Appropriation: $ 210,000

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 2 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 3 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Acquire 42 acres of significant habitat in project area 10 of Metro Conservation Corridors.			*na*			*na*				
BUDGET ITEM			0			0			0	0	0
Land acquisition	210,000	210,000	0			0			0	210,000	0
COLUMN TOTAL	**$210,000**	**$210,000**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$210,000**	**$0**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Metropolitan Area Wildlife Corridors – Phase III: DNR Fish & Wildlife Acquisition & Development (3.5)
PROJECT MANAGER: Mike Halverson
AFFILIATION: Minnesota Department of Natural Resources – Division of Fish & Wildlife
MAILING ADDRESS: Box 20, 500 Lafayette Road
CITY/STATE/ZIP: St. Paul, MN 55155
PHONE: (651) 259-5209
FAX: (651) 297-4916
E-MAIL: Mike.Halverson@dnr.state.mn.us
WEBSITE: *www.dnr.state.mn.us*
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 4C.

APPROPRIATION AMOUNT: $172,000

Overall Project Outcome and Results

The project goal was for Fish & Wildlife to acquire Aquatic Management Areas (AMAs) adjacent to lakes and streams to ensure the protection of critical riparian habitat, angler access, and management access. Specific goals were to secure fee title or permanent easements on approximately 32 acres and/or 0.4 miles of lakeshore and stream shoreline including sensitive watershed, riparian, or headwaters areas.

This project resulted in the completion of two fee title acquisition parcels on the Vermillion River in Dakota County. Totals for the two acquisitions equal 46.9 acres, including 0.89 total miles of shoreline. One of the parcels on the Vermillion River was also paid for with Phase II acquisition dollars, resulting in both acres and miles being divided proportionately between the two phases. As part of this project, Environmental and Natural Resources Trust dollars ($160,000) directly acquired approximately 33.2 acres of the total, including 0.62 miles of stream. Other state dollars ($60,250) acquired approximately 13.7 acres, including 0.27 miles of stream.

Vermillion River, Parcel 2, Dakota County

Trust Acres	Trust Miles	Trust $	Other St. $	Other $	Other St. Acres	Other St. Miles	Other Acres	Other Miles	Total Acres	Total Miles
29.5	0.59	$130,000	$60,250	$0	13.7	0.27	0	0	43.2	0.86

Vermillion River, Parcel 4, Dakota County

Trust Acres	Trust Miles	Trust $	Other St. $	Other $	Other St. Acres	Other St. Miles	Other Acres	Other Miles	Total Acres	Total Miles
3.7	0.03	$30,000	$0	$0	0	0	0	0	3.7	0.03

Total

33.2	0.62	$160,000	$60,250	$0	13.7	0.27	0	0	46.9	0.89

Project Results Use and Dissemination

Information about these sites will be disseminated through the DNR's network of information systems. These Aquatic Management Areas will be included on DNR PRIM maps, indicating that they are open for public use.

LCCMR Final Work Program Report – 2007
Metropolitan Area Wildlife Corridors – Phase III

Date of Report: February 12, 2009
LCCMR Work Program Update Report : NA
Date of Next Status Report: NA
Date of Work program Approval: July 1,2007
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Metropolitan Area Wildlife Corridors – Phase III: DNR Fish & Wildlife Acquisition & Development (3.5)

Project Manager: Mike Halverson
Affiliation: Minnesota Department of Natural Resources – Division of Fish & Wildlife
Mailing Address: Box 20, 500 Lafayette Road
City / State / Zip : St. Paul, MN 55155
Telephone Number: (651) 259-5209
E-mail Address: Mike.Halverson@dnr.state.mn.us
FAX Number: (651) 297-4916
Web Page address: *www.dnr.state.mn.us*

Location: Greater Metro Region (targeted portions of 15 counties – see map)

Total Biennial LCCMR Project Budget:	**LCCMR Appropriation:**	**$172,000**
	Minus Amount Spent:	**$172,000**
	Equal Balance:	**$ 0**

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 4C.

Appropriation Language: Metropolitan Area Wildlife Corridors – Phase III. $2,500,000 is from the trust fund to the commissioner of natural resources for acceleration of agency programs and cooperative agreements with The Trust for Public Land; Friends of the Mississippi River; Great River Greening; Minnesota Land Trust; Minnesota Valley National Wildlife Refuge Trust, Inc.; Trout Unlimited; and Friends of the Minnesota Valley for the purposes of planning, restoring, and protecting important natural areas in the metropolitan region, as defined by Minnesota Statutes, section 473.121, subdivision 2, and portions of the surrounding counties, through grants, contracted services, conservation easements, and fee acquisition. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards as determined by the commissioner. Expenditures are limited to the identified project corridor areas as defined in the work program. This appropriation may not be used for the purchase of residential structures, unless expressly approved in the work program. All conservation easements must be perpetual and have a natural resource management plan. Any land acquired in fee title by the commissioner of natural resources with money from this appropriation must be designated: (1) as an outdoor recreation unit under

Minnesota Statutes, section 86A.07; or (2) as provided in Minnesota Statutes, sections 89.018, subdivision 2, paragraph (a); 97A.101; 97A.125; 97C.001; and 97C.011. The commissioner may similarly designate any lands acquired in less than fee title.

II. & III. FINAL PROJECT SUMMARY:
This project resulted in the completion of two fee title acquisition parcels on the Vermillion River in Dakota County. Totals for the two acquisitions equal 46.9 acres, including 0.89 total miles of shoreline. One of the parcels on the Vermillion River was also paid for with Phase II acquisition dollars, resulting in both acres and miles being divided proportionately between the two phases. As part of this project, Environmental and Natural Resources Trust dollars ($160,000) directly acquired approximately 33.2 acres of the total, including 0.62 miles of stream. Other state dollars ($60,250) acquired approximately 13.7 acres, including 0.27 miles of stream.

As part of this project, Environmental and Natural Resources Trust dollars ($10,000) were allocated for site development. Development is being accomplished with other state dollars (Heritage and Game & Fish), so this $10,000 was directed towards acquisition.

Professional Services costs for Phase III acquisitions totaled $12,000

IV. OUTLINE OF PROJECT RESULTS: Acquisition will focus on linkages that provide both fish and wildlife habitat values. The acquired lands will be designated and managed as Aquatic Management Areas (AMA) or Wildlife Management Areas (WMA) or a combination of both. Any shoreline easements acquired will provide environmental protection of the shoreline and riparian zone as well as public angler access.

Result 1: Fish and Wildlife Land Acquisition
Allocation $172,000 Balance $0

Within the Focus Areas, DNR Fish & Wildlife will acquire AMAs and WMAs adjacent to lakes and streams to ensure the protection of critical riparian habitat, angler access, and management access. The monies will be used to secure fee title or permanent easements on approximately 32 acres and/or 0.4 miles of lakeshore and stream shoreline including sensitive watershed, riparian, or headwaters areas. These lands will be used for angler access and protection of critical habitats. Spending of trust monies and parcel information will be reported as it occurs under each result.

Program Area/Result	Trust Dollars Spent	Trust Accomplishments
	$ 172,000	47 acres with .09 miles of shoreline

Professional services in the amount of $12,000 related to land acquisition is included.

Completion Date: June 30, 2009

Description: Within the Focus Areas, DNR Fish & Wildlife will acquire AMAs and WMAs adjacent to lakes and streams to ensure the protection of critical riparian habitat, angler access, and management access. The monies will be used to secure fee title or permanent easements on approximately 32 acres and/or 0.4 miles of lakeshore and stream shoreline including sensitive watershed, riparian, or headwaters areas. These lands will be used for angler access and protection of critical habitats.

Vermillion River, Parcel 2, Dakota County

Trust Acres	Trust Miles	Trust $	Other St. $	Other $	Other St. Acres	Other St. Miles	Other Acres	Other Miles	Total Acres	Total Miles
29.5	0.59	$130,000	$60,250	$0	13.7	0.27	0	0	43.2	0.86

Vermillion River, Parcel 4, Dakota County

Trust Acres	Trust Miles	Trust $	Other St. $	Other $	Other St. Acres	Other St. Miles	Other Acres	Other Miles	Total Acres	Total Miles
3.7	0.03	$30,000	$0	$0	0	0	0	0	3.7	0.03

Total

33.2	0.62	$160,000	$60,250	$0	13.7	0.27	0	0	46.9	0.89

Professional Services Total:
Grand Total (Trust only: professional + trust $): $ 12,000

Summary Budget Information for Result 1: LCMR Budget $ 172,000
Balance $ 0

Result 2: Fish and Wildlife Land Acquisition Development
Allocation $10,000 Balance $ 0

This project will bring lands purchased with Metropolitan Area Wildlife Corridors dollars up to minimum management standards. Dollars will be used for improvements such as site clean-up, access, parking areas, gates, and habitat improvement. Development will be conducted on lands acquired with both Metropolitan Area Wildlife Corridors Phase I and Phase II dollars.

Completion Date: June 30, 2009

Description Acquisition improvements, including signage of parcel, parking, clean-up, building removal, plantings, etc.

Summary Budget Information for Result 1: LCMR Budget $ 10,000
Balance $ 0

Result Status as of February 8, 2008

None of our monies have been spent to date.

Result Status as of August 1, 2008:
Result Status as of February 1, 2009
$10,000 was shifted to acquisition

Final Report Summary: $10,000 was shifted to acquisition

TOTAL LCMR PROJECT BUDGET: SEE ATTACHMENT A

All Results: Personnel: $
All Results: Equipment: $
All Results: Development: $ 0
All Results: Acquisition: $ 172,000
All Results: Other:

TOTAL LCMR PROJECT BUDGET: $172,000

Explanation of Capital Expenditures Greater Than $3,500: NA

V. OTHER FUNDS & PARTNERS: Other Fish & Wildlife funds may be used to compliment LCMR monies, including, Trout Stamp, Heritage, RIM, or Fish & Wildlife Bonding.

A. Project Partners: See Table 1.

B. Other Funds being spent during the Project Period:

Year	Funding Source	Fisheries	Wildlife
2006	Bonding	$2,000,000	$14,000,000
Total		$2,000,000	$14,000,000

C. Required Match (if applicable): NA

D. Past Spending:

Year	Funding Source	Fisheries	Wildlife
1995	ETF*	$ 300,000	$ 510,000
1995	ERF**		$ 140,000
1997	ETF	$ 567,000	$ 500,000
2001	ETF	$2,000,000	
2003	ETF – Metro	$ 384,000	$ 240,000
2003	ETF – Outstate	$ 600,000	
2005	ETF - Metro	$ 290,000	
2005	ETF - Outstate	$ 280,000	

Total	$4,421,000	$1,390,000

*Environment and Natural Resources Trust Fund

**Future Resources Fund

E. Time: 2 years, until June 30, 2009.

VII. DISSEMINATION: Metro Corridors will periodically distribute information about the program through the widely broadcasted emails to people on the Regional Greenways Collaborative (RGC) database, through the RGC quarterly meetings, and jointly held county meetings. As projects are completed, Counties will be notified and acquisitions will be published in the State Register.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than February 1st and August 1st each year, starting with February 1st, 2008. A final work program report will be submitted by July 1st, 2009.

IX. RESEARCH PROJECTS: NA

Attachment A: Budget Detail for 2007 Metro Corridors Project **Final Report** **date: February 12, 2009**
Project Title: DNR Fish & Wildlife Acquisition & Development (3.5)

Project Manager Name: Mike Halverson
LCMR Requested Dollars: **$ 172,000**

BUDGET ITEM	Result 1: Acquisition			Result 2: Development			TOTAL			Comments
	Amount Budgeted ($)	Amount Spent ($)	Balance ($)	Amount Budgeted ($)	Amount Spent ($)	Balance ($)	Amount Budgeted ($)	Amount Spent ($)	Balance ($)	
PERSONNEL										
Staff expenses, wages, salaries, & benefits			$ -			$ -	$ -	$ -	$ -	*[list here names &/or titles of staff budgeted, what they will do,their FTE pd w/LMCR $s, & % fringe paid]*
DEVELOPMENT										
Land improvement			$ -		$ -	$ -	$ -	$ -	$ -	Parking and signs
DEVELOPMENT - SUBTOTAL	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
ACQUISITION										
Land acquisition *(fee title & conservation easement)*	$ 160,000	$ 160,000	$ -			$ -	$ 160,000.00	$ 160,000.00	$ -	Fee Title
Land transaction costs *(e.g. survey, title, appraisal, environmental, & legal)*	$ 12,000	$ 12,000	$ -		$ -	$ -	$ 12,000.00	$ 12,000.00	$ -	
ACQUISITION - SUBTOTAL	$ 172,000	$ 172,000	$ -	$ -	$ -	$ -	$ 172,000.00	$ 172,000.00	$ -	
OTHER										
Travel expenses in Minnesota			$ -			$ -	$ -	$ -	$ -	
OTHER - SUBTOTAL	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
TOTAL LCMR Funding	$ 172,000	$ 172,000	$ -	$ -	$ -	$ -	$ 172,000.00	$ 172,000.00	$ -	

2007 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Local Water Management Matching Challenge Grants
PROJECT MANAGER: David Weirens
AFFILIATION: Board of Water and Soil Resources
MAILING ADDRESS: 520 Lafayette Road
CITY/STATE/ZIP: St. Paul, MN 55155
PHONE: 651-297-3432
FAX: 651-297-5615
E-MAIL: david.weirens@state.mn.us
WEBSITE: www.bwsr.state.mn.us
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap.30, Sec. 2, Subd. 5.

APPROPRIATION AMOUNT: $350,000

Overall Project Outcome and Results

Grants were awarded to 4 counties, 5 soil and water conservation districts, 2 water management organizations, and 1 joint powers board for the purpose of implementing high priority actions identified in current state approved and locally adopted comprehensive water management plans. The funds were used to complete the following projects:

- Prevented agricultural tile flows from discharging to surface waters and monitored nitrate concentrations of these flows in the Nile Mile Creek watershed.
- Protected nearly 900 acres of land adjacent to lakes and streams in Cass and Aitkin Counties.
- Implemented 10 grazing plans to reduce fecal coliform loading to the Root River.
- Generated watershed delineations and lake volume calculations that contributed to the adoption of development restrictions on 44 lakes in Itasca County.
- Completed preparations that ultimately will stabilize a streambank to protect a cemetery in Hallock from a slumping streambank.
- Designed and stabilized a 2-mile segment of a judicial ditch in the Bostic Creek watershed of Lake of the Woods County.
- Demonstrated that straw bales result in decreased phosphorus concentrations in ditch flows to Lake Volney in Le Sueur County.
- Installed a grade stabilization structure in a gully to prevent the deposit of sediment into the St. Croix River.
- Restored shoreland along Mille Lacs Lake in Mille Lacs County.
- Reduced the discharge of stormwater from the City of Wadena.
- Tested the quality of water in the Mt. Simon Aquifer and sealed three wells in Washington County.

Project Results Use and Dissemination

Results of the specific projects are available upon request from the Board of Water and Soil Resources.

Trust Fund 2007 Work Program Final Report

Date of Report: August 13, 2010
Trust Fund 2007 Work Program Final Report
Date of Work Program Approval: June 5, 2007
Project Completion Date: June 30, 2010

I. PROJECT TITLE: Local Water Management Matching Challenge Grants

Project Manager:	David Weirens
Affiliation:	Board of Water and Soil Resources
Mailing Address:	520 Lafayette Road
City / State / Zip:	St. Paul, MN 55155
Telephone Number:	651-297-3432
E-mail Address:	david.weirens@bwsr.state.mn.us
FAX Number:	651-297-5615
Web Page address:	www.bwsr.state.mn.us

Location: Statewide application.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	$350,000
	Minus Amount Spent:	$277,326
	Equal Balance:	$72,674

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 5.

Appropriation Language: $350,000 is from the trust fund to the Board of Water and Soil Resources to accelerate the local water management challenge grant program under Minnesota Statutes, sections 103B.3361 to 103B.3369, through matching grants to implement high priority activities in state-approved comprehensive water management plans. For the purposes of this paragraph, the match must be a nonstate contribution and may be either cash or qualifying in-kind. The grants may be provided on an advance basis as specified in the work program. This appropriation is available until June 30, 2010, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. and III. FINAL PROJECT SUMMARY.

Grants were awarded to 4 counties, 5 soil and water conservation districts, 2 water management organizations, and 1 joint powers board for the purpose of implementing high priority actions identified in current state approved and locally adopted comprehensive water management plans. The funds were used to complete the following projects:

- Prevented agricultural tile flows from discharging to surface waters and monitored nitrate concentrations of these flows in the Nile Mile Creek watershed.
- Protected nearly 900 acres of land adjacent to lakes and streams in Cass and Aitkin Counties.

- Implemented 10 grazing plans to reduce fecal coliform loading to the Root River.
- Generated watershed delineations and lake volume calculations that contributed to the adoption of development restrictions on 44 lakes in Itasca County.
- Completed preparations that ultimately will stabilize a streambank to protect a cemetery in Hallock from a slumping streambank.
- Designed and stabilized a 2-mile segment of a judicial ditch in the Bostic Creek watershed of Lake of the Woods County.
- Demonstrated that straw bales result in decreased phosphorus concentrations in ditch flows to Lake Volney in Le Sueur County.
- Installed a grade stabilization structure in a gully thereby preventing the deposit of sediment into the St. Croix River.
- Restored shoreland along Mille Lacs Lake in Mille Lacs County.
- Reduced the discharge of stormwater from the City of Wadena.
- Tested the quality of water in the Mt. Simon Aquifer and sealed three wells in Washington County.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1 Grants to Implement Local Water Management Activities

Description: Eligible local governments (counties, watershed districts, watershed management organizations, and soil and water conservation districts) will be invited to submit applications via email, eLINK and the BWSR website. Partner agencies will be invited to review and rank applications received. All project categories require a 50 percent cash or in kind match.

The solicitation to eligible local governments will specify that priority funding consideration will be given to projects that develop and implement innovative practices, programs, or plans to protect or restore surface and ground waters.

<u>Project Categories:</u> The grant maximums that will be imposed for each project category are shown below as is the target budget for each category that will guide funding decisions.

<u>Land and Water Treatment</u>. (Target Budget: $150,000) The maximum grant is $25,000/LGU or $75,000/project.
<u>Planning and Environmental Controls</u>. (Target Budget: $100,000) The maximum grant is $25,000/LGU or $75,000/project.
<u>Monitoring and Modeling</u>. (Target Budget: $100,000) The maximum grant is $25,000/LGU or $75,000/project.

In anticipation of the enactment of the LCCMR's funding proposals, BWSR opened an application period for eligible local governments that ran from March 1 to April 13. This open application period generated 63 proposals requesting $1,459,705 in grant funds

Summary Budget Information for Result 1:	**Trust Fund Budget:**	$350,000
	Amount Spent:	$277,326
	Balance:	$72,674

Deliverable	Completion Date	Budget	Status
1. List of project applications	April 13, 2007	$0	Completed
2. Process, review and ranking of applications	May 23, 2005	$0	Completed
3. List of funded projects, descriptions, deliverables, and grant contracts	June 27, 2007	$350,000	Completed
4. Project deliverables-specific activities that each project has completed	June 30, 2010	$0	Completed

Final Report Summary: Eleven of the 12 funded projects completed all or substantial portions of their project workplans. Significant outcomes of each project are briefly discussed below.

Brown-Nicollet-Cottonwood Joint Powers Board. The project pumped flows from tile lines in agricultural fields to a wetland that was previously restored under the USDA Continuous Reserve Program. The project's purpose was to prevent these flows from discharging to surface waters with resulting nitrate contributions. Very little of the water pumped to the wetland (an average of 865 cubic feet per day) drained out via surface flows. Approximately 58% percent of tile flows were exported to the wetland. Nitrate concentrations were very low (6 ppm) likely due to dry conditions that drew water from another nearby wetland. This project also included a field day that was attended by drainage contractors, farmers and landowners. Grant funds of $16,641 were matched with $29,692 of local funds. Granted funds ($7,859) were returned as the proposed wind generator pump was not installed due to excessive cost.

Cass County. This project was a partnership between Cass, Crow Wing, and Aitkin Counties that resulted in the protection of nearly 900 acres of land adjacent to lakes and streams. The initial step was assembling a database of all parcels on 10 lakes in each county with a width 4 times the minimum lot width. This information was shared with lake associations and landowners. This project offered landowners funds to cover the costs of enrolling lands in conservation easements – appraisals, surveys, legal fees and other expenses. The grant of $56,000 leveraged match of $869,310 largely in the form of the value of land placed in conservation easements.

Fillmore Soil and Water Conservation District. The purpose of this project is to reduce fecal coliform loading to the Root River through improved grazing management. This project resulted in the implementation in whole or in part of 10 grazing management plans. Plans implemented through this project addressed overgrazing, reduced cattle interactions with streams, and must be located in a riparian area. Best management practices implemented on these farms included developing animal trails and walkways, implementing prescribed grazing, and fencing. Outreach and education for producers was accomplished by co-sponsoring and conducting 15 field days, 3 educational pasture walks and a four-day grazing school throughout the Root River watershed. Grant funds spent on these initiatives totaled $35,642, which was matched by a like amount of local funds. In addition, over $120,000 of federal and other state funds were leveraged by this project. However, $39,358 in grant funds were returned. This was principally due to the Southeast Minnesota Flood of 2007 that required a response by the Fillmore SWCD and other SWCD's in the Root River watershed. The return of grant funds resulted in fewer grazing plans being implemented than otherwise would have occurred.

Itasca Soil and Water Conservation District. This project completed watershed delineations and volume calculations of 100 lakes in Itasca County. The data generated by this project was used by Itasca County in adopting development restrictions on 44 lakes. Work is continuing to make this data publicly accessible on the District website. The $24,690 in grant funds were matched by $24,690 of local funds.

Kittson Soil and Water Conservation District. The original purpose of this project was to stabilize a streambank to protect Greenwood Cemetery in Hallock, Minnesota. Adverse weather conditions did not allow completion of the project during the grant period. Grant funds were used to survey the project site, design the project, and relocate graves in preparation for the stabilization portion of the project. Grant funds of $17,798 were matched by $17,798 of local funds. Granted funds of $7,202 were returned due to the inability to complete the project in the grant period as stated above. A conifer revetment will be installed this fall at a cost of $26,560 that will be fully paid by local sources.

Lake of the Woods County. This project completed a topographic survey of the channelized portion of Bostic Creek and several tributary ditches. This survey was used to design the project and get County Board approval to stabilize a two mile segment of judicial ditch 28 (a tributary of Bostic Creek). The design of the stabilization was intended to allow for greater water storage under peak conditions, reduce flow speed, and allow the ditch to meander under low flow conditions. Water quality monitoring (transparency, water temperature, conductivity, dissolved oxygen, ph, turbidity, total phosphorus, and TSS) was conducted to gather baseline data and to determine if the Bostic Creek watershed is impaired. $11,553 in grant funds were matched by a like amount of local funds.

Le Sueur County. This project installed barley straw bales into a ditch that flowed into Lake Volney. The purpose was to reduce phosphorus inputs to help reduce algae blooms. Test results determined that phosphorus concentrations decreased downstream from the barley straw. Grant funds of $6,896 were matched by $6,896 of local funds.

Middle St. Croix Water Management Organization. In 2006, the Afton-Lakeland Gully Erosion Preliminary Engineering Report was completed. This report was implemented through this project by strategically placing 11 rock veins and 2 boulder drop structures. In addition erosion control blankets and live stakes were installed along with bio-logs where necessary. The installation of these grade stabilization structures will prevent sediment from being deposited into the St. Croix River. Grant funds of $75,000 were matched by $114,758 of local funds.

Mille Lacs Soil and Water Conservation District. This project demonstrated how restored shoreland can benefit fish habitat and water quality while being visually attractive. This project was completed using $2,005 of grant funds and $3,005 of local match. Funds totaling $1,995 were returned as the project was completed under budget.

Shingle Creek Watershed Management Commission. This project as proposed intended to utilize grant funds to install in stream habitat and aeration features and stabilize the banks of Shingle Creek in Brooklyn Park. However, the project did not complete survey and design and receive local government approvals prior to the end of the grant period. All grant funds were returned ($16,025).

Wadena Soil and Water Conservation District. This project reduced the discharge of stormwater from the City of Wadena by purchasing and installing 60 rain barrels and abating stormwater runoff from the parking lot of the West Central Telephone Association. This project utilized $21,265 of grant funds that was matched by $28,792 of local funds. $235 in grant funds were returned as the project was completed under budget.

Washington County. Two existing boreholes were drilled out to allow data and water quality samples to be collected from the Mt Simon Aquifer. Testing results detected nitrate-nitrogen as high as 11 milligrams per liter. Coliform bacteria was detected in one of the borings, and a PFC chemical was detected in both borings. The boreholes were sealed at the conclusion of the data gathering to prevent contamination. An additional 3 wells were sealed. $10,000 in grant funds were matched with a like amount of local funds.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: **$**0
Equipment: **$**0
Development: $0
Restoration: $0
Acquisition, including easements: $0*
Other: $350,000 (grants to local governments)

TOTAL TRUST FUND PROJECT BUDGET: $350,000

Explanation of Capital Expenditures Greater Than $3,500: None

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

1. Partners Receiving LCCMR Funds

Minnesota Counties

Minnesota Watershed Districts

Minnesota Watershed Management Organizations

Minnesota Soil and Water Conservation Districts

2. Project Cooperators

Mn Department of Agriculture

Mn Department of Natural Resources

Mn Pollution Control Agency

B. Other Funds Proposed to be Spent during the Project Period: BWSR will spend additional state funds for in-kind services to manage the grant process and oversee the grants once the funding allocation has been approved by the Board.

C. Past Spending: BWSR received an appropriation from the Legislative Commission on Minnesota Resources of $1,000,000 for the 2006-2007 fiscal biennium. The one-to-one match requirement applied to these projects. The total match that recipients will be providing for their projects is $1,699,369.

D. Time: The appropriation provides authority to spend through June 30, 2010. Projects that receive grant funds will be expected to complete the project within two years with the ability for a one year extention, if necessary.

VII. DISSEMINATION: Detailed project work plans; budgets and reports will be maintained by BWSR for successful grant applicants. These materials are available for inspection upon request. Project summaries will be prepared after awarding of grants and will be broadly distributed through cooperating agencies, the LCMR, BWSR newsletters, and BWSR's web site. Final project results will be available in an electronic format through the required use of BWSR's local government reporting system (eLINK).

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than December 31, 2007, June 30, 2008, December 31, 2008, and June 30, 2009. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR.

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: Local Water Management Matching Challenge Grants

Project Manager Name: David Weirens

Trust Fund Appropriation: $ 350,000

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** June 30, 2010	**Balance** June 30, 2010	**TOTAL BALANCE**
	Grants to Implement Local Water Management Activities			
BUDGET ITEM			0	0
Other (grants to local units of government)		277,326	72,674	72,674
COLUMN TOTAL	**$0**	**$277,326**	**$72,674**	**$72,674**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Protection of Rare and Unique Rock Outcrop Wetlands
PROJECT MANAGER: Thomas J. Kalahar
AFFILIATION: Renville Soil & Water Conservation District
MAILING ADDRESS: 1008 West Lincoln
CITY/STATE/ZIP: Olivia MN 56277
PHONE: 320-523-1559
FAX: 320-523-2389
E-MAIL: kalahar@yahoo.com
WEBSITE: www.renvilleswcd.com
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec 2, Subd. 5(b)

APPROPRIATION AMOUNT: $563,000

Overall Project Outcome and Results

The Minnesota River Valley contains ancient bedrock outcrops with associated wetlands that provide unique habitats for specialized plant and animal communities rarely found elsewhere in Minnesota. These resources are threatened by mining and other development interests, as removal of the rock results in the severe degradation or permanent loss of the wetlands located among the rock complexes. Although the wetlands vary greatly in size and duration, some of the smallest and most temporary basins harbor the rarest and most specialized plants. Many of these wetlands may not be protected due to de minimis (i.e. minimum size) exceptions to the Wetland Conservation Act. Rock outcrops are also a component of the Minnesota River's riparian zone and destruction of this unique habitat will continue to degrade the water quality and aquatic habitat of the Minnesota River and its tributaries. Unlike other mining operations, there is no reclamation plan possible for replacing this very unique landscape feature once it is removed. This project consisted of efforts to protect these unique habitats through conservation easements and habitat restoration activities.

For the conservation easements portion of the project, applications from 9 landowners totaling 788 acres were scored by a team of natural resource professionals to determine the highest quality sites under grant guidelines. The goal of this project was to protect 200 acres with Reinvest in Minnesota (RIM) perpetual conservation easements in Renville and Redwood Counties. That goal was exceeded and 212.4 acres were protected. Four landowners received $517,411 in easement payments from grant funds. In accordance with the RIM program, landowners retain ownership.

For the habitat restoration portion of the project, $16,049 in grant funds were used for invasive species control, along with $31,441 leveraged from other sources to assist in meeting the goals of the conservation plans developed on each easement as part of the RIM process.

Project partners were USDA NRCS, MN DNR Wildlife (Heritage Enhancement), DNR ECO-Non Game (Heritage Enhancement), State of Minnesota Native Buffer Cost Share Program, and US Fish & Wildlife Service.

Project Results Use and Dissemination

Initially staff from the Renville & Redwood Soil & Water Conservation Districts (SWCD) had face-to-face contact with landowners. This proved to be a very successful way of generating applications, as 788 acres were offered. The applications that were not funded were kept for future reference and landowners have all been contacted and given an opportunity to apply for dollars from the ML 2009 Environment and

Natural Resources Trust Fund appropriation for $1.5 million, for which we have a goal of enrolling an additional 530 acres in perpetual easements.

Several newspaper articles have been published since the inception of the 2007 grant. The regional West Central Tribune in Willmar, MN has done articles about the program. In addition local newspapers have included articles about the program. Tom Kalahar, Project Manager, was interviewed by Fred Harris for an article published in the March-April 2009 issue of the Minnesota Conservation Volunteer. The early articles caused landowners in other counties to request information on how they could enroll their land into the program. This landowner interest resulted in Chippewa, Yellow Medicine and Lac qui Parle SWCD offices joining Renville & Redwood in making application for the 2009 funds.

The Renville SWCD continues to update the public on the status of the grants on their website www.renvilleswcd.com Tom Kalahar has done informational/educational talks on the Minnesota River Basin and the unique features of the Granite Rock Outcrops. Audiences included the general public in both Redwood Falls and New Ulm, a presentation for landowners in the Renville/Chippewa DNR Working Lands Initiative area, as well as a presentation to the Upper Sioux Community. DNR Private Lands Program staff have used their one-on-one contacts with landowners to promote the program in addition to sponsoring the Landowner Workshop which included Tom's presentation on the Rock Outcrop program.

In August 2008, Renville SWCD hosted the Board of Water & Soil Resources (BWSR) meeting. A one day tour for about 60 people included stopping at a rock outcrop site. SWCD staff used this opportunity to inform the BWSR and guests about the uniqueness of the natural resource and to give them an update on progress toward meeting the goals for the grant.

Local SWCD staff and supervisors continue to keep their local County Boards informed about progress of not only the 2007 grant but also about landowner interest for future funding.

Trust Fund 2007 Work Program Final Report

Date of Report: 6-30-2009
Trust Fund 2007 Work Program Final Report

I. PROJECT TITLE: Protection of Rare and Unique Rock Outcrop Wetlands

Project Manager: Thomas J. Kalahar
Affiliation: Renville SWCD
Mailing Address: 1008 W. Lincoln
City / State / Zip : Olivia MN 56277
Telephone Number: 320-523-1559
E-mail Address: kalahar@yahoo.com
FAX Number: 320-523-2389
Web Page address: n/a

Location: Redwood and Renville Counties, Minnesota

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$563,000.00**
	Minus Amount Spent:	**$563,000.00**
	Equal Balance:	**$ 0**

Legal Citation: ML 2007, Chap. 30, Sec.2, Subd. 5(b).

Appropriation Language: $563,000 is from the trust fund to the Board of Water and Soil Resources in cooperation with Renville and Redwood Soil and Water Conservation Districts for perpetual easements of unique wetland and riparian habitats associated with rock outcrops in the Minnesota River Valley.

II & III. FINAL Project Summery:

The Minnesota River Valley contains ancient bedrock outcrops with associated wetlands that provide unique habitats for specialized plant and animal communities rarely found elsewhere in Minnesota. These resources are threatened by mining and other development interests, as removal of the rock results in the severe degradation or permanent loss of the wetlands located among the rock complexes. Although the wetlands vary greatly in size and duration, some of the smallest and most temporary basins harbor the rarest and most specialized plants. Many of these wetlands may not be protected due to de minimis (i.e. minimum size) exceptions to the Wetland Conservation Act. Rock outcrops are also a component of the Minnesota River's riparian zone and destruction of this unique habitat will continue to degrade the water quality and aquatic habitat of the Minnesota River and its tributaries. Unlike other mining operations, there is no reclamation plan possible for replacing this very unique landscape feature once it is removed. This project consisted of efforts to protect these unique habitats through conservation easements and habitat restoration activities.

For the conservation easements portion of the project, applications from 9 landowners totaling 788 acres were scored by a team of natural resource professionals to determine the highest quality sites under grant guidelines. The goal of this project was to protect 200 acres with Reinvest in Minnesota (RIM) perpetual conservation easements in Renville and Redwood Counties. That goal was exceeded and 212.4 acres were protected. Four landowners received $517,411 in easement payments from grant funds. In accordance with the RIM program, landowners retain ownership.

For the habitat restoration portion of the project, $16,049 in grant funds were used for invasive species control, along with $31,441 leveraged from other sources to assist in meeting the goals of the conservation plans developed on each easement as part of the RIM process.

Project partners were USDA NRCS, MN DNR Wildlife (Heritage Enhancement), DNR ECO-Non Game (Heritage Enhancement), State of Minnesota Native Buffer Cost Share Program, and US Fish & Wildlife Service.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Habitat Protection via Perpetual Easements:

Description: This project will protect 200 acres of rock outcrop complexes within riparian corridors and/or with associated wetlands. Compensation for easements to willing landowners will be secured using local cropland rates of the Reinvest In Minnesota easement program administered through the Minnesota Board of Soil and Water Resources (BWSR) and the Renville and Redwood Soil and Water Conservation Districts (SWCDs). Easement applications will be prioritized by a local work group comprised of technical experts from local, state and federal agencies. A total of twenty easements will be recorded. The goal of the local SWCD offices is to have applications taken for the entire 200 acres within the first year of the grant. Due to the sometimes lengthy easement process, this would ensure signed agreements with landowners before the end of the grant period.

Summary
Budget Info for Result 1: **Trust Fund Budget:** **$546,951**
Amount Spent: **$546,951**
Balance: **$ 0**

Amendment Approved: January 28, 2009

Deliverable	Completion Date	Budget	Status
1. 20 easements Totaling 200 acres	6-30-2008	$546,951	Complete

Final Report Summary: 6-30-2009

Four easements totaling 212.4 acres were recorded and landowners paid by the fall of 2008. Total acres exceeded the original goal while the number of easements was less than originally anticipated. In hindsight, we did not anticipate the amount of landowner interest in this program and did not anticipate interest from landowners outside the two original partner counties. Having just made application for our third and final grant, we realize we would have been wise to request more funds initially instead of having to come back with supplemental applications which included additional partners. A larger original application would have avoided scoring some applications more than once which also would have saved staff time and saved some landowners from making multiple applications for the same piece of property. We did not anticipate landowners offering larger tracts of land with multiple granite rock outcrops on those tracts. Therefore, we originally expected smaller easements. A positive outcome of less easements was that staff were able to spend more time with each landowner and vendor as restoration work progressed.

Result 2: Habitat Restoration:

Description: To provide appropriate habitat management practices including but not limited to invasive species management and livestock management facilities (e.g. fencing and watering sites) on the acres protected by easements. We will continue to seek additional funding from federal and private agencies to augment this budget item.

Summary Budget Info for Result 2: Trust Fund Budget: $16,049

Amount Spent: $16,049

Balance: $ 0

Amendment Approved: January 28, 2009

Deliverable	Completion Date	Budget	Status
1. Practice implementation	6-30-2009	$16,049	Complete

Completion Date: Practice completion within six months after recorded conservation easement. This could be delayed due to weather and season of the year.

Final Report Summary: 6-30-2009

A total of $6,049 was paid for invasive species removal which completed this portion of the grant. In addition, $31, 441 was obtained from other sources to assist in practice implementation as outlined in the easement conservation plans. Other funding sources included USDA EQIP program ($21,537), US Fish & Wildlife Service ($2,500), DNR Wildlife Heritage Enhancement ($1,513), DNR ECO-non game Heritage Enhancement ($2,100) and State of Minnesota Native Buffer Cost Share Program ($3,791). SWCD Staff in both counties sought out funding sources from these partners. Staff from the partner agencies worked with each other and the landowners to accomplish the goals laid out in the conservation plans. When the original grant was written, we hoped to get funding for practice implementation from some of these sources but with annual budget cycles and budget uncertainty, it was never a guarantee. Both Renville & Redwood SWCD offices enjoy a good working relationship with all the partner agencies and again found them to be willing to assist SWCD staff and the landowners by using their programs to help implement the goals laid out in the easement conservation plans.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services : $23,000 for Renville & Redwood SWCD Staff to promote project, process applications and easements, design conservation plans and supervise construction of practices. $1,400 to BWSR to process easements. $5,140 for attorney fees for title searches, title opinions and to purchase title insurance.

Equipment: $0

Development: $ 0

Restoration: $ $10,000 for staff time to the Renville & Redwood SWCD offices for staff time for technical assistance, conservation plan development, supervision of practice implementation. $6,049 in grant funds for native species removal. $31, 441 from other sources including MN DNR both Wildlife & Eco, US Fish & Wildlife Service, USDA NRCS, &State of Minnesota Native Buffer Cost-Share program.

Acquisition, including easements: $517,411 for 4 easements totaling 212.4 acres using September 2007 RIM cropland rates.

TOTAL TRUST FUND PROJECT BUDGET: $563,000

Explanation of Capital Expenditures Greater Than $3,500: n/a

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: BWSR Easement Team Staff, DNR Private Lands Specialist, US FWS staff and NRCS staff in addition to Redwood & Renville SWCD staff.

B. Other Funds Proposed to be Spent during the Project Period:

At the time the proposal was written the only funds pledged were in-kind from the SWCD offices for office space, vehicles, etc. As the project progressed, funds were secured from several sources to assist in practice implementation. Those sources were the USDA Natural Resource Conservation Service EQIP program, both the Wildlife and Eco sections of the Minnesota Department of Natural Resources, the US Fish & Wildlife Service and funds were obtained through the State of Minnesota Native Buffer Cost-Share Program which is administered by the BWSR and the local SWCD offices. A total of $31,441 in payments to vendors and landowners came from these sources. Staff time was not tracked for the purposes of this reporting and therefore we do not have a dollar amount to assign to that.

Staff time was also used as in-kind match when the initial site visits were done to score applications. A team of natural resource professionals including staff from DNR, US FWS and the local SWCD offices visited each individual site to determine which applications would be funded.

C. Past Spending: none

D. Time: The project was completed within the timelines laid out in the original proposal. Due to weather conditions, some invasive species removal was done on one site in Spring 2009 but that was completed well before the end of the grant period. Staff in both Renville & Redwood SWCD offices are very experienced with the RIM easement process and have a good working relationship with the easement staff at BWSR. There were no unexpected delays with applications and easement processing.

VII. DISSEMINATION:

Initially staff from the Renville & Redwood Soil & Water Conservation Districts (SWCD) had face-to-face contact with landowners. This proved to be a very successful way of generating applications as 788 acres were offered. The applications that were not funded were kept for future reference and landowners have all been contacted and given an opportunity to apply for the 2009 grant which was funded for $1.5 million with a goal of enrolling an additional 530 acres in perpetual easements.

Several newspaper articles have been published since the inception of the 2007 grant. The regional West Central Tribune in Willmar, MN has done articles about the program. In addition local newspapers have included articles about the program. Tom Kalahar, Project Manager, was interviewed by Fred Harris for an article published in the March-April 2009 issue of the Minnesota Conservation Volunteer. The early articles caused landowners in other counties to request information on how they could enroll their land into the program. That landowner interest resulted in Chippewa, Yellow Medicine and Lac qui Parle SWCD offices joining Renville & Redwood in making application for the 2009 funds.

The Renville SWCD continues to update the public on the status of the grants on their website www.renvilleswcd.com Tom Kalahar has done informational/educational talks on the Minnesota River Basin and the unique features of the Granite Rock Outcrops. Audiences included the general public in both Redwood Falls and New Ulm, a presentation for landowners in the Renville/Chippewa DNR Working Lands Initiative area, as well as a presentation to the Upper Sioux Community. DNR Private Lands Program staff have used their one-on-one contacts with landowners to promote the program in addition to sponsoring the Landowner Workshop which included Tom's presentation on the Rock Outcrop program.

In August 2008, Renville SWCD hosted the Board of Water & Soil Resources (BWSR) meeting. A one day tour for about 60 people included stopping at a rock outcrop site. SWCD staff used this opportunity to inform the BWSR and guests about the uniqueness of the natural resource and to give them an update on progress toward meeting the goals for the grant.

Renville & Redwood SWCD staff and supervisors continue to keep their respective County Boards informed about progress of not only the 2007 grant but also about landowner interest for future funding.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than December 31, 2007, June 30, 2008, December 31, 2008 and June 30, 2009

IX. RESEARCH PROJECTS: *N/A*

Attachment A: Budget Detail for 2007 Projects - **Summary and a Budget page for each partner (if applicable)**

Project Title: **Protection of Rare and Unique Rock Outcrop Wetlands Subd. 5 (b)**

Project Manager Name: **Thomas J. Kalahar**

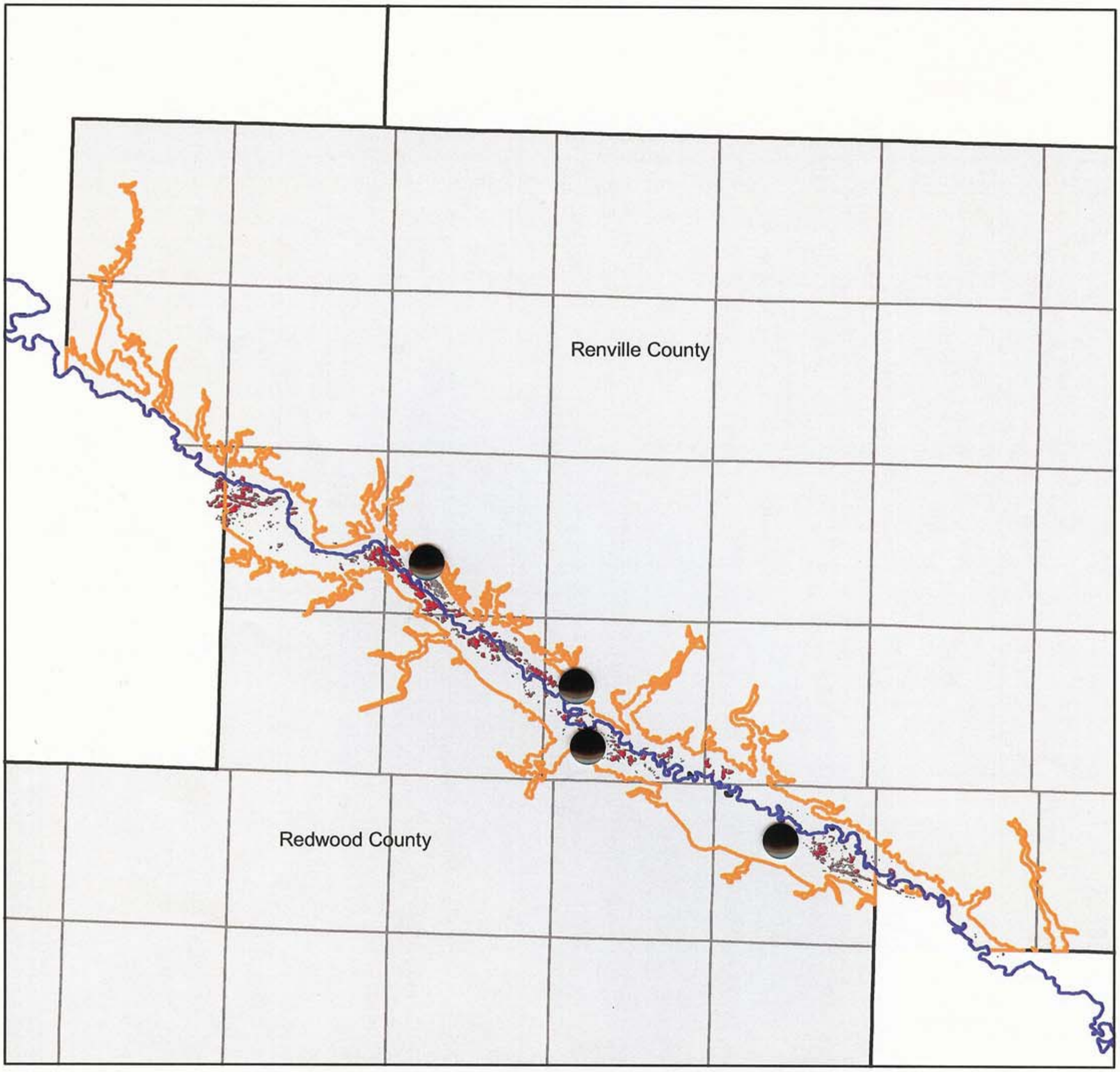
Trust Fund Appropriation:

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	Final Result 1 budget 6-30-2009	Amount Spent	Balance 6-30-2009	Final Result 2 Budget 6-30-2009	Amount Spent	Balance 6-30-2009	TOTAL BUDGET	TOTAL BALANCE
	Habitat protection via Perpetual Easements			*Habitat Restoration*				
PERSONNEL: wages and benefits: SWCD Personnel	$ 23,000.00	$ 23,000.00	$ -	10,000	$ 10,000.00	$ -	$ 33,000.00	$ -
Land rights acquisition *(less than fee)* *	$ 517,410.72	$ 517,410.72	$ -			$ -	$ 517,410.72	$ -
Professional Services for Acquisition (BWSR=$1400/Attny=$5140))**	$ 6,540.00	$ 6,540.00	$ -			$ -	$ 6,540.00	$ -
Construction			$ -			$ -	$ -	$ -
Other land improvement: Invasive species removal, livestock management			$ -	6,049.28	$ 6,049.28	$ -	$ 6,049.28	$ -
COLUMN TOTAL	**$ 546,950.72**	**$ 546,950.72**	**$ -**	**$ 16,049.28**	**$ 16,049.28**	**$ -**	**$ 563,000.00**	**$ -**

Protection of Rock Outcrop Riparian and Wetland Habitats Map



Legend
- MN River
- Grant Eligible Area
- County Boundaries
- Known Rock Outcrops

0 2 4 8 12 16 20 Miles

N W E S

Renville and Redwood Counties

Maps are for graphical purposes only. They do not represent a legal survey. While every effort has been made to ensure that these data are accurate and reliable within the limits of the current state of the art, NRCS cannot assume liability for any damages caused by any errors or omissions in the data, nor as a result of the failure of the data to function on a particular system. NRCS makes no warranty, expressed or implied, nor does the fact of distribution constitute such a warranty.

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Land Retirement Effects on Minnesota River Basin Streams
PROJECT MANAGER: Victoria Christensen
AFFILIATION: U.S. Geological Survey
MAILING ADDRESS: 2280 Woodale Drive
CITY/STATE/ZIP: Mounds View, MN 55112
PHONE: 763-783-3100
FAX: 763-783-3103
E-MAIL:vglenn@usgs.gov
WEBSITE: http://mn.water.usgs.gov/projects/description/8607C0Z.html
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, [Chap. HF 293], Sec.[2], Subd. 5(c).

APPROPRIATION AMOUNT: $275,000

Overall Project Outcome and Results

The Minnesota River Basin lies within one of the most productive and intensively managed agricultural regions in the world. Current agricultural practices use large quantities of chemical fertilizer to maintain productivity—as much as 7.4 and 2.9 tons/mi^2 for nitrogen and phosphorus, respectively. The excess of these nutrients have the potential for deleterious effects on stream quality through runoff. To address concerns about degradation of agricultural streams, the state of Minnesota was requested to provide funding to retire an additional 100,000 acres of agricultural lands to improve water quality and aquatic biology. This study was designed to provide a comprehensive evaluation of agricultural set-aside programs on a basin scale and their effect on water quality.

This study was divided into two phases. The primary Phase 1 objective was to compare water quality and aquatic biological conditions across three basins similar with respect to physical setting and hydrology, but differing in the degree of agricultural land retirement. The Phase 2 objective was to assess the relation between biotic integrity and land retirement across the Minnesota River Basin.

Fully-instrumented sampling sites with automated samplers, water-quality monitors, and streamflow gages were installed from 2005-2008. Findings include:

- Nitrogen concentrations were highest, with a mean of 15.0 mg/L, in South Branch Rush River, the subbasin with little land retirement; nitrogen concentrations were lower in Chetomba Creek (mean of 10.6 mg/L) and West Fork Beaver Creek (mean of 7.9 mg/L), subbasins with more land retirement at the basin scale.
- Total phosphorus concentrations were not directly related to land retirement percentages with average concentrations of 0.259 mg/L at West Fork Beaver Creek, 0.164 mg/L at Chetomba Creek, and 0.180 mg/L at South Branch Rush River.
- Index of biotic integrity (IBI) scores increased as local land retirement percentages (within 50 and 100 meters of the streams) increased.
- Comparisons made within the basins showed that nutrient, suspended-sediment, and chlorophyll-*a* concentrations decreased with increasing land retirement.

Data from this study can be used to evaluate the success of land retirement programs for improving stream quality. Two reports will be published in September 2009, describing Phase 1 and Phase 2 of the study.

Project Results Use and Dissemination

The results from this study were disseminated through USGS and BWSR websites, two abstracts, a conference proceeding paper, and several presentations and posters. The water-quality and streamflow information was provided in real-time through the USGS website. USGS and BWSR personnel have participated in basin activities highlighting the selected subbasins and emphasizing the effects of land retirement. A USGS Scientific Investigations Report entitled, "Water-Quality and Biological Characteristics and Responses to Agricultural Land Retirement in Streams of the Minnesota River Basin, Water Years 2006–08" is scheduled to be published by September 30, 2009. A manuscript has been completed covering Phase 2 of the study and will be submitted to a peer reviewed journal in September 2009.

Trust Fund 2007 Work Program Final Report

Date of Report: August 10, 2009
Trust Fund 2007 Work Program Final Report
Date of Work program Approval:
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Land Retirement Effects on Minnesota River Basin Streams

Project Manager: Victoria Christensen
Affiliation: U.S. Geological Survey
Mailing Address: 2280 Woodale Drive
City / State / Zip: Mounds View, MN 55112
Telephone Number: 763-783-3100
E-mail Address: vglenn@usgs.gov
FAX Number: 763-783-3103
Web Page address:

Location: Minnesota River Basin

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$ 275,000**
	Minus Amount Spent:	**$ 275,000**
	Equal Balance:	**$ 0**

Legal Citation: ML 2007, [Chap. HF 293], Sec.[2], Subd. 5(c).

Appropriation Language:
$275,000 is from the trust fund for the second biennium to the board of water and soil resources for a cooperative agreement with the United States Geological Survey to define the relation between land retirement and water quality and biological integrity in Minnesota River sub-basins and determine if nutrient transport reductions improve habitat and bio-diversity in order to enhance prioritization of future land retirements. This appropriation must be matched by an equal amount of nonstate money.

II. And III. FINAL PROJECT SUMMARY

The Minnesota River Basin lies within one of the most productive and intensively managed agricultural regions in the world. Current agricultural practices use large quantities of chemical fertilizer to maintain productivity—as much as 7.4 and 2.9 tons/mi^2 for nitrogen and phosphorus, respectively. The excess of these nutrients have the potential for deleterious effects on stream quality through runoff. To address concerns about degradation of agricultural streams, the state of Minnesota was requested to provide funding to retire an additional 100,000 acres of agricultural lands to improve water quality and aquatic biology. This study was designed to provide a comprehensive evaluation of agricultural set-aside programs on a basin scale and their effect on water quality.

This study was divided into two phases. The primary Phase 1 objective was to compare water quality and aquatic biological conditions across three basins similar with respect to physical setting and hydrology, but differing in the degree of agricultural land retirement. The Phase 2 objective was to assess the relation between biotic integrity and land retirement across the Minnesota River Basin.

Fully-instrumented sampling sites with automated samplers, water-quality monitors, and streamflow gages were installed from 2005-2008. Findings include:

- Nitrogen concentrations were highest, with a mean of 15.0 mg/L, in South Branch Rush River, the subbasin with little land retirement; nitrogen concentrations were lower in Chetomba Creek (mean of 10.6 mg/L) and West Fork Beaver Creek (mean of 7.9 mg/L), subbasins with more land retirement at the basin scale.
- Total phosphorus concentrations were not directly related to land retirement percentages with average concentrations of 0.259 mg/L at West Fork Beaver Creek, 0.164 mg/L at Chetomba Creek, and 0.180 mg/L at South Branch Rush River.
- Index of biotic integrity (IBI) scores increased as local land retirement percentages (within 50 and 100 meters of the streams) increased.
- Comparisons made within the basins showed that nutrient, suspended-sediment, and chlorophyll-*a* concentrations decreased with increasing land retirement.

Data from this study can be used to evaluate the success of land retirement programs for improving stream quality. Two reports will be published in September 2009, describing Phase 1 and Phase 2 of the study.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Stream gaging

Description:

Streamflow was collected at 3 USGS sites (one in each basin) through the 2008 water year (ending September 2008). In addition, streamflow and water-quality samples were collected at an additional site (South Branch Rush River, these water samples are discussed under Result 2). The Hawk Creek Watershed Project collects stream flow data at 2 additional sites (one on Chetomba Creek and one on West Fork Beaver Creek), so that between the agencies there are 2 sites in each basin, for a total of six sites. The USGS provided continuous (30-minute interval) real-time stream flow from the 4 USGS sites on the USGS National Water Information System website (http://waterdata.usgs.gov/nwis/rt). The selected water-quality parameters included on the website were temperature, pH, dissolved oxygen, specific conductance, and turbidity.

Summary Budget Information for Result 1:		
	Trust Fund Budget:	**$ 43,200**
	Amount Spent:	**$ 43,200**
	Balance:	**$ 0**
	Match Funds Spent	**$ 37,515**

Deliverable	**Completion Date**
1. Streamflow and water-quality data available on the web.	Sept. 1, 2007

Completion Date: September 30, 2008

Final Report Summary: Streamflow data was collected at 4 USGS sites and 1 Hawk Creek Watershed site. The streamflow records for South Branch Rush River near Bernadotte, South Branch Rush River near Norseland, West Fork Beaver Creek near Bechyn, and Chetomba Creek near Renville were reviewed and published in the annual data reports (http://wdr.water.usgs.gov/). Streamflow data from the three basins was disseminated through the web until September 2008. Water-quality records for specific conductance, pH, temperature, dissolved oxygen, and turbidity were disseminated in real-time to the web through the growing season. The water-quality meters were removed from the streams in September 2008.

Streamflow at Chetomba Creek near Renville ranged from 0–38.5 cubic meters per second (m^3/s; or 1,360 cubic feet per second (ft^3/s)) during 2005–08. Streamflow at West Fork Beaver Creek ranged from 0–12.5 m^3/s (442 ft^3/s) during 2005–08. Streamflow at South Branch Rush River near Norseland ranged from 0–16.5 m^3/s (584 ft^3/s) during 2006–08. Mean annual streamflow was greater in water year 2006 than in water year 2007 for Chetomba Creek, West Fork Beaver Creek, and South Branch Rush River. The maximum instantaneous peak flow for Chetomba Creek near Renville and South Branch Rush River near Norseland occurred in water year 2006, and the maximum peak flow for West Fork Beaver Creek occurred in water year 2007. Streamflow in water year 2008 was lower than water years 2006 and 2007 for Chetomba Creek and West Fork Beaver Creek. However, temporal streamflow patterns for South Branch Rush were different than other study sites, having higher flow in water year 2008 than in water years 2006 and 2007.

Water years 2007 and 2008 were historically dry years regionally. Zero flow occurred during many days in water years 2007 and 2008 for Chetomba Creek and South Branch Rush River. For the 10-year period of record at Chetomba Creek near Maynard (site 05314518), the annual mean streamflow was 2.59 m^3/s (91.3 ft^3/s), which is greater than the mean annual flows at this site during water years 2007 and 2008. Although the period of record is shorter at the other sites compared to site 05314518, water years 2007 and 2008 likely were low-flow years compared to historical flows at those sites as well (Chetomba Creek, West Fork Beaver Creek, and South Branch Rush River). Because of the effect of streamflow on water quality, concentrations of nutrients and sediment collected during this study may not be representative of historical conditions.

Result 2: Water-Quality and Biological Sampling

Description:

This enhancement to the Retired Lands project added water-quality sampling at a second South Branch Rush site during 2007. The sampling schedules described in previous work plans provided to the LCCMR (funded under ML 2005, First Special Session, [Chap.1], Art. 2, Sec.[10], Subd. 7(c)) was continued through 2008. This sampling includes 4 routine (low-flow) samples at each USGS site and at the Hawk Creek Watershed site on Chetomba

Creek and 3 event samples (high-flow). The samples collected by the USGS were analyzed for turbidity, sediment, and nutrients. The Hawk Creek Watershed Project continues to collect biweekly and event samples at their Chetomba Creek and West Fork Beaver Creek sites and this data was evaluated by the USGS to assess the paired sites in those basins. Additional sediment samples were collected during storm events, in order to compare the change in sediment delivery with the hydrograph. This enhancement to the project included up to 12 samples per site collected at USGS sites with automated samplers. Biological sampling was focused at several sites in the Chetomba basin in 2008, in order to characterize the difference in biology between the two sites with substantial land retirement between them.

Summary Budget Information for Result 2:

Trust Fund Budget:	**$ 144,800**
Amount Spent:	**$ 139,600**
Balance:	**$ 5,200**
Match Funds Spent	**$ 73,038**

Deliverable	**Completion Date**
1. Real time water-quality data will be posted on the web.	September 30, 2007

Completion Date: September 30, 2008

Final Report Summary: About 200 water-quality samples were collected from the three basins during 2008. This number is larger than collections in past years due to the storm samples that we were able to capture and process for sediment analysis. In-stream water quality monitors also were installed at South Branch Rush River near Bernadotte, South Branch Rush River near Norseland, and Chetomba Creek near Renville for the 2008 season and data was available in real-time from the USGS website: http://waterdata.usgs.gov/nwis/rt. The website provided continuous and real-time measures of specific conductance, pH, temperature, dissolved oxygen, and turbidity in the streams during the summer sampling season. A water-quality monitor was installed at Judicial Ditch No. 1. Data from this site was not available in real-time—it was downloaded every two weeks to the USGS data base. Autosamplers were installed at 3 of the sites (on the South Branch Rush and Chetomba Creek).

Although dissimilarities existed among the three subbasins, considerable effort was made to select subbasins that were similar with respect to some of the most important factors for water quality and biology. Concentrations of nitrite plus nitrate and total nitrogen decreased with increasing retired land percentage in the Minnesota River Basin. Nitrate plus nitrate concentrations were highest in South Branch Rush River, the subbasin with little or no land retirement, and lower in Chetomba Creek and West Fork Beaver Creek, subbasins with more total land retirement. Total phosphorus concentrations did not decrease with an increase in total (basin) land retirement. Total phosphorus concentrations were greatest at the site with the greatest retired land percentages within the subbasin, and increased with increases in the retired land percentage in the 50-m influence zone (defined as a 50-m zone on both sides of the stream). Chlorophyll *a* also did not follow a consistent trend with retired land characteristics except that concentrations were greatest at the site with the least amount of retired land in the 50-m influence zone.

The relation of benthic algal, benthic invertebrate, and fish metrics with retired land characteristics also was evaluated. Biological responses to retired land varied among the different taxa (algae, invertebrates, and fish) and varied with the proximity of retired land considered (total subbasin compared to influence zone). More clear relations were apparent for retired land within the 50-m influence zone than for retired land in the subbasin. The small sample size precludes a statistical analysis; however, an analysis of the trends observed can provide insight into the influence of retired land characteristics on biological resource quality. Although the algal measures analyzed showed no clear relations, the total algal biovolume (indicator of stream productivity) and the percentage of algal biovolume composed of blue-green algae were greatest at the site with the least retired land in the 50-m influence zone (Chetomba Creek near Renville).

Very few of the invertebrate measures were related directly with the percentage of land retirement in the subbasin, possibly due to differences in physical habitat among the streams. However, more clear relations were apparent between the invertebrate measures and retired land within the 50-m influence zone than for the percentage of land retirement in the subbasin. The number of fish species collected at each site was not related to the percentage of land retirement. However, the percentage of tolerant species decreased with increasing land retirement percentage, indicating better resource quality at sites with higher percentages of land retirement. In this study, IBI scores increased as the local land retirement percentages (50- and 100-m influence zones) increased. The relation was not as clear with retired land percentages in wider zones of influence.

Wilcox signed rank tests were performed on the paired samples from the upstream and downstream sites in Chetomba Creek and South Branch Rush River in order to test the significance of the differences. When concentrations at the upstream Chetomba Creek near Renville site are compared to concentrations at the downstream Chetomba Creek near Maynard site (Judicial Ditch No. 1), nitrite plus nitrate (p=0.03), total nitrogen (p=0.01), total phosphorus (p.0.03), and chlorophyll-*a* (p=0.02) concentrations decrease between the sites and the retired land percentage in the 50-m influence zone increases from 5.01 to 8.18 percent. Although orthophosphorus concentrations and SSCs decreased as well, these differences were not statistically significant using the Wilcox signed rank test. The decrease in concentrations between the upstream and downstream sites may indicate that the retired land between the two sites leads to improved water quality.

Biological and habitat data were collected from Chetomba Creek in August 2008 by Dr. Richard Kiesling and two USGS student employees. Two abstracts and a proceedings paper on the water-quality and biology in these basins were completed in spring 2008. (Christensen, V.G. and Lee, K.E., 2008, Effects of agricultural land retirement in the Minnesota River basin [abstract and paper], proceedings of the American Water Resources Specialty Conference, June 30-July 2, 2008: Virginia Beach, Virginia, 6p.; Christensen, 2008, Estimation of nutrient loads in streams affected by agricultural land retirement using continuous monitoring and laboratory concentrations [abstract], Minnesota Water Resources Conference, October 27-28, 2008, St. Paul, Minnesota.).

Result 3: Biological Data and GIS Analysis and Reporting

Description:
Existing biological data, compiled by the MPCA at about 100 randomly selected sites in the Minnesota River basin, was compared to biological data collected from this study and GIS coverages of land retirement. This comparison allowed the results from this study to be extended to other sites in the Minnesota River basin. This work was done by the USGS with the help of a graduate student to address the relation of retired land characteristics and biological integrity.

Summary Budget Information for Result 3:	**Trust Fund Budget:**	**$87,000**
	Amount Spent:	**$92,200**
	Balance:	**$- 5,200**
	Match Funds Spent	**$66,671**

Deliverable	**Completion Date**
1. USGS Scientific Investigations Report	September 30, 2009

Completion Date: September 30, 2009; extra time is required for the report to go through USGS review and for printing.

Final Report Summary: A student was hired to assist with the GIS data analysis for this project. Biological data was compiled into a GIS database. Watersheds were delineated, percent land retirement was recalculated for each watershed, a model was created that can calculate percent of other GIS layers in the watersheds. The data base was combined with an MPCA discharger data set, in order to adjust or eliminate sites that are affected by wastewater discharges. For each basin, land retirement percent within 50, 100, 200, 300, and 400 meter zones of influence was calculated, in order to compare with the results in Chetomba Creek, West Fork Beaver Creek, and South Branch Rush River. MPCA sites and data were queried and some initial adjustments were made to the database in order to exclude data that doesn't meet certain criteria (for example, data older than 10 years were removed).

81 sites were selected between 4.3 and 2200 km^2 to examine biological indicators, such as fish IBI response to environmental and instream factors, such as basin size and degrees of agricultural land retirement. Spearman's rho results indicate IBI was marginally correlated to retired land percentage in the basin (rho=.2014,p=.0698); however, IBI was significantly correlated to retired land percentage in the 50- to 400-m zones of influence surrounding the streams ($p<0.05$), indicating the local or riparian land retirement may have more influence on stream quality than land retirement in upland areas. These results suggest that retired land is significant to IBI and that a combination of instream factors act together to influence IBI scores. MANCOVA and ANCOVA models indicated that other environmental factors (such as drainage basin size and water storage) often were correlated to biological response, as were in-stream factors (standard deviation of water depth and substrate type). Metabolism was calculated from diurnal variations in dissolved oxygen for 2006 and 2007 data. Dissolved oxygen and metabolism calculations will be

published in a separate journal article at a later date (scheduled to be submitted by December 2009).

Results of the Land Retirement study were disseminated through USGS and BWSR websites, two abstracts, a conference proceeding paper, and several presentations and posters. The water-quality and streamflow information was provided in real-time through the USGS website. USGS and BWSR personnel have participated in basin activities highlighting the selected subbasins and emphasizing the effects of land retirement. Results also were presented to the Minnesota Board of Water and Soil Resources in August 2008 and at the Minnesota Water Resources conference in October 2008. A USGS Scientific Investigations Report entitled, "Water-Quality and Biological Characteristics and Responses to Agricultural Land Retirement in Streams of the Minnesota River Basin, Water Years 2006–08" is scheduled to be published by September 30, 2009. A manuscript has been completed covering Phase 2, tentatively titled, **"**Retired Land Characteristics Affect Aquatic Community Responses in Small Streams", will be submitted to a peer reviewed journal in September 2009.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: Streamgaging $43,200 (technician; stage sensor, data collection platform (DCP) rental; travel) Water-quality and biological sampling $144,800 (technician, biologist, hydrologist, students; water-quality equipment rental; travel; Lab analysis; supplies) Biological data and GIS analysis $87,000 (hydrologist, aquatic biologist, GIS specialist, GIS specialist, student; Travel; Printing)
Equipment: no equipment purchases; total equipment rentals=$37,200
Development: $ none
Restoration: $ none
Acquisition, including easements: $ none

TOTAL TRUST FUND PROJECT BUDGET: $ 275,000

Explanation of Capital Expenditures Greater Than $3,500: no capital expenditures greater than $3,500; however, total equipment rentals do exceed $3,500. No one piece of equipment exceeds $300/month.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: The USGS and the BWSR will be partners in the effort. The USGS will provide project design, management and evaluation, equipment, personnel, and half of the costs, in cash, for this project, through a joint funding agreement with the BWSR. The MPCA and Minnesota River Board have been consulted and are in support of the project. The BWSR and other agencies will provide in-kind support and may provide supplemental funding. A graduate student from Minnesota State University, Mankato or University of Minnesota will assist with the biological data and GIS analysis under the supervision of the USGS. The Hawk Creek Watershed Project will continue to assist with data acquisition.

B. Other Funds Proposed to be Spent during the Project Period: Because this project is a good fit with local and national science priorities of the USGS, federal matching funds (1:1) are available for this effort. The remainder of the USGS matching funds will be spent completing the Scientific Investigations report and 2 journal articles.
C. Past Spending: $ 260,000 in LCMR funds and $260,000 in USGS funds were spent prior to July 1, 2007.

D. Time: The project will include sampling from July 2007 through August 2008. Data analysis and report preparation will be complete by September 2009.

VII. DISSEMINATION:

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports were submitted not later than December 31, 2007, June 30, 2008, and December 31, 2008. A final work program report and associated products was submitted August 10, 2009 as requested by the LCCMR.

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: Land Retirement Effects on Minnesota River Basin Streams 5(c)

Project Manager Name: Victoria Christensen

Trust Fund Appropriation: $

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(06/30/09)*	**Balance** *(06/30/09)*	**Result 2 Budget:**	**Amount Spent** *(06/30/09)*	**Balance** *(06/30/09)*	**Result 3 Budget:**	**Amount Spent** *(06/30/09)*	**Balance** *(06/30/09)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Streamgaging			*Water-quality and biological monitoring*			*Biological Data and GIS Analysis and Reporting*				
BUDGET ITEM			0			0			0	0	0
PERSONNEL: wages and benefits for Hydrologist, Hydrologic Technicians (3), Biologist, Geographer (GIS), students	34,000	34,000	0	57,000	57,974	-974	81,000	88,439	-7,439	172,000	-8,413
Contracts			0			0			0	0	0
Professional/technical *(with whom?, for what?)*			0			0			0	0	0
Other contracts National Water-Quality Laboratory and Iowa Sediment Lab			0	33,000	25,513	7,487			0	33,000	7,487
Biological sampling				12,600	12,847	-247				12,600	-247
Other direct operating costs *(for what? – be specific)*			0			0			0	0	0
Equipment / Tools *(what equipment? Give a general description and cost)*			0			0			0	0	0
Stage sensor rental	2,000	2,000	0			0				2,000	0
Data collection platform rental	1,200	1,200	0			0				1,200	0
Water Quality equipment rental (water-quality monitors, autosamplers)			0	34,000	34,000	0				34,000	0
Office equipment & computers - NOT ALLOWED unless unique to the project			0			0			0	0	0
Repairs to water-quality equipment			0		211	-211			0	0	-211
Printing			0			0	2,000		2,000	2,000	2,000
Other Supplies *(list specific categories)*			0			0	0		0	0	0
Lab supplies			0	3,400	3,974	-574	0		0	3,400	-574
Postage and Freight			0		241	-241	0		0	0	-241
Travel expenses in Minnesota	6,000	6,000	0	4,800	4,800	0	4,000	3,761	239	14,800	239
Travel outside Minnesota *(where?)*			0			0			0	0	0
Construction *(for what?)*			0			0			0	0	0
Other land improvement *(for what?)*			0			0			0	0	0
Other (AWRA conference registration fee)			0		40	-40			0	0	-40
COLUMN TOTAL	**$43,200**	**$43,200**	**$0**	**$144,800**	**$139,600**	**$5,200**	**$87,000**	**$92,200**	**-$5,200**	**$275,000**	**$0**
Other project costs to be covered by the USGS:											
Personnel: Support Staff (Distributed Direct)	**$19,000**	**$5,515**	**$13,485**	**$43,000**	**$15,772**	**$27,228**	**$38,000**	**$25,729**	**$12,271**	**$100,000**	52,984
Facilities	**$5,000**	**$5,000**	**$0**	**$10,000**	**$6,540**	**$3,460**	**$9,000**	**$2,823**	**$6,177**	**$24,000**	9,637
Cost Center Assessment	**$17,000**	**$17,000**	**$0**	**$39,000**	**$41,051**	**-$2,051**	**$34,000**	**$34,000**	**$0**	**$90,000**	-2,051
Project specific laptop upgrade							**$1,000**	**$0**	**$1,000**	**$1,000**	1,000
Bureau Assessment	**$10,000**	**$10,000**	**$0**	**$29,000**	**$9,675**	**$19,325**	**$21,000**	**$4,119**	**$16,881**	**$60,000**	36,206
TOTAL USGS COSTS	$51,000	$37,515	**$13,485**	$121,000	$73,038	**$47,962**	$103,000	$66,671	**$36,329**	$275,000	97,776
TOTAL PROJECT COST	**$94,200**	**$80,715**	**$13,485**	**$265,800**	**$212,638**	**$53,162**	**$190,000**	**$158,871**	**$31,129**	**$550,000**	97,776

2007 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Demonstrating Benefits of Conservation Grasslands on Water Quality
PROJECT MANAGER: James E. Almendinger
AFFILIATION: Science Museum of Minnesota, St. Croix Watershed Research Station
MAILING ADDRESS: 16910 152nd St N
CITY/STATE/ZIP: Marine on St. Croix, MN 55047
PHONE: 651-433-5953, ext. 19
E-MAIL: dinger@smm.org
WEBSITE: www.smm.org/scwrs/
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 5(d)

APPROPRIATION AMOUNT: $374,000

Overall Project Outcome and Results

This study used sediment accumulation rates in 26 lakes in southern and western Minnesota as a measure of the delivery of eroded soil and phosphorus from watershed uplands to the lakes. Accumulation rates were calculated for the periods 1963-1986 and 1986-2007 to characterize sediment and phosphorus delivery before and after 1986, when many agricultural lands were converted to grasslands as part of the Conservation Reserve Program (CRP). Inorganic sediment accumulation rates decreased with increasing area of conservation grassland in the watershed. This linear relation explained only about 20% of the variance, leaving substantial unexplained scatter. The relation predicted that sediment accumulation would decrease by 3-4% for every 10% of cropland converted to grassland. Consideration of wetland sediment traps within the watershed did not measurably improve the relationship, nor did consideration of soil erodibility, slope, or flow accumulation factors. The decrease in sediment phosphorus accumulation rates as a function of increasing grassland area was not statistically significant at the $p = 0.05$ level. Diatom analyses demonstrated biotic change in selected lakes over time. In two of these lakes the change appeared to be driven by lake-water phosphorus concentrations, which declined in the post-1986 period perhaps in response to increased grassland area. In the absence of substantial land-cover change, inorganic sediment accumulation increased by about 20% and sediment phosphorus increased by about 35%, indicating that other factors were influential. These factors could include changes in annual rainfall, artificial drainage, in-lake sediment transport processes, and lag effects in transport from uplands to lowlands.

We conclude that this study demonstrated a fundamental incoherence between field-scale parameters influencing erosion and watershed-scale measurements of erosion. We recognize the fundamental importance of the empirical plot-scale studies that have quantified the effects of erodibility, slope, flow length, land cover, and other factors on erosion and nutrient transport. Yet, the complexities of transport paths between field and receiving waters make watershed-scale erosion highly variable and difficult to predict. Use of plot-scale parameters without modification to predict watershed-scale sediment yields is inappropriate. We need better understanding to re-scale such parameters appropriately, which can only be achieved by intensive studies that bridge the intermediate scales between fields and watersheds. New data sets, especially improved topographic data from LiDAR, will help with this effort. However, nothing can replace the actual measurement of sediment yield at different scales, which will provide the necessary constraints for theoretical equations to give realistic results.

Project Results Use and Dissemination

• An interpretive summary report will be downloadable from the Museum web site.
• A short (2-4 pp.) fact sheet likewise will be downloadable from the Museum web site, with hardcopies made available as requested.
• Results will be published in the academic peer-reviewed literature.

Trust Fund 2007 Work Program Final Report

Date of Report: 16 August 2010
Final Report
Date of Work program Approval: 5 June 2007
Project Completion Date: 30 June 2010

I. PROJECT TITLE:
Demonstrating Benefits of Conservation Grasslands on Water Quality

Project Manager: James E. Almendinger
Affiliation: Science Museum of Minnesota, St. Croix Watershed Research Station
Mailing Address: 16910 152nd St N
City / State / Zip : Marine on St. Croix, MN 55047
Telephone Number: 651-433-5953, ext. 19
E-mail Address: dinger@smm.org
FAX Number: 651-433-5924
Web Page address: www.smm.org/scwrs/

Location: central southern Minnesota; see attached map for potential study counties

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	**374,000**
	Minus Amount Spent:	**$**	**374,000**
	Equal Balance:	**$**	**0**

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 5(d).

Appropriation Language:
(d) Demonstrating Benefits of Conservation Grasslands on Water Quality
$374,000 is from the trust fund to the Science Museum of Minnesota to assess the long-term benefits of conservation grasslands in reducing sediment and nutrient loads through quantitative lake sediment analysis in small watersheds with different grassland acreages. This appropriation is available until June 30, 2010, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. and III. FINAL PROJECT SUMMARY:
This study used sediment accumulation rates in 26 lakes in southern and western Minnesota as a measure of the delivery of eroded soil and phosphorus from watershed uplands to the lakes. Accumulation rates were calculated for the periods 1963-1986 and 1986-2007 to characterize sediment and phosphorus delivery before and after 1986, when many agricultural lands were converted to grasslands as part of the Conservation Reserve Program (CRP). Inorganic sediment accumulation rates decreased with increasing area of conservation grassland in the watershed.

This linear relation explained only about 20% of the variance, leaving substantial unexplained scatter. The relation predicted that sediment accumulation would decrease by 3-4% for every 10% of cropland converted to grassland. Consideration of wetland sediment traps within the watershed did not measurably improve the relationship, nor did consideration of soil erodibility, slope, or flow accumulation factors. The decrease in sediment phosphorus accumulation rates as a function of increasing grassland area was not statistically significant at the $p = 0.05$ level. Diatom analyses demonstrated biotic change in selected lakes over time. In two of these lakes the change appeared to be driven by lake-water phosphorus concentrations, which declined in the post-1986 period perhaps in response to increased grassland area. In the absence of substantial land-cover change, inorganic sediment accumulation increased by about 20% and sediment phosphorus increased by about 35%, indicating that other factors were influential. These factors could include changes in annual rainfall, artificial drainage, in-lake sediment transport processes, and lag effects in transport from uplands to lowlands.

IV. OUTLINE OF PROJECT RESULTS:

Result 1: Water-quality benefits of conservation grasslands

Description:

To measure how water quality may have been improved by the replacement of cropland by grassland, we compared watershed-scale erosion before and after 1986, the first year of the Conservation Reserve Program. Because lakes trap most of the sediment that erodes in their watersheds, we used lake-sediment accumulation as a measure of watershed-scale erosion. We also explored how phosphorus in lake sediment might provide a similar measure of watershed-scale transport from fields to receiving waters.

In using lake sediment accumulation as a measure of watershed scale erosion, we put forth the following three hypotheses:

• Hypothesis (1): Lake sediment and phosphorus accumulation rates (and therefore landscape erosion rates) were lowest under natural prairie conditions, increased dramatically from 20th century agriculture practices, and decreased somewhat after the establishment of conservation grasslands.

• Hypothesis (2): Reductions in lake sediment and phosphorus accumulation rates accrued by establishment of conservation grasslands can be related primarily (a) to areal extent of these grasslands and other perennial vegetation, and (b) to the location of these vegetation units relative to overland flow paths from the uplands to the lake.

• Hypothesis (3): The algal community in the lakes has responded over time to phosphorus loading and will therefore be related to phosphorus accumulation rates in the sediment.

To test these hypotheses, we selected 26 lakes in small watersheds with different acreages of conservation grasslands. Sediment and phosphorus accumulation rates were measured in each lake via the analysis of lake sediment cores, thereby addressing Hypotheses (1) and (2). Five lakes were selected for analysis of sedimentary diatoms, a type of algae sensitive to phosphorus and well-preserved in lake sediments, thereby addressing Hypothesis (3). Results helped determine the degree to which agriculture has impacted landscape erosion and lake eutrophication, and how much the establishment of conservation grasslands may have improved the situation.

The project consisted of five tasks plus report preparation:

Task 1, Site Selection and Fieldwork: Site selection required significant review of available digital data to choose appropriate study lakes. Out of more than 40,000 open-water bodies in the 44-county study area in the southwestern half of Minnesota, we chose 20 lakes that had significant areas of CRP grassland in their watersheds. Six other lake watersheds with virtually no grassland were included as a contrast. One sediment core was collected from near the center of each lake, with the goal of collecting sediment dating back to the 1800s if possible.

Task 2, Sediment Analyses: Sediments were analyzed to separate the components that originated within the lake (organic matter and calcium carbonate) from those that eroded from the watershed. Radiometric methods were used to date the cores, which allowed us to calculate the rate of lake-sediment accumulation for eroded material for selected periods of time. Analysis of sediment phosphorus allowed a parallel calculation of phosphorus accumulation rates as well.

Task 3, Diatom Analyses: Five lakes were analyzed for sedimentary diatom remains to estimate past lake-water phosphorus concentrations. The time-consuming and specialized nature of diatom analysis precluded analysis of more lakes.

Task 4, Spatial Data Analyses: Lake watersheds were analyzed with geographic information system (GIS) software for two principal purposes. First, the landscape was topographically analyzed to determine the contributing areas for water and sediment, taking into account that some landscape depressions (identified with open water or wetland vegetation in aerial photographs) may trap some runoff-borne sediment that was otherwise bound for the lake. Second, land uses in the so-identified contributing areas were analyzed to determine their area and location for selected time periods. In particular, how much of the cropland in the watershed was replaced with grassland after 1986, and were those grasslands located in places where erosion would be stanched?

Task 5, Data Synthesis: Here, we related the changes in the rates of lake-sediment accumulation to the changes in land use (as cropland was converted to grassland), from before to after 1986, when the Conservation Reserve Program was effective. That is, how much did sediment accumulation change from before to after 1986? How much did land use (conversion of cropland to grassland) change from before to after 1986? How did the change in sediment accumulation rate relate to the change in land use?

We summarize the results of our findings below in the Final Report Summary section and have produced an interpretive report that discusses the methods, results, and conclusions in greater detail.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$**	**374,000**
	Amount Spent:	**$**	**374,000**
	Balance:	**$**	**0**

In the table below, deliverable products are categorized according to the tasks listed above. Completion date given below was the target for full achievement of each task. Fieldwork and lab work were completed mostly during years 1 and 2. Diatom analyses, GIS analyses, and data synthesis were done mostly during Years 2 and 3. Note that we actually sampled 26 lakes, rather than just the 10 planned for below; we did this by analyzing only one core per lake, rather than two or three.

Deliverable	**Completion Date**	**Budget**	**Status**
1. Site Selection & Fieldwork (10 sites, $5000/site)	31 Dec 2008	$50,000	100%
2. Sediment Analyses			
(a) LOI & magnetics (10 lakes, $1425/lake)	30 Jun 2009	$14,250	100%
(b) Core dating (10 lakes, $7675/lake)	30 Jun 2009	$76,750	100%
(c) Phosphorus & biogenic silica (10 lakes, $3400/lake)	31 Dec 2010	$34,000	100%
3. Diatom Analyses			
(a) Sample prep & counting (5 lakes, $8400/lake)	31 Dec 2009	$42,000	100%
(b) Inferred lake total phosphorus (5 lakes, $2100/lake)	31 Mar 2010	$10,500	100%
4. Spatial Data Analysis			
(a) Watershed current land use (10 lakes, $1575/lake)	30 Jun 2009	$15,750	100%
(b) Past land use (10 lakes, $2100/lake)	31 Dec 2009	$21,000	100%
(c) Grassland location analysis (10 lakes, $1575/lake)	31 Dec 2009	$15,750	100%
5. Data Synthesis			
(a) Temporal trend analysis	30 Sep 2009	$25,000	100%
(b) Relation to grass area & location	31 Mar 2010	$35,000	100%
6. Report Preparation	30 Jun 2010	$34,000	100%

Final Report Summary:

Task 1, Site Selection and Fieldwork:

Geographic information software (ArcGIS) was used to systematically search for study lakes across the 44-county study area (Figure 1). The ideal study lake would have a clearly delineated area of conservation grassland in its watershed; it would be deep enough to have a continuous sediment record; and it would have no perennial unvegetated channelized inlet that could contribute non-field (near-channel) erosion, as opposed to only field erosion, to the lake. Out of a total of 40,276 lakes in the study area identified in the 24K open-water data set available from the Minnesota Department of Natural Resources (MDNR), 1,155 were selected as being potentially deep (>6 m, or 20 ft) and without an inlet stream. For each of these lakes, a 1-km buffer was created (as a screening proxy for the lake watershed) and the percentage areas of grassland and Conservation Reserve Program (CRP) lands in this buffer were calculated. Grassland was identified from the Minnesota 2000 Level 1 Landsat Landcover Classification data set, produced by the University of Minnesota and available from the MDNR. CRP polygons as of 1993 and 2007 were obtained from the Farm Services Agency, and lakes were ranked according to the percentages of grassland and CRP in their 1-km buffers. About 150 lakes were examined in aerial photographs and screened for accessibility, with about 40 being chosen as possible sites. About half were rejected in the field, resulting in 20 lakes with different areas of CRP and other grassland in their watersheds being selected for study. Six other lakes with virtually no grassland in their watersheds were selected as control sites where land use did not change appreciably during the 1963-2007 study period, at least not with regards to the amount of CRP and grassland.

Sediment cores from the lakes were collected during the 2007-08 field seasons. Despite our screening process to target deep lakes, most lakes were in fact shallow (median depth of 2.78 m) and most appeared to have dried out (or nearly so) during the 1930s dust-bowl era. One core was collected from near the deepest part of each lake with a hand-operated piston sampler fit with a 7-cm diameter, 2-m long polycarbonate tube. The median core length was 83 cm. Commonly, the coring was stopped short by a layer of dense sediment, often with soil-like texture likely representing times in the past when the lake had dried out. Generally the top 10 cm of sediment was subsampled in 1-cm increments and deeper portions in 2-cm increments. Subsamples were stored in polycarbonate specimen cups in the cold room until further analysis.

Task 2, Sediment Analyses:

Basic sediment content was determined by loss-on-ignitions (LOI) analysis, which involves heating a sediment sample to increasingly higher temperatures and weighing the sample after each step to determine the weight loss. Three fractions are determined: organic matter, calcium carbonate, and residual inorganic matter. Our focus here was on the residual inorganic matter because it is derived mostly from soil erosion, which is what this project is trying to measure. We also determined the amount of biogenic silica (glass cell walls from diatoms, a type of algae) on several cores, to make sure that it was not a large part of the residual inorganic matter. Total phosphorus was also measured on the lake sediment with a chemical digestion procedure that dissolves all forms of phosphorus in the sediment.

The lake cores were dated principally with ^{210}Pb (lead-210), a naturally occurring radioisotope that is deposited in the sediment. This method can be used to date sediments back to about 1800 A.D. in many cases. The ^{210}Pb dating was confirmed or improved by analyzing for ^{137}Cs (cesium-137), a bomb product that peaked in 1963, which can generally be identified in sediment cores. We note here that developing sediment chronologies for these shallow lakes was challenging, partially because of processes that can slightly disturb sediment accumulation in shallow lakes, especially if these lakes dried in the past. Nonetheless, because ^{137}Cs can anchor the 1963 date, and because we know the core-top date is 2007-08 (when we cored the lakes), the period from 1963-2007 is the best-dated segment of each core. This segment is a convenient interval for testing the effect of conservation grasslands on erosion, because the 1986 initiation of such grasslands is about at the midpoint of the interval. In lakes that never went dry, such as Solem Lake, the sediment record is well-dated back to about the time of European settlement.

In combination, the ^{210}Pb and LOI analyses resulted in an estimated rate of dry matter accumulation rate (g cm^{-2} yr^{-1}) for selected points (time slices) in each core. Multiplying these dry-matter accumulation rates by the percentage of residual inorganic matter and sediment phosphorus concentrations gave the accumulation rates of eroded sediment and total phosphorus. The average accumulation rates from 1963-1986 and from 1986-2007 were calculated for each lake to quantify the percentage change in accumulation rate that could be related to the period before (pre-1986) and after (post-1986) the establishment of conservation grasslands.

Here we give an example of data from one lake, Solem Lake in Douglas County, which was well-dated back to at least 1850. Figure 2a shows that as agriculture became established in the late 1800s, the sediment became more inorganic, and its density increased. Beginning in 1986, about of the cropland (92%) was converted to grassland, and the sediment became slightly less inorganic. Sediment phosphorus concentrations increased gradually over the entire record. Note that biogenic silica (glass cell-walls from diatoms) was never a large component. The rates of sediment accumulation show a similar story. The accumulation rate of inorganic sediment (which we believe is a measure of watershed-scale erosion) peaked in the 1963-1986 period, and then declined about 28% after grassland was established (Figure 2b). In contrast, the accumulation rate of sediment phosphorus shows no such decline (Figure 2c).

Task 3, Diatom Analyses:

Diatoms are a type of microscopic algae that are responsive to lake-water chemistry and that have glass (biogenic silica) cell walls called “valves,” unique to each species, that tend to be preserved in lake sediments. Consequently, the analysis of diatom valves in lake sediments can show how the diatom community (the array of species present at any one time) changed over time, which in some lakes can be related to past lake-water total phosphorus (TP) concentrations. Because of the time-consuming and specialized nature of sedimentary diatom analysis, only six lakes were selected for diatom analysis. For each of these lakes, 10 down-core subsamples were processed to extract the diatom valves, which were mounted on microscope slides and examined under 1250X magnification. About

400 valves were identified to species on each slide and tallied to assess relative (percent) abundance.

Of six lakes examined, one was unsuitable because of poor preservation (dissolution) of diatom valves. Three showed diatom community change over time, but the changes were not clearly related to TP concentrations. Two lakes did show a relation to TP, however, and here we show the example from Little Lower Elk Lake, in Grant County (Figure 3). The species names mean little to anyone who is not a trained diatom specialist, but each of these species has a preferred, optimum TP concentration. For each level in the core, an aggregate TP concentration can be calculated by weighting these optimum concentrations by the relative abundance of each species in a sample. The result for Little Lower Elk Lake was that the TP concentrations in the lake water apparently peaked in about 1986 and declined thereafter, coincident with the increase in grassland in the watershed. However, because of the few lakes analyzed, this result may not be representative of other sites.

Task 4, Spatial Data Analyses:

We used the commercial ArcGIS package of geographic information system (GIS) software to analyze spatial data, both topographical and land-use data. Topographic analysis was critical to this project to identify the landscape areas contributing water, sediment, and nutrients to each lake. The principal data sets used were the digital elevation models (DEMs) surrounding each study lake. DEMs were obtained from the National Elevation Dataset (NED) website administered by the U.S. Geological Survey. A DEM is essentially an electronic map of an area comprising contiguous squares (grid cells), about 9x9 m in size, each of which is given the value of the land elevation at the center of that square. ArcHydro is a module within ArcGIS that analyzes the elevations of nearby grid cells to infer landscape slope, landscape depressions, flow directions, drainage networks, and watershed boundaries. We used ArcHydro to identify the hydrologic watershed for each lake, and we checked the result against recent aerial photographs and topographic maps for consistency, in case there were large errors in the digital data set.

Besides the hydrologic watershed, we also identified alternative contributing areas that may better represent the “sediment-shed” of each lake, that is, the area of landscape that may contribute sediment to each lake. To this end we excluded areas of the watershed that drain internally to wetlands depressions, which presumably trap incoming sediment. We used ArcHydro to identify depressions and examined aerial photos to estimate whether each depression was major or minor, based on the presence of standing water and wetland vegetation cover. We labeled the full hydrologic watershed of each lake WS1. Then, the secondary watershed (WS2) started with the WS1 polygon and then excluded the drainage areas of major depressions. In turn, the tertiary watershed (WS3) started with the WS2 polygon and then excluded the drainage areas of minor depressions. Figure 4 shows the resulting contributing areas for Solem Lake, which had a very simple watershed. Most lakes had larger watersheds with a more complex array of wetland depressions.

Digital land-use data were obtained for all study sites. Maps of set-aside lands enrolled in the CRP were obtained for about 1993 and 2007 from the Farm Services Agency (FSA) in Minnesota. Land use over time was acquired from several different data sets. Aerial photographs from 2006 were obtained from the Farm Services Administration National Aerial Image Program. Photographs from the 1980s and 1990s were obtained principally from the National Aerial Photography Program (NAPP), and the National High Altitude Photography Program (NHAP). In addition, we also used the National Land Cover Datasets (NLCD) for 1992 and 2001, which are based on interpretations of satellite imagery at a resolution of 30-m grid cells. Figure 5 shows example land uses for (again) Solem Lake in Douglas County. Note that this lake had most (92%) of the cropland in its pre-1986 watershed (WS1) converted to grassland in the 1990s and 2000s.

The above data sets allowed quantification of the areas of CRP lands and other perennial vegetation land-cover types, and how these areas changed over time, in particular from the pre- to post-1986 periods (before and after establishment of CRP). The locations of these vegetation patches must also be important in modifying watershed-scale erosion processes and rates. To address this concern, we quantified two factors known to influence erosion as determined by their inclusion in the Universal Soil Loss Equation (USLE). The K factor is soil erodibility, which was available from the digital Soil Survey Geographic Database (SSURGO). The LS factor in the USLE combines the effect of land slope length and steepness, which was calculated from the DEM for each watershed. The larger the K and LS factors, the greater the potential for erosion at that point in the watershed. We used these factors to weight the areas of grassland in each watershed, to see if grassland located where K and LS were large had an identifiable effect in reducing erosion.

Task 5, Data Synthesis:

Our goal in data synthesis was to search for a simple relationship between watershed-scale erosion (our y, or dependent, variable) and area of grassland in the contributing watershed (our x, or independent, variable). Watershed-scale erosion can also be called the sediment yield. Comparing the sediment yield in one watershed to that of another with different grassland area is imprecise, because all watersheds are different in more ways than just land cover. Instead, we normalized for all between-watershed differences by comparing each watershed with itself. That is, we compared sediment yields in the same watershed before (pre-1986), and after (post-1986), conservation grasslands were established.

Our principal method here was to construct our dependent (y) variable as the change in accumulation rate of residual inorganic sediment from pre- to post-1986, as a percentage relative to the pre-1986 rate: 100 * (rate 2 – rate 1) / rate 1. This y variable was then regressed against various selected possible independent (x) variables quantifying in different ways the conversion of cropland to grassland. We likewise constructed a dependent (y) variable as the relative change in sediment phosphorus accumulation, and regressed that y variable against the same set of x variables.

The first independent (x) variable was simply the relative change in grassland area from pre-1986 to post-1986, calculated here as a percent of the pre-1986 cropland area it replaced. For the WS1 level of watershed delineation, the percent change in residual inorganic sediment accumulation was negatively related to the percent change of cropland replaced by grassland from the pre- to post-1986 period (Figure 6a). In seeking a tighter relation with less scatter, we recalculated the regression for the same variables, except this time for the WS2 and WS3 watershed delineations, reasoning that the relation between land cover and sediment accumulation should be improved by excluding those areas of landscape that do not appear to contribute sediment (Figure 6b and c). These efforts in fact worsened the relationship, which became progressively less significant (p values increased) and explained even less variance (R^2 values decreased). The scatter about the lines, and the difference between the three watershed delineations, indicate that the regression parameters should be viewed as only approximate.

The same set of regressions were run for the percent change in accumulation rate of sediment total phosphorus as a function of percent cropland converted to grassland within WS1, WS2, and WS3 delineations (Figure 6 d, e, and f). All regressions had negative slopes, qualitatively suggesting that replacing cropland with grassland results in lower accumulation of sediment phosphorus. However, none of these relations was significant at the $p = 0.05$ level and the variance explained was small ($R^2 = 0.12$ at most, for the WS1 delineation). As for the sediment accumulation rates, recalculating the regressions for the WS2 and WS3 delineations worsened the relationship (smaller R^2 values and larger p values).

Placing the grassland in areas where it could armor the watershed against potential erosion as measured by K and LS factors produced similar, but not strikingly better, results (Figure 7). Our dependent variable here was again the percent change in inorganic sediment accumulation rate from the pre- to post-1986 period. The relation shown in Figure 7a is entirely parallel to that shown in Figure 6a, except here the change in grassland area is given as a percent of total upland area, rather than cropland area, without taking into consideration where that grassland was located. Figures 7b and c show that incorporating the effects of K and LS factors did not substantially improve our understanding of the relation between sediment accumulation and conversion of cropland to grassland. This analysis does not mean that the K and LS factors are not important, only that their effects were not demonstrated in our data configuration at the watershed scale.

The principal results above are epitomized in Figures 6a and 7a, which indicate that watershed-scale erosion decreased as area of conservation grassland (either as percent of cropland or as percent of upland) increased. Two characteristics of this relationship beg explanation. Why was the intercept so much greater than zero? Why was there so much scatter about the regression line?

The positive intercept indicated that something systematically changed across the study area such that rates of sediment accumulation increased about 20% from the pre- to post-1986 period. Annual normal precipitation has increased by as much as two inches in parts of the study area over this time, which could contribute to increased erosion and transport to receiving waters. Increased artificial drainage practices that concentrate flow to erosive gullies could also contribute. This increase in sediment transport is contrary to what would be expected from increased use of conservation tillage, which we presume has increased during the post-1986 period. Perhaps the increase would have been greater than 20% without such practices.

Scatter about the regression line is expected in all such studies based on field data and points to the value of studying as many lakes as possible. The scatter could have been caused by errors in the sediment data, errors in the land-use data, or the influence of unaccounted factors. Errors in sediment data analysis were no larger for this project than others, where sediment content (LOI and phosphorus) analyses and ^{210}Pb dating methods have been substantiated many times. Probably the largest sediment-related errors are related to whether the one core we collected from each lake was representative for that lake, though comparison of rates within the same core should minimize the effects of differences among cores. Errors in land use also do not seem to be overly problematic. Interpretation of satellite imagery can fairly reliably distinguish between cropland and grassland, and CRP polygons were reliably grassland when we field-checked each watershed.

Many unaccounted factors could have contributed to the scatter in Figures 6 and 7. Foremost among these is that lands other than cropland may have been major sediment sources; replacement of cropland with conservation grassland would have had little or no effect on erosion from these sources. Even though we chose lakes without perennial inlet streams that could contribute sediment from channel erosion, erosion from intermittent channels, ravines, or gullies could have continued unabated. Wind-blown sediment is another potential source unaffected by conversion of local cropland to grassland, though we doubt regional dustfall can account for drastic differences between lakes. Finally we speculate that there may be time lags in operation, wherein eroded sediment is temporarily stored in intermediate locations and later mobilized by runoff to points farther downgradient. The toes of slopes along the valley walls of intermediate streams and floodplains of perennial streams may provide such temporary storage locations. Likewise, macrophyte beds in shallow lakes may provide temporary holding locations for fine-grained sediment before being resuspended and moved toward the middle of lake, where our sediment cores are typically collected. These temporary storage locations may be envisioned as an intermittent conveyor belt, effecting a time lag between the initial erosion in the upland and the eventual deposition at the coring site.

We conclude that this study demonstrated a fundamental incoherence between field-scale parameters influencing erosion and watershed-scale measurements of erosion. We recognize the fundamental importance of the empirical plot-scale studies that have quantified the effects of erodibility, slope, flow length, land cover, and other factors on erosion and nutrient transport. Yet, the complexities of transport paths between field and receiving waters make watershed-scale erosion highly variable and difficult to predict. Use of plot-scale parameters without modification to predict watershed-scale sediment yields is inappropriate. We need better understanding to re-scale such parameters appropriately, which can only be achieved by intensive studies that bridge the intermediate scales between fields and watersheds. New data sets, especially improved topographic data from LiDAR, will help with this effort. However, nothing can replace the actual measurement of sediment yield at different scales, which will provide the necessary constraints for theoretical equations to give realistic results.

V. TOTAL TRUST FUND PROJECT BUDGET:
Staff or Contract Services: $360,150

Staff: $206,150
- Almendinger (~50%) & Schottler (~17%) (PIs)
- Edlund &/or Ramstack (~15%) (Diatom analyses)

Analytical expenses: $154,000
- Sediment analyses ($104,000)
- GIS analysis ($50,000)

Equipment/Other: $13,850

Supplies (5% analytical): $10,200
Travel: $3,650

Development: $0
Restoration: $0
Acquisition, including easements: $0

TOTAL TRUST FUND PROJECT BUDGET: $374,000

Explanation of Capital Expenditures Greater Than $3,500:

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

Local partnerships will be developed upon site selection

B. Other Funds Proposed to be Spent during the Project Period:

None.

C. Past Spending:

Several LCMR-recommended projects totaling about $400,000 allowed us to develop novel sediment fingerprinting methods and gain watershed modeling expertise which is relevant to this project.

D. Time:
Years 1 and 2 were occupied largely by fieldwork and laboratory analyses of the lake sediment. Year 3 was devoted to final laboratory analyses, GIS analyses, statistical analyses, and data synthesis.

VII. DISSEMINATION:
• The academic community will be informed via the technical interpretive report, conference presentations, and peer-reviewed journal articles. The interpretive report will be downloadable from the Museum web site.
• Local resource managers in the counties where lake sites are located will be given hard copies of the report.
• LCCMR members and other selected legislators at the state and federal level will be informed via a fact sheet that summarizes the principal findings of this project. The fact sheet will also be available via the Museum web site.
• Dissemination activities:
None to date.

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports were submitted in January 2008, July 2008, January 2009, July 2009, and January 2010. This final work program report was submitted August 16, 2010 as requested by the LCCMR

IX. RESEARCH PROJECTS:
The associated research report for this project provides greater detail on the methods, results, and discussion.

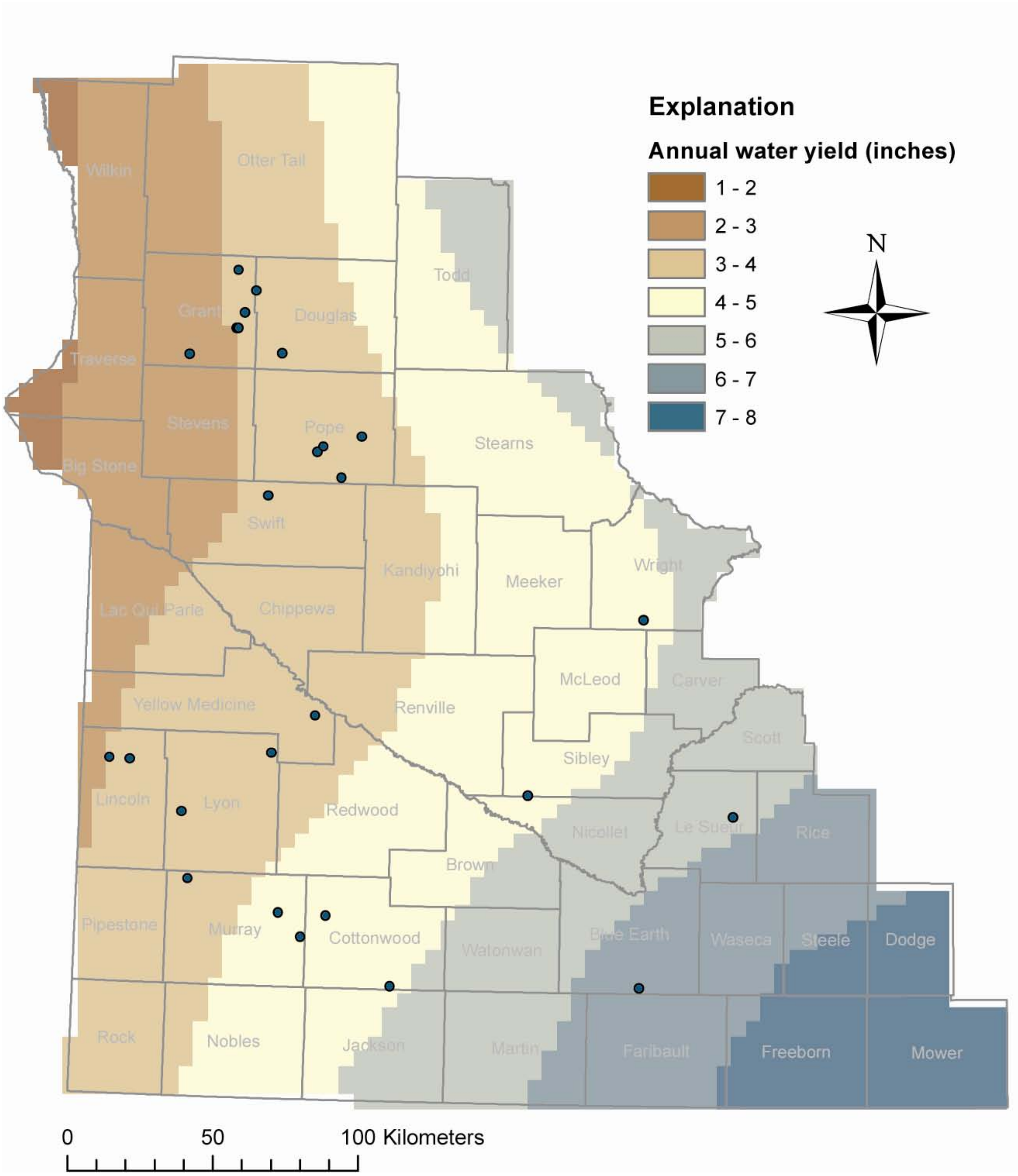


Figure 1. Study lake locations in 44-county area of southwestern Minnesota in relation to mean annual water yield
(Water yield, also called generalized runoff, was based on 1940-2005 flow data; gridded map shown here courtesy of D.L. Lorenz, U.S. Geological Survey, personal communication, 2010)

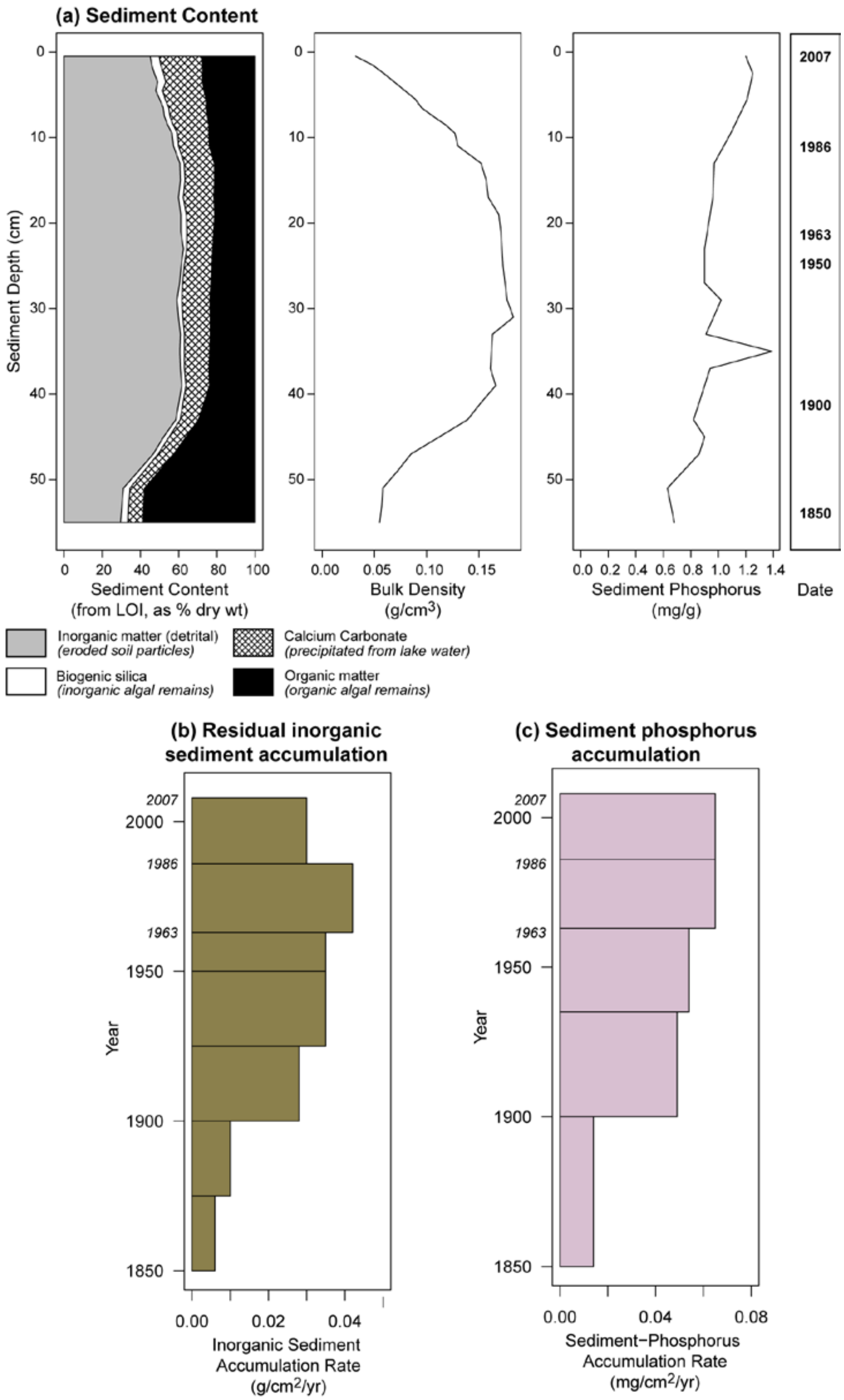


Figure 2. Sediment data for Solem Lake, Douglas County.

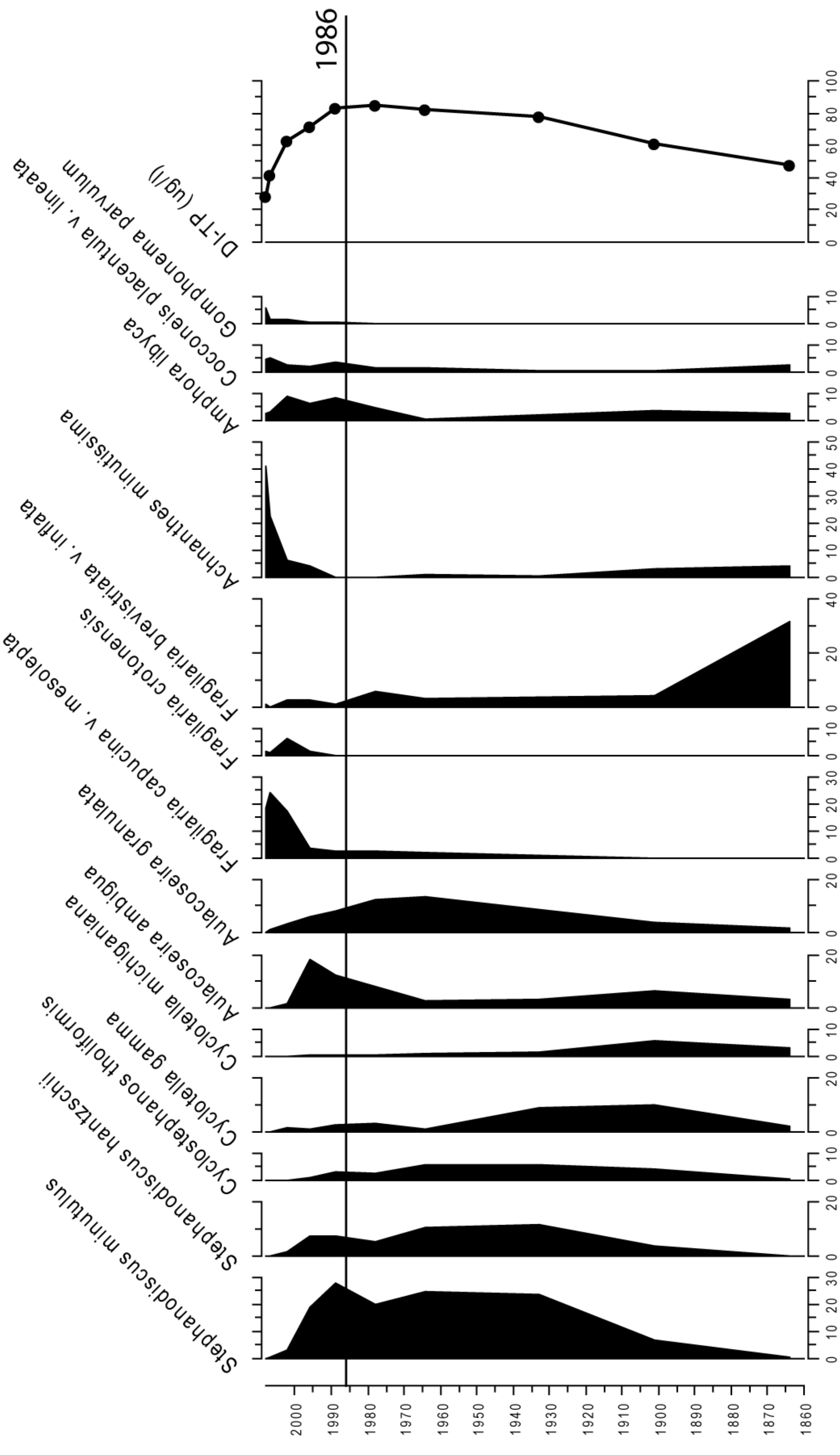


Figure 3. Diatom stratigraphy and diatom-inferred total phosphorus (DI-TP) for Little Lower Elk Lake, Grant County

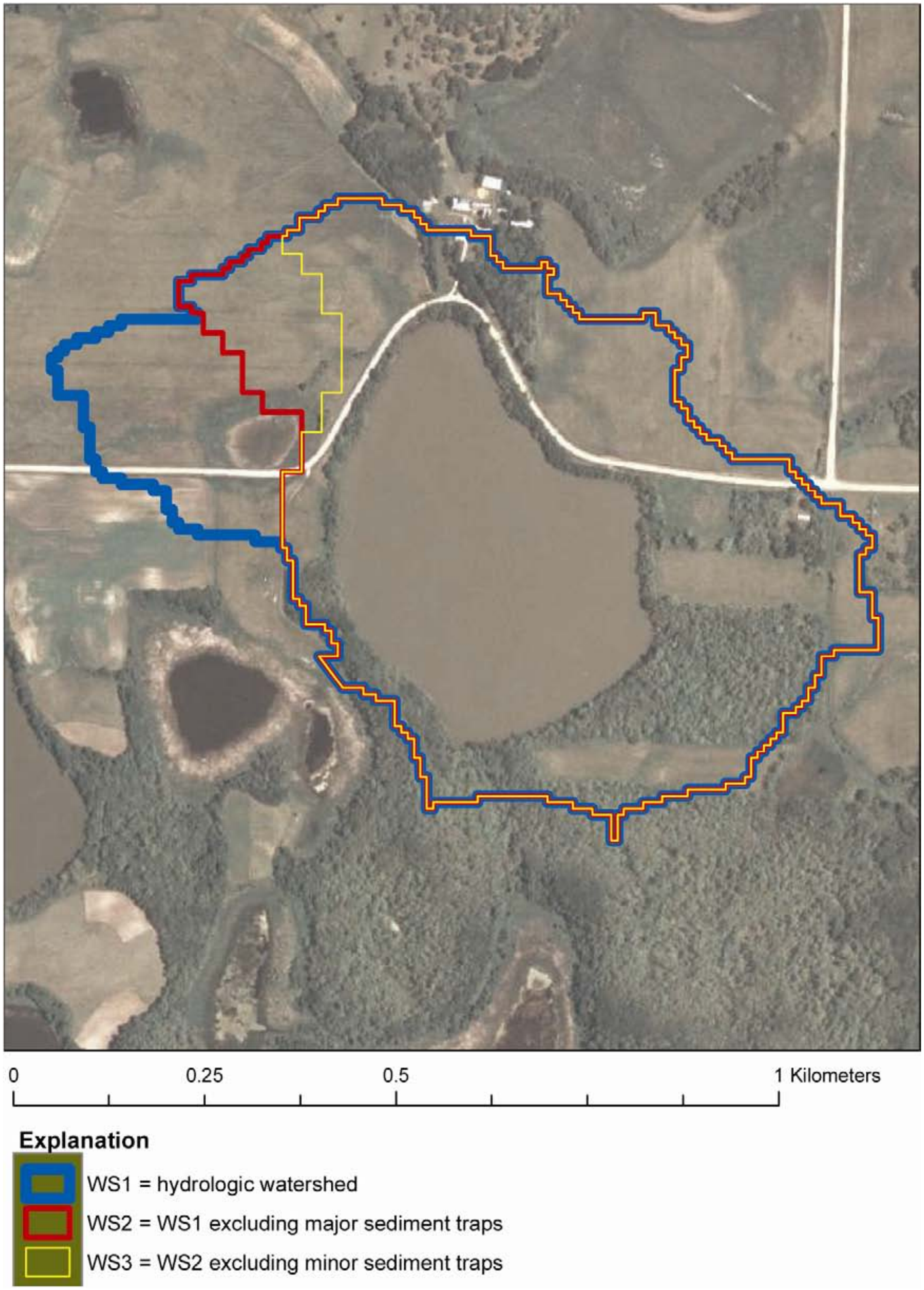


Figure 4. Watershed delineations for Solem Lake, Douglas County.

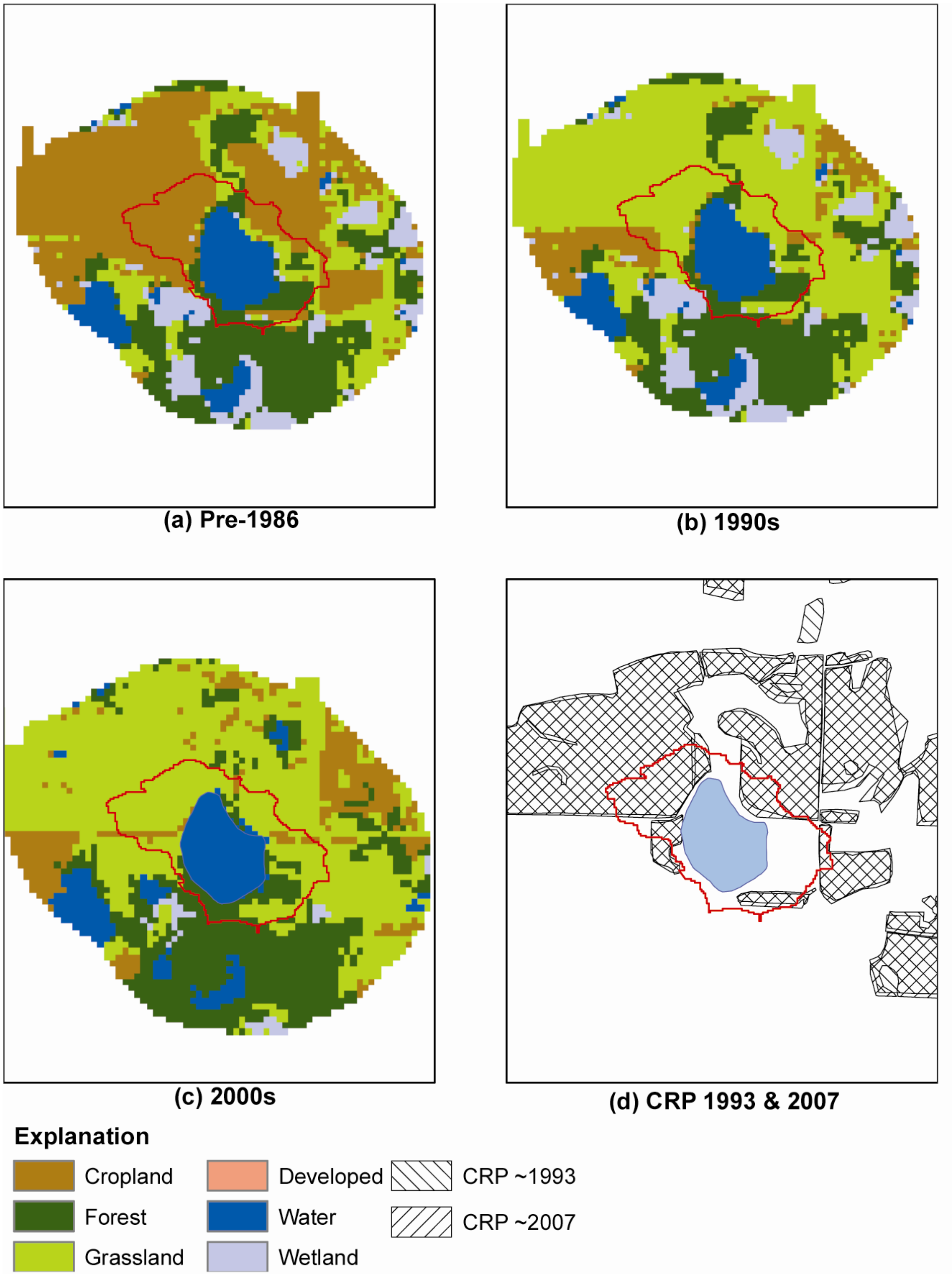


Figure 5. Land use surrounding Solem Lake, Douglas County.
Red line delineates the WS1 watershed boundary.

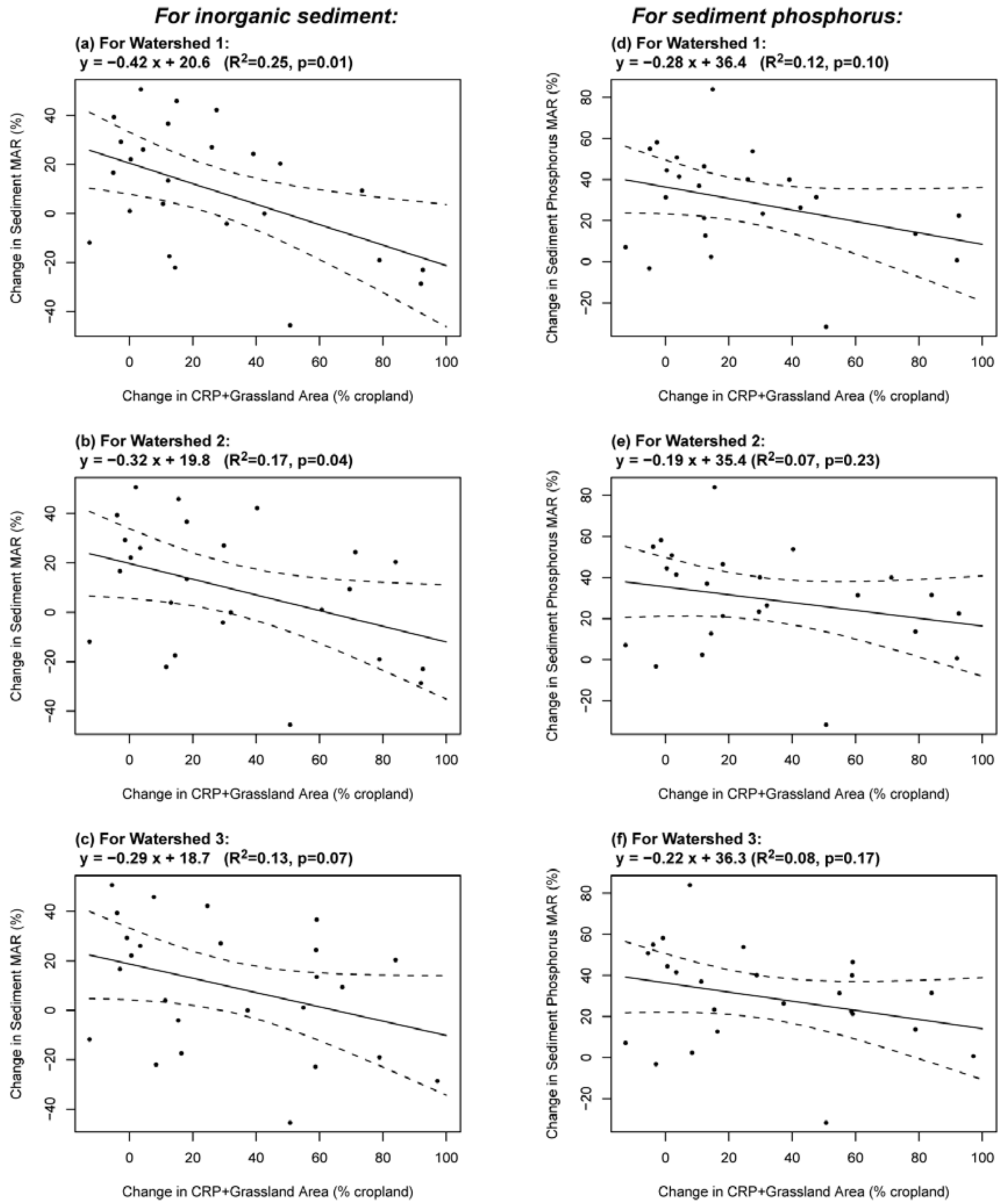


Figure 6. Relations between change in grassland cover, change in inorganic sediment mass accumulation rate (MAR), and change in sediment-phosphorus MAR, for three levels of watershed delineation.
CRP = Conservation Reserve Program

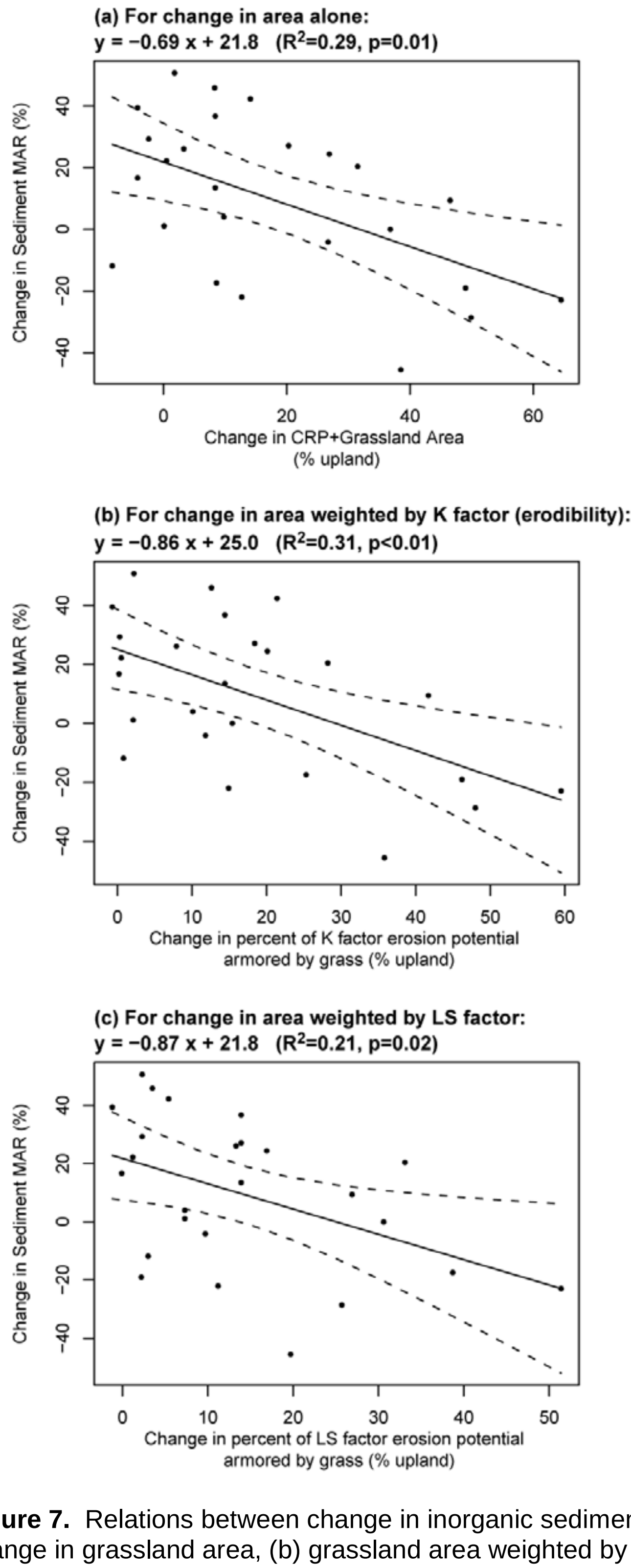


Figure 7. Relations between change in inorganic sediment mass accumulation rate (MAR) and (a) change in grassland area, (b) grassland area weighted by K factor, and (c) grassland area weighted by LS factor.

Attachment A: Budget Detail for 2007 Projects

Project Title: 5(d) Demonstrating Benefits of Conservation Grasslands on Water Quality

Project Manager Name: James E. Almendinger

Trust Fund Appropriation: $374,000

2007 Trust Fund Budget		**Result 1 Budget:**	**Amount Spent as of 30 Jun 2010**	**Balance as of 30 Jun 2010**	**TOTAL BUDGET**	**TOTAL BALANCE**
BUDGET ITEM		Water-quality benefits of conservation grasslands				
Personnel: wages and benefits	**Subtotal -->**	**$206,150**	**$206,150**	**$0**	**$206,150**	**$0**
Almendinger *(project manager) -- 50% time* ***Schottler*** *-- 17% time* ***Ramstack*** *&/or* ***Edlund*** *(diatom analyses) -- 15% time*		*$161,687*	*$161,687*			
Benefits *(FTE's only) -- Approx. 27.5% FTE salaries*		*$44,463*	*$44,463*			
Medical: Single $200/mon; Family $720/mon *Dental: Single, $25/mon; Family $55/mon* *Life Insurance: 0.16*2*annual salary/1000* *Retirement: 8% annual salary/year*						
Other direct operating costs	**Subtotal -->**	**$154,000**	**$154,000**	**$0**	**$154,000**	**$0**
Sediment analyses		*$104,000*	*$104,000*			
LOI, magnetics, radiometric dating, phosphorus, and biogenic silica						
Diatom analyses		*$0*	*$0*			
Sample preparation and counting; statistical inference of lake-water total phosphorus concentration ($50,000 expense moved to Personnel category -- see Ramstack & Edlund above)						
GIS analyses		*$50,000*	*$50,000*			
Watershed delineation, present and past land use, and grassland location analysis						
Other Supplies	**Subtotal -->**	**$10,200**	**$10,200**	**$0**	**$10,200**	**$0**
Lab supplies (reagents, glassware, etc.) and field supplies (core tubes, tape, hardware, etc.)						
Travel expenses in Minnesota	**Subtotal -->**	**$3,650**	**$3,650**	**$0**	**$3,650**	**$0**
COLUMN TOTAL		**$374,000**	**$374,000**	**$0**	**$374,000**	**$0**

Attachment A: Budget Detail for 2007 Projects

Project Title: 5(d) Demonstrating Benefits of Conservation Grasslands on Water Quality

Project Manager Name: James E. Almendinger

Trust Fund Appropriation: $374,000

2007 Trust Fund Budget		Result 1 Budget:	Amount Spent as of 30 Jun 2010	Balance as of 30 Jun 2010	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM		Water-quality benefits of conservation grasslands				
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Almendinger *(project manager) -- 50% time* ***Schottler*** *-- 17% time* ***Ramstack*** *&/or* ***Edlund*** *(diatom analyses) -- 15% time*		*$161,687*	*$161,687*			
Benefits *(FTE's only) -- Approx. 27.5% FTE salaries* *Medical: Single $200/mon; Family $720/mon* *Dental: Single, $25/mon; Family $55/mon* *Life Insurance: 0.16*2*annual salary/1000* *Retirement: 8% annual salary/year*		*$44,463*	*$44,463*			
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Diatom analyses *Sample preparation and counting; statistical inference of lake-water total phosphorus concentration ($50,000 expense moved to Personnel category -- see Ramstack & Edlund above)*		*$0*	*$0*			
GIS analyses *Watershed delineation, present and past land use, and grassland location analysis*		*$50,000*	*$50,000*			
Other Supplies	**Subtotal -->**	**$10,200**	**$10,200**	**$0**	**$10,200**	**$0**
Lab supplies (reagents, glassware, etc.) and field supplies (core tubes, tape, hardware, etc.)						
Travel expenses in Minnesota	**Subtotal -->**	**$3,650**	**$3,650**	**$0**	**$3,650**	**$0**
COLUMN TOTAL		**$374,000**	**$374,000**	**$0**	**$374,000**	**$0**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Improved River Quality Monitoring Using Airborne Remote Sensing
PROJECT MANAGER: Fei YUAN
AFFILIATION: Earth Science Program, Minnesota State University, Mankato
MAILING ADDRESS: 7 Armstrong Hall, Department of Geography, Minnesota State University
CITY/STATE/ZIP: Mankato, MN, 56001-6026
PHONE: 507-389-2376 (Office); 507-389-2617 (Geog Dept.)
FAX: 507-389-2980
E-MAIL: fei.yuan@mnsu.edu
WEBSITE: http://sbs.mnsu.edu/geography/people/feiyuan.html
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, [Chap.30], Sec.[2], Subd.5(e).

APPROPRIATION AMOUNT: $159,000

Overall Project Outcome and Results

To improve the study and monitoring of river water quality and riparian habitat in Minnesota this project proposed and successfully implemented a new and innovative research methodology, *airborne dynamic hyperspectral remote sensing* (remote sensing measures properties of the environment using sensors placed on aircraft or spacecraft). This study has more accurately and cost effectively identified water quality and critical sediment supply areas than possible through traditional or previously used monitoring methods. All methods and results developed here can readily be applied to other watersheds.

For the first time ever in the USA we employed the highly cost effective Civil Air Patrol (CAP) ARCHER (Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance) remote sensing system to monitor water quality in a river. In addition to successfully piloting this new methodology in the highly impacted Blue Earth River (BER) watershed, tangible results and products include:

- Located highly erodible lands in the BER riparian corridor.
- ARCHER can successfully identify Total Suspended Sediment, Turbidity and other water quality measures thus potentially reducing time and costs using traditional methods in any watershed.
- Identified locations of high sediment input areas and spatial and temporal patterns of river water quality.
- Developed a hydrologic model to predict amount and location of sediment and stream flow based upon the size and intensity of precipitation events.
- A Geographic Information System database was developed that contains all project data.
- Two full years of detailed water quality data collected from ARCHER flights, traditional field sampling methods and related laboratory analyses. Water samples were collected along the entire river system at the same time as ARCHER flyovers, during spring runoff and during nearly all rainfall events.
- Processed remote sensing imagery and laboratory data from this study is ready for use in future studies and management decisions.

Project Results Use and Dissemination

The results and findings were documented in project updates to the LCCMR, through multiple conference presentations by the project scientists and their graduate students, three Minnesota State University (MSU) Geography Department master's theses, several academic articles, and further professional presentations are in preparation, with some of these items already available on the web. Partnerships established to complete the project include local, county, regional, state and federal agencies and scientists at those agencies and at other universities. Communication and outreach has flourished with the creation of a nation-wide ARCHER working group founded by this project's scientists: members include MSU, and professionals from 13 other state and federal agencies, universities, and the private sector. A meeting of the working group will take place April 2010 at the annual meeting of the Association of American Geographers (AAG) in Washington, DC.

To implement and complete the project we established partnerships with MPCA, Faribault & Martin Co. Soil & Water Conservation Districts, U.S. Army Corps of Engineers, and University of Minnesota. In 2008, we were contacted by USGS and Missouri (Mo) DNR who were interested in knowing more about our projects and findings. Thereafter, we formed an ARCHER working group to "provide a forum for agencies/researchers with on-going or anticipated projects using ARCHER imagery to collaborate, exchange information on promising applications and share analytical techniques" (http://rmgsc.cr.usgs.gov/awg/index.shtml). Besides us, other members include CAP, USGS, USFWS, EPA, FEMA, BLM, MoDNR, MoRAP (Missouri Resource Assessment Partnership), Space Computer Corporation, and other university and industry-based individuals. The working group holds monthly conference calls and exchanges lots of e-mail and phone communications. We have organized special sessions on ARCHER applications in the 2010 national conference of the AAG (Association of American Geographers) in Washington, DC.

Especially noteworthy is our partnership with the CAP (Civil Air Patrol). Based on methodologies we developed specifically for this project to pre-process ARCHER data, the CAP has now adopted our methods and has now supplied the needed software to all 16 ARCHER stations across the country. This is of great significance because of the potential for using ARCHER in environmental monitoring nationwide.

Trust Fund 2007 Work Program Final Report

Date of Report: October 7, 2009
Date of Work program Approval: June 5, 2007; March 4, 2008; September, 2008
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Improved River Quality Monitoring Using Airborne Remote Sensing

Project Manager: Fei Yuan
Affiliation: Earth Science Program, Minnesota State University, Mankato
Mailing Address: 7 Armstrong Hall, Department of Geography, Minnesota State University, Mankato
City / State / Zip: Mankato, MN, 56001
Telephone Number: 507-389-2376 (Office); 507-389-2617 (Geog Dept.)
E-mail Address: fei.yuan@mnsu.edu
FAX Number: 507-389-2980
Web Page address: http://sbs.mnsu.edu/geography/people/feiyuan.html

Location: Blue Earth County, Blue Earth River (see Figure 1 in attached research addendum)

Trust Fund 2007 Work Program Final Report

	Actually Spent**	Requested**
Total Trust Fund Project Budget:	159,000.00	159,000.00
Expenditures:	-146,812.22	-158,872.00
Balance Remaining:	**$12,187.78**	**$128.00**

***Please see section III*

Legal Citation: ML 2007, [Chap.30], Sec.[2], Subd.5(e).
Appropriation Language:

Title: Improved River Quality Monitoring Using Airborne Remote Sensing
$159,000 is from the trust fund to Minnesota State University, Mankato, to monitor river water quality and riparian habitat through airborne dynamic hyperspectral remote sensing on the Blue Earth River.

II. FINAL PROJECT SUMMARY

To improve the study and monitoring of river water quality and riparian habitat in Minnesota this project proposed and successfully implemented a new and innovative research methodology, *airborne dynamic hyperspectral remote sensing* (remote sensing measures properties of the environment using sensors placed on aircraft or spacecraft). This study has more accurately and cost effectively identified water quality and critical sediment supply areas than possible through traditional or previously used monitoring methods. All methods and results developed here can readily be applied to other watersheds.

For the first time ever in the USA we employed the highly cost effective Civil Air Patrol (CAP) ARCHER (Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance) remote sensing system to monitor water quality in a river. In addition to successfully piloting this new methodology in the highly impacted Blue Earth River (BER) watershed, tangible results and products include:

- Located highly erodible lands in the BER riparian corridor.
- ARCHER can successfully identify Total Suspended Sediment, Turbidity and other water quality measures thus potentially reducing time and costs using traditional methods in any watershed.
- Identified locations of high sediment input areas and spatial and temporal patterns of river water quality.
- Developed a hydrologic model to predict amount and location of sediment and stream flow based upon the size and intensity of precipitation events.
- A Geographic Information System database was developed that contains all project data.
- Two full years of detailed water quality data collected from ARCHER flights, traditional field sampling methods and related laboratory analyses. Water samples were collected along the entire river system at the same time as ARCHER flyovers, during spring runoff and during nearly all rainfall events.
- Processed remote sensing imagery and laboratory data from this study is ready for use in future studies and management decisions.

III. PROGRES SUMMARY

Retroactive Amendment Request Update
The discrepancy in funds spent on the project, approximately $12,000, is due to a payroll request being submitted to the State payroll system after the deadline for previous fiscal years. However, the project scientists were unaware of separate payroll and project expense deadlines and began pursuing release of funds allocated to this project with the Minnesota Office of Management and Budget but have now abandoned those efforts. Thus, our total expenses are $12,187.78 less than total funds budgeted to this project. Complete details are described immediately below.

Background and details:
In December 2008, due to unforeseen circumstances we discovered that our equipment and supply budgets were not sufficient to successfully complete the project so we applied for an amended budget which was approved. At the very end of the project, in May and June of 2009, we were pleasantly surprised to find that the costs for remote sensing provided by a vendor, in this case the Civil Air Patrol (CAP), were significantly less than originally anticipated and that our travel expenses were significantly less than budgeted. It also appeared that we were under the revised budget for personnel costs.

In our attempt to be good fiscal managers and to not overspend, we waited into July for all accounts to settle before requesting the final $12,059.37 in personnel costs to be paid to the project scientists for work performed in May and June, i.e. FY 09. All student salaries, equipment, supply and vendor costs were accounted for. We submitted paperwork to our university on July 22, which was received by our human resources office on July 24 and the request was entered in the university payroll system on Friday, July 31 which then rolled over to the State payroll system by the next working day, August 3.

Previously unbeknownst to us, the state has a deadline of noon on July 24 to submit payroll requests from the previous fiscal year to the State payroll system. Indeed, our request was late to the State but not to the university and we were acting in good faith to not overspend.

Unfortunately, this discrepancy has resulted in the university system (MnSCU) paying $12,059.37 in salary to the project scientists but MnSCU has not, in turn, been made whole by the State because of the late submission of the payroll request.

As of this writing we are supplying LCCMR both budget summaries for your information, however we are no longer pursing reimbursement. The two summaries:

	2007 Trust Funds actually spent	2007 Trust Funds requested
Total Trust Fund Project Budget:	159,000.00	159,000.00
Expenditures:	-146,812.22	-158,872.00
Balance Remaining:	**$12,187.78**	**$128.00**

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Identify Critical Sediment and Riparian Management Areas.

Description:
We will develop a (GIS) integrating hyperspectral data, water quality and riparian characteristics that identify critical environmental management areas. Watershed characteristics to be included in the GIS data layers include soil survey data, digital elevation models (DEM's), vegetation, land use, and geology. Other remote sensing resources such as 30-m Landsat images and 1-m NAIP color aerial photographs can be obtained and used to classify land covers of the remainder of the watershed. A geodatabase will be created using ArcGIS and Arc Hydro software. Critical sediment and riparian management areas will then be identified.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$ 72,936**
	Amount Spent:	**$ 68,165**
	Balance:	**$ 3,602**

Deliverable
1. A two-year GIS geodatabase that allows the researchers to look for critical areas through the GIS watershed analyses will be deliverable by June 2009.
2. Files and maps of critical sediment and riparian management areas will be deliverable by the end of the project.
Completion Date: June 30, 2009

In a GIS and with standard statistical techniques we used results from accepted water sampling analyses and field-based mapping to "ground truth" results from remotely sensed data. This allowed us to successfully identify critical sediment supply and riparian management areas at the "patch" level. Patches are groups of pixels in the remotely sensed imagery and in a GIS; in this study each patches average 34 acres.

From various sources we collected existing GIS data layers for the State and the BER watershed including land use, high-resolution digital elevation data, soil survey data, and many others. From these we created a custom geodatabase within a GIS exclusively for the study area, the BER watershed.

From various time periods over the past 30 years, medium resolution (30m) Landsat images and high resolution (1m) NAIP color aerial photographs were obtained and used to classify land cover types along the BER mainstream buffer areas (Figure 1). Our results reveal more than 80% of the total lands in the BER watershed are croplands. Forest and natural grasslands are located mainly along the BER mainstem and two major tributaries.

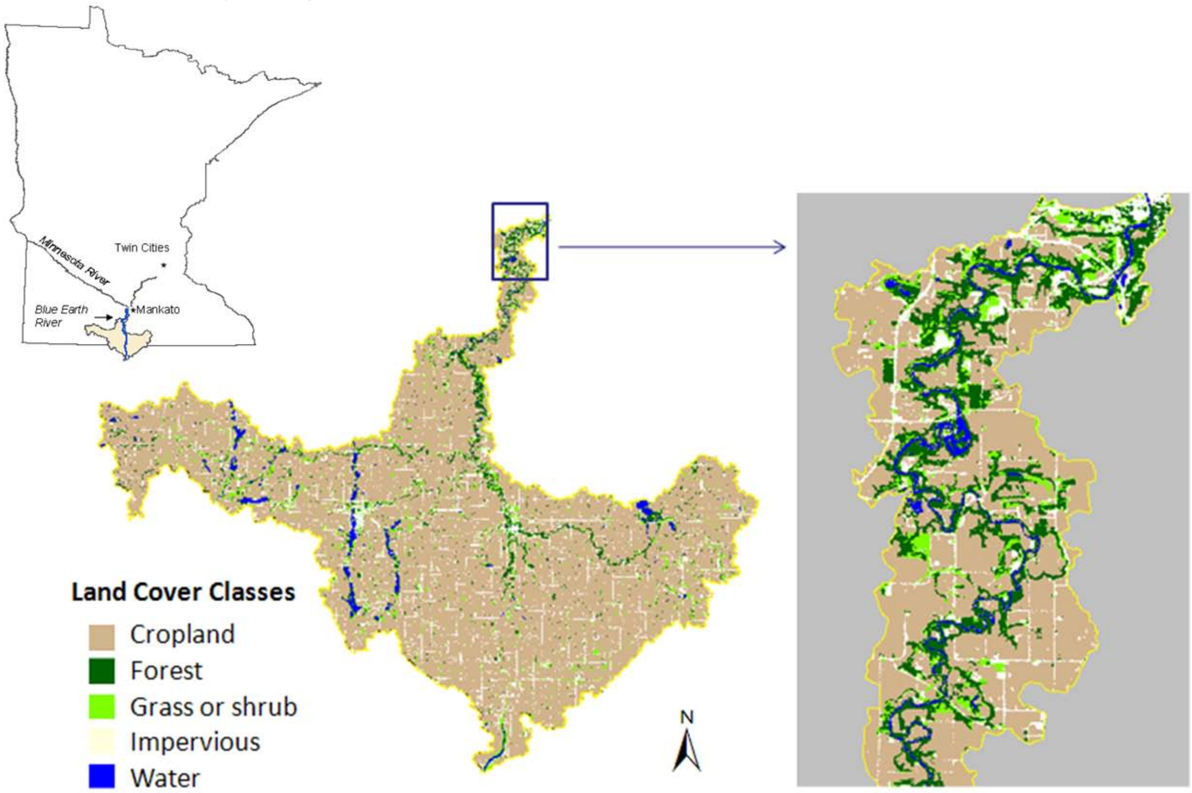
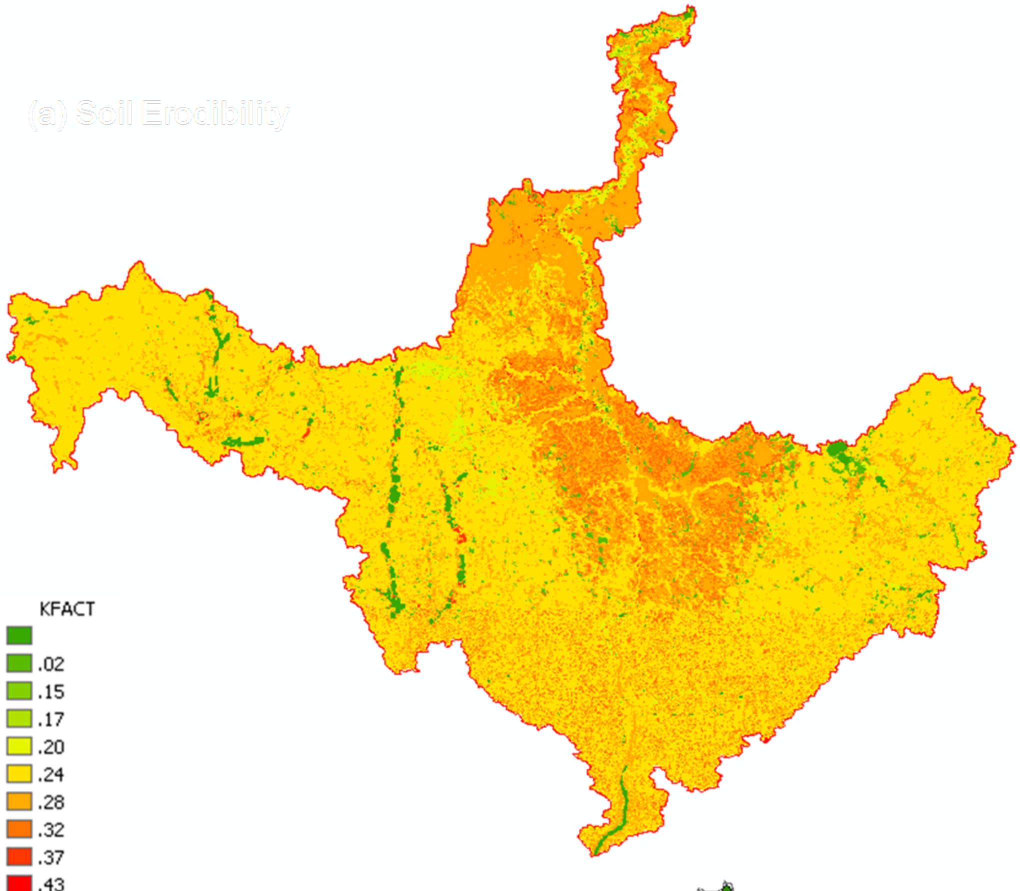


Figure 1. Land cover classification of the Blue Earth River Watershed. Stream flow is from south to north.

This land cover image was used in the next stage: analysis and modeling to identify the sources of pollution in the river and critical riparian management areas.

Using our classified land use and other collected GIS layers of the riparian corridor, such as elevation, SSURGO (Soil Survey Geographic) data, precipitation, and land use practice data, we estimated annual soil loss for the BER watershed using the process-based RUSLE (Revised Universal Soil Loss Equation) model. Figure 2a shows the areas along the middle- and down-stream portions of the BER mainstem that have the highest erodibility values, or 'K' factor in the RUSLE model. Figure 2b indicates areas with the highest erosion rates which, of course, are of concern for river water quality management. Areas of critical concern are also indicated on Figure 2b in the darkest color shade, some 29,000 acres located along steep riverbanks and fields immediately adjacent to those riverbanks (See Figure 3) where no soil conservation methods are currently employed. These areas of extremely high erosion are located on the BER mainstem downstream of the confluence with Elm Creek (sampling site FTC12).


(a) Soil Erodibility
KFACT
.02
.15
.17
.20
.24
.28
.32
.37
.43

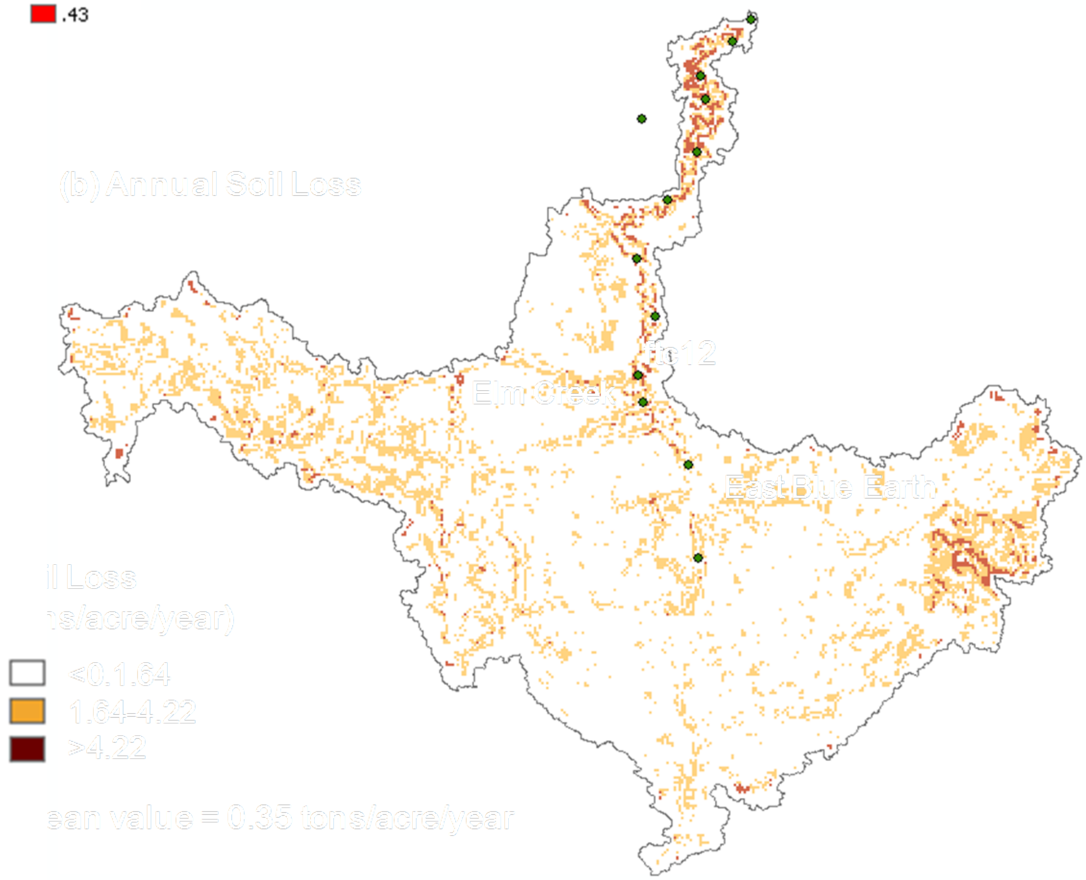

(b) Annual Soil Loss

Figure 2. (a). Soil erodibility factor in the Blue Earth River Watershed extracted from SSURGO soil data. (2) Calculated average annual soil erosion (tons/ac/yr) based on the RUSLE Model.

Figure 3. An example of crop fields immediately adjacent to the Blue Earth riverbanks

Result 2: Increased Knowledge of Dynamic Riverine & Riparian Systems

Description:

We will ascertain the seasonal variability of water quality by field sampling at twelve pre-determined river access points at the same time as airborne spectral measurements are flown. Samples will then be analyzed in the laboratory or field as appropriate for: total suspended solids (TSS), total suspended volatile solids (TSVS), turbidity, chlorophyll-a, phaeophytin-a, total phosphorus (TP), total Kjeldahl nitrogen (TKN), nitrates (NO_3), pH, and conductivity. Weather and solar radiation observations will help calibrate the hyperspectral imagery. Spectral and field data will be collected monthly from May to November 2007-2009.

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$ 71,768**
	Amount Spent:	**$ 67,681**
	Balance:	**$ 4,087**

Deliverable

1. Remote sensing images will be collected regularly and delivered from the spring melt (March) through the first snows (November) during 2007- 2009.

2. Field sampling at twelve pre-determined river access points will be collected regularly and delivered from the spring melt (March) through the first snows (November) during 2007-2009.
3. Partial regression models that identify relationships between river quality and spectral data will be available in the spring of 2008; complete and refined models will be deliverable by June 2009.
4. A website for project results and data distribution will be deliverable by the end of the project.
Completion Date: June 30, 2009

Field water quality sampling was implemented on thirteen sites (five primary sites and eight secondary sites) throughout the monitoring seasons from 2007-2009 (Table 1). Sampling dates corresponded to rising, cresting, falling, and low-flow conditions. Hundreds of discrete measurements of physical, chemical, and biological water quality indicators were completed. Parameters recorded include pH, oxygen reduction potential (ORP), specific conductivity, total suspended solids (TSS), total volatile suspended solids (TSVS), turbidity, ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), total Kjeldahl nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), sulfate (SO_4), chloride, and chlorophyll-a (Chl-a). All data were recorded in our database, which can be accessed and used very conveniently.

Table 1: Sample site names, locations, and elevations used for streamflow measurements and water quality sampling points.

Site	Latitude (N)	Longitude (W)	USPLS	Subbasin No.	Datum
FTC4	43°34.37’	94°06.14’	T101N, R27W, S5	2101	Bridge BM 1049’
FTC8	43°40.42’	94°07.13’	T103N, R27W, S31	2201	Bridge No. 22822 (1972) BM 1053’
FTC10	43°44’25.11”	94°11’12.21”	T103N, R28W, S10	2300	Bridge No. 22554 (1981) BM 1044’
FTC12	43°46’10.32”	94°11’42.24”	T104N R28W, S33	2500	Bridge BM 1030’
FTC14	43°49.98’	94°10.27’	T104N, R28W, S3	2500	Bridge No. 7217 (1959) BM 1015’
ST30	43°53.68’	94°11.88’	T105N, R28W, S16	2500	Bridge No. 07038 W Pier GL 995’
BEC10	43°46’10.32”	94°11’42.24”	T106N, R28W, S26	8901	Bridge N Pier GL 973’
BEC13BE	44°00’38.59”	94°06’41.08”	T106N, R27W, S6	9100	Bridge SW Pier GL 929’
BEC34	44°04.08’	94°06.09’	T107N, R27W, S17	9100	Bridge SE BM 901’
BEC13W	44°02’46.49”	94°11’41.32”	T107N, R28W, S28		Info. maintained by USGS
BEC9	44°05’50”	94°06’34”	T107N, R27W, S6	9201	Info. maintained by USGS
BEC33	44°07.79’	94°03.74’	T108N, R27W, S27	9201	Bridge SE Pier GL 799’
US169	44°09’16.1”	94°01’58”	T108N, R27W, 14	9201	Bridge SW Pier GL 790’

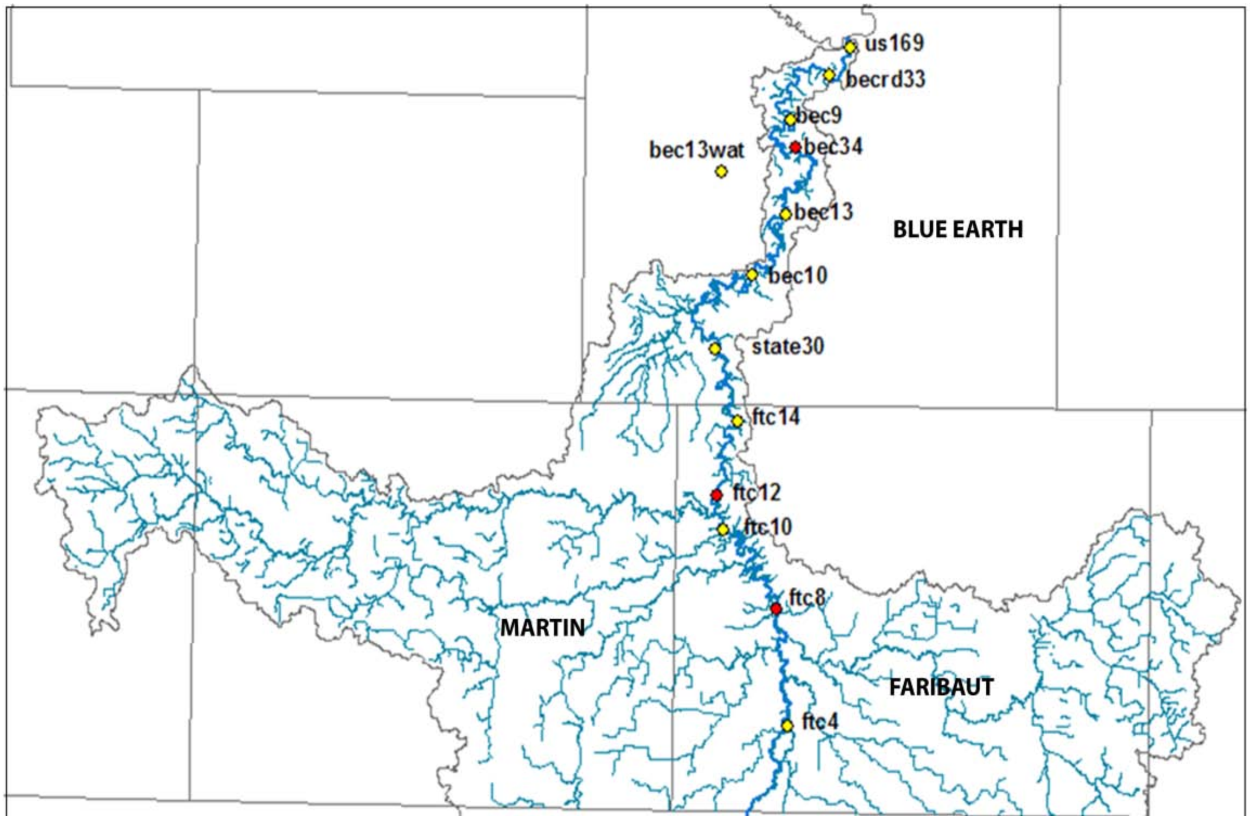


Figure 4. Sampling site map. Note sites FTC8, FTC12, BEC34, each are immediately below the three largest confluences in the watershed above Rapidan Dam. Stage height monitors were emplaced at these sites allowing us to generate new and more accurate rating curves.

Our data were merged with results from monitoring programs administered by the Minnesota Pollution Control Agency and Metropolitan Council on the Watonwan and Blue Earth rivers, respectively, to more fully characterize surface water quality throughout the watershed. An example of the recorded data is given in Table 2.

Table 2. An example of processed and recorded field water sample data.

Site	Date	pH	Spec Cond.	TSS	TSVS	Turbidity	NH3 - Ammonia	NO2 -	NO3 - Nitrate	NO2+NO3	TKN	TP Corrected	SRP	SO4 - Sulfate	Cl	ORP	Chl-a	Chl-a HL
BEC34	8/17/2007	8.05	1623	5.625	4.75	6.00	0.00	0.000	0.33	0.33	0.90	0.07	0.10	111.33	26.67	527.00	1.60	1.35
BEC13	8/17/2007	8.23	2194	13.25	10.25	14.80	0.01	0.000	0.83	0.83	1.10	0.12	0.05	146.00	42.40	519.00	1.70	2.04
BEC9	8/17/2007	8	1759	73.25	14.95	50.20	0.05	0.007	0.00	0.01	0.70	0.14	0.08	139.33	42.13	543.00	1.20	1.65
BEC34	8/19/2007	7.77	730	199	18.00	228.00	0.13	0.000	1.33	1.33	1.00	0.17	0.27	138.00	24.00	479.00	5.00	2.15
BEC13	8/19/2007	7.63	1129	139.5	25.50	116.10	0.14	0.250	2.10	2.35	1.60	0.30	0.15	268.00	31.07	553.00	2.50	1.23
BEC9	8/19/2007	7.52	1037	163	27.00	133.50	0.28	0.011	1.07	1.08	1.00	0.25	0.03	134.67	29.87	551.00	2.50	1.14
BEC34	8/21/2007	7.84	771	492	60.00	245.50	0.10	0.022	3.20	3.22	2.70	0.26	0.07	236.00	31.53	423.00	52.90	5.85
BEC13	8/21/2007	7.7	830	139	25.50	94.80	0.05	0.027	5.50	5.53	1.40	0.21	0.32	252.00	25.53	526.00	2.50	1.54
BEC9	8/21/2007	7.67	671	495	59.50	301.60	0.13	0.030	8.53	8.56	2.60	0.26	0.32	232.00	29.20	461.00	25.60	3.75
BEC34	8/28/2007	8.05	682	121	19.00	85.10	0.02	0.024	3.80	3.82	1.40	0.27	0.15	134.00	22.80	307.00	6.30	3.32
BEC13	8/28/2007	8.2	811	45.5	16.00	24.30	0.00	0.013	2.40	2.41	2.00	0.27	0.19	168.00	24.80	326.00	18.40	4.43
BEC9	8/28/2007	8.11	706	125.5	21.00	100.10	0.05	0.018	4.10	4.12	1.70	0.28	0.17	130.00	21.20	323.00	8.70	3.44
BEC34	9/11/2007	8.3	684	24.2	20.80	43.40	0.02	0.007	3.13	3.14	1.70	0.23	0.15	216.00	25.10	379.00	18.80	4.76
BEC13	9/11/2007	8.37	828	9.1	5.60	2.50	0.01	0.085	3.43	3.52	1.40	0.15	0.25	164.00	40.20	398.00	13.70	2.06
BEC9	9/11/2007	8.28	695	25.1	21.20	40.20	0.01	0.007	4.50	4.51	1.60	0.24	0.30	280.00	27.20	383.00	16.10	6.41

We established three new permanent stage-monitoring stations (FTC8, FTC12, BEC34, cf. Table 1 and Figure 4) within the channel of the BER mainstream immediately downstream of the confluences of the three main tributaries (Elm Creek, East Blue Earth River, Watonwan River) above the Rapidan Dam. By combining our data with MPCA and other stream flow data sources, rating curves were generated for all three sites. Discharge corresponding to severe drought conditions and record-breaking precipitation events were recorded. As one example of a hydrograph generated at the new stage-monitoring sites, Figure 5 shows the stage data for BEC34 during the two-year span. Correspondingly, the derived rating curve for BEC34 is displayed in Figure 6. Based on the rating curves, discharge hydrographs were calculated for all principal study sties. These hydrographs were also validated. An example of the validation is shown in Figure 7.

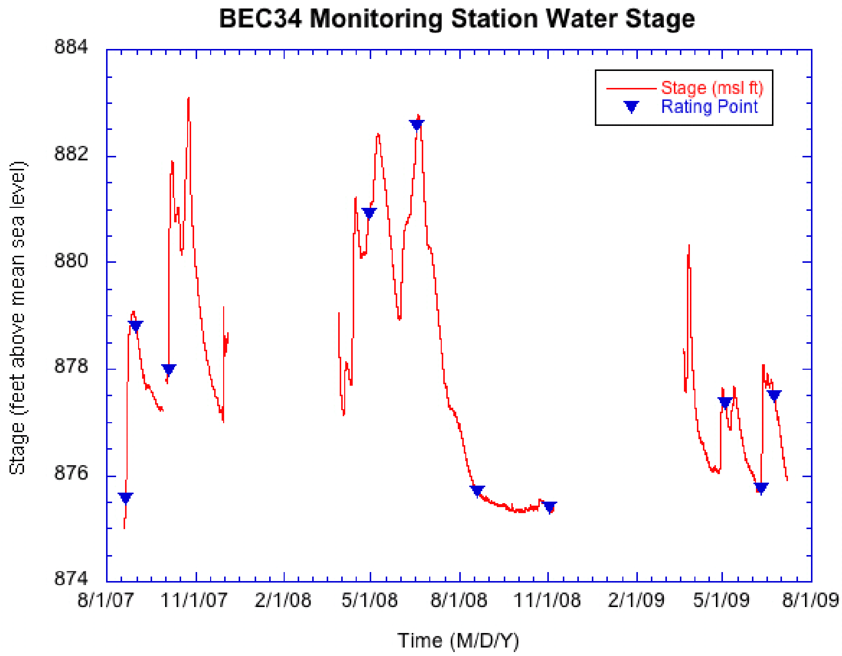


Figure 5. Stage data and rating points for BEC34, 2007-2009. Routine temporal spacing and good coverage of maximum and minimum flows imply that rating curves derived from these measurements should adequately predict discharge from continuous stage monitoring data.

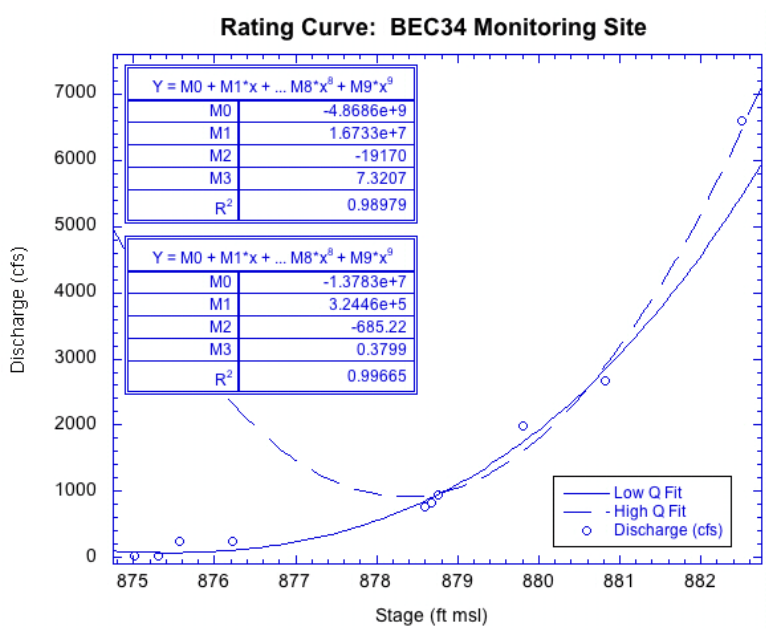


Figure 6. Rating curves for BEC34. A break-point of 880.5 ft marks the transition between two third-order polynomial equations needed to accurately portray discharges under low and high stage regimes.

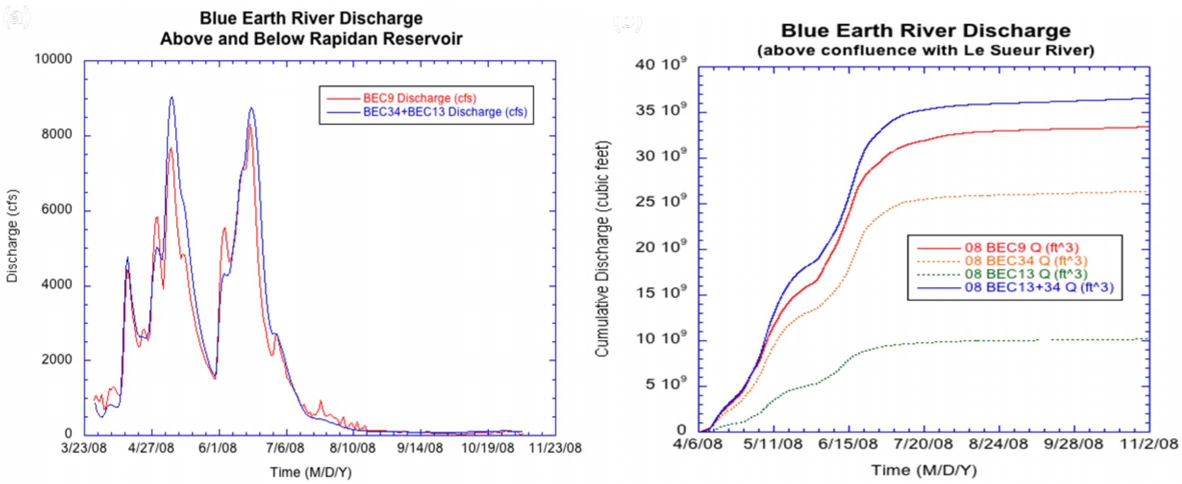


Figure 7. (a) the close temporal and reasonable matching discharge values for the site established and maintained through this grant and that maintained by the USGS at BEC9 (accepted here as the standard of accuracy) for the 2008 monitoring season. (b) the accuracy of discharge values at new monitoring station BEC34. Additive discharge at BEC34 and BEC13W exceed discharge at BEC9 by 8% (~3 billion cubic feet) for the 2008 monitoring season. Given possible groundwater and evapotranspirative losses presented by the channel bed and Rapidan Reservoir, the close agreement among these estimated discharges supports their validity.

Using the discharge hydrographs, we find the transit time for the reach of the BER from Blue Earth city (FTC8) to Mankato (BEC34) (cf. Figure 4 for a map of locations) is approximately 72 hours. Knowledge of this relationship is important to accurately track trends in water quality that develop as a result of first-flush characteristics versus localized contaminant contributions to mainstem discharges.

By analyzing the total cumulative discharge hydrographs, we also find for this period of study, northern Iowa and East Branch Blue Earth River tributaries deliver 41% of the cumulative discharge to the mainstem hydrologically above the monitoring station FTC8; the Elm Creek tributary system contributed an additional 4% of the cumulative discharge to the mainstem as gauged at FTC12. As shown by the wide separation of FTC 12 and BEC 34 cumulative discharge curves in Figure 8, the relatively small area of the watershed below FTC12 contributed approximately 53% of the total seasonal discharge for the period of monitoring.

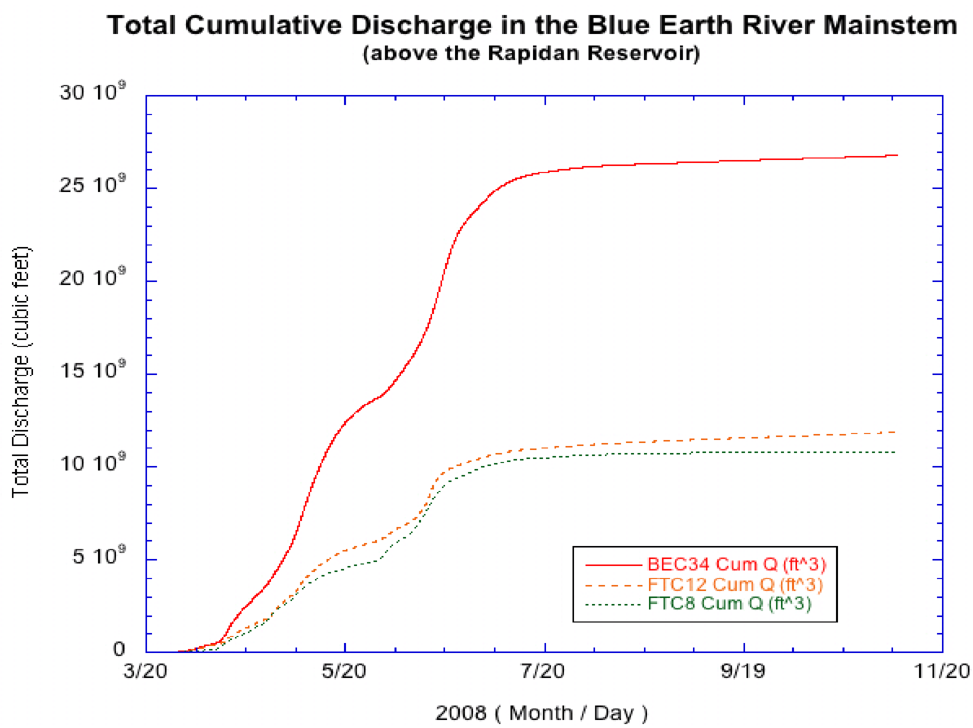


Figure 8. Total discharge variability in the BER mainstem above Rapidan Dam in 2008.

Sediment and nutrient loads in the Blue Earth River by reach were also calculated. Figure 9 is an example of total suspended loads and nitrogen loads for the March to November 2008 monitoring season at principle mainstem monitoring sites.

A most noteworthy finding from our results is - the relatively small basin areas between FTC12 and BEC34 contributes most significantly to the total TSS yield in the BER mainstem.

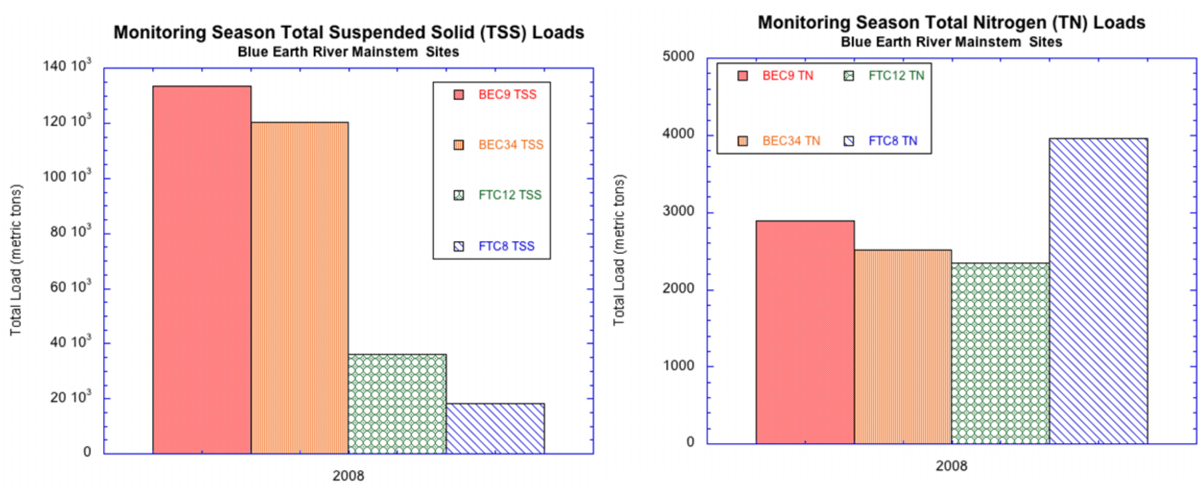


Figure 9. Total suspended solids loads for the 28 March to 6 November 2008 monitoring season at principal mainstem monitoring sites.

To map continuous water quality patterns we collected extensive field-based data and remote sensing data including ARCHER hyperspectral imagery, Landsat imagery, NAIP aerial photography and in-situ remote sensing data collected by hand-held spectrometer.

ARCHER hyperspectral data were obtained in six flight missions on 5/11/2008, 6/7/2008, 6/21/2008, 8/10/2008, 5/17/2009, and 5/30/2009. At the same time as airborne spectral measurements were flown, water quality samples were collected. ARCHER data includes both 1meter resolution hyperspectral (52 bands) imagery and 3 inch resolution panchromatic (black & white) imagery. Each flight mission took approximately 2 hours. Every minute the ARCHER sensor is in operation one hyperspectral data file and one panchromatic data file are generated. Six flights generated approximately 200 Gigabytes of remotely sensed data. To process these data into a useable format, the data volume nearly triples, thus creating 0.6 Terabytes of data to simply begin mapping and analyzing water quality. Figure 10 is one small example of a color composite image from the ARCHER sensor and its associated spectral profile. It is these spectral data that are necessary to correlate with and "ground truth" our field data.

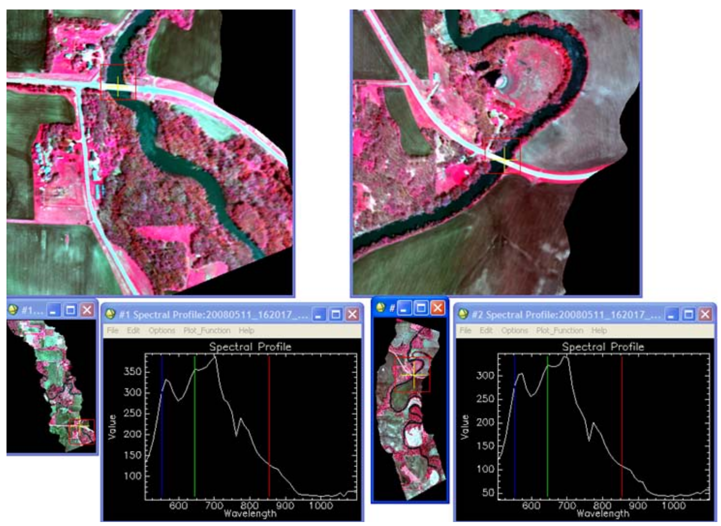


Figure 10. HSI Images at site "STATE30" and Site "FTC12" acquired on May 11, 2008 (Band 22, 13, &1 color composite).

Spectra profiles for all the water samples were extracted from the images and saved into spectral libraries (Cf. Figure 11). Based on the profiles, in all of our data sets, the strongest spectral response region were identified between 690 and 700nm (bands 17 & 18 of the ARCHER HSI data) and an absorption region around 600 and 610nm (bands 9 & 10).

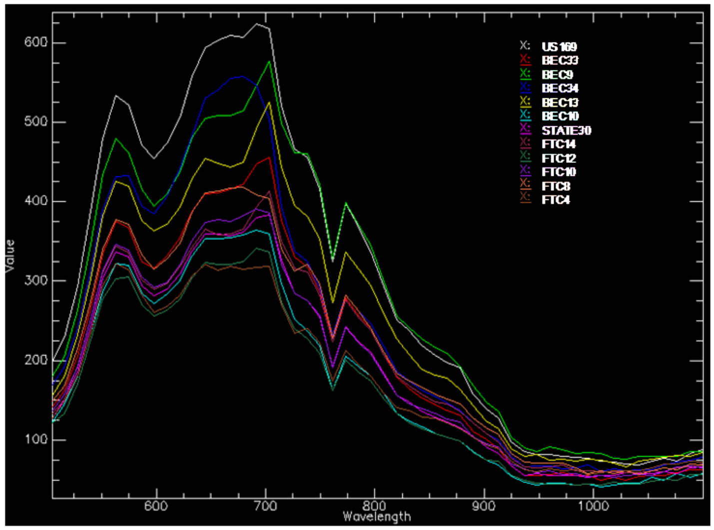


Figure 11. Spectra profiles of water samples (May 11, 2008).

Also most noteworthy, we found the higher the suspended sediment load in the river, the higher the peak spectral response around 690 - 700nm. By correlating those hyperspectral data against water quality parameters, we found the ratio of band 17 and band 9 can determine turbidity of the river effectively. While the exact equations change slightly from date to date, the general trend of the relationship between HSI spectra and Turbidity is similar (Figure 12).

Thus, the highly cost-effective ARCHER hyperspectral system can readily identify areas of increased turbidity in riverine systems thus allowing managers to identify high sediment input and hence polluted areas. This study is the first in the nation to employ ARCHER in this way, and to document its use in water quality monitoring and assessment. We believe the MnDNR could develop a most effective water quality monitoring program using ARCHER.

(a) 5/11/2008 (b) 6/21/2008

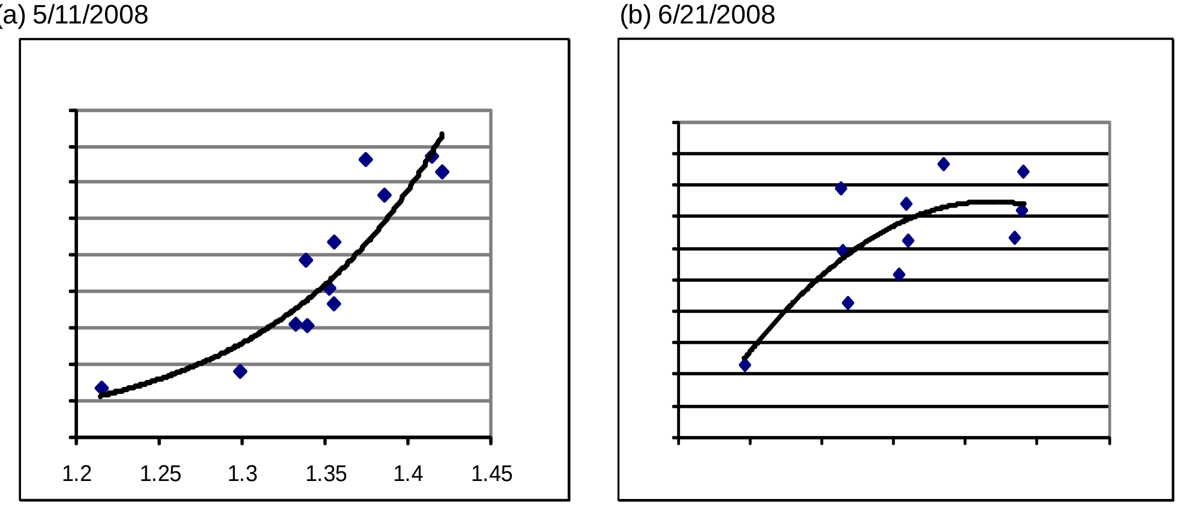


Figure 12. Relationship between HSI spectra (band 17/ban 9) and Turbidity for two different dates.

Based on these correlations and field water samples along the river, continuous water turbidity surfaces were mapped. As shown in Figure 13, different turbidity patterns can be identified. By comparing the turbidity patterns with the surrounding environment along the river, we found river reaches with narrower channel widths, shallow water, and less surrounding forest cover tend to have higher turbidity.

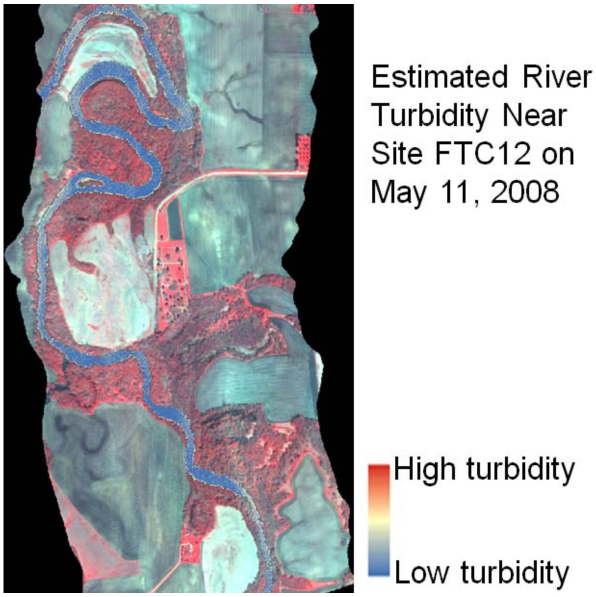


Figure 13. Estimated river turbidity map based on the regression equation overlaid with the false-color composite image of ARCHER HSI data.

Besides airborne hyperspectral data, we constructed a spectral reflectance database for samples of dried total suspended solids acquired from filtered water samples drawn from the BER during significant runoff events using a hand-held spectrometer. Figure 14 provides an example of the spectral reflectance curves of dry samples generated using the hand-held spectrometer. We found a strong absorption spectral region around 670 to 680 nm, indicating different chlorophyll concentrations in the river at different sites. Thus, the higher the amount of chlorophyll in the water, the stronger the absorption around this spectral region.

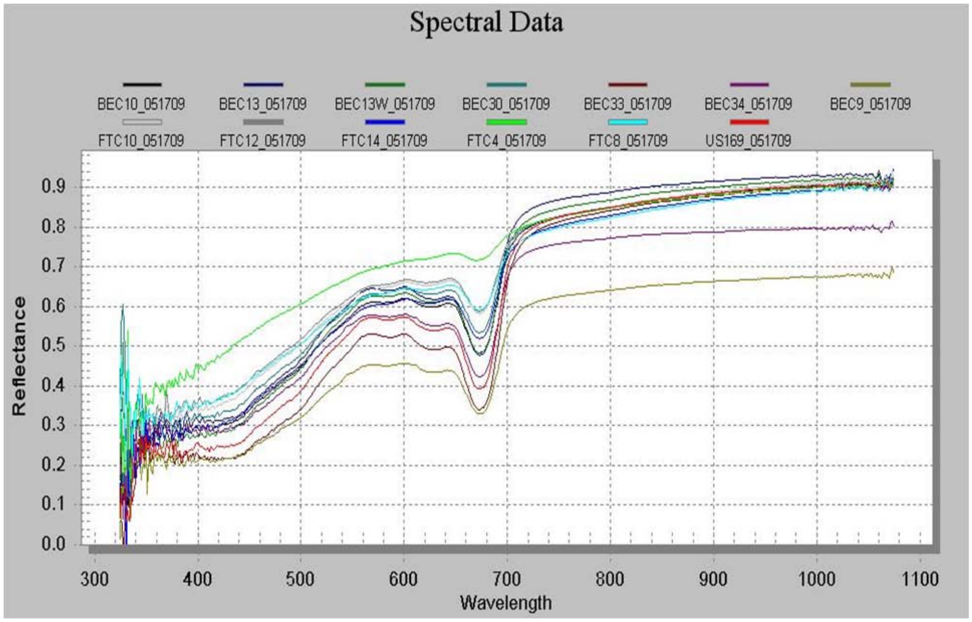


Figure 14. Spectral reflectance curve extracted from dye samples on 5/17/2009

Analyses were also performed to quantify the relationships among the hyperspectral reflectance curves and turbidity found in the water samples. We found spectral responses of the dry samples correlate well, especially in the 690 - 720nm region, with the field measurement values of river turbidity (Figure 15).

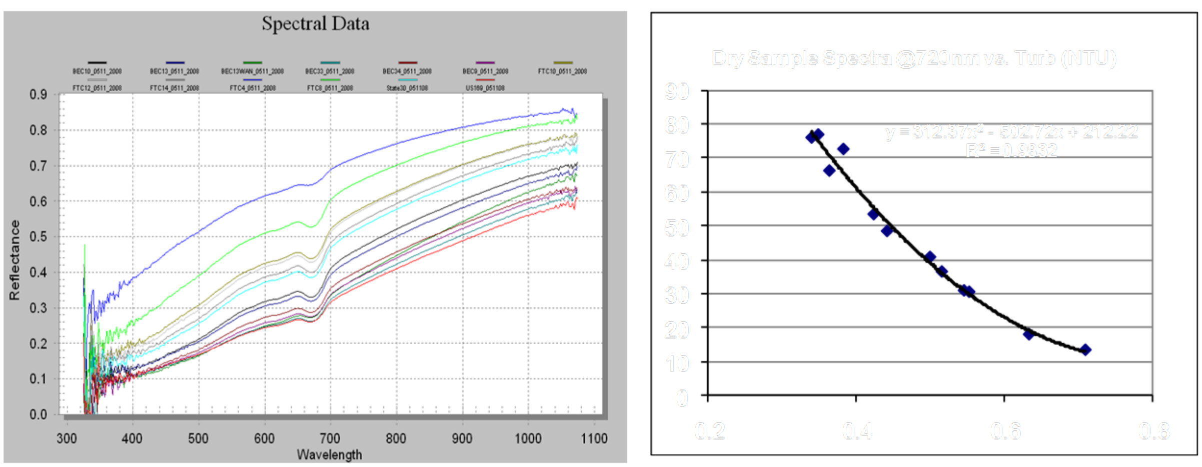


Figure 15. Spectral reflectance curve extracted from dye samples on 5/11/2008 and its correlation with the field-measured river water turbidity.

<u>Result 3: Correlate Water Quality with Riparian Characteristics</u>

Description:

Based on remote sensing and ground sampling data, spectral, water quality and riparian parameters will be correlated that identifies significant links between water quality and riparian environments. Corresponding land cover and precipitation data will be incorporated with available soil and topographic data to construct a numerical hydrologic model of the watershed using the distributed flow model, Vflo™. Calibrated to the continuous discharge and stage data from the new gaging stations, the model will form the basis for interpreting the origin and flow of discharging water throughout the Blue Earth River and its tributaries.

Summary Budget Information for Result 3:	**Trust Fund Budget:**	**$ 15,465**
	Amount Spent:	**<u>$ 10,966</u>**
	Balance:	**$ 4,499**

Deliverable

1. A numerical hydrologic model with preliminary results will be deliverable by the end of the project.

Completion Date: June 30, 2009

To identify significant links between water quality and riparian environments, we constructed, tested, and calibrated a numerical hydrologic model of the watershed using the kinetic hydrological model, Vflo™. This results in the ability to predict amount and location of sediment and stream flow based upon the size and intensity of precipitation events.

We also measured cross-sectional widths and depths of the river's mainstem channel, levees, and surrounding floodplain at the three previously mentioned sites (FTC8, FTC12, BEC34, Figure 4). These measurements are necessary components of distributed flow hydrologic models and are key to linking computer-estimated stage and discharge estimates to those measured in the field using stage-recording instruments.

Land use, continuous flow discharge and stage data, along with topography, drainage networks, and infiltration data derived from a digital elevation model and SSURGO soil layers were input into the flow model to predict flow rate and depth. Figures 16 through 18 illustrate the hydrologic model, preliminary modeling and validation results.

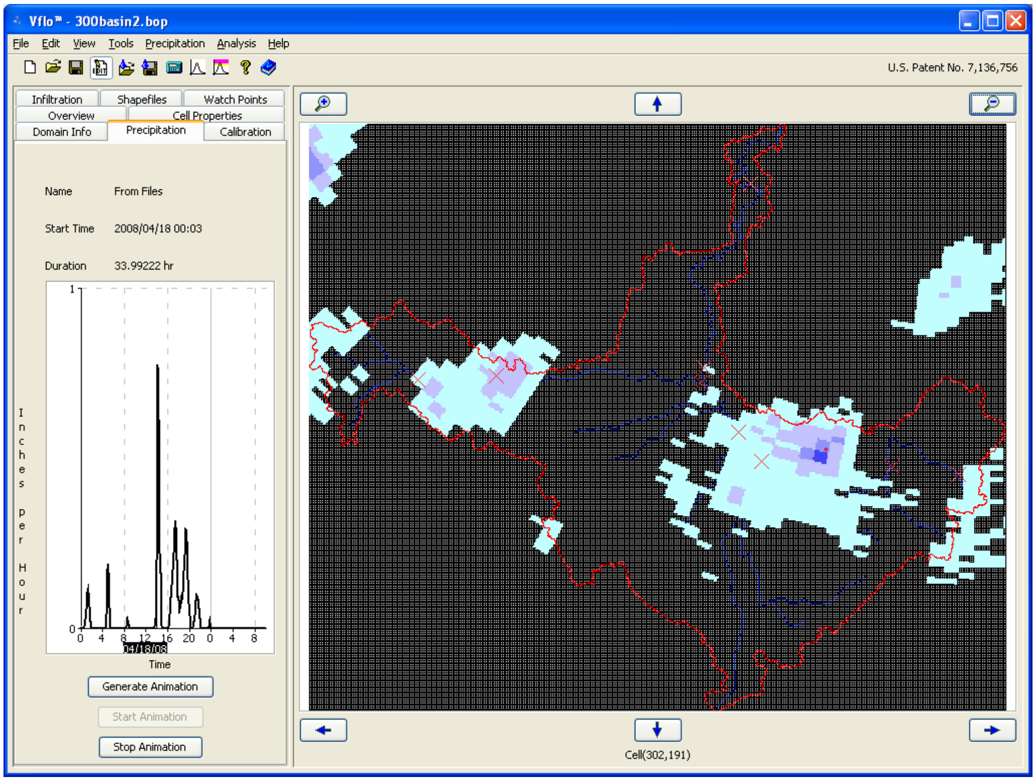


Figure 16. Illustration of the hydrologic model captured during the 28 March 2008 precipitation event. Screen capture images of Vflo model environment shows rainfall intensity for a single cell in the model while the larger window shows the spatial distribution of the rainfall for a single 15-minute period of a 24-hour-long precipitation event.

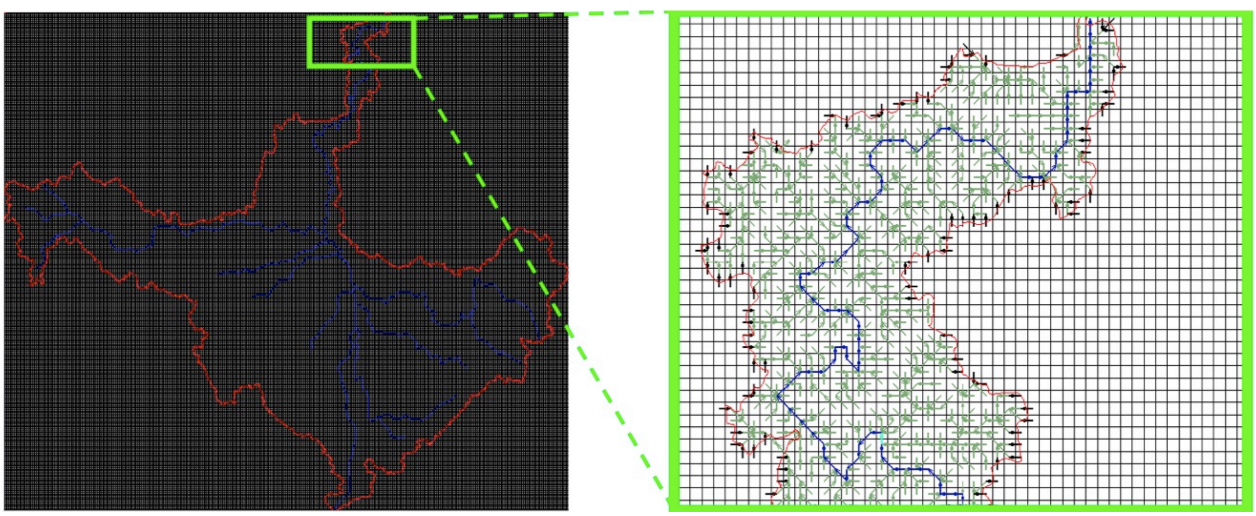


Figure 17. This figure showing hydrologic modeling results consists of a screen capture image of the 44,000 active modeling cells to the left with an expanded inset to the right that shows the detail of channel position (blue) and edited flow directions (green).

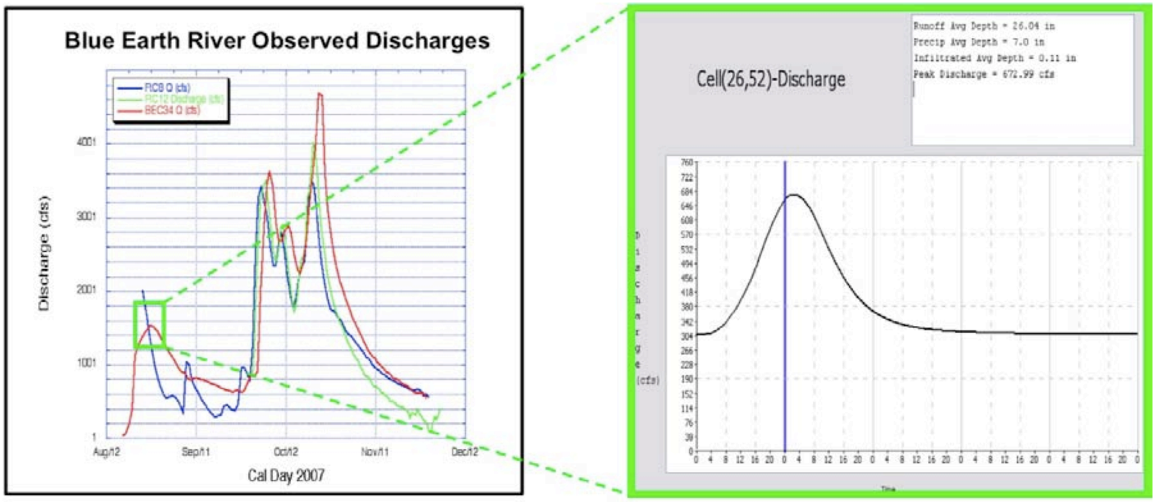


Figure 18. One example of model to hydrograph calibration are shown for discharge at BEC34 for the 19 through 21 August 2007 precipitation event and ensuing runoff. The figure on the left shows the discharge hydrograph developed through traditional methods while the figure on the right shows the hydrograph developed in the model environment.

Our stream flow modeling results indicate the model can simulate real world flow events accurately. With this model, dynamic flow discharges can be modeled accurately for any rainfall event at any location along the BER. This methodology can be readily applied to any watershed in Minnesota, or across the globe.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: • 12% of FTE per year for each of five faculty members • Six student research assistants (2 Graduate & 4 Undergraduate) • CAP ARCHER System aircraft flights with hyperspectral sensor	$120,729
Equipment and supplies: • Supplies, materials, and software for field sampling, laboratory analyses, and image analyses	$36,271
Travel: • Mileage, meals and lodging related to field work	$2,000
TOTAL TRUST FUNDS BUDGETED:	$159,000
TOTAL TRUST FUND AMOUNT SPENT:	**$146,812**

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: In addition to the project scientists (Drs. Fei Yuan, Bryce Hoppie, Donald Friend, Ginger Schmid and Forrest Wilkerson) associated with the Earth Science Program at Minnesota State University, Mankato, to implement and complete the project we established partnerships with MPCA, Faribault & Martin Co. Soil & Water Conservation Districts, U.S. Army Corps of Engineers, and University of Minnesota. In 2008, we were contacted by USGS and Missouri (Mo) DNR who were interested in knowing more about our projects and findings. Thereafter, we formed an ARCHER working group to "provide a forum for agencies/researchers with on-going or anticipated projects using ARCHER imagery to collaborate, exchange information on promising applications and share analytical techniques" (http://rmgsc.cr.usgs.gov/awg/index.shtml). Besides us, other members include CAP, USGS, USFWS, EPA, FEMA, BLM, MoDNR, MoRAP (Missouri Resource Assessment Partnership), Space Computer Corporation, and other university and industry-based individuals. The working group holds monthly conference calls and exchanges lots of e-mail and phone communications. We have organized special sessions on ARCHER applications in the 2010 national conference of the AAG (Association of American Geographers) in Washington, DC.

Especially noteworthy is our partnership with the CAP (Civil Air Patrol). Based on methodologies we developed specifically for this project to pre-process ARCHER data, the CAP has now adopted our methods and has now supplied the needed software to all 16 ARCHER stations across the country. This is of great significance because of the potential for using ARCHER in environmental monitoring nationwide. We wish to laud and thank LCCMR for authorizing a change in our work plan that allowed the unforeseen but necessary expense to purchase specialized software needed to pre-process ARCHER data (GeoReg™ from Space Computer Corp.).

We would also like to mention that this project provided great opportunities for our students. Three MSU Mankato Geography graduate students developed MS theses from this research and several undergraduate students were actively involved in the project.

B. Other Funds Spent during the Project Period:

MSU Mankato has an existing geospatial laboratory that has all the hardware, software, and service that preexist for teaching and research. To include the funds of in-kind, we estimate:

$100,000: Existing remote sensing, GIS, GPS software and hardware at MSU

$10,000: Existing field & laboratory equipment for water sample collection and analysis at MSU

$16,000: Purchase of a hand-held spectrometer

C. Past Spending: None

D. Time: Two years, July 2007 through June 2009.

VII. DISSEMINATION:

The results and findings were documented in project updates to the LCCMR, through multiple conference presentations by the project scientists and their graduate students, three Minnesota State University (MSU) Geography Department master's theses; several academic articles and further professional presentations are in preparation, and some results are already available on the web. Partnerships established to complete the project include local, county, regional, state and federal agencies and scientists at those agencies and at other universities. Communication and outreach has flourished with the creation of a nation-wide ARCHER working group founded by the project scientists: members include MSU, and professionals from 13 other state and federal agencies, universities and the private sector. A meeting of the working group will take place April 2010 at the annual meeting of the Association of American Geographers (AAG) in Washington, DC.

To date, the following presentations resulting from the study were given at national meetings of the AAG, at the state-wide MNGIS/LIS conference, at the regional level South Dakota State Geography Convention (SDSG), and at a Macalester College invited lecture series:

(1) "River Quality Monitoring Using Airborne Remote Sensing on the Blue Earth River, MN" (AAG, 2008);

(2) "Rapid Recharge of a Prairie Pothole Region Water Table Aquifer Following Severe Drought Conditions" (AAG, 2008)

(3) "Downstream Effects of Draining a Silted Reservoir: Rapidan Reservoir, Blue Earth County, Minnesota" (AAG, 2008)

(4) "Soil loss of the Blue Earth River riparian corridor and its effect on water quality" (MNGIS/LIS, 2008)

(5) "River Quality Mapping Using Hyperspectral Sensing and Field Methods, Blue Earth River, Minnesota, USA" (AAG, 2009)

(6) "Land Use Practices of the Blue Earth River Riparian Corridor and their Affect on Soil Loss using GIS and Remote Sensing" (AAG, 2009)

(7) "River Flow Modeling Using a Kinematic Wave Model for the Blue Earth River Watershed" (AAG, 2009 and SDSG, 2009)

(8) "Using GIS and Remote Sensing to Investigate the effects of Land Use on Soil Loss within the Blue Earth River Riparian Corridor" (SDSG, 2009)

(9) "Improved River Water Quality Monitoring Using Hyperspectral Remote Sensing" ("EnviroThursday" Lecture, Sponsored by the Environmental Studies Program, Department of Geography and Mellon Curricular Pathways, Macalester College, 2009)

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than March, 2008, August, 2008; January, 2009 **A final work program report and associated products will be submitted between June 30 and ~~August~~ September 1, 2009 as requested by the LCCMR**

Attachment A:
The attachment A is enclosed as Excel file in the same email.

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: *Improved River Quality Monitoring Using Airborne Remote Sensing 5(e)*

Project Manager Name: *Fei Yuan*

Trust Fund Appropriation: $ *159,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet
2) Remove any budget item lines not applicable

2007 Trust Fund Budget	Result 1 Budget:	Result 1 REVISED REQUEST (Dec. '08)	Result 1 REVISED REQUEST (June '09)	Amount Spent (June 30, 2009)	Balance (June 30, 2009)	Result 2 Budget:	Result 2 REVISED REQUEST (Dec. '08)	Result 2 REVISED REQUEST (June '09)	Amount Spent (June 30, 2009)	Balance (June 30, 2009)	Result 3 Budget:	Result 3 REVISED REQUEST (Dec. '08)	Result 3 REVISED REQUEST (June '09)	Amount Spent (June 30, 2009)	Balance (June 30, 2009)	TOTAL BUDGET	REVISED TOTAL BUDGET REQUEST (Dec '08)	REVISED TOTAL BUDGET REQUEST (June '09)	TOTAL BALANCE
	Identify Critical Sediment and Riparian Management Areas					Increased Knowledge of Dynamic Riverine & Riparian Systems					Correlate Water Quality with Riparian Characteristics								
BUDGET ITEM																			
PERSONNEL: wages and benefits (12% of FTE per year for each of five faculty members; Six student research assistants (2 Graduate & 4 Undergraduate))	52,999	50,999	54,250	49,479	1,520	53,000	50,000	54,250	48,480	1,520	9,582	8,582	8,710	7,063	1,519	115,581	109,581	117,210	4,559
Vendors (CAP ARCHER System for 14 aircraft flights with hyperspectral sensor)	3,882	3,882	1,552	1,552	2,330	3,883	3,883	1,552	1,552	2,331	3,883	3,383	1,403	1,403	1,980	11,648	11,148	4,507	6,641
Equipment / Tools *for field sampling, laboratory analyses, and image analyses (In-stream chlorophyll sensor peripherals; Field photospectrometer; specialized small remote sensing software and hydrologic modeling software)*	4,925	9,925	9,326	9,326	599	4,925	9,925	9,326	9,326	599		2,500	2,500	2,500	0	9,850	22,350	21,152	1,198
Other Supplies *(Stream gaging; river water sampling; water testing; meteorological observations)*	6,961	6,961	7,808	7,808	-847	6,960	6,960	7,808	7,808	-848		0	0	0	0	13,921	13,921	15,616	-1,695
Travel expenses in Minnesota	3,000	0	0	0	0	3,000	1,000	515	515	485	2,000	1,000	0	0	1,000	8,000	2,000	515	1,485
COLUMN TOTAL	**$71,767**	**$71,767**	**$72,936**	**$68,165**	**$3,602**	**$71,768**	**$71,768**	**$73,451**	**$67,681**	**$4,087**	**$15,465**	**$15,465**	**$12,613**	**$10,966**	**$4,499**	**$159,000**	**$159,000**	**$159,000**	**$12,188**

2007 Project Abstract
For the Period Ending June 30, 2007

PROJECT TITLE: Evaluating Riparian Timber Harvesting Guidelines: Phase 3
PROJECT MANAGER: Charles R. Blinn
AFFILIATION: Department of Forest Resources
College of Food, Agricultural and Natural Resource Sciences
University of Minnesota
MAILING ADDRESS: 1530 Cleveland Ave. North
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PHONE: (612) 624-3788
FAX: (612) 625-5212
E-MAIL: cblinn@umn.edu
WEBSITE: http://rmzharvest.cfans.umn.edu/
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 5(f).

APPROPRIATION AMOUNT: $400,000

Overall Project Outcome and Results

This project continues research begun with M.L. 2001 and M.L. 2005 appropriations from the Environment and Natural Resources Trust Fund.

Research addressing the long-term effectiveness of riparian guidelines to mitigate harvesting impacts is critical to resolve management conflicts and sustain Minnesota's forest resources. This project:

1. Evaluated the long-term effectiveness of Minnesota's riparian timber harvesting guidelines within Pokegama Creek (single-basin study) and on eight separate basins located across northern Minnesota (multiple-basin study);
2. Began to combine and synthesize data from the various study components through a "meta-analysis";
3. Provided outreach information.

Terrestrial findings that can help guide future management of Minnesota's forests and streams include:

- Partially-harvested riparian management zone (RMZ) treatments resulted in fully-stocked stands, however, species composition differed among treatments;
- Northern white cedar and balsam fir seedlings survive and grow well in non-wet microsites with medium residual basal area; cedar seedlings require protection from deer browsing;
- Different treatments had minimal impact on the amount of organic matter input to streams;
- Residual tree blowdown was low, but future potential is still high.

Effects of riparian harvest on fish and fish habitat were assessed at the basin scale. Sediment levels remained above 1997 pre-harvest conditions until fall 2007. Riparian harvest may have contributed to increased stream temperatures, but fish abundances were negatively associated with differences in mean summer air temperature.

Aquatic findings that can help guide future management of Minnesota's forests and streams include:

- No differences in water chemistry between harvested and unharvested riparian reaches;

- Trends toward higher in-stream light levels and elevated periphyton standing crops within harvested riparian areas compared to control reaches;
- Trends toward a greater proportion of scraper invertebrates and fewer shredder invertebrates in harvested riparian reaches.

At the single-basin tributary sites, the majority of bird species present were associated with mature forest habitat pre-harvest. After harvest, early successional habitat associated species maintained dominance in all sites. The pre-harvest bird community was neither maintained nor able to reestablish on unharvested riparian buffers 9-11 years after harvest.

We observed interannual variation in diversity and species richness within the macroinvertebrate and fish communities, but few effects related to harvest treatments. Few changes in diversity and richness were observed in the bird community but changes were observed by the replacement of mature forest species by early successional avian species, related closely to the vegetation type.

There is a need to continue monitoring the sites to more fully assess effects over time.

Project Results Use and Dissemination

A workshop entitled "At the Water's Edge: Current State of Riparian Forest Management Research in Minnesota" was presented in Grand Rapids on May 20, 21, and 22, 2008. The purpose of the workshop was to interpret research results from the single- and multiple-basin riparian effectiveness monitoring studies as well as the Minnesota Forest Resource Council's Riparian Science Technical Committee findings for natural resource managers and loggers. The program included both indoor and outdoor components. There were 102 participants over the course of the three days.

A website was developed to provide information about the project, including a project overview, more detailed descriptions of our research, information about project personnel, a listing of project cooperators, project publications, and information presented during our workshop. The url for that website is http://rmzharvest.cfans.umn.edu/. A second website was created to allow project researchers to access data (http://rmzharvest.cfans.umn.edu/login).

Beyond the workshops and website, project results were disseminated to scientists, natural resource managers, private landowners, researchers, and others through nine presentations, one refereed manuscript, and one field tour. Three additional manuscripts are in preparation. One graduate student produced a thesis from their project work. Other graduate students continue to collect, analyze, and summarize data which will result in additional theses. Annual summaries of project results were provided to the Minnesota Forest Resources Council for inclusion in their Annual Report.

As this research study was designed to be a long-term assessment with little dissemination during the initial project phases, researchers will continue to monitor, analyze, and report post-harvest effects in the future as funding permits. With that additional information, we will be able to assess how birds and terrestrial and aquatic ecosystems respond to timber harvesting within RMZs over the long-term. Results will then be used to inform on-the-ground decision making as well as suggest changes to the guidelines to more effectively manage forested riparian areas.

Trust Fund 2007 Work Program Final Report

Date of Report: August 17, 2009

Trust Fund 2007 Work Program Final Report

Date of Report: June 30, 2009
Date of Work Program Approval: March 23, 2007
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Evaluating Riparian Timber Harvesting Guidelines: Phase 3

Project Manager: Charles R. Blinn
Affiliation: Department of Forest Resources
College of Natural Resources
University of Minnesota
Mailing Address: 1530 Cleveland Ave. North
City/State/Zip: St. Paul, MN 55108
Telephone Number: (612) 624-3788
E-mail address: cblinn@umn.edu
FAX Number: (612) 625-5212
Web Page address: http://rmzharvest.cfans.umn.edu/

Location: Beltrami, Carlton, Cook, Itasca, Lake, and St. Louis Counties.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$400,000.00**
	Minus Amount Spent:	**$393,494.96**
	Equal Balance:	**$ 6,505.04**

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 5(f).

Appropriation Language: $400,000 is from the trust fund to the University of Minnesota to assess the timber harvesting riparian management guidelines for postharvest impacts on terrestrial, aquatic, and wildlife habitats.

II. and III. FINAL PROJECT SUMMARY

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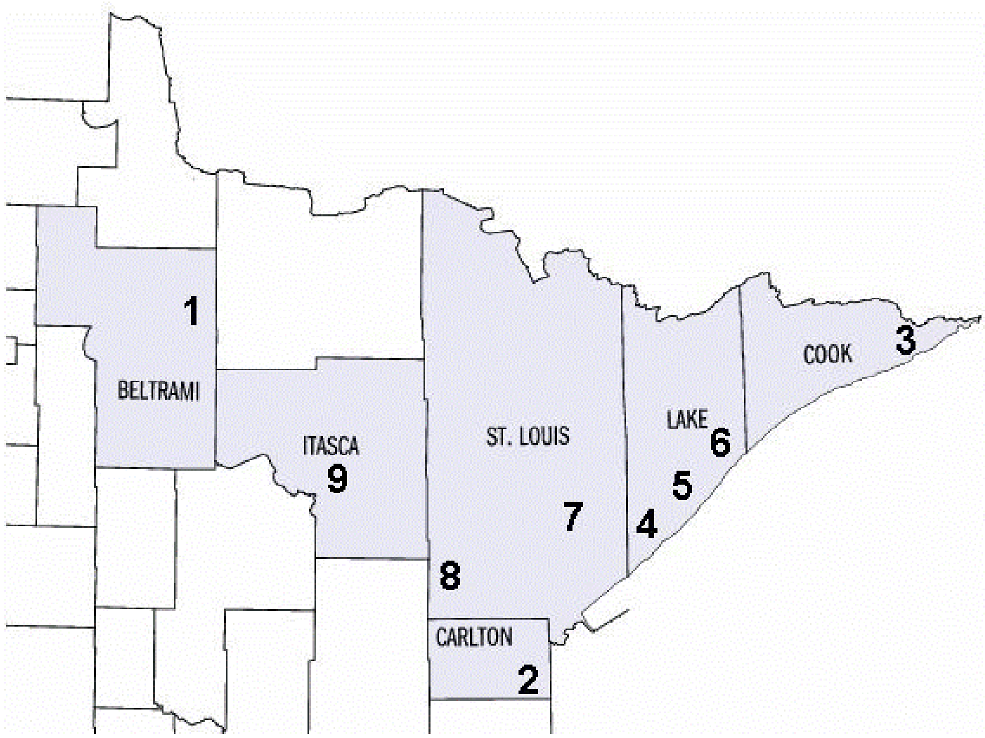

Multiple-basin sites (1-8):

Site 1: Shotley Brook, Blackduck DNR

Site 2: No Name, Nemadji State Forest, Cloquet DNR

Site 3: Reservation tributary, Two Harbors DNR, Grand Marais Office

Site 4: West Split Rock River, Two Harbors DNR

Site 5: East Beaver River, Two Harbors DNR

Site 6: East Baptism River, Lake Co Land Dept, Finland Office

Site 7: Cloquet River trib, St. Louis Co Land Dept, Pike Lake Office

Site 8: St. Louis River trib, St. Louis Co Land Dept, Pike Lake Office

Single-basin site (9):

Site 9: Pokegama Creek, UPM (Blandin Paper Company)

Figure 1. Study site locations.

IV. OUTLINE OF PROJECT RESULTS:

Result 1: Evaluate terrestrial impacts

Description: We evaluated the effects of our management treatments on riparian tree regeneration responses and blowdown of residual trees. We evaluated regeneration in summer 2008 and blowdown in fall 2007 (single- and multiple-basin sites) and 2008 (multiple-basin sites only).

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$138,296.00**
	Amount Spent:	**$134,971.93**
	Balance:	**$ 3,324.07**

Deliverable	Completion date	Budget	Status
1. Measure recent blowdown of riparian trees on 24 study sites	11/1/07	$23,050	Completed
2. Summarize and analyze data from deliverable 1	2/1/08	$23,049	Completed
3. Measure regenerating trees on 12 study sites	9/1/08	$23,049	Completed
4. Measure recent blowdown of riparian trees on 12 study sites	11/1/08	$23,050	Completed
5. Summarize and analyze data from deliverables 3 and 4	3/1/09	$23,049	Completed
6. Prepare and submit final report	6/30/09	$23,049	Completed

Completion Date: June 2009

Final Report Summary:

Introduction

Thomas et al. (1979) suggested that riparian areas represent ecosystems with maximum potential for conflict among multiple users. This reflects the diverse values associated with riparian areas, including timber production, recreation, protection of water quality and aquatic habitat, and provision of terrestrial habitat for a diverse flora and fauna. Response to these real and potential conflicts between uses and values often takes the form of guidelines designed to protect or conserve riparian resources (Knopf 1985).

In Minnesota, voluntary site-level forest management guidelines and best management practices (BMPs) for water quality were developed in the late 1980s (Anonymous 1989), revised in 1995 (Anonymous 1995), and further revised in 1999 (Minnesota Forest Resources Council 1999). As noted within the current guidebook, the guidelines are designed to help forest landowners, resource managers, and loggers meet two goals: 1) to conduct forest management activities such as timber harvesting, while addressing the continued long-term sustainability of riparian areas, and 2) to promote or enhance the functions and values of water resources and riparian areas (Minnesota Forest Resources Council 1999).

The geographic importance of riparian areas in Minnesota is widely recognized (Palik et al. 2004), yet little information is available about regeneration dynamics of tree species in response to different management approaches within forested riparian areas. Moreover, we have limited information on the fate of residual trees in riparian management areas. Finally, measures of functional changes in riparian areas after harvest are limited for the region. To address these needs, riparian areas at eight locations in northern Minnesota have been harvested and monitored for various measures of riparian functionality including regeneration and plant community responses, blowdown of residual trees, and changes in the flux of coarse particulate organic matter into the streams from the adjacent forest. Results may lead to changes in the management guidelines so that they will more effectively sustain forested riparian areas and associated resources.

Objectives

The primary objective was to continue to evaluate the effects of our management treatments on riparian tree regeneration responses, riparian plant communities, and blowdown of residual trees. We evaluated five year post-harvest riparian plant community and tree regeneration responses in 2008 and residual tree blowdown in 2007 (single- and multiple basin sites) and 2008 (multiple-basin sites only). Specifically, we examined how different levels of overstory tree retention in RMZs affect these variables, five years after harvest.

Study location and design

Multiple-basin study

Eight forested riparian areas were located in northern Minnesota. Each site was divided into two 3.2 ha stands that were separated by a 61 m unmanaged buffer strip. Each stand was further subdivided into two zones: a 183 x 183 m upland, and a 46 x 183 m RMZ. The upstream stand was considered a local control (i.e., the upstream RMZ was not harvested). The downstream stand was harvested either to a target "low" RBA of 5.7 m^2 ha^{-1} or to a "medium" RBA of 11.5 m^2 ha^{-1}. All upland stands, including those above RMZ areas in control stands, were clearcut. The protocol for harvesting followed the Minnesota Forest Resource Council's riparian guidelines for timber harvesting (Minnesota Forest Resources Council 1999). With the exception of the Reservation Tributary site that was harvested during the winter of 2004-2005, timber harvesting commenced in mid-December of 2003, and was completed by March of 2004.

Single-basin study

Twelve 4.6 ha plots located along 3 first to third order streams (Pokegama Creek, Little Pokegama Creek, unnamed stream) draining into Pokegama Lake (south of Grand Rapids) were selected within a 2 km^2 area. Three replicates of 4 treatments were used: true control plots (no harvest in riparian zone or upland), riparian control (uplands clearcut/riparian zone uncut), whole-tree harvest (uplands and riparian zone cut using the feller-buncher grapple skidder system), and cut-to-length (uplands and riparian zone cut using cut-to-length system). Harvesting took place in late summer-fall 1997.

Methods

Vegetation assessment
Permanently monumented plots were established along transects running perpendicular to the stream. Each of these monumented plots was 4.6 m wide by 7.6 m long (Figure 1.1). A total of 50 plots were established in each treatment site and the following variables were quantified in each plot using a nested design.

Trees (diameter ≥ 10 cm at 1.37 m [diameter at breast height or DBH]) and saplings (2.5 cm > DBH < 10 cm) were sampled in 4.6 m by 7.6 m rectangular plots, with the long axis parallel to the stream. Species, diameter, and total height were recorded for all species greater than 2.5 cm. Tall woody regeneration less than 2.5 cm DBH but ≥ 0.76 m tall was sampled in two 0.6 by 4.6 m nested plots within the larger tree plot. Each woody stem was classified into 0.2 cm size classes based upon diameter at 15 cm from the ground. Species, diameter, and a subset of total heights were measured for each species tallied. Small woody regeneration (tree and shrub stems < 0.76 m tall) was measured in six 0.61 by 0.61 m plots nested within the tall regeneration plots (labeled 1A through 2C in Figure 1.1). In each of these plots, we tallied the number of stems of individual woody species.

Although not officially part of the work plan, herbaceous vegetation was also sampled so that we could track changes in ground layer plant communities and their potential interactions with tree regeneration. Herbaceous cover was tallied by major life form (herb/forb, fern, sedge/grass, bryophyte, and coarse woody debris) within the small regeneration plots with coverage visually quantified into the following classes: **1**=trace-1%, **2**=1-5%, **3**=6-15%, **4**=16-30%, **5**=31-60%, **6**=61-100%.

Assessment of northern white cedar and balsam fir seedling survival and growth
In a related study, three-year old northern white cedar (*Thuja occidentalis* L.) and balsam fir (*Abies balsamea* (L.) Mill.) were established at three multiple-basin study sites (Red Lake, Nemadji State Forest and East Branch Beaver River) in 2004. Plantings utilized microsites (mound, pit and slash) as identified in the existing literature. We erected deer exclosure fencing, with duplicate plantings inside and outside, in order to compare establishment of both browsed and unbrowsed seedlings. In the summer of 2006, environmental field measurements were performed at each replicate plot in order to characterize the vegetation and soil features. In October 2008, final field measurements were performed on planted individuals for mortality, vitality, height, basal diameter, and browse.

Blowdown of residual trees
Blowdown of RMZ residual trees was sampled in October-November 2007 and 2008. Sampling included 100% assessment of all blown down trees in each riparian stand. Data collected for each blowdown tree included basal area around that tree, tree diameter, height, landform position, distance from the stream, and type of damage to the individual. Trees were also permanently marked with numbered tags and recorded spatially with a GPS. The latter will allow us to track the fate of blowdown trees and continue to track new blowdown over time.

Leaf litter input to streams
Coarse particulate organic matter (CPOM) input to steams was measured using a series of litter traps placed adjacent to the stream bank in each study site. Litter was collected periodically from 2007 to 2009, dried, weighed, and reported on an annual basis.

Results

<u>Vegetation responses</u>

Overstory structure
Harvesting treatments were successful in creating significantly different overstory residual basal area among all RMZ and upland treatments immediately after harvest. These differences were still strong ($p < 0.0001$) five years after harvest, although slight changes in basal area and increased variability led to fewer significant differences among all treatment combinations at year 5 (Table 1.1). The majority of standing basal area in the harvested RMZs was aspen and paper birch. Residual conifers and mast-producing trees were very limited in abundance and consisted mainly of balsam fir and spruce. Tree harvesting intensity, and hence the distribution of residual basal area, was not uniform throughout the entire RMZ. Basal area tended to decrease with distance from stream. As a consequence, light availability increased with distance from stream ($p = 0.007$, data from 2005 report). Compared to average light levels in the control treatments, average light levels in RMZ harvest treatments were 151% and 189% higher in the medium RMZ and low RMZ treatments, respectively.

Tree regeneration
Total regeneration density (all stems <2.5 cm diameter), while not significantly different among treatments after five years (Table 1.1), was 28 to 41 % greater in the two riparian harvest treatments compared to the uncut RMZ. Regeneration density also increased with increasing harvest intensity from the uncut RMZ to the upland clearcut (Table 1.1). Aspen and birch regeneration (stems ha^{-1}) increased from the uncut RMZ to the medium and low basal area treatments, to the clearcuts. Aspen and birch densities were significantly higher in the upland clearcuts compared to the uncut RMZ ($p = 0.013$), but not different among riparian harvest treatments (Table 1, Figure 1.2). Densities of aspen and birch have consistently been decreasing annually since the first year after harvest and are presently less than half of their original densities in all harvest treatments (Figure 1.2).

Recruitment of aspen and birch into larger sizes classes over time is evident. In the first year after harvest, the density of stems less than 0.75 m in height were significantly greater ($p = 0.016$) in the clearcut compared to the riparian control. By the third year after harvest this difference ($p < 0.001$) existed only in the tall regeneration layer (>0.75m and <2.5cm dbh). Five years after treatment, aspen and birch densities in the tall regeneration layer were again significantly greater in the clearcuts and low RBA treatments, compared to riparian controls ($p < 0.0001$). Moreover, significantly greater sapling (10 cm < dbh > 2.5cm) densities were observed in the clearcuts, when compared to the medium RBA and riparian controls ($p = 0.007$).

Regeneration densities of hardwoods other than aspen and birch have remained similar among treatments over time ($p = 0.51$ at year 5, Table 1.1). However, total densities of hardwood species added substantially to total regeneration amounts and exceeded aspen and birch in all treatments. Composition of hardwoods varied among the eight study sites, but commonly included sugar maple, red maple, and black ash. The medium basal area treatment had the highest hardwood densities five years after harvest (Table 1.1).

Conifer regeneration has decreased substantially from pre-treatment to five years after treatment. There were no significant differences among treatments in conifer regeneration densities at any sampling period ($p = 0.69$, Table 1.1). However, conifer regeneration densities were consistently greatest in the control RMZ and lowest in the clearcut uplands, but had greater variability in the medium and low RBA riparian zones.

Five years after harvest, all multiple-basin riparian treatments have sufficient commercial tree densities to be considered adequately stocked stands. However, composition of regeneration differed among treatments. Shrub species, notably hazel, and aspen densities increased with decreasing residual basal area from the riparian controls, through the medium and low residual basal areas treatments, to the upland clearcut. Notably, densities in the medium basal area RMZ treatment were not substantially different than the uncut RMZ for several species groups, suggesting that this treatment mitigated changes in the regeneration environment to some degree.

Shrub and herbaceous response

Potential deterrents to successful tree regeneration include various shrub species, which increased substantially by five years after treatment in all but the uncut RMZ treatment (Table 1.1). By the fifth year after treatment, shrub densities (exclusive of hazel) were highest in the upland clearcuts, followed by the low basal area treatment and the medium basal area treatment, and were lowest in the uncut RMZ treatment (Table 1.1). Non-commercial shrub species and aspen regeneration densities both decreased with increasing overstory residual basal area retention.

Hazel densities specifically illustrated the trend of increasing densities with decreasing residual tree density (Table 1.1). Five years after treatment, hazel stem densities had increased substantially in both the low RBA treatment and the upland clearcuts, relative to pre-harvest levels (Table 1.1). Hazel densities in medium RBA treatment also were nearly doubled their pre-harvest levels, but were 2.5 times lower than densities observed in the low RBA and clearcut treatments.

Herbaceous vegetation also illustrated responses to riparian treatments. Five years after RMZ treatments, both bryophyte and fern cover was highest in the control and medium RBA RMZs (Figure 1.3). Moreover, forb cover was greatest in the harvested treatments and lowest in the riparian control, while sedge and grass cover was greatest in the clearcut treatment (Figure 1.3).

Northern white cedar and balsam fir seedling survival and growth

Inside deer exclosures, survival of both species was highest on mounds and slash microsites. Both species suffered significant losses in pit microsites, with survival roughly 50% and lower. Cedar had no survival differences between RMZ overstory treatments, while fir survival was significantly lower in controls than in medium harvests (Figure 1.4). Outside of exclosures, survival patterns were the same but lower for both species. Survival was highest on mounds and slash microsites; pit microsites again had the lowest survival. Cedar showed no survival difference between RMZ overstory treatments, while fir exhibited significantly lower survival in controls than in medium harvests (Figure 1.5). Overall, survival of cedar was much higher than for fir.

Cedar height and basal diameter inside exclosures differed between overstory treatments, with greater growth in medium harvest RMZs over controls. Growth did not differ between microsites within treatments. Balsam fir height and basal diameter also differed between overstory treatments, responding with greater growth to medium harvest treatments, and did not differ significantly between microsites (Figures 1.6-1.7). Outside of exclosures, the incidence of repeated herbivory on cedar reduced all growth so that there were no significant effects of overstory treatments or microsites. Balsam fir height and basal diameter outside of exclosures showed significantly greater growth in harvest RMZs than in controls, though not between microsites (Figures 1.8-1.9).

Blowdown of riparian residual trees

Multiple-basin study sites

Blowdown of residual trees in the multiple-basin riparian areas occurred in all treatments. Expressed as either percentage of original basal area (Figure 1.10) and density (Figure 1.11), blowdown was highest in both the harvested treatments, compared to the control. Five years after treatment, the medium RBA treatment had the greatest percentage of basal area and density blown down, followed by the low RBA treatment and riparian control (Figures 1.10 and 1.11). However, the differences among treatments were generally small. Blowdown did differ dramatically among species independent of RMZ treatment. Trembling aspen lost the greatest percentage of basal area in the RMZs over the five year period since treatment origin, followed by balsam fir and red maple (Figure 1.12).

Single-basin study sites

Blowdown of residual riparian trees were remeasured in the fall of 2007 and spring of 2008, 10 years after treatment. The riparian controls (uplands harvested) and the two RMZ harvest treatments lost 30-35% of residual basal area to blowdown over 10 years, significantly more than the control treatment (uplands not harvested) (P=0.03, Figure 1.13). Similarly, the riparian control and the riparian harvest treatments had the highest percent residual tree density lost to blowdown (Figure 1.14). In general, these results suggest the potential for substantial loss of the original RMZ to blowdown, with the amount of loss continuing to increase over time through at least 10 years.

Riparian area treatment effects on stream organic matter inputs

In 2008, lateral coarse particulate organic matter (CPOM: leaf litter, twigs, seeds, etc.) input from the riparian forest to the stream was highest in the medium RBA RMZ treatment, followed by the control and the low RBA treatment (Figure 1.15). Overhead input of CPOM was more variable within treatments, with no treatment related trend evident (Figure 1.16).

Significance of results

<u>Vegetation responses</u>

Residual overstory

A key observation of this study is that it is difficult to meet residual basal area targets uniformly across an RMZ. Rather, there is a trend towards leaving more basal area (i.e., above the residual target) nearer the stream and less than the target farther from the stream, while on average the entire RMZ may be at the target level.

This pattern results from generally wetter soil conditions nearer the stream, limiting operability at certain times of the year, as well as more difficult access nearer the stream due to topography. A tendency to retain higher than target residual basal areas nearer the stream is likely of ecological benefit as trees nearer the stream have a greater functional connection to the water then do trees farther from the stream (Palik et al. 1999). Lower than target residual basal area farther from the streams, but still within the RMZ, is a primary reason that aspen regeneration was approaching adequate numbers with the partially harvested treatments.

Tree regeneration

Fifth year results demonstrate that both the medium and low partial harvest treatments in the RMZ result in lower aspen (and birch) regeneration density than typically occurs in a clearcut. However, density of aspen suckers is still within the range of full stocking on low BA treatment. It is a bit below the lower end of this range in the medium basal area treatment and potentially declining. Hardwood regeneration density (red maple, sugar maple, black ash) was variable among the treatments, but highest in medium basal area treatment

In combination, these results indicate that the partial harvest treatments used in this study have the potential to regenerate aspen-mixed wood stands, as opposed to purely aspen dominated stands. Aspen can regenerate successfully in either treatment. However, the lower residual basal area treatment favors aspen to a greater degree, whereas the medium residual basal area treatment favors other hardwood species to a greater degree.

Conifer regeneration was not favored by any of the RMZ treatments. Conifer densities declined dramatically in all treatments over time, including the riparian control. The latter result suggests a mechanism other than direct harvest related impacts to account for conifer decline, e.g., increased deer browsing with enhanced edge environment.

Shrub and herbaceous responses

Woody shrub densities, including hazel, and some herbaceous life forms responded in a similar pattern as aspen regeneration. Shrub responses increased with increasing amount of overstory removal, from the uncut RMZ, to the low and then medium basal area treatments, to the upland clearcut. Since these responses paralleled aspen regeneration responses, an increase in understory competitor abundance in the partial harvest treatments cannot be implicated as a cause of reduced aspen suckering in these treatments. Bryophyte and fern life forms positively responded with an increase in residual overstory, while sedge, grass, and forbs all responded positively to an increase in overstory removal, indicating direct treatment influence on establishment and growth.

Northern white cedar and balsam fir seedling survival and growth
Results from this related study show that mound and slash microsites within medium RBA treatment are the best places to plant northern white-cedar and balsam fir to maximize survival. Mortality in pits can be high for both species due to seasonal flooding. Three year old cedar seedlings appear to transplant with a higher rate of survival success than balsam fir. Outside of exclosures where seedlings are subject to deer browse, survival after three years declines significantly for cedar which is browsed preferentially. Mortality will continue, and we expect to see cedar survival percentages decline in relation to fir in coming seasons.

Harvest areas in general emerge as the best places to plant cedar and balsam fir to maximize growth. At this stage of development (3 years *in situ*), cedar shows higher mean height growth than fir, while basal diameters are more similar. This demonstrates resource allocation differences between species. Protection from herbivory is important for continued cedar growth and recruitment; balsam fir is not routinely browsed and so will fare better over the long run if unprotected.

<u>Blowdown of residual trees in riparian management zones</u>
When trees left at the edge of RMZ adjacent to clearcuts are exposed to wind, they are more susceptible to blowdown (Ruel et al. 2001). Residual trees left after a thinning carry the same risk. Therefore, blowdown after RMZ creation is a potential concern. Excessive blowdown can lead to a reduction in RMZ ecological function.

Multiple-basin study sites
In the multiple-basin study, blowdown of residual trees has been moderate after five years, averaging about 10% of basal area and density in the harvested RMZ treatments and 6% in the riparian control. The later rate is within the range of background mortality rates for similar forests, while the rates for the two harvested treatments are above background expectations. Such events tend to be episodic, so the potential still exists that substantial numbers of trees in the RMZs could blow down over time. Continued losses of residual overstory trees would likely increase the growth of aspen and other early seral species that have already established the riparian treatments.

Results indicate that trembling aspen is at high risk of blowdown in RMZs as 32% of residual aspen basal area had blown down by 5 years. Balsam fir was moderately susceptible, with 19% of its basal area blowing down after five years. White spruce, black ash, paper birch, basswood, and sugar maple appear to be at much lower risk of blowdown.

Single-basin study sites
At the single-basin study site, a high percentage of blowdown, measured as both basal area and tree density, has occurred since harvest 10 years ago. The riparian control and the harvested RMZ treatments were all about equally high. The implication of this is that RMZ, at least in this study, are at risk of damage from blowdown, and that loss of these trees can reduce the functionality of the RMZ. The need for wider RMZs (100 foot in this study) is suggested by these results.

Coarse particulate organic matter input to streams

In 2008, our results show that coarse particulate organic matter input to the multiple-basin study streams was only slightly different between the low and medium basal area treatments and the uncut control RMZ. There, results suggest no strong longer-term effect of treatment of the amount of coarse particulate organic matter entering streams with similar treatments or geomorphic settings of the riparian area.

Temporal dimension

The results presented above report mid-term (five years) responses following riparian harvest treatments. To fully understand the longer-term consequences (i.e., 8-10 year post-harvest), follow-up study will be necessary.

Unanticipated and unresolved problems

The procedures used to meet the objectives of this Result were adequate and sufficient. One aspect of the overall study that could have been changed, given sufficient land area and cooperators, is use of a complete block design, where all three harvesting treatments were included at each of the study locations. There were no unresolved problems relative to this Result. All work was completed as planned.

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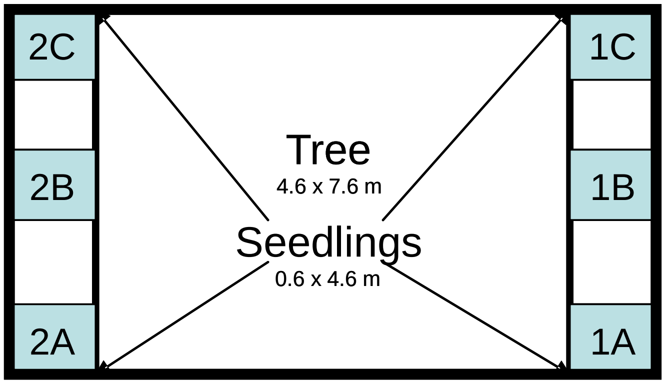

Figure 1.1. Depiction of vegetation sampling nested plot design.

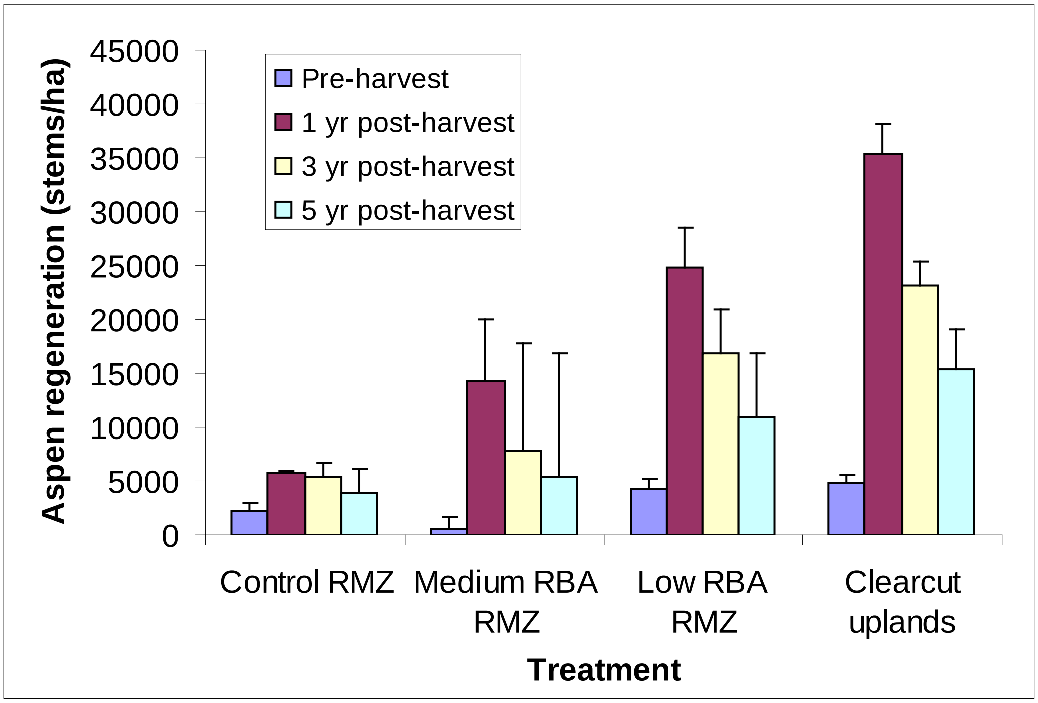

Figure 1.2. Trembling aspen regeneration densities (stems/hectare) among treatments over time.

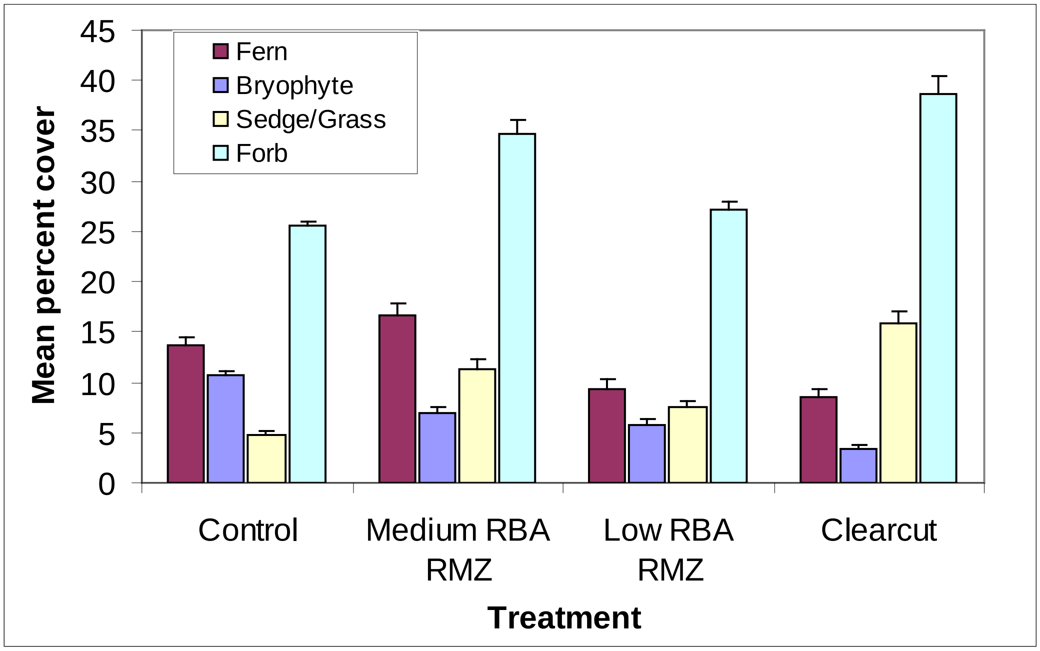

Figure 1.3. Mean percent cover (± standard error) of ferns, bryophytes, sedge/grasses, and forbs five years after the RMZ treatments occurred.

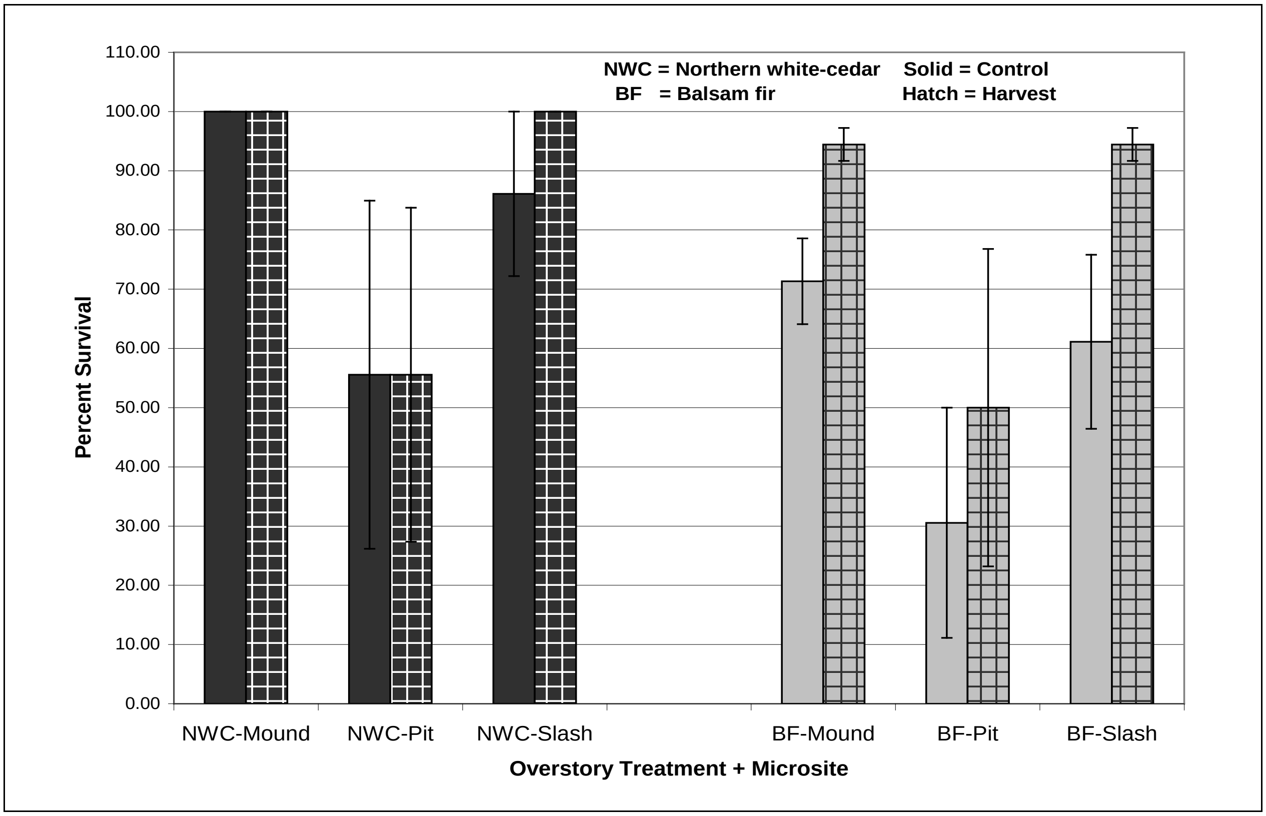

Figure 1.4. Inside exclosure survival of northern white-cedar (NWC) and balsam fir (BF) seedlings in overstory treatments (control vs. harvest) and microsite at the Red Lake, Nemadji State Forest and East Branch Beaver River multiple-basin study sites.

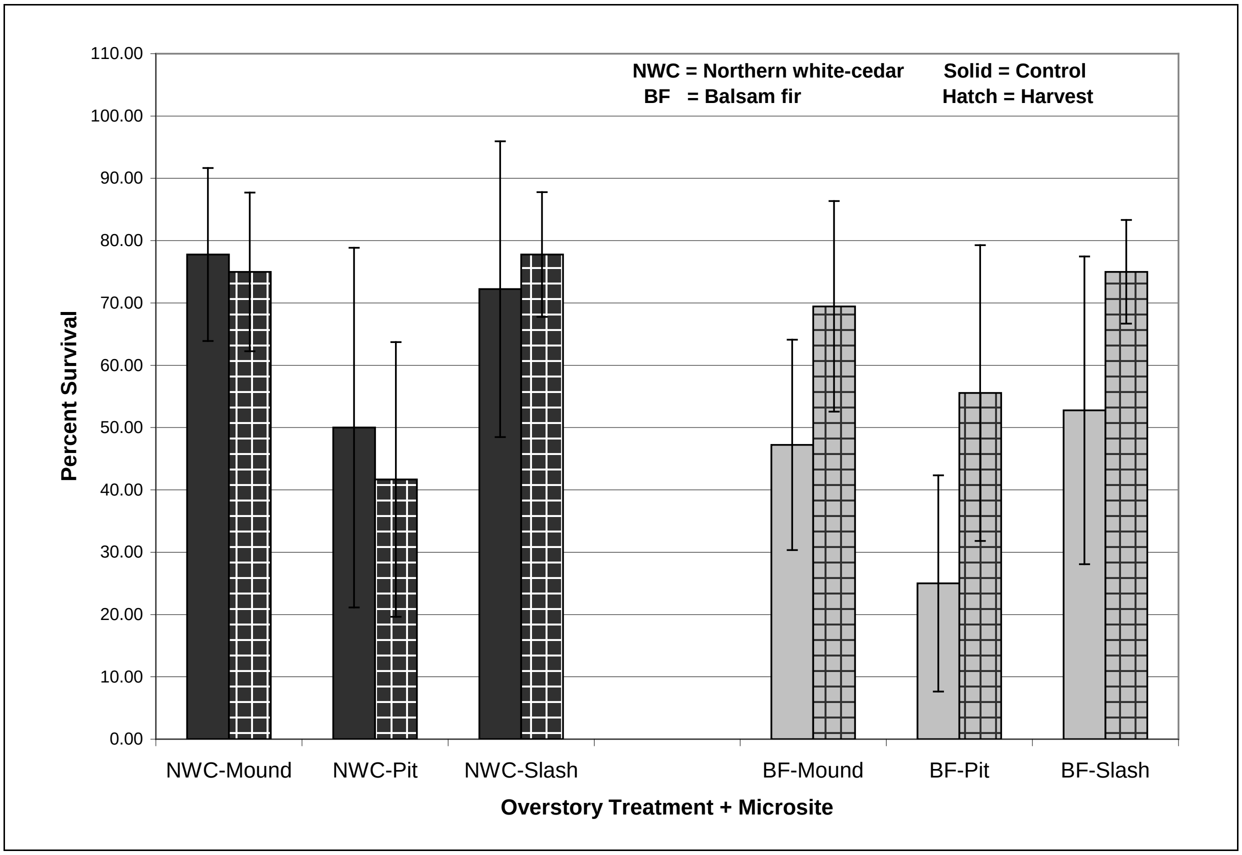

Figure 1.5. Outside exclosure survival of northern white-cedar (NWC) and balsam fir (BF) seedlings in overstory treatment (control vs. harvest) and microsite at the Red Lake, Nemadji State Forest and East Branch Beaver River multiple-basin study sites.

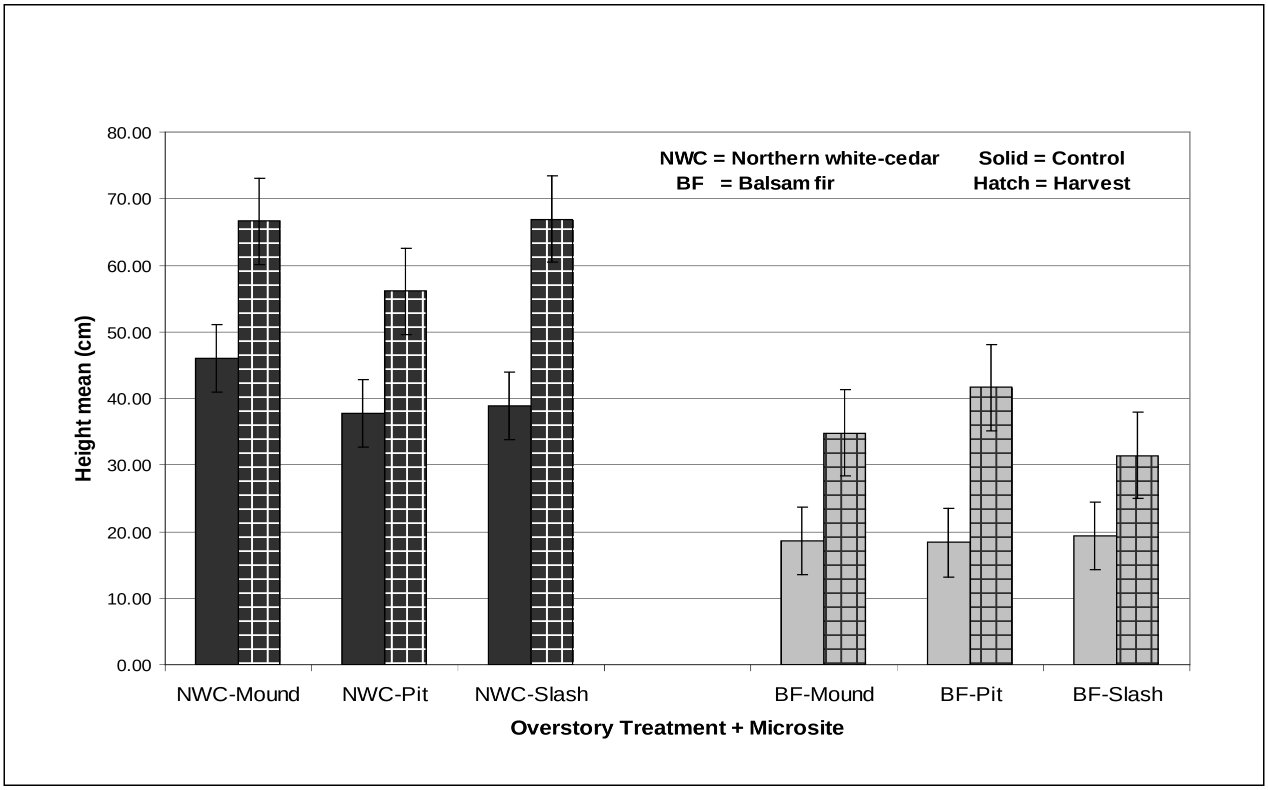

Figure 1.6. Inside exclosures: northern white-cedar and balsam fir seedling height response to overstory treatment (control vs. harvest) and microsite at the Red Lake, Nemadji State Forest and East Branch Beaver River multiple-basin study sites.

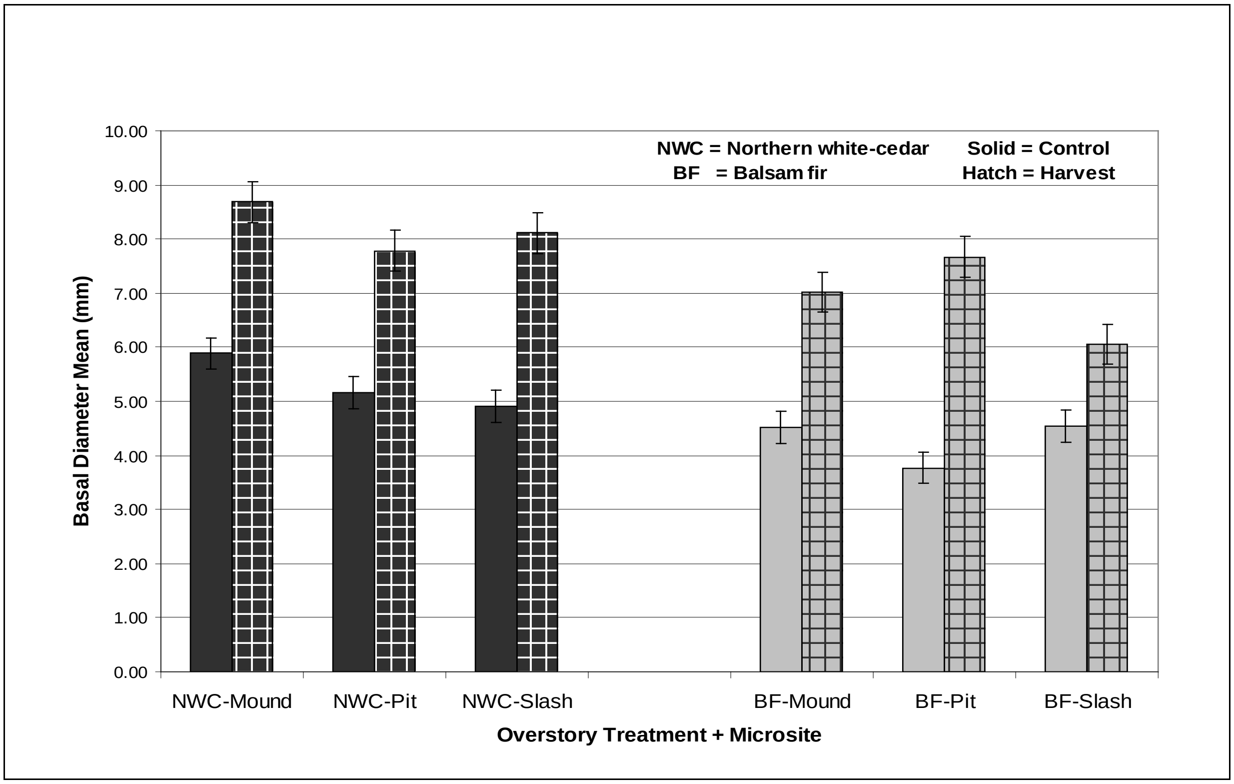

Figure 1.7. Inside exclosures: northern white-cedar and balsam fir seedling basal diameter response to overstory treatment (control vs. harvest) and microsite at the Red Lake, Nemadji State Forest and East Branch Beaver River multiple-basin study sites.

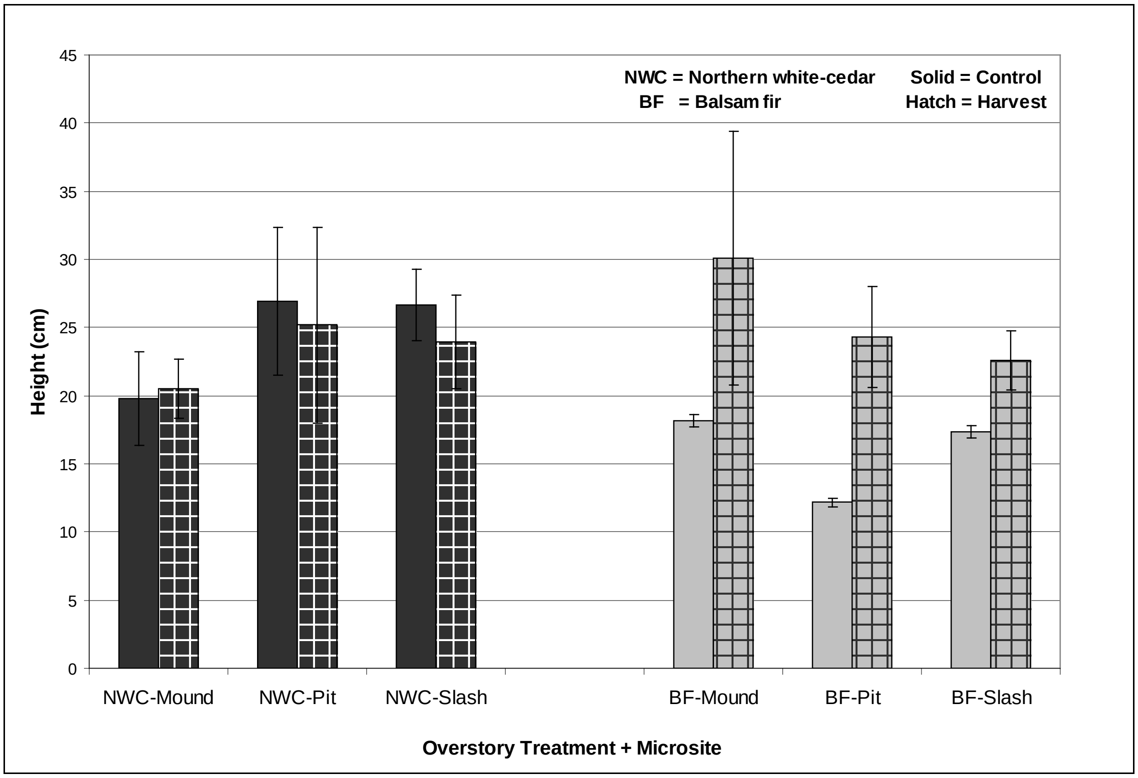

Figure 1.8. Outside exclosures: northern white-cedar and balsam fir seedling height response to overstory treatment (control vs. harvest) and microsite at the Red Lake, Nemadji State Forest and East Branch Beaver River multiple-basin study sites.

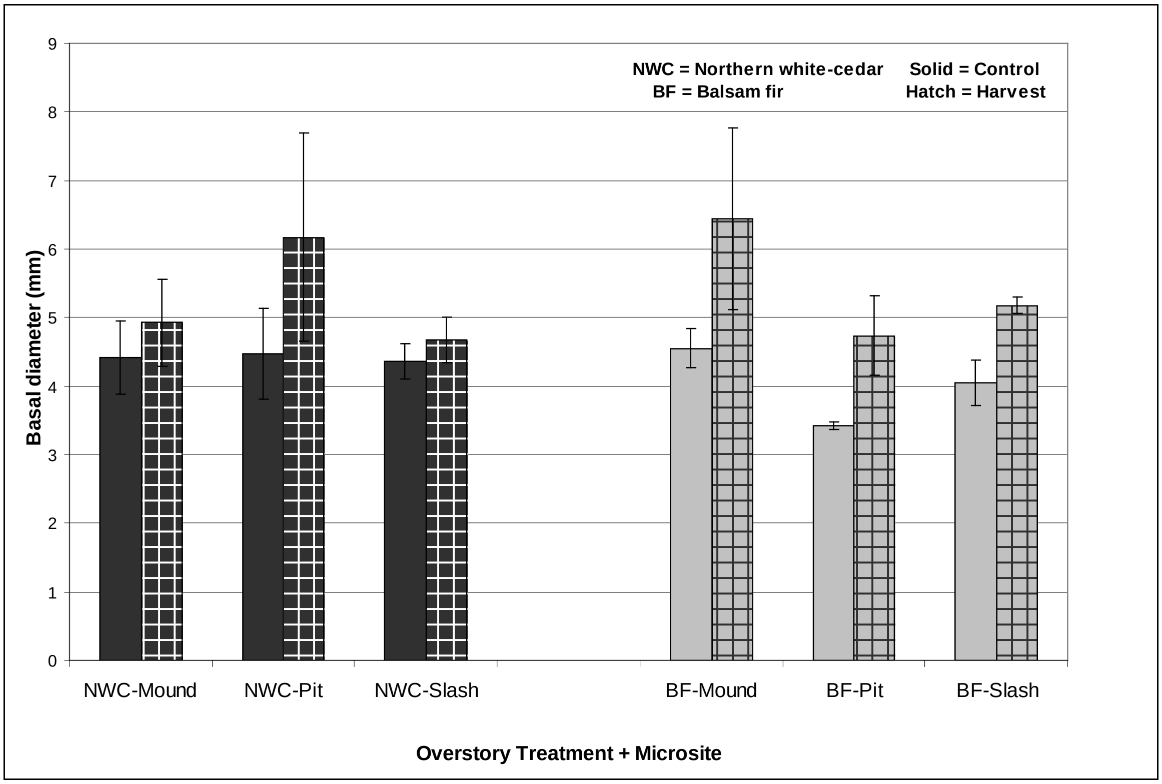

Figure 1.9. Outside exclosures: northern white-cedar and balsam fir seedling basal diameter response to overstory treatment (control vs. harvest) and microsite at the Red Lake, Nemadji State Forest and East Branch Beaver River multiple-basin study sites.

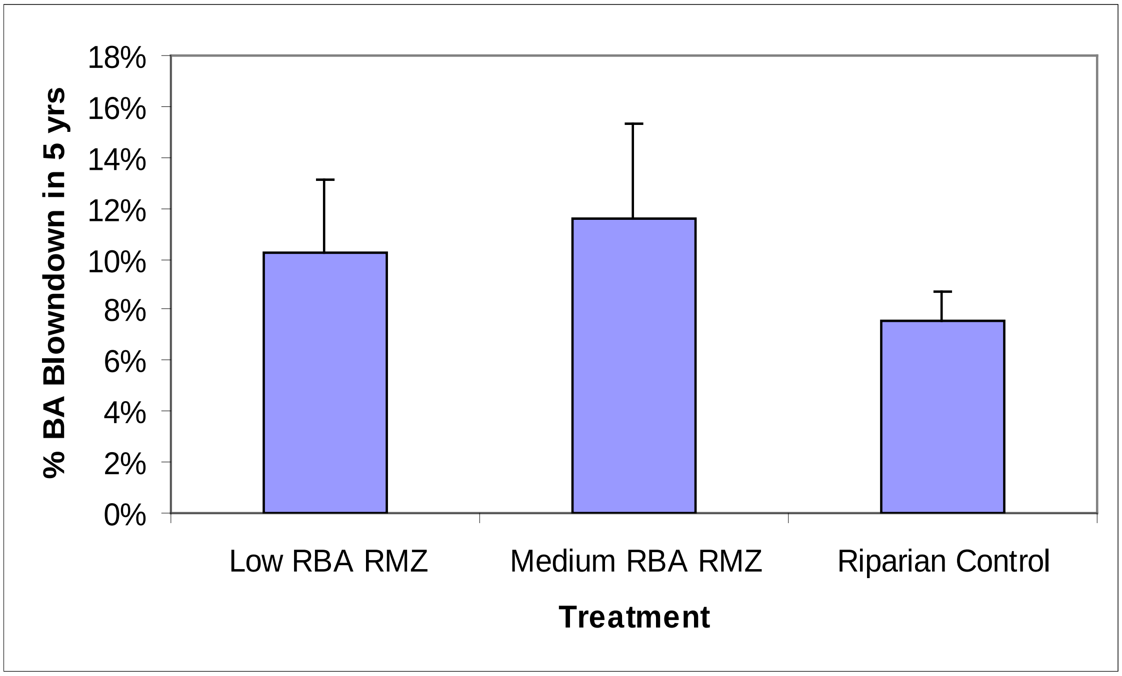

Figure 1.10. Percent (± standard error) residual tree basal area lost to blowdown five years after the RMZ treatments occurred.

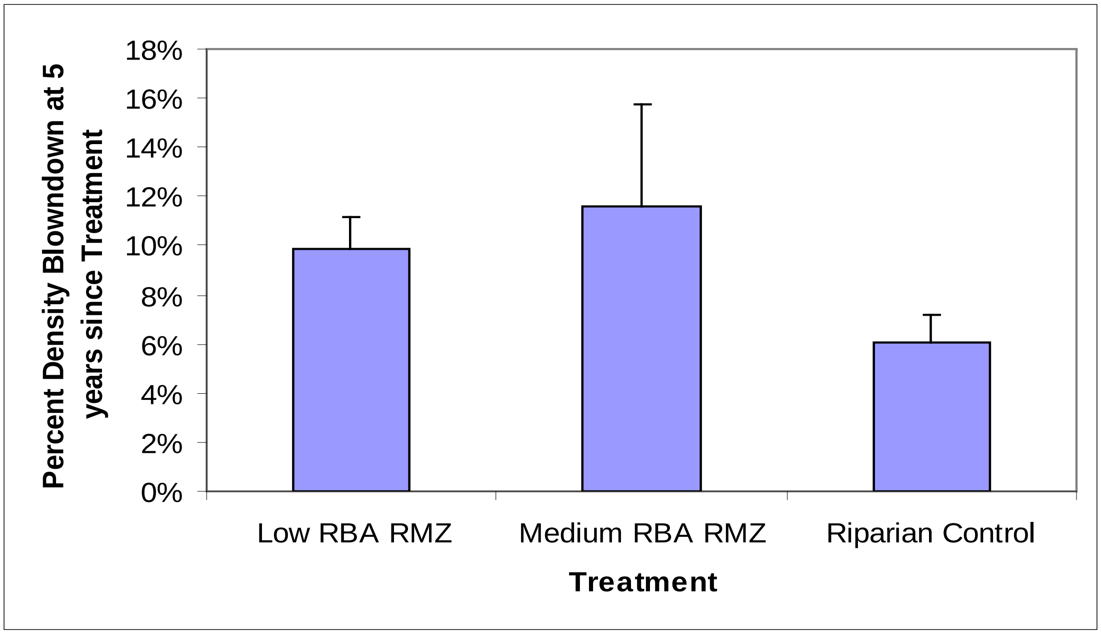

Figure 1.11. Percent (± standard error) residual tree density blown down five years after the RMZ treatments occurred.

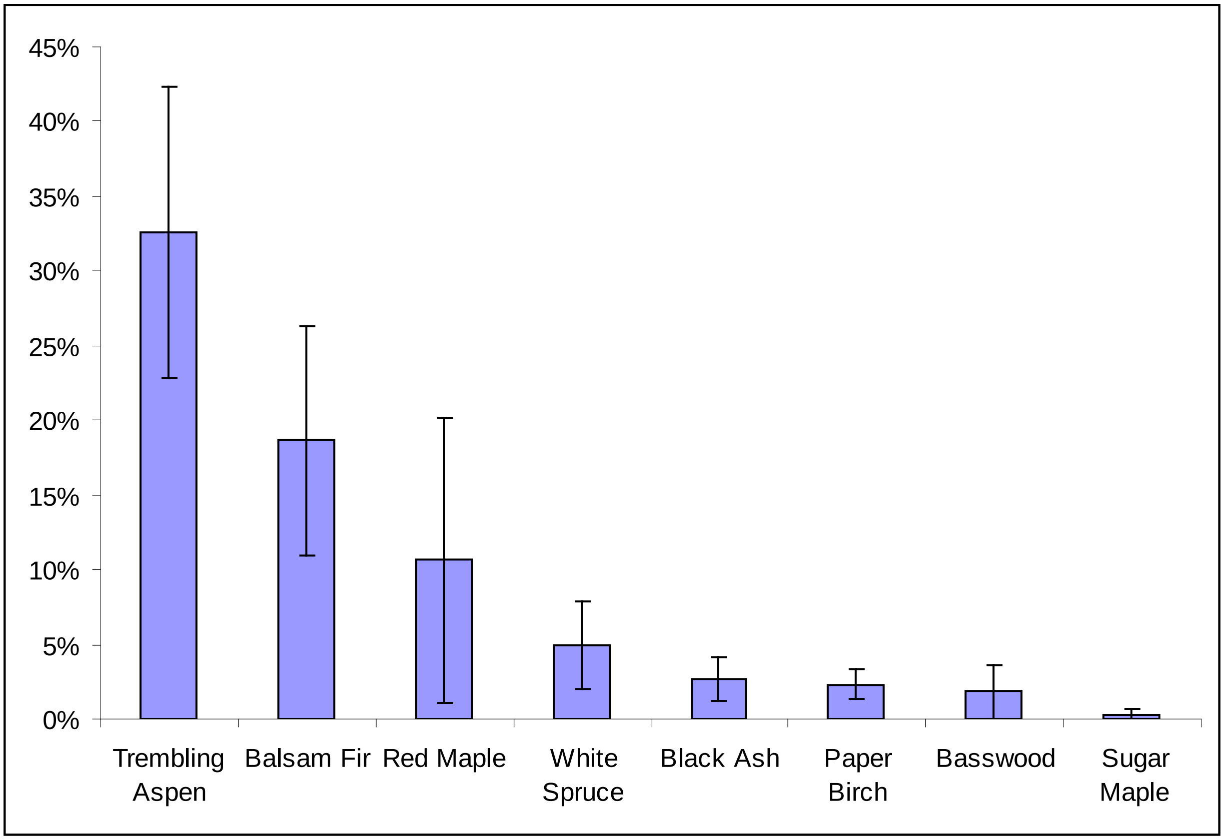

Figure 1.12. Percent basal area blown down (± standard error) by individual species (percent of that species post-harvest basal area) in riparian management zones five years after the harvesting occured.

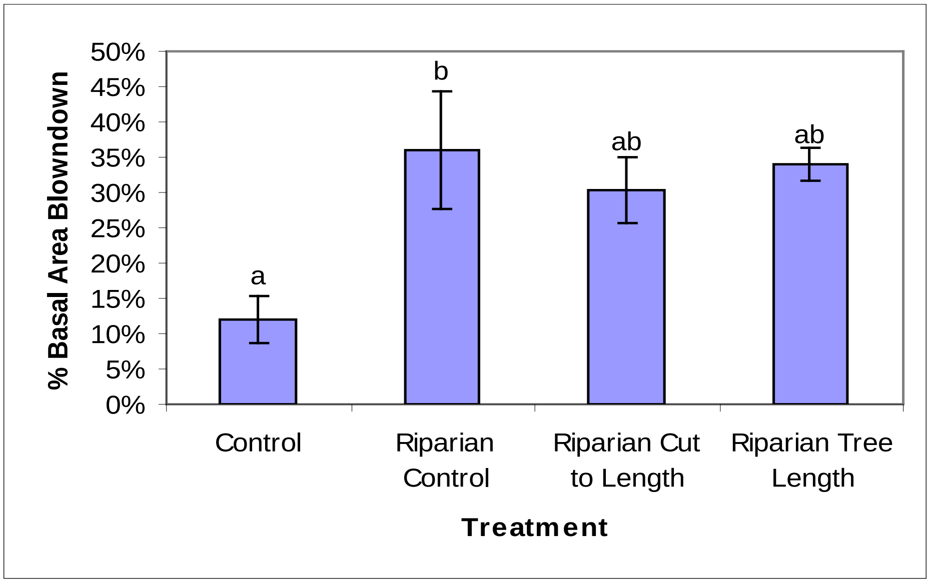

Figure 1.13. Average (± standard error) percentage of residual tree basal area lost to blowdown among riparian treatments ten years after treatments originated at the single-basin study site. Columns with differing letters are significantly different at (• =0.05).

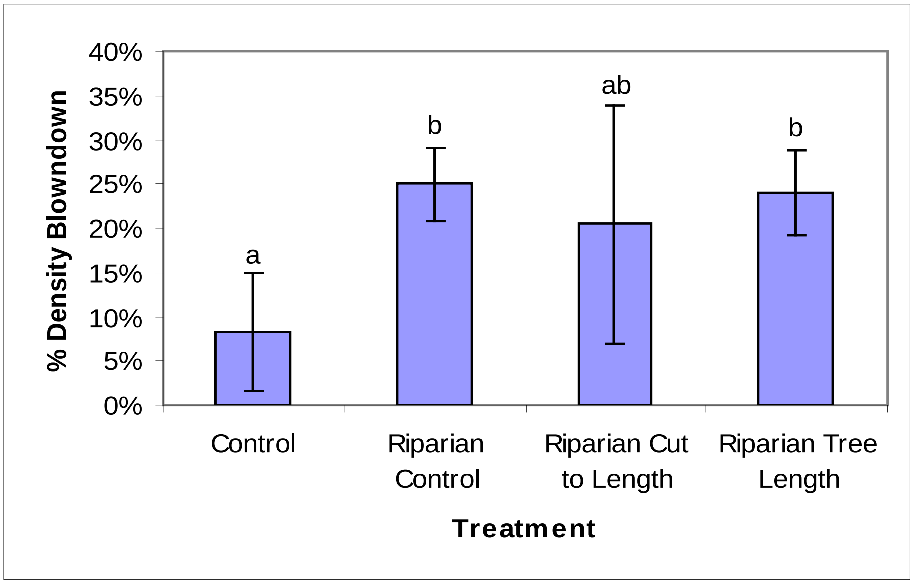

Figure 1.14. Average (± standard error) percent residual tree density lost to blowdown among riparian treatments at the single-basin study site ten years after the treatments occurred. Columns with differing letters are significantly different at (• =0.05).

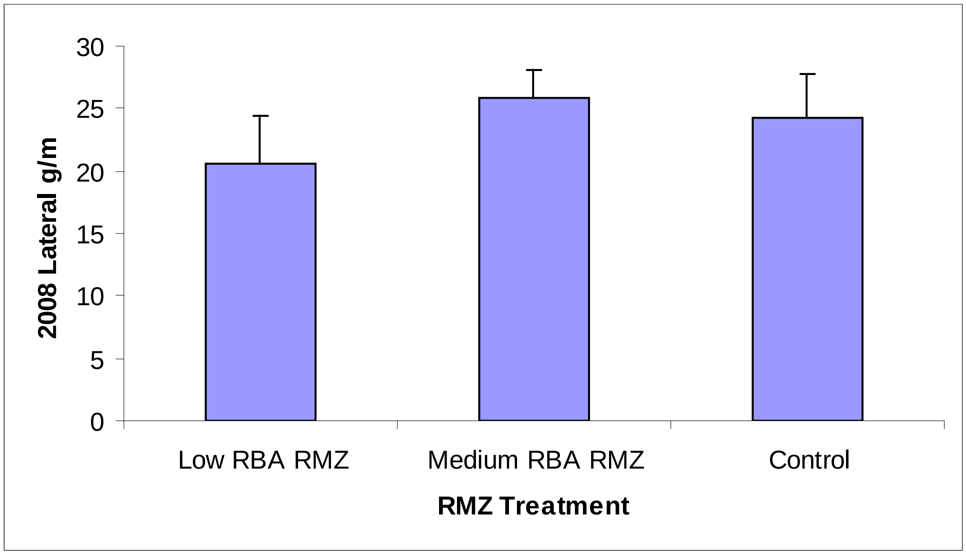

Figure 1.15. Mean (± standard error) lateral coarse particulate organic matter (g/m) collected in lateral traps among all RMZ treatments in 2008.

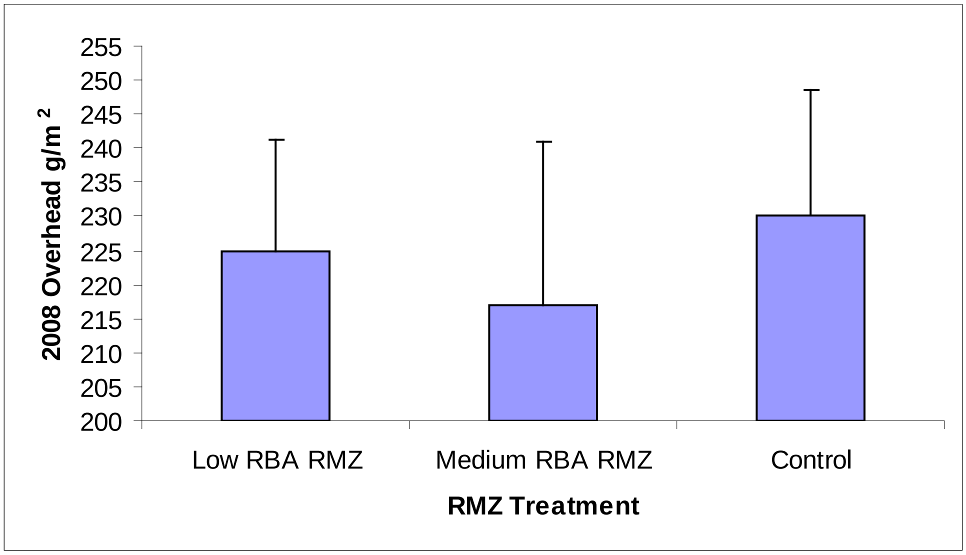

Figure 1.16. Mean (± standard error) overhead coarse particulate organic matter (g/m^2) collected in overhead traps among all RMZ treatments in 2008.

Result 2: Evaluate aquatic habitat impacts

Description: We evaluated the effects of our treatments on stream ecosystem functioning using measures of invertebrate biomass, in-stream leaf and wood decomposition rates, and food web analyses. We evaluated these response variables, along with in-stream habitat in 2007. We also reevaluated in-stream habitat and fish communities in the single-basin system in 2007. These results are divided below into two components: a) effects on fish habitats and communities and b) effects on macroinvertebrates and organic matter dynamics.

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$175,195.78**
	Amount Spent:	**$170,045.54**
	Balance:	**$ 5,150.24**

Result 2a: Evaluate long-term effects on fish habitats and communities

Description: We evaluated the effects of past harvest treatments in the single-basin system on fish habitat (temperature, sediment composition and embeddedness, depth, width, cover, bank stability, canopy coverage, woody debris, etc.) and stream fish communities (fish abundance, index of biotic integrity). We also assessed stream geomorphic measurements, including bank stability, sediment composition, and residual pool depth. We evaluated these response variables in summer of 2007 and compared them with measurements made in 1997-2000 and 2006 in the single-basin system.

Summary Budget Information for Result 2a:	**Trust Fund Budget:**	**$ 40,964.78**
	Amount Spent:	**$ 40,964.78**
	Balance:	**$ 0.00**

Deliverable	Completion date	Budget	Status
1. Collect fish habitat, fish abundance, stream geomorphic measurements, and submit update report	1/31/08	**$27,156**	Completed
2. Summarize and analyze data from deliverable 1	6/30/08	**$13,808.78**	Completed
3. Prepare and submit final report	6/30/09		Completed

Completion Date: June 2009

Final Report Summary:

Introduction

Timber harvesting has the potential to impact stream ecosystems. It has been related to decreased inputs of leaf litter and wood, and community shifts in invertebrates and other biota (Salo and Cundy 1987, Chamberlin et al. 1991, Palik et al. 2000). Timber harvesting can also affect stream hydrology. In a study in British Colombia, peak snowmelt discharge remained above pre-harvest levels for the five-year duration of the study (Macdonald et al. 2003). Verry (2004) noted that channel-forming flows double or triple after 60% of a catchment is converted from forest to non-forest conditions in the upper Midwest; however, little work has been done on the effect of elevated flows on sediment inputs. An altered stream hydrograph can lead to increased bank erosion (Brooks et al. 1997), and may take decades to recover after timber harvesting (Moore and Wondzell 2005). Excess sediment from timber harvesting can manifest as increases in total suspended sediment (Gomi et al. 2005), streambed aggradation (Keim and Schoenholtz 1999), or the proportion of surficial fine substrates (Davies and Nelson 1994, Thompson et al. 2009). For example, suspended sediment during stormflow events increased significantly in a Fiji catchment after salvage logging and slash burning; much of the sediment was mobilized from new logging roads and landing areas (Waterloo et al. 2007). Similarly, thinning only 11% of the standing timber volume with horse skidding produced a significant increase in suspended sediment to a stream in Turkey (Serengil et al. 2007a). Hydrographs also indicated significantly more stormflow in both study areas (Waterloo et al. 2007, Serengil et al. 2007b).

Impacts from riparian timber harvesting can be more direct. Machine traffic in riparian areas can damage stream banks and lead to large inputs of fine sediment (Keim and Schoenholtz 1999). Riparian timber harvesting can also decrease stream shading and cause warmer stream temperatures in summer (Brown 1970, Beschta et al. 1987, DeGroot et al. 2007). Warmer temperatures can lead to changes in growth rates for fish and invertebrates (Weatherley and Ormerod 1990) and alter the competitive balance between species (Baltz et al. 1982, Reeves 1985).

Although the potential for timber harvesting to impact streams is clear, it remains difficult to predict the exact effects of a particular harvest treatment in a specific location. Previous work documented short-term effects of timber harvesting on sediment in the single-basin system, and suggested that basin-scale effects were more important than local-scale effects or harvesting technique (Hemstad et al. 2008). Thus, the purpose of our analyses was to examine changes over a ten-year period at the basin scale.

Methods

Data collection in 2006-2007 followed the same methods as previous sampling in 1997 – 2000 (Hemstad et al. 2008); additional variables were also measured as described below. Unless noted otherwise, data were collected from three 50-m reaches at each plot: 50-m immediately upstream from the plot, 50-m at the downstream end of the plot, and 50-m immediately downstream from the plot. Data were not included from Plot 9 because the stream contained no fish during 2006 or 2007 sampling and contained little water.

Geomorphology and fish habitat
A variety of data were collected at the study plots for examination of basin-scale year effects (i.e., overall differences between years when considering all plots). Six variables were measured to characterize stream bank and channel conditions: proportion of unstable banks, canopy cover, surficial fine substrates, embeddedness, streambed depth of refusal, and residual pool depth. Visual estimates of the proportion of bank area that was unstable (not covered by vegetation,

roots, or rocks) were made in the three 50-m reaches at each plot. The value for each 50-m reach was the mean of three 17-m sections. Canopy cover was also determined at the center of each 17-m section using a spherical concave forest densiometer in all four directions. Unstable banks and canopy cover were assessed in July 1997-2000 and 2006-2007.

Surficial substrates were examined in the three reaches at each of the 11 study plots. Each 50-m reach at each plot was divided into five 10-m subreaches, to avoid sampling substrates exclusively at the upstream or downstream end of a 50-m reach. Seven circular quadrats (28 cm in diameter) were placed in random locations in each 10-m subreach to visually estimate the percentage of sand, silt, or clay (i.e., fine substrates) on the streambed surface (for a total of 1,155 quadrats per year). Embeddedness was estimated in each quadrat as the degree to which larger substrates were buried in fine substrates (e.g., a quadrat with cobbles half-buried in sand was 50% embedded, whereas a quadrat with only fine substrates visible was 100% embedded). Surficial substrates were examined in July 1997-2000 and 2006-2007.

Sediment storage in the channel was evaluated using depth of refusal and residual pool depth. At each of the 11 study plots, the ten riffles with the largest substrates and the ten deepest pools were sampled. Depth of refusal was determined at each riffle and pool by probing with a tapered aluminum rod to determine the thickness of the fine sediment layer (i.e., sand or silt) in the stream channel. The depth of refusal for each plot was the mean of the ten riffles and ten pools. Depth of refusal was measured in summer 1997, 1998, 2006, and 2007. Residual pool depth (i.e., pool depths minus riffle depths) was determined for each plot in summer 1997, 2006, and 2007 with a laser level.

In fall 2007, rain events that totaled 112 mm above the August/September mean for the study period caused high flows throughout the study area (Minnesota State Climatology Office). Depth of refusal data were collected at all plots in November 2007 to investigate whether sediment had been flushed from the streams by these high flows.

Basin-scale year effects were evaluated at all study plots, regardless of harvest treatment, using repeated measures ANOVAs that included new data from 2006-2007. Two factors were included in each analysis: a factor for year and a blocking factor for the four streams. The blocking factor was necessary to address a lack of independence between sampling units on the same stream. Variables were transformed as needed to reduce heteroscadasticity and improve normality. A repeated measures ANOVA was examined separately for canopy coverage, unstable banks, embeddedness, and surficial fine substrates. In addition, repeated measures ANOVAs were used to evaluate year effects on depth of refusal and residual pool depth, using a year factor but no blocking factor (due to greater separation between sampling units and lower replication). When ANOVAs were significant ($P < 0.05$), Tukey's HSD was used to compare differences in mean values for the response variable between years. The statistical software R was used for all analyses.

Large wood was assessed in July 1997-2000 and 2006-2007 as an indicator of fish habitat. Large wood was assessed at five evenly-spaced transects in each 50-m reach. The total length was recorded for each piece of large wood that intersected a transect and that met the following criteria: the piece had to include a portion within the bankfull channel that was at least 0.05 m in diameter for at least 1 m of length. Large wood measurements were summarized as total length density (m/m^2), which is the length of pieces per unit area of stream bed.

Fish and temperature
Fish were sampled during August in 1997 (pre-harvest), 1998-2000, and 2006-2007. All sampling was conducted with a Wisconsin AbP-3 backpack electrofisher. A coldwater fish index of biotic integrity (IBI) value was calculated for each 50-m reach (Mundahl and Simon 1999). The IBI increases with the proportion of species that are ranked as intolerant, top carnivores, and coldwater obligates (e.g., brook trout [*Salvelinus fontinalis*]) and decreases with the proportion of tolerant species (e.g., central mudminnow [*Umbra limi*, Kirtland] or creek chub [*Semotilus atromaculatus*, Mitchill]). The southern stream contained > 99% brook trout, thus brook trout analyses only used data from that stream; analyses for other individual species only used data from the three northern streams, and the IBI analyses used data from all four streams.

Basin-scale trends in fish variables were examined using the mean from all plots in the single-basin system each year. Univariate regressions were used to investigate temporal trends for the basin means for fish index of biotic integrity and abundances, and to investigate relationships between fish and habitat variables (i.e., large wood and fine substrates) at the basin scale. Univariate regressions were also used to examine the relationships between fish variables and two climate variables. The first climate variable was summer air temperature, using the mean air temperature from June through August of each year at the nearest monitoring station 10 km to the north (Minnesota State Climatology Office). The second climate variable was total spring precipitation, the cumulative precipitation from April 1 through July 12 (prior to field sampling) of each year. The proportion that each fish species contributed to total fish abundance was also examined with a rank abundance curve for each year sampled.

Plot-level effects on stream temperature were examined in 2006 and 2007 during August (the warmest month). An Onset® Pro v2 temperature recorder was placed 0-50 m upstream and another was placed 0-50 m downstream of each plot. Each recorder was cabled to a brick in the deepest pool available and was set to measure water temperature every 15 minutes. The response variable examined for water temperature was the mean temperature in August for the downstream recorder minus the mean temperature in August for the upstream recorder (i.e., plot-level warming). Of the 24 recorders set each year, two became exposed to air due to low water levels, one was buried by bedload, and one was vandalized; the corresponding plots were omitted from the plot-level analysis. A two-factor ANOVA was used to evaluate plot-level warming. The first factor for the ANOVA was year (2006 versus 2007) and the second factor was treatment (unharvested control, riparian buffer, or thinned riparian). No transformations were necessary; Tukey's HSD was used to compare mean values.

Results

Geomorphology and fish habitat
Canopy cover, unstable banks, embeddedness, and surficial fine substrates were significantly different across years during the study period (Table 2a.1). Although canopy cover at the basin scale was not directly affected by harvest itself (i.e., 1997 and 1998 were not significantly different), canopy cover declined as a result of windthrow (an indirect effect of harvesting) by

2000 and had recovered to pre-harvest levels by 2006 (Figure 2a.1A). The proportion of unstable banks increased between 1997 and 2000, but had recovered by 2007 (Figure 2a.1B). Embeddedness increased from 1997 to 1998 and remained above pre-harvest levels through 2007 (Figure 2a.1C). Surficial fine substrates also increased from 1997 to 1998, but partially recovered in 1999 after a heavy summer storm (Figure 2a.1D). The proportion of surficial fine substrates again increased significantly relative to pre-harvest levels in 2000 and 2006, but recovered in 2007.

Sediment storage was also significantly different across years during the study period. Residual pool depths were shallower than pre-harvest conditions in both 2006 and 2007 (Figure 2a.2A). Depth of refusal was not significantly different between 1997 and 1998 but increased significantly between 1998 and 2006, and remained significantly greater than pre-harvest levels in summer of 2007 (Figure 2a.2B). However, following heavy rains in fall 2007 large amounts of freshly deposited sand were noted on the floodplains and depth of refusal in November was no longer significantly different from pre-harvest levels (Figure 2a.2B).

Fish and temperature
The IBI scores and fish abundances generally indicated trends over the study period (Table 2a.2). IBI scores decreased significantly over time (Table 2a.2), as did mean abundance for brook trout and northern redbelly dace (*Phoxinus eos*, Cope) (Table 2a.2). Mean abundance of brook stickleback (*Culaea inconstans*, Kirtland) also decreased over time, whereas creek chub increased, although neither trend was significant (r = -0.70 and 0.79, P = 0.12 and 0.06). Central mudminnow and finesecale dace (*Phoxinus neogaeus*, Cope) indicated no trend. Other species (i.e., emerald shiner [*Notropis atherinoides*, Rafinesque], fathead minnow [*Pimephales promelas*, Rafinesque], Iowa darter [*Etheostoma exile*, Girard], and northern pike [*Esox lucius*, Linnaeus]) were uncommon (Table 2a.2) and were not included in species-level analyses. In terms of relative abundances, brook trout were the most abundant species from 1997 through 1999 but declined to fourth and third most abundant by 2006 and 2007. Central mudminnow were fourth or fifth most abundant from 1997 through 2000 and became the most abundant species in 2006 and 2007 (Figure 2a.3).

Some changes occurred with instream habitat and local weather. Fine substrates increased after 1997, large wood decreased, and total spring precipitation increased through 1999 and subsequently decreased (Table 2a.3). On average, summer air temperatures increased over the study period by 0.062 °C/year at the nearest weather station (Figure 2a.4), which is comparable to the regional trend of 0.06 °C/year (Austin and Colman 2008).

Fish index of biotic integrity and abundances were not significantly related to habitat variables or spring precipitation at the basin scale (Table 2a.4). However, some fish variables were significantly related (P • 0.05) to estimated summer air temperatures. IBI scores and abundances for brook trout, northern redbelly dace, and brook stickleback (Figure 2a.5) as well as finescale dace (r^2 = 0.49, not shown) were negatively related to warmer summer air temperatures. Abundances of creek chub or central mudminnow were not significantly related to any variables.

There were significant plot-level treatment effects on stream warming (i.e., downstream-upstream differences in water temperature, Figure 2a.6). The ANOVA for plot-level warming indicated that the year factor was not significant (P = 0.65), but the treatment factor was significant (P = 0.02). Tukey's HSD comparison indicated that warming was significantly greater (P = 0.01) in thinned riparian plots compared to riparian buffer plots. However, warming at the unharvested control plots was not significantly different from the riparian buffer plots or the thinned riparian plots (P > 0.17).

Discussion

Geomorphology and fish habitat

Our study demonstrated that headwater streams in moraine landscapes may require ten years to recover after a large input of fine sediment, depending on the rate of stream bank revegetation and the frequency of large storm events. Embeddedness, depth of refusal, and residual pool depth values remained significantly changed ten years after the input of sediment between 1997 and 1998. The year effects we documented may be related to changes in bank scour, windthrow, storm events, and damage from timber harvesting equipment.

Bank scour throughout the study area may have contributed fine sediment through at least 2000, as evidenced by higher proportions of unstable banks. Banks were fully revegetated by 2007, by which time bank scour was presumably reduced. Excess sediment (i.e., embeddedness, depth of refusal, and residual pool depth) remained in the streams through summer 2007. Storm events in fall 2007 led to high streamflows that flushed enough sediment onto the floodplain to return depth of refusal values to 1997 conditions.

Local weather patterns can influence windthrow, sediment storage, and sediment transport (Brooks et al. 1997). Storm events occurred during 1998 and 1999 (Minnesota State Climatology Office), followed by a period through 2001 with no storm events when sediment likely stayed in the channel. Heavy rainfall events occurred again in 2001-2005, many caused by summer storms with high winds that may have caused windthrow and inputs of associated sediment (Grizzel and Wolff 1998). Another period followed from 2006 through mid-2007 when sediment likely remained in the channel, until the storms of fall 2007 led to sediment deposition onto the floodplains. The analysis of decade-long studies should be interpreted in the context of such weather cycles.

Windthrow along the channel banks (Hemstad et al. 2008) may also have led to increases in unstable banks and channel sediment (Grizzel and Wolff 1998). Rootwads exposed by windthrow influenced channel morphology by adding associated sediment, partially blocking the channel, and inducing bank cutting around the rootwad. Studies of windthrow in riparian buffers in the upper Midwest are rare (Heinselman 1955, Heinselman 1957, Elling and Verry 1978) but suggest that windthrow rates are greatest near the edge of buffers (*sensu* Martin and Grotefendt [2007]); thus wider buffers may protect streamside trees from windthrow.

High discharge may also have contributed to the increases in unstable banks and channel sediment. The streams in the single-basin system may have experienced increases in bankfull discharge due to increases in water yield from harvested areas (Verry 2004, Brooks et al. 1997, Macdonald et al. 2003, Detenbeck et al. 2005, Moore and Wondzell 2005, Waterloo et al. 2007). Although the harvested percentages of the four basins were only 2 to 11%, Serengil et al. (2007b) found hydrologic effects after 11% of a basin was harvested. Lower thresholds may simply be precluded by the accuracy of hydrologic measurements (Verry 1986). Hemstad et al. (2008) found few plot-level effects of timber harvesting in the single-basin system from 1997-2000, but suggested that basin-scale changes may have masked impacts at the plot level. Hemstad and Newman (2006) also found few plot-level effects in the Knife River basin in northeast Minnesota, but observed basin-scale increases in unstable banks and surficial fine substrates 0-2 years after timber harvesting. It is noteworthy that the greatest changes in surficial fine substrates and embeddedness during the study period occurred immediately after timber harvesting, indicating a possible response to altered hydrology or soil disturbance from harvesting equipment.

Small tributary channels, if impacted by harvesting equipment, can also contribute to sediment loading in mainstem channels. Study plot 3 contained a small, yet steep (7.2%) intermittent tributary 1.2 m wide and 15 cm deep that was crossed repeatedly with harvesting equipment (*sensu* unrestricted harvest treatment of Keim and Schoenholtz [1999]). Machine traffic broke down the banks and razed the intermittent channel. In subsequent years the channel was reformed by bankfull discharges, delivering large amounts of fine sand into the mainstem of Pokegama Creek North. The pool in Pokegama Creek North just below the confluence of the tributary was nearly filled with sediment (89% loss of cross sectional area) and mean depth was reduced by 82% (E. Verry, unpubl. data). Use of a temporary bridge at a designated crossing site on the intermittent tributary would likely have preserved channel dimensions and prevented sediment delivery to the mainstem channel. Minnesota's voluntary guidelines for timber harvesting now recommend such crossings for intermittent channels as well as perennial channels (MFRC 2005).

Fish and temperature

We found that IBI scores and the abundances of brook trout, northern redbelly dace, and brook stickleback were significantly related to mean summer air temperatures at the basin scale, but not to fine substrates, large wood, or total spring precipitation. Below we discuss overall changes in the fish community, followed by discussion of changes in abundance for common species.

Although the four headwater streams in this study were all within a single basin, the spatial scale matched well with the life cycles of the fish species (Fausch et al. 2002). Brook trout were apparently isolated in one of the streams, and the other small-bodied species likely spent their entire life cycles within the stream system. IBI scores showed a significant negative trend over the study period, and abundances of more sensitive species (i.e., brook trout, northern redbelly dace [Stasiak 1972], and brook stickleback [Winn 1960]) also appeared to decline. Meanwhile, the abundance of tolerant creek chubs increased.

Overall fish numbers were markedly lower in 2006 and 2007; there are several possible explanations for the decline. First, diminished leaf litter inputs after timber harvesting (Palik et al. 2000) may have led to bottom-up trophic effects, as could decreased retention of leaf litter due to less large wood in the channels. Second, another study in the single-basin documented a decrease in macroinvertebrate diversity from 1997 through 2000, driven largely by increasing proportions of Chironomids (Chizinski et al. *Submitted*). Chironomids may be less available as prey for the fish species in the single-basin system, which could potentially lead to increased mortality over time through chronic undernourishment. Third, total spring precipitation in 2006 and 2007 was the lowest of the study period, thus low water levels (Lake 2003) are another possible explanation for reduced fish numbers.

The fish community in the single-basin system appears to have responded to different environmental conditions over the study period. Prior research in the single-basin system showed a negative relationship between IBI scores and fine substrates from 1997-2000 (Hemstad et al. 2008). However, our analyses showed no relationship between IBI scores and fine substrates at the basin scale. Our analyses indicate a strong connection between summer air temperatures and the fish community; warmer temperatures may favor some species (e.g., creek chub) at the expense of others (e.g., brook trout).

Brook trout: The abundance of brook trout declined consistently during the study period. Based on previous research with salmonids (Alexander and Hansen 1986, Waters 1995, Finstad et al. 2007), a chronic response to elevated levels of fine sediment was feasible. While low levels of large wood provide little habitat for macroinvertebrates (Johnson et al. 2003), we found no basin-scale relation between brook trout abundance and large wood. Our study design could not rule out bottom-up trophic effects or reduced availability of macroinvertebrate prey as explanations for the chronic reduction in brook trout abundance, although the study basin was free from confounding effects of agriculture (Durance and Ormerod 2009). Overall, the most compelling explanation for the brook trout decline is that warming temperatures over the study period caused mortality (or emigration to the nearest coldwater stream 5 km south). Although the highest seven-day mean water temperatures we observed (17.9° C in 2006 and 17.4° C in 2007) did not reach the critical thermal maximum of 22.3° C for brook trout (Eaton et al. 1995), sublethal thermal effects on fish can be subtle (Boughton et al. 2007). Invertebrate production may have been limited by high levels of fine sediment (Waters 1995, Matthaei et al. 2006) or warming temperatures (Durance and Ormerod 2007), and thus precluded fish from consuming sufficient quantities of invertebrates during warmer temperatures (Ries and Perry 1995).

Northern redbelly dace: Abundance of northern redbelly dace decreased significantly over time. At the basin scale, northern redbelly dace abundance had a negative relation to warmer air temperatures in summer. Stasiak (1972) noted that northern redbelly dace prefer streams with a constant flow of cool groundwater; warmer summer temperatures in our study may have caused direct mortality or emigration.

Brook stickleback: Abundance of brook sticklebacks decreased over time, although not significantly. As for northern redbelly dace, brook stickleback abundance at the basin scale was negatively related to warmer air temperatures in summer. Brook sticklebacks require cool water (Winn 1960), but they are also sensitive to environmental degradation (Lyons 2006). Although increased fine sediment after timber harvesting (Hemstad et al. 2008) could have reduced invertebrate prey numbers (Waters 1995, Matthaei et al. 2006), there was no significant relationship between fine substrates and brook stickleback abundance.

Creek chub: The creek chub was the only species that increased significantly over time. Contrary to previous studies, creek chub abundance was not significantly related to large wood (Quist and Guy 2001) or spring precipitation (Franssen et al. 2006) at the basin scale. The increasing temporal trend for creek chubs is not surprising, as previous studies have also documented increases in creek chub numbers after timber harvesting (Jones et al. 1999, Sutherland et al.

2002). Creek chub abundance may have increased due to less predation on their eggs and fry from other species (i.e., northern redbelly dace and brook stickleback), or less competition for invertebrate prey. Creek chubs may also have gained a competitive advantage from warmer water temperatures, as has been documented with other pairs of species (Baltz et al. 1982, Reeves 1985). Finally, creek chubs build a clean gravel nest by exporting mouthfuls of sand and importing gravel (Ross 1977), which may have made their reproductive success more resistant to increased levels of fine sediment.

Central mudminnow: The abundance of central mudminnows was fairly stable for the duration of the study, and was not related to temperature or habitat variables at the basin scale. Central mudminnows are eurythermal (Klinger et al. 1982), generalist feeders (Paszkowski 1984) and can use fine sediment as habitat by burrowing into the substrate (Peckham and Dineen 1957). Central mudminnows appear to have become the most abundant species in 2006 and 2007 by default, as most species had declined in abundance and creek chubs, though increasing, remained relatively uncommon.

Warming due to timber harvesting: Stream warming was significantly greater in thinned riparian plots relative to riparian buffer plots, possibly due to patches of open canopy (Hemstad et al. 2008). Although stream warming associated with narrowed buffers has been documented in the past (Beschta et al. 1987), the current study is unusual in that we have documented warming ten years post-harvest. Removal of riparian vegetation may exacerbate the effects of warmer air temperatures by reducing shade. However, the sample size was limited for testing plot-scale warming, and it is not clear why warming at unharvested control plots was not significantly different from other treatments.

Conclusions

Previous research has shown that headwater streams can be negatively impacted by fine sediment following riparian logging and concomitant changes in land use in the catchment (Kreutzweiser and Capell 2001, Gomi et al. 2005, Hemstad et al. 2008). Although our study did not discern between changes due to timber harvesting, road crossings, or natural causes, we evaluated recovery after a large input of fine sediment. Our study demonstrated that moraine, headwater streams can require an enabling event (e.g., high stormflows) to recover from large inputs of fine sediment. Although study plots were relatively small (4.9 ha) and retained some riparian trees, we observed basin-scale year effects for fine sediment in the stream channels that are consistent with timber harvesting effects documented elsewhere (Gomi et al. 2005).

This study also demonstrated relationships between temperature and abundance of sensitive fish species. Ongoing climate change (Rosenzweig et al. 2008) can be more important to fish communities than direct anthropogenic effects (Daufresne and Boet 2007), highlighting a pressing need to protect cool water temperatures (Eaton and Scheller 1996, Pilgrim et al. 1998, Stefan et al. 2001, Chu et al. 2008). The effects of warmer temperatures on fish may be exacerbated in streams where degraded habitat prevents prey production from keeping pace with increased metabolic demands (Ries and Perry 1995). Forest management can preserve cool water temperatures by maintaining or restoring wide forested buffers with sufficient overstory to fully shade the stream (Beschta et al. 1987). Based on previous literature (Salo and Cundy 1987, Chamberlin et al. 1991), a conservative approach would be to maintain pre-harvest levels of leaf litter inputs, hydrologic fluctuations, large wood inputs, and fine sediment loading.

To fully understand the long-term consequences (i.e., minimum of nine years post-harvest as suggested in prior studies), further study will be necessary.

Result expenditures

Funds in the amount of $866.78 were shifted from Result 4 to get the Result 2a budget to a zero balance.

Unanticipated and unresolved problems

The procedures used to meet the objectives of this Result were adequate and sufficient. There were no unresolved problems relative to this Result. All work was completed as planned.

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Table 2a.1. Basin-scale year effects for canopy cover, unstable banks, embeddedness, and surficial fine substrates from 1997 (pre-harvest) to 2007 (ten years post-harvest) using repeated measures ANOVAs. The significance of the year factor is shown for each response; blocking factors are not shown.

	Df	Sum Sq	F value	p
Canopy cover	5	450.98	13.0034	<0.001
Residual error	152	1054.33		
Unstable banks	5	5111.7	14.3824	<0.001
Residual error	152	10804.5		
Embeddedness	5	11958.2	30.8455	<0.001
Residual error	152	11785.5		
Surficial fines	5	5325	13.5825	<0.001
Residual error	152	11919		

Table 2a.2. Yearly average IBI score and mean number of fish by species per 50-m reach, based on calculated abundance estimates. Standard errors of the mean are in *italics*. The Pearson correlation coefficient (r) and p-value (p) are for the regression with year. *species counts were too small to compute a meaningful statistic.

	1997	1998	1999	2000	2006	2007	r	p
IBI score	57.78	55.56	62.92	59.86	39.44	39.31	-0.91	0.01
	5.84	*5.54*	*5.19*	*5.71*	*5.16*	*6.24*		
Brook trout	13.34	12.77	10.16	8.84	1.03	1.83	-0.99	0.00
	5.29	*4.16*	*3.57*	*2.31*	*0.55*	*0.79*		
Northern redbelly dace	4.8	3.85	2.41	5.23	0.89	0.36	-0.86	0.03
	2.15	*2.21*	*0.84*	*2.32*	*0.37*	*0.19*		
Brook stickleback	10.69	11.35	1.92	8.78	2.19	3.19	-0.70	0.12
	4.93	*2.86*	*0.6*	*2.87*	*0.81*	*1.88*		
Creek chub	0.06	0.71	0.14	1.02	0.86	1.83	0.79	0.06
	0.06	*0.33*	*0.09*	*0.39*	*0.29*	*0.94*		
Central mudminnow	4.74	7.57	1.75	3.74	5.39	3.42	-0.14	0.79
	1.26	*1.44*	*0.55*	*0.87*	*1.35*	*1.22*		
Finescale dace	0.16	5.57	2.09	19.11	1.83	1.22	-0.19	0.72
	0.16	*2.01*	*0.79*	*8.38*	*0.78*	*0.44*		
Fathead minnow	0	11.34	1.01	0.53	0	0	*	*
	0	*4.04*	*0.45*	*0.51*	*0*	*0*		
Iowa darter	0	0	0.03	0	0	0	*	*
	0	*0*	*0.03*	*0*	*0*	*0*		
Northern pike	0	0	0	0	0	0.03	*	*
	0	*0*	*0*	*0*	*0*	*0.03*		
Emerald shiner	0	0	0.03	0	0	0	*	*
	0	*0*	*0.03*	*0*	*0*	*0*		

Table 2a.3. Yearly average values for all reaches for the proportion of fine substrates, large wood, estimated summer water temperature, and total spring precipitation. Standard errors are in *italics*.

	1997	1998	1999	2000	2006	2007
Fine substrates (%)	53.6 *3.4*	69.2 *1.9*	60.9 *2.9*	62.6 *2.6*	67.2 *4.1*	60.8 *3.1*
Large wood (m/m^2)	0.03 *0.006*	0.021 *0.003*	0.016 *0.003*	0.017 *0.004*	0.017 *0.003*	0.015 *0.002*
Estimated summer water temperature (°C)	15.31	15.33	15.57	15.03	15.95	15.70
Total spring precipitation (mm)	274	388	404	260	247	231

Table 2a.4. Coefficients of determination (r^2) for IBI scores and fish abundances in relation to the proportion of fine substrates, large wood, summer air temperature, or total spring precipitation at the basin scale. P-values are in *italics*.

	Fine substrates (%)	Large wood (m/m^2)	Summer air temperature (°C)	Total spring precipitation (mm)
Index of Biotic Integrity	0.08 *0.59*	0.10 *0.54*	0.56 *0.05*	0.41 *0.17*
Brook trout	0.07 *0.61*	0.41 *0.17*	0.53 *0.05*	0.40 *0.18*
Northern redbelly dace	0.07 *0.62*	0.34 *0.23*	0.85 *0.01*	0.05 *0.67*
Brook stickleback	0.01 *0.86*	0.48 *0.13*	0.62 *0.03*	0.02 *0.81*
Creek chub	0.10 *0.55*	0.37 *0.20*	0.05 *0.35*	0.32 *0.23*
Central mudminnow	0.28 *0.28*	0.14 *0.46*	0.01 *0.45*	0.01 *0.92*
Finescale dace	0.05 *0.67*	0.07 *0.61*	0.49 *0.07*	0.01 *0.85*

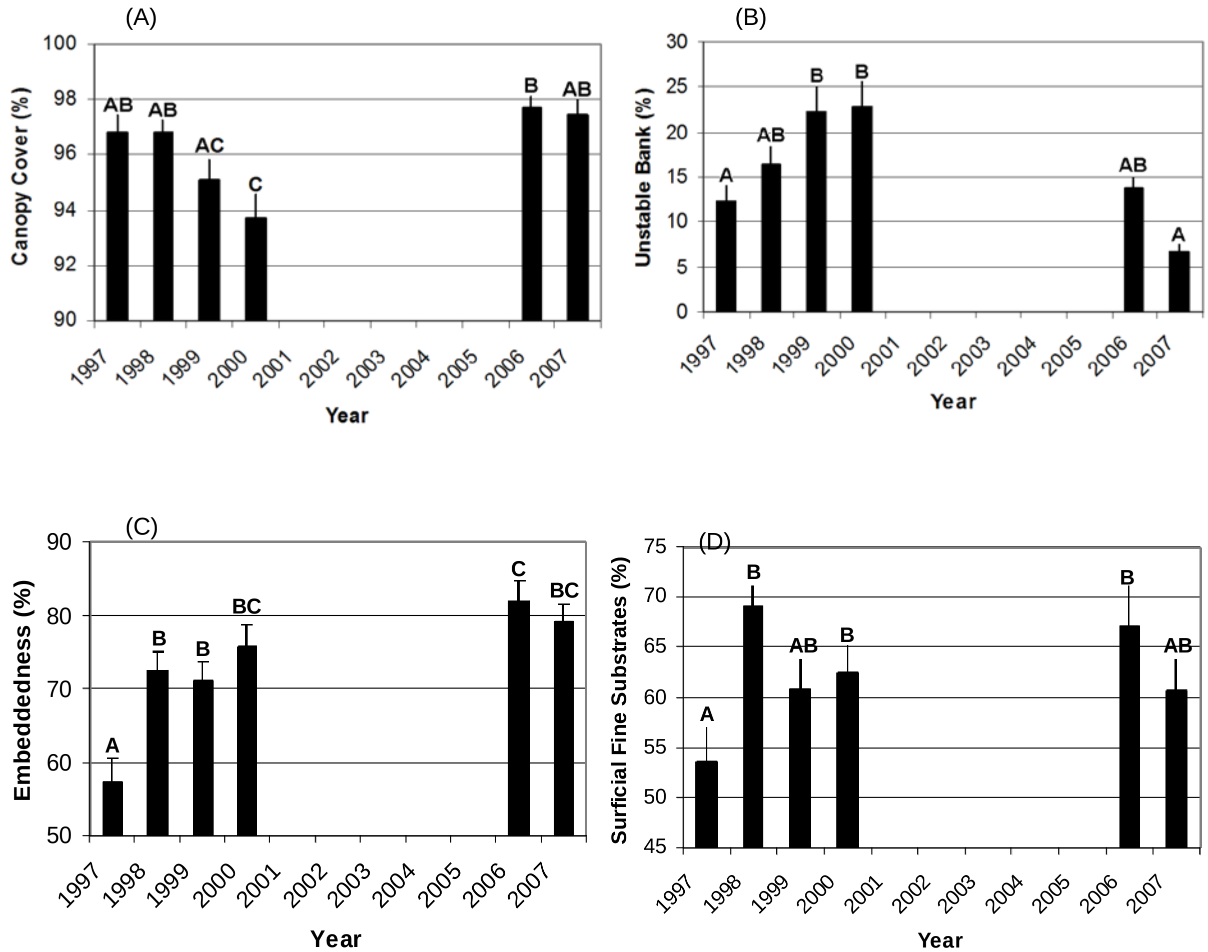

Figure 2a.1. (A) Canopy cover remained high in 1998 the year after harvest, declined in 1999 and 2000 from windthrow, and recovered by 2006. (B) Unstable banks increased in the 3 years after harvest but recovered by 2006. (C) Embeddedness increased after harvest and remained high, as did (D) the proportion of surficial fine substrates. For all graphs, error bars are 1 standard error; columns with a letter in common are not significantly different ($P < 0.05$, Tukey's HSD).

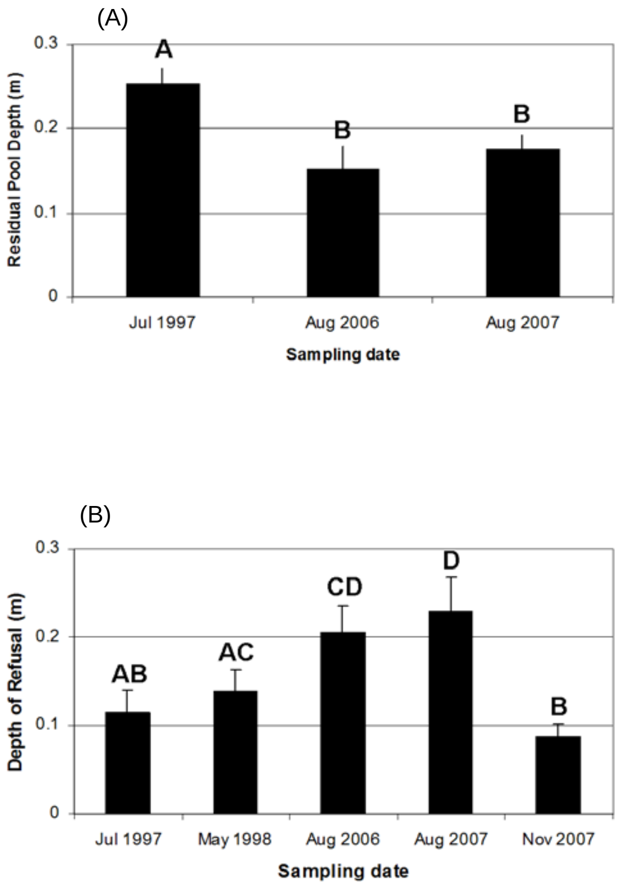

Figure 2a.2. (A) Residual pool depth reflected filling with sand after the pre-harvest 1997 measurement, (B) depth of refusal increased through all sample periods until after a large storm in November 2007. For all graphs, error bars are 1 standard error; columns with a letter in common are not significantly different (P > 0.05, Tukey's HSD).

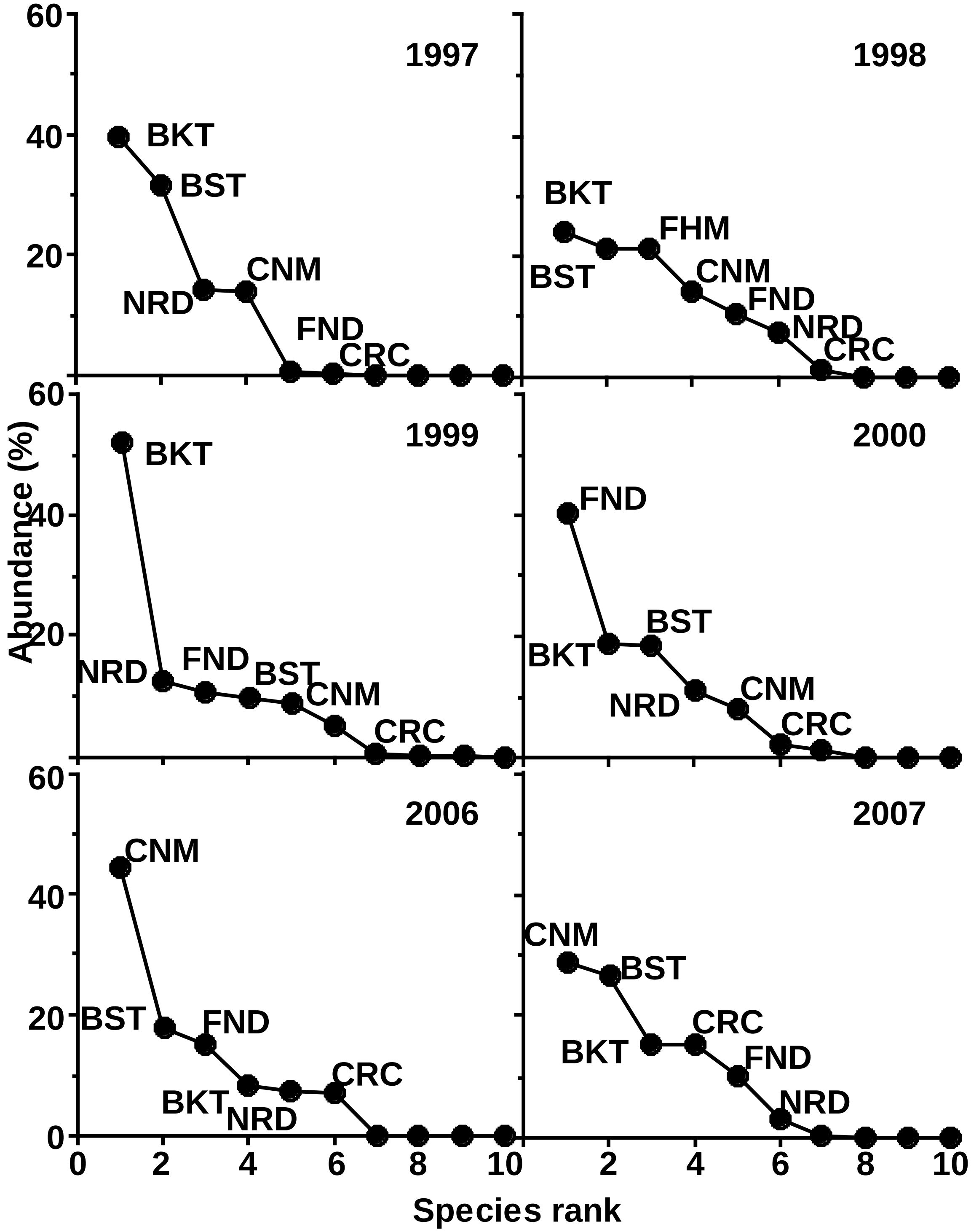

Figure 2a.3. Rank abundance curves for fish species across all plots. BKT = brook trout, BST = brook stickleback, NRD = northern redbelly dace, CNM = central mudminnow, FND = finescale dace, CRC = creek chub, FHM = fathead minnow.

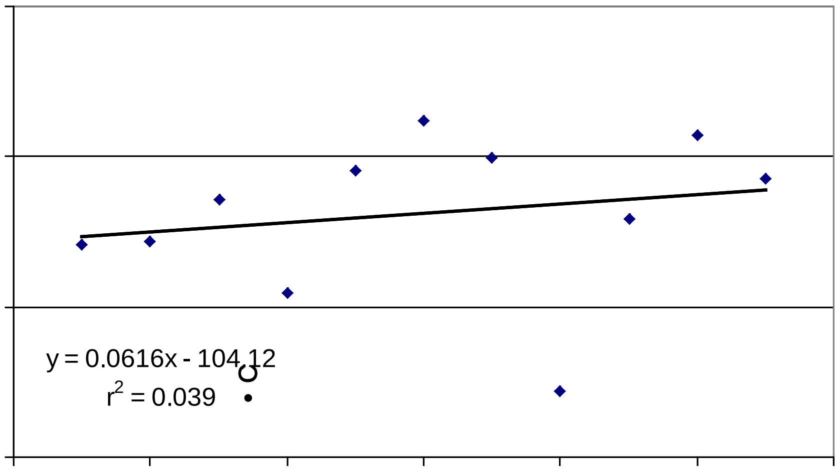

Figure 2a.4. Mean summer air temperatures for June through August 1997 through 2007.

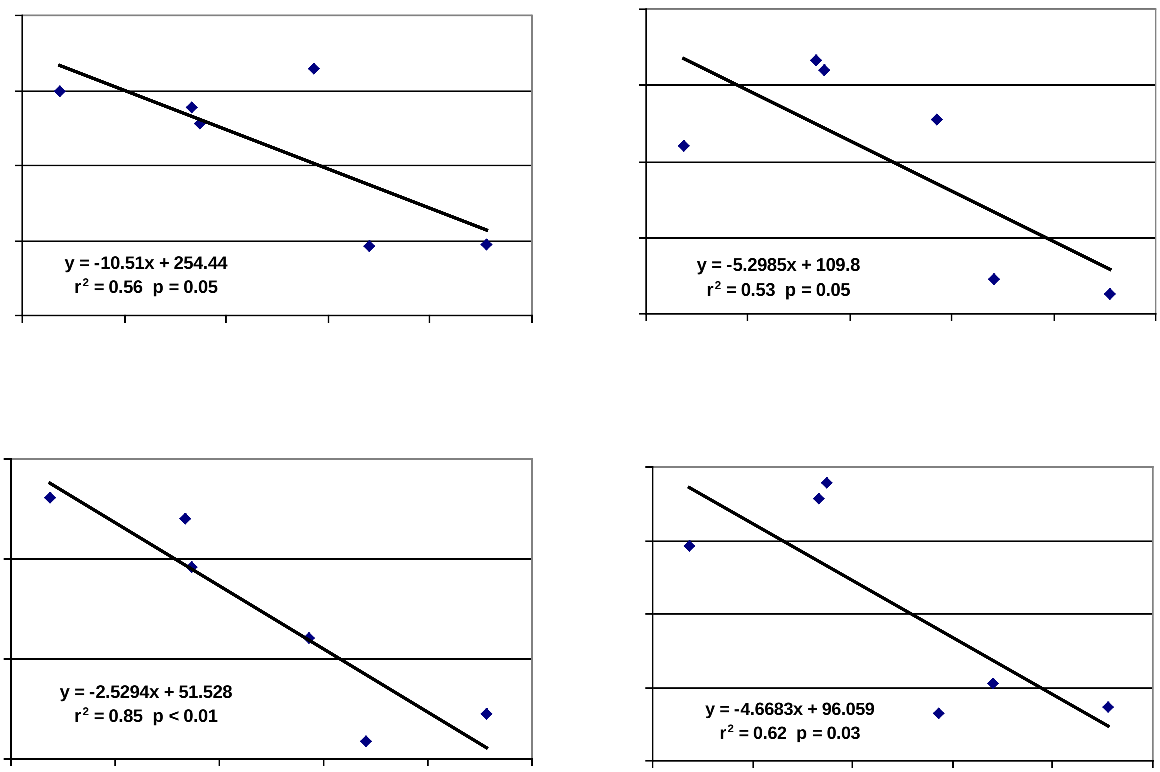

Figure 2a.5. The relationship between mean summer air temperature from June through August and the IBI scores and abundance (annual mean for all 50-m reaches in the basin) of brook trout, northern redbelly dace, and brook stickleback.

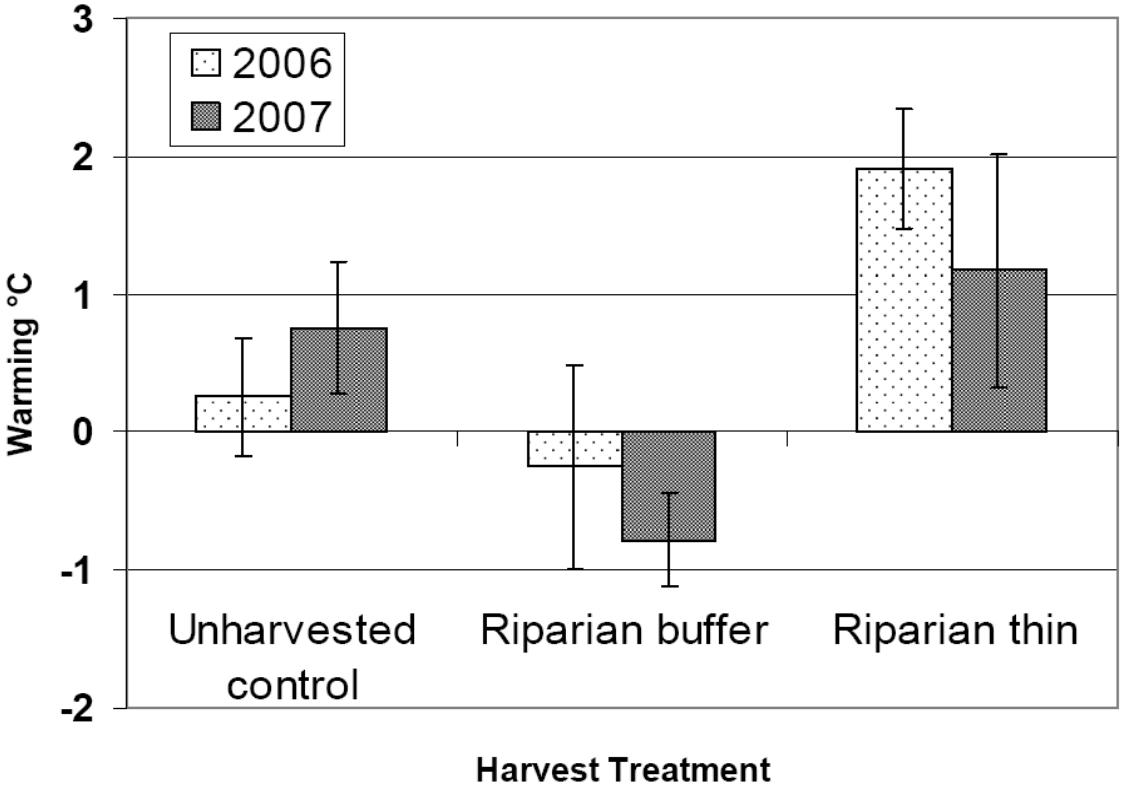

Figure 2a.6. Mean August temperature just downstream of each plot minus the mean August temperature just upstream of each plot (i.e., stream warming) by harvest treatment and year. Error bars are the standard error of the mean.

Result 2b: Evaluate macroinvertebrates and organic matter dynamics

Description: We evaluated the effects of our management treatments on stream ecosystem functioning using measures of invertebrate biomass, in-stream leaf and wood decomposition rates, and food web analyses. We evaluated these response variables during summer, autumn, and winter 2007 and spring 2008.

Summary Budget Information for Result 2b:		
	Trust Fund Budget:	**$ 134,231.00**
	Amount Spent:	**$ 131,952.67**
	Balance:	**$ 2,278.33**

Deliverable	Completion date	Budget	Status
1. Collect summer and autumn samples, initiate litter decomposition study, and submit update report	1/31/08	$52,468	Completed
2. Collect spring samples, complete litter decomposition study, and submit update report	6/30/08	$52,467	Completed
3. Process summer and autumn samples and submit update report 3	1/31/09	$14,648	Completed
4. Process spring and litter decomposition samples and prepare and submit final report	6/30/09	$14,648	Completed

Completion Date: June 2009

Final Report Summary:

Introduction

The Minnesota Forest Resources Council (MFRC) was charged under the Sustainable Forest Resources Act with coordinating the development of voluntary site-level timber harvesting and forest management guidelines. Finalized in 1998, these guidelines recommend practices to address riparian, wildlife habitat, soil, water quality, wetlands, visual quality, and historic and cultural resources. Guideline users include timber harvesters, owners of private forest land, and the state, county land departments, US Forest Service, and major forest products companies.

Riparian timber harvesting guideline research was conducted in two regions in northern Minnesota. Multiple-basin study sites were previously harvested and monitored after one, two and three year post-harvest. Another set of twelve sites located in the single-basin watershed were harvested in 1997 and monitored after one and six year post-harvest. This study documents stream ecosystem responses after five years (4 years for Reservation Tributary) post-harvest at the multiple-basin sites and 10 and 11 years post-harvest at the single-basin watershed and will be used to evaluate how effective the guidelines are at protecting forested riparian areas at a site-level.

Objectives

Our primary objective was to assess long-term effects of riparian management techniques on stream ecosystem function at both the LCMR sites and single-basin sites. Based on results from previous studies from the scientific literature we hypothesized that any long-term effects of riparian timber harvesting at the experimental levels within this study would result in increased: nutrient concentrations, water temperatures, fine sediment, wood inputs, in-stream light (reduced canopy cover), periphyton, number of invertebrates that feed on periphyton (scrapers), and leaf and wood breakdown rates (Tank and Webster 1998, Swank et al. 2001, Eggert and Wallace 2003, Moore et al. 2005, Thompson et al. 2009). We also expected that riparian timber harvesting might result in decreased leaf inputs to streams and a decline in number of invertebrates that feed on leaf material (shredders) (Wallace et al. 1999, Stone and Wallace 1998, Nislow and Lowe 2006). A growing body of scientific literature indicates that measurements of ecological processes and ecosystem function can be sensitive indicators of disturbances to stream function (Bunn et al. 1999, Gessner and Chauvet 2002, Young et al. 2003). Initial research conducted at these sites suggested that litter inputs to streams were significantly less in harvested riparian buffers, with unknown consequences for the stream food webs (Palik in Perry et al. 1998). Our research examined these linkages between stream functions (food resources and detrital processing) and riparian harvest practices. Specific objectives included: 1) quantifying fish and invertebrate habitat, available food resources for stream food webs, and macroinvertebrate response in stream reaches subjected to various riparian management treatments, and 2) evaluating breakdown rates of leaf litter and wood in streams under the different riparian treatments.

Study Sites

Multiple-basin sites

Eight study sites were established in northern Minnesota (Beltrami, Carlton, Cook, Lake, and St. Louis counties) in 2003 to monitor the biological and ecological effects of riparian forest management. Site 1: Shotley Brook, Site 2: Nemadji River Trib., Site 3: Reservation River Tributary, Site 4: West Split Rock River, Site 5: East Branch of Beaver River, Site 6: East Branch of Baptism River, Site 7: Cloquet River tributary, Site 8: St. Louis River tributary.

Treatments were designed to comply with Minnesota's current site-level guidelines (Minnesota Forest Resources Council 2005). Within the eight study sites, riparian management treatments were applied to compare no riparian management with the two different RBA levels. The two treatments of residual basal area were chosen to test "low" and "medium" levels of the current recommended values for riparian management within a fixed width RMZ of 45.7 m. The target "low" and "medium" residual basal area values were 5.7 m^2/ha and 11.5 m^2/ha respectively, however due to logger and topography issues those target RBAs were not always consistent within a site and across all sites (Kastendick 2005). Each of the eight sites was split into two blocks. The upstream block was treated using a passive management approach where no harvesting was allowed within the RMZ, and the downstream block RMZ was randomly assigned one of the two residual basal areas. After assigning treatments to the study sites, they were paired based upon similarities in species composition, soil and aquatic characteristics. This pairing allows comparisons to be made between the low and medium residual basal area treatments and their respective management controls. We also sampled a non-harvested control reach (upland and riparian zone not harvested). Samples could not be collected at the control reach at Site 7 due to a beaver dam downstream of the reach.

Harvest operations began in December 2003 and were completed in seven of the eight sites in March 2004 and the eighth site in March 2005. All harvest operations used conventional harvesting equipment (i.e., feller-buncher and grapple skidder on all sites except the West Split Rock River site where trees were chainsaw felled and cable skidded).

Single-basin sites

Riparian management techniques were also studied within the single-basin watershed in north central Minnesota. Twelve 4.6 ha plots located along 3 first to third order streams (Pokegama Creek, Little Pokegama Creek, unnamed stream) draining into Pokegama Lake (Itasca County, 47’ 05” N latitude 93’ 35” W longitude) were selected within a 2 km^2 area. Streams reaches through the plots were 1-3 m wide, 137-198 m in length, and contain a mixture of sand and cobble substrate. Dominant tree species on the plots included sugar maple (*Acer saccharum*), paper birch (*Betula papyrifera*), basswood (*Tilia americana*), and quaking aspen (*Populus tremuloides*). Three replicates of 4 treatments were used: True Control plots (no harvest in riparian zone or upland), Riparian Control (uplands clearcut/riparian zone uncut), Whole-tree harvest (uplands and riparian zone cut using the feller-buncher grapple skidder system), and cut-to-length (uplands and riparian zone cut using cut-to-length system). In plots where cutting took place within the 30m riparian zone, 6-10 m^2/ha basal area was left in place (Perry et al. 1998, Kastendick 2005). Harvesting took place in late summer-fall 1997.

Methods

Water quality and habitat measurements

In situ measurements of dissolved oxygen (YSI DO 200 meter), pH, and conductivity (EXTECH ExStickII) were made during June and July 2008 at the multiple-basin sites and during August 2006, June 2007, and July 2007 at the single-basin plots. Water samples for turbidity (LaMotte 2020e Turbidimeter) and alkalinity were collected, returned to the laboratory and processed according to APHA (1995) methods. Anions and cations were analyzed using ICP-MS in the laboratory. Water temperature was monitored continuously during ice-free months using HOBO temperature recorders. Stream discharge was measured in each stream during the ice-free months using Solonist level recorders and stage/discharge regression relationships. Canopy cover was estimated at each reach with a spherical densiometer. Data for qualitative habitat evaluation index (QHEI) scores at the eight multiple-basin study sites were collected in August 2008. Substrate was quantified visually (silt, sand, gravel, pebble, cobble and boulder) at multiple transects in each reach. Current velocity and depth were also recorded at each reach. Data could not be collected at the control reach at Site 7 due to a beaver dam downstream of the reach.

Periphyton (algal) standing crop

We assessed differences in algal standing crop biomass by measuring chlorophyll *a* content of algae growing on three rocks at each site (upstream and within) in each plot at the single-basin location and within each of the multiple-basin reaches. Chlorophyll *a* was extracted from rocks and measured on a spectrophotometer using APHA (1995) methods. Rock area was measured to estimate algal biomass in grams of chlorophyll *a* per unit rock surface area.

Organic matter standing crop – FBOM, CBOM

We quantified the amount of detrital food resources (Fine Benthic Organic Matter – FBOM; Coarse Benthic Organic Matter – CBOM) available to aquatic consumers in summer 2007 (single-basin study sites) and June 2008 (multiple-basin study sites). CBOM and FBOM was collected with the quantitative macroinvertebrate samples (methods described below) was separated from the invertebrates and separated into organic matter types (e.g. leaves, wood). Each fraction was dried at 60ºC, weighed, ashed at 500 ºC, and reweighed to obtain ash-free dry mass (AFDM) per m^2. Samples could not be collected at the control reach at Site 7 due to a beaver dam downstream of the reach. We also collected CBOM according to previously established methods (Newman in Perry et al. 1998) at each single-basin plot.

Leaf and wood breakdown rates

Breakdown rates of sugar maple (*Acer saccharum*) and balsam popular (*Populus balsamifera* L.), the dominant tree species of the pre- and post-harvest overstory at the single-basin sites, respectively, were estimated within and above each plot during autumn 2008 to autumn 2009 using methods of Eggert and Wallace (2003). Litter bags were filled with 15 grams of dried leaves, deployed in the streams at peak leaf fall, and replicate bags picked up at approximately 200, 250, and 300 day intervals dependent on breakdown rates and access to bags (bags could be picked up from frozen streams or when cooperator closed access roads to plots during spring months). Ten litterbags of each species were taken out to the field, returned to the lab immediately, and reweighed to correct for handling loss. In the lab, litterbag contents were washed to remove invertebrates and sediments, oven dried at 60ºC, weighed, ashed at 500 ºC, and re-weighed to obtain AFDM remaining for each date. Breakdown rates were calculated using the exponential decay model (Petersen and Cummins 1974). Invertebrates associated with litterbag contents were saved for a portion of the litterbags and will be analyzed at a later date. Wood breakdown rates were measured using aspen veneers anchored in the stream bottom (Tank and Webster 1998). Wood veneers were placed in the streams in June 2008 and are being retrieved as long as sufficient material remains. Lab processing of wood veneers was similar to that for litterbags. Wood breakdown rates were calculated using the same exponential decay model described above.

Macroinvertebrate community

Qualitative samples were collected within each of the three reaches at each multiple-basin site in August 2008 using Atuke's (2007) methods. Using a 500 µm-mesh D-frame net, we sampled each reach 20 times approximately every 2.5 meters, taking care to include all habitats within a reach. Samples were preserved in alcohol and brought back to the lab for sorting and identification to the lowest practical taxonomic unit. Samples could not be collected at the control reach at Site 7 due to a beaver dam downstream of the reach. Our goal was to examine responses of those invertebrate taxa most likely to change with riparian harvesting. We calculated taxa richness, percent Ephemeroptera/Plecoptera/Trichoptera (EPT) taxa, and percent scrapers, shredders, collector-gatherers, collector-filterers, and predators for each reach at each site. Four quantitative invertebrate samples were collected within each reach at the multiple-basin sites during June 2008 using Hess or Surber samplers. Invertebrates have been separated from the organic matter and will be identified at a later date. We will do more intensive analysis of invertebrates from these samples (e.g., biomass).

Two quantitative Surber samples from riffle habitat within and above each treatment plot at the single-basin site were collected in August 2006, June 2007, July 2007, and October 2007. Invertebrates from the August 2006, June 2007, and July 2007 collection periods were identified to the lowest practical taxonomic unit and classified by functional feeding group using methods of Lugthart and Wallace (1992). Substrate type, water depth, and current velocity at each Surber sample location were recorded at the time of sample collection. We calculated taxa richness, percent Ephemeroptera/Plecoptera/Trichoptera (EPT) taxa, and percent scrapers and shredders for upstream and within plot reaches. Below we present results from the June 2007 data set.

Macroinvertebrate and fish diets

Macroinvertebrates for diet analyses were collected at the single-basin site in June and October 2007. Fish for diet analyses were collected in July 2007 at the single-basin plots by Eric Merten (UMN) and saved for diet analyses. Due to a prolonged drought, fish specimens were not found at each plot. Macroinvertebrates and fish samples for diet and isotope analyses were also collected during June and July 2008 at each of the multiple-basin reaches. A University of Minnesota graduate student (funded by the US Forest Service) initiated lab processing of the diet samples during fall 2008. No results are currently available.

Statistical analyses

Due to the lack of “before” data and possible upstream effects on downstream treatments, we used an upstream (reference) and downstream (within treatment) approach at the single-basin plots. We calculated differences between reaches, pooled the plot differences for each treatment and tested for differences among treatments using one-way ANOVA. For the multiple-basin data, we used one-way ANOVA to test for differences among control, riparian control, and treatment reaches for each of the treatment levels (control, riparian control, and low and medium RBA). Tukey’s HSD test was run to test for differences between sites when significant ANOVA results were found.

Results

Water quality and habitat measurements

Multiple-basin sites

We hypothesized that the most likely differences in water chemistry between harvested and control sites at both the single- and multiple-basin study sites would be higher nutrient concentrations (nitrate and dissolved inorganic phosphorus [DIP]) at the harvested sites. Five years after harvest we found no significant differences in either NO_3-N or DIP among treatments during the months of June or July 2008 (Tables 2b.1A and 2b.1B). Nitrate-N was at or below detection limits (<0.02 mg/L) during June at most sites. During July there was a non-significant trend of higher nitrate-N concentrations at the riparian control and treatment reaches than controls at most sites. DIP generally was at or below detection limits (<0.03 mg/L) at all sites during both months (Tables 2b.1A and 2b.1B). Conductivity varied widely among the eight sites, and was highest at Shotley Brook and West Split Rock River, indicative of high productivity at those sites (Tables 2b.1A and 2b.1B). Baseflow turbidity levels were all low at each reach of each site during both months (Tables 2b.1A and 2b.1B). Dissolved oxygen concentrations in all reaches at all eight sites were all well above the threshold that limits aquatic life (5 mg/L).

Previous research showed that riparian timber harvesting may result in increased water temperatures at harvested sites due to increase exposure of stream water to sunlight. Light available for periphyton growth was estimated as percent open canopy (Figure 2b.1). We observed a trend ($p=0.09$) of higher light levels in the low RBA treatment reaches compared to control and riparian control reaches and no differences between medium RBA treatment and control reaches (Figure 2b.1). Water temperature and stream level loggers were removed from the multiple-basin study sites in early October 2008 and downloaded in the lab. During the downloading process it was determined that a number of loggers were not launched properly prior to installing them in the field. Those loggers were relaunched and redeployed at the multiple-basin study sites in late October. Data available for loggers that were deployed properly showed that temperatures were significantly higher in harvested reaches than in control reaches for two sites (one site each in low and medium RBA) (Table 2b.2). We found no statistically significant differences in mean summer and fall temperatures when data from low RBA and medium RBA sites were pooled by treatment. It should be noted that due to the high variability among the four sites for this and other parameters examined in this study, some trends were not found to be statistically significant at the $p<0.05$ level. We caution that statistically insignificant results may not necessarily be biologically insignificant. Remaining data will be analyzed from redeployed loggers at the end of summer 2009.

Single-basin sites

Ten years after riparian timber harvesting we found no significant differences among the four treatments for all chemical parameters analyzed. Nitrate-N was higher at some plots than others (plots 1 and 2), but there was no trend in increased nutrients within harvested reaches (Tables 2b.3A, 2b.3B, and 2b.3C). Conductivity and cation concentrations were high at all plots indicating high productivity in these low gradient streams. Baseflow turbidity was higher at the single-basin plots than at the multiple-basin sites, but still well below levels that impair aquatic life (approximately 25 NTU, R. Jackson unpublished data). We did not collect turbidity samples during storm events, which would be a better measure of sediment impacts on aquatic life. Dissolved oxygen concentrations in all reaches at all eight sites were all well above the threshold that limits aquatic life (5 mg/L).

Water temperature loggers at 3 plots were not deployed properly. Results will available at the end of summer 2009 after the redeployed temperature loggers are retrieved. Canopy cover was measured intensely (at ten meter intervals) upstream and within each single-basin plot in August 2007. Differences between upstream and within treatment measurements of percent open canopy were not significantly different ($p>0.05$), but were greatest for the cut-to-length and whole-tree harvest treatments (Figure 2b.2).

Periphyton standing crop

<u>Multiple-basin sites</u>

Long-term effects of riparian harvesting may result in increased in-stream algal levels. We did not observe significant ($p>0.05$) differences between harvested and control reaches at either harvesting level (Figure 2b.3). There was significantly higher periphyton levels at all of the low RBA reaches compared to the medium RBA reaches, which may be related to initial site selection. Periphyton standing crop was positively and significantly related to light levels in the treatment reaches of all sites, which suggests that periphyton is responding to light levels in the treatment reaches (Figure 2b.4). There was no relationship between periphyton and light in the control and riparian control reaches.

<u>Single-basin sites</u>

Periphyton standing crop at the single-basin plots in August 2006 was similar at upstream and within reaches for all treatments except whole-tree harvesting (Figure 2b.5). We observed no significant differences between upstream and downstream reaches for any treatment in June 2007 or October 2007, although high variability among plots may have prevented us from detecting small differences (Figures 2b.6 and 2b.7).

Litter inputs

<u>Multiple-basin sites</u>

We predicted that removal of timber from the riparian management zones would result in reduced leaf litter inputs to treatment reaches of streams (low RBA reaches would have lower leaf inputs than either medium RBA, riparian controls or control reaches) immediately following harvesting with recovery through time as vegetation regenerated. We also expected wood inputs to be higher in treatment plots most susceptible to blowdown (low RBA> medium RBA).

Five years after harvest, plots with the lowest RBA within the riparian zone had higher overhead wood inputs to streams (Figures 2b.8A and 2b.8B). Average wood inputs to all reaches were relatively small compared to leaf inputs, suggesting that the observed differences in wood inputs among reaches were due to differences in small woody debris (twigs) rather than large woody debris (stems). No differences were found for overhead or lateral leaf inputs, which dominated total organic matter inputs (Figures 2b.8A and 2b.8B).

Single-basin sites

Eleven years after harvest, overhead leaf inputs to low-gradient single-basin streams were significantly lower in the whole-tree harvest treatment compared to streams with unharvested RMZs (Figure 2b.9). We found no significant differences between leaf inputs to true control, riparian control, or cut-to-length treatment plots (Figure 2b.9). Increased wood inputs likely resulted from increased blowdown over time (Figure 2b.10 photo). Note that the limited area of the eight overhead traps per reach is not sufficient to accurately estimate wood inputs to these streams. The large input of wood for the whole-tree harvest treatment (1 kg/m^2) was a result of a large blown down stem in plot 4 that landed directly on an overhead litter trap between June and October 2008. Our estimates of wood inputs are clearly an underestimate of wood falling into the streams.

Organic matter standing crop – CBOM, FBOM, seston

Multiple-basin sites

Detrital food resources (Fine Benthic Organic Matter – FBOM; Coarse Benthic Organic Matter – CBOM; and seston – fine organic matter in transport) available to aquatic invertebrates were sampled at the multiple-basin sites June 2008. There were no significant differences in leaf or wood standing crop among reaches within the low and medium RBA treatment levels (Figures 2b.11A and 2b.11B). In general, leaf and wood standing crops were higher at the medium RBA sites than at the low RBA sites. These data along with the periphyton data (Figure 2b.3) suggest that food webs in the medium RBA sites are naturally more detrital based, while food webs within the low RBA sites are more autochthonous (algal) based. There were no significant differences in FBOM among reaches for either the low or medium RBA treatment sites (Figure 2b.12A). Fine Benthic Inorganic Matter (FBIM) is a quantitative measure of fine sediments in the stream bottom. Our estimates of FBIM in riffle habitats at the multiple-basin sites show that there is not significantly more sediment in the treatment reaches than control or riparian control reaches (Figure 2b.12B). It is worth noting that FBIM (Figure 2b.12B) and FBOM (Figure 2b.12A) closely relate to leaf standing crops (Figure 2b.11A) and wood standing crops (Figure 2b.11B), respectively, at the low and medium RBA sites. There were no differences in seston transport among sites, although we only measured seston in the water column during baseflow conditions. Future work should include measurements of storm transport of fine organic and inorganics.

Single-basin sites

We collected CBOM samples in August 2007 from riffle and depositional habitats at each single-basin plot using methods previously established by multiple-basin project researchers. We refined the method by separating collected CBOM into “leaf”, “wood”, and “other” categories rather than lumping all organic matter types together. We anticipated that differences in leaf and small wood standing crops among harvested treatments might exist due to differences in vegetation regeneration and blowdown in various treatments. These differences are ecologically relevant to invertebrate community structure and function, and in-stream organic matter dynamics. Leaf standing crop in August 2007 was lower than small wood in both habitats across all treatments (Figures 2b.13a and 2b.13b). More organic matter (leaf and small wood) was found in depositional habitat than in riffle habitat across all treatments. Differences between reaches (upstream - within) for leaf and wood standing crops appeared to be similar among treatments, except depositional wood in the whole-tree harvest treatment where more wood was found within the treatment reach (probably not statistically different due to very high variability among plots). There were no significant differences between upstream and within reaches for any treatment for either FBOM or FBIM (Figure 2b.14). The amount of sediment (mean of 45-90 g/m^2) found in the true control plots suggest that the increased sediment load associated with the culvert issues at the beginning of the study still remain and may be masking any riparian harvesting effects.

Leaf and wood breakdown rates

Single- and multiple-basin sites

We hypothesized that leaf and wood breakdown rates would either be higher in riparian harvested streams due to increased nutrient concentrations from runoff and the consequent increase in breakdown due to microbial stimulation, or lower due to the loss of shredder invertebrates associated with reduced leaf inputs from riparian harvesting.

The lack of access to the single-basin sites during spring 2009 delayed spring litterbag and wood veneer pickups until June 1-4, 2009. Preliminary data analyses of wood breakdown rates at the single-basin sites (based on available data points) suggest that breakdown rates are similar ($p > 0.05$) across treatments (Figure 15). Breakdown rates were extremely variable over all 12 plots and with treatments ranging from -0.0007 (cut-to-length) to -0.0027 (true control). Many of the sets of veneers were buried in sediments which may have accounted for the extreme variability among plots and within treatments. Additional veneers and litterbags will be picked up over summer and fall 2009. Final data analyses will be completed after remaining samples have been collected and processed in the lab.

Macroinvertebrate community

Multiple-basin sites

We collected, sorted, and identified 127,267 individuals of 157 different invertebrate taxa from the eight multiple-basin sites during August 2008 (Table 2b.4). Taxa richness was highest at the riparian control and the low RBA treatment sites (Figure 2b.16A). The percent EPT taxa, or those taxa most sensitive to low dissolved oxygen conditions, was greatest at each of the reaches associated with the medium RBA treatments (Figure 2b.16B). Although not significantly different at the $p<0.05$ level, there was a trend toward higher proportions of scraper taxa (invertebrates that scrape and feed on attached algae), in each of the treatment reaches (Figure 2b.16C). Shredders made up a minor portion of the communities at all sites (Figure 2b.16D). Collector-gatherers dominated (38-49%) the communities at all sites (Figure 2b.16E), which is not unexpected since most of the collector-gatherer taxa are small bodied organisms which have high turnover rates. We also observed a trend toward greater proportions of collector-filterers at each of the medium RBA reaches (Figure 2b.16F). Predators made up a significantly greater proportion of the community at the low RBA riparian control reaches than either the control or treatment reaches (Figure 162b.G). Further investigation revealed that the high numbers of predators at these reaches were composed of the small-bodied Acari (water mites), Tanypodinae (midge larvae), *Atherix* (water snipe larvae), and young instars of Gomphidae (dragonfly larvae) collected from Sites 4 (W. Split Rock R.) and 6 (East Br. Beaver River) (Table 2b.5).

Single-basin sites

We collected, sorted and, identified 65,688 individuals of 67 different invertebrate taxa from the twelve single-basin plots during June 2007 (Table 2b.5). Taxa richness was similar in upstream control reaches compared to within plot reaches for all treatments (Figure 2b.17A). Although not significantly different, we found higher total invertebrate abundances within the cut-to-length plots (Figure 2b.17B). The high abundances within this treatment was attributed to very high densities of the collector-filterer *Simulium* (blackfly larvae) and collector-gatherer Chironomidae (midge larvae) at plot 8 (Table 2b.5). Scrapers were more abundant (Figure 2b.17C) and proportionately more dominant (Figure 2b.17E) at the riparian control, cut-to-length, and whole-tree harvest plots, although not significantly so due to high plot-to-plot variability. Shredders were more abundant (Figure 2b.17D) and dominant at the control plots (upstream and within) than in the other treatments. Percent EPT taxa were similar between upstream and within reaches for all treatments except the upstream control plots (particularly plots 1 and 7) where we found large numbers of young instar stonefly larvae (Figure 2b.17G). Overall all of the plots were dominated by collector-gatherer and collector-filterer taxa (Chironomidae and *Simulium*) which made up 81% of the invertebrate community in some samples.

Conclusions

Multiple-basin sites

Five years after harvest, we observed no statistically significant differences in water chemistry between reaches for either the low or medium residual RBA treatments. It is likely that the elevated nitrate levels observed immediately after harvesting (Atuke 2005) have been mitigated through vegetative regeneration. Light levels were highest in the low RBA treatment reaches compared to all other reaches. Although not statistically significant, this result does not suggest that the difference is not biologically meaningful. We observed a significant relationship between light levels and periphyton standing crop in the treatment reaches but not the control or riparian control reaches. Despite the fact that we did not observe differences in leaf inputs to treatment plots, we did see higher leaf and wood standing crops at the medium RBA sites than at the low RBA sites. These data along with the periphyton results suggest that stream food webs within the medium RBA sites are naturally more detrital based, while food webs within the low RBA sites are more autochthonous (algal) based. The invertebrate results closely tracked available food resources at the multiple-basin sites. There were proportionately greater numbers of scrapers collected at sites with the highest periphyton levels and greater numbers of shredders found at sites with the highest leaf and wood standing crops. It is likely that the major reason why we did not see larger harvesting impacts on the aquatic invertebrate community either five years after harvest or at the beginning of the study (Atuke 2007), was due to the lack of uniform residual basal areas left across the harvested riparian areas at some sites (Palik, Result 1 of this report). It was visually obvious during site visits that riparian areas closest to the streams at some sites (e.g. Site 6 – East Baptism R.) had higher residual basal areas than riparian areas further away from the stream, thus reducing any potential impacts to the aquatic community.

Single-basin sites

The harvest method used in 1997 did not result in any statistically significant differences in water chemistry, light levels, periphyton levels, or invertebrate abundances among plots. However, based on the functional feeding characteristics of the invertebrate community we found that scraper taxa abundances tended to be higher in the harvested plots (corresponding to higher periphyton levels), while shredders were less abundant. We measured lower overhead leaf inputs to streams in the whole-tree harvest plots, but not the cut-to-length plots where shredder abundances were lowest. Those organisms that are morphologically able to utilize fine benthic organic matter (FBOM) as a food resource were also very abundant in most plots. This FBOM is likely the result of sediments deposited in the streams during road building/culvert failures earlier in the study, continuing bank erosion, and the breakdown of leaf litter inputs by microbes. Preliminary data suggested no differences in wood breakdown rates although many of the wood veneers became buried in sediment over the winter and spring months. It is possible that the continuing movement of sediment throughout the stream reaches may be masking any real harvesting impacts on the aquatic invertebrate food web. Ideally some sort of restoration/sediment removal effort should be undertaken (perhaps in the form of an experimental manipulation), which would allow the currently buried cobble substrates to surface and provide an opportunity to more accurately measure of harvesting effects.

To fully understand the long-term consequences (i.e., minimum of nine years post-harvest as suggested in prior studies), further study will be necessary.

Unanticipated and unresolved problems

The procedures used to meet the objectives of this Result were adequate and sufficient. The only unresolved problem relative to this Result was the water temperature loggers which were not deployed properly at 3 plots within the single-basis study. Data from those redeployed temperature loggers will available at the end of summer 2009 after they are retrieved. All other work was completed as planned. Additional analyses will be conducted during and after the summer of 2009 as additional data becomes available.

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Table 2b.1A. Water chemistry at the multiple-basin sites during June 2008. No data at Site 7 Control reach due to a beaver dam within the reach.

Site	Reach	pH	Conductivity uS/cm	Turbidity NTU	Alkalinity mg/L CaC03	Cl^- mg/L	NO_3^--N mg/L	Diss Inorg P mg/L	SO_4^{-2} mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	K+ mg/L	Na^+ mg/L	Fe^{2+} mg/L
1	Control	7.41	188.5	1.4	88.0	1.56	0.14	<0.03	10.29	30.80	8.68	1.30	3.93	0.83
1	Rip Control	7.35	186.1	1.7	81.5	1.58	0.09	<0.03	10.31	29.70	8.36	2.10	3.03	0.84
1	Tmt - Med RBA	7.86	188.1	1.4	86.3	1.57	<0.02	<0.03	10.26	29.90	8.57	1.10	2.79	0.84
2	Control	6.33	41.0	0.9	18.5	0.12	<0.02	<0.03	0.76	6.12	2.17	0.70	1.56	1.28
2	Rip Control	6.75	41.6	1.0	17.7	0.13	<0.02	<0.03	0.81	6.77	2.29	<0.08	1.44	0.76
2	Tmt - Med RBA	7.21	37.2	1.1	20.3	0.14	<0.02	<0.03	0.90	6.18	2.26	2.69	1.51	1.25
3	Control	7.41	77.4	4.5	34.5	0.20	<0.02	<0.03	3.16	9.67	2.87	0.62	1.61	1.05
3	Rip Control	7.41	75.9	4.5	32.7	0.23	<0.02	<0.03	3.19	9.41	2.74	0.23	1.63	1.02
3	Tmt - Med RBA	7.36	73.4	5.9	31.8	0.20	<0.02	<0.03	3.18	9.52	2.81	0.22	1.54	1.03
4	Control	7.34	94.1	1.1	43.5	0.26	0.09	<0.03	2.47	13.30	3.81	0.32	3.20	0.90
4	Rip Control	7.37	93.4	0.9	43.8	0.26	0.09	<0.03	2.46	12.40	3.63	0.20	3.53	0.83
4	Tmt - Low RBA	7.32	92.8	0.9	44.2	0.32	0.09	<0.03	2.46	12.70	3.65	<0.08	2.68	0.86
5	Control	7.20	47.5	0.8	28.0	0.28	<0.02	<0.03	2.99	7.24	2.54	1.29	2.19	2.05
5	Rip Control	7.40	48.2	0.9	27.0	0.23	<0.02	<0.03	2.98	6.96	2.34	3.87	3.07	0.82
5	Tmt - Med RBA	7.62	49.2	0.9	25.0	0.28	<0.02	<0.03	2.98	6.86	2.33	0.94	1.82	0.81
6	Control	7.05	35.2	0.4	15.2	0.48	<0.02	<0.03	2.64	5.58	1.82	2.20	1.60	0.86
6	Rip Control	7.13	36.8	0.4	15.1	0.50	<0.02	<0.03	2.65	5.63	1.81	0.82	1.73	0.87
6	Tmt - Low RBA	7.27	37.1	0.4	15.3	0.55	<0.02	<0.03	2.64	5.69	1.86	1.37	1.63	0.86
7	Control	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	Rip Control	5.91	35.2	0.9	11.4	0.12	<0.02	<0.03	0.39	5.13	2.15	0.09	1.19	0.89
7	Tmt - Low RBA	6.31	35.1	0.7	9.5	0.13	<0.02	<0.03	0.48	5.07	2.13	0.08	1.20	0.89
8	Control	6.07	37.0	1.0	20.0	0.14	<0.02	<0.03	0.16	6.73	2.00	1.56	1.31	1.01
8	Rip Control	6.29	33.5	1.3	16.0	0.15	<0.02	<0.03	<0.02	5.34	1.59	3.36	1.16	1.08
8	Tmt - Low RBA	6.60	35.1	5.6	20.0	0.18	<0.02	<0.03	0.24	6.24	1.82	2.10	0.94	1.01

Table 2b.1B. Water chemistry at the multiple-basin sites during July 2008. No data at Site 7 Control reach due to a beaver dam within the reach.

Site	Reach	pH	Conductivity uS/cm	Turbidity NTU	Alkalinity mg/L CaC03	Cl^- mg/L	NO_3^--N mg/L	Diss Inorg P mg/L	SO_4^{-2} mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	K+ mg/L	Na^+ mg/L	Fe^{2+} mg/L
1	Control	7.43	344.0	2.7	185.0	1.48	<0.02	<0.03	0.85	51.40	14.40	0.61	3.96	1.01
1	Rip Control	7.43	342.0	2.0	186.9	1.56	0.08	<0.03	0.91	55.20	15.40	0.51	5.02	0.90
1	Tmt - Med RBA	7.46	334.0	2.2	189.0	1.48	0.08	<0.03	1.05	55.20	15.60	0.46	3.63	0.96
2	Control	6.36	109.8	9.7	53.2	0.35	<0.02	<0.03	0.39	16.00	5.61	0.16	2.58	2.84
2	Rip Control	6.95	101.5	6.3	49.8	0.26	0.08	<0.03	0.53	14.80	5.30	0.21	8.20	2.17
2	Tmt - Med RBA	6.86	96.8	4.9	48.0	0.31	0.09	<0.03	0.86	15.00	5.37	0.68	4.32	1.90
3	Control	7.25	101.6	2.9	46.2	0.25	0.09	<0.03	2.37	13.30	3.77	0.20	3.77	1.23
3	Rip Control	7.45	101.9	2.6	45.9	0.38	0.11	<0.03	2.42	13.30	3.84	0.37	2.28	1.15
3	Tmt - Med RBA	7.38	102.0	2.4	45.4	0.33	0.13	<0.03	2.47	13.30	3.86	0.44	3.71	1.11
4	Control	7.36	129.1	2.0	60.2	0.38	0.14	<0.03	2.79	17.90	5.07	0.60	2.83	0.91
4	Rip Control	7.47	128.8	1.6	63.8	0.42	0.15	<0.03	2.77	18.20	5.16	0.33	3.82	0.91
4	Tmt - Low RBA	7.40	134.4	1.5	64.3	0.41	0.15	<0.03	2.85	18.40	5.22	0.36	2.76	0.91
5	Control	7.29	79.4	1.2	37.1	0.28	<0.02	<0.03	1.60	10.90	3.52	0.14	2.38	1.23
5	Rip Control	7.32	80.3	1.1	38.2	0.28	<0.02	<0.03	1.64	10.40	3.45	<0.08	2.88	1.21
5	Tmt - Med RBA	7.24	82.7	1.9	37.7	0.29	<0.02	<0.03	1.66	10.90	3.59	0.14	6.31	1.20
6	Control	7.08	59.6	0.3	26.6	0.43	<0.02	<0.03	2.14	7.86	2.59	0.27	2.04	0.99
6	Rip Control	7.22	60.6	0.3	26.3	0.48	0.08	<0.03	2.18	7.74	2.58	<0.08	1.88	0.97
6	Tmt - Low RBA	7.37	62.5	0.3	27.2	0.63	0.09	<0.03	2.25	8.26	2.63	0.37	2.13	1.01
7	Control	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	Rip Control	7.17	62.2	1.6	30.0	0.18	0.10	<0.03	0.47	7.33	3.15	1.37	1.74	2.40
7	Tmt - Low RBA	6.54	47.9	1.4	30.0	0.18	0.11	<0.03	0.50	6.44	2.68	0.17	1.16	1.92
8	Control	6.21	44.5	0.9	22.7	0.20	<0.02	<0.03	<0.02	9.18	2.68	0.35	1.12	1.27
8	Rip Control	7.04	47.9	1.8	13.6	0.20	0.15	0.12	0.19	8.28	2.36	0.69	0.65	1.86
8	Tmt - Low RBA	6.20	48.6	1.8	16.0	0.16	0.12	<0.03	0.19	8.20	2.40	0.47	0.74	1.61

Table 2b.2. Water temperature at the multiple-basin control, riparian control, and treatment reaches from 24 June 2008 to 23 October 2008. No data available from Reservation Trib. (Medium residual basal area [RBA] site) and Cloquet Trib. (Low RBA site). Letters indicate significant differences ($p<0.05$) between reaches within a site.

Low Residual Basal Area

	West Split Rock R.			East Br. Baptism R.			St. Louis Trib.		
	Control	Riparian Control	Tmt	Control	Riparian Control	Tmt	Control	Riparian Control	Tmt
mean (ºC)	13.9[a]	14.2[b]	14.1[a,b]	15.8[a]	15.2[b]	15.1[c]	14.0[a]	13.7[b]	13.7[b]
se (ºC)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
max (ºC)	23.2	23.2	23.2	26.0	25.6	24.8	23.6	20.6	20.6
min (ºC)	2.9	5.0	3.3	4.6	4.2	4.6	2.9	5.0	5.0
range (ºC)	20.4	18.3	19.9	21.4	21.4	20.2	20.7	15.6	15.6

Medium Residual Basal Area

	Shotley Bk.			Nemadji Trib.			East Br. Beaver R.		
	Control	Riparian Control	Tmt	Control	Riparian Control	Tmt	Control	Riparian Control	Tmt
mean (ºC)	15.8[a]	15.4[b]	15.3[b]	13.1[a]	13.5[b]	13.7[c]	15.9[a]	15.6[b]	15.1[c]
se (ºC)	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
max (ºC)	25.2	23.6	22.9	18.7	19.0	21.0	26.7	26.3	26.0
min (ºC)	5.0	4.6	3.7	5.4	3.7	3.7	4.2	3.7	3.7
range (ºC)	20.2	19.1	19.1	13.3	15.3	17.2	22.6	22.6	22.2

Table 2b.3A. Water chemistry at the single-basin plots during August 2006.

Tmt	Plot	Reach	pH	Conductivity uS/cm	Turbidity NTU	Alkalinity mg/L CaC03	Total P mg/L	Total N mg/L	Cl^- mg/L	NO_3^--N mg/L	Diss Inorg P mg/L	SO_4^{-2} mg/L	NH_3N mg/L	NO_3 +NO_2N mg/L	Tot Org C mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	K+ mg/L	Na^+ mg/L	Fe^{2+} mg/L
True Control	1	Up	7.09	267	7.4	148	0.08	0.67	1.12	0.27	<.03	1.58	0.09	0.27	11.53	38.70	10.70	2.37	5.54	0.08
True Control	1	Down	7.25	270	6.2	155	0.06	0.56	1.33	0.30	<.03	1.77	<.02	0.29	11.77	36.20	10.10	2.10	5.34	0.08
True Control	7	Up	7.88	246	2.2	127	0.07	0.45	0.59	0.17	<.03	6.71	<.02	0.14	12.76	27.10	9.90	0.74	4.73	0.10
True Control	7	Down	7.92	294	1.8	146	0.04	0.38	0.47	0.16	<.03	7.25	<.02	0.13	10.12	28.10	11.10	0.86	5.41	0.10
True Control	9	Up	8.14	478	0.9	242	0.06	0.26	0.45	0.18	<.03	9.16	<.02	0.15	5.87	14.30	15.00	0.91	5.07	0.07
True Control	9	Down	8.22	483	0.3	249	0.05	0.24	0.45	0.17	<.03	8.71	<.02	0.14	2.10	14.00	13.90	0.75	4.45	0.06
Rip Control	3	Up	8.06	224	2.0	118	0.05	0.27	1.15	0.09	<.03	7.59	<.02	0.06	13.65	19.50	9.39	0.96	2.70	0.15
Rip Control	3	Down	8.13	232	2.9	126	0.07	0.26	1.11	0.10	<.03	7.67	<.02	0.06	12.77	24.60	9.09	0.95	2.63	0.12
Rip Control	5	Up	8.10	244	5.7	125	0.07	0.31	1.12	0.10	<.03	7.56	<.02	0.06	11.42	33.20	11.60	1.25	3.38	0.13
Rip Control	5	Down	8.13	249	5.7	122	0.07	0.30	1.07	0.09	<.03	7.18	<.02	0.06	11.01	30.10	10.30	1.04	2.93	0.12
Rip Control	12	Up	7.82	415	0.4	224	0.08	0.12	0.51	0.13	<.03	8.95	<.02	0.11	4.54	39.00	18.20	1.11	4.02	0.07
Rip Control	12	Down	7.74	407	0.4	214	0.06	0.16	0.49	0.14	<.03	8.62	<.02	0.11	4.87	32.00	16.20	1.04	3.69	0.07
Cut-to-length	2	Up	7.20	254	2.8	147	0.06	0.45	1.26	0.22	<.03	1.64	<.02	0.20	7.78	35.30	9.94	1.81	5.02	0.08
Cut-to-length	2	Down	6.99	263	1.2	139	0.05	0.27	1.24	0.12	<.03	2.11	<.02	0.09	6.45	35.80	9.82	2.05	5.07	0.07
Cut-to-length	8	Up	7.84	308	1.8	151	0.07	0.37	0.50	0.16	<.03	8.02	<.02	0.13	8.86	27.30	11.10	0.80	5.21	0.09
Cut-to-length	8	Down	7.97	313	1.7	158	0.06	0.37	0.58	0.15	<.03	7.91	<.02	0.13	10.57	19.10	12.40	0.99	5.87	0.08
Cut-to-length	11	Up	7.68	422	0.8	232	0.08	0.13	0.50	0.12	<.03	8.63	<.02	0.09	4.31	23.10	17.90	1.08	3.98	0.07
Cut-to-length	11	Down	7.68	417	0.7	224	0.06	0.12	0.49	0.13	<.03	8.68	<.02	0.10	4.49	27.50	18.10	1.14	3.96	0.07
Whole-tree harvest	4	Up	8.08	242	3.6	122	0.05	0.23	1.12	0.09	<.03	7.58	<.02	0.06	11.86	32.60	11.10	1.32	3.38	0.14
Whole-tree harvest	4	Down	8.02	250	3.8	127	0.06	0.32	1.12	0.09	<.03	7.84	<.02	0.06	11.50	34.50	11.60	1.28	3.45	0.14
Whole-tree harvest	6	Up	7.41	179	3.4	82	0.06	0.74	0.48	0.21	<.03	12.02	0.04	0.19	21.82	26.00	7.55	0.59	2.72	0.26
Whole-tree harvest	6	Down	7.58	190	3.6	96	0.05	0.64	0.39	0.19	<.03	9.93	<.02	0.17	19.52	26.60	8.03	0.65	3.05	0.17
Whole-tree harvest	10	Up	7.94	479	1.2	239	0.07	0.19	0.47	0.13	<.03	8.49	<.02	0.11	0.86	22.00	18.80	1.02	5.77	0.07
Whole-tree harvest	10	Down	7.63	442	1.0	247	0.05	0.16	0.49	0.12	<.03	8.77	<.02	0.08	3.94	23.80	19.10	1.16	4.93	0.07

Table 2b.3B. Water chemistry at the single-basin plots during June 2007.

Tmt	Plot	Reach	pH	Conductivity uS/cm	Turbidity NTU	Alkalinity mg/L CaC03	Cl^- mg/L	NO_3^--N mg/L	Diss Inorg P mg/L	SO_4^{-2} mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	K+ mg/L	Na^+ mg/L	Fe^{2+} mg/L
True Control	1	Up	6.99	229	2.17	116	1.15	0.24	<.03	1.37	30.80	8.24	1.93	4.92	0.10
True Control	1	Down	7.2	222	2.11	124	1.17	0.29	<.03	1.09	24.00	6.38	1.69	4.14	0.09
True Control	7	Up	6.94	163	1.23	85	0.35	0.17	<.03	2.93	19.70	5.86	0.75	2.94	0.32
True Control	7	Down	7.12	158	0.67	91	0.38	0.16	<.03	2.86	23.40	6.86	0.71	3.51	0.35
True Control	9	Up	7.34	417	0.16	241	0.55	0.13	<.03	7.00	34.30	16.70	1.01	6.59	0.07
True Control	9	Down	7.26	417	0.25	247	0.52	0.12	<.03	6.07	37.90	15.40	0.89	5.60	0.07
Rip Control	3	Up	7.38	256	0.38	130	1.92	0.12	<.03	5.60	31.50	9.11	0.82	3.09	0.13
Rip Control	3	Down	7.23	267	0.39	152	1.51	0.10	<.03	5.84	25.40	8.48	0.85	3.06	0.09
Rip Control	5	Up	7.35	247	0.69	141	1.38	0.08	<.03	5.88	35.00	10.40	0.87	3.34	0.11
Rip Control	5	Down	7.39	266	0.46	141	1.41	0.09	<.03	5.91	25.90	8.37	0.77	3.13	0.10
Rip Control	12	Up	7.53	386	0.12	221	0.67	0.10	<.03	8.83	53.20	19.00	1.12	4.40	0.06
Rip Control	12	Down	7.54	396	0.25	222	0.65	0.09	<.03	9.32	39.90	17.40	1.14	5.89	0.07
Cut-to-length	2	Up	7.13	230	2.11	121	1.24	0.28	<.03	0.98	18.00	5.21	1.56	3.69	0.08
Cut-to-length	2	Down	7.4	228	0.93	129	1.23	0.27	<.03	1.48	25.10	7.03	1.74	4.68	0.08
Cut-to-length	8	Up	6.98	175	0.47	90	0.37	0.14	<.03	2.68	19.70	5.86	0.66	2.83	0.22
Cut-to-length	8	Down	7.07	186	0.78	101	0.42	0.13	<.03	3.43	22.90	7.57	0.80	3.92	0.24
Cut-to-length	11	Up	7.53	409	0.31	224	0.58	0.10	<.03	9.51	39.20	17.20	1.02	3.94	0.07
Cut-to-length	11	Down	7.52	392	0.31	225	0.57	0.09	<.03	9.25	43.40	18.80	1.07	4.73	0.07
Whole-tree harvest	4	Up	7.39	246	0.25	138	1.46	0.09	<.03	5.89	28.50	8.90	0.83	3.10	0.11
Whole-tree harvest	4	Down	7.23	244	0.77	141	1.49	0.09	<.03	6.07	25.10	7.34	0.71	3.14	0.10
Whole-tree harvest	6	Up	6.6	114	4.25	59	0.26	0.20	<.03	1.34	13.50	4.03	0.63	1.79	0.44
Whole-tree harvest	6	Down	6.7	124	2.15	63	0.36	0.19	<.03	1.50	15.40	4.74	0.62	2.18	0.46
Whole-tree harvest	10	Up	7.36	419	0.43	231	0.61	0.09	<.03	10.34	37.40	18.50	1.04	5.09	0.07
Whole-tree harvest	10	Down	7.48	426	0.19	240	0.55	<.02	<.03	10.35	36.30	17.90	1.01	4.77	0.07

Table 2b.2C. Water chemistry at the single-basin plots during July 2007.

Tmt	Plot	Reach	pH	Conductivity uS/cm	Turbidity NTU	Alkalinity mg/L CaC03	Cl^- mg/L	NO_3^--N mg/L	Diss Inorg P mg/L	SO_4^{-2} mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	K+ mg/L	Na^+ mg/L	Fe^{2+} mg/L
True Control	1	Up	7.11	244	7.8	140	1.25	0.33	<.03	0.70	29.40	9.52	1.74	5.83	0.08
True Control	1	Down	7.27	245	4.1	141	1.20	0.30	<.03	0.66	31.00	9.41	1.70	5.20	0.09
True Control	7	Up	7.43	285	1.6	149	0.62	0.12	<.03	4.60	31.60	10.70	0.99	6.12	0.11
True Control	7	Down	7.22	275	1.8	140	0.72	0.13	<.03	4.17	26.50	10.50	0.85	5.99	0.11
True Control	9	Up	7.54	429	1.1	239	0.80	0.13	<.03	8.67	26.70	14.90	0.64	4.60	0.07
True Control	9	Down	7.30	462	0.6	260	0.77	0.20	<.03	5.38	46.10	18.50	0.90	5.75	0.07
Rip Control	3	Up	7.56	343	1.4	184	1.82	0.17	<.03	5.18	27.00	13.30	1.08	4.39	0.08
Rip Control	3	Down	7.53	334	0.7	178	1.09	0.11	<.03	5.82	27.70	12.70	1.07	4.50	0.07
Rip Control	5	Up	7.58	318	1.3	169	1.54	0.17	<.03	5.48	35.10	12.20	1.18	4.16	0.08
Rip Control	5	Down	7.50	313	1.5	170	1.19	0.14	<.03	4.15	37.80	12.30	1.05	4.07	0.09
Rip Control	12	Up	7.65	416	0.4	228	0.72	0.15	<.03	7.86	21.90	16.00	1.16	3.78	0.07
Rip Control	12	Down	7.72	421	0.6	239	0.78	0.16	<.03	7.75	25.20	17.80	1.26	4.16	0.07
Cut-to-length	2	Up	7.20	238	2.8	129	1.23	0.22	<.03	1.23	32.60	9.27	1.49	5.02	0.09
Cut-to-length	2	Down	7.40	249	1.2	137	1.28	0.24	<.03	1.24	26.20	8.97	1.57	5.24	0.08
Cut-to-length	8	Up	7.10	291	2.9	151	0.59	0.14	<.03	3.96	34.80	11.50	0.98	5.89	0.11
Cut-to-length	8	Down	7.34	300	2.8	150	0.54	0.13	<.03	3.83	34.80	11.60	1.03	5.24	0.09
Cut-to-length	11	Up	7.63	425	0.8	226	0.76	0.14	<.03	7.88	33.70	18.00	1.15	3.80	0.06
Cut-to-length	11	Down	7.70	428	1.2	234	0.75	0.13	<.03	8.30	28.80	17.80	1.10	3.84	0.07
Whole-tree harvest	4	Up	7.39	320	2.1	170	1.45	0.14	<.03	5.02	37.00	12.50	0.98	4.42	0.10
Whole-tree harvest	4	Down	7.64	371	1.7	171	1.24	0.14	<.03	5.22	38.50	12.60	1.17	4.35	0.10
Whole-tree harvest	6	Up	6.89	127	5.6	70	0.29	0.18	<.03	0.52	17.90	5.46	0.43	2.17	0.49
Whole-tree harvest	6	Down	7.08	184	3.2	96	0.42	0.10	<.03	1.36	25.30	7.91	0.62	3.29	0.38
Whole-tree harvest	10	Up	7.36	434	0.9	252	0.80	0.09	<.03	10.40	38.60	18.10	1.00	4.47	0.07
Whole-tree harvest	10	Down	7.63	435	1.0	241	0.68	0.09	<.03	9.59	30.30	18.40	1.00	4.34	0.07

Table 2b.3. Water temperature at the multiple-basin control, riparian control, and treatment reaches from 24 June 2008 to 23 October 2008. No data available from Reservation Trib. (Medium residual basal; area [RBA] site) and Cloquet Trib. (Low RBA site).

Low Residual Basal Area

	West Split Rock R.			East Br. Baptism R.			St. Louis Trib.		
	Control	Riparian Control	Tmt	Control	Riparian Control	Tmt	Control	Riparian Control	Tmt
mean (ºC)	13.9	14.2	14.1	15.8	15.2	15.1	14.0	13.7	13.7
se (ºC)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
max (ºC)	23.2	23.2	23.2	26.0	25.6	24.8	23.6	20.6	20.6
min (ºC)	2.9	5.0	3.3	4.6	4.2	4.6	2.9	5.0	5.0
range (ºC)	20.4	18.3	19.9	21.4	21.4	20.2	20.7	15.6	15.6

Medium Residual Basal Area

	Shotley Bk.			Nemadji Trib.			East Br. Beaver R.		
	Control	Riparian Control	Tmt	Control	Riparian Control	Tmt	Control	Riparian Control	Tmt
mean (ºC)	15.8	15.4	15.3	13.1	13.5	13.7	15.9	15.6	15.1
se (ºC)	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
max (ºC)	25.2	23.6	22.9	18.7	19.0	21.0	26.7	26.3	26.0
min (ºC)	5.0	4.6	3.7	5.4	3.7	3.7	4.2	3.7	3.7
range (ºC)	20.2	19.1	19.1	13.3	15.3	17.2	22.6	22.6	22.2

Table 2b.4. Invertebrate taxa list for the multiple-basin sites during August 2008.

Insects

Order	Family	Lowest taxonomic level	Functional Feeding Group
Coleoptera	Dryopidae	Helichus (**adult** and **larva**)	Scraper
Coleoptera	Dytiscidae	Acilius (adult)	Predator
Coleoptera	Dytiscidae	Agabus (**adult** and larva)	Predator
Coleoptera	Dytiscidae	Dytiscus (larva)	Predator
Coleoptera	Dytiscidae	Hydrocolus (adult)	Predator
Coleoptera	Dytiscidae	Hygrotus (adult)	Predator
Coleoptera	Dytiscidae	Neoporus (adult)	Predator
Coleoptera	Elmidae	Dubiraphia (adult and **larva**)	Collector-gatherer
Coleoptera	Elmidae	Macronychus (adult and **larva**)	Collector-gatherer
Coleoptera	Elmidae	Optioservus (adult and **larva**)	Scraper
Coleoptera	Elmidae	Promoresia (adult and larva)	Collector-gatherer
Coleoptera	Elmidae	Stenelmis (adult and **larva**)	Scraper
Coleoptera	Haliplidae	Haliplus (adult and **larva**)	Shredder
Coleoptera	Hydraenidae	Gymnochthebius (adult)	Scraper
Coleoptera	Hydraenidae	Hydraena (adult)	Scraper
Coleoptera	Hydrophilidae	Anacaena (adult)	Collector-gatherer
Coleoptera	Hydrophilidae	Crenitis (adult)	Collector-gatherer
Coleoptera	Hydrophilidae	Cymbiodyta (adult)	Collector-gatherer
Coleoptera	Hydrophilidae	Enochrus (adult)	Collector-gatherer
Coleoptera	Hydrophilidae	Helophorus (adult)	Collector-gatherer
Diptera	Athericidae	Atherix	Predator
Diptera	Ceratopogonidae	Ceratopogoninae	Predator
Diptera	Ceratopogonidae	Forcipomyiinae	Collector-gatherer
Diptera	Chironomidae	Chironomidae (non-Tanypodinae)	Collector-gatherer
Diptera	Chironomidae	Tanypodinae	Predator
Diptera	Dixidae	Dixella	Collector-gatherer
Diptera	Dolichopodidae	Dolichopodidae	Predator
Diptera	Empididae	Hemerodromia	Predator
Diptera	Empididae	Neoplasta	Predator
Diptera	Empididae	Roederiodes	Predator
Diptera	Ephydridae	Ephydridae	Collector-gatherer
Diptera	Psychodidae	Pericoma	Collector-gatherer
Diptera	Ptychopteridae	Bittacomorpha	Collector-gatherer
Diptera	Sciomyzidae	Sciomyzidae	Predator
Diptera	Simuliidae	Simulium	Collector-filterer
Diptera	Stratiomyidae	Nemotelus	Collector-gatherer
Diptera	Stratiomyidae	Odontomyia	Collector-gatherer
Diptera	Tabanidae	Tabanidae	Predator
Diptera	Tipulidae	Antocha	Collector-gatherer
Diptera	Tipulidae	Dicranota	Predator
Diptera	Tipulidae	Hexatoma	Predator
Diptera	Tipulidae	Limonia	Shredder
Diptera	Tipulidae	Ormosia	Collector-gatherer
Diptera	Tipulidae	Pedicia	Predator

Table 2b.4 (continued). Invertebrate taxa list for the multiple-basin sites during June 2008.

Diptera	Tipulidae	Tipula	Shredder
Ephemeroptera	Baetidae	Acentrella	Collector-gatherer
Ephemeroptera	Baetidae	Acerpenna	Collector-gatherer
Ephemeroptera	Baetidae	Baetis	Scraper
Ephemeroptera	Baetidae	Centroptilum	Collector-gatherer
Ephemeroptera	Baetidae	Diphetor	Collector-gatherer
Ephemeroptera	Baetidae	Procloeon	Collector-gatherer
Ephemeroptera	Baetidae	Pseudocentroptiloides	Collector-gatherer
Ephemeroptera	Baetidae	Pseudocloeon	Collector-gatherer
Ephemeroptera	Baetiscidae	Baetisca	Collector-gatherer
Ephemeroptera	Caenidae	Brachycercus	Collector-gatherer
Ephemeroptera	Caenidae	Caenis	Collector-gatherer
Ephemeroptera	Ephemerellidae	Ephemerella	Collector-gatherer
Ephemeroptera	Ephemerellidae	Eurylophella	Collector-gatherer
Ephemeroptera	Ephemerellidae	Serratella	Collector-gatherer
Ephemeroptera	Ephemeridae	Ephemera	Collector-gatherer
Ephemeroptera	Ephemeridae	Hexagenia	Collector-gatherer
Ephemeroptera	Heptageniidae	Epeorus	Scraper
Ephemeroptera	Heptageniidae	Leucrocuta	Scraper
Ephemeroptera	Heptageniidae	Maccaffertium	Scraper
Ephemeroptera	Heptageniidae	Stenacron	Scraper
Ephemeroptera	Isonychiidae	Isonychia	Collector-filterer
Ephemeroptera	Leptohyphidae	Tricorythodes	Collector-gatherer
Ephemeroptera	Leptophlebiidae	Paraleptophlebia	Collector-gatherer
Hemiptera	Corixidae	Sigara (adult)	Collector-gatherer
Hemiptera	Gerridae	Aquarius (**adult** and larva)	Predator
Hemiptera	Gerridae	Trepobates (larva)	Predator
Hemiptera	Nepidae	Ranatra (larva)	Predator
Hemiptera	Veliidae	Rhagovelia (**adult** and larva)	Predator
Megaloptera	Corydalidae	Nigronia	Predator
Megaloptera	Sialidae	Sialis	Predator
Odonata	Aeshnidae	Aeshna	Predator
Odonata	Aeshnidae	Boyeria	Predator
Odonata	Calopterygidae	Calopterygidae	Predator
Odonata	Cordulegastridae	Cordulegaster	Predator
Odonata	Cordulegastridae	Epitheca	Predator
Odonata	Corduliidae	Corduliidae	Predator
Odonata	Corduliidae	Somatochlora	Predator
Odonata	Gomphidae	Ophiogomphus	Predator
Odonata	Libellulidae	Perithemis	Predator
Plecoptera	Capniidae	Capniidae	Shredder
Plecoptera	Leuctridae	Leuctra	Shredder
Plecoptera	Nemouridae	Amphinemura	Collector-gatherer
Plecoptera	Perlidae	Acroneuria	Predator
Plecoptera	Perlidae	Paragnetina	Predator
Plecoptera	Perlidae	Perlesta	Predator

Table 2b.4 (continued). Invertebrate taxa list for the multiple-basin sites during June 2008.

Plecoptera	Perlodidae	Isogenoides	Predator
Plecoptera	Pteronarcyidae	Pteronarcys	Shredder
Trichoptera	Apataniidae	Apatania	Scraper
Trichoptera	Brachycentridae	Brachycentrus	Collector-filterer
Trichoptera	Brachycentridae	Micrasema	Shredder
Trichoptera	Dipseudopsidae	Phylocentropus	Collector-filterer
Trichoptera	Glossosomatidae	Glossosoma	Scraper
Trichoptera	Glossosomatidae	Protoptila	Scraper
Trichoptera	Goeridae	Goera	Scraper
Trichoptera	Helicopsychidae	Helicopsyche	Scraper
Trichoptera	Hydropsychidae	Ceratopsyche	Collector-filterer
Trichoptera	Hydropsychidae	Cheumatopsyche	Collector-filterer
Trichoptera	Hydropsychidae	Diplectrona	Collector-filterer
Trichoptera	Hydropsychidae	Hydropsyche	Collector-filterer
Trichoptera	Hydroptilidae	Hydroptila	Scraper
Trichoptera	Hydroptilidae	Ithytrichia	Scraper
Trichoptera	Hydroptilidae	Leucotrichia	Scraper
Trichoptera	Hydroptilidae	Mayatrichia	Scraper
Trichoptera	Hydroptilidae	Neotrichia	Scraper
Trichoptera	Hydroptilidae	Oxyethira	Collector-gatherer
Trichoptera	Lepidostomatidae	Lepidostoma	Shredder
Trichoptera	Leptoceridae	Ceraclea	Collector-gatherer
Trichoptera	Leptoceridae	Mystacides	Collector-gatherer
Trichoptera	Leptoceridae	Oecetis	Predator
Trichoptera	Limnephilidae	Hydatophylax	Shredder
Trichoptera	Limnephilidae	Pycnopsyche	Shredder
Trichoptera	Philopotamidae	Chimarra	Collector-filterer
Trichoptera	Philopotamidae	Dolophilodes	Collector-filterer
Trichoptera	Phryganeidae	Ptilostomis	Shredder
Trichoptera	Polycentropodidae	Neureclipsis	Collector-filterer
Trichoptera	Polycentropodidae	Polycentropus	Collector-filterer
Trichoptera	Psychomyiidae	Psychomyia	Collector-gatherer
Trichoptera	Rhyacophilidae	Rhyacophila	Predator
Trichoptera	Uenoidae	Neophylax	Scraper
Other aquatic invertebrates			
		Subclass Acari	Predator
		Class Branchiopoda (Cladocera)	Collector-gatherer
		Order Collembola	Collector-gatherer
		Class Copepoda	Collector-gatherer
		Class Hydrozoa	Predator
		Phylum Nematoda	Collector-gatherer
		Class Ostracoda	Collector-gatherer
		Class Turbellaria	Predator
Amphipoda	Hyalellidae	Hyalella	Shredder
Arhynchobdellida	Erpobdellidae	Dina	Predator

Table 2b.4 (continued). Invertebrate taxa list for the multiple-basin sites during June 2008.

Arhynchobdellida	Erpobdellidae	Mooreobdella	Predator
Basommatophora	Ancylidae	Ancylidae	Scraper
Basommatophora	Ancylidae	Ferrissia	Scraper
Basommatophora	Lymnaeidae	Fossaria	Scraper
Basommatophora	Lymnaeidae	Lymnaeidae	Scraper
Basommatophora	Physidae	Physa	Scraper
Basommatophora	Planorbidae	Gyraulus	Scraper
Basommatophora	Planorbidae	Helisoma	Scraper
Basommatophora	Planorbidae	Planorbidae	Scraper
Veneroida	Sphaeriidae	Musculium	Collector-filterer
Veneroida	Sphaeriidae	Pisidium	Collector-filterer
Veneroida	Sphaeriidae	Sphaerium	Collector-filterer
Rhynchobdellida	Glossiphoniidae	Glossiphonia	Predator
Rhynchobdellida	Glossiphoniidae	Helobdella	Predator
Rhynchobdellida	Glossiphoniidae	Placobdella	Predator
Rhynchobdellida	Glossiphoniidae	Theromyzon	Predator
Neotaenioglossa	Hydrobiidae	Hydrobiidae	Scraper
Lumbriculida	Lumbriculidae	Lumbriculidae	Collector-gatherer
Haplotaxida	Naididae	Naididae (Naidinae)	Collector-gatherer
Haplotaxida	Naididae	Naididae (Tubificinae) - with capillary setae	Collector-gatherer
Haplotaxida	Naididae	Naididae (Tubificinae) - without capillary setae	Collector-gatherer
Decapoda	Cambaridae	Orconectes	Shredder

Table 2b.5. Invertebrate taxa list for the single-basin plots during June 2007.

Insects

Order	Family	Lowest taxonomic level	Functional Feeding Group
Coleoptera	Dryopidae	Helichus (adult)	Scraper
Coleoptera	Dytiscidae	Agabus (adult and **larva**)	Predator
Coleoptera	Elmidae	Optioservus (adult and **larva**)	Scraper
Diptera	Ceratopogonidae	Ceratopogoninae	Predator
Diptera	Chironomidae	Chironomidae (non-Tanypodinae)	Collector-gatherer
Diptera	Chironomidae	Tanypodinae	Predator
Diptera	Dixidae	Dixa	Collector-filterer
Diptera	Empididae	Neoplasta	Predator
Diptera	Empididae	Roederiodes	Predator
Diptera	Psychodidae	Pericoma	Collector-gatherer
Diptera	Simuliidae	Simulium	Collector-filterer
Diptera	Stratiomyidae	Oxycera	Scraper
Diptera	Tabanidae	Tabanidae	Predator
Diptera	Tipulidae	Dicranota	Predator
Diptera	Tipulidae	Hexatoma	Predator
Diptera	Tipulidae	Limnophila	Predator
Diptera	Tipulidae	Pedicia	Predator
Diptera	Tipulidae	Tipula	Shredder
Ephemeroptera	Baetidae	Acentrella	Collector-gatherer
Ephemeroptera	Baetidae	Baetis	Scraper
Ephemeroptera	Leptophlebiidae	Leptophlebiidae	Collector-gatherer
Hemiptera	Gerridae	Trepobates (adult)	Predator
Hemiptera	Pleidae	Neoplea (adult)	Predator
Odonata	Aeshnidae	Boyeria	Predator
Odonata	Calopterygidae	Calopterygidae	Predator
Odonata	Cordulegastridae	Cordulegaster	Predator
Plecoptera	Capniidae	Capniidae	Shredder
Plecoptera	Nemouridae	Amphinemura	Collector-gatherer
Plecoptera	Nemouridae	Nemoura	Collector-gatherer
Trichoptera	Brachycentridae	Micrasema	Shredder
Trichoptera	Glossosomatidae	Glossosoma	Scraper
Trichoptera	Hydropsychidae	Ceratopsyche	Collector-filterer
Trichoptera	Hydropsychidae	Cheumatopsyche	Collector-filterer
Trichoptera	Hydropsychidae	Hydropsyche	Collector-filterer
Trichoptera	Hydropsychidae	Parapsyche	Collector-filterer
Trichoptera	Lepidostomatidae	Lepidostoma	Shredder
Trichoptera	Limnephilidae	Hesperophylax	Shredder
Trichoptera	Limnephilidae	Ironoquia	Shredder
Trichoptera	Limnephilidae	Limnephilus	Shredder
Trichoptera	Limnephilidae	Pycnopsyche	Shredder
Trichoptera	Molannidae	Molanna	Scraper
Trichoptera	Philopotamidae	Dolophilodes	Collector-filterer
Trichoptera	Polycentropodidae	Neureclipsis	Collector-filterer
Trichoptera	Polycentropodidae	Polycentropus	Collector-filterer

Table 2b.5 (continued). Invertebrate taxa list for the single-basin plots during June 2007.

Trichoptera	Psychomyiidae	Lype	Scraper
Trichoptera	Rhyacophilidae	Rhyacophila	Predator
Trichoptera	Uenoidae	Neophylax	Scraper

Other aquatic invertebrates

		Subclass Acari	Predator
		Order Collembola	Collector-gatherer
		Class Copepoda	Collector-gatherer
		Phylum Nematoda	Collector-gatherer
		Phylum Nematomorpha	Predator
		Class Ostracoda	Collector-gatherer
		Class Turbellaria	Predator
Amphipoda	Gammaridae	Gammarus	Shredder
Arhynchobdellida	Erpobdellidae	Mooreobdella	Predator
Arhynchobdellida	Erpobdellidae	Nephelopsis	Predator
Basommatophora	Lymnaeidae	Fossaria	Scraper
Basommatophora	Lymnaeidae	Lymnaeidae	Scraper
Basommatophora	Physidae	Physa	Scraper
Basommatophora	Planorbidae	Gyraulus	Scraper
Basommatophora	Planorbidae	Planorbidae	Scraper
Veneroida	Sphaeriidae	Pisidium	Collector-filterer
Lumbriculida	Lumbriculidae	Lumbriculidae	Collector-gatherer
Haplotaxida	Naididae	Naididae (Naidinae)	Collector-gatherer
Haplotaxida	Naididae	Naididae (Tubificinae) - with capillary setae	Collector-gatherer
Haplotaxida	Naididae	Naididae (Tubificinae) - without capillary setae	Collector-gatherer

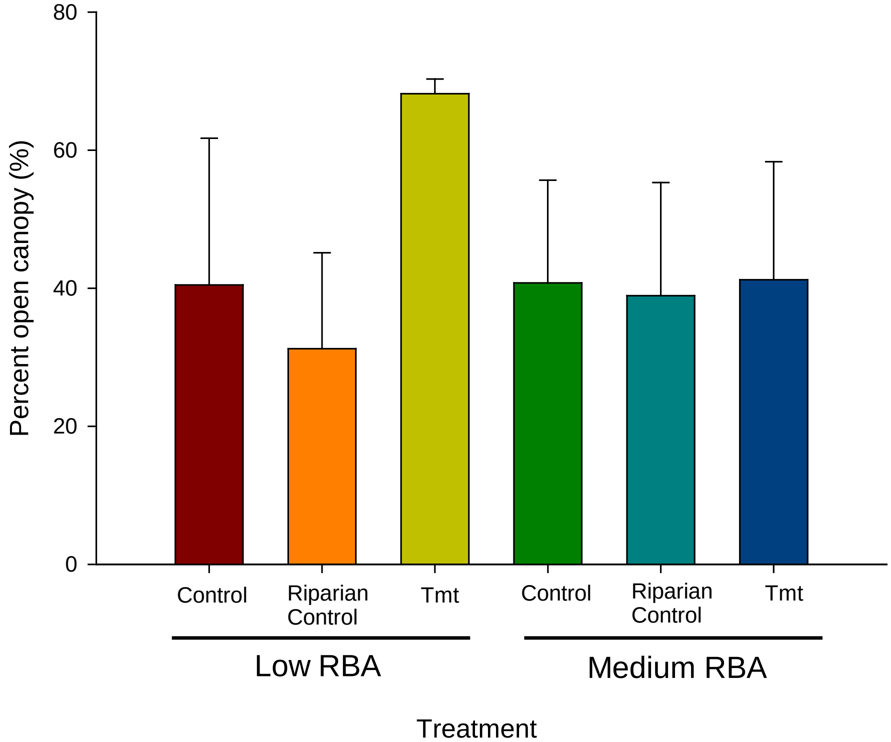

Figure 2b.1. Mean (± standard error) percent open canopy within control, riparian control, and low and medium residual basal area (RBA) treatments at the multiple-basin sites in June 2008.

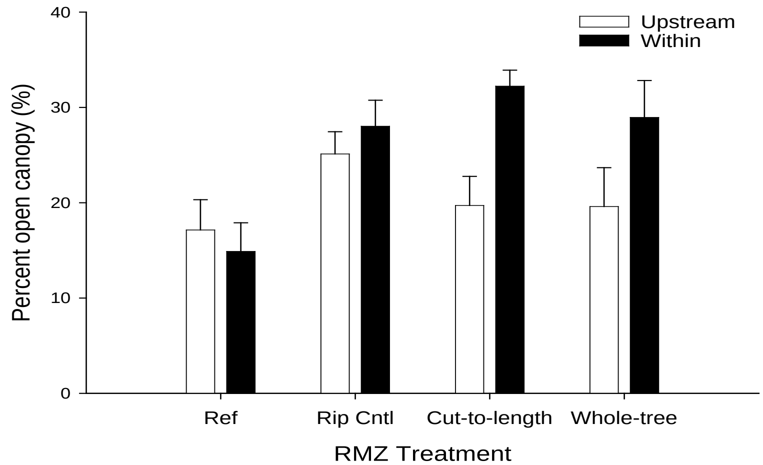

Figure 2b.2. Mean (± standard error) percent open canopy upstream and within RMZ treatments at the single-basin plots in August 2007.

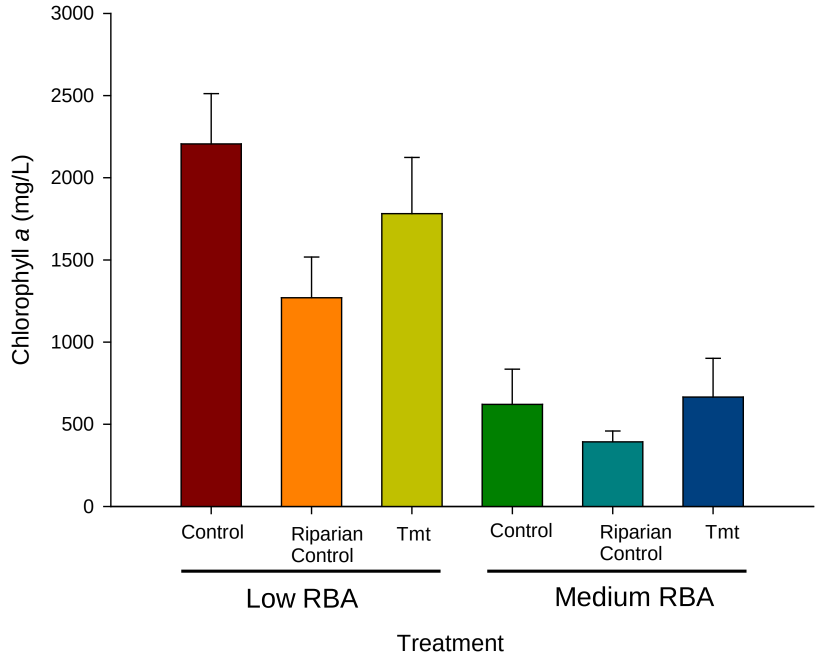

Figure 2b.3. Mean (± standard error) algal biomass standing crop within control, riparian control and low and medium residual basal area (RBA) treatments at the multiple-basin sites in June 2008.

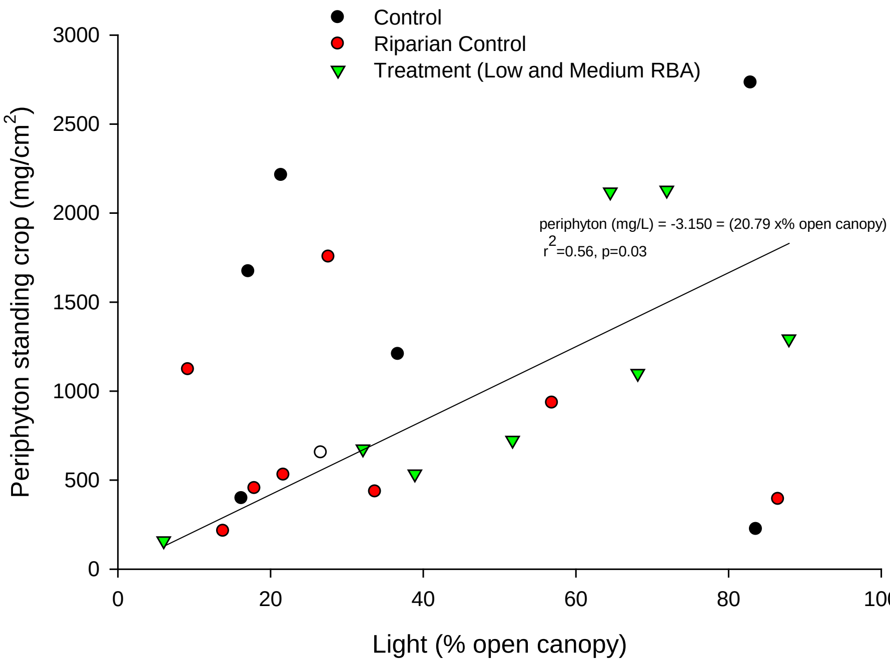

Figure 2b.4. Relationship between light levels within the stream and periphyton standing crop for treatment reaches (control, riparian control, and harvested RMZs) at the multiple-basin sites during June 2008. No significant relationship between light and periphyton at control reaches.

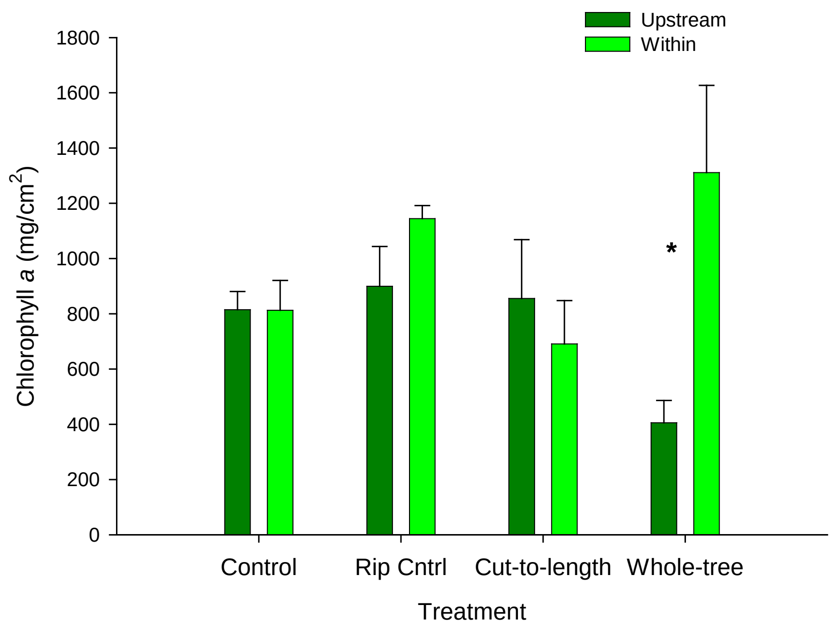

Figure 2b.5. Mean (± standard error) algal biomass standing crop upstream and within RMZ treatments at the single-basin plots in August 2006.

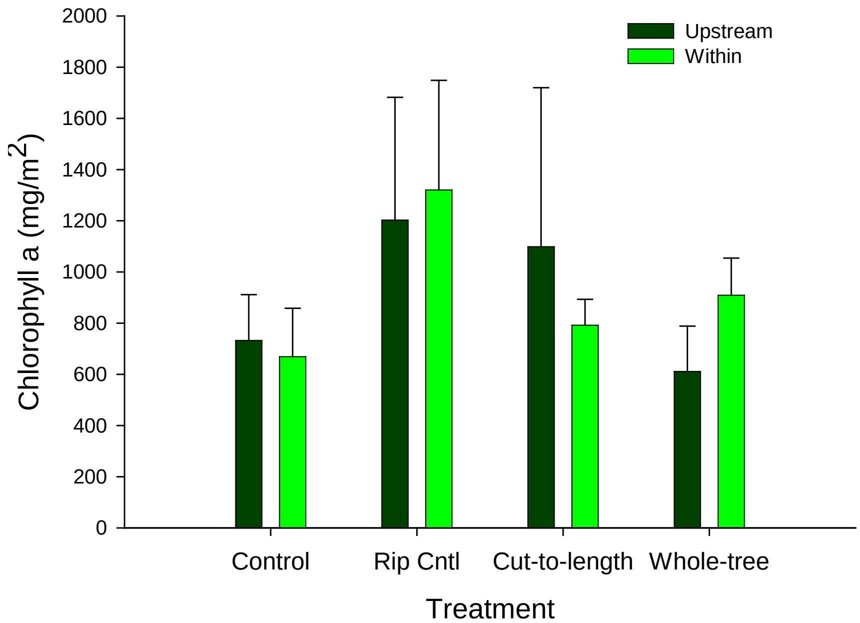

Figure 2b.6. Mean (± standard error) algal biomass standing crop upstream and within RMZ treatments at the single-basin plots in June 2007.

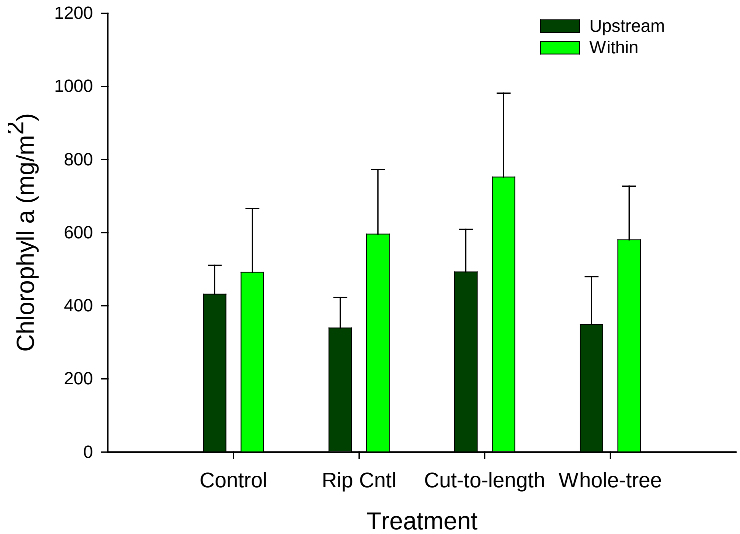

Figure 2b.7. Mean (± standard error) algal biomass standing crop upstream and within RMZ treatments at the single-basin plots in October 2007.

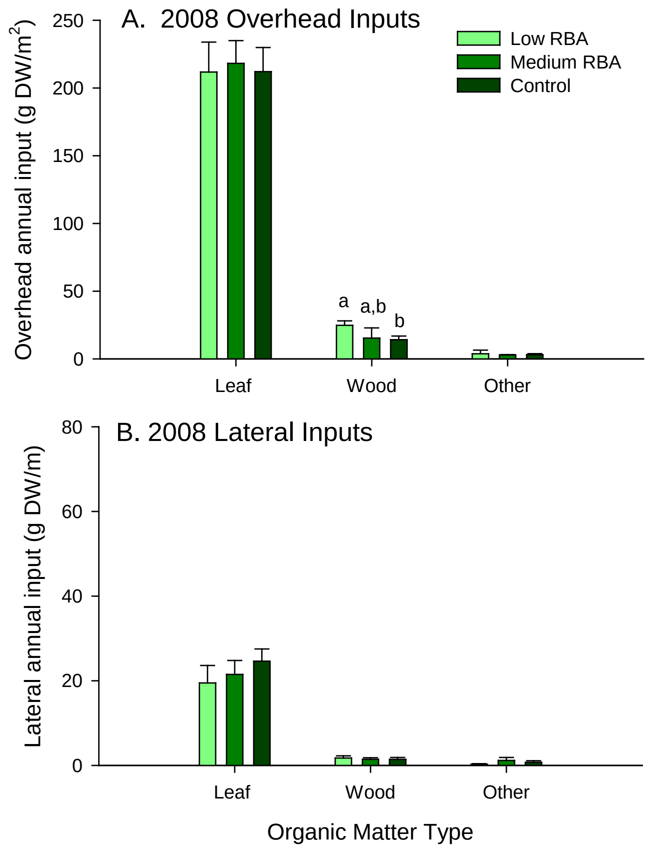

Figure 2b.8. Annual litter inputs by organic matter type during 2008 at the multiple-basin sites. Letters indicate significant differences at $p<0.05$.

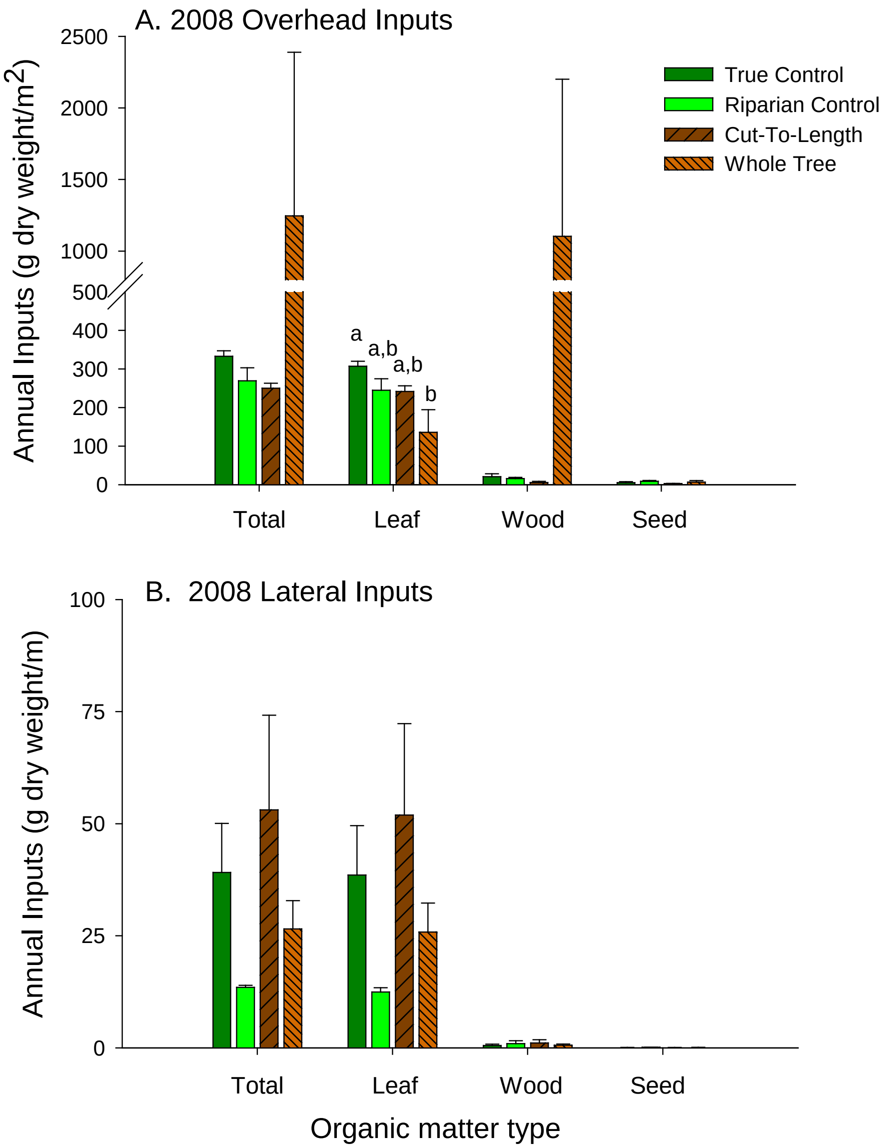

Figure 2b.9. Annual litter inputs by organic matter type at the single-basin sites in 2008. Letters indicate significant differences at $p<0.05$.

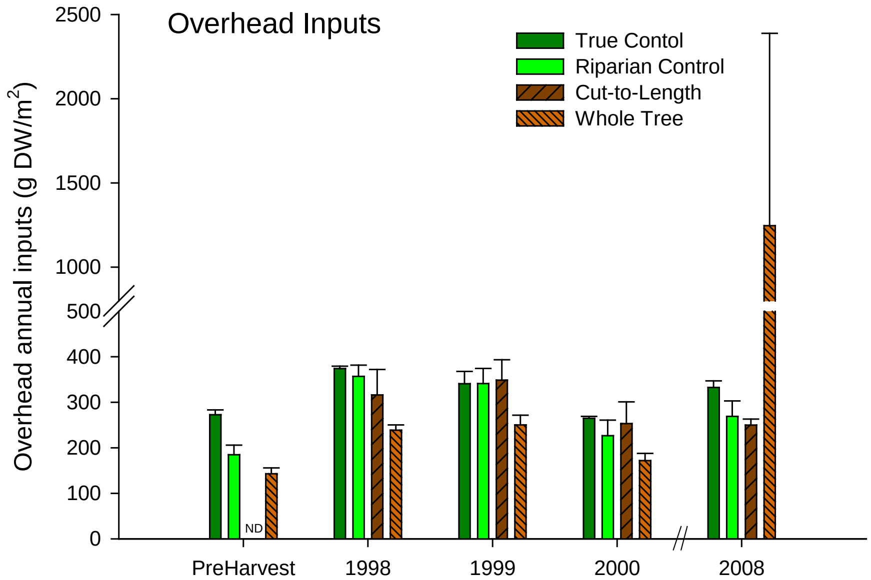

Figure 2b.10. Total litter inputs during pre-harvest year, early post-harvest years and year 11 post-harvest at the single-basin sites. Photo shows blowdown into overhead litter trap at plot 4 (Whole-tree harvest) during 2008.

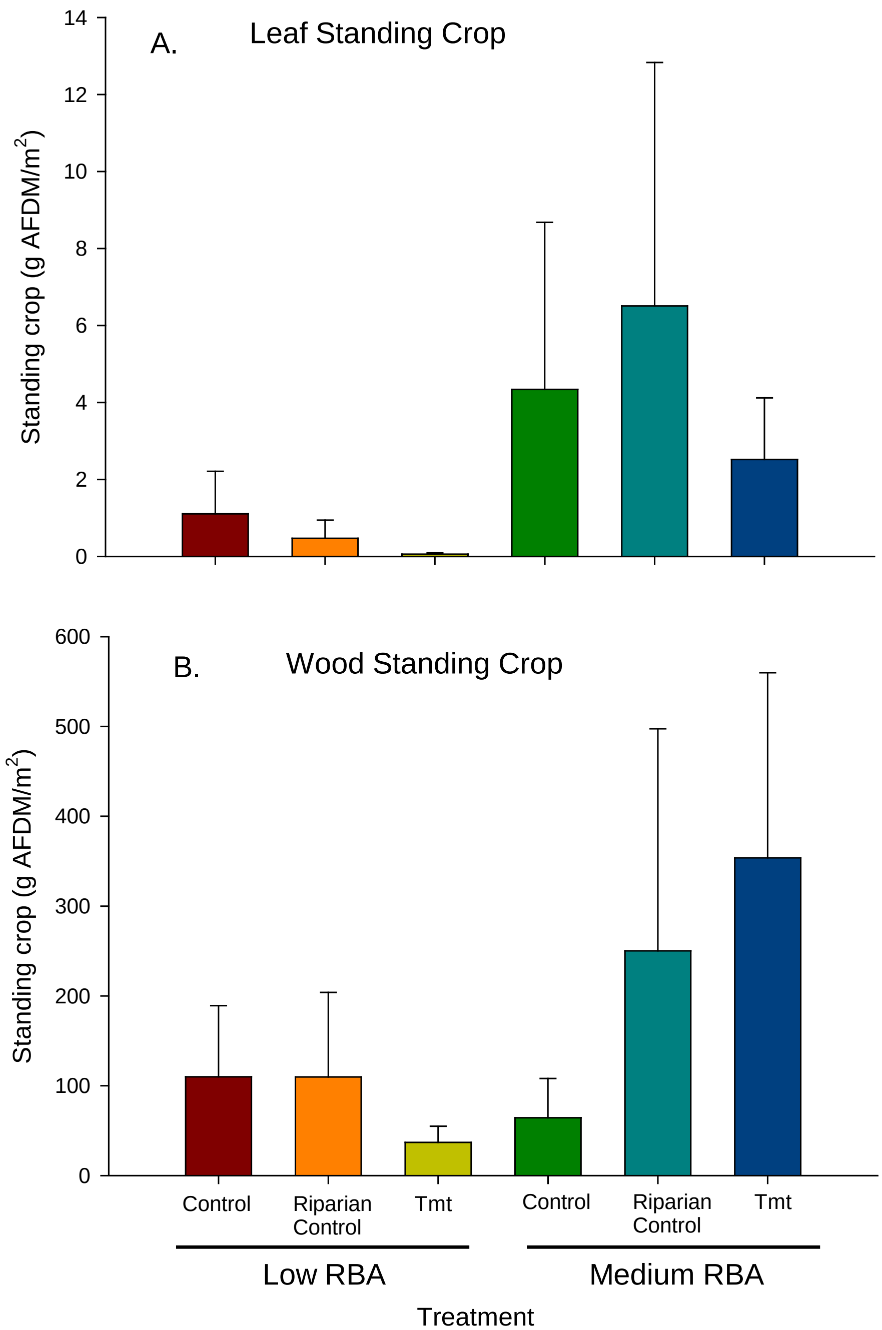

Figure 2b.11. Mean (± standard error) standing crop of leaf A.) and small wood B.) within control, riparian control, and low and medium residual basal area (RBA) treatments at the multiple-basin sites in June 2008.

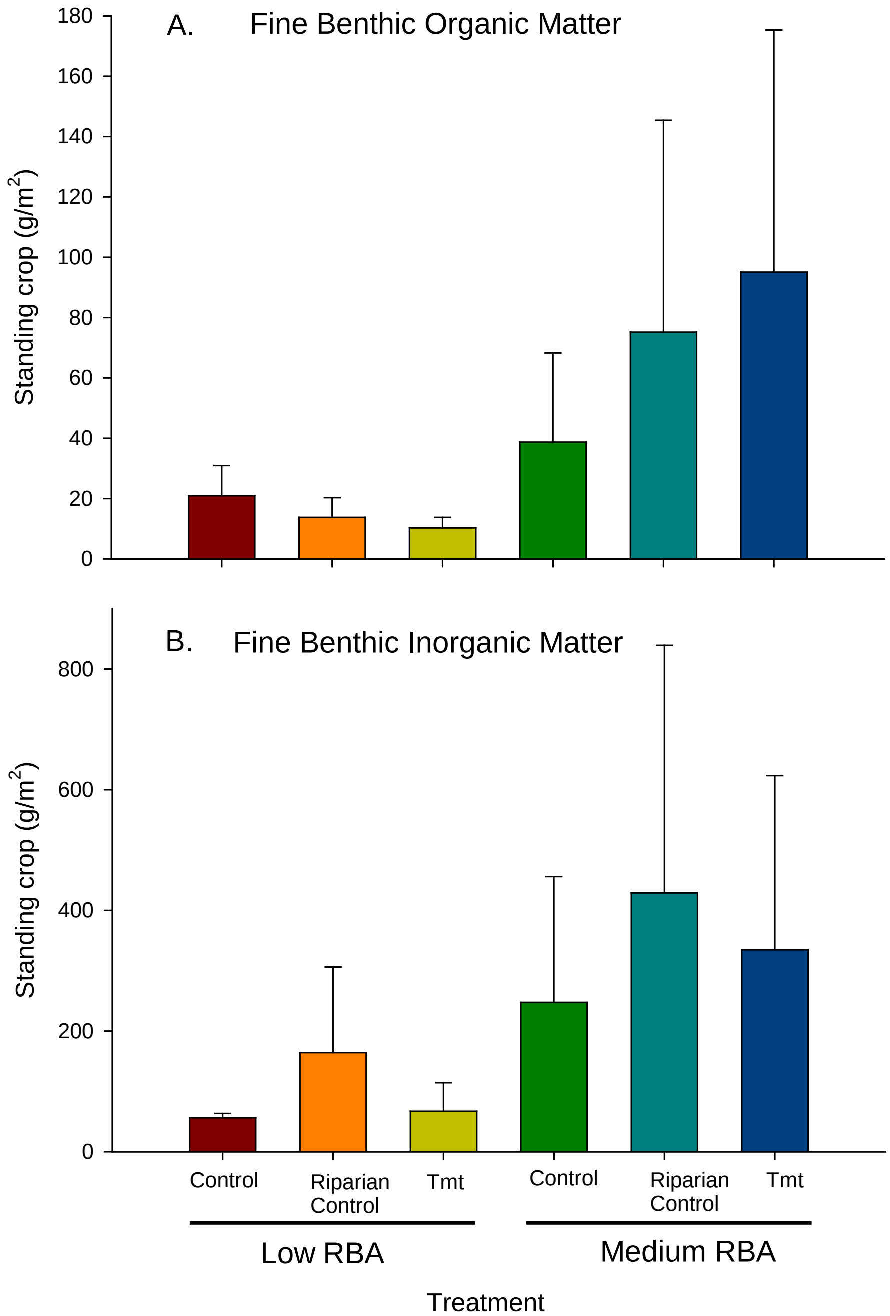

Figure 2b.12. Mean (± standard error) standing crop of Fine Benthic Organic Matter (FBOM) and Fine Benthic Inorganic Matter (FBIM) within control, riparian control, and low and medium residual basal area (RBA) treatments at the multiple-basin sites in June 2008.

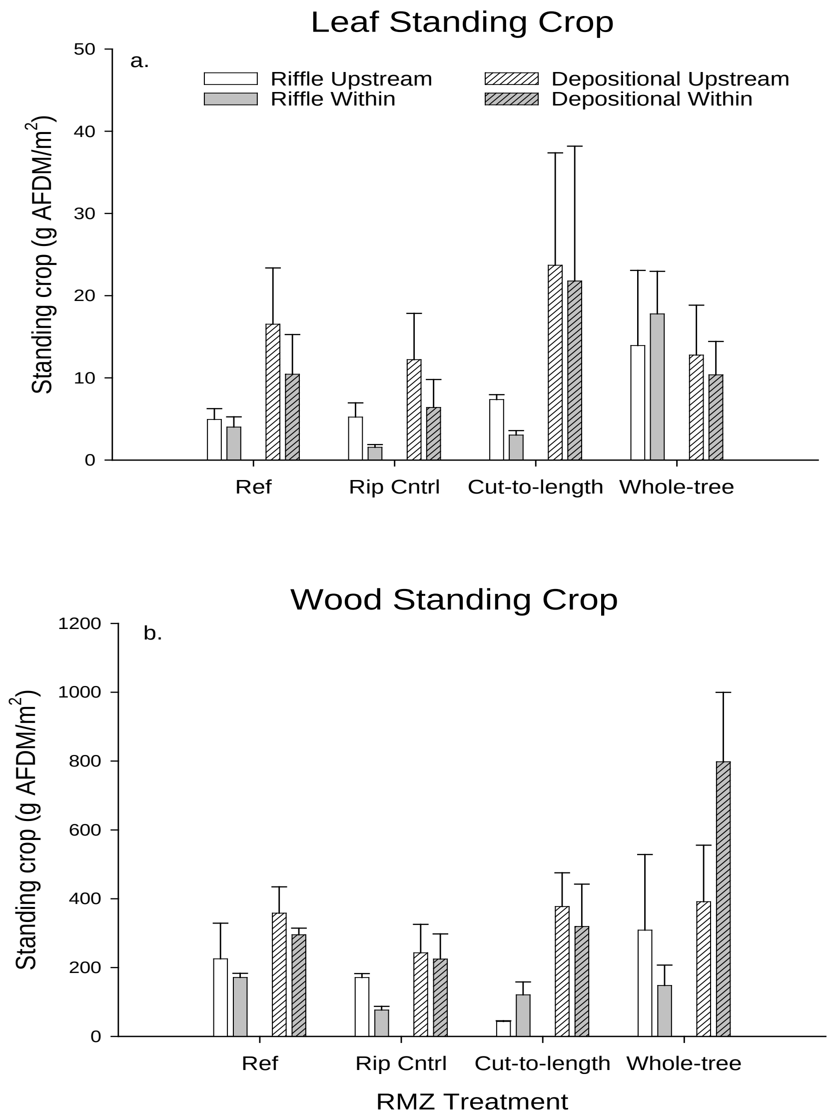

Figure 2b.13. Mean (± standard error) standing crop of a.) leaf and b.) wood upstream and within RMZ treatment reaches at the single-basin plots in August 2007.

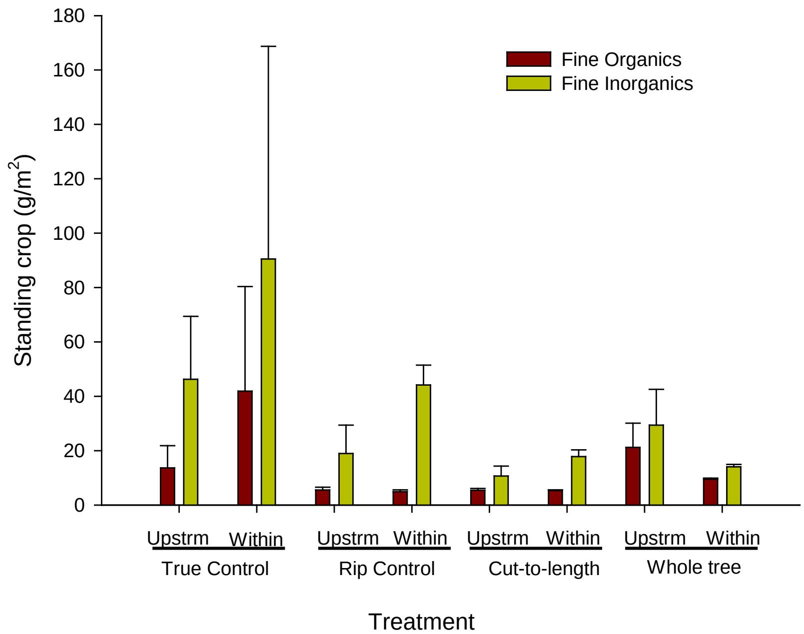

Figure 2b.14. Mean (± standard error) standing crop of Fine Benthic Organic Matter (FBOM) and Fine Benthic Inorganic Matter (FBIM) upstream and within RMZ treatment reaches at the single-basin plots in October 2007.

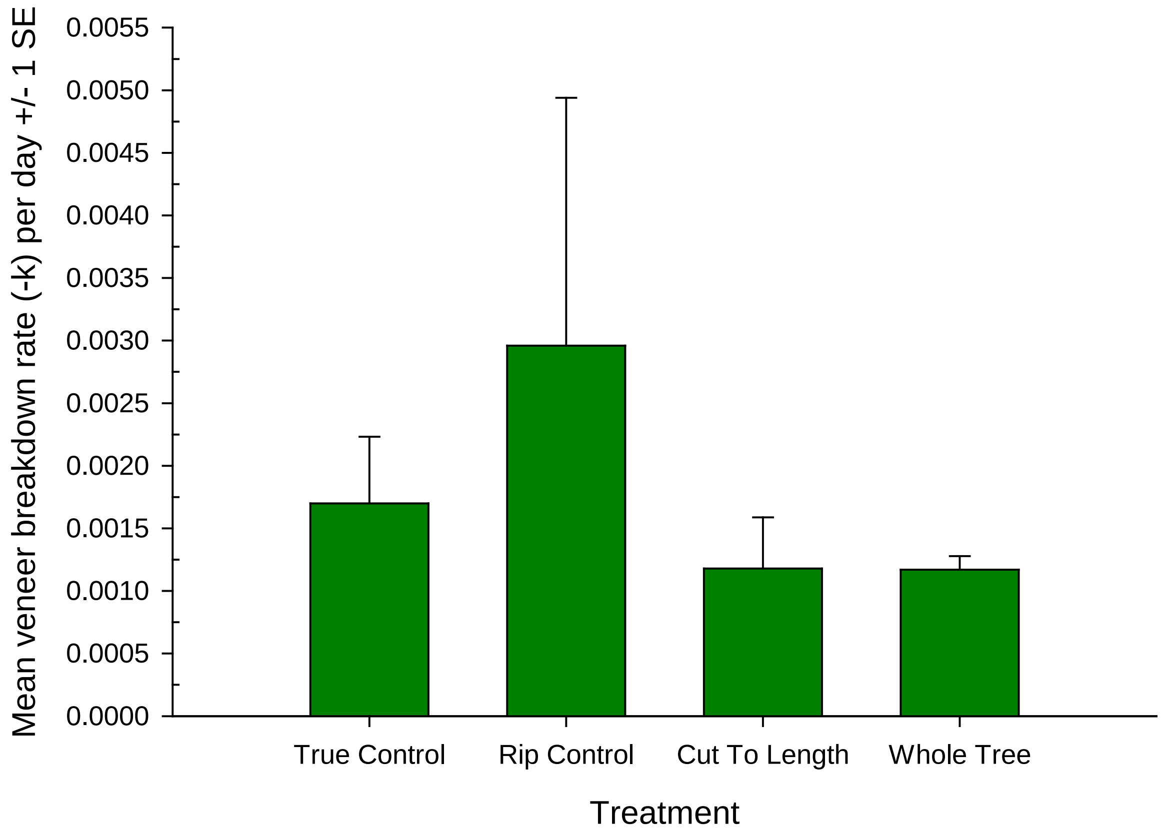

Figure 2b.15. Mean wood veneer breakdown rates (-k) +/- 1 SE from June 2008 to June 2009 at the single-basin plots. No significant ($p > 0.05$) difference among treatments.

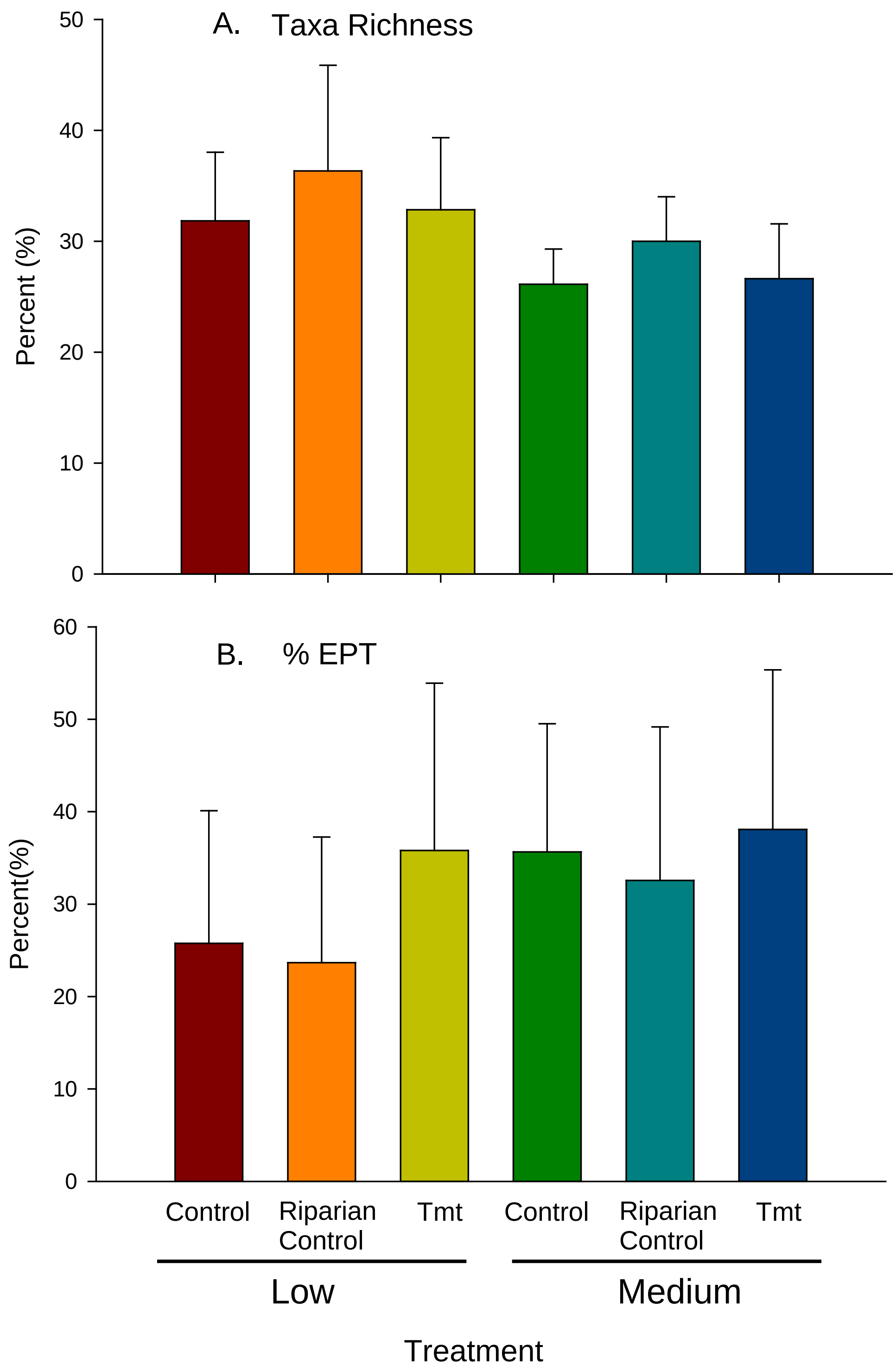

Figure 2b.16. Mean (+/- 1 SE) Taxa richness A), and Percent Ephemeroptera/Plecoptera/Trichoptera (EPT) taxa B) during August 2008 at the multiple-basin sites. No significant ($p > 0.05$) differences among control, riparian control, and treatment reaches at low or medium residual basal area (RBA) levels.

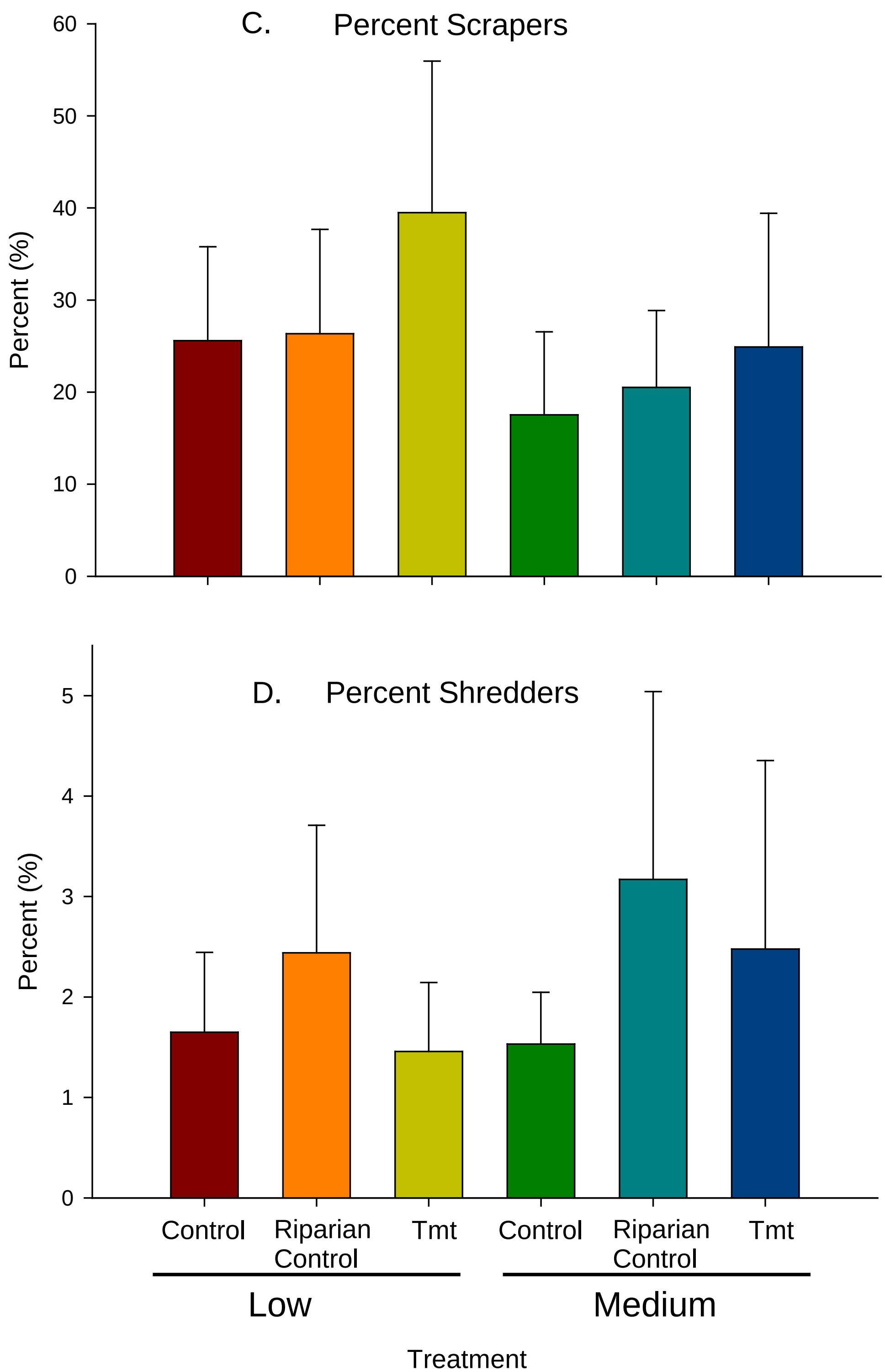

Figure 2b.16 (continued). Mean (+/- 1 SE) Percent scrapers C) and Percent shredders D) during August 2008 at the multiple-basin sites. No significant ($p > 0.05$) differences among control, riparian control, and treatment reaches at low or medium residual basal area (RBA) levels.

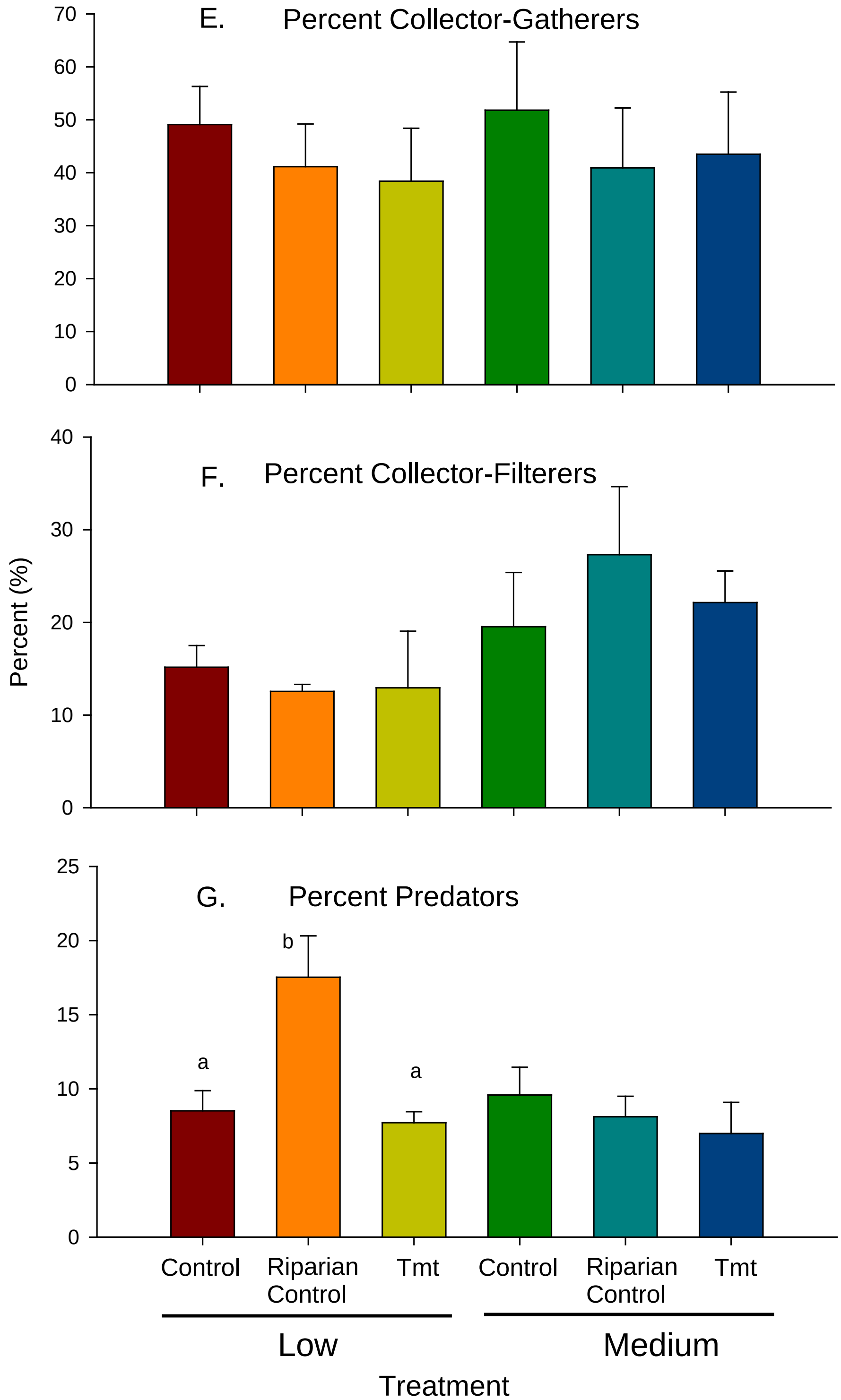

Figure 2b.16 (continued). Mean (+/- 1 SE) Percent collector-gatherers E), Percent collector-filterers F), and Percent predators G) during August 2008 at the multiple-basin sites. Significant ($p < 0.05$) differences among control, riparian control, and treatment reaches indicated by letters.

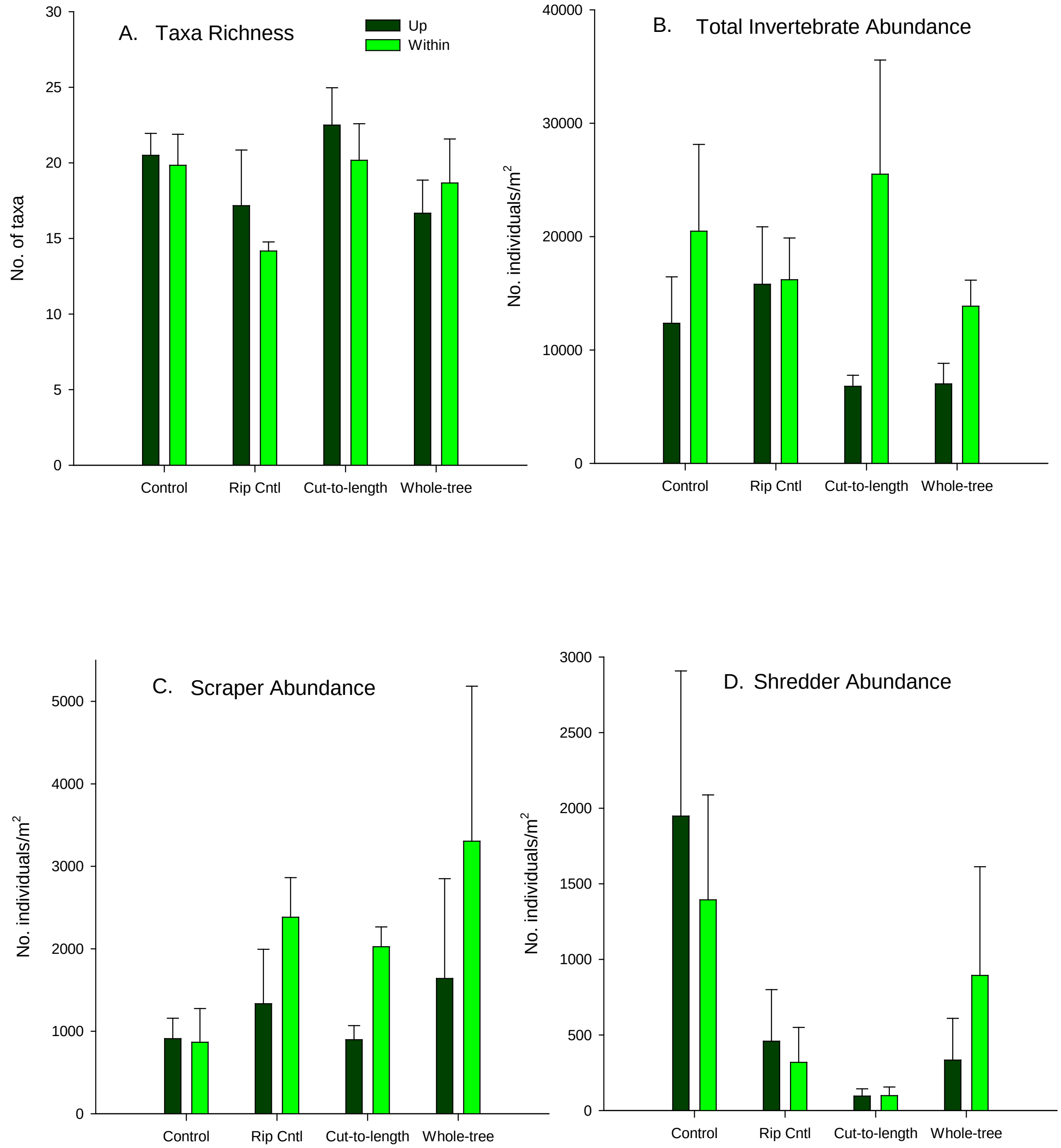

Figure 2b.17. Mean (+/- 1 SE) Taxa richness A), Total invertebrate abundance B), Scraper abundance C), and Shredder Abundance D) during June 2007 at the single-basin plots. No significant ($p > 0.05$) upstream-within plot differences among treatments.

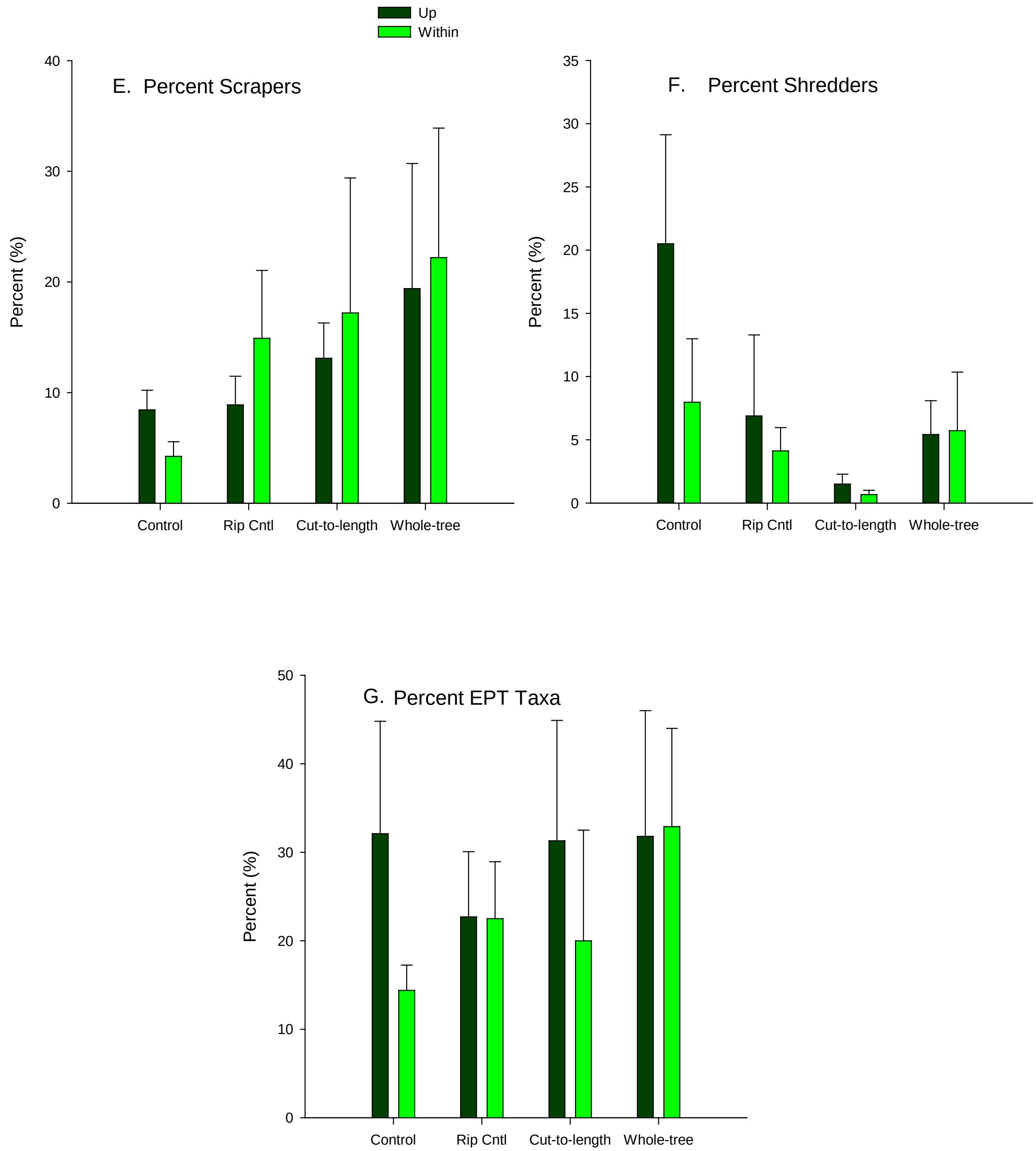

Figure 2b.17 (continued). Mean (+/- 1 SE) Percent scrapers E), Percent shredders F), and Percent Ephemeroptera/Plecoptera/Trichoptera (EPT) taxa G) during June 2007 at the single-basin plots. No significant ($p > 0.05$) upstream-within plot differences among treatments.

Result 3: Evaluate bird impacts

Description: We evaluated the effects of our treatments on breeding birds in northern Minnesota. Breeding bird response to habitat elements within these treated sites such as conifers, snags, long-lived tree species and mast-producing trees and shrubs were evaluated. We evaluated these response variables in 2007 and 2008.

Summary Budget Information for Result 3: **Trust Fund Budget: $5,570.18**
Amount Spent: $5,570.18
Balance: $ 0.00

Deliverable	Completion date	Budget	Status
1. Census riparian -associated bird species and habitat elements at treated and control sites in northern Minnesota. Summarize data and submit progress report.	1/31/08	$1,392	Completed
2. Census riparian-associated bird species and habitat elements at treated and control sites. Summarize data and submit progress report.	6/30/08	$1,392	Completed
3. Analysis of field data gathered in summer 2007 and 2008. Submit progress report**.**	1/31/09	$1,392	Completed
4. Summarization of data gathered and prepare and submit final report	6/30/09	$1,394.18	Completed

Completion Date: June 2009

Final Report Summary:

Introduction

Of the seven components of Minnesota's forest management guidelines, the riparian guidelines have been among the most controversial. Research addressing the long-term effectiveness of riparian guidelines is critical to resolving riparian management conflicts, informing the ongoing revisions of riparian guidelines, and sustaining Minnesota's forest resources. The objective of this study was to examine the population response of forest birds to riparian harvest and to assess the effectiveness of Minnesota's riparian guidelines. In 1997 a riparian harvest project began near Grand Rapids, Minnesota in which 12 study sites along single-basin tributaries on Pokegama Creek were subjected to different harvest types and regimes. Hanowski et al. (2003) documented breeding bird response to riparian forest harvest using 2 types of harvest equipment at these study sites and Hanowski et al. (2007) reported on bird response to riparian harvest at 9 years post-harvest. This report synthesizes overall breeding bird response to riparian harvest at single-basin tributary sites to 11-years post-harvest and complements previous research on forest birds including additional publications by Hanowski et al. (2002 and 2005). For a more comprehensive review of general riparian and riparian breeding bird literature see Wegner (1999) and Hanowski et al. (2002, 2003).

Methods

During May, June, and July breeding birds were sampled at the 12 single-basin sites near Grand Rapids, Minnesota. Study sites were located in areas where no upland or riparian harvest occurred (Control), riparian control sites in which uplands were harvested with no riparian buffer harvest (Cut/Control), or treatment sites in which upland areas were harvested and riparian buffers harvested with a goal of 25 ft^2/acre residual basal area (Cut). Although the initial study purpose was to compare two harvest treatments (full-tree and cut-to-length harvesting), analyses here combine all treatments as a single treatment (Cut). Breeding birds were sampled using standard point counts along transects within these areas (Hanowski *et al.* 1990). Study survey years included one pre-harvest year (1997), three initial post-harvest years (1999-2000), and 3 late post-harvest years (2006-2008). Surveys were not conducted during the years 2001 to 2005. Surveys were completed by experienced observers who passed a bird identification test, a hearing test, and received training to standardize counts (Hanowski and Niemi 1995). All surveys were completed during early morning hours (within 4 hours of sunrise) with little wind <20 kph and little to no precipitation. During 2007 and 2008 breeding bird surveys occurred exclusively in June, therefore analyses here incorporate only mid-season (June) breeding bird data.

To understand the effects of riparian harvest on the bird community, individual bird species as well as bird guilds based on life history traits (nesting substrate, migration strategy, and broad habitat type use) were utilized and compared among study sites and years. Bird species and associated guilds are listed in Appendix 3.1. Total bird species abundance by year is reported in Appendix 3.2. These data were compared graphically and using t-statistical tests at a significance level of 0.05. Study years were analyzed individually and combined into three time stages, pre-harvest (1997), 1-3 years post-harvest (1998-2000) and 9-11 years post-harvest (2006-2008) to better examine large-scale changes in relative abundances of the bird community over time. Results are reported as a synthesis of riparian harvest effects on bird community dynamics.

Results

A total of 58 bird species were recorded at the single-basin sites throughout the study period from 1997 – 2008 (Appendix 2). The five most abundant bird species present at all sites pre-harvest were (in order of decreasing abundance) the Ovenbird, Red-eyed Vireo, Least Flycatcher, Black-throated Green Warbler, and Veery (Appendix 3.2). All of these species are associated with mature forest habitat (Lind et al. 2006, Appendix 3.1). At one-year post harvest Ovenbirds, Red-eyed Vireos, and Least Flycatchers remained the most abundant species but were followed in abundance by Mourning Warblers and White-throated Sparrows, two early successional species. Two-years post harvest, the Chestnut-sided Warbler, an early successional species, had become the most dominant bird at the single-basin study sites followed by the

Ovenbird and Mourning Warbler. At 4-years, 9-years, and 10-years post-harvest, the Chestnut-sided Warbler remained the most abundant bird at the study sites. It was not until 11-years post-harvest that the Chestnut-sided Warbler's relative abundance decreased and was replaced by the abundance of a mature forest species, the Red-eyed Vireo. Chestnut-sided Warbler abundance on Cut/Control and Cut plots did not begin to increase until 2-years post harvest (Figure 3.1) but remained significantly higher on Cut/Control and Cut sites when compared to Control sites post-harvest ($p<0.01$, $p<0.00$, respectively). Chestnut-sided Warbler abundance decreased at 10 and 11-years post-harvest. Ovenbirds remained relatively high in abundance throughout the study, however abundance on Cut/Control and Cut sites decreased significantly after harvest and remained significantly less than abundances on Control plots throughout the study ($p<0.00$, Figure 3.2). Ovenbird abundance remained relatively constant on Control plots throughout the study.

At the single-basin pre-harvest sites, the relative abundance of mature forest species ranged from 0.97-1.0 indicating an overall bird composition comprised of nearly all mature forest birds. In contrast, the relative abundance of early successional species ranged from 0-0.03 indicating these birds were nearly absent at the single-basin study sites pre-harvest. Mature and early successional species abundance changed drastically in the years post-harvest (Figure 3.3a-b). The relative abundance of mature forest species on both Cut/Control and Cut plots decreased at 1-3 years post-harvest and remained low at 9-11 years post-harvest and were significantly different than Control plot abundance at both post-harvest stages ($p<0.01$, Figure 3.3a). The relative abundance of early successional species increased on Cut/Control and Cut plots 1-3 years post-harvest and remained significantly higher than Control abundance at 9-11 years post-harvest ($p<0.00$, Figure 3.3b). As expected, abundances of mature and early successional species remained stable at Control plots throughout the study.

Long-distance and short-distance migrant birds exhibited opposing trends in relative abundance throughout the study period (Figures 3.4a-b). Relative abundance measurements showed long-distance migrants to be a dominant guild during the pre-harvest year with an abundance range of 0.80-0.89 as opposed to the relative abundance of short-distance migrants which ranged from 0.07-0.13 of total bird abundance. However, at 1-3 years post-harvest long-distance migrant abundance had decreased on both Cut/Control and Cut sites while short-distance migrant abundance increased on these two sites. The relative abundance of short-distance migrants returned to Control site levels at 9-11 years post-harvest as did the relative abundance of long-distance migrants on Control/Cut sites. However, the relative abundance of long-distance migrants continued to decrease on Cut sites at 9-11 years post-harvest. The relative abundance of these two migration guilds remained constant on Control sites throughout the study period.

Among the nesting guilds, no significant differences between sites at different years were detected. However trends in relative abundance did occur throughout the study period (Figure 3.5a-d). Canopy nesters declined in relative abundance throughout the study at all sites, including Controls sites. Cavity nesters slightly decreased in relative abundance on Cut/Control and Cut sites and increased on Control sites. Shrub nesters slightly decreased in relative abundance on Control sites throughout the study but increased on both Cut/Control and Cut sites and 1-3 years post-harvest. At 9-11 years post-harvest, the relative abundance of shrub nesters was similar on both Control and Cut/Control sites but decreased substantially at Cut sites.

Ground nesters increased very slightly in relative abundance at all sites throughout the study period.

Discussion

The results of the single-basin riparian study showed riparian bird community change at two time periods after upland and riparian harvest events. The riparian bird community was affected by both of these harvest events when compared to unharvested control sites. Maintaining an intact riparian buffer did not alleviate upland harvest effects on the riparian bird community. Only long-distance migrant birds increased to pre-harvest levels on the unharvested riparian buffers which may be a result of an increase of shrub nesting and early successional bird species with long-distance migrant life histories (Red-eyed Vireo, American Redstart, Mourning Warbler). Most harvest effects continued to be evident on unharvested riparian buffers at 9-11 years post harvest including the low abundance of cavity nesters, canopy nesters, and Ovenbirds. Ovenbirds are a high priority "watch list" species of northern Minnesota forests (Rich et al. 2004, Lind et al. 2006). This study showed that retaining an unharvested riparian buffer was not sufficient in maintaining pre-harvest abundance of canopy and cavity nesters, or maintaining Ovenbird populations in northern Minnesota.

Early successional species were virtually absent from study sites pre-harvest due to the dominant mature forest type which supported a bird community of nearly all mature forest associated species. The abundance of early successional species, including the Chestnut-sided Warbler, increased to highest study abundance by the first post-harvest time stage. Although Chestnut-sided Warbler abundance decreased towards the end of the study period, the relative abundance of early successional species remained high at 9-11 years post-harvest at both Cut/Control and Cut sites. Early successional species were the dominant habitat guild in Cut/Control sites throughout the post-harvest period. This reveals that retaining an unharvested riparian buffer is not sufficient to support the mature forest associated species population that was predominant in the area pre-harvest. This also reveals that riparian areas are affected by harvest in the landscape illustrated by the increase of early successional species in unharvested riparian areas.

Results of this study show that the pre-harvest bird community is neither maintained nor able to reestablish on unharvested riparian buffers at 9-11 years after an upland harvest event. These results suggest that riparian guidelines need to be flexible, the population status and life history of bird species of conservation priority should be fully considered in riparian management, and that management plans for riparian areas should be done on a landscape level.

The results from this study only reflected relatively short-term dynamics following harvest in the RMZs. To fully understand the long-term consequences (i.e., minimum of nine years post-harvest as suggested in prior studies), further study will be necessary.

Result expenditures

Funds in the amount of $1.18 were shifted from Result 4 to get the Result 3 budget to a zero balance.

Unanticipated and unresolved problems
The procedures used to meet the objectives of this Result were adequate and sufficient. There were no unresolved problems relative to this Result. All work was completed as planned.

Literature cited

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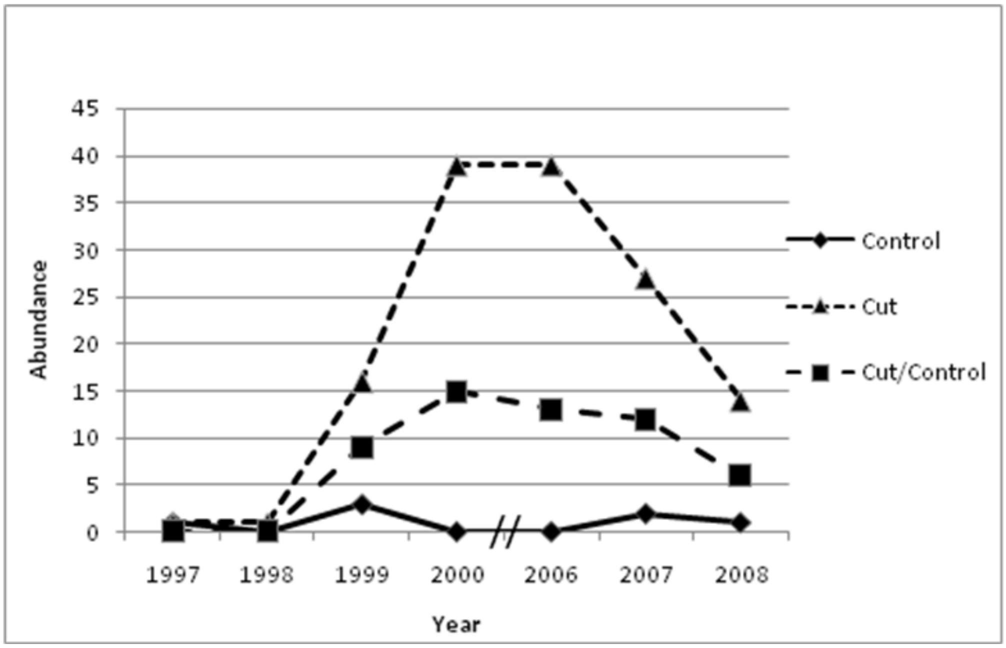


Figure 3.1. Chestnut-sided Warbler abundance at the single-basin Control, Cut/Control, and Cut sites during June over all survey years.

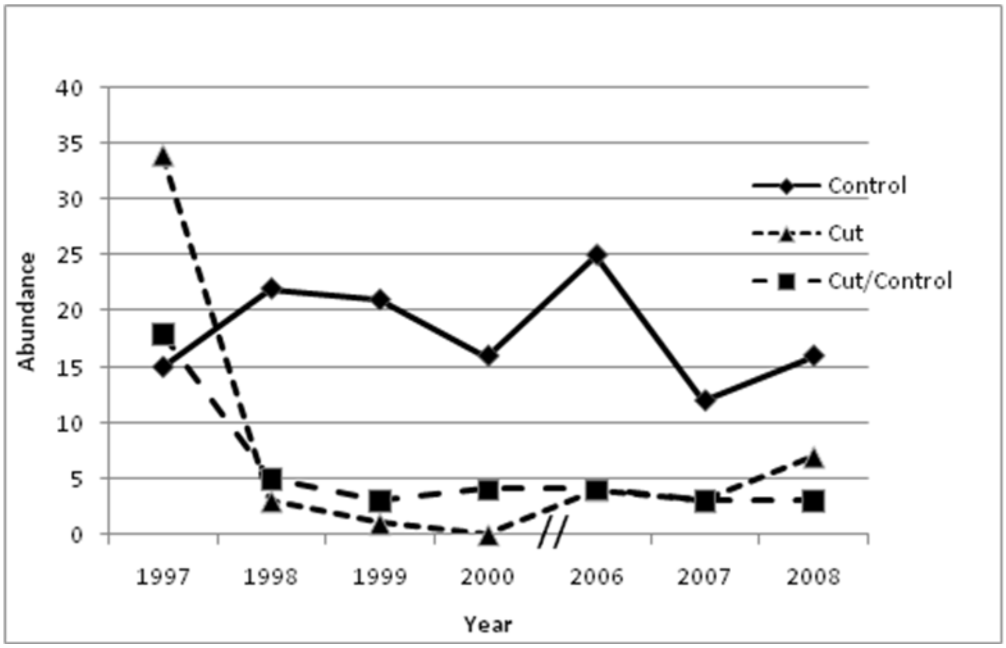


Figure 3.2. Ovenbird abundance at the single-basin Control, Cut/Control, and Cut sites during June over all survey years.

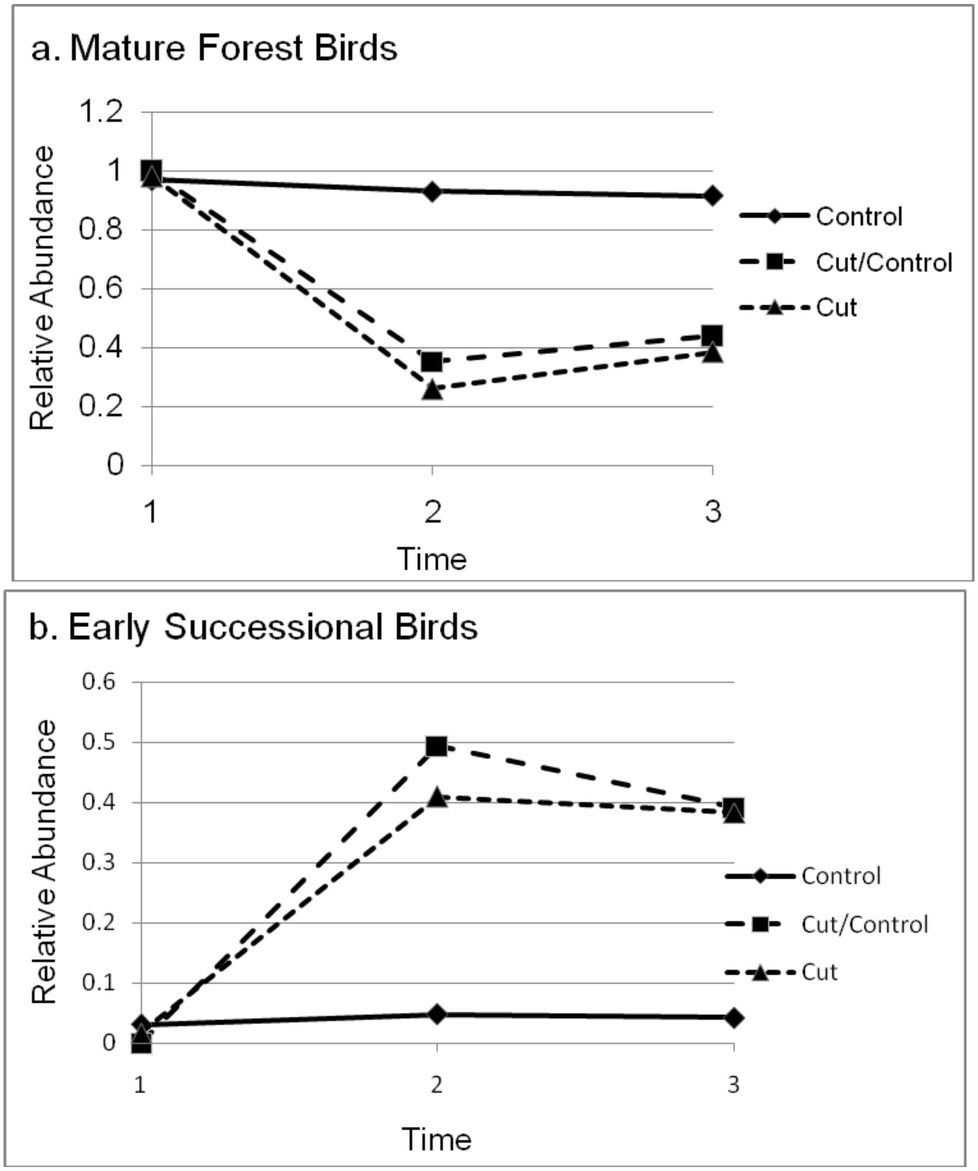


Figure 3.3a and b. Mature and early successional forest associated bird guild relative abundances at the single-basin Control, Cut/Control, and Cut sites at pre-harvest (Time 1), post-harvest 1-3 years (Time 2), and post-harvest 9-11 years (Time 3).

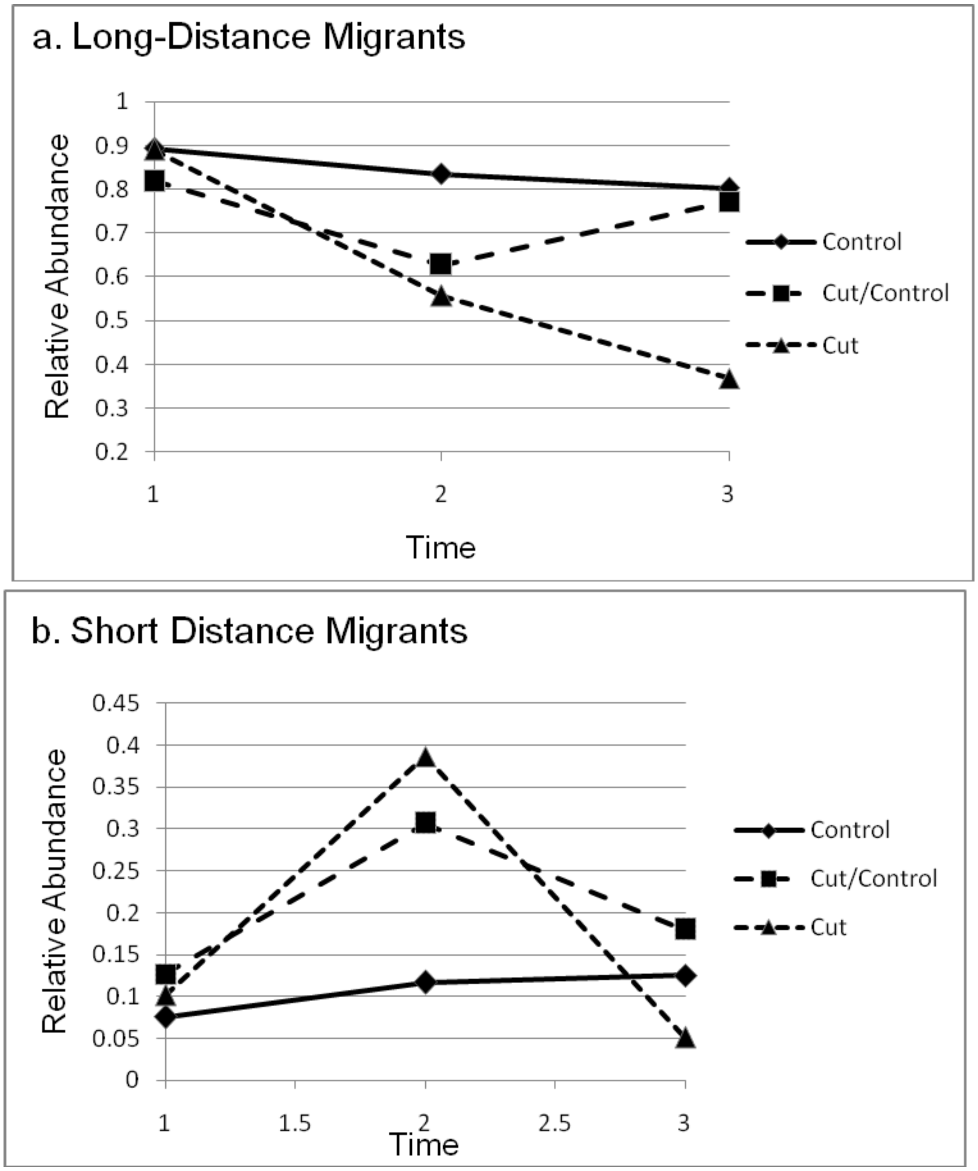
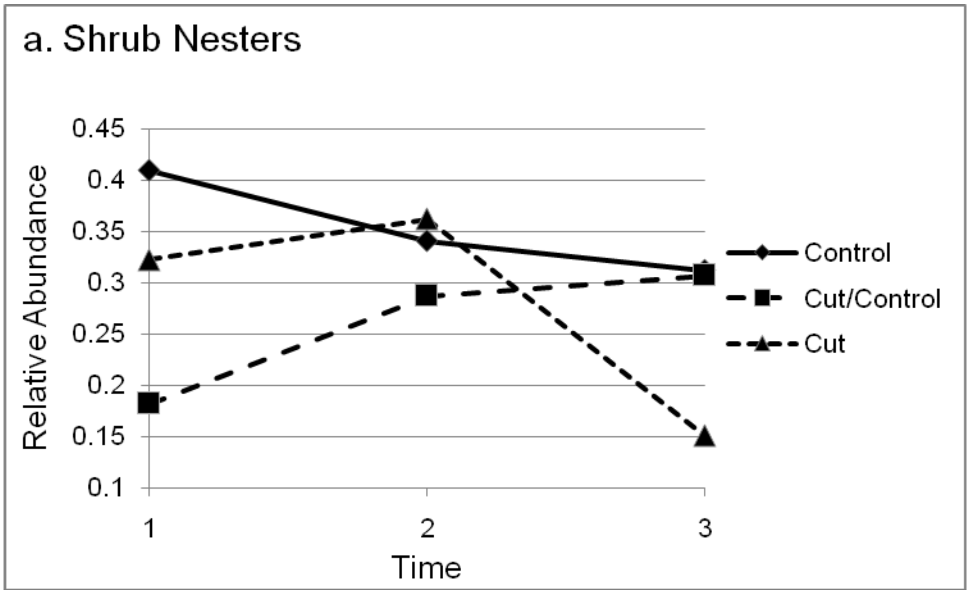


Figure 3.4a and b. Long-distance and short-distance migrant relative abundances at the single-basin Control, Cut/Control, and Cut sites at Pre-harvest (Time 1), Post-harvest 1-3 years (Time 2), and Post-harvest 9-11 years (Time 3).



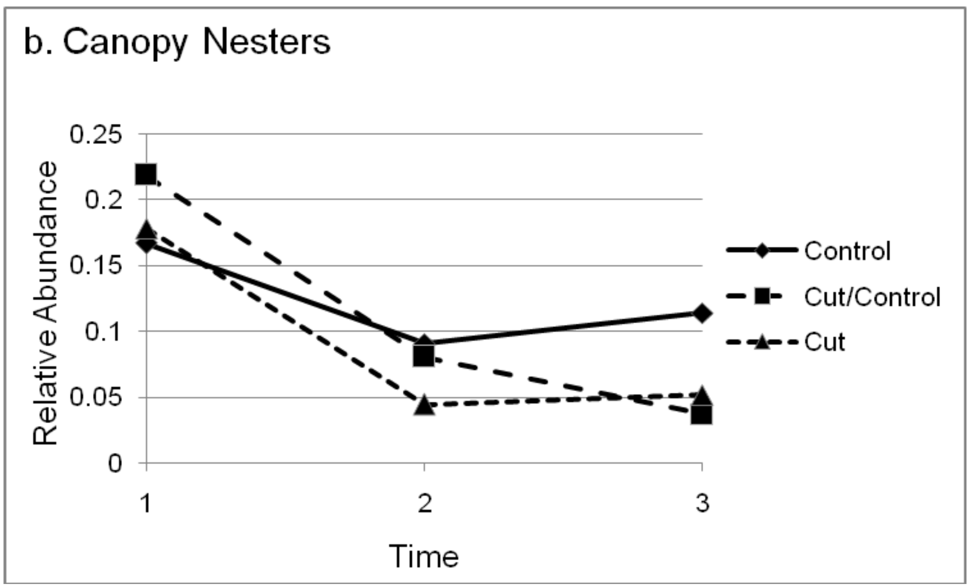


Figure 3.5a-d. Nesting guild relative abundances at the single-basin Control, Cut/Control, and Cut sites at pre-harvest (Time 1), post-harvest 1-3 years (Time 2), and post-harvest 9-11 years (Time 3).

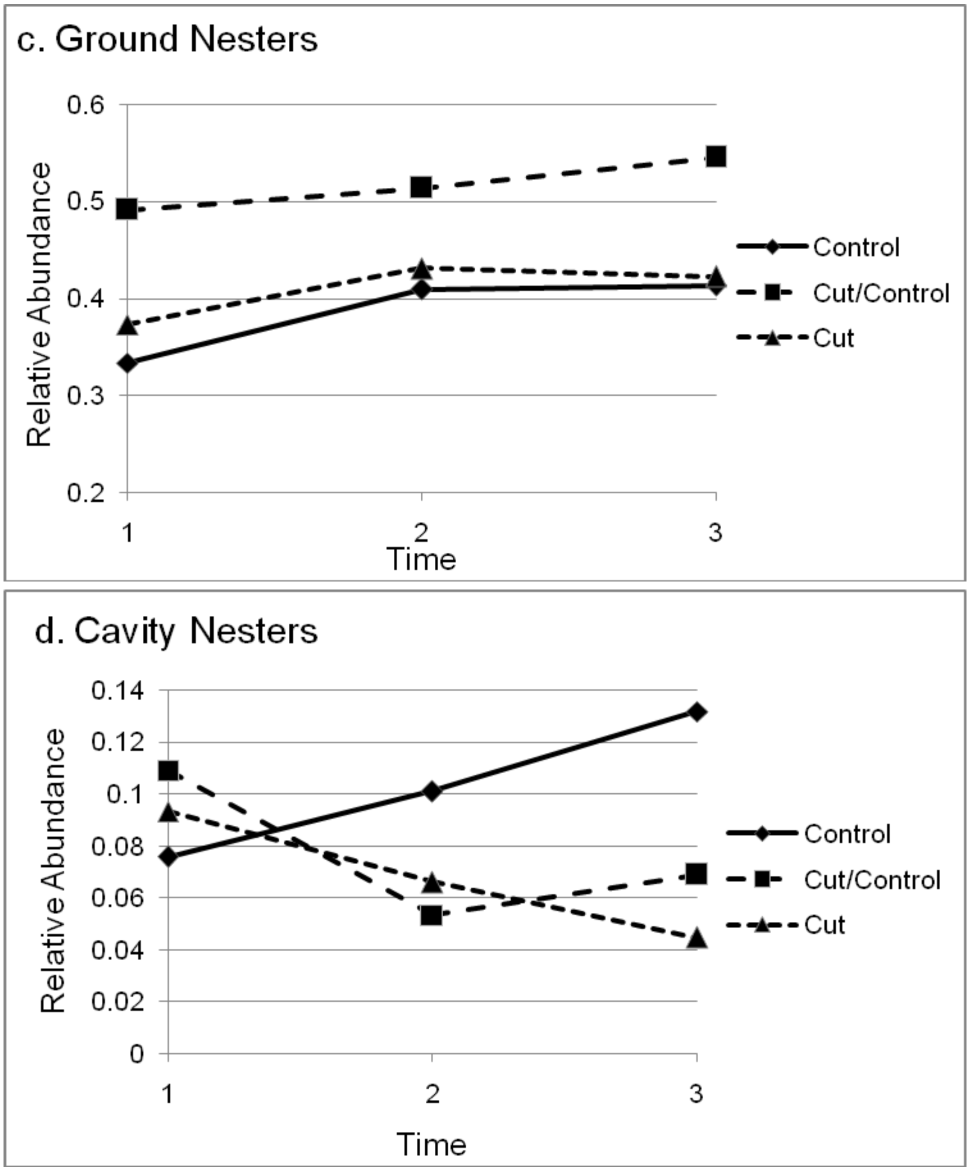


Figure 3.5a-d (continued). Nesting guild relative abundances at the single-basin Control, Cut/Control, and Cut sites at pre-harvest (Time 1), post-harvest 1-3 years (Time 2), and post-harvest 9-11 years (Time 3).

Appendix 3.1a. English and taxonomic bird species names and guild associations for species recorded at the single-basin study sites for all study years 1997 – 2008. Guild associations are taken from Lind et al. (2006). Migration Guild: Long = Long Distance Migrant, SHRT = Short Distance Migrant, PERM = Permanent Resident. Nesting Guild: CNPY = Canopy, CVTY = Cavity, GRND = Ground, PRST = Nest Parasite, SCPY = Subcanopy, SHRB = Shrub. Habitat Guild: ES = Early Successional, FLME = Fields and Meadows, MAT = Mature, UBIQ = Ubiquitous, URBN = Urban.

English Name	Taxonomic Name	Migration Guild	Nesting Guild	Habitat Guild
Alder Flycatcher	*Empidonax alnorum*	LONG	SHRB	ES
American Goldfinch	*Carduelis tristis*	SHRT	SHRB	FLME
American Redstart	*Setophaga ruticilla*	LONG	SHRB	ES
American Robin	*Turdus migratorius*	SHRT	SCPY	FLME
Black-and-white Warbler	*Mniotilta varia*	LONG	GRND	MAT
Black-capped Chickadee	*Poecile atricapillus*	PERM	CVTY	MAT
Brown-headed Cowbird	*Molothrus ater*	SHRT	PRST	FLME
Blackburnian Warbler	*Dendroica fusca*	LONG	CNPY	MAT
Blue Jay	*Cyanocitta cristata*	PERM	CNPY	MAT
Brown Creeper	*Certhia americana*	SHRT	CVTY	MAT
Black-throated Blue Warbler	*Dendroica caerulescens*	LONG	SHRB	MAT
Black-throated Green Warbler	*Dendroica virens*	LONG	CNPY	MAT
Broad-winged Hawk	*Buteo platypterus*	LONG	CNPY	MAT
Canada Warbler	*Wilsonia canadensis*	LONG	GRND	MAT
Cedar Waxwing	*Bombycilla cedrorum*	SHRT	SHRB	UBIQ
Chipping Sparrow	*Spizella passerina*	SHRT	CNPY	MAT
Chimney Swift	*Chaetura pelagica*	LONG	CNPY	URBN
Common Raven	*Corvus corax*	PERM	CNPY	MAT
Common Yellowthroat	*Geothlypis trichas*	SHRT	GRND	SBSW
Chestnut-sided Warbler	*Dendroica pensylvanica*	LONG	SHRB	ES
Downy Woodpecker	*Picoides pubescens*	PERM	CVTY	MAT
Eastern Phoebe	*Sayornis phoebe*	SHRT	SHRB	URBN
Eastern Wood-pewee	*Contopus virens*	LONG	SCPY	MAT
Evening Grosbeak	*Coccothraustes vespertinis*	PERM	CNPY	MAT
Great Crested Flycatcher	*Myiarchus crinitus*	LONG	CVTY	MAT
Golden-crowned Kinglet	*Regulus satrapa*	SHRT	CNPY	MAT
Gray Catbird	*Dumetella carolinensis*	LONG	SHRB	UBIQ
Golden-winged Warbler	*Vermivora crysoptera*	LONG	GRND	ES
Hairy Woodpecker	*Picoides villosus*	PERM	CVTY	MAT
Hermit Thrush	*Catharus guttatus*	SHRT	GRND	MAT

Appendix 3.1b. English and taxonomic bird species names and guild associations for species recorded at the single-basin study sites for all study years 1997 – 2008. Guild associations are taken from Lind et al. (2006). Migration Guild: Long = Long Distance Migrant, SHRT = Short Distance Migrant, PERM = Permanent Resident. Nesting Guild: CNPY = Canopy, CVTY = Cavity, GRND = Ground, PRST = Nest Parasite, SCPY = Subcanopy, SHRB = Shrub. Habitat Guild: ES = Early Successional, FLME = Fields and Meadows, MAT = Mature, UBIQ = Ubiquitous, URBN = Urban.

English Name	Taxonomic Name	Migration Guild	Nesting Guild	Habitat Guild
House Wren	*Troglodytes aedon*	SHRT	CVTY	MAT
Indigo Bunting	*Passerina cyanea*	LONG	SHRB	FLME
Least Flycatcher	*Empidonax minimus*	LONG	SHRB	MAT
Mourning Warbler	*Oporornis philadelphi*	LONG	GRND	ES
Nashville Warbler	*Vermivora ruficapilla*	LONG	GRND	MAT
Northern Flicker	*Colaptes auratus*	SHRT	CVTY	FLME
Northern Parula	*Parula americana*	LONG	CNPY	MAT
Northern Waterthrush	*Seiurus noveboracensis*	LONG	GRND	MAT
Ovenbird	*Seiurus aurocapilla*	LONG	GRND	MAT
Pileated Woodpecker	*Dryocopus pileatus*	PERM	CVTY	MAT
Purple Finch	*Carpodacus purpureus*	PERM	CNPY	MAT
Rose-breasted Grosbeak	*Pheuctuicus ludovicia*	LONG	SHRB	MAT
Red-breasted Nuthatch	*Sitta canadensis*	PERM	CVTY	MAT
Red-eyed Vireo	*Vireo olivaceus*	LONG	SHRB	MAT
Ruby-throated Hummingbird	*Archilochus colubris*	LONG	CNPY	MAT
Ruffed Grouse	*Bonasa umbellus*	PERM	GRND	ES
Scarlet Tanager	*Piranga olivacea*	LONG	CNPY	MAT
Song Sparrow	*Melospiza melodia*	SHRT	GRND	FLME
Swamp Sparrow	*Melospiza georgiana*	SHRT	SHRB	FLME
Tennessee Warbler	*Vermivora peregrina*	LONG	GRND	MAT
Veery	*Catharus fuscescens*	LONG	GRND	MAT
White-breasted Nuthatch	*Sitta carolinensis*	PERM	CVTY	MAT
Winter Wren	*Troglodytes troglodytes*	SHRT	GRND	MAT
Wood Thrush	*Hylocichla mustelina*	LONG	CNPY	MAT
White-throated Sparrow	*Zonotrichia albicollis*	SHRT	GRND	ES
Yellow-bellied Sapsucker	*Sphyrapicus varius*	SHRT	CVTY	MAT
Yellow-rumped Warbler	*Dendroica coronata*	LONG	CNPY	MAT
Yellow-throated Vireo	*Vireo flavifrons*	LONG	CNPY	MAT

Appendix 3.2a. Total abundance of bird species recorded by year at the single-basin sites for 1997 – 2000 and 2006 – 2008.

English Name	1997	1998	1999	2000	2006	2007	2008
Alder Flycatcher			3	1			
American Goldfinch				15	5		
American Redstart					20	12	9
American Robin		2	1	5	3	1	
Black-and-white Warbler	2	1			5	15	18
Black-capped Chickadee	1	3	1	9	13	6	5
Brown-headed Cowbird		6	8	6	2		2
Blackburnian Warbler	6					2	
Blue Jay		2	3	2	5	1	4
Brown Creeper	6	3	1		2	2	4
Black-throated Blue Warbler	1						
Black-throated Green Warbler	24	4	3	3	6	2	3
Broad-winged Hawk					2		
Canada Warbler					3	1	4
Cedar Waxwing				6	6	1	1
Chipping Sparrow	1						
Chimney Swift		1					
Common Raven				1			
Common Yellowthroat	1		6	17	6	4	3
Chestnut-sided Warbler	2	1	28	54	52	41	21
Downy Woodpecker		1		1		1	
Eastern Phoebe				1			
Eastern Wood-pewee	4	1	1	5	2		3
Evening Grosbeak				6			
Great Crested Flycatcher	6	2	4				4
Golden-crowned Kinglet	1						
Gray Catbird				1	4		1
Golden-winged Warbler			6	16	4	9	17
Hairy Woodpecker							1
Hermit Thrush	6	3	3	3		1	4

Appendix 3.2b. Total abundance of bird species recorded by year at the single-basin sites for 1997 – 2000 and 2006 – 2008.

English Name	1997	1998	1999	2000	2006	2007	2008
House Wren				1			
Indigo Bunting			2	6	1		
Least Flycatcher	26	15	6	8	5	5	3
Mourning Warbler	1	13	21	40	16	8	9
Nashville Warbler	4				2	3	20
Northern Flicker		1					1
Northern Parula	2			1	1	2	
Northern Waterthrush						1	
Ovenbird	67	30	25	20	33	18	26
Pileated Woodpecker					2		
Purple Finch			1		1		
Rose-breasted Grosbeak	2	2	1	10	17	7	13
Red-breasted Nuthatch	3						2
Red-eyed Vireo	44	20	18	24	26	18	27
Ruby-throated Hummingbird		2		8	2		2
Ruffed Grouse	1			3			4
Scarlet Tanager	5	3	2	3	1	1	3
Song Sparrow		3	21	22	2		
Swamp Sparrow			1			1	
Tennessee Warbler							1
Veery	8	4	3	4	38	30	26
White-breasted Nuthatch	1			4	4		
Winter Wren	4	6	3	4	4	1	3
Wood Thrush	2				3		6
White-throated Sparrow		7	9	11	8	6	8
Yellow-bellied Sapsucker	5	6	4	7	6	4	6
Yellow-rumped Warbler	2						1
Yellow-throated Vireo	1	1			1		

Result 4: Meta-analysis of terrestrial and aquatic results

Description: We evaluated the effects of our management treatments through time on both the terrestrial (trees and understory species) and aquatic habitat components, as well as changes of terrestrial and aquatic communities (fish and invertebrate) in a meta-analysis. We evaluated the response variables collected in previous years on the single- and multiple-basin study sites.

Summary Budget Information for Result 4: **Trust Fund Budget: $71,026.08**
Amount Spent: $70,123.44
Balance: $ 902.64

Deliverable	Completion date	Budget	Status
1. Assemble datasets for meta-analysis	4/30/08	$38,400	Completed
2. Analyze and synthesize datasets	9/30/08	$30,626.08	Completed
3. Prepare and publish meta-analysis; prepare and submit final report	6/30/09	$2,000	Completed

Completion Date: June 2009

Final Report Summary:

Introduction

Relatively few evaluations of bird communities, terrestrial vegetation, aquatic macroinvertebrate and fish communities have been published in peer-reviewed literature that detail the effect of varying RBA after timber harvesting in RMZs. This study evaluates data from two experiments in northern Minnesota, comparing the response of these riparian communities to partially harvested RMZs and riparian control plots for three years following harvest. The primary objectives were to: 1) evaluate the effectiveness of partial harvesting within the RMZ at mitigating disturbances to aquatic macroinvertebrate and fish communities; 2) identify similarities or differences in responses between invertebrate and fish communities, 3) examine the response of the avian community to different levels of RBA following harvest, and 4) identify the vegetative components affecting the avian community response after harvest.

Methods

Each experiment (single-basin and multiple-basin experiment) included one-year of pre-harvest data and three years of post-harvest data. In both experiments, the stream in each plot was divided into three reaches: upstream, within, and downstream of treatment to assess the aquatic communities. For the purpose of this study, only the within reach was used in the analysis. Initial analyses indicated few differences among reaches at a plot (Atuke, 2008; Hemstad et al., 2008), so the within-plot location was viewed as representative of the plot.

Aquatic macroinvertebrates

In the single-basin experiment plots, invertebrate samples were taken mid-summer (late July or early August) in each year at random locations within two consecutive riffles using a $0.1 m^2$ Waters-Knapp Hess sampler in the within-plot location. Invertebrate samples from the single-basin experiment plots were preserved in 95% ethanol and returned to the laboratory, where they were identified to the lowest practical taxon, typically genus (Merritt and Cummins, 1996). In the multiple-basin experiment plots, macroinvertebrates were sampled mid-summer (late July or early August) using a 30.4-cm wide kicknet with 500 µm mesh. Sampling started downstream of the plot and moved upstream to avoid impacting subsequent samples. Samples were collected after every 2.5 m of stream channel length for a total of 20 sampling points per 50-m reach length. Generally, two leg kicks were made per sampling point and all habitats available in the reach were sampled. Invertebrate samples from the multiple-basin experiment plots were preserved in 80% ethanol and returned to the laboratory where they were identified to the lowest practical taxon, typically genus.

Fish

In the single-basin experiment plots, fish were sampled in August with a Wisconsin™ Abp-3 pulsed DC backpack electrofisher (Engineering Technical Services). At each site, fish were collected from a 50-m reach within the treatment plot with a single pass. Fish were identified to species and returned to the stream. In the multiple-basin experiment plots, fish were sampled once a year (August) with the backpack electrofisher. Fish were collected from a 100-m reach with a single pass. Fish were identified to species and returned to the stream. The number of fish per sample was standardized by 50-m reach of the stream ($n \cdot 50\ m^{-1}$). Further detailed descriptions of fish collection methods can be found in Atuke (2008) for the multiple-basin experiment.

Birds

Before- and after-harvest data on breeding birds were collected using standardized methods in seven riparian study areas (multiple-basin experiment) in northern Minnesota during 2003 (pre-harvest) and 2004-2006 (post-harvest). One transect was established on both the treatment and control riparian management zone plots running parallel to the stream, and centered midway between the stream and the adjacent upland clearcut edge. Bird surveys were conducted at each site once during each of the three breeding season months (May-June-July) within 4 hours of sunrise during favorable weather conditions (no rain, and winds <20 kph). Breeding birds were sampled using standard point counts along transects within the RMZs (Hanowski et al. 1990). Only those birds detected within the RMZ were recorded and analyzed. Surveys were completed by experienced observers who passed both a bird identification test and hearing test, and received training to standardize counts (Hanowski and Niemi 1995).

Terrestrial data
Terrestrial data for each site in the multiple-basin experiment was obtained from Olszewski (2009). The data included understory woody biomass (W_{bio}), herbaceous biomass (H_{bio}), and tree basal area (T_{ba}). Above ground biomass for each structural layer was obtained by either destructive sampling (herbaceous and woody regeneration layers) or by the use of published allometric biomass equations (trees and shrubs) from study areas with similar species composition in Minnesota (see list of references in Kastendick [2005]). Biomass samples of herbaceous and woody regeneration less than 0.76 m tall were collected using destructive sampling techniques in two subplots, (0.61 by 0.61 m each) adjacent to the regeneration plots. Vegetation was clipped at the time of peak standing crop biomass, separated, and oven-dried at 70º C to a constant weight. Total basal area was calculated for all tree species > 12.7 cm dbh. There were a total of 56 samples that included both vegetation and avian community data. Further detail on the vegetation data collection methods can be found in Kastendick (2005) and Olszewski (2009). Vegetation data was not collected in 2005 so missing values were estimated by linear interpolation data from one year prior (2004) and one year after (2006).

Analysis
We compared aquatic macroinvertebrate and fish metrics between treatments using mixed models in R using the *nlme* package (Pinheiro et al. 2009) for each experiment separately. For the analysis of aquatic macroinvertebrates, we focused on commonly reported aquatic macroinvertebrate metrics (taxa richness, percent Ephemoptera, Plecoptera, and Trichopetera [EPT], and diversity [Shannon H']). For the analysis of fish, we focused on commonly-reported metrics (abundance, taxa richness, and diversity). Analyses were separated between experiments because of the different experimental designs that required different blocking protocols. For the single-basin experiment plots, we modeled the community metrics as a function of treatment (TRT) and year since harvest (YearSince) as a covariate. In this analysis, we blocked by stream, which was included as a random effect. In the multiple-basin experiment, the main effects were identical to the single-basin experiment but each treatment was nested by site (a random effect). We assessed significance of all analyses at • = 0.05 but assumed weak evidence at • = 0.10.

We examined the response of avian abundance, avian diversity (Shannon H'), species richness, community composition, mature forest species (total abundance) and early successional species (total abundance). We modeled site means with reduced maximum likelihood (REML). The main effects in these models were treatment (riparian control [RC], a "medium" level of residual basal area [MED RBA], and a low level of residual basal area [LOW RBA]), year (YEAR) since harvest, and intercept, which was included as a random factor. The repeated measure was treatment nested within site. We also tested for a treatment by year interaction, where a significant interaction would indicate an effect of the RMZ, and tested for the simple effects of year on each harvest level (SAS; SLICE option). We assessed significance of all analyses at • = 0.05 but assumed weak evidence at • = 0.10.

Results

Aquatic macroinvertebrate community following timber harvesting

Individual macroinvertebrate metrics displayed variable responses to treatment and temporal effects in the two experiments. We observed a general decline in the invertebrate taxa diversity throughout the single-basin experiment (Figure 4.1), but we did not observe significant ($P > 0.05$) treatment effects (Table 4.1). Likewise, in the multiple-basin experiment, we did not observe significant treatment effect on invertebrate diversity ($P > 0.05$) for all treatments, as the invertebrate diversity increased after harvest (Figure 4.1). Invertebrate richness in the single-basin experiment displayed a marginally significant temporal effect ($P = 0.067$), whereas in the multiple-basin experiment displayed a significant temporal effect ($P < 0.001$) as the number of taxa increased immediately following harvest. After the initial post-harvest increase in invertebrate richness observed in both experiments, there was a general decline in taxa richness in the single-basin experiment, whereas invertebrate richness in the RC and MED RBA treatments continued to increase in the multiple-basin experiment. However, taxa richness declined in the LOW RBA treatment (Figure 4.1).

Fish community following timber harvesting

As with the invertebrate metrics, fish metrics indicated a variable response to treatment and temporal effects. Fish diversity and richness tended to increase following harvest in both experiments ($P < 0.05$) (Table 4.2; Figure 4.2). Catch per 50 m indicated a significant treatment-by-year effect in the single-basin experiment (Table 2). Catch per 50 m increased two years after harvest in the multiple-basin experiment (Figure 4.2), reflecting the significant temporal effect (Table 4.2).

Bird community composition following timber harvesting

Mean avian abundance (± SE) was from 25.2 ± 5.7 birds in the riparian control plots, 20.4 ± 4.2 in the MED RBA treatment sites, and 19.8 ± 3.5 in the LOW RBA treatment sites (Figure 3) prior to harvest. There were no indications of significant treatment ($F_{2,11} = 0.64$, $P = 0.55$), temporal ($F_{3,33} = 1.75$, $P = 0.18$), or associated interaction ($F_{6,33} = 1.27$, $P = 0.30$) effects on species richness (Table 4.3). Likewise, mean species richness ranged from 10.8 - 11.8 in the riparian control sites, from 9.8 – 11.8 in the MED RBA treatment sites, and 9.5 – 11.5 in the LOW RBA treatment sites (Figure 4.3). There were no indications of significant treatment ($F_{2,11} = 0.51$, $P = 0.61$), temporal ($F_{3,33} = 0.62$, $P = 0.61$), or associated interaction ($F_{6,33} = 0.64$, $P = 0.70$) effects on species richness. In addition, mean species diversity did not indicate significant treatment ($F_{2,11} = 0.74$, $P = 0.50$), temporal ($F_{3,33} = 0.82$, $P = 0.49$), or associated interaction ($F_{6,33} = 1.08$, $P = 0.39$) effects.

There was a significant response of the avian community to harvesting in the RMZ. The environmental variables accounted for 15.6% of the variation in the avian community data set. The significant environmental variables were log woody biomass (• = 0.05, $P < 0.01$), log herbaceous biomass (• = 0.03, $P < 0.01$), and log tree basal area (• = 0.02 $P < 0.01$). Partitioning the variance into understory (woody biomass and herbaceous biomass) and overstory biomass (tree basal area) components indicated that the understory component explained 48.1% ($P < 0.01$) of the constrained variation and the overstory component explained 32.5% ($P < 0.01$) of the constrained variation. Variation that could not be effectively portioned as either understory or overstory components was 19.4%.

The first RDA axis (RDA1) was correlated with decreased log transformed tree basal area (r = -0.82) and positively associated with woody biomass (r = 0.88) and herbaceous biomass (r = 0.79) (Figure 4.4). Hence, RDA1 was closely associated with harvested RMZs. The five avian species most associated with this axis (positive RDA1 values; decreasing strength of association [i.e., correlation]) were White-throated Sparrow (*Zonotrichia albicollis*) (r = 0.60), Chestnut-sided Warbler (*Dendroica pensylvanica*) (r = 0.54), Mourning Warbler (*Oporornis philadelphia*) (r = 0.42), Veery (*Catharus fuscescens*) (r = 0.29), and White-breasted Nuthatch (*Sitta carolinensis*) (r = 0.18). Alternatively, the five avian species most negatively associated with this axis (negative RDA1 values; decreasing strength of association) were Ovenbird (*Seiurus aurocapillus*) (r = -0.50), Black-throated Green Warbler (*Dendroica virens*) (r = -0.50), Red-eyed Vireo (*Vireo olivaceus*) (r = -0.28), Nashville Warbler (*Verivora ruficapilla*) (r = -0.21), and Red-breasted Nuthatch (*Sitta canadensis*) (r = -0.19).

The second RDA axis (RDA2) was primarily associated with increased herbaceous biomass (r = 0.51) but also increased tree basal area (r = 0.54). Avian species associated with this axis (positive axis 2 values; decreasing strength of association) were White-breasted Nuthatch (r = 0.43), Ovenbird (r = 0.39), American Redstart (*Setophaga ruticilla*) (r = 0.39), Red-eyed Vireo (r = 0.37), and Chestnut-sided Warbler (r = 0.30). Alternatively, the five avian species most negatively associated with this axis (negative RDA2 values; decreasing strength of association) were White-throated Sparrow (r = -0.25), Black-throated Green Warbler (r = -0.23), American Robin (*Turdus migratorius*) (r = -0.21), Northern Flicker (*Colaptes auratus*) (r = -0.18), and Ruby-throated Hummingbird (*Archilochus colubris*) (r = -0.15).

Treatment and site-specific avian community changes were apparent following harvest (Figure 4.4). Riparian control sites displayed temporal changes but there was little pattern in the community changes over the period of the study. Alternatively, we did observe changes in the vegetative community following harvest. Following harvest, there was a marked decrease in basal area and a general increase in the amount of woody biomass. With the increase in woody biomass, the avian communities shifted toward an association with early successional species (White-throated sparrow and Chestnut-sided Warbler). One MED RBA treatment and one LOW RBA treatment indicated a shift toward increased herbaceous biomass and greater association with the Chestnut-sided Warbler.

Discussion and conclusions

Macroinvertebrate and fish communities

Stream fish communities, as with macroinvertebrates communities, typically display large temporal variation, depending on the scale observed (Lohr and Fausch, 1997). Because lotic systems are open systems, stream fishes are subjected to many temporally changing factors that can influence their community dynamics, such as weather, migration, variation in competition (Oberdorff et al., 2001), or instream habitat cover and refugia (Pusey et al., 1993). Community stability often depends on the physical and temporal stability of habitats and on the interactions between the species in the community (Collins, 2000). In our analysis, we observed a strong temporal effect on diversity and species richness of the fish communities in the single-basin experiment but less so in the multiple-basin experiment. Interestingly, temporal variation was observed on instream habitat variables in the single-basin experiment (Hemstad et al., 2008) and in the multiple-basin experiment (Atuke, 2008). There are two explanations for this difference in the extent of temporal variation. The greater temporal variation in the single-basin experiment could be an artifact of the differences in the spatial extent between the two experiments, where the variability of any single stream would likely be minimized from the other sites across the large spatial extent. Another possible explanation for the high temporal variation of instream habitat in the single-basin experiment is that it may be a more dynamic and disturbed watershed than the multiple-basin plots. The history of logging within the two experiments was similar. The multi-basin experiment consisted of even-aged stands originating after an initial cutover 60-70 years ago and the single-basin experiment consisted of even aged stand originating 70-80 years ago (B. Palik, unpubl. data). The single-basin experiment streams were not as wide on average as in the multiple-basin experiment, potentially making these smaller streams more susceptible to disturbance (Gomi et al., 2002). Initial macroinvertebrate richness, diversity, and abundance in the single-basin experiment were much less than observed in the pre-harvest collection in the multiple-basin experiment.

The inherent variation observed in stream communities poses a significant challenge for resource managers, because this variation makes detection of anthropogenic disturbances difficult (Grossman et al., 1990). Regardless of the temporal variation in the fish communities in these experiments, we were able to detect some changes in the communities as a result of the partially harvested RMZs. In both experiments, fish community turnover in the medium RBA treatment was the greatest as brook sticklebacks and central mudminnows, two relatively tolerant fish species, increased. Interestingly, the low RBA treatment in the multiple-basin experiment had lower community turnover than the RC. The RAC for low RBA treatments indicated that the change in communities was primarily due to the increase in abundance of brook stickleback, whereas the relative ranking of the fish in the less common species changed. Increases in the slope of the RAC following harvest suggests that the fish community became more dominated by a single species one year after harvest, but resembled pre-harvest community rankings three years after harvest. In addition, measures of diversity and richness did not indicate significant treatment effects. The lack of significant responses to treatments by the fish communities indicated that the presence of partially harvested RMZs did not result in large changes in the fish communities.

Bird community

Mature forest species, such as the Ovenbird and Red-eyed Vireo, declined with increasing rates of timber removals from the RMZs, yet continued to be abundant in the riparian control sites. This result is also consistent with other studies (Hanowski et al., 2005; Holmes and Pitt, 2007) that observed similar responses of the mature forest species to timber harvesting. The Ovenbird, a species that we observed to have a significant decline following harvest in all treatment plots, is a "species of greatest conservation need" in the Minnesota Department of Natural Resources' Comprehensive Wildlife Conservation Plan (Minnesota Department of Natural Resources, 2006). The Ovenbird is dependent on mature forests and forest interior habitat and thus, very sensitive to timber harvesting (Lambert and Hannon, 2000; Manolis et al., 2002). Bourque and Villard (2001) observed not only lower densities of Ovenbirds in selection cuts than in uncut plots, but also significantly lower reproductive performance of Ovenbirds. Bourque and Villard (2001) suggested that the effects of selection cutting (i.e., removal of approximately 30% of the basal area) on demography are species-specific and that Ovenbird persistence in selection cuts may be compromised unless the intensity (i.e., degree to which basal area is reduced) is decreased or frequency (i.e., time between harvest) of cutting is maximized. The decline of mature forest species in the partially harvested treatments indicates that maintaining an unharvested riparian buffer adjacent to an upland harvest may aid in maintaining abundance of "species of greatest conservation need" in northern Minnesota.

The response of the avian community within the MED RBA treatment differed little from the avian community within the riparian control plots, both of which indicated striking differences to the LOW RBA treatments. In an analysis of the vegetation response in these experimental treatments, Kastendick (2005) observed that regeneration layer biomass increased with increasing harvest intensity, resulting in clearcut uplands and LOW RBA treatment biomasses that were more than double those of MED RBA or riparian control treatments. He noted that there was a rapid response after harvest of early-seral, shade-intolerant species in both the shrub and woody regenerations layers in the RMZ. Multivariate analysis of our sites in the RDA, indicated the same response of a movement from greater influence of tree basal area to that dominated by woody biomass, of which the LOW RBA treatments appeared to indicate the greatest change. The connection of avian communities to the vegetation structure is well-established (DeGraaf et al., 1998; Sanders and Edge, 1998; Pey-Yi and Rotenberry, 2005) and is one of the unifying theories in avian biology (Block and Brennan, 1993). This analysis suggests that maintaining a basal area • 11.5 m2/ha may have retained enough overstory vegetation and minimized the increase in understory woody biomass to mitigate the significant changes in the avian community that were observed in the LOW RBA treatments, although the decrease in Ovenbird numbers was still evident.

Management implications

Overall, our analyses suggest that timber harvesting on both sides of the stream that leaves RBA • 12.4 ± 1.3 m2• ha-1 along reaches • 200 m in length or timber harvesting that retains RBA • 8.7 ± 1.6 m2• ha-1 on a single side of the stream may be adequate to protect instream habitat and invertebrate and fish communities. The large temporal variation observed in the instream habitat and invertebrate and fish communities were typical of these systems, but could have confounded treatments effects (Grossman et al., 1990). This difficulty may have been influenced by only having one year pre-harvest data for both sites. While studies that only include one year pre-harvest data in the published literature are common (e.g., Wang et al. 2006; Wilkerson et al., 2006, de Graaf et al. 2008), we attempted to overcome this limitation by examining across a larger spatial extent. The large number of plots included in our study and the relative consistency of our analysis suggest that the treatment effects were minimal. However, the relatively small size of our treatment plots and short lengths of stream reach harvested (although the sizes of harvest blocks are typical for the region) may have limited the impacts of harvest as compared to what has been observed in larger harvest treatments (Barton et al., 1985; Carroll et al., 2004). For example, Carroll et al. (2004) observed significant increases in stream water temperatures where timber harvesting occurred on both sides of the stream although there were no significant changes in stream temperature observed where harvesting occurred on a single side. Further studies that examine the effect of partially harvested RMZ on low-gradient stream systems should consider the effects of larger harvested plots and harvest along longer reaches and include multiple years of pre-harvest data to identify the natural temporal variation observed in the communities. Finally, although the invertebrate and fish communities appeared to return to pre-harvest conditions within three years post-harvest, a longer term assessment of the dynamics of partially harvested RMZs should be undertaken.

The changes in the avian community following timber harvesting within RMZs differed from the macroinvertebrate and fish communities. The choice of taxa is an important question in assessing the effects of timber harvesting in riparian communities (Lindenmayer, 1999; Lindenmayer et al., 2000), and can lead to differing and sometimes conflicting results accenting the different needs of the groups. For example, windthrow can recruit trees into the stream channel to provide a variety of ecosystem functions, such as high quality aquatic habitat for fish and macroinvertebrates (Hemstad et al., 2008). Alternatively, increased windthrow from management practices decreases the amount of habitat for bird species requiring mature forest stands. The difference in the response of the aquatic and terrestrial communities in this study highlights the need to assess multiple taxa communities when trying to understand the effects on organisms within riparian ecosystem communities.

Overall, breeding bird species management should occur at a landscape scale, attempting to provide a maximum level of forest stand types to provide habitat for breeding bird species across a broad geographic scale. At the stand-level, management decisions should not overlook the impacts of windthrow. However, simply leaving an unharvested buffer is not always the best solution. Thinning an RMZ adjacent to clearcut uplands may make trees in the RMZs more susceptible to windthrow (Ruel, 2000; Ruel, Pin & Cooper, 2001) and influence the structure of the mature forest stands and hence, mature forest bird species. The decision about how to design an RMZ to minimize windthrow should consider management objectives as well as stand and site conditions for the area. Items to consider include, but are not limited to 1) development of a site inventory to assess stand and site conditions for windthrow hazards; 2) minimization of potential hazards such as high topographic exposure, soil conditions that create weak or shallow rooting patterns, and prevailing wind direction; 3) providing a wider RMZ, reserve more windfirm species, and a gradual increase in residual basal area as you approach the water's edge (i.e., feather the cut edge) where windthrow hazards exist; and 4) reserving super-canopy trees that have become acclimated to wind. Susceptible species such as balsam fir, white spruce, black spruce, and aspen should be considered first for removal near the RMZ edge adjacent to the clearcut.

To truly understand the effect of forest timber harvest in the RMZ on these communities it is essential that continued monitoring of these experimental sites continues. Hanowski et al. (2007) indicated that breeding bird communities only began to resemble pre-harvest conditions 10 years following harvest. It is likely that such a time frame would be required in the multiple-basin experiment to observe these communal shifts.

Result expenditures

Funds in the amount of $866.78, $1.18, and $1,805.96 were shifted from Result 4 to get the Result 2a, Result 3 and Result 5 budgets, respectively, to a zero balance.

Unanticipated and unresolved problems

The procedures used to meet the objectives of this Result were adequate and sufficient. There were no unresolved problems relative to this Result. All work was completed as planned.

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Table 4.1. Fixed effects from mixed model analyses on invertebrate community metrics for the single- and multiple-basin experiments. Treatment effects within the riparian management zone (RMZ) were riparian control (unharvested RMZ) and medium residual basal area (RBA) for the single-basin experiment and riparian control and low and medium RBA for the multiple-basin experiment. Abundance, total invertebrate abundance; Diversity (H'), Shannon diversity index; Richness (r), total species richness; Percent EPT, percent Ephemeroptera, Plecoptera and Trichoptera (EPT) richness. Abundance, total fish abundance adjusted for effort and distance (50 m^2). All proportions were arcsine square-root transformed and abundance was log(x+1) transformed.

Effect	Parameter	Value	Std.Error	DF	t-value	p-value
	Single-basin experiment (1997 - 2000)					
Abundance	Intercept	4.176	0.458	30	9.116	< 0.001
	TRT-MED	0.672	0.444	30	1.516	0.140
	YearSince	0.464	0.187	30	2.483	0.019
Diversity (H')	Intercept	1.868	0.117	30	16.006	< 0.001
	TRT-MED	0.010	0.113	30	0.086	0.932
	YearSince	-0.147	0.048	30	-3.079	0.004
Richness (r)	Intercept	15.688	1.640	30	9.564	< 0.001
	TRT-MED	1.158	1.464	30	0.791	0.435
	YearSince	-1.089	0.572	30	-1.903	0.067
Percent EPT	Intercept	0.969	0.033	30	29.172	< 0.001
	TRT-MED	-0.031	0.032	30	-0.978	0.336
	YearSince	0.000	0.014	30	-0.019	0.985
	Multiple basin experiment (2003- 2006)					
Abundance	Intercept	5.793	0.075	36	77.129	< 0.001
	TRT-MED	0.147	0.100	5	1.466	0.203
	TRT-LOW	0.052	0.095	5	0.553	0.604
	YearSince	-0.003	0.033	36	-0.107	0.916
Diversity (H')	Intercept	1.423	0.123	36	11.577	< 0.001
	TRT-MED	-0.004	0.139	5	-0.029	0.978
	TRT-LOW	-0.105	0.132	5	-0.794	0.463
	YearSince	0.182	0.046	36	3.910	0.000
Richness (r)	Intercept	16.313	2.011	36	8.111	< 0.001
	TRT-MED	0.460	1.303	5	0.353	0.738
	TRT-LOW	-2.131	1.233	5	-1.728	0.145
	YearSince	1.574	0.413	36	3.810	0.001
Percent EPT	Intercept	0.795	0.020	36	39.745	< 0.001
	TRT-MED	-0.043	0.024	5	-1.798	0.132
	TRT-LOW	0.000	0.022	5	-0.015	0.988
	YearSince	0.020	0.008	36	2.550	0.015

Table 4.2. Fixed effects from mixed model analyses on fish community metrics for the single- and multiple-basin experiments in northern Minnesota following timber harvest. Treatment effects within the riparian management zone (RMZ) were riparian control (unharvested RMZ) and medium residual basal area (RBA) for the single-basin experiment and riparian control and low and medium RBA for the multiple-basin experiment. Abundance, total fish abundance adjusted for effort and distance (50 m); Diversity (H'), Shannon diversity index; and Richness (r), total species richness. Proportions were arcsine square-root transformed and abundance was log(x+1) transformed.

Effect	Parameter	Value	Std.Error	DF	t-value	p-value
		Single-basin experiment (1997 - 2000)				
Abundance	Intercept	-0.140	0.322	40	-0.434	0.666
	TRT-MED	-0.263	0.341	40	-0.771	0.445
	YearSince	-0.153	0.040	40	-3.855	< 0.001
Diversity (H')	Intercept	0.647	0.195	40	3.315	0.002
	TRT-MED	-0.053	0.138	40	-0.388	0.700
	YearSince	-0.018	0.015	40	-1.152	0.256
Richness (r)	Intercept	2.877	0.537	40	5.353	< 0.001
	TRT-MED	-0.168	0.370	40	-0.454	0.653
	YearSince	-0.082	0.041	40	-1.991	0.053
		Multiple-basin experiment (2003- 2006)				
Abundance	Intercept	-0.278	0.242	35	-1.149	0.258
	TRT-MED	0.034	0.304	5	0.112	0.915
	TRT-LOW	-0.112	0.289	5	-0.388	0.714
	YearSince	0.301	0.108	35	2.773	0.009
Diversity (H')	Intercept	1.036	0.167	35	6.219	< 0.001
	TRT-MED	-0.308	0.140	5	-2.203	0.079
	TRT-LOW	-0.205	0.135	5	-1.520	0.189
	YearSince	0.112	0.045	35	2.468	0.019
Richness (r)	Intercept	5.095	0.840	35	6.067	< 0.001
	TRT-MED	-0.913	0.648	5	-1.410	0.218
	TRT-LOW	-0.777	0.625	5	-1.243	0.269
	YearSince	0.463	0.208	35	2.224	0.033

Table 4.3. Results of the repeated measures ANOVA. "H" =Shannon diversity index); Richness= total species richness; Abundance= log transformed abundance; %Mature= proportional abundance of species within the mature forest habitat guild; and %Early= proportional abundance of species within the early successional habitat. F-value (*P*-value). NDF are the numerator degrees of freedom and DDF are the denominator degrees of freedom. Values in **bold** indicate a significant (*P* < 0.05) effect.

Effect	NDF	DDF	H	Richness	Abundance	% Mature	%Early
Treatment	2	11	0.74 (0.501)	0.51 (0.612)	0.64 (0.547)	**5.55 (0.022)**	3.11 (0.085)
Year	3	33	0.82 (0.494)	0.62 (0.605)	1.75 (0.176)	**11.19 (<0.001)**	**7.19 (<0.001)**
Treatment x year	6	33	1.08 (0.394)	0.64 (0.699)	1.27 (0.297)	1.47 (0.220)	0.28 (0.743)

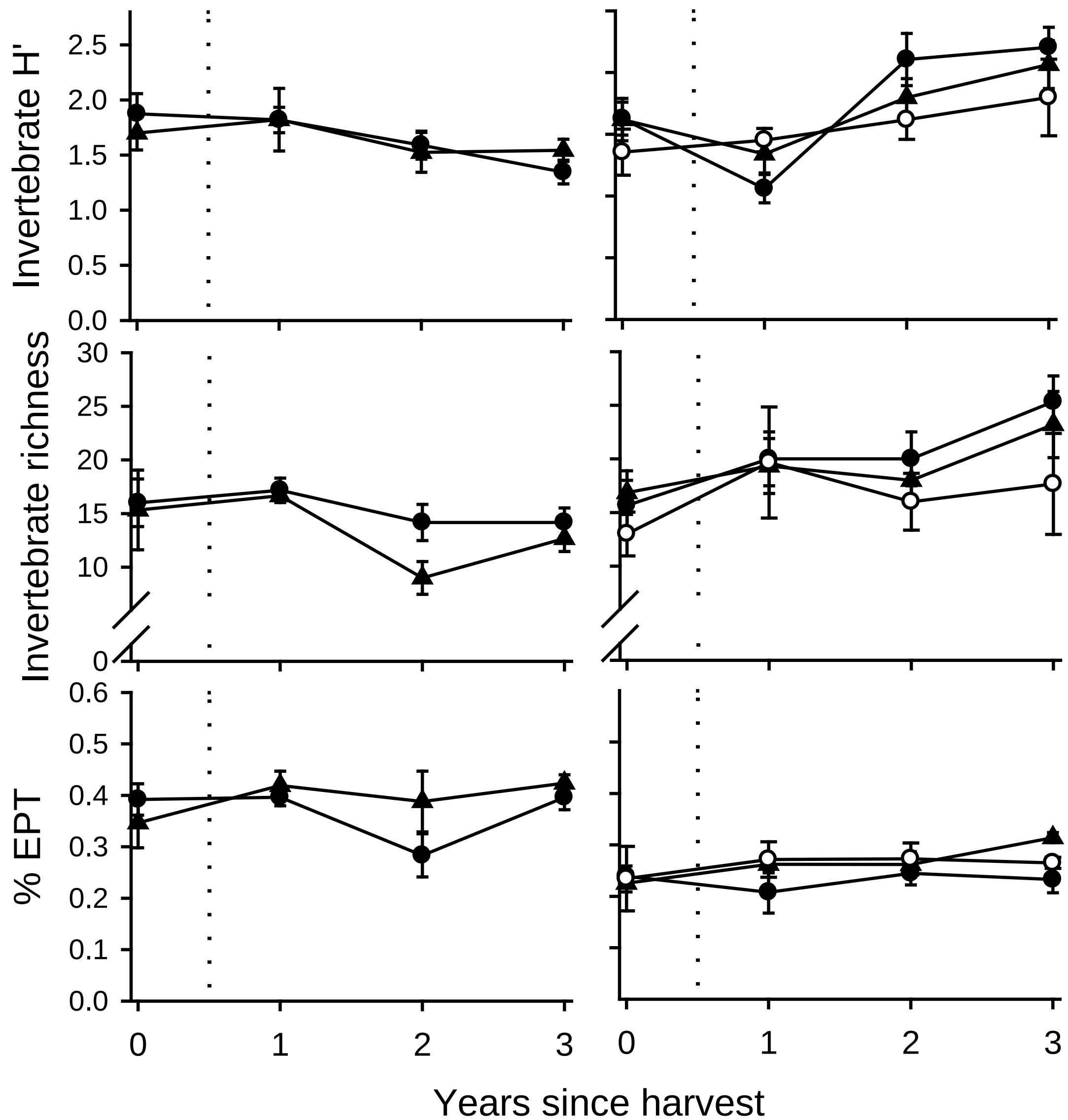

Figure 4.1. Mean (± standard error) invertebrate metrics (diversity, richness, and % EPT) in the single- (left column) and multiple-basin (right column) experiments following harvest in the riparian management zones. Triangles, riparian control; closed circle, medium residual basal area (RBA) treatment; and open circle, low RBA treatment.

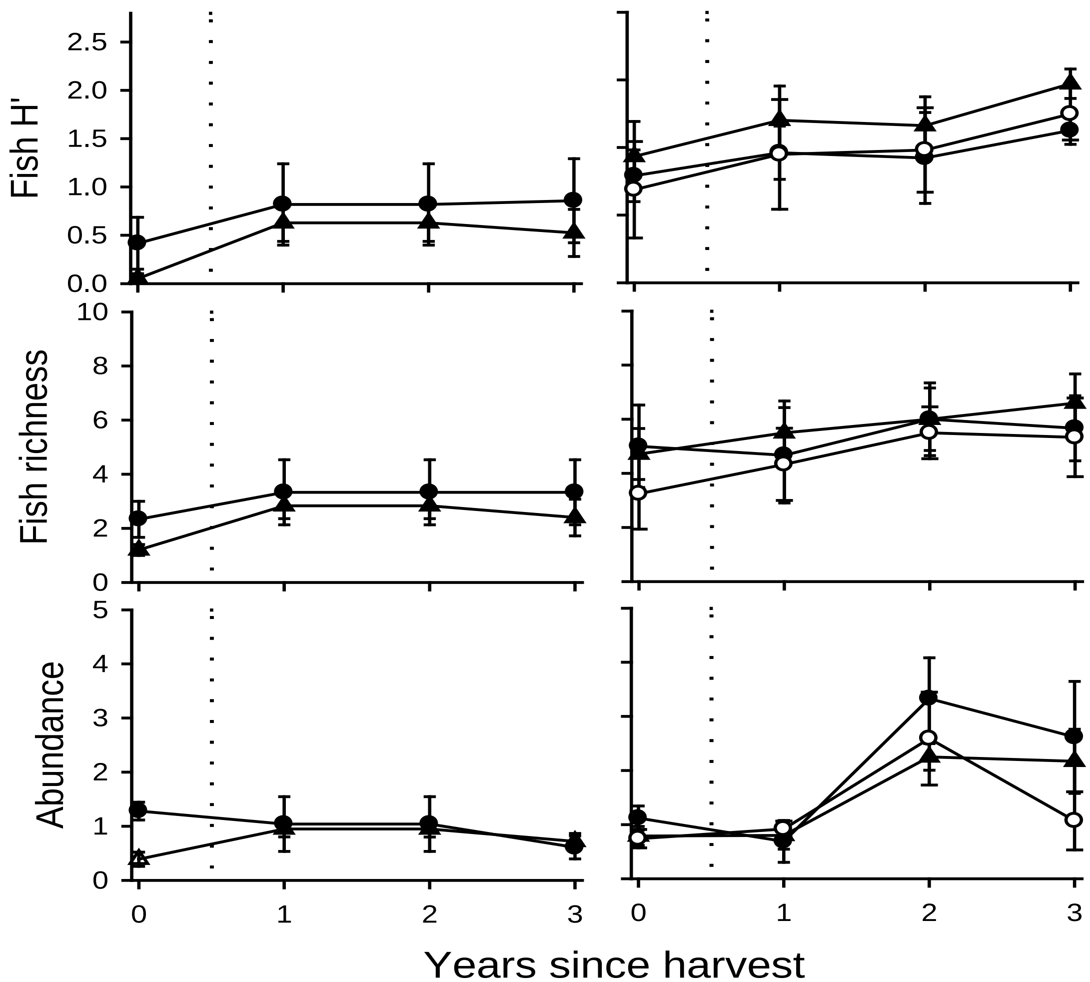

Figure 4.2. Mean (± standard error) fish metrics (diversity, richness, and catch per 50 m in the single- (left column) and multiple-basin (right column) experiments after harvest in the riparian management zones. Triangles, riparian control; closed circle, medium residual basal area (RBA) treatment; and open circle, low RBA treatment.

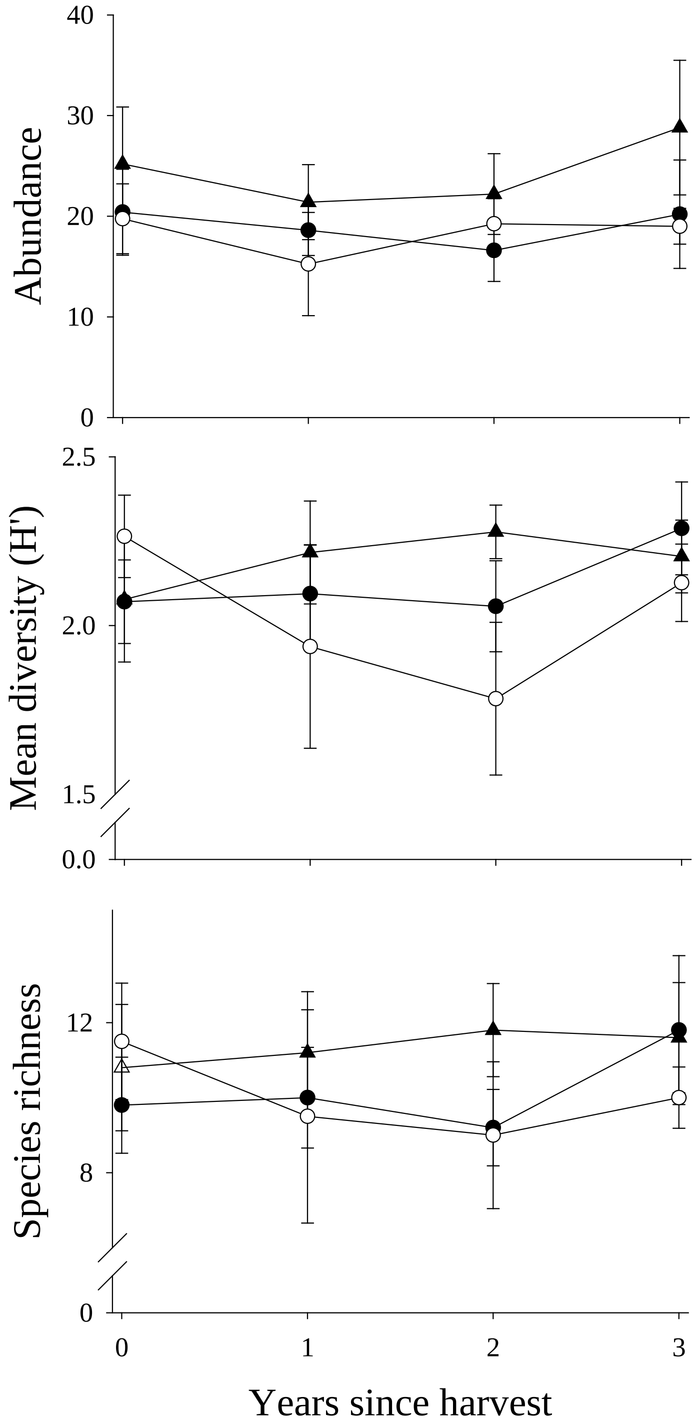

Figure 4.3. Mean (± standard error) abundance, Shannon diversity index (H'), and species richness for birds in experimental plots in northern Minnesota. The riparian control = triangles, medium residual basal area (RBA) treatment = closed circles, and low RBA treatment = open circles.

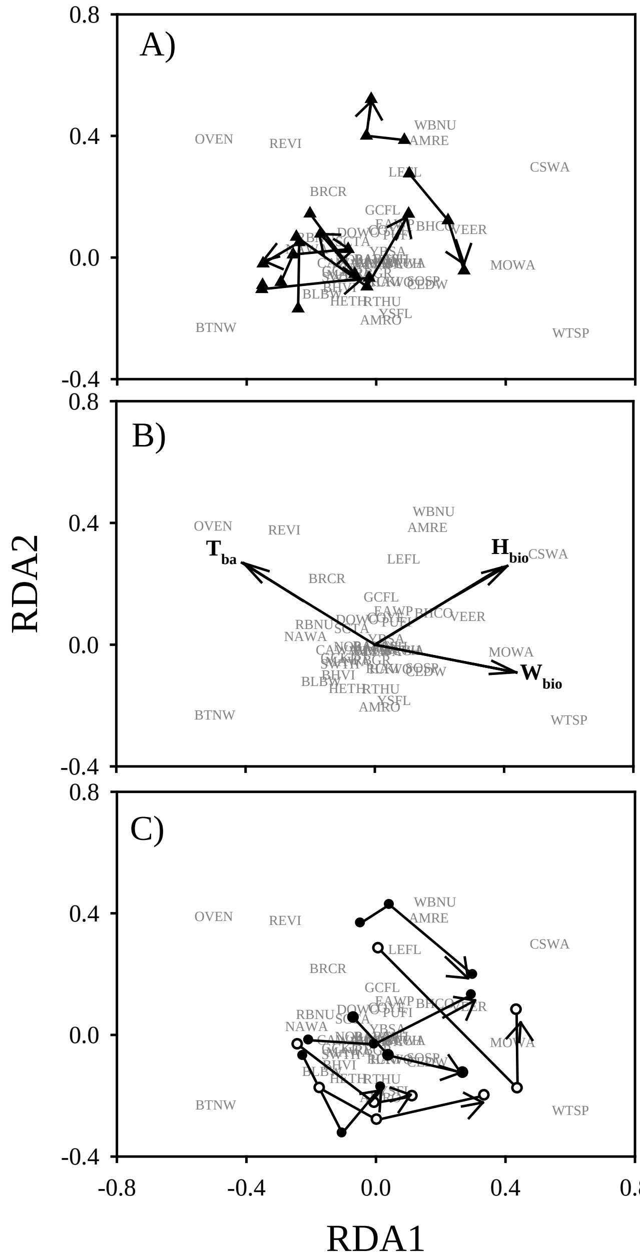

Figure 4.4. Ordination plot of the redundancy analysis (RDA) showing the first and second axis. Lines connect the sequential plots through time and arrows indicate the direction of change. Four letter avian abbreviations can be found in Appendix A. A) Riparian control sites in years 2003 (pre-harvest), 2004, and 2006 (3 years post-harvest). B) Significant vegetation factors: Hbio = log transformed herbaceous biomass, Wbio = log transformed woody biomass and Tba = log transformed tree basal area. C) Medium basal area treatment (closed circle) and low basal area treatment (open circle) in years 2003, 2004, and 2006.

Result 5: Outreach riparian research information

Description: We conducted three one-day workshops for natural resource professionals to present information from our research as well key findings from the Minnesota Forest Resource Council's Riparian Science Technical Committee process. Each workshop included indoor and on-site components. A website was developed. Data and photographs were processed to facilitate communication and additional analyses in the future.

Summary Budget Information for Result 5: **Trust Fund Budget: $9,911.96**
Amount Spent: $9,911.96
Balance: $ 0.00

Deliverable	Completion date	Budget	Status
1. Develop and promote workshop agenda	6/30/08	$5,000	Completed
2. Conduct two workshops and create project website	10/31/08	$2,106	Completed
3. Process data and photographs. Prepare and submit final report	6/30/09	$2,805.96	Completed

Completion Date: June 2009

Final Report Summary:

Introduction

A variety of data has been collected and analyzed from the two study areas (single- and multiple-basin study sites) since their inception. In addition, the Minnesota Forest Resource Council's Riparian Science Technical Committee synthesized relevant literature to provide unbiased scientific information about riparian areas and timber management practices necessary to protect riparian functions on the site level. Field managers need updated information about management within forested riparian management zones to provide appropriate protection during management activities.

Results

A one-day workshop entitled "At the Water's Edge: Current State of Riparian Forest Management Research in Minnesota" was presented in Grand Rapids on May 20, 21, and 22, 2008. The purpose of the workshop was to interpret research results from the single- and multiple-basin riparian effectiveness monitoring studies as well as the Minnesota Forest Resource Council's Riparian Science Technical Committee findings for natural resource managers and loggers. The program included both indoor and outdoor components. There were 102 participants over the course of the three days. Overall, participants indicated that they learned a bit more than they expected to learn. Both the indoor and outdoor components received positive reviews.

A website was developed to provide information about the project, including a project overview, more detailed descriptions of our research, information about project personnel, a listing of project cooperators, project publications, and information presented during our workshop. The url for that website is http://rmzharvest.cfans.umn.edu/. A second website was created to allow project researchers to access data (http://rmzharvest.cfans.umn.edu/login).

To facilitate better communication with outside individuals and researchers within the project, all available data was entered electronically, data codes and spreadsheet formatting were made consistent across all the data files from all the disciplines, and thoroughly error checked. In addition, meta-data were created for all the data files that described who collected the data and explained all codes used in the data file. Finally, all photographs from the sites were catalogued to describe the subject of the photo, who, when and where the photo was taken. Each image was edited to allow easier upload to the website. These files and photos were added to the website to enhance its utility for project researchers and to allow for easier dissemination of the information.

Result expenditures

Funds in the amount of $1,805.96 were shifted from Result 4 to get the Result 5 budget to a zero balance.

Unanticipated and unresolved problems

The procedures used to meet the objectives of this Result were adequate and sufficient. There were no unresolved problems relative to this Result. All work was completed as planned.

V. TOTAL TRUST FUND PROJECT BUDGET

Staff or Contract Services: $336,772 One post-doctoral research associate (1 FTE for 1 year), graduate students (0.5 FTE for 16 months), four undergraduate research assistants (6 weeks during 2 summers for three individuals and 12 weeks during one Spring Semester for one individual) were employed by the University of Minnesota. Two technicians (1 FTE for 1 year and 1 FTE for 2 years) and two undergraduate research assistants (0.4 FTE for 1 year) were employed by the US Forest Service because that is the most cost-effective approach and our need to have personnel dedicated to this research study who are located close to the field sites. Three technicians (1.5 FTE for 1 year) were employed through the US Forest Service to assist with sample processing.

Equipment: $26,659 Digital clinometer ($1,000), miscellaneous expendable supplies (including flagging, paint, binoculars, tree tags, field notebooks and paper, pens, ethanol, sampling bottles, sampling nets, GPS receiver, chemicals for water quality assessment, replacement temperature loggers, and batteries – $25,059), computer software for data analysis ($600).

Development: $0

Restoration: $0

Acquisition, including easements: $0

Other: $36,569 Lodging/per diem/mileage ($13,104), vehicle rental with mileage ($21,500), bus rental for workshops ($365), publication page charges ($1,600).

TOTAL TRUST FUND PROJECT BUDGET: $400,000

Explanation of Capital Expenditures Greater than $3,500: N/A

V. OTHER FUNDS & PARTNERS

A. Project Partners

Project team members from the University of Minnesota and US Geological Survey (USGS) who contributed time and effort to the project are Gerald Niemi (received $5,570 from the request); Ray Newman and Bruce Vondracek (USGS) (received $40,965 from the request); and Charlie Blinn (received $80,938 from the request). Randy Kolka and Susan Eggert (received $134,231 from the request through a subcontract with University of Minnesota) and Brian Palik (received $138,296 from the request through a subcontract with University of Minnesota) from the US Forest Service contributed $144,000 worth of time, effort, and equipment to the project. The Minnesota Department of Natural Resources, St. Louis County Land Department, Lake County Land Department, and Blandin UPM-Kymmene cooperated by providing their lands for study treatments. Dr. Casey Huckins, Department of Biological Sciences, Michigan Technological University, Houghton, MI and Dr. Jacques Finlay, Department of Ecology, Evolution and Behavior, University of Minnesota, St. Paul, MN assisted with Result 2b.

B. Other Funds being Spent during the Project Period

Project partners solicited additional funds from outside sources during the biennium. The US Forest Service and Minnesota Forest Resources Council each committed $10,000 to Result 3. In-kind support of $144,000 was provided from the US Forest Service. Workshop income ($2,100) was used to defray expenses for catering and photocopying.

C. Past Spending

The LCMR provided $333,000 during the 2005 biennium to collect 2- and 3-year post-harvest data from the multiple-basin watersheds. The US Forest Service provided $75,000 worth of time and effort to the project and $80,400 to partially fund graduate research assistants. The National Council for Air and Stream Improvement provided $60,000 and the Minnesota Department of Natural Resources Section of Fisheries provided $18,000 in support of data collection and analysis at Pokegama Creek (single-basin location).

D. Time
It is anticipated that the entire project will be completed in 2013. The post-harvest assessment would continue through 2011 with increasing focus on longer-term data collection, analysis, reporting, and dissemination of study results. Additional funds would be requested from LCCMR in future biennia. Throughout the entire project, additional monies to support this research will be solicited from other sources. Results will provide information that is critical to ongoing revisions of the MFRC's riparian guidelines.

VII. **DISSEMINATION:**

Presentations
Blinn, C. R. May 20, 21 and 22, 2008. What is a riparian area and why are they important? At the water's edge: Current state of riparian forest management research in Minnesota. Conference for general public. Grand Rapids, MN.

Chizinski, C. J., D. Atuke, N. Hemstad, E. Merten, B. Vondracek, R.M.Newman, and C. Blinn. August 7, 2008. Effects of riparian forest harvesting on the aquatic ecosystem in northern Minnesota streams. Milwaukee, WI. 93rd Annual Meeting of the Ecological Society of America.

Chizinski, C. J., A. C. Peterson, and C. R, Blinn. December 17, 2008. The influence of riparian buffers on bird, aquatic invertebrate, and fish assemblages. 69th Midwest Fish and Wildlife Conference, Columbus, Ohio.

Eggert, S .L. 2007. Stream ecosystem response to a changing environment. Natural Resources Research Institute, University of Minnesota, Duluth, MN.

Eggert, S. L. 2008. The stream and its valley: Small streams as integrators of the landscape. Michigan Technological University, Houghton, MI.

Eggert, S. L., B. Palik, D. Kastendick, J. Kragthorpe, R.K. Kolka, and J.N. Baldauf. 2009. Organic matter inputs to northern Minnesota headwater streams following riparian timber harvesting. North American Benthological Society Meeting, Grand Rapids, MI.

Kolka, R. May 20, 21 and 22, 2008. Overview of effectiveness monitoring studies. At the water's edge: Current state of riparian forest management research in Minnesota. Grand Rapids, MN.

Merten, E. C. N. A. Hemstad, R. M. Newman, B. Vondracek, L. B. Johnson, R. K. Kolka, E. S. Verry, and S. L. Eggert. August 7, 2008. Forest harvest effects on a northern Minnesota stream system: A study spanning 11 years. Annual Meeting of the Ecological Society of America, Milwaukee, WI.

Palik, B. J. May 20, 21 and 22, 2008. Evaluating riparian timber harvesting guidelines: Terrestrial vegetation responses. At the water's edge: Current state of riparian forest management research in Minnesota. Conference for general public. Grand Rapids, MN.

Peterson, A. May 20, 21 and 22, 2008. Evaluating riparian timber harvesting guidelines: Wildlife responses. At the water's edge: Current state of riparian forest management research in Minnesota. Conference for general public. Grand Rapids, MN.

Peterson, A. C., C .J. Chizinski, and G. J. Niemi. August 4-9, 2008. Breeding bird community response to harvest in riparian buffers in northern Minnesota, USA. 126th Meeting of the American Ornithologists' Union. Portland, OR.

Vondracek, B. May 20, 21 and 22, 2008. Evaluating riparian timber harvesting guidelines: Aquatic responses. At the water's edge: Current state of riparian forest management research in Minnesota. Conference for general public. Grand Rapids, MN.

Vondracek, B. and S. Eggert. May 20, 21 and 22, 2008. Aquatic system response to harvesting in northern Minnesota riparian management zones. At the water's edge: current state of riparian forest management research in Minnesota. Grand Rapids, MN.

Vondracek, B. and S. Eggert. 2007. Northeast Forest Soils Conference. Presentation at the East Beaver River site near Silver Bay, MN.

Publications

Olszewski, S. L. 2009. Structural and compositional changes in the terrestrial vegetation of forested riparian areas as a result of a gradient of timber harvesting regimes. University of Minnesota. M.S. Thesis. 41 p.

Steil, J. C., C. R. Blinn, and R. K. Kolka. 2009. Foresters' perceptions of windthrow dynamics in northern Minnesota riparian management zones. Northern Journal of Applied Forestry. 26(2):76-82.

Manuscripts submitted

Chizinski, C.J., B. Vondracek, C.R. Blinn, R.M. Newman, D. Atuke, K. Fredricks, N. Hemstad, E. Merten, and N. Schlesser. (Submitted 6/25/09). The influence of partial harvest in riparian management zones on macroinvertebrate and fish assemblages on small streams. Forest Ecology and Management

Chizinski, C.J., A. Peterson, C.R. Blinn, G. Niemi, B. Vondracek.(Submitted 6/25/09) Breeding bird response to partially harvested riparian management zones in northern Minnesota. Forest Ecology and Management.

Manuscripts in preparation
Chizinski, C.J., B. Vondracek, C.R. Blinn, Palik, B.J., Ozslewski, S.L., Kastendick, D.N., and Martin, M. Woody regeneration on clearcut and partial-cut riparian management zones. Proposed outlet: Forest Ecology and Management.

Eggert, S. and R. Kolka, B. Vondracek, E. Merten, L. Johnson, R. Newman, K. Fredrick, M. Fox and J. Perry. Long-term effects of riparian timber harvesting on stream function in northern Minnesota. Proposed outlet: Fundamental and Applied Limnology.

Eggert, S, B. Palik, D. Kastendick, J. Kragthorpe, R. Kolka. Organic matter inputs to northern Minnesota aquatic ecosystems following riparian timber harvesting. Proposed outlet: Canadian Journal of Forest Research.

Project website
Information about the research project (project overview, current research, project personnel, cooperators, publications) and the 2008 workshop are available at:
http://rmzharvest.cfans.umn.edu/

Other products
A reference collection of voucher invertebrate specimens has been assembled for the single- and multiple-basin sites. The collection is being maintained by the USDA Forest Service, Northern Research Station, Aquatics Laboratory, Grand Rapids, MN.

Available data have been made available to project personnel through the internal project website (http://rmzharvest.cfans.umn.edu/login).

VI. REPORTING REQUIREMENTS: Periodic workprogram progress reports were submitted in January 2008, July 2008, and January 2009. A final workprogram report and associated products was submitted by August 17, 2009 as requested by the LCCMR.

VII. RESEARCH PROJECTS: N/A

Attachment A: Budget Detail for 2007 Projects

Project Title: *Evaluating Riparian Timber Harvesting Guidelines: Phase 3 5(f)*

Project Manager Name: *Charles R. Blinn*

Trust Fund Appropriation: $ *400,000*

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(date)*	**Balance** *(6/09)*	**Result 2a Budget:**	**Amount Spent** *(date)*	**Balance** *(6/09)*	**Result 2b Budget:**	**Amount Spent** *(date)*	**Balance** *(6/09)*	**Result 3 Budget:**	**Amount Spent** *(date)*	**Balance** *(6/09)*	**Result 4 Budget:**	**Amount Spent** *(date)*	**Balance** (6/09)	**Result 5 Budget:**	**Amount Spent** *(date)*	**Balance** *(6/09)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Evaluate terrestrial impacts			Evaluate long-term effects on fish habitats and communities			Evaluate macroinvertebrates and organic matter dynamics			Evaluate bird impacts			Meta-analysis of terrestrial and aquatic results			Outreach riparian research information				
BUDGET ITEM																				
PERSONNEL: Staff Expenses, wages, salaries and fringe – *Personnel employed through University of Minnesota to collect, process, and report data*	0	0	0	39,372.93	39,372.93	0	0	0	0	5,558.21	5,558.21	0.00	67,641.44	67,641.44	0.00	8,104.91	8,104.91	0	120,677.49	0.00
Contracts																				
Professional/technical *(University of Minnesota subcontract with US Forest Service to collect, process, and report data) (7901)*	138,296	134,971.93	3,324.07	0	0	0	134,231	131,952.67	2,278.33	0	0	0	0	0	0			0	272,527	5,602.40
Printing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other supplies *(list specific categories)*																				
Lab/field supplies (7320)	0	0	0	514.25	514.25	0	0	0	0	11.97	11.97	0	0	0	0	0	0	0	526.22	0
Computer software (7330)	0	0	0	0	0	0	0	0	0	0	0	0	600	545	55	0	0	0	600	55
Courier and mailing services (7340)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel expenses in Minnesota	0	0	0	1,077.60	1,077.60	0	0	0	0	0	0	0	2,784.64	1,937.00	847.64	1,442.25	1,442.25	0	5,304.49	847.64
Other *(Describe the activity and cost) be specific*																				
Sponsored publication costs (7311)**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Postage (7341)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Short-term lease (7702)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	364.80	364.80	0	364.80	0
COLUMN TOTAL	$138,296	$134,971.93	$3,324.07	$40,964.78	$40,964.78	$0.00	$134,231	$131,952.67	$2,278.33	$5,570.18	$5,570.18	$0.00	$71,026.08	$70,123.44	$902.64	$9,911.96	$9,911.96	$0.00	$400,000	$6,505.04

*Mailing reports, manuscripts, communications

**Page charges for 2 papers x 10 pages x $100/page

Innovative Springshed Mapping for Trout Stream Management
Subd. 5g $270,000

E. Calvin Alexander, Jr.
U of M
Geology & Geophysics
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Minneapolis, MN 55455

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RESEARCH

Overall Project Outcomes and Results

Trout streams depend on a steady supply of clean, cold water to exist. The U of M's Geology and Geophysics Dept. and the DNR Waters worked to identify and map the karst springs and their recharge areas that supply water to southeastern Minnesota's 173 trout streams and to assess the impacts that both land and aquatic development are having on these springs.

Delineation of the recharge areas or springsheds of the trout springs is a crucial first step in the protection of the trout fisheries and the restoration of those that have been degraded. Established fluorescent dye tracing techniques were refined, accelerated and expanded into springsheds parts of southeastern Minnesota not previously traced. Traces in Fillmore and Olmsted counties defined new trout stream springsheds and expanded and refined information on previously known trout stream springsheds in the Galena Aquifer. The traces in Winona and Houston Counties began the definition of trout stream springsheds draining the Prairie du Chien Aquifer. Prairie du Chien springs supply water to several major fish hatcheries and trout streams.

Although many of southeastern Minnesota's trout stream are headed by springs flowing from the St. Lawrence Formation, the St. Lawrence has been assumed to be an aquitard in Minnesota Rules. Three successful traces through the St. Lawrence Formation in Winona and Houston Counties demonstrated that water flows rapidly through the St. Lawrence to trout springs. This unexpected discovery is a major advance in our understanding and management of these trout springs and is resulting in a significant reevaluation the hydrogeology of the St. Lawrence Formation.

In addition to dye tracing, four innovative Trout Springshed Assessment protocols were investigated. The first was the use of data logger technology to characterize time variations in the thermal and chemical properties of trout springs. The temperature loggers identified at least four distinct patterns of temperature variations present in trout springs which inturn yield information about the respective springsheds. The second innovative technique was the construction of new, high precision structural contour maps of the geologic strata hosting trout springsheds. This tool looks promising but will require more precise mapping that is currently available. The third innovation was an investigation of the relationship between the size of springsheds and the base flow volume of the trout springs. This technique is promising but requires more well defined springsheds to become a practical tool. The last technique investigated was the measurement of dissolved organic compounds (DOC) in the springs. Significant differences in the amount and composition of the DOCs were observed which may be relatable to varying land uses in the springsheds.

The springsheds defined by the tracing and the other tools allow an accurate documentation of the rapid, direct impact of surface land uses in the springsheds and the water quality in the trout streams. This inturn allows better management of the springsheds to protect the trout streams and groundwater resources.

Project Results, Use and Dissemination

The dissemination and use of the results of the trout springsheds delineation has varied depending on the level of the user. At the local level one of the most effective dissemination tools has been to get the landowners and users involved in the research itself. This has included getting Harmony High School students involved in the traces around Harmony, Minnesota. Getting many of the local residents involved in the tracing. Getting the County staffs, local organizations, the trout fishing community and the trout hatchery staffs involved in the tracing. We send copies of the reports into the hands to the affected landowners and residents involved. All of these people now know the speed at which the surface runoff can reach their trout streams. They are the “first line of defense” in maintaining and improving the water quality in the trout streams.

At the regional and state levels Alexander and Green have made numerous presentations various state water management and ground water meetings. We have led field trips highlighting the results of this project. Contribute the results of this information at a variety of levels inside the Minnesota State Government. The information is built into short courses, training sessions, technical comments and University of Minnesota courses. The discovery that water moves rapidly through the St. Lawrence “aquitard” is already impacting management rules and practices in several State Agencies. The increasingly detailed knowledge of the springsheds is an important part of the TMDL effort to protect and improve water quality in trout streams in southeasten Minnesota.

At the national level the results obtained in this project were presented at the 11th Multidisciplinary Conference on Sinkhole and the Engineering and Environmental Impacts of Karst, at Geological Society of America meetings and published in their Proceedings. National Science Foundation summer interns have participated in the research effort and taken the knowledge and experience back to other states.

Copies and electronic versions of 15 reports were transmitted to the LCCMR staff.

FINAL REPORT
Project completed: 6/30/2009

Trust Fund 2007 Work Program

Date of Report: 23 December 2009 (completion report)
Date of Next Status Report:
Date of Work program Approval:
Project Completion Date: 30 June 2009

I. PROJECT TITLE: Innovative Springshed Mapping for Trout Stream Management

Project Manager:	E. Calvin Alexander, Jr.
Affiliation:	Geology & Geophysics Department
Mailing Address:	310 Pillsbury Dr. SE
City / State / Zip :	Minneapolis, MN 55455
Telephone Number:	(612) 624-3517
E-mail Address:	alexa001@umn.edu
FAX Number:	(612) 625-3819
Web Page address:	

Location: Houston, Fillmore, Mower, Olmsted, Winona, Wabasha, Goodhue, Dakota and Washington Counties.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$** 270,000
	Minus Amount Spent:	**$** 270,000
	Equal Balance:	**$** 0

Legal Citation: ML 2007, [Chap. 30], Sec.[2], Subd. 5g .

Appropriation Language: (g) Innovative Springshed Mapping for Trout Stream Management. $270,000 is from the trust fund to the University of Minnesota to identify and delineate supply areas and springsheds, for springs serving as coldwater sources for modern and historic trout streams, and to assess the impacts from development and groundwater appropriations.

II. PROJECT SUMMARY AND RESULTS: Trout streams depend on a steady supply of clean, cold water to exist. Minnesota's karst lands contain 173 designated trout streams each of which is sourced from springs. Those trout springs are under increasing pressure from changing land use. Additional large groundwater withdrawals for energy production and other development loom in the future. Delineation of the recharge areas or springsheds of the trout springs is a crucial first step in the protection of the trout fisheries and the restoration of those that have been degraded. This project is to develop innovative identification and delineation tools to determine the supply areas (springsheds) for springs serving as coldwater sources for modern and historic trout streams and assessing impacts on them from land and water development.

III. PROGRESS SUMMARY AS OF ***(30 June 2009)*****:**

The personnel on this project, in addition to the Project Manager and Project Partner included Andrew Peterson (DNR), Andrew Luhmann (UM) and Scott Alexander (UM). We profited from NSF REU summer interns Sarah Eagle (2007)[1], Shannon Flynn (2008)[4,5] and Kelsey Peterson (2008)[6,7] at UM whose various research project in southeastern Minnesota karst hydrogeology were significant additions to the LCCMR effort. Matthew Covington, a NSF Post-Doctoral researcher, has also contributed significantly to the overall project since his arrival at UM in January 2009. Two High School student groups, their Science Teacher and the owner of Niagara Cave helped run a successful series of traces on the northwest side of Harmony. Both high school student projects, summer interns and the Post-Doc were means of leveraging the LCCMR resources against outside resources to accelerate the overall process.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Innovative Trout Streamshed Maps and Reports

Springsheds that feed source springs of trout streams will be delineated in the Galena and Prairie du Chien karst lands. Only about 8% of trout streams springsheds have had any dye tracing conducted in them. We propose to double that number while developing techniques and supplemental mapping tools for rapid accurate springshed delineation. We will prioritize the watersheds for work based on their current condition and the threat to their water quality from current and proposed land usage and groundwater appropriations.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$ 163,025**
	Amount Spent:	**$ 163,025**
	Balance:	**$ 0**

Deliverable 1	**Completion Date**	**Budget**	**Status**
GIS based maps and written reports identifying and describing the springsheds delineated.	30 June 2009	$163,025	

Final Report Summary: 30 June 2009:

Thirty-six dye traces were conducted between 1 July 2007 and 30 June 2009 to define the springsheds of trout stream. These traces were run in Fillmore, Houston, Olmsted and Winona Counties. The traces in Fillmore and Olmsted counties defined new trout stream springsheds and expanded and refined information on previously known trout stream springsheds in the Galena Group[1,2,3,4,5,10,11,14,15]. The traces in Winona and Houston Counties began the definition of trout stream springsheds draining the Prairie du Chien Group. Prairie du Chien springs several major fish hatcheries and trout streams.

Perhaps the most exciting results, however, are three successful traces through the St. Lawrence Formation in Winona and Houston Counties[9,12]. Although many of southeastern Minnesota's trout stream are headed by springs in this part of the geologic column, up until these traces the St. Lawrence Formation has been assumed to be an aquitard. The St. Lawrence traces demonstrates that dye tracing can be conducted to St. Lawrence springs and is a major step forward in our understanding and management of these trout springs.

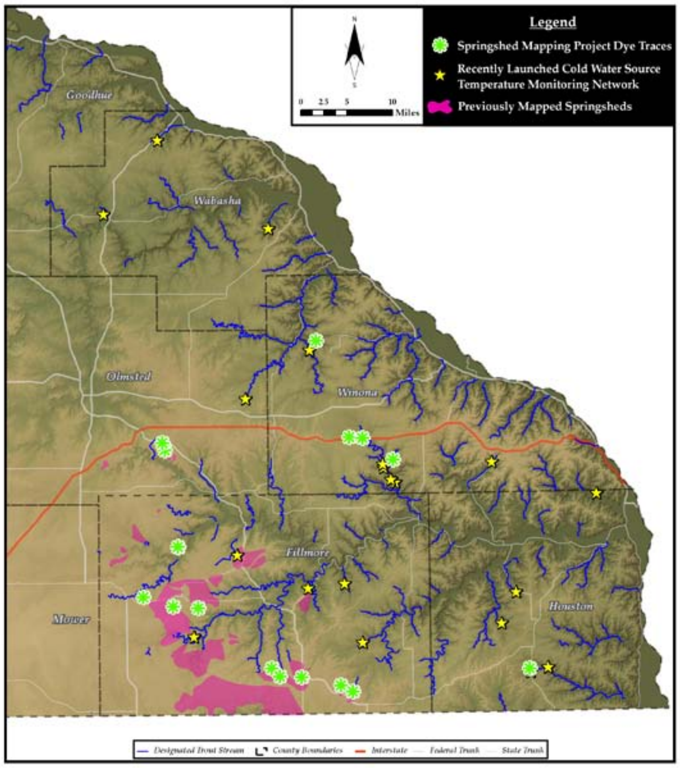


Figure 1. Location of Dye Traces and Temperature Monitoring Network

Figure 1 shows the location of the dye traces and the spring monitoring network discussed below.

Result 2: <u>Trout Springshed Assessment Protocols</u>

The assessment of impacts of land use changes and new large water withdrawals and the offsetting improvements in recharge and water quality of the springs' flows requires new protocols in addition to dye tracing and all of the protocols need to be documented. We propose to use data logger technology and Karst Landscape Unit mapping to develop protocols for karst hydrogeology-based springshed assessment.

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$ 90,000**
	Amount Spent:	**$ 90,000**
	Balance:	**$ 0**

Deliverable 2	**Completion Date**	**Budget**	**Status**
Reports describing the Springshed Assessment Protocols for the springsheds analyzed.	30 June 2009	$ 90,000	

Final Report Summary: 30 June 2009:

Four innovative Trout Springshed Assessment protocols were investigated. The first innovative technique was the use of data logger technology to characterize time variations in the chemical and properties of trout springs[8,12]. Figure 1 shows the network of spring thermal monitoring points that has been established. These temperature data loggers have found that there are at least four distinct patterns of temperature variations present in SE Minnesota trout springs. These patterns can be correlated with the hydrogeology of the respective springsheds[8,9,12]. The second innovative technique was the construction of new, high precision structural contour maps of the geologic strata hosting the trout springsheds[8]. This tool is promising but will require more detailed structural contour mapping than is currently available. The third innovative technique is the use of well defined springsheds to determine a relationship between the size of the springheds and their base flows. This technique is promising but needs more, better defined springsheds to become a practical tool. The fourth innovative technique is to use the dissolved organic carbon (DOC) compounds in the springs to deduce the properties of the spring sheds. The analytical equipment used to measure the fluorescent dyes in the dye trace studies can also be used to measure the DOC in the water. One of our summer interns initiated a study on this tool and obtained encouraging results[6,7].

The combination of these tools with dye trace work allow a much more robust classification of the trout springsheds.

Result 3: BMP Handbook for Trout Streansheds

A critical examination of existing and new BMPs will be necessary for management of the trout stream springsheds. We will review karst related BMPs from other states and compile, in consultation with the University of Minnesota Extension, DNR, MGS and other interested parties, a Handbook of karst trout stream springshed BMPs for southeastern Minnesota.

Summary Budget Information for Result 3:	**Trust Fund Budget:**	**$ 16,975**
	Amount Spent:	**$ 16,975**
	Balance:	**$ 0**

Deliverable 3	**Completion Date**	**Budget**	**Status**
Handbook of recommending BMPs for trout stream springsheds in southeastern Minnesota.	30 June 2009	$ 16,975	

Final Report Summary: 30 June 2009:

Although there is a considerable literature on water quality BMPs in karst, little of it explicitly includes karst hydrogeology. Most of the literature is about agricultural production. Currens (2001) [J.C. Currens, Changes in groundwater quality in a conduit-flow dominated karst aquifer following BMP implementation, Envirnonmental Geology, v. 42, n. 5, p. 525-531] demonstrated that conventional BMPs when applied in karst actually decrease groundwater quality. A compounding problem is the continued fixation on surface karst features with the assumption that their apparent absence is evidence that karst processes are not operating at a particular place. The formation of a new sinkhole entrance to the previously unknown major new cave, Holy Grail Cave in June 2008 illustrates the problem[13]. The recent recognition that several of the trout streams in SE Minnesota are impaired for nitrates, turbidity or both illustrates the problem. The TMDL process which is focused on water quality may provide a vehicle to more realistically protect trout springsheds.

V. TOTAL TRUST FUND PROJECT BUDGET: $ 270,000

Staff:

$99,800 – DNR Waters staff hydrogeologist, 100% time, Result 1, 2 & 3.
$70,392 – 1 U of Mn graduate student Research Assistant, 50% time, Result 1,2 & 3.
$56,960 – PI 5% time, U o Mn staff scientist, 40% time, Result 1, 2 & 3.

Equipment, Supplies and Field Travel (U of Mn staff):

$5,000 – Travel for field work.
$5,648 – Expendable field and laboratory supplies (dye tracing supplies [dye, sample bottles, chemicals, lab supplies, etc.], field supplies, etc.
$7,000 – Equipment purchase (3 data loggers, 3 pressure transducers, misc. field equipment).

Equipment, Supplies and Travel (MNDNR/Waters staff):

$5,000 – Vehicle mileage costs
$800 – Lodging and meals in MN
$2,000 – Office and field operations (mail, printing, office supplies, cell phone service)
$4,700 – Field equipment (conductivity probes [to use with data loggers previously purchased] notebook computer to download data loggers, water sampling equipment, mapping equipment)
$6,700 – Sample analysis (water chemistry, stable isotopes)
$4,000 – GIS software for field laptop
$2,000 – Presentation of preliminary findings at the 11th International Multidisciplinary Conference on the Environmental and Engineering Aspects of Karst (Sept. 2008, Tallahassee, FL)

Explanation of Capital Expenditures Greater Than $3,500:

A single user license is required by the soft ware provider for use on field laptops.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

Jeffrey A. Green, DNR Waters.

B. Other Funds Spent during the Project Period:

$50,000, DNR Waters, 0.25 FTE Hydrologist 3 plus expenses.
$5,000, South Branch Root 319 Project for the Governor's Root River Initiative.

$15,000, three NSF REU summer interns, Sarah Eagle (2007), Shannon Flynn (2008) and Kelsey Peterson(2008)

C. Time:

1 July 2007 - Initiate Project

1. Arrange contracts between University and MNDNR/Waters for Jeff Green's section of the project.
2. ASAP initiate multiple dye traces in the priority areas.
3. Contact as many individuals and agencies as possible that can provide information on the trout streams and begin assembling the available information on stream flows, chemistry, isotopes, etc.

4. Contact as many individuals and agencies as possible that can provide information on BMPs for karst aquifers.
5. Evaluate existing watershed data storage/delineation tools at the MNDNR for use in this project.

1 July 2007 to ~ 15 November 2007 – 1st field season.

1. Conduct multiple dye traces in multiple basins. This major activity has a significant weather component. Traces can be conducted in both wet and dry periods and each gives somewhat different, individually useful information on the springsheds. The end of the field season is also very weather dependent. Heavy snowfall terminates dye tracing activities.
2. Interpret the results of the dye traces as they become available. Interim dye trace results will be available as GIS shape files and derived products.
3. Compile and analyze the available data on trout stream flows, chemistry, etc.
4. Compile and evaluate karst BMPs.

~ 15 November 2007 to ~28 February 2008 – Planning for 2nd field season.

1. Evaluate results from 1st Field season and plan strategy for 2nd field season.
2. Progress report to LCCMR on 1st season on 30 Dec 2007.

~1 March 2008 to ~15 November 2008 – 2nd Field season.

1. Conduct multiple dye traces in multiple basins beginning with snowmelt runoff tracing in February/March 2008.
2. Interpret the results of the dye traces as they become available. Post the results of the individual traces.
3. Progress report to LCCMR on 30 June 2008.
4. Compile and analyze the available data on trout stream flows, chemistry, etc.
5. Compile and evaluate karst BMPs.
6. Present preliminary results at 11th International Sinkhole Conference, Sept 2008, Tallahassee, FL.

~ 15 November 2008 to 28 February 2009 – Data reduction and Interpretation.

1. Evaluate results from 2nd Field Season
2. Progress report to LCCMR on 30 December 2008.
3. Draft of karst BMP manual sent out for review and comment by 1 February 2009.

1 Mar 2009 to 30 June 2009 – Interpretation and Report writing.

1. Compiling results from all accumulated traces.
2. Revise and finalize BMP manual.
3. Final report and BMP manual to LCCMR by 30 June 2009

VII. DISSEMINATION: GIS based maps and written reports of the springsheds will be prepared and disseminated to the LCCMR and interested residents and to local, regional and state resource managers and regulators interested in specific targeted areas. Interim dye trace results will be available as GIS shape files and derived products on a dye trace by dye trace basis. Data tables of discharge and chemistry will be available as developed.

Reports will be prepared and disseminated of the springshed delineation protocols will be prepared and disseminated to the LCCMR and interested residents and to local, regional and state resource managers and regulators interested in specific targeted areas. Interim dye trace results will be available as GIS shape files and derived products on a dye trace by dye trace basis.

A Handbook of BMPs for the protection of trout stream springsheds in karst will be developed and disseminated.

Both the project manager and project partner presented the interim and final results of the project at the 11th International Multidisciplinary Conference on Sinkholes in September 2008 and at other appropriate local, state, and national meetings. The results are being published in appropriate professional journals.

Project Reports (copies attached):

[1] Sarah D. Eagle and E. Calvin Alexander, Jr. (2007) *2 July 2007 Morehart Farm Dye Trace*, 16 p. [word Doc]

[2] Jeffrey A. Green Andrew J. Peters, Andrew J. Luhmann, E. Calvin Alexander, Jr. and Scott C. Alexander (2008) *Frego Creek Dye Trace March 11, 2008 to June 16, 2008*, 69 p. [pdf]

[3] Jeffrey A. Green Andrew J. Peters, Andrew J. Luhmann, E. Calvin Alexander, Jr. and Scott C. Alexander (2008) *Harmony Spring 2008 Dye Trace*, 22 p. [pdf]

[4] Shannon Flynn, E. Calvin Alexander, Jr. and Scott Alexander (2008) *A Quantitative Dye Trace in the Bat River System*, 7 p. [word Doc]

[5] Shannon Flynn, E. Calvin Alexander, Jr. and Scott Alexander (2008) *A Quantitative Dye Trace in the Bat River System*, poster. [pdf]

[6] Kelsey Peterson, Scott C. Alexander, E. Calvin Alexander, Jr. and Shannon Flynn (2008) *Peptidoglycan Degradation Fluorescence: Applications to Karst Groundwater Mapping*, 12 p. [word Doc]

[7] Kelsey Peterson, Scott C. Alexander, E. Calvin Alexander, Jr. and Shannon Flynn (2008) *Peptidoglycan Degradation Fluorescence: Applications to Karst Groundwater Mapping*, poster. [pdf]

[8] Scott C. Alexander, Andrew J. Luhmann, E. Calvin Alexander, Jr., Jeffrey A. Green and Andrew J. Peters (2008) *Spring Characterization Methods & Springshed Mapping*. *In:* (Yuhr, Lynn B., Alexander, E. Calvin, Jr. and Beck, Barry F., editors) ***Sinkholes and the Engineering and Environmental Impacts of Karst, Proceedings of the 11th Multidisciplinary Conference***. ASCE/GI Geotechnical Special Publication No. 183, Amer. Soc. Civil Eng., Reston, VA, p. 485-494. [Word doc.]

[9] Jeffrey A. Green, Andrew J. Luhmann, Andrew J. Peters, Anthony C. Runkel, E. Calvin Alexander, Jr., and Scott C. Alexander (2008) *Dye Tracing Within the St. Lawrence Confining Unit in Southeastern Minnesota*. *In:* (Yuhr, Lynn B., Alexander, E. Calvin, Jr. and Beck, Barry F., editors) ***Sinkholes and the Engineering and Environmental Impacts of Karst, Proceedings of the 11th Multidisciplinary Conference***. ASCE/GI Geotechnical Special Publication No. 183, Amer. Soc. Civil Eng., Reston, VA, p. 477-484. [Word doc.]

[10] Jeffrey A. Green Andrew J. Peters, Andrew J. Luhmann, E. Calvin Alexander, Jr. and Scott C. Alexander (2008) *Forestville North Dye Trace*, 9 p. [pdf]

[11] E. Calvin Alexander, Jr., Scott C. Alexander, Andrew J. Luhmann, Cale T. Anger, Jeffrey A. Green and Andrew P. Peters (2009) *Sinks and Rises of the South Branch Root River, Fillmore County, Minnesota*. (abs. 10-4). 2009 Abstracts with Program, North Central Section, Rockford, IL, V. 41, n. 4, p. 18. [Word doc.]

[12] Andrew J. Luhmann, Scott C. Alexander, E. Calvin Alexander, Jr., Jeff A. Green and Andew P. Peters (2009) *Flow Path Characterization using Spring Thermographs* (abs. 10-3). 2009 Abstracts with Program, North Central Section, Rockford, IL, V. 41, n. 4, p. 17. [Word doc.]

[13] John G. Ackerman, Clayton T. Kraus, David W. Gerboth, Daniel S. Dornink and E. Calvin Alexander, Jr. (2009) *Holy Grail Cave, Fillmore County, Minnesota* (abs. 10-5). 2009 Abstracts with Program, North Central Section, Rockford, IL, V. 41, n. 4, p. 18. [Word doc.]

[14] Jeffrey A. Green Andrew J. Peters, Andrew J. Luhmann, E. Calvin Alexander, Jr. and Scott C. Alexander (2009) *Harmony Fall 2008 Dye Trace*, 23 p. [pdf]

[15] Jeffrey A. Green Andrew J. Peters, Andrew J. Luhmann, E. Calvin Alexander, Jr. and Scott C. Alexander (2008) *Frego Creek Spring 2009 Dye Trace*, 23 p. [pdf]

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than 31 December 2007, 30 June 2008, 31 December 2008. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR.

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: Innovative Springshed Mapping for Trout Stream Management, ML 2007, [Chapt. 30], Sec. [2], Subd. 5g.

Project Manager Name: E. Calvin Alexander, Jr.

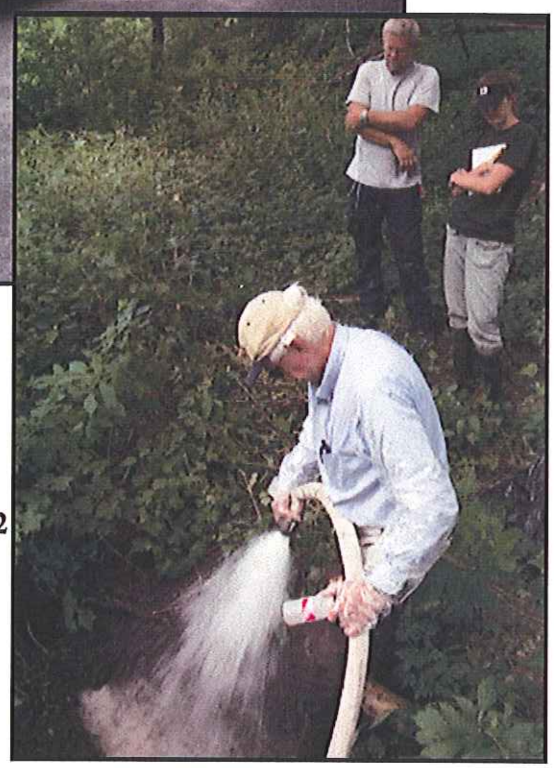
Trust Fund Appropriation: $ 270,000

$145,000 to U of Mn, $125,000 Contract to DNR/Waters

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent (30 Jun 09)	Balance (30 Jun 09)	Result 2 Budget:	Amount Spent (30 Jun 09)	Balance (30 Jun 09)	Result 3 Budget:	Amount Spent (30 Jun 09)	Balance (30 Jun 09)	TOTAL BUDGET	TOTAL BALANCE
	Springshed Maps and Reports			*Springshed Assessment Protocols*			*Trout Springshed BMPs*				
BUDGET ITEM											
U of MN PERSONNEL: wages and benefits (PM 5% time, Staff Scientist 40% time, RA 50% time**)**	75,468	74,827	641	42,451	45,204	-2,753	9,433	9,430	3	127,352	-2,109
U of MN Field Equipment: (3 data loggers @ $1,200 each, 3 pressure transduces @ $800 each, misc. field equipment)	4,667	4,667	0	2,333	2,045	288	0	0	0	7,000	288
U of MN Expendable field and laboratory supplies (dye, sample bottles, chemicals, labs supplies, field supplies, etc.)	3,765	4,324	-559	1,883	0	1,883	0	0	0	5,648	1,324
U o Mn In State Travel Expenses for Field Work	3,333	3,436	-103	1,667	1,067	600	0	0	0	5,000	497
Contracts - DNR Waters (Project Partner, Jeffrey Green, SE Minnesota Groundwater Specialist)											
DNR PERSONNEL: wages and benefits (Staff Hydrogeologist 100% time)	59,140	59,140	0	33,267	33,267	0	7,393	7,393	0	99,800	0
DNR Field Equipment: (conductivity probes [to be used with previously purchased data loggers], notebook computer to download data loggers, water sampling equipment, mapping equipment)	3,133	3,133	0	1,567	1,567	0	0	0	0	4,700	0
DNR In State Travel Expenses for Field Work	3,867	3,867	0	1,933	1,933	0		0	0	5,800	0
DNR Out of State Travel (Presentation of preliminary findings at 11th Multidisciplinary Conference on the Environmental and Engineering Aspect of Karst, Sep. 2008, Tallahassee, FL)	1,333	1,333	0	667	667	0	0	0	0	2,000	0
DNR Sample Analyses (water chemistry and stable isotopes)	4,467	4,467	0	2,233	2,233	0	0	0	0	6,700	0
DNR GIS Software for Field Laptop (Manufacturer requires purchase of single user Arcview 9.2 license for use in field laptop.)	2,667	2,667	0	1,333	1,333	0	0	0	0	4,000	0
DNR Office and Field Operations Mail (printing, office supplies,cell phone service.)	1,185	1,185	0	666	666	0	149	149	0	2,000	0
COLUMN TOTAL	**$163,025**	**$163,046**	**-$21**	**$90,000**	**$89,982**	**$18**	**$16,975**	**$16,972**	**$3**	**$270,000**	**$0**

2 July 2007 Morehart Farm Dye Trace

Left: Trucks from Chatfield Fire Department.



Below: Introduction of Sulforhodamine B dye in sinkhole MN55:D0162.

by

Sarah D. Eagle[1]

E. Calvin Alexander, Jr.[2]

August 2007

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2 July 2007 Morehart Farm Dye Trace

Abstract

Our research is designed to delineate springsheds feeding trout streams in Olmsted County, Minnesota. Trout streams are highly dependent on springs discharging large volumes of cool, clear spring water in order to sustain trout populations. Olmsted County is an area of Southeastern Minnesota with mature karst, and as such, the surficial bedrock aquifer is highly vulnerable to pollution and contamination. In particular, highly turbid ground water from storm events can reach springs and thereby adversely affecting trout populations. Fluorescent dye tracing was utilized to delineate springshed areas and conduit connections of springs feeding the east side of Kinney Creek in Pleasant Grove and Orion Townships. In late June 2007, background monitoring was started at selected locations and on 2 July 2007 a double dye trace was initiated by introducing the fluorescent dyes eosin (CAS 17372-87-1) and sulforhodamine B (CAS 3520-42-1) to sinkholes MN55:D0133 and MN55:D0162, respectively. Direct water samples and activated carbon detectors were analyzed by scanning spectrofluorometric methods revealing both introduction points to be in the springshed McConnell's Spring (MN55:A0006). Travel times were faster than three days per kilometer.

Introduction

Karst aquifers are both extremely productive and highly vulnerable to pollution and contamination. Protection and management of karst springs requires detailed knowledge of their hydrogeologic properties such as recharge areas (springsheds), discharge points (springs), and flow channels (conduits). The delineation of such features helps identify the source of pollution as well as enabling effective efforts at protection from water quality degradation.

Fluorescent dye tracing was utilized for springshed mapping for watershed management in Southeastern Minnesota, specifically for the protection of spring-fed trout streams. Fluorescent dye tracing provides an effective, environmentally sound way to trace groundwater flow in preferential flow systems where high resolution certainty is desired (Green, Alexander, and Alexander 2005).

In late June and early July 2007 a qualitative double dye trace, using eosine and sulforhodamine B, was conducted in Pleasant Grove and Orion Townships (Twp.), Minnesota. The purpose was to determine conduit connections and spring shed areas in Pleasant Grove Twp. and Orion Twp., of springs feeding the east side of Kinney Creek. Charcoal detectors were used to detect the dye in monitored springs and surface streams. The springs and most of the flow paths are located on and under the Harland Morehart farm. The locations of the monitored springs and surface water points are shown in Figure 7 and listed below in "Detector Locations".

Hydrogeologic Setting

Pleasant Grove Twp. and Orion Twp. are located in the active karst region of Olmsted County in Southeastern Minnesota (Figure 1). In Olmsted County the active karst is characterized by high sinkhole density, subsurface drainage and springs, many of which feed trout streams. The first and most important aspect in the development of karst is soluble bedrock. The Galena Group (Stewartville Formation, Prosser Limestone, and Cummingsville Formation) and the Prairie Du Chien Group (Shakopee Formation and Oneota Dolomite) are the first bedrock under much of Olmsted County and provide the first condition necessary for the formation of karst (Ford and Williams 1989, Olsen 1988). In this study area the Galena Group is the first bedrock and contains the surficial aquifer.

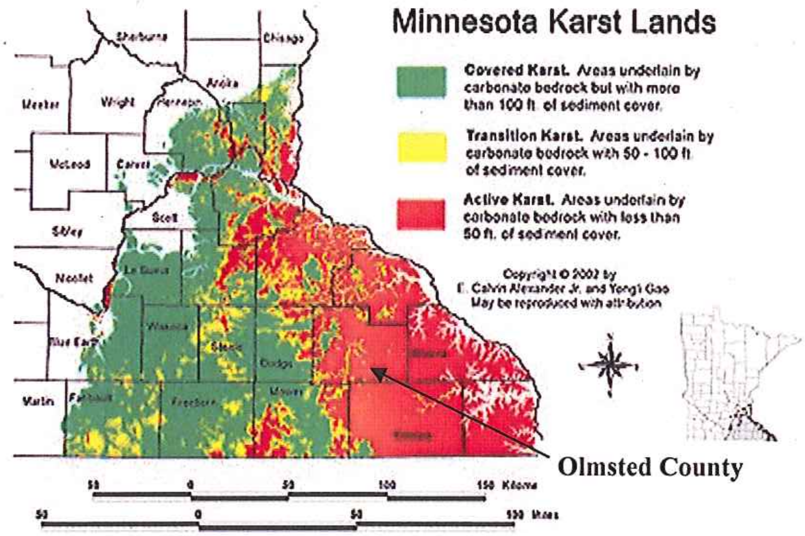

Figure 1. Minnesota Karst Lands (Alexander and Gao).

Key controls determining karst activity and development, including sinkhole probability, are the amount of surficial cover over the bedrock as well as the degree of historical karstification. These chemical processes creating the karst environment have been active more or less since their deposition in the Ordovician.

Due to the nature of multi-porosity karst aquifers, the groundwater of Olmsted County has varied residence times. This project deals with the fast-flow portion of the groundwater system in conduits, which has the shortest residence times and therefore the highest sensitivity to contamination (Olsen and Hobbs 1988). Figure 2 illustrates an idealized hydrogeologic cross section of the local karst system in Olmsted County where a hypothetical porous media water table, following a subdued version of the *surface topography*, is shown in red. The actual water table lies below a thicker unsaturated zone and is dominated by *bedrock topography*. Figure 3 below shows the relevant geologic formations in the Middle Ordovician.

Alexander and Maki's (1988) sinkhole mapping of Olmsted documented a sinkhole plain in Orion Township south of the US 52 Highway, north of the Middle Branch of the Root River ("Middle Branch" hereafter) and east of Kinney Creek. That effort also identified springs draining the sinkhole plain into Kinney Creek on the west and to the Middle Branch to the south.

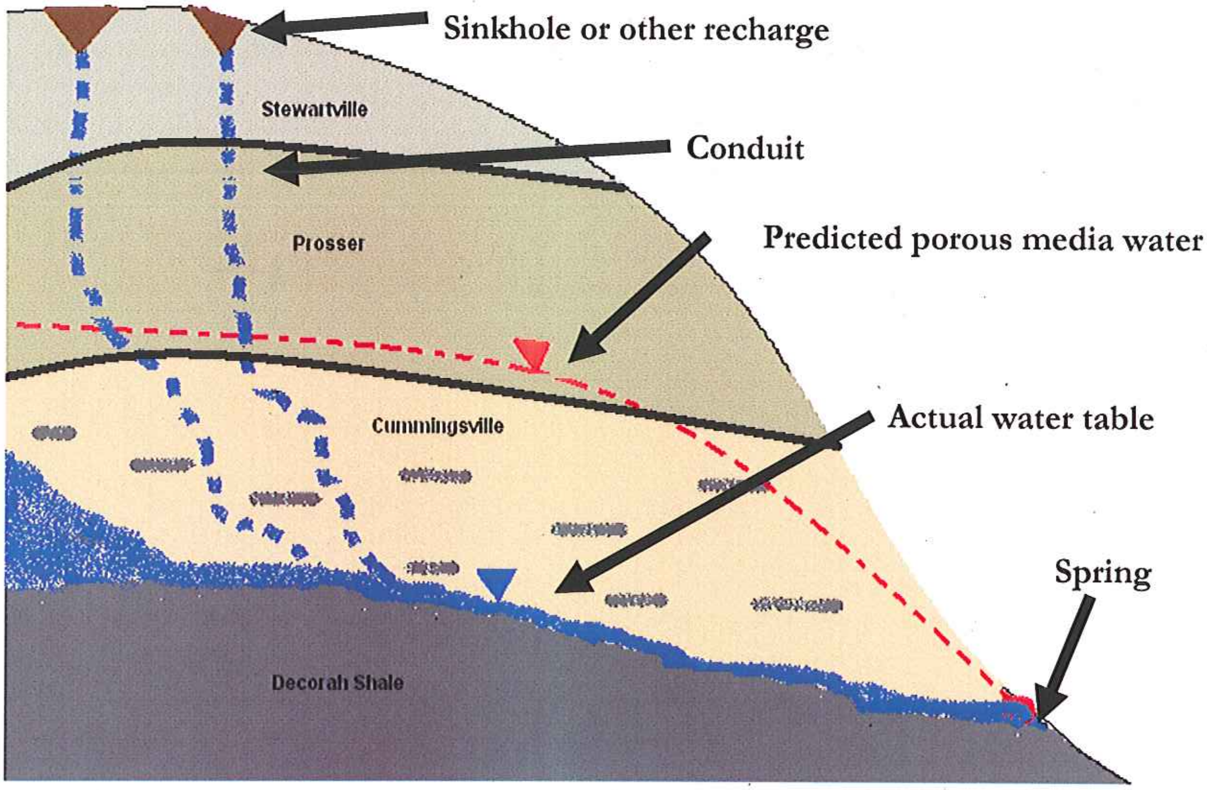

Figure 2. Hydrogeologic cross section.

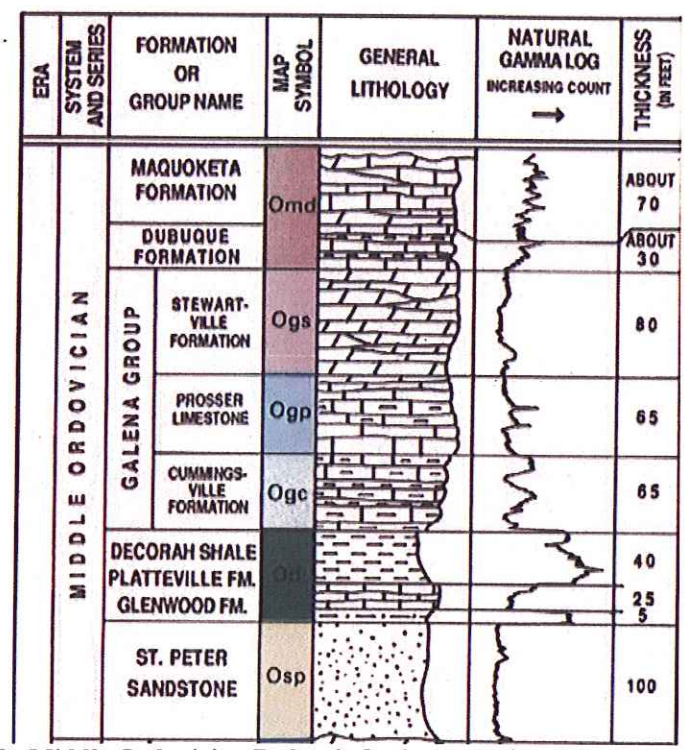

Figure 3. Middle Ordovician Bedrock Geology stratigraphic column (Olsen 1988).

Kinney Creek is one of southeastern Minnesota's trout streams. Dye tracing in the area began in the spring of 2002, Lopez Burgos and others (2003) conducted dye traces near the middle of the sinkhole plain and began to define springshed of the springs on the Burnap farm, which drain south into the Middle Branch (see Figure 4). Their work demonstrated the utility of structural contour mapping in mapping springsheds. This structural contour mapping was largely based on information from the County Well Index; Figure 5 shows wells, first bedrock contours representing the base of the given geologic member, as well as the elevation of the Decorah Shale.

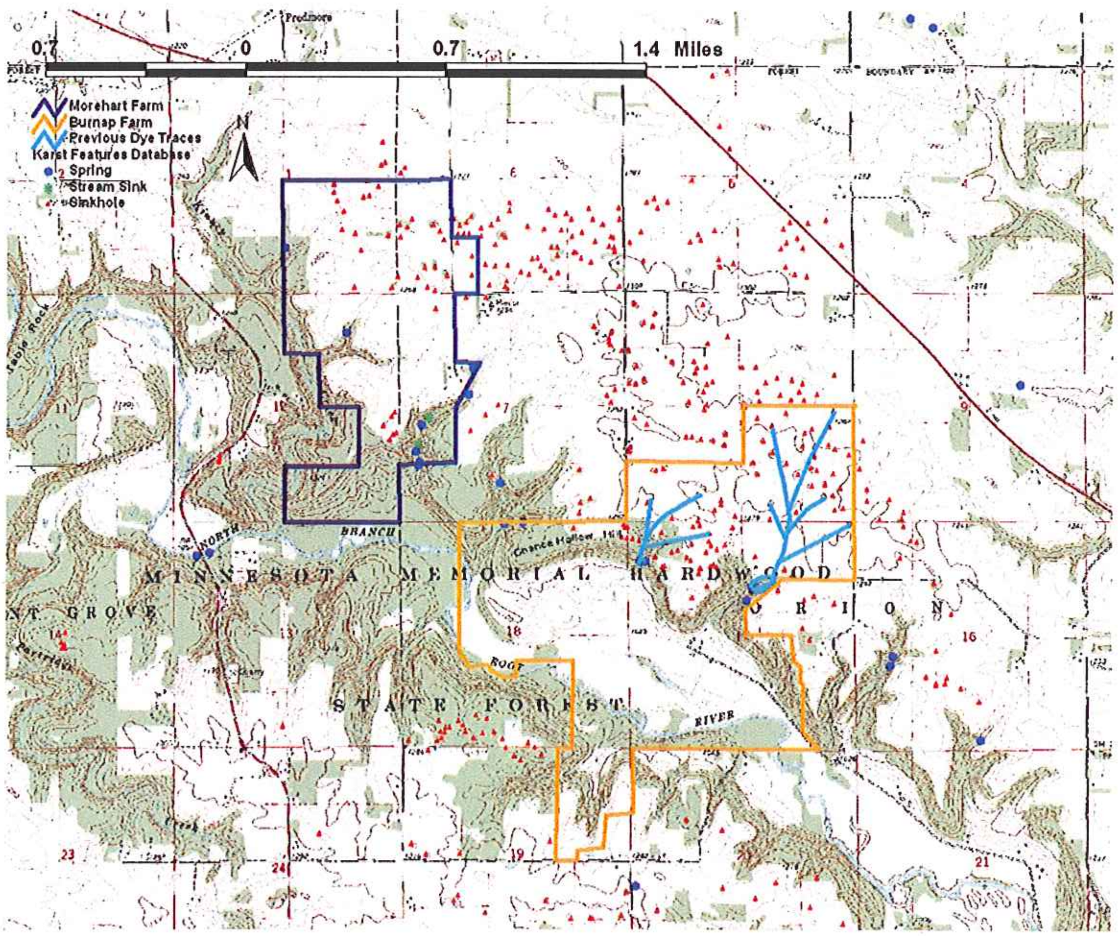

Figure 4. Previous Dye Traces.

This study focused on the west edge of the sinkhole plain where springs feed the east side of Kinney Creek (see Figure 7).

Methods

Prior to dye trace initiation, detector locations were determined and background sampling was initiated. Land in Olmsted County, with the exception of relatively small parcels of land

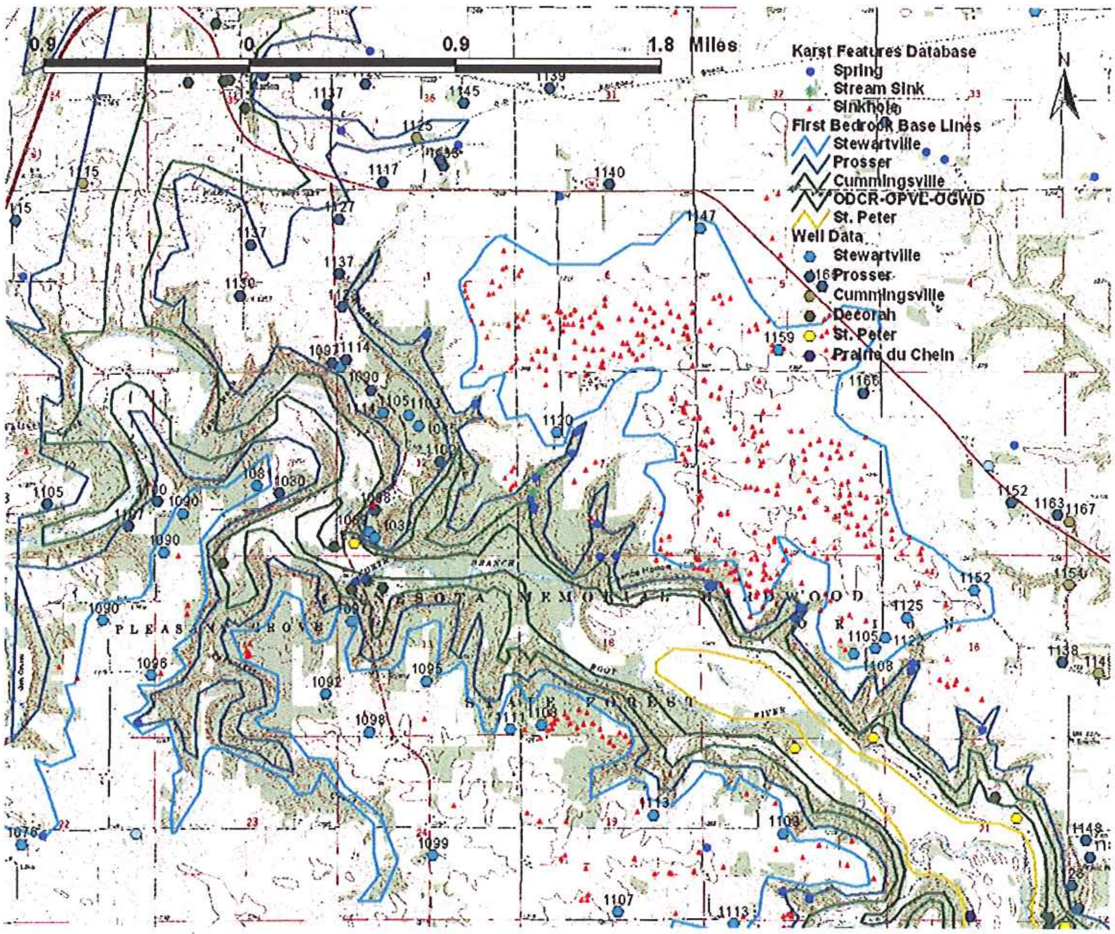

Figure 5. Well Data with Bedrock Contours.

belonging to the Minnesota Department of Natural Resources, is privately owned. In order to conduct this field research it was necessary to contact landowners and gain their permission to sample on their property. Four out of the six detector locations were on the property of a single landowner, Harland Morehart. In the first weeks of the research Mr. Morehart was on vacation and the field research was brought to a standstill until communication was established.

Additionally, many of the detection locations and potential dye introduction points had difficult or restricted access. For example, some of the detectors were located across creeks (Figure 6), in ravines, and some were surrounded by growing crops. Some potential introduction points were no longer accessible due to filling of historic sinkholes to return the land to crop production..

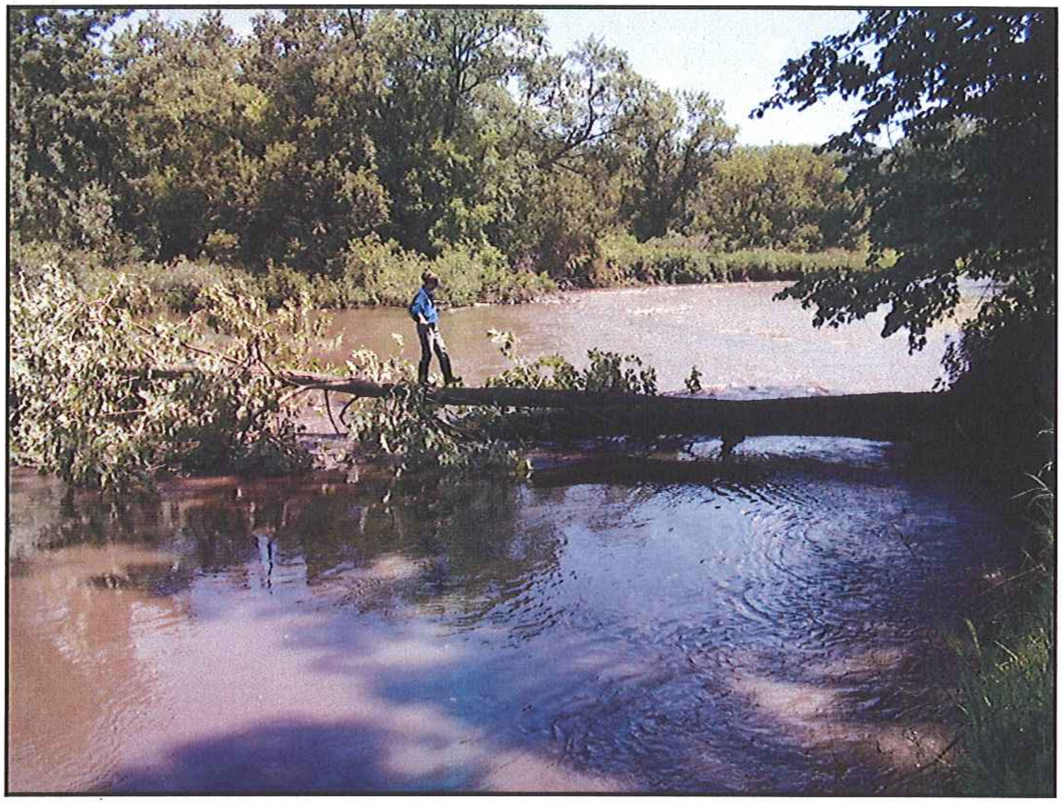

Figure 6. Challenging access to detector location X-8.

Detector Locations:

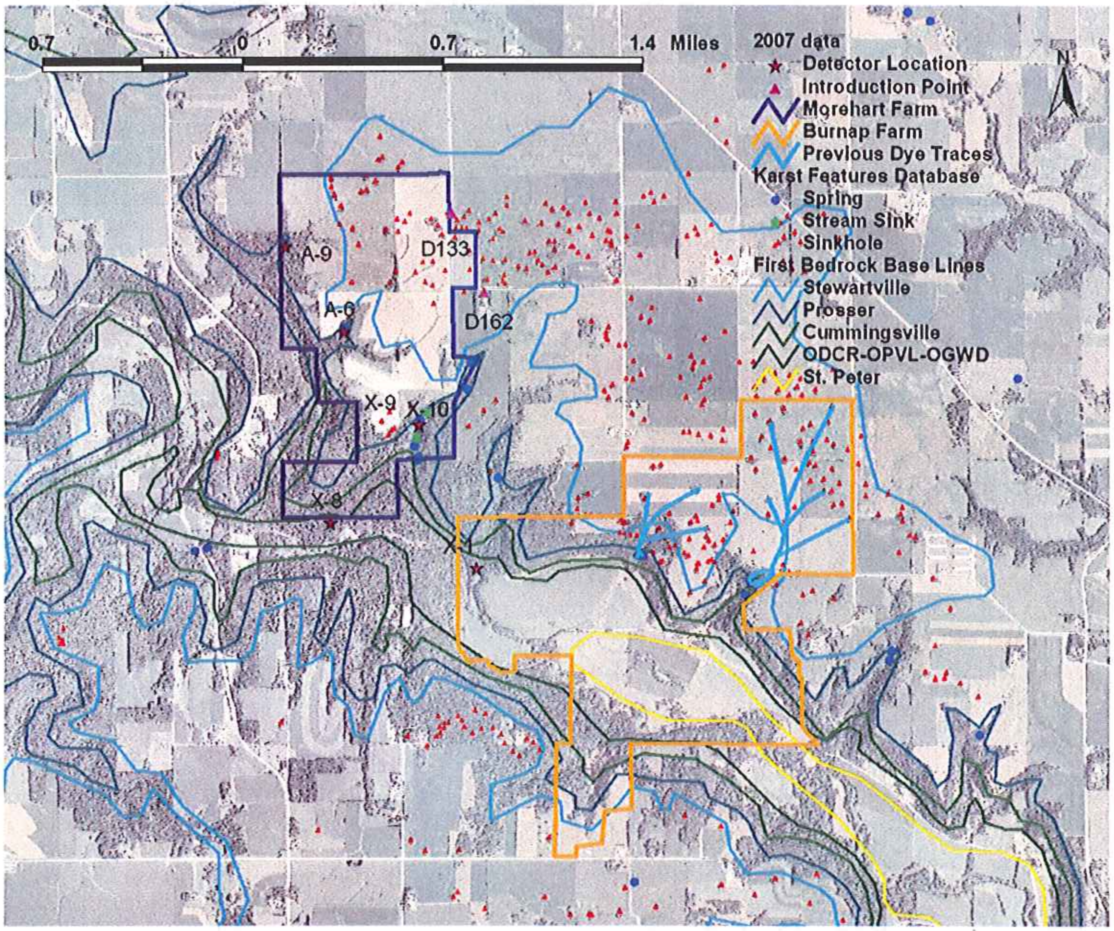

Figure 7. Detector Locations and First Bedrock Data.

A-6 McConnell's Spring: MN55:A0006; 554,344 E, 4,862,923 N (± 6.5 m), ~1210' elevation, in sec 12, Pleasant Grove Twp. Bug was placed in main discharge channel of spring and tied to protruding bedrock (Figure 8).

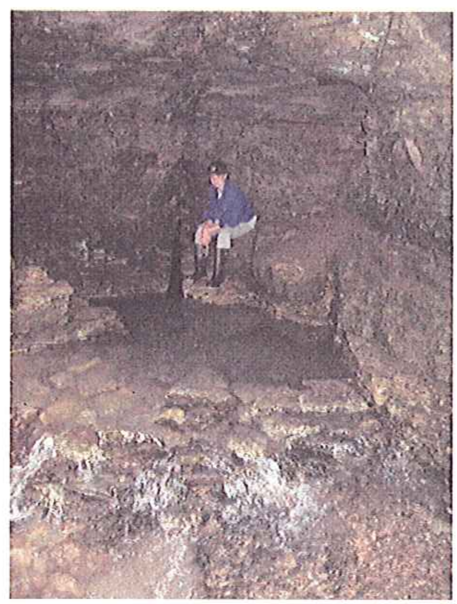

Figure 8. Detector location A-6, McConnell's Spring.

A-9 Old Jug Spring: MN55:A0009; 553,932 E, 4,863,520 N (± 5.0 m), ~1210' elevation, in sec 1, Pleasant Grove Twp. Bug was placed in main discharge channel and tied to a protruding rock on the north side of spring steep head (Figure 9).

Figure 9. Detector location A-9, Old Jug Spring.

X-1 Chance Hollow Stream: 555,273 E, 4,861,262 N (± 3.8 m), ~ 1025' elevation, in sec 18, Orion Twp. Bug was placed in the stream that drains Chance Hollow.

X-8 Mouth of Kinney Creek: 554,251 E, 4,861583 N (± 6.2 m), ~1033' elevation, in sec 13, Pleasant Grove Twp. Bug was placed in Kinney Creek upstream of its junction with the Middle Branch of the Root River Figure 10).

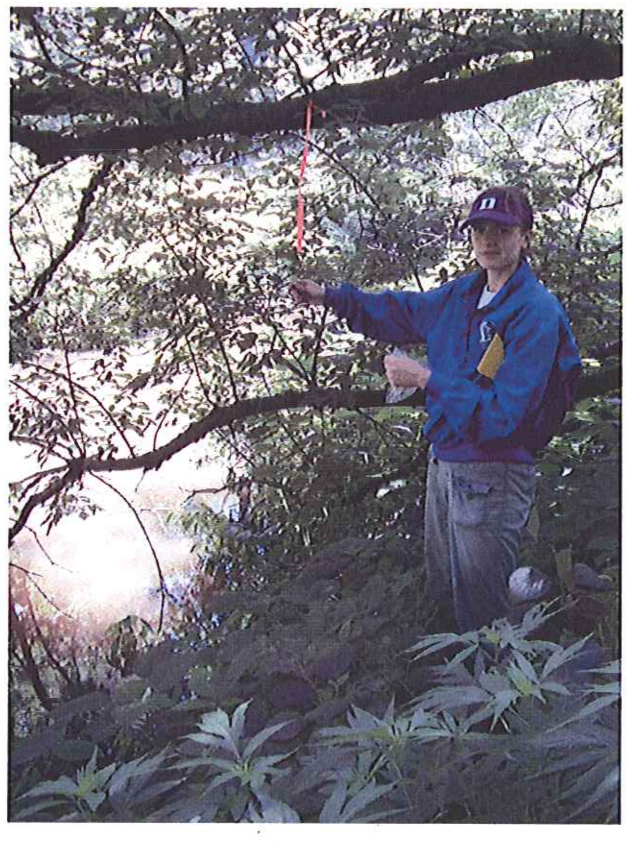

Figure 10. Detector location X-8, mouth of Kinney Creek.

(X-9) A-40 Morehart Ravine Spring: MN55:A0040; 554,869 E, 4,862,268 N (± 6.0 m), ~1125' elevation, in sec 7, Orion Twp. Bug was placed inside a small spring orifice.

X-10 Morehart Ravine Stream; 554,873 E, 4,862,277 N, ~1125' elevation, in sec 7 Orion Twp. Bug was placed in the stream draining the Morehart Ravine about 10 m upstream of X-9.

After the selection of detection locations, at least one round of pre-dye introduction sampling was conducted in order to quantify the natural, background fluorescence. The number of background samples varies for each detector location because as the research progressed, detector locations were added; see Table 1 sampling dates of charcoal detectors. On 2 July 2007 the double dye trace was initiated using the xanthene dyes eosine and sulforhodamine B to sinkholes MN55:D0133 and MN55:D0162, respectively. With the assistance of the Chatfield Fire Department, sulforhodamine dye was washed into the D162 with 1,200 gallons of water and eosine dye was washed into D133 with 1,500 gallons of water. The water moved the dye through the dry sinkholes into the subsurface conduits and diluted the concentrated dyes to reasonable concentrations.

Dye Introduction Points:

Sinkhole D162: MN55:D0162; 555,324 E, 4,863,195 N, T105N, R12W (Orion Twp., Olmsted Co.) sec 7, BAABBD, ~1285' elevation. At 14:30 CDT on 2 July 2007 100.3 grams of **sulforhodamine B** dye (CAS 3520-42-1) (286.6 g of 35 wt. % sulforhodamine B dye solution) was introduced into an open swallow hole in D162 with 1,200 gallons of water. (About 1/3 of the water was poured into the sinkhole, the dye was poured and then the remaining 2/3 of the water was poured into the sinkhole.)

Figure 11. Introduction of sulforhodamine B to sinkhole D162.

Sinkhole D133: MN55:D0133; 555,101 E, 4,863,745 N, T105N, R12W (Orion Twp., Olmsted Co.,) sec 6, CACBCB, ~1285' elevation. At 15:00 CDT on 2 July 61.39 grams of **eosine** CAS 17372-87-1) dye 2007 (175.4 g of 35 wt. % eosin dye (solution) was introduced into an open swallow hole in D133 with 1,500 gallons of water. (About 1/3 of the water was poured into the sinkhole, the dye was poured and then the remaining 2/3 of the water was poured into the sinkhole.)

Figure 12. Calvin Alexander introducing water and eosine dye into sinkhole D133.

On 5 July 2007, three days after dye introduction, water samples were taken at the detection sites and the charcoal detectors were replaced by a set of fresh detectors. Charcoal detectors were also replaced on 9 July, 2007 and the final set of detectors was collected on 19 July 2007; water samples were taken on these two dates, as well.

All charcoal detectors and water samples were returned to the University of Minnesota Geology & Geophysics Department Hydrochemistry Laboratory for analysis. There, the charcoal detectors were opened, the charcoal was removed, and using an eluent solution of 70% isopropyl alcohol, 30% deionized water, and 10g/L NaOH, the fluorescent materials were then extracted for analysis. This elutant was then run through the Shimadzu RF5000U scanning spectrofluorometer to detect and record the spectra; the water samples were analyzed in the same fashion. Spectral components, including the background spectral components, were quantified using PeakFit software as described in Alexander (2005).

Results and Discussion

The results of the charcoal detectors and water samples are summarized in Table 1 and 2, respectively. The fitted spectra for both the charcoal detectors and water samples are found in the appendix.

Table 1. Results of Charcoal Detectors.

Site	14 - 23 June	23 - 29 June	27 June - 29 June[1]	29 June - 2 July	2 - 5 July	5 -9 July	9 - 19 July
A-6	---	nd	---	nd	eos, SRB	eos, SRB	eos, SRB
A-9	---	nd	---	nd	nd	nd	nd
X-1	nd	nd	---	nd	nd	nd	nd
X-8	nd	nd	---	nd	eos, SRB	eos, SRB[2]	SRB[4]
X-9	---	---	nd	nd	nd	nd	nd
X-10	---	---	---	nd	nd	nd[3]	nd

Table Notes: **set** = charcoal detectors installed, **nd** = no dye detected, **---** = no detector installed, **eos** = eosine dye detected, **SRB** = Sulforhodamine B dye detected.

[1] On 27 June only one charcoal detector was installed and none of the preexisting charcoal detectors were replaced.

[2] On 9 July charcoal detector X-8 was found out of the creek channel and strung in a bush on the bank, likely caused by thunderstorm event in the previous day.

[3] On 9 July charcoal detector X-10 was found out of the stream trough it was placed in, likely caused by the thunderstorm event in the previous day.

[4] On 19 July charcoal detector X-8 was found on dry surface of the creek channel, due to dramatically decreased flow.

Table 2. Results of Water Samples.

Site	5 July	9 July	19 July
A-6	eos, SRB	SRB	eos, SRB
A-9	nd	nd	nd
X-1	nd	nd	nd
X-8	SRB	SRB	SRB
X-9	nd	nd	nd
X-10	nd	nd	nd

Table Notes: **set** = charcoal detectors installed, **nd** = no dye detected, **eos** = eosine dye detected, **SRB** = sulforhodamine B dye detected.

As shown in both the charcoal detectors (Table 1) and the water samples (Table2), the two dyes were detected at McConnell's Spring (MN55:A0006) and at the mouth of Kinney Creek (X-8). (Charcoal detector X-8 was located downstream from A-6.) The recharge area encompassing the two introduction locations, sinkholes MN55:D0162 and MN55:D0133, are in the springshed of McConnell's Spring. This connection is shown diagrammatically by the magenta lines in Figure 13.

Dye was present in the charcoal detectors from McConnell's Spring and the mouth of Kinney Creek, which were change three days after dye introduction. The flow through time is therefore less than three days.

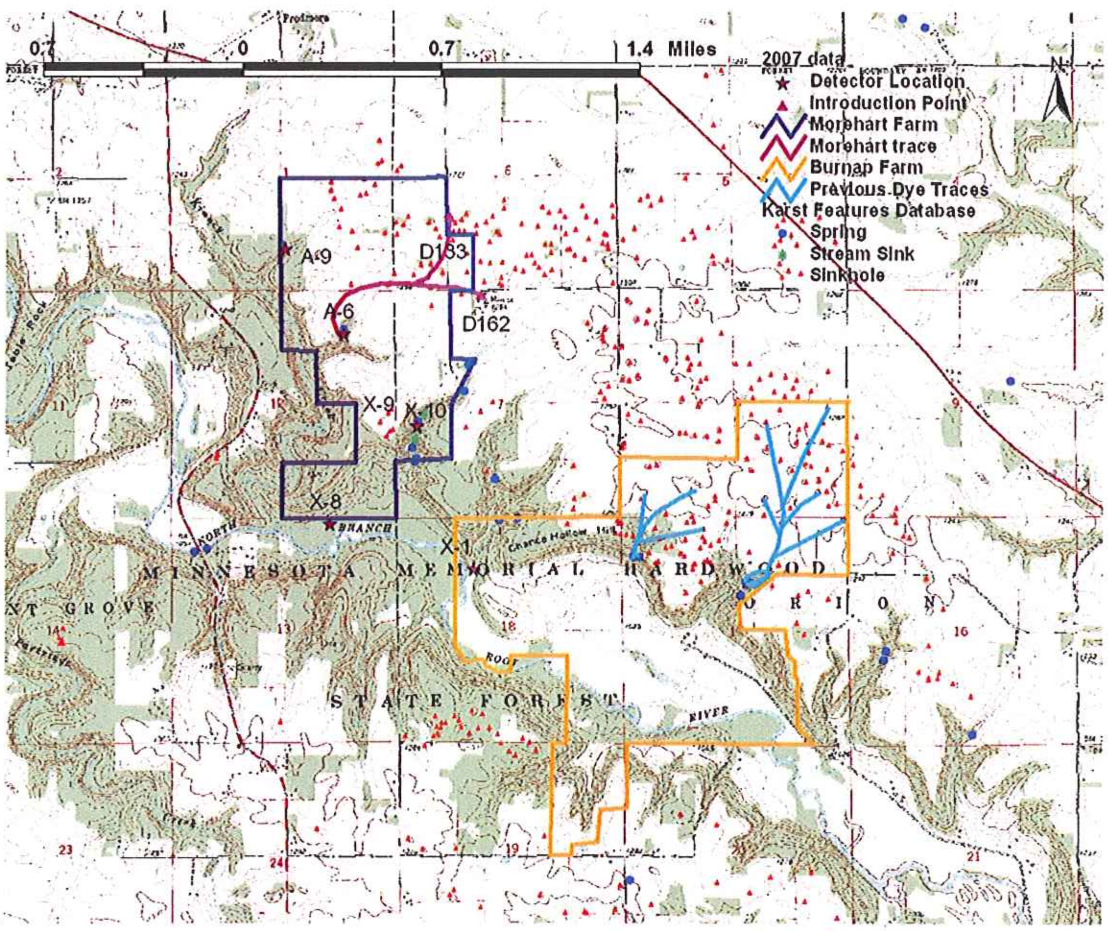

Figure 13. Springshed of McConnell's Spring: MN55:A0006

This trace was the initial determination of sinkhole to spring connection in the west part of the Orion Sinkhole Plain. It begins to define the springshed of McConnell's Spring and of the springsheds feeding Kinney Creek. Further traces are necessary to define the springsheds of the several springs in the study are. Future quantitative tracing can refine the conduit flow velocity determinations and refine knowledge of the relationships between the adjacent springsheds.

Acknowledgments

Many individuals and organizations assisted in making this research possible. First, The National Science Foundation Research Experience for Undergraduates Program made it possible for me to spend my summer at the University of Minnesota Department of Geology and Geophysics. Because of this program I was able to work with E. Calvin Alexander, Jr., whom guided and advised me in nearly every aspect of both this research and the finer facets of field work in Southeastern Minnesota. Thank you to my REU contacts here at the University of Minnesota, Marc Hirschmann and Sharon Kressler. Mr. Harland Morehart consented to our presence on his property to map this springshed. Thank you to the Chatfield Fire Department for the 2,700 gallons of water necessary for the trace and specifically to Tony Lammers and Brian Burkholder for their assistance on the day of the dye introduction. Lastly, thank you to Scott Alexander for being consistently approachable about all things laboratory and software related, Daniel Callahan, who never tired of the drive down Highway 52 and wild parsnip, and Viviana Lopez Burgos, a former REU intern, for her previous research.

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Appendix

Dye Analysis Spectra

Copies of the spectral decompositions of all of the scanning spectrofluorophotometric spectra from the water and charcoal eluent from samples analyzed in this work are available in pdf format from the authors on request.

Dye Tracing Within the St. Lawrence Confining Unit in Southeastern Minnesota

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ABSTRACT: Southeastern Minnesota's karst lands support numerous trout streams. These trout streams are formed by springs discharging from Paleozoic bedrock. Dye tracing has been the tool of choice for mapping the springsheds (karst groundwater basins) that feed these springs. Previous work was focused on the Galena limestone karst. In order to accelerate springshed mapping, a two-year study was funded by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR). Across southeastern Minnesota, numerous springs discharge from the Cambrian St. Lawrence formation. The St. Lawrence is considered to be a confining unit under the Minnesota well code. A dye trace was initiated when a stream sink was discovered in the upper St. Lawrence Formation. The sampling points included springs, stream crossings, and a municipal well that may be at risk for surface contamination. Dye was recovered at one spring in less than two weeks and at two other springs in less than three weeks. This translates into travel times of 200-300 meters/day. The springs all discharge from the lower St. Lawrence Formation. The St. Lawrence contains beds of dolostone; the dye trace demonstrates that there is a karst conduit flow component in this formation. This is evidence that these springs are significantly more susceptible to degradation than previously thought.

INTRODUCTION

Trout streams depend on a steady supply of clean, cold water. Southeastern Minnesota's karst lands contain 173 designated trout streams each of which is sourced from springs. Those springs are under increasing pressure from changing land use. Additional large groundwater withdrawals for energy production and other development loom in the future. Delineation of the recharge areas or springsheds of springs is a crucial first step in their protection (Paylor, 2001; Mull et al, 1998).

The primary tool for delineating springsheds has been dye tracing. Paleozoic bedrock aquifer systems serve as the water supply source for the trout stream springs. Virtually all of the trout stream springshed delineation efforts have been conducted in the Ordovician Galena limestone (Alexander et al.,1995; Green et al., 2005) . To date springsheds have been delineated for only 12 trout streams.

In southeastern Minnesota, numerous springs discharge from the Cambrian St. Lawrence Formation (Figure 1). The St. Lawrence is interbedded fine-grained sandstone, siltstone, dolostone and shale (Mossler, 2008). Groundwater chemistry and discharge measurements on selected St. Lawrence springs have demonstrated that they receive recent recharge. The St. Lawrence formation is considered to be a confining unit under the Minnesota Well Code but in shallow conditions the St. Lawrence functions as an aquifer and exhibits secondary porosity similar to that of fractured carbonate aquifers (Runkel et al., 2006). The hydrology of these springs has been studied only to a limited extent despite their importance for trout stream water supply.

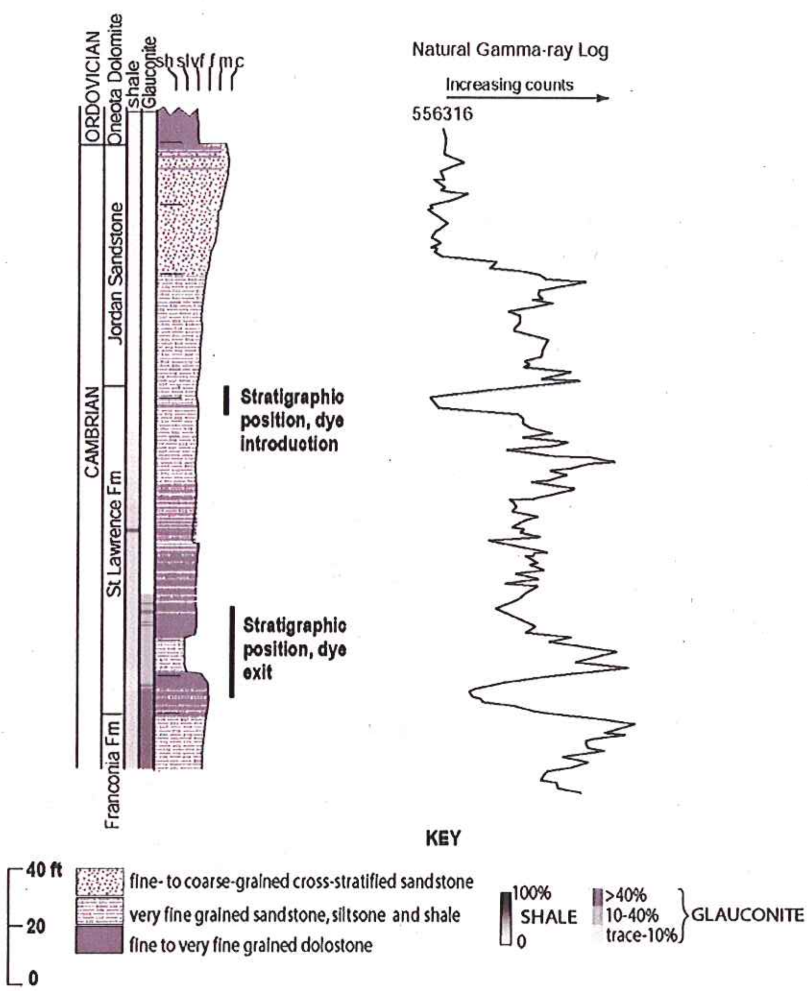

FIG. 1. Stratigraphic Column for Southeastern Minnesota.

In September of 2007, local government staff in the City of Rushford, Minnesota located a stream sink in Ahrensfeld Creek north of the city. Subsequent field investigation by the Minnesota Department of Natural Resources and the Minnesota Geological Survey determined that the stream sink is in the upper St. Lawrence Formation. City staff members were concerned that the sinking point was in hydraulic connection to the underlying Cambrian Tunnel City Group and Wonewoc Sandstone (Mossler, 2008) which serves as the city's primary water source. In order to investigate the hydraulic attributes of St. Lawrence springs and address the staff's concern, a dye trace was initiated in the fall of 2007.

METHODS

The Minnesota Karst Features Database (KFDB) (Gao et al., 2005) contained locations of several springs in the area of interest. Several more were located through a karst field hydrogeologic survey. Passive charcoal detectors were placed at these springs, selected stream crossings, and a City of Rushford municipal well (Figure 2). Background sampling was initiated on 25 October 2007 with charcoal detectors changed weekly.

On 1 November 2007, 3.6 Kg of 35 wt % solution of Uranine C (Lot #051807C-4 Chromatint, Color Index # 45350, Chem. Abs. # 518-47-8) were poured into the disappearing point of Ahrensfeld Creek. The flow in the stream was estimated at 500 l/min. which was all disappearing underground through the stream bed. The dye was poured into a riffle at the head of the sinking pool to facilitate mixing.

The charcoal detectors were changed weekly beginning on 8 November 2007. All charcoal detectors were returned to the University of Minnesota Geology & Geophysics Department Hydrochemistry Laboratory for analysis. There, the charcoal detectors were opened; the charcoal was removed; and using an eluent solution of 70% isopropyl alcohol, 30% deionized water, and 10g/L NaOH; the fluorescent materials were then extracted for analysis. This elutant was then run through the Shimadzu RF5000U scanning spectrofluorophotometer to detect and record the spectra; the water samples were analyzed in the same fashion. Spectral components, including the background spectral components, were quantified using PeakFit software (Alexander, 2005).

RESULTS

Dye was detected at a stream crossing sampling site 1-2 weeks after introduction. Subsequent air photo and field investigations determined that the dye was discharging from Ehlenfeldt Spring, which was not in the KFDB. The straight line distance from the stream sink to Ehlenfeldt Spring is approximately 2200 meters. Dye was detected in the 2-3 week samples at Wolfram Spring and Borson Spring which are 3500 meters and 4000 meters from the stream sink. This translates into time of travel of 150-300 meters/day which indicates karst conduit flow. All of these springs discharge from the lower part of the St. Lawrence formation. Spectra for selected samples from Borson Spring are presented in Figure 3. The Uranine C peak is at 514-515 nm. Dye has continued to discharge from the springs through March 2008, and it has not been detected at any other springs in that area or in the City of Rushford municipal well. The stream sink to spring connections discovered are shown in Figure 4 and are depicted based on standard methods (Ray, 2001)

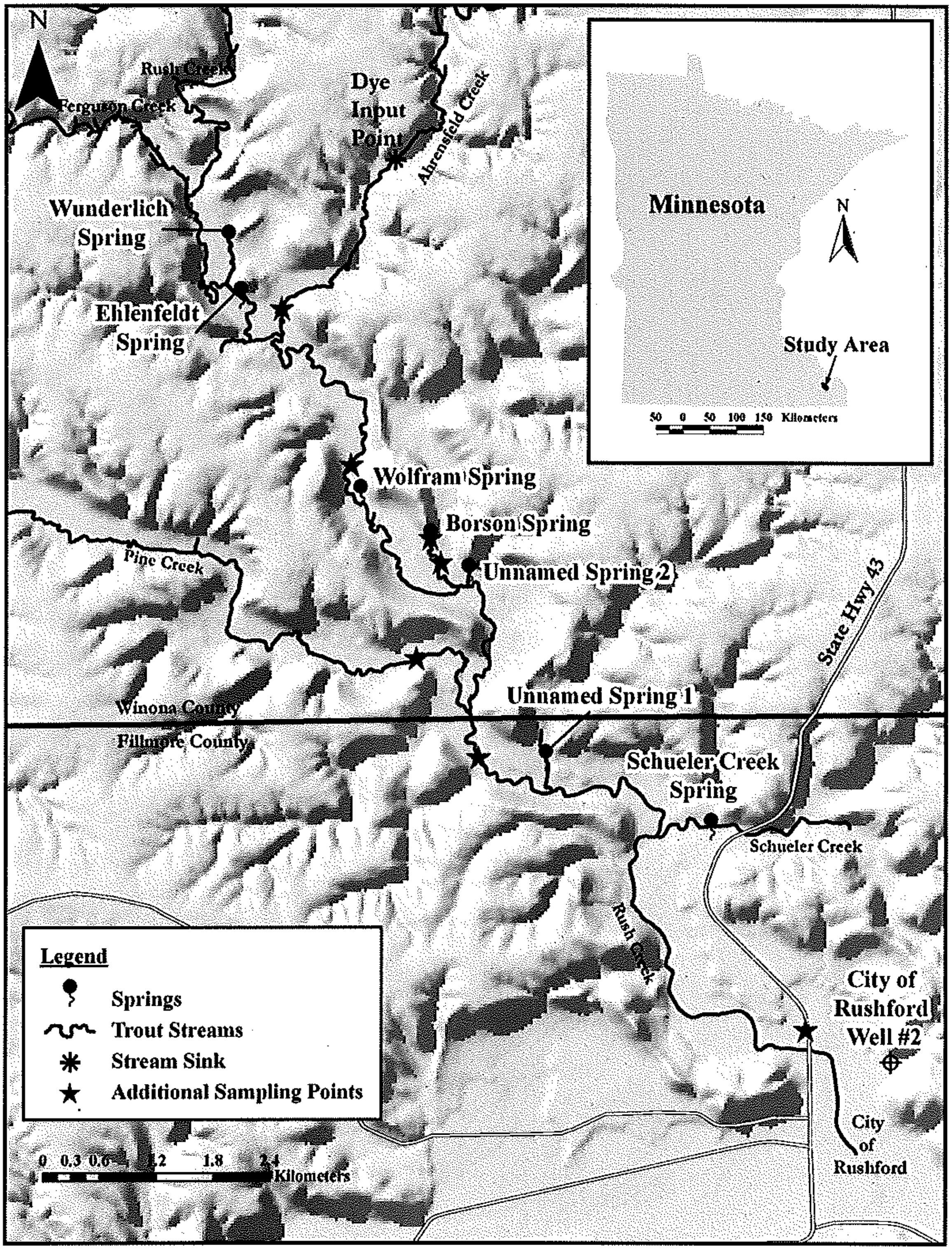

FIG. 2. Site Map of the Ahrensfeld Trace.

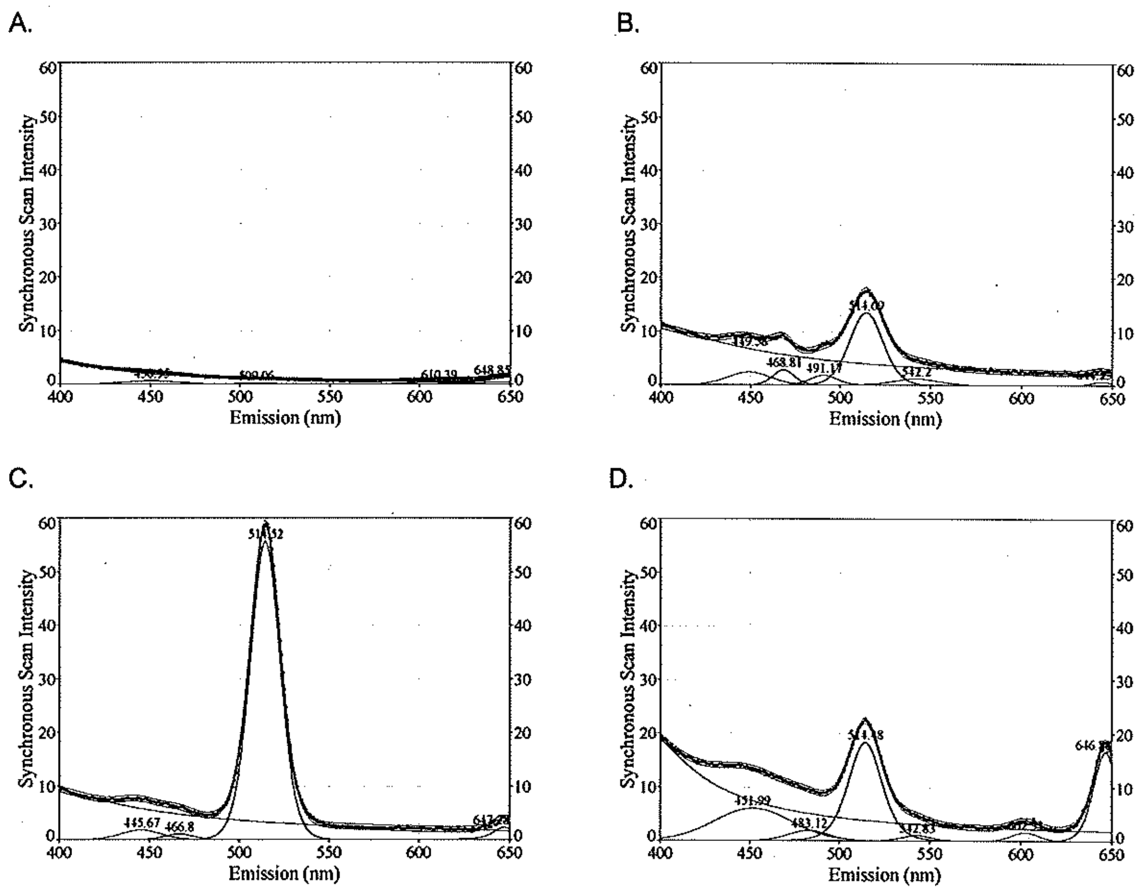

FIG. 3. Scans from Borson Spring bugs. In and out dates are: A. October 25-November 1, 2007; B. November 15-23, 2007; C. November 23-29, 2007; D. April 22-May 7, 2008.

DISCUSSION

To our knowledge this is the first dye trace to be run within the St. Lawrence Formation. This dye trace demonstrates a high velocity horizontal flow rate. Since the dye entered the top of the formation and exited at a point approximately 25m stratigraphically lower, it also demonstrates enhanced vertical hydraulic conductivity. Prior to this dye trace, it was generally believed that St. Lawrence springs served as discharge points for the overlying Prairie du Chien carbonate aquifer and the Jordan sandstone aquifer. Since these springs typically are at the base of a forested hill slope, it is believed that there is a recent recharge component from those slopes. There was no indication that there was a karst conduit flow component to their hydrology. The springs are typically large (flows greater than 600 l/min.) and serve as critical sources for trout streams. The discovery of the karst conduit flow component indicates that these springs are even more vulnerable to degradation than previously believed. One of the aspects of the springshed mapping project includes the development of Best Management Practices (BMPs) for spring and springshed protection (Currens, 2001). Prior to this dye trace, it was assumed that protecting the forested hillslopes above them was the key to water quality protection in St. Lawrence springs. Direct connections to surface water inputs will require the addition of watershed management components to the BMPs.

This dye trace also has improved our understanding of the hydrology of the landscape in southeastern Minnesota. The area is a dissected Paleozoic bedrock plateau that was missed by the last continental glaciation. The St. Lawrence springs often are found at the base of the nose of a bedrock ridge (Figure 4). A system of solution-enlarged conduits in the St. Lawrence that converge at these noses could explain this pattern.

The development of a karst conduit network would provide for the rapid flow rates seen in this dye trace and account for the dye resurgence at three separate springs several kilometers apart.

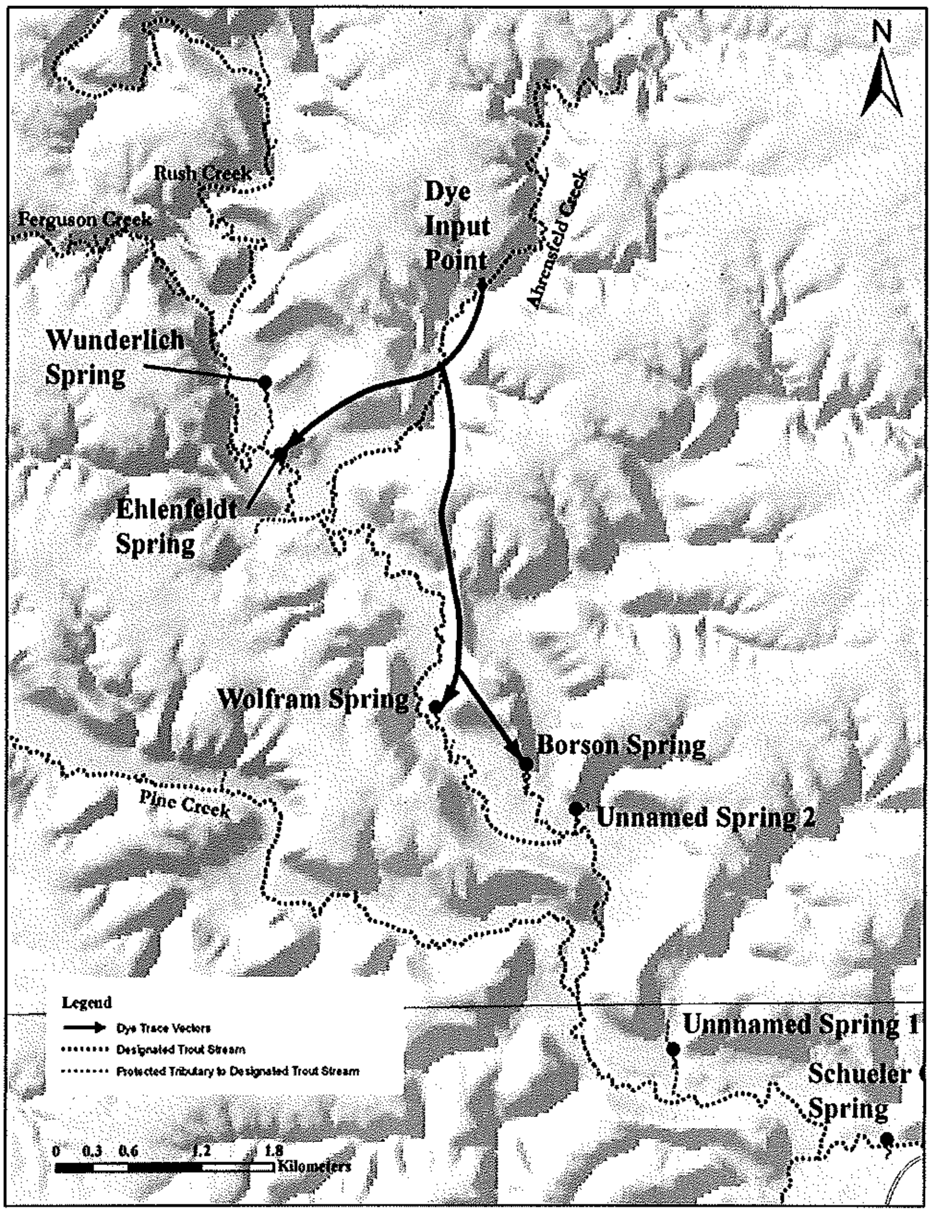

FIG. 4. Inferred Flow Routes and Spring Landscape Position.

SUMMARY

In response to a need for more detailed investigation into the hydrology of St. Lawrence Formation springs, a dye trace was initiated from a sinking stream in the upper St. Lawrence formation. The dye traveled to three down gradient lower St. Lawrence springs at rates of 150-300 meters/day. To our knowledge, this is the first time a dye trace has been run in the St. Lawrence and documents Runkel et al.'s (2006) conclusions that the St. Lawrence Formation is not everywhere a confining unit under shallow bedrock conditions.

ACKNOWLEDGEMENTS

Funding for this project was provided by Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR) and the Minnesota Department of Natural Resources-Division of Waters. This dye trace would not have been possible without the cooperation of local landowners and the City of Rushford's staff.

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North-Central Section - 43rd Annual Meeting (2-3 April 2009)
Paper No. 10-3
Presentation Time: 1:50 PM-2:10 PM

FLOW PATH CHARACTERIZATION USING SPRING THERMOGRAPHS

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Karst aquifers dominate the local and regional hydrogeology in southeastern Minnesota where a thick sequence of Paleozoic carbonate and siliciclastic rocks are found. These aquifers can be defined as triple permeability systems, where flow occurs through the matrix of the rock, fractures and bedding planes, and conduits. Continuous monitoring at springs of physical and chemical parameters allows the relative influence of each of these three flow components to be quantified. Springs fed by larger permeability components show more variable behavior as defined by storm events. Springs fed predominantly by matrix permeability portray relatively stable behavior. Other factors including basin size, conduit development and surface connectivity can influence spring responses.

Temperature probes are stable, sturdy and economical environmental probes allowing their deployment in multiple springs for time-scales of years. Spring temperature time series are dependent on flow path length and flow rate of waters feeding that spring. We summarize here field data from 25 time series spring temperatures in SE MN. A few springs shows stable thermal behavior, with seasonal fluctuations of less than 0.02°C. Many springs exhibit annual sinusoidal temperature cycles, varying by less than a few °C, which can be months out of phase with surface temperatures. Other springs portray greater variability, fluctuating more than 10°C following snowmelt or storm events.

Springs with a sinusoidal annual response may be a measure of lower permeability matrix and fracture flow paths based on how far out of phase their maxima and minima are from seasonal surface temperatures. Rapid response following storm events provides a measure of the higher permeability flow fracture and conduit flow components. However, storm events are rarely a single, spike input which can complicate the analysis. Spring snowmelt often produces a periodic, repeating temperature signal over several days to weeks. Snowmelt can therefore provide an alternative input function to complex inputs from rain storms.

Temperature monitoring of springs can provide a low cost method to help elucidate bedrock

flow characteristics and basin size. Thermographs can be used to help design more efficient dye traces, especially in systems with flow paths that are months to years long.

North-Central Section - 43rd Annual Meeting (2-3 April 2009)
General Information for this Meeting

Session No. 10
Water Resources in Karst Terranes of the Midwestern U.S.
Northern Illinois University Rockford: 201
1:00 PM-5:00 PM, Thursday, 2 April 2009

Geological Society of America *Abstracts with Programs*, Vol 41, No. 4, p. 17

Forestville North Dye Trace

September 5, 2008 to November 12, 2008

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Introduction

A dye trace was conducted in an area near Forestville State Park in Minnesota from September 5, 2008 to November 12, 2008 (Figure 1). Numerous dye traces have been completed in this area in the past and this effort was made in order to better delineate the springsheds in this area due to the close proximity of numerous State of Minnesota designated trout streams. Achieving a better understanding of the connection of these sinkholes receiving surface water flow and their connectivity to springs that provide a cold water source for the designated trout streams in the area was the goal of this trace.

However, the goal of this trace was two-fold, one sinkhole that received dye, Minnesota Karst Feature Database number 23:D2474, had previously been studied and was shown to be connected to cold water sources for two trout streams. The previous dye trace was completed during wet, spring conditions and this trace was completed during a much drier time in the late fall. Completing the trace during these differing conditions may help to better understand the seasonal changes of the subsurface flow of groundwater.

Dye tracing entails using fluorescent dyes to track groundwater flow directions and travel times. The dye is poured into a sinkhole or sinking stream; from there, it flows through the karst conduit system until it re-emerges at a spring or springs. For this project, the dyes used were Eosine and Rhodamine WT. Both direct water samples and passive dye detectors were used and all the samples were analyzed at the University of Minnesota Geology Department using a scanning spectrofluorophotometer. The traces were designed and executed by Jeff Green and Andrew Peters of MNDNR Waters. E. Calvin Alexander, Jr., Andrew Luhmann, and Scott Alexander of the University of Minnesota Geology Department performed the sample analysis and interpretation.

Results

The MNDNR Waters and the Fillmore County SWCD had previously contacted the landowners who owned the relevant sinkholes and springs. Prior to dye injection, bugs had been placed at all the sampling points to determine background levels of dyes. The dye trace began on September 5, 2008, using water provided by MNDNR. Table 1 summarizes the dye input information.

Dye Inputs				
Dye Input Point	Dye (type, quantity)	Time	Water Input (Est.)	Dye Detection Point
Sinkhole 23:D2474	Eosine, 1,090 grams	1423 hrs.	500 Gallons	Springs 23:A002 and 23:A003
Sinkhole 23:D2140	Rhodamine WT, 632 grams	1529 hrs.	500 Gallons	Springs 23:A002 and 23:A003

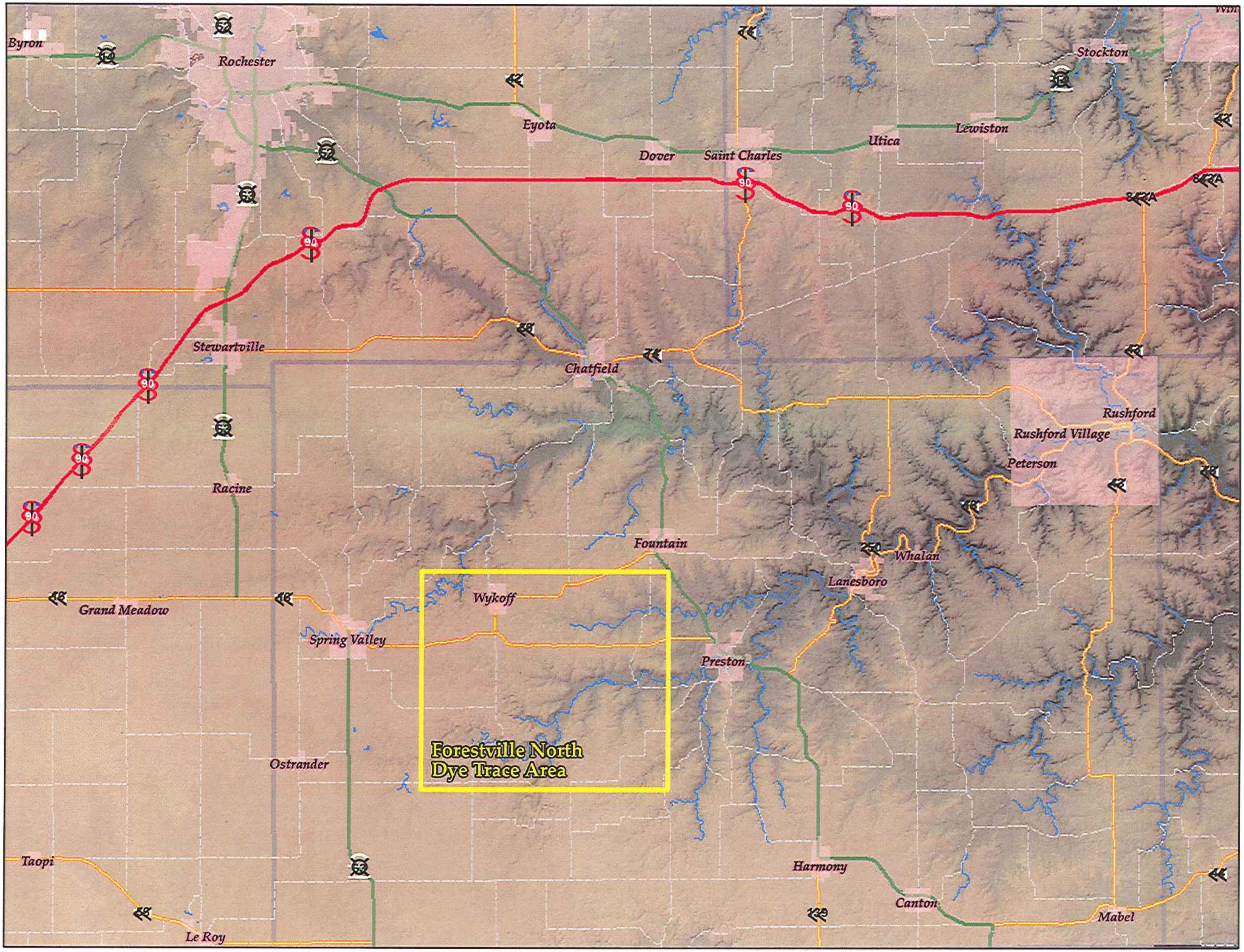
Table 1: Dye Inputs, Forestville North Dye Trace, Minnesota

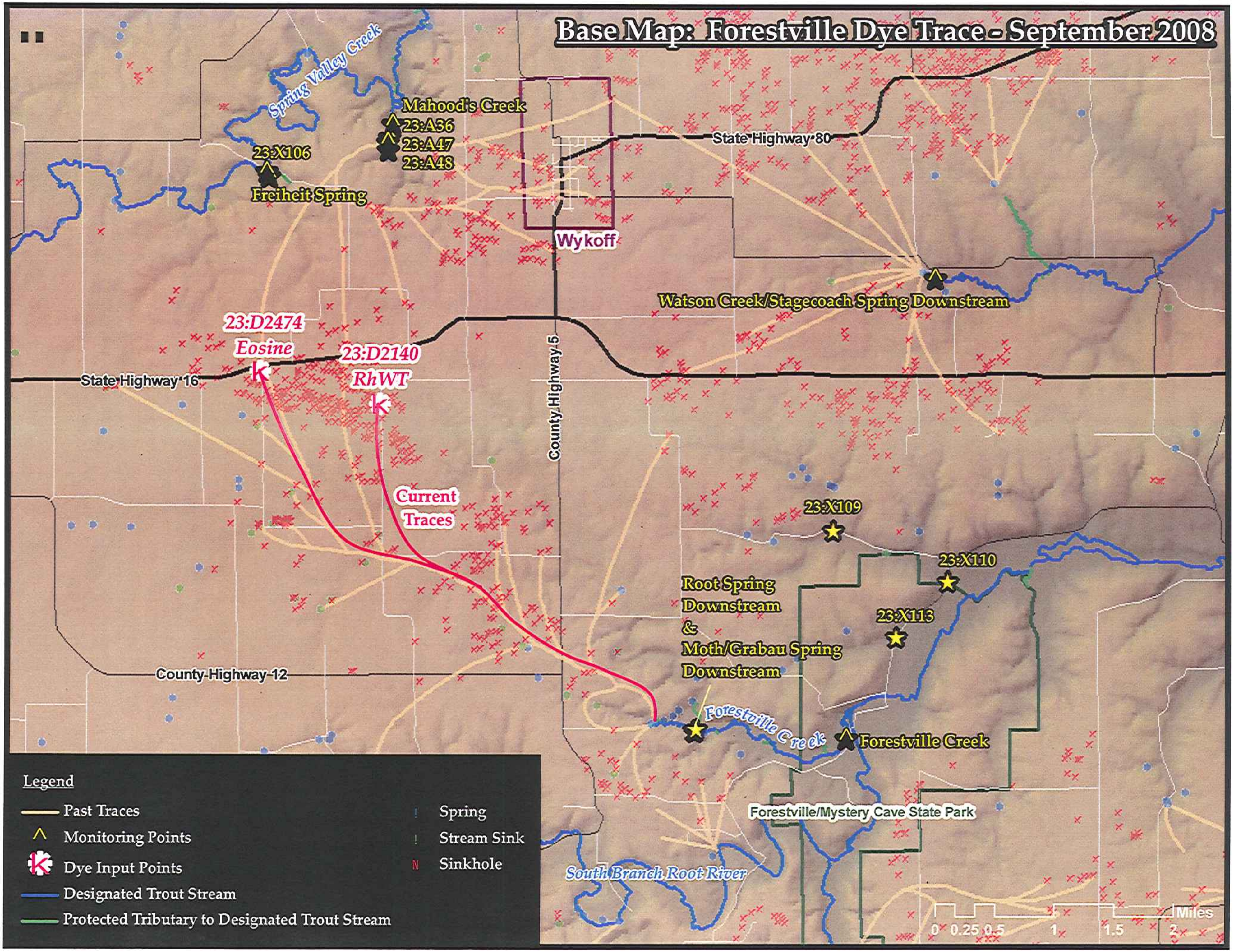
Direct water samples were collected and charcoal dye detectors were in placed at all sampling locations from the start of the trace until mid-November. Both dyes were detected at levels high enough for positive identification. The dyes, Rhodamine WT and Eosine, were detected in the charcoal detectors no more than 18 days later. This translates to a groundwater flow rate of no greater than approximately 0.20 to 0.25-mile per day. This is consistent with previous traces in this geologic setting (Ordovician Galena limestone).

The dye input points and their known connections from this dye trace in addition to previously completed traces are shown in Figure 2. Through this double trace, we have further delineated the springshed feeding springs 23:A002 & 23:A003. This new trace has expanded the known boundaries of that springshed. In addition, sinkhole 23:D2474 was shown in this trace to be connected only to springs 23:A002 & 23:A003 that are a cold water source for Forestville Creek. Previously this sinkhole was thought to be connected to two separate springs and respective trout streams. This trace has shown that the connection of subsurface water flows from sinkholes to springs in this area may be governed by seasonal fluctuations and the respective amount of subsurface waters during times of drought or, conversely, wet periods.

Appendix 1

Figures


Byron
Rochester
Stockton
Eyota
Lewiston
Dover
Saint Charles
Utica
Stewartville
Chatfield
Rushford
Rushford Village
Peterson
Racine
Fountain
Whalan
Lanesboro
Wykoff
Grand Meadow
Spring Valley
Preston
Forestville North
Dye Trace Area
Ostrander
Taopi
Harmony
Canton
Mabel
Le Roy



Base Map: Forestville Dye Trace - September 2008
Spring Valley Creek
Mahood's Creek
23:A36
23:A47
23:A48
23:X106
Freiheit Spring
State Highway 80
Wykoff
Watson Creek/Stagecoach Spring Downstream
23:D2474
Eosine
23:D2140
RhWT
State Highway 16
County Highway 5
Current
Traces
23:X109
23:X110
23:X113
Root Spring
Downstream
&
Moth/Grabau Spring
Downstream
County Highway 12
Forestville Creek
Forestville Creek
Forestville/Mystery Cave State Park
South Branch Root River
Legend
Past Traces
Monitoring Points
Dye Input Points
Designated Trout Stream
Protected Tributary to Designated Trout Stream
Spring
Stream Sink
Sinkhole
0 0.25 0.5 1 1.5 2
Miles

Appendix 2

Dye Input

Forestvile North Dye Trace: September 5, 2008 to November 12, 2008

Dye Input Points:

Input Point #1:

Sinkhole D2474:	**Minnesota Karst Feature Database Number - MN23:D2474**
UTM:	**554,847 E, 4,836,815 N**
Township, Range, Section:	**SE ¼ of the NW ¼ of Section 31, T103N, R12W**
Elevation:	**~1330 feet**

At 1423 CDT on 5 September 2008, approximately 1,090 grams of Eosine dye solution was introduced into an open swallow hole in D2474 with approximately 500 gallons of water.

Input Point #2:

Sinkhole D2140:	**Minnesota Karst Feature Database Number - MN23:D2140**
UTM:	**556,472 E, 4,836,376 N**
Township, Range, Section:	**NE ¼ of the SW ¼ of Section 32, T103N, R12W**
Elevation:	**~1345 feet**

At 1529 CDT on 5 September 2008, approximately 632 grams of Rhodamine WT dye solution was introduced into an open swallow hole in D2140 with approximately 500 gallons of water.

Forestville North Trace 5 Sept 2008
Sunny, 70°F J.G./A.P.

Sinkhole 554847/4836815 ±197 ft
Chromatint Red Eosine 0143
Lot 020706 Chromatech
500 gal DNR tank 1.09 Kg
Dye @ 1423, Water start @
1419, end @ ≈1428
Water sinking in 3 small
swallets, no ponding
Sinkhole was traced to [illegible] during
1993-94 Fillmore [illegible] Atlas
Springshed Map tracing

Sinkhole 556472/4836376 ±30 ft.
Rhodamine WT Chromatech
Chromatint Lot # 041807E
529.5 gm
Crompton & Knowles RhWT 102.8 gm
Water start 1529, end 1536 ≈500 gal.
from DNR tank
Dye @ 1531, no ponding
sinkhole has a 1m wide & 1m deep
collapse in bottom - Water sprayed
in that, drained into a 10 cm hole.

Frego Creek Spring 2009 Dye Trace

March 6, 2009 to May 5, 2009

Jeffrey A. Green, Andrew J. Peters[1], Andrew J. Luhmann[2],
E. Calvin Alexander, Jr.[2] and Scott C. Alexander [2]

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emails: luhm0031@umn.edu, alexa001@umn.edu & alexa017@umn.edu

Introduction

A dye trace was conducted in an area near the city of Canton, Minnesota from March 6, 2009 to May 5, 2009. Dye traces have been completed in this area in the past and this effort was made to further refine delineation the springsheds in this area due to the close proximity of Frego Creek, a Minnesota designated trout stream. Much of the city of Canton's stormwater flows to sinkholes throughout the city limits and some just outside of city limits. Achieving a better understanding of the connection of these sinkholes receiving this stormwater flow and their connectivity to springs that provide a cold water source for Frego Creek was the goal of this trace.

Dye tracing entails using fluorescent dyes to track groundwater flow directions and travel times. The dye is poured into a sinkhole or sinking stream; from there, it flows through the karst conduit system until it re-emerges at a spring. For this project, the dyes used were Uranine, Eosine, and Rhodamine WT. Both direct water samples and passive dye detectors were used for sample collection and all the samples were analyzed at the University of Minnesota Geology Department using a scanning spectrofluorophotometer. The traces were designed and executed by Jeff Green and Andrew Peters of MNDNR Waters. E. Calvin Alexander, Jr., Andrew Luhmann, and Scott Alexander of the University of Minnesota Geology Department performed the sample analysis and interpretation.

Results

The MNDNR Waters and the Fillmore County SWCD had previously contacted the landowners who owned the relevant sinkholes and springs. Prior to dye injection, bugs had been placed at all the sampling points to determine background levels of dyes. The dye trace was run on March 6, 2009, using runoff from melting snow. Table 1 summarizes the dye input information.

Dye Inputs				
Dye Input Point	Dye (type, quantity)	Time	Runoff (Est.)	Dye Detection Point
Sinkhole 23:D7964	Eosine, 509.96 grams	15:46 hrs.	8-16 G.P.M.	Spring A445 (A632)
Sinkhole 23:D7648	Rhodamine WT, 485.96 grams	15:26 hrs.	10-15 G.P.M.	Spring A445 (A632)
Sinkhole 23:D7963	Uranine, 506.14 grams	15:04 hrs.	10-20 G.P.M.	Spring A445 (A632)

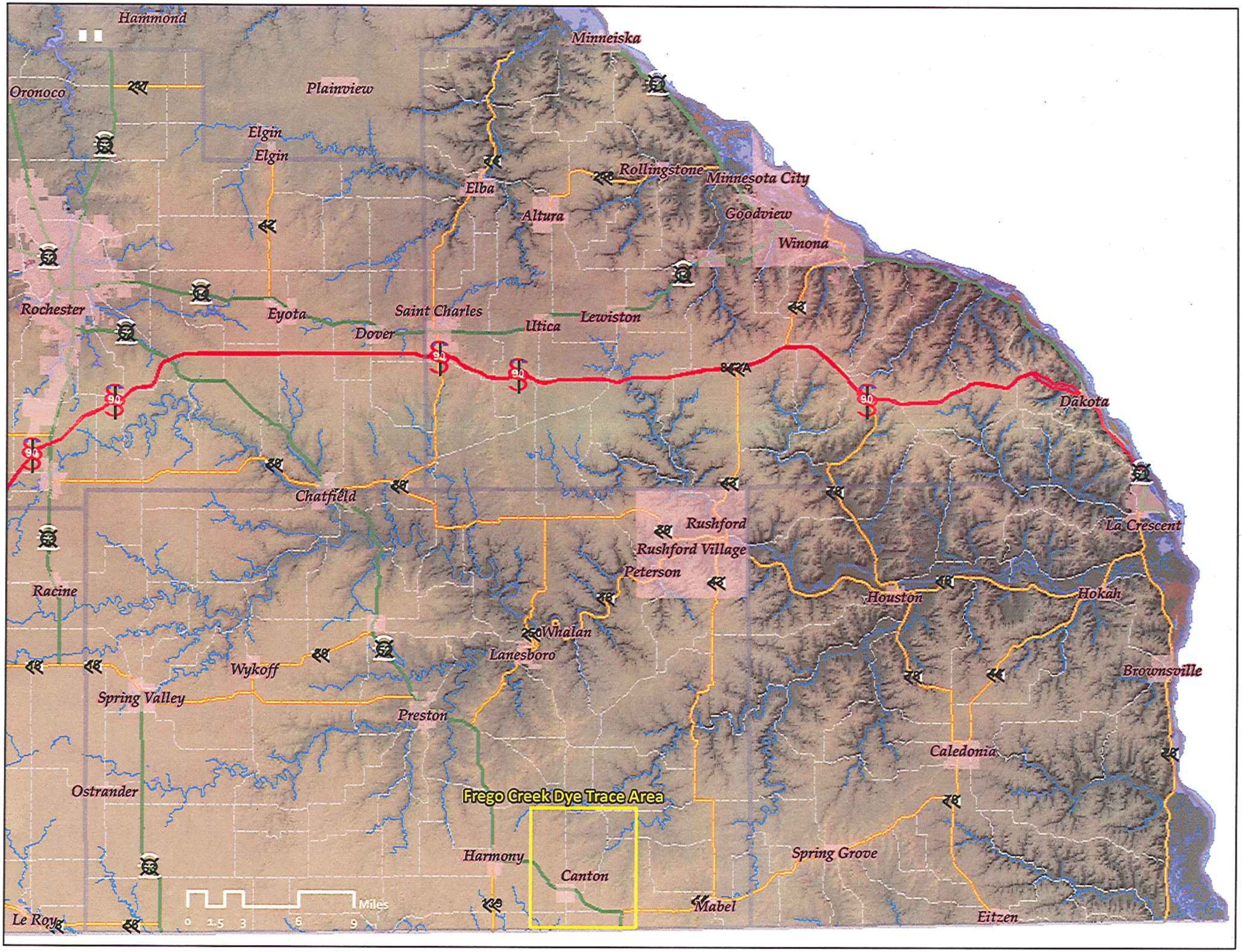
Table 1: Dye Inputs, Frego Creek Dye Trace, Canton, Minnesota

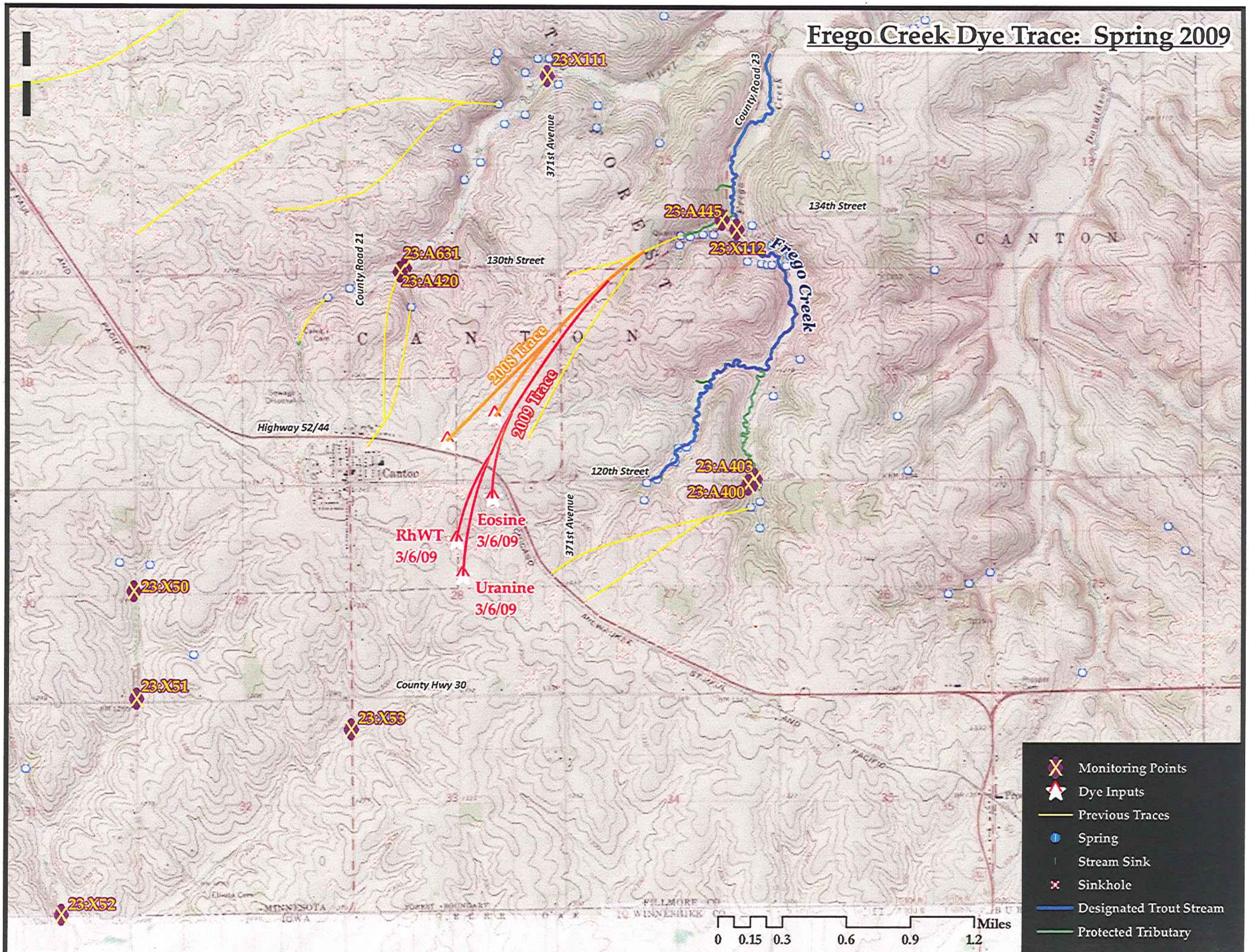
Dye receptors were in place at all sampling locations from March 6th until May 5th. All three dyes were detected at levels high enough for positive identification. The dyes, Eosine, Rhodamine WT and Uranine, were detected in the charcoal detectors no more than 10 days later. This translates to a groundwater flow rate range of no greater than approximately 775 feet to 988 feet per day. This is consistent with previous traces in this geologic setting (Ordovician Galena limestone).

The dye points and connections from this dye trace in addition to previously completed traces are shown in Figure 2. Through this triple trace, we have further delineated the springshed feeding Spring A445 (A632). There are several springs visible in the immediate area of A445 (A632) but they all feed the same coldwater tributary to Frego Creek. The new trace from these sinkholes that was detected in the flow from the springs in this area has expanded the known boundaries of that springshed.

Appendix 1

Figures


Hammond
Minneiska
Oronoco
Plainview
Elgin
Elgin
Rollingstone
Minnesota City
Elba
Altura
Goodview
Winona
Rochester
Eyota
Saint Charles
Dover
Utica
Lewiston
Dakota
Chatfield
Rushford
Rushford Village
Peterson
La Crescent
Racine
Houston
Hokah
Whalan
Lanesboro
Wykoff
Spring Valley
Preston
Brownsville
Caledonia
Ostrander
Frego Creek Dye Trace Area
Harmony
Canton
Spring Grove
Miles
0 1.5 3 6 9
Le Roy
Mabel
Eitzen



Frego Creek Dye Trace: Spring 2009
23:X111
23:A445
23:X112
23:A631
23:A420
23:A403
23:A400
23:X50
23:X51
23:X53
23:X52
County Road 23
County Road 21
371st Avenue
134th Street
130th Street
120th Street
Highway 52/44
County Hwy 30
Frego Creek
2008 Trace
2009 Trace
Eosine
3/6/09
RhWT
3/6/09
Uranine
3/6/09
CANTON
Canton
0
0.15
0.3
0.6
0.9
1.2
Miles
Monitoring Points
Dye Inputs
Previous Traces
Spring
Stream Sink
Sinkhole
Designated Trout Stream
Protected Tributary

Appendix 2

Dye Input

Frego Creek Spring 2009 Dye Trace: March 6, 2009 to May 5, 2009

Dye Input Points:

Input Point #1:

Sinkhole D:7964	**Minnesota Karst Feature Database Number - MN23:D7964**
UTM:	**587,581 E, 4,820,094 N**
Township, Range, Section:	**NW ¼ of the NE ¼ of Section 28, T101N, R9W**
Elevation:	**~1320 feet**

At 1546 CDT on 3 March 2009, approximately 510 grams of Eosine dye solution was introduced into an open swallow hole in D7964 during flow of approximately 8-16 gallons per minute of snow melt runoff into the swallow hole.

Input Point #2:

Sinkhole D7648:	**Minnesota Karst Feature Database Number - MN23:D7648**
UTM:	**587,308 E, 4,819,765 N**
Township, Range, Section:	**SW ¼ of the NE ¼ of Section 28, T101N, R9W**
Elevation:	**~1330 feet**

At approximately 1526 CDT on 3 March 2009, approximately 486 grams of Rhodamine WT dye solution was introduced into an open swallow hole in D7648 during flow of approximately 10–15 gallons per minute of snow melt runoff into the swallow hole.

Input Point #3:

Sinkhole D7963:	**Minnesota Karst Feature Database Number - MN23:D7963**
UTM:	**587,357 E, 4,819,503 N**
Township, Range, Section:	**SW ¼ of the NE ¼ of Section 28, T101N, R9W**
Elevation:	**~1345 feet**

At approximately 1504 CDT on 3 March 2009, approximately 506 grams of Uranine dye solution was introduced into an open swallow hole in D7963 during flow of approximately 10-20 gallons per minute of snow melt runoff into the swallow hole.

3/6/09: Fargo Pour - 50°F, Sunny

Pour #1: Uranine 4819503, 587357
Lot#: 041808C 506.14 gm
1504 poured 10-20 gpm
Chromatint, Uranine HS *into swallet.

Pour #2: RhWT 4819765, 587308
Lot: 041807E 485.96 gm
1526 poured 10-15 gpm
Chromatint, RhWT *into run above swallet

Pour #3: Eosine 4820094, 587581
Lot: 020706 509.96 gm
1546 poured 8-16 gpm
Chromatint Red 0143 Liquid
* into swallet under snow and ice

Appendix 3

Dye Receptors

Frego Creek Dye Trace: March 3, 2009 to May 5, 2009

Dye Receptor Locations:

Dye Receptor #1:
23:A631 Minnesota Karst Feature Database Number - MN23:A631
UTM: 586,868 E, 4,821,780 N
Notes: Receptor located on north side of spring. Accessed through farm.

Dye Receptor #2:
23:A420 Minnesota Karst Feature Database Number - MN23:A420
UTM: 586,841 E, 4,821,756 N
Notes: Receptor located south side of road on the east side of culvert

Dye Receptor #3:
23:A445 Minnesota Karst Feature Database Number - MN23:A445
UTM: 589,265 E, 4,822,137 N
Notes: Receptor located on west side of county road 23 along the north side of the culvert

Dye Receptor #4:
23X112 Minnesota Karst Feature Database Number - MN23:X112
UTM: 589,375 E, 4,822,077 N
Notes: Receptor located on the south side of the road tied to small tree on the west side of the east culvert

Dye Receptor #5:
23:A403 Minnesota Karst Feature Database Number - MN23:A403
UTM: 589,514 E, 4,820,195 N
Notes: Receptor located in culvert and is tied to debris on the south side of 120th street

Dye Receptor #6:
23:A400 Minnesota Karst Feature Database Number - MN23:A400
UTM: 589,551 E, 4,820,220 N
Notes: Receptor located just upstream of 23:A403 along the west side of the stream

Dye Receptor #7:

23:X111 Minnesota Karst Feature Database Number - MN23:X111

UTM: 588,000 E, 4,823,275 N

Notes: Receptor located on the west side of the road dangling from a tree above the south culvert

Dye Receptor #8:

23:X50 Minnesota Karst Feature Database Number - MN23:X0050

UTM: 584,873 E, 4,819,376 N

Notes: Receptor is tethered to a sign post on the west side of the road in a culvert

Dye Receptor #9:

23:X51 Minnesota Karst Feature Database Number - MN23:X0051

UTM: 584,894 E, 4,818,567 N

Notes: Receptor is tethered to a tree branch on the east bank of the stream approximately 30 feet upstream of the road crossing

Dye Receptor #10:

23:X52 Minnesota Karst Feature Database Number - MN23:X0052

UTM: 584,337 E, 4,816,942 N

Notes: Receptor is tethered to a bridge post near the southeast corner of the bridge

Dye Receptor #11:

23:X53 Minnesota Karst Feature Database Number - MN23:X0053

UTM: 586,518 E, 4,818,341 N

Notes: Receptor is on the east, upstream side of crossing. The receptor is buried under a large limestone rock near other large limestone slabs in the waterway, approximately 30 feet upstream of the road crossing.

Appendix 4

Summary of Analytical Results

Frego Creek Spring 2009 Dye Trace: Summary of Analytical Results				
Sampling Location	**3/6/09 to 3/16/09**	**3/16/09 to 3/23/09**	**3/23/09 to 4/8/09**	**4/8/09 to 5/4/09**
23:A400	ND	ND	-	ND
23:A403	ND	ND	-	ND
23:A420	ND	ND	ND	ND
23:A631	ND	ND	ND	ND
23:A445	**E*, WT*, U***	**E*, WT*, U***	**E*, WT*, U***	**E*, WT*, U***
23:X111	-	-	-	-
23:X112	ND	ND	ND	ND
23:X50	ND	ND	ND	ND
23:X51	ND	ND	ND	ND
23:X52	ND	ND	ND	ND
23:X53	ND	ND	ND	ND

*** E – Eosine, WT – Rhodamine WT, U – Uranine**

ND – No Detections

Appendix 5

Scanning Spectrofluorophotometer Results

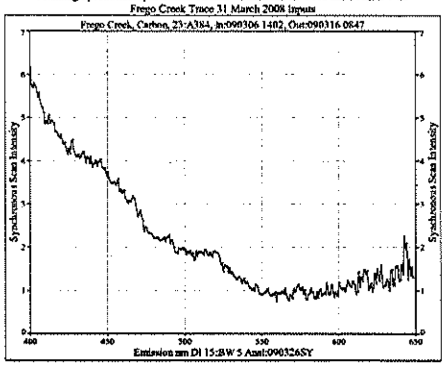
The following analytical results were completed by project participants associated with the Geology & Geophysics Department at the University of Minnesota. Analysis of the samples was completed by Andrew J. Luhmann[2] and Scott C. Alexander[2]. Interpretation of the analytical results was completed by Jeffrey A. Green[1], Andrew J. Peters[1], Andrew J. Luhmann[2], E. Calvin Alexander, Jr.[2] and Scott C. Alexander[1].

[1] Minnesota Department of Natural Resources, Division of Waters, 2300 Silver Creek Road NE, Rochester, Minnesota, 55906; Phone (507) 285-7430; Fax (507) 285-7144; emails: jeff.green@dnr.state.mn.us & andrew.peters@dnr.state.mn.us

[2] Geology & Geophysics Department, University of Minnesota, 310 Pillsbury Drive. SE., Minneapolis, Minnesota, 55455; Phone (612) 624-3517; Fax (612) 625-3819; emails: luhm0031@umn.edu, alexa001@umn.edu & alexa017@umn.edu

Archived file source: Andrew Peters – D:/Documents/Final Trace Reports/Frego Creek Spring 2009/FregoCreekSpring2009AllCurves

Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



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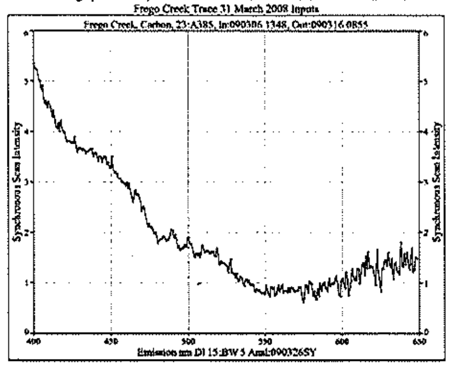
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



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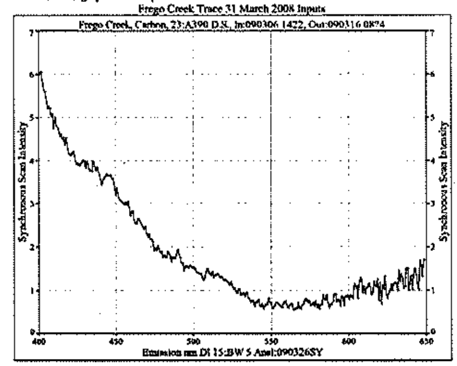
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



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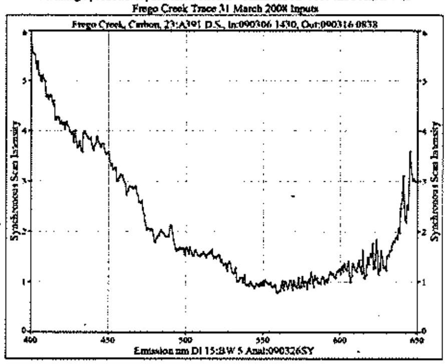
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



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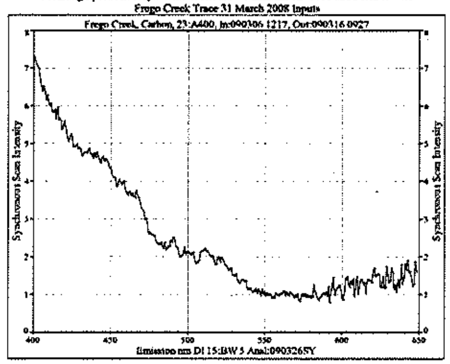
Frego Creek Trace 31 March 2008 Inputs



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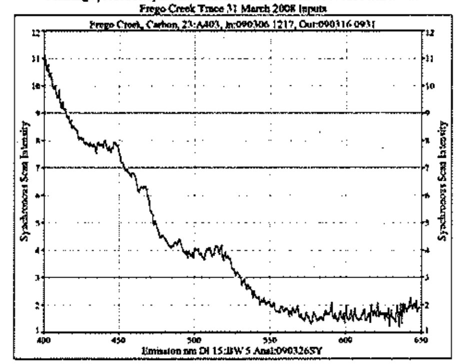

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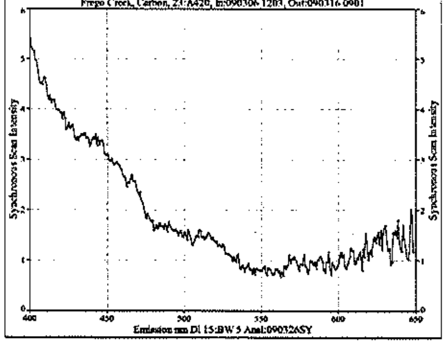
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



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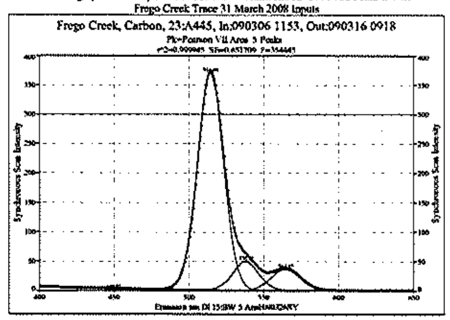
Frego Creek Trace 31 March 2008 Inputs



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X Variable: Emission nm ΔλA 15:BW 5 Anal:090326SY
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek090306-090316\fo450316

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99994452	0.99994150	0.65170879	3.5445e+05

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	7085.69858	351.882412	109.212643	0.58151718
2	Pearson VII Area	24.9259650	449.712640	25.2873560	10.0000000
3	Pearson VII Area	7899.65302	514.678789	19.8220610	17.7307058
4	Pearson VII Area	1114.91282	538.155000	20.0721097	5.66515020
5	Pearson VII Area	899.756819	564.850532	23.0028107	32.4498177

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	12.6089563	370.402299	128.241797	0.55179789	0.00000000	0.00000000
2	Pearson VII Area	0.90643277	449.712639	25.2873560	1.00000013	52.8190100	1.00000007
3	Pearson VII Area	370.018703	514.676738	19.8220610	1.00000023	40.6321407	1.00000012
4	Pearson VII Area	50.1622705	538.155000	20.0721097	1.00000000	43.3715510	1.00000000
5	Pearson VII Area	36.5144160	564.850532	23.0028107	1.00000000	46.6430182	1.00000000

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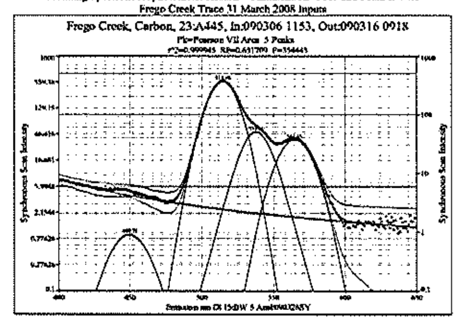
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



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Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek090306-090316\fo450316

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99994452	0.99994150	0.65170879	3.5445e+05

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	7085.69858	351.882412	109.212643	0.58151718
2	Pearson VII Area	24.9259650	449.712640	25.2873560	10.0000000
3	Pearson VII Area	7899.65302	514.678789	19.8220610	17.7307058
4	Pearson VII Area	1114.91282	538.155000	20.0721097	5.66515020
5	Pearson VII Area	899.756819	564.850532	23.0028107	32.4498177

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	12.6089563	370.402299	128.241797	0.55179789	0.00000000	0.00000000
2	Pearson VII Area	0.90643277	449.712639	25.2873560	1.00000013	52.8190100	1.00000007
3	Pearson VII Area	370.018703	514.676739	19.8220610	1.00000000	40.6321407	1.00000000
4	Pearson VII Area	50.1622705	538.155000	20.0721097	1.00000000	43.3715510	1.00000000
5	Pearson VII Area	36.5144160	564.850532	23.0028107	1.00000000	46.6430182	1.00000000

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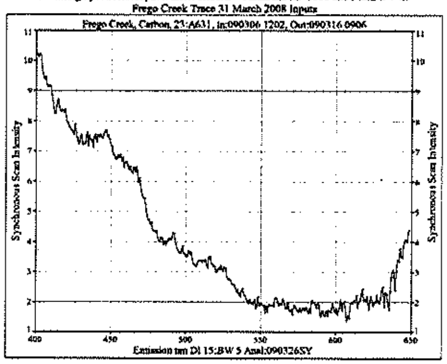
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



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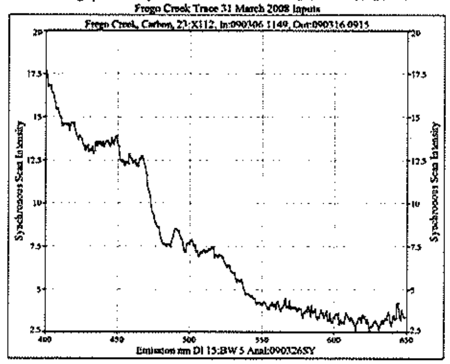

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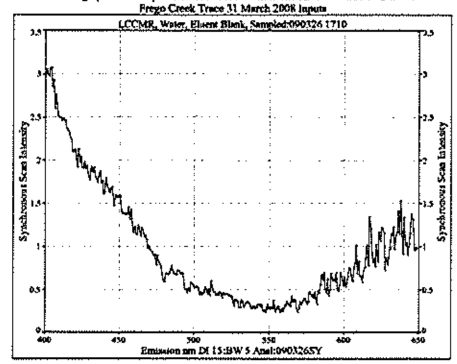

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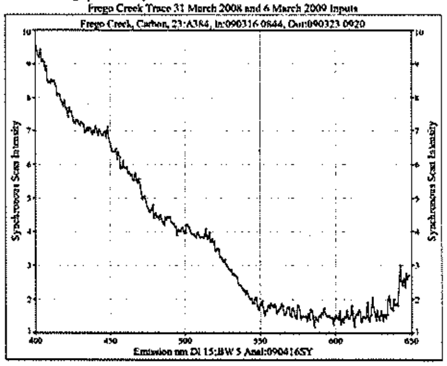
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 and 6 March 2009 Inputs



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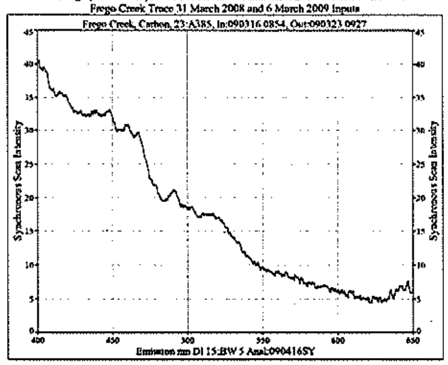

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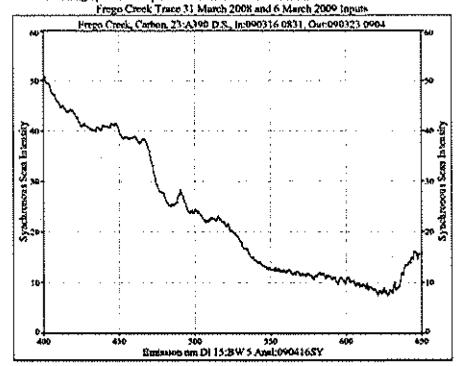

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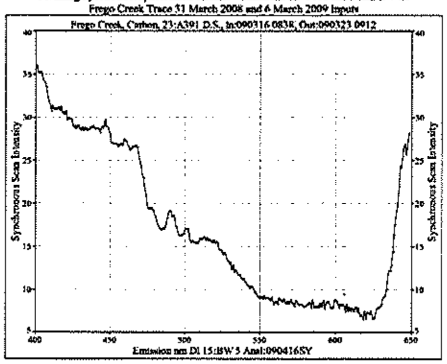

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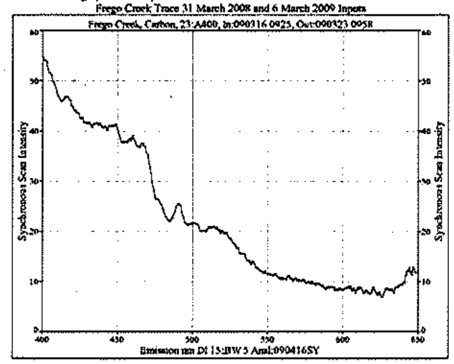

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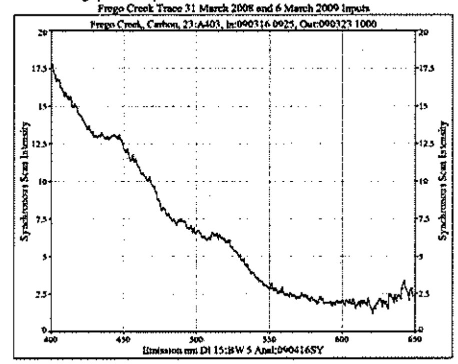

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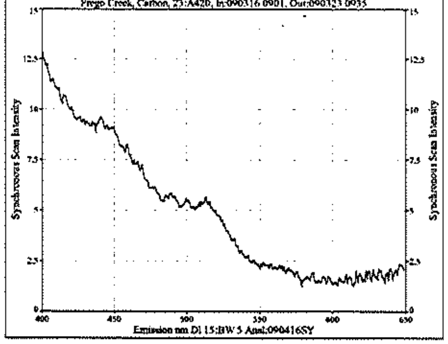

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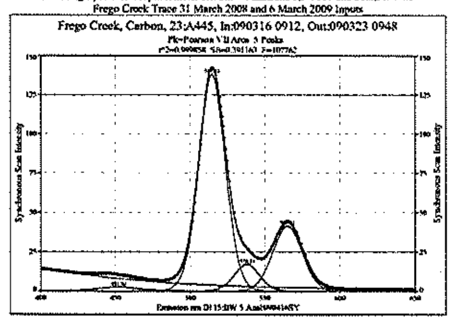

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Y Variable: Synchronous Scan Intensity
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Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99985789	0.99984809	0.39116268	1.0776e+05

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	4358.92404	363.678700	170.681165	1.05773932
2	Pearson VII Area	126.091551	451.921275	36.8140188	1.41647704
3	Pearson VII Area	3043.81353	514.834229	20.3022561	10.2096495
4	Pearson VII Area	372.278346	538.126262	19.7257765	7.02873489
5	Pearson VII Area	1018.87669	565.314382	22.8154449	14.7061787

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	16.8555491	365.229885	170.735452	0.96430731	0.00000000	0.00000000
2	Pearson VII Area	2.57968370	451.921274	36.8140188	1.00000015	103.643042	1.00000006
3	Pearson VII Area	137.931116	514.834229	20.3022561	1.00000004	42.3684798	1.00000002
4	Pearson VII Area	17.1856321	538.126262	19.7257765	1.00000000	41.9753254	1.00000000
5	Pearson VII Area	41.3586291	565.314380	22.8154449	1.00000034	47.0009134	1.00000018

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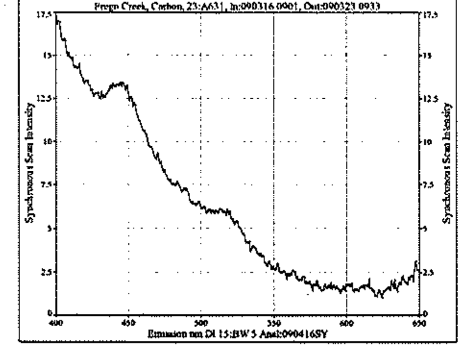

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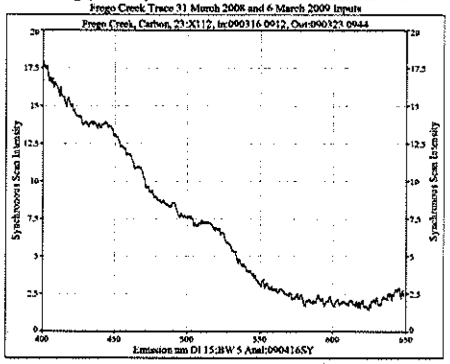

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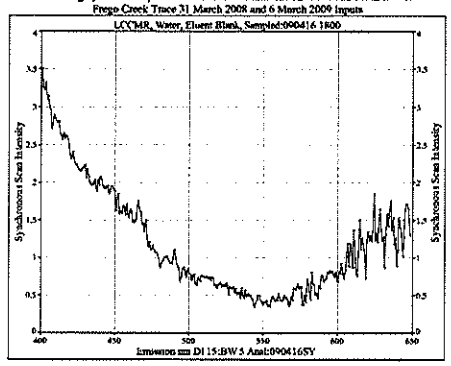

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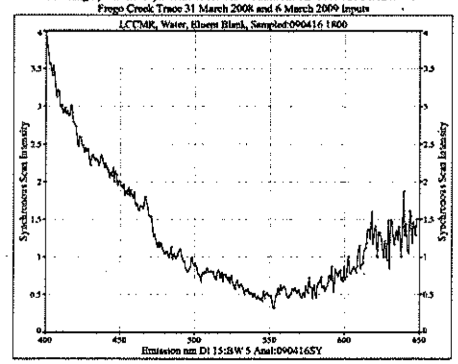

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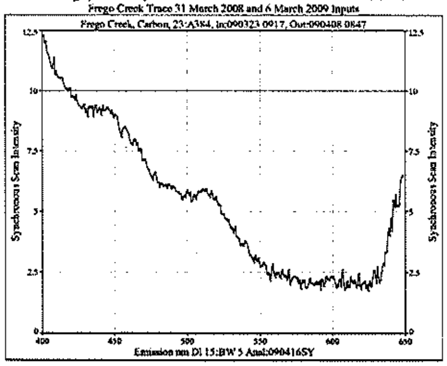

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Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
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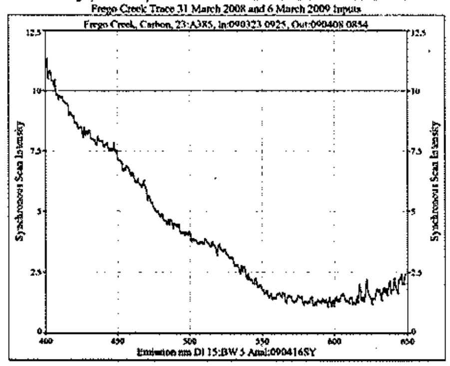

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Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
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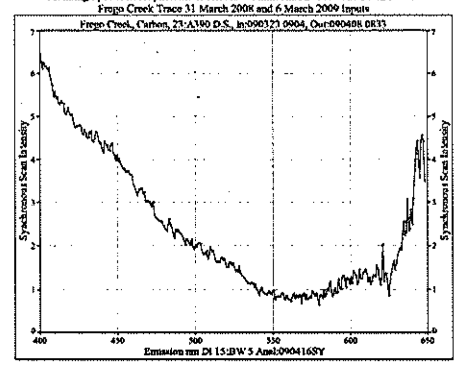

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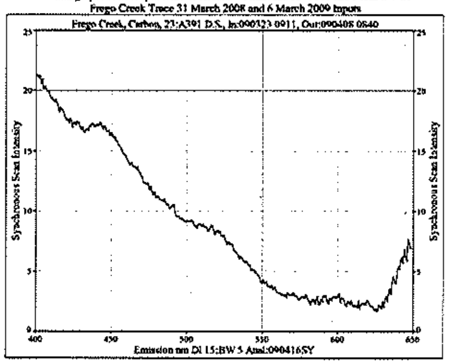
Frego Creek Trace 31 March 2008 and 6 March 2009 Inputs



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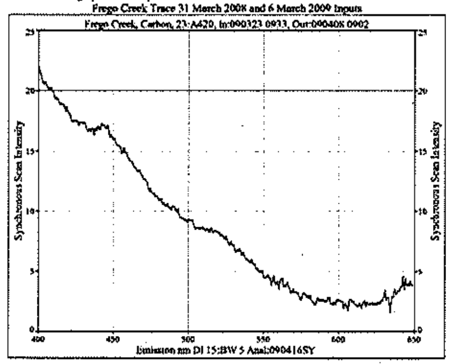
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 and 6 March 2009 Inputs



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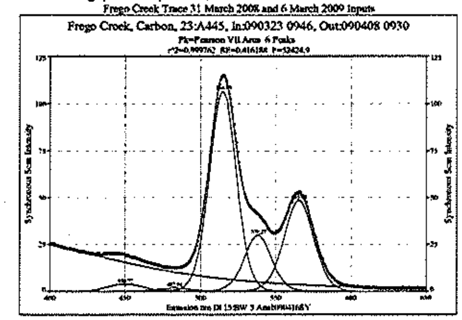
Frego Creek Trace 31 March 2008 and 6 March 2009 Inputs



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Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331_090306\fregocreek090323-090408\b45040

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99976204	0.99974207	0.41618764	52424.9252

Peak	Type				
1	Pearson VII Area	6803.19405	361.945663	191.489103	1.81616067
2	Pearson VII Area	118.103035	450.570318	28.2252802	167.627713
3	Pearson VII Area	54.1055811	482.935181	28.4852922	20.6986989
4	Pearson VII Area	2365.77307	514.950933	20.4957923	10.5123028
5	Pearson VII Area	686.791841	538.271795	20.6894381	5.71530232
6	Pearson VII Area	1200.84859	565.446682	22.6383519	7.76980858

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	28.5684835	361.945665	457.690215	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	3.92802984	450.570317	28.2252802	1.00000011	56.6392722	1.00000006
3	Pearson VII Area	1.76659904	482.935181	28.4852922	1.00000000	58.1895406	1.00000000
4	Pearson VII Area	106.260747	514.950932	20.4957923	1.00000012	42.7199318	1.00000006
5	Pearson VII Area	29.9896765	538.271793	20.6894381	1.00000037	44.6742824	1.00000019
6	Pearson VII Area	48.4578371	565.446681	22.6383519	1.00000013	47.8846477	1.00000007

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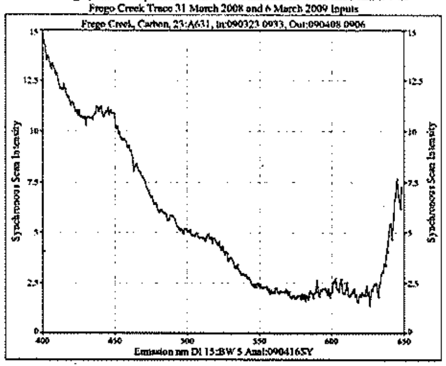
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 and 6 March 2009 Inputs



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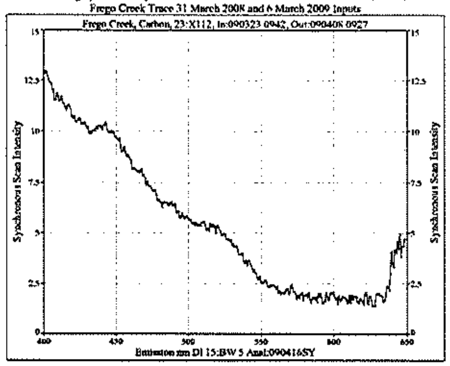

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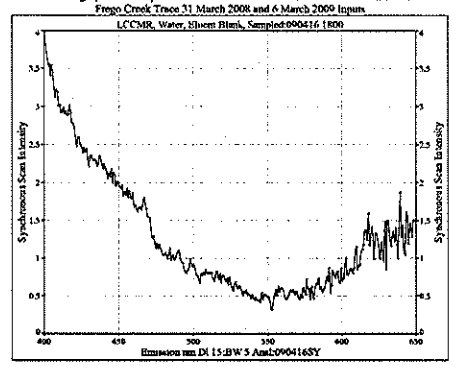

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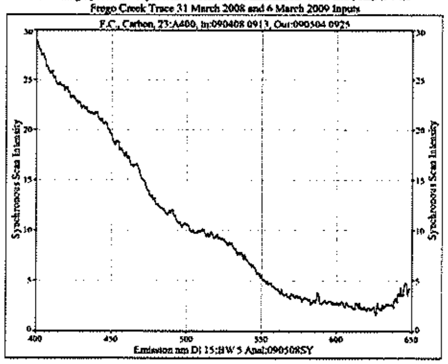

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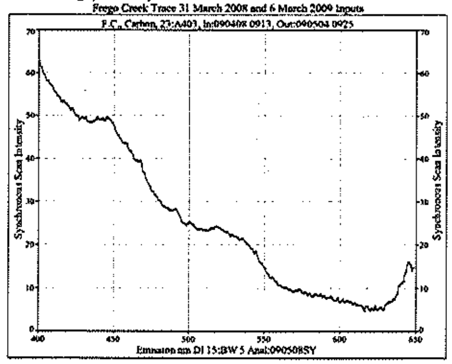

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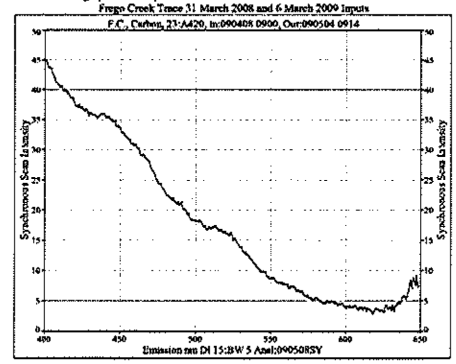

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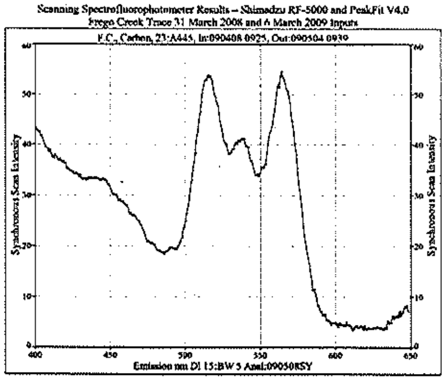

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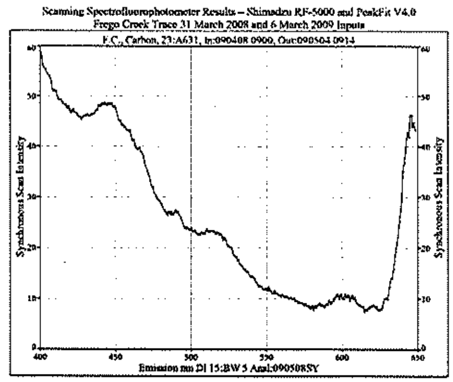

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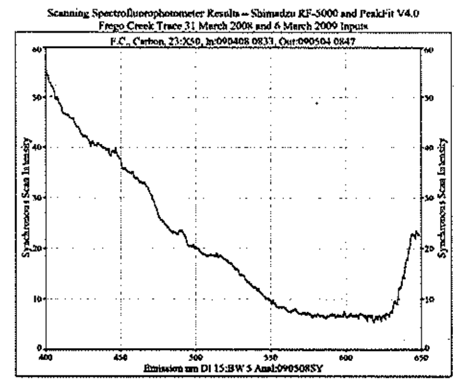

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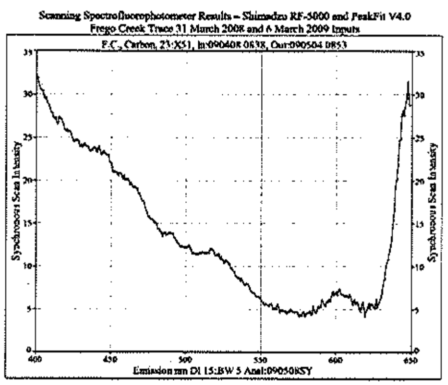

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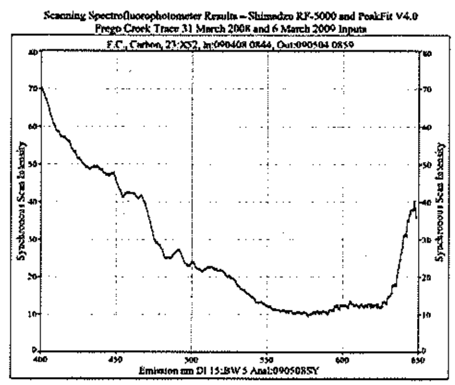

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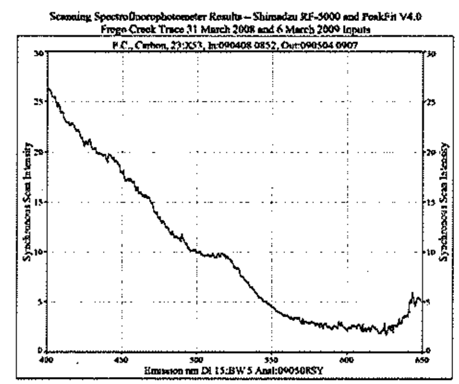

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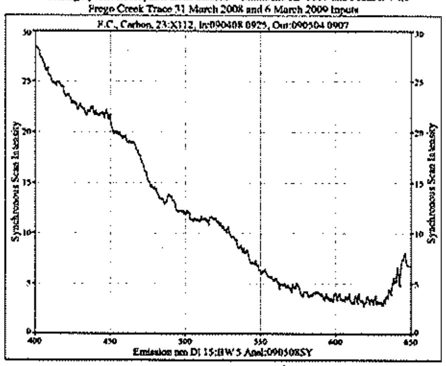
Frego Creek Trace 31 March 2008 and 6 March 2009 Inputs



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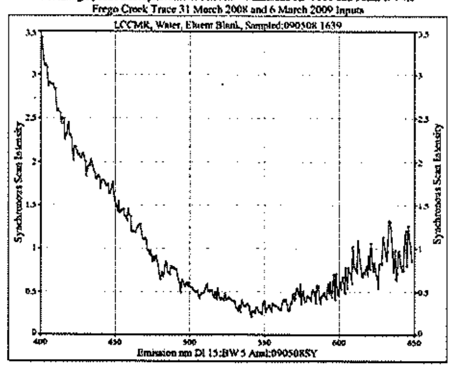

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Frego Creek Dye Trace

March 11, 2008 to June 16, 2008

Jeffrey A. Green[1], Andrew J. Peters[1], Andrew J. Luhmann[2], E. Calvin Alexander, Jr.[2] and Scott C. Alexander [2]

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DNR Waters

Table of Contents

Introduction

A dye trace was conducted in an area near the city of Canton, Minnesota from March 11, 2008 to June 16, 2008. Dye traces have been completed in this area in the past and this effort was made to further refine delineation the springsheds in this area due to the close proximity of Frego Creek, a Minnesota designated trout stream. Much of the city of Canton's stormwater flows to sinkholes throughout the city limits and some just outside of city limits. Achieving a better understanding of the connection of these sinkholes receiving this stormwater flow and their connectivity to springs that provide a cold water source for Frego Creek was the goal of this trace.

The city of Canton, Minnesota is located in southern Fillmore County, Minnesota, very near the Minnesota/Iowa border (Figure 1).

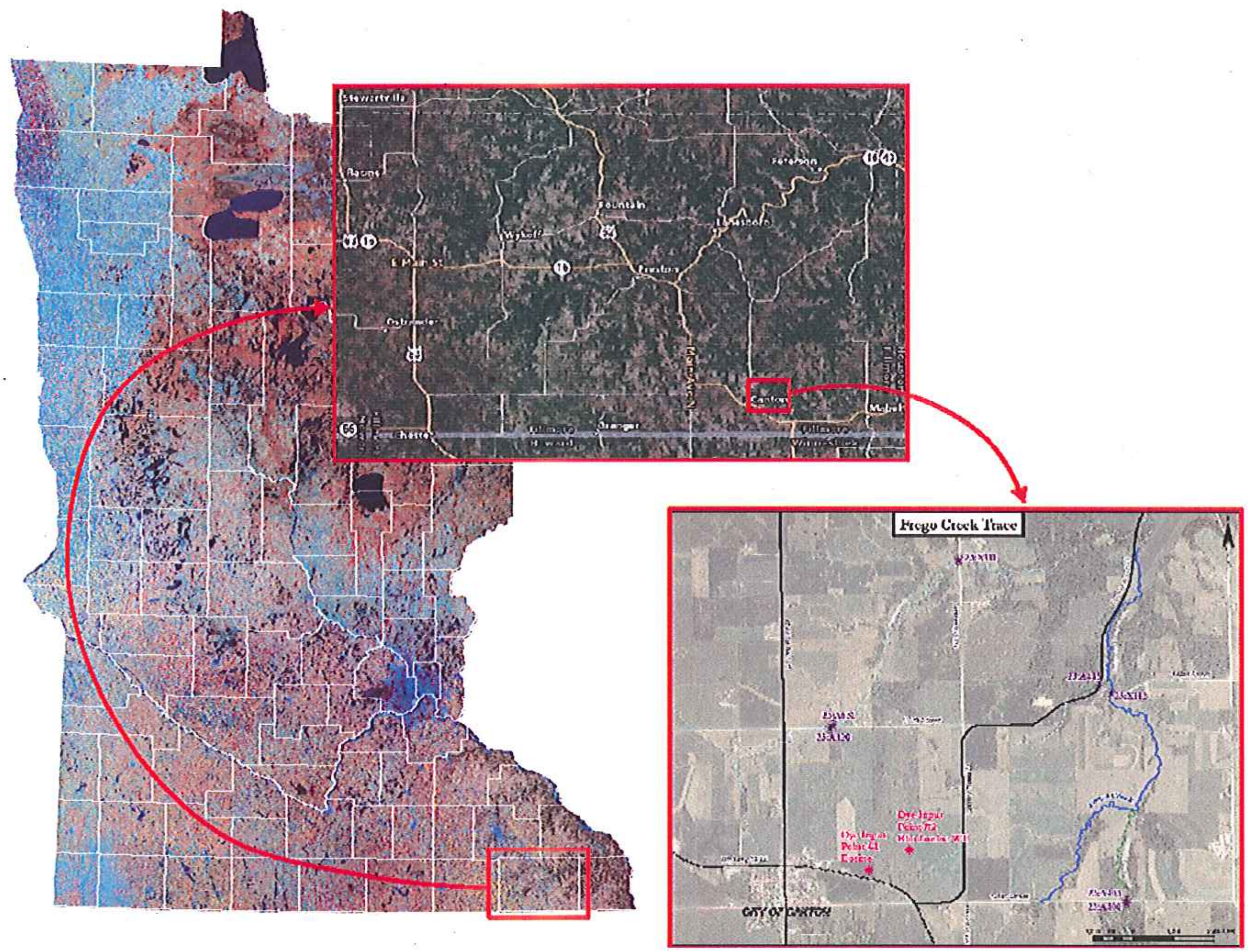


Figure 1: Location of Frego Creek Dye Trace, Canton, Minnesota

Dye tracing entails using fluorescent dyes to track groundwater flow directions and travel times. The dye is poured into a sinkhole or sinking stream; from there, it flows through the karst conduit system until it re-emerges at a spring. For this project, the dyes used were Eosine and Rhodamine WT. Both direct water samples and passive dye detectors (packets of coconut charcoal also known as "bugs") were used and all the samples were analyzed at the University of Minnesota Geology Department using a scanning spectrofluorophotometer. The traces were designed and executed by Jeff Green and Andrew Peters of MNDNR Waters. E. Calvin Alexander, Jr., Andrew Luhmann, and Scott Alexander of the University of Minnesota Geology Department performed the sample analysis and interpretation.

Results

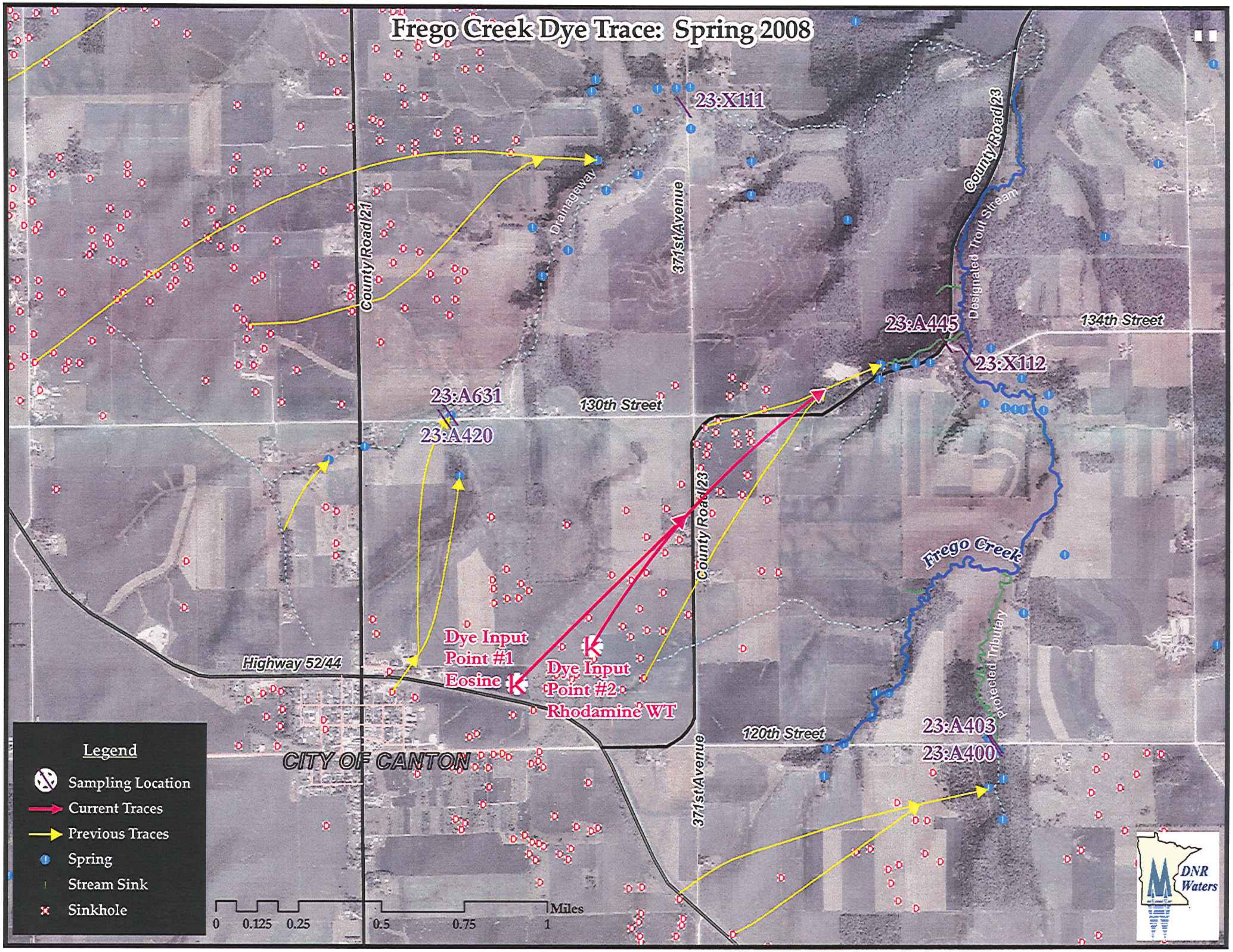
The MNDNR Waters and the Fillmore County SWCD had previously contacted the landowners who owned the relevant sinkholes and springs. Prior to dye injection, bugs had been placed at all the sampling points to determine background levels of dyes. The dye trace was run on March 31, 2008, using runoff from melting snow and recent precipitation events. Table 1 summarizes the dye input information.

Dye Inputs				
Dye Input Point	Dye (type, quantity)	Time	Runoff (Est.)	Dye Detection Point
Sinkhole 23:D7667	Rhodamine WT, 834.42 grams	1210 hrs.	2 - 4 G.P.M.	Spring A445 (A632)
Sinkhole 23:D7460	Eosine, 1186.91 grams	1313 hrs.	500 - 750 G.P.M.	Spring A445 (A632)

Table 1: Dye Inputs, Frego Creek Dye Trace, Canton, Minnesota

Direct water samples were taken at some or all the sampling sites on March 13th, March 25th, March 31st, April 2nd, April 9th, April 24th, May 7th, and May 30th of 2008 and are continuing to be sampled. Charcoal detectors were in place at all sampling locations from March 11th until present. Both dyes were detected at levels high enough for positive identification. The dyes, Rhodamine WT and Eosine, were detected in the charcoal detectors no more than 48 hours later. This translates to a groundwater flow rate of no greater than approximately ¾-mile per day. This is consistent with previous traces in this geologic setting (Ordovician Galena limestone).

The dye points and connections from this dye trace in addition to previously completed traces are shown in Figure 2. Through this double trace, we have further delineated the springshed feeding Spring A632. There are several springs visible in the immediate area of A632 but they all feed the same coldwater tributary to Frego Creek. The new trace from these sinkholes that was detected in the flow from the springs in this area has expanded the known boundaries of that springshed.


Frego Creek Dye Trace: Spring 2008
23:X111
Drainageway
371st Avenue
County Road 21
County Road 23
Designated Trout Stream
134th Street
23:A445
23:X112
23:A631
130th Street
23:A420
Frego Creek
Protected Tributary
Dye Input Point #1 Eosine
Dye Input Point #2 Rhodamine WT
Highway 52/44
120th Street
23:A403
23:A400
CITY OF CANTON
Legend
Sampling Location
Current Traces
Previous Traces
Spring
Stream Sink
Sinkhole
0 0.125 0.25 0.5 0.75 1 Miles
DNR Waters

Appendix 1

Dye Input

Frego Creek Dye Trace: March 11, 2008 to June 16, 2008

Dye Input Points:

Input Point #1:

Sinkhole D7667:	**Minnesota Karst Feature Database Number - MN23:D7667**
UTM:	**587,597 E, 4,820,714 N**
Township, Range, Section:	**NW ¼ of the SE ¼ of Section 21, T101N, R9W (Canton Twp., Fillmore Co.)**
Elevation:	**~1300 feet**

At 1210 CDT on 31 March 2008, 834.42 grams of Rhodamine WT dye solution was introduced into an open swallow hole in D7667 with an undetermined amount of water. Melting snow and on going precipitation were used to flush the dye into the sinkhole.

Input Point #2:

Sinkhole D7460:	**Minnesota Karst Feature Database Number - MN23:D7460**
UTM:	**587,238 E, 4,820,521 N**
Township, Range, Section:	**SE ¼ of the SW ¼ of Section 21, T101N, R9W (Canton Twp., Fillmore Co.)**
Elevation:	**~1290 feet**

At 1313 CDT on 31 March 2008, 1186.91 grams of Eosine dye solution was introduced into water flow into the sinkhole D7460. The water flow into the sinkhole was approximately 500 to 750 gallons per minute. Melting snow and on going precipitation were used to flush the dye into the sinkhole.

Photograph of Sinkhole D7460 After Dye Input

3/31/08:

Frego Creek Trace:

Rain/Sleet 35°; High winds

Sinkhole 23D7667 on Terkeest Property

- Small flow, likely larger under ice, 2-4 gpm visible
- No ponding, swallet still snow covered, dye poured into void in bottom of sink
- RhWT Chromatint Lot 041807E, 834.42 gm
- UTM- 4820714, 587597
- Dye Poured at 1210

2nd Pour

↓

3/31/08 cont.

Fryso Creek Trace:

Rain/Sleet, 35°, High Winds

Sinkhole 23D7460 on Lirstikow Property

just north of

- Large flow, viewed 1.5 hrs. previously with no flow visible. Current flow of 500-750 gpm. Runoff burst through snow and ice and filled the two depressions until levels stabilized.
- Dye Poured into flow that directly entered the two depressions
- 1) Eosine Chromatint Red 0143, Lot 020706, 590.92 gm
  2) Eosine Chromatint Red 0143, Lot 020706, 595.99 gm
- UTM - 4820521, 597238
- Dye Poured at 1313

Appendix 2

Dye Receptors

Frego Creek Dye Trace: March 11, 2008 to June 16, 2008

Dye Receptor Locations:

Dye Receptor #1:
23:A631 Minnesota Karst Feature Database Number - MN23:A631
UTM: 586,868 E, 4,821,780 N
Notes: Receptor located on north side of spring. Accessed through farm.

Dye Receptor #2:
23:A420 Minnesota Karst Feature Database Number - MN23:A420
UTM: 586,841 E, 4,821,756 N
Notes: Receptor located south side of road on the east side of culvert

Dye Receptor #3:
23:A445 Minnesota Karst Feature Database Number - MN23:A445
UTM: 589,265 E, 4,822,137 N
Notes: Receptor located on west side of county road 23 along the north side of the culvert

Dye Receptor #4:
23X112 Minnesota Karst Feature Database Number - MN23:X112
UTM: 589,375 E, 4,822,077 N
Notes: Receptor located on the south side of the road tied to small tree on the west side of the east culvert

Dye Receptor #5:
23:A403 Minnesota Karst Feature Database Number - MN23:A403
UTM: 589,514 E, 4,820,195 N
Notes: Receptor located in culvert and is tied to debris on the south side of 120th street

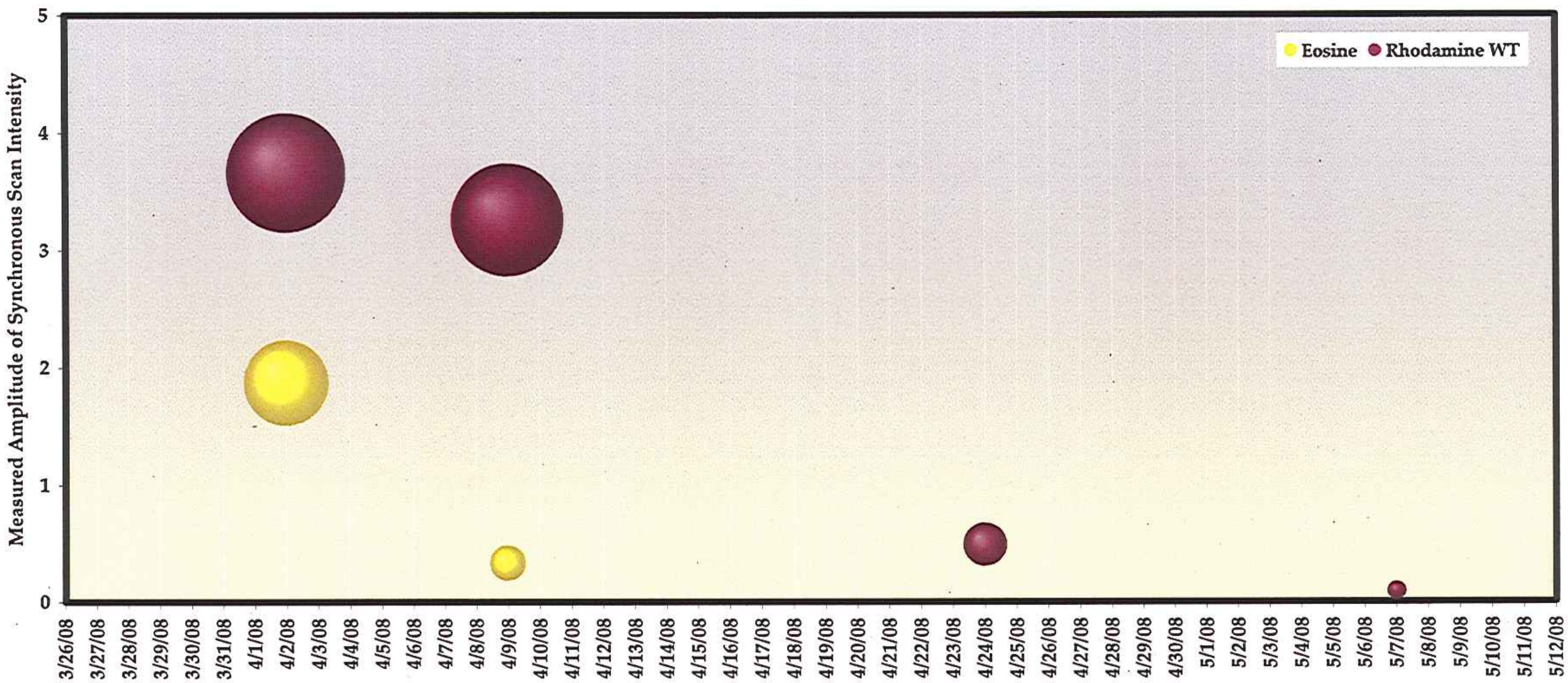
Dye Receptor #6:
23:A400 Minnesota Karst Feature Database Number - MN23:A400
UTM: 589,551 E, 4,820,220 N
Notes: Receptor located just upstream of 23:A403 along the west side of the stream

Dye Receptor #7:
23:X111 Minnesota Karst Feature Database Number - MN23:X111
UTM: 588,000 E, 4,823,275 N
Notes: Receptor located on the west side of the road dangling from a tree above the south culvert

Appendix 3

Summary of Analytical Results

Frego Creek Dye Trace: Analytical Results of 23:A445 Water Samples

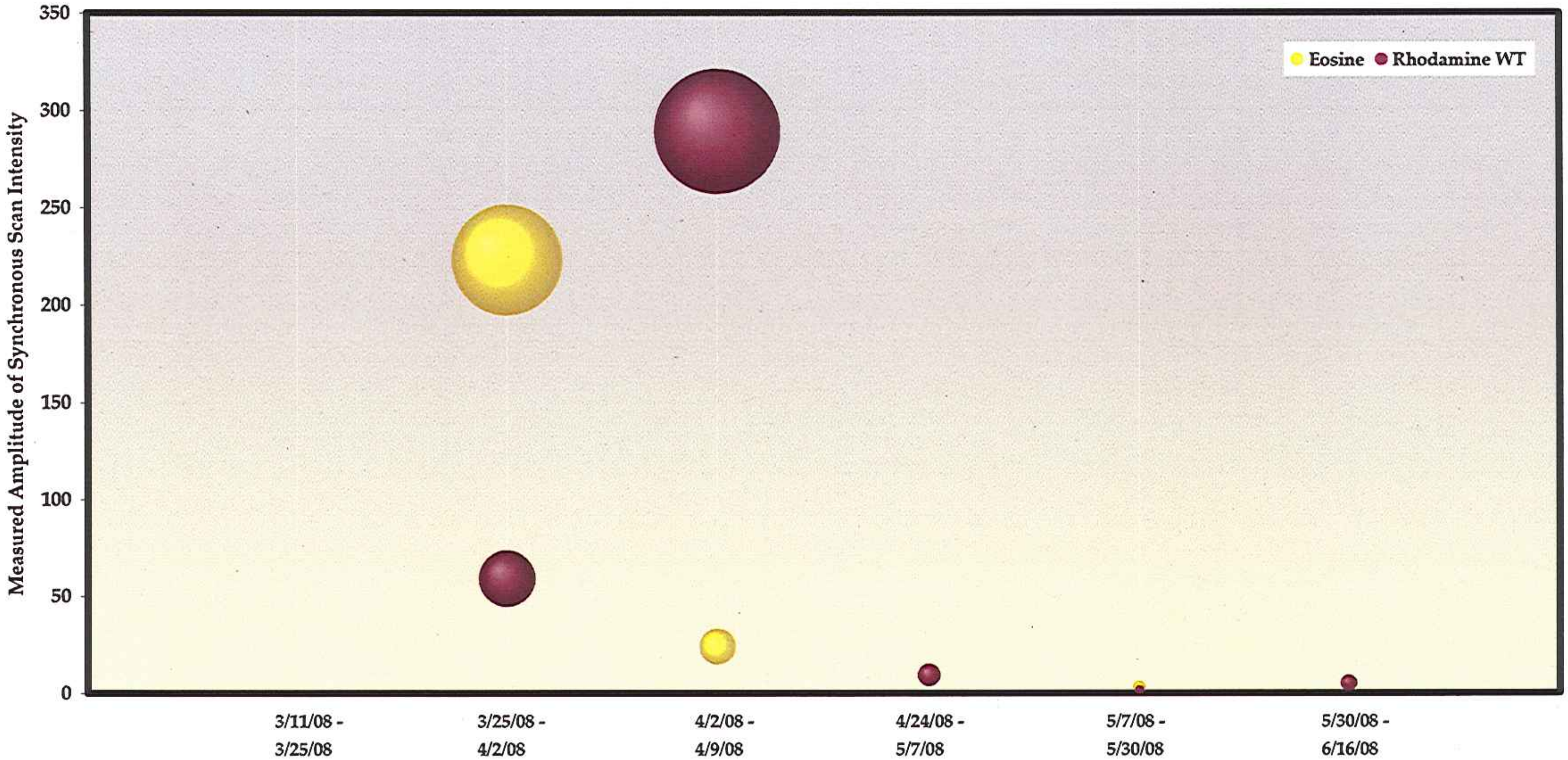


Frego Creek Dye Trace: Summary of Analytical Results

Sampling Location	3/11/08-3/25/08 (Carbon)	3/25/08-4/2/08 (Carbon)	3/31/08 (Water)	4/2/08-4/9/08 (Carbon)	4/2/08 (Water)	4/9/08 (Water)	4/9/08-4/24/08 (Carbon)	4/24/08 (Water)	4/24/08-5/7/08 (Carbon)	5/7/08 (Water)	5/7/08-5/30/08 (Carbon)	5/30/08-6/16/08 (Carbon)
23:A400	None	None	-	None	-	-	None	-	None	-	None	-
23:A403	None	None	-	None	-	-	-	None	-	-	None	-
23:A420	None	None	-	None	-	-	None	-	None	-	None	-
23:A631	None	None	None	None	-	-	None	-	None	-	None	None
23:A445	None	E*, WT*	-	E*, WT*	E*, WT*	E*, WT*	-	WT*	WT*	WT*	E*, WT*	WT*
23:X111	None	None	-	None	-	-	None	-	None	-	None	-
23:X112	None	None	-	None	-	-	None	-	None	-	None	-

* E – Eosine, WT – Rhodamine WT

Frego Creek Dye Trace: Analytical Results of Dye Receptor 23:A445 Samples



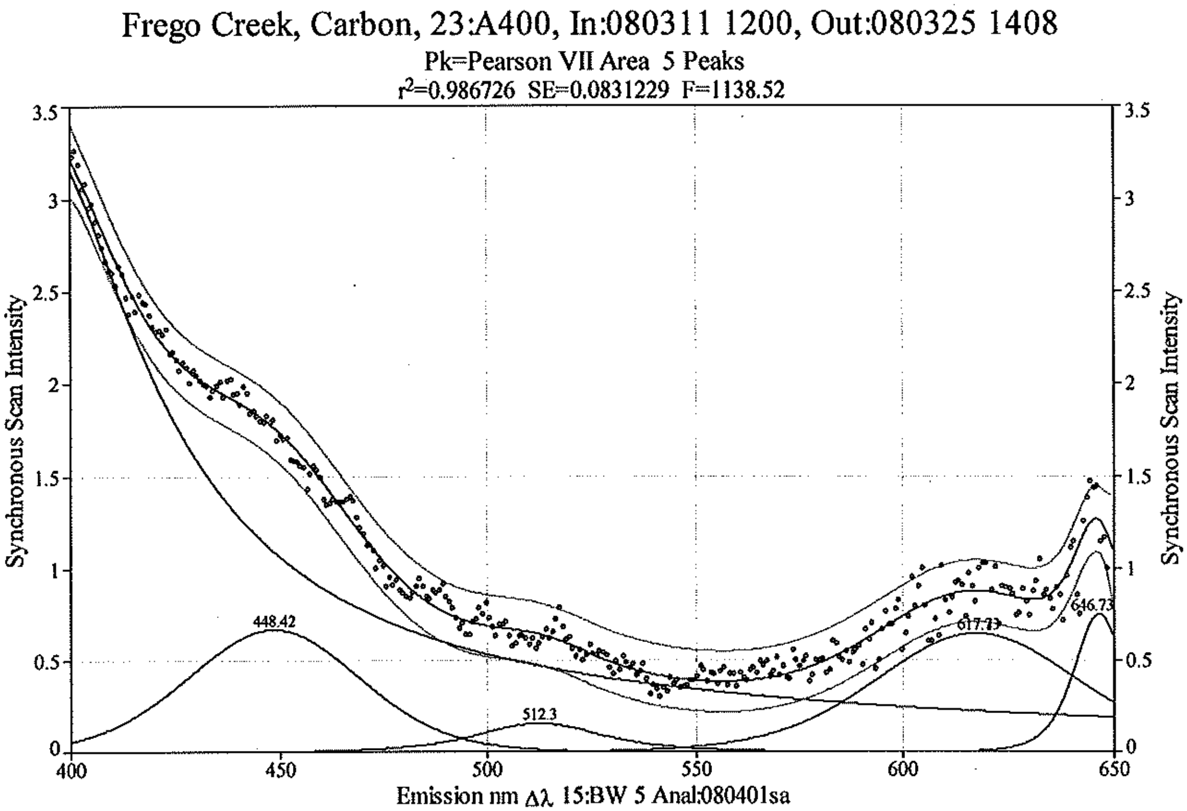
Frego Creek Dye Trace: Summary of Analytical Results											
Sampling Location	3/11/08-3/25/08 (Carbon)	3/25/08-4/2/08 (Carbon)	3/31/08 (Water)	4/2/08-4/9/08 (Carbon)	4/2/08 (Water)	4/9/08 (Water)	4/9/08-4/24/08 (Carbon)	4/24/08 (Water)	4/24/08-5/7/08 (Carbon)	5/7/08 (Water)	5/7/08-5/30/08 (Carbon)	5/30/08-6/16/08 (Carbon)
23:A400	None	None	-	None	-	-	None	-	None	-	None	-
23:A403	None	None	-	None	-	-	-	None	-	-	None	-
23:A420	None	None	-	None	-	-	None	-	None	-	None	-
23:A631	None	None	None	None	-	-	None	-	None	-	None	None
23:A445	None	E, WT	-	E, WT	E, WT	E, WT	-	WT	WT	WT	E, WT	WT
23:X111	None	None	-	None	-	-	None	-	None	-	None	-
23:X112	None	None	-	None	-	-	None	-	None	-	None	-

* E – Eosine, WT – Rhodamine WT

Appendix 4

Scanning Spectrofluorophotometer Results

Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace



Description: Frego Creek, Carbon, 23:A400, In:080311 1200, Out:080325 1408
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Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080311-080325\fc000325

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98672621	0.98581077	0.08312287	1138.52104

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	870.106293	391.760292	71.2414583	0.60813336
2	Pearson VII Area	35.6843158	448.419296	48.9421460	8.64187232
3	Pearson VII Area	6.87005739	512.299422	35.7645193	1.96623006
4	Pearson VII Area	41.0674689	617.728414	57.3774079	5.71008770
5	Pearson VII Area	12.4324289	646.729483	14.1421564	2.64704630

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	3.37073987	391.972477	71.2454095	0.98815765	0.00000000	0.00000000
2	Pearson VII Area	0.66807253	448.419296	48.9421460	1.00000000	102.932676	1.00000000
3	Pearson VII Area	0.15691827	512.299422	35.7645193	1.00000000	90.7113383	1.00000000
4	Pearson VII Area	0.64659932	617.728414	57.3774079	1.00000000	123.902784	1.00000000
5	Pearson VII Area	0.75063712	646.729483	14.1421564	1.00000001	33.5910595	1.00000001

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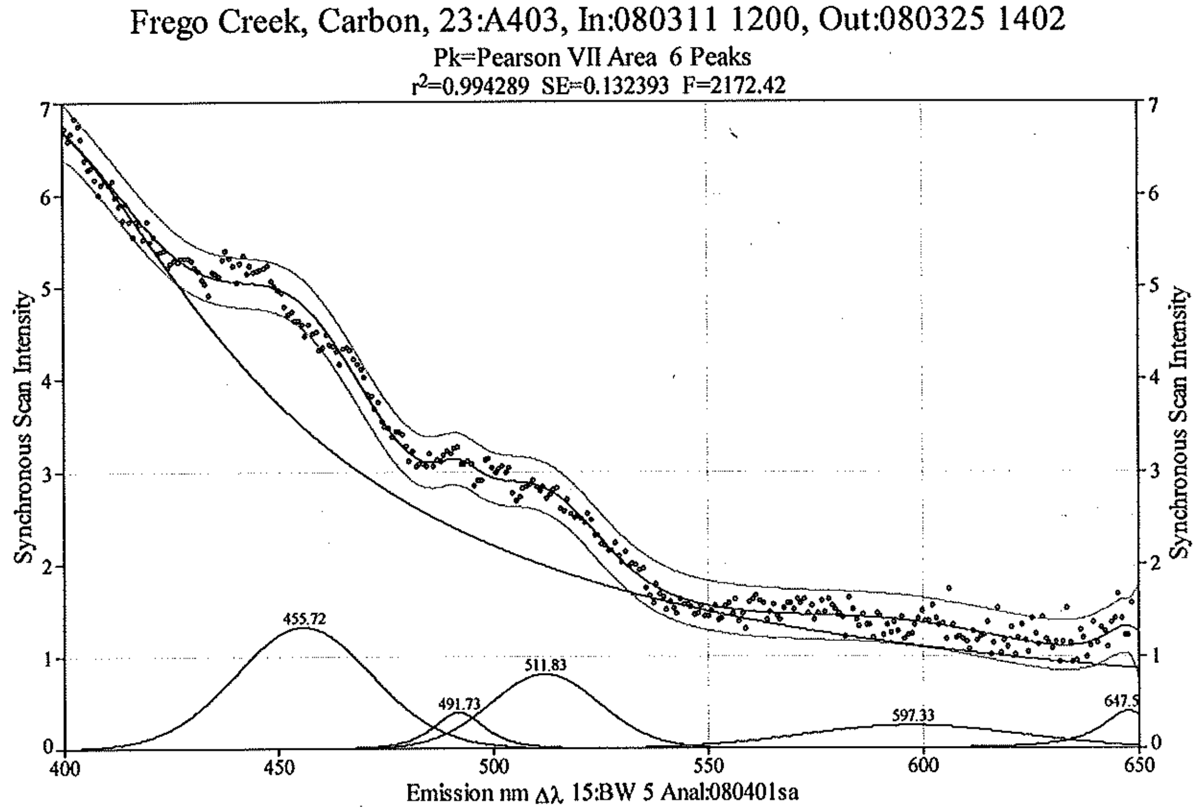
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace



Description: Frego Creek, Carbon, 23:A403, In:080311 1200, Out:080325 1402
X Variable: Emission nm Δλ 15:BW 5 Anal:080401sa
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080311-080325\fc030325

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99428886	0.99380960	0.13239278	2172.41953

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	4087.09892	388.223822	135.469600	0.58524239
2	Pearson VII Area	53.6120958	455.720399	37.5753546	14.0589815
3	Pearson VII Area	7.00140552	491.732927	14.1354000	1.84349460
4	Pearson VII Area	26.4663988	511.834401	30.3440952	19.4271140
5	Pearson VII Area	16.1114226	597.326555	60.2283640	167.899758
6	Pearson VII Area	9.11331821	647.498872	15.2070969	1.10337567

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.95731664	388.245413	135.469622	0.99936268	0.00000000	0.00000000
2	Pearson VII Area	1.32049336	455.720399	37.5753546	1.00000000	77.5111869	1.00000000
3	Pearson VII Area	0.39953354	491.732927	14.1354000	1.00000000	36.4853061	1.00000000
4	Pearson VII Area	0.81066979	511.834403	30.3440952	0.99999968	62.0701781	0.99999983
5	Pearson VII Area	0.25100194	597.326554	60.2283640	1.00000004	120.858923	1.00000002
6	Pearson VII Area	0.40543732	647.498872	15.2070969	0.99999995	47.9714491	0.99999998

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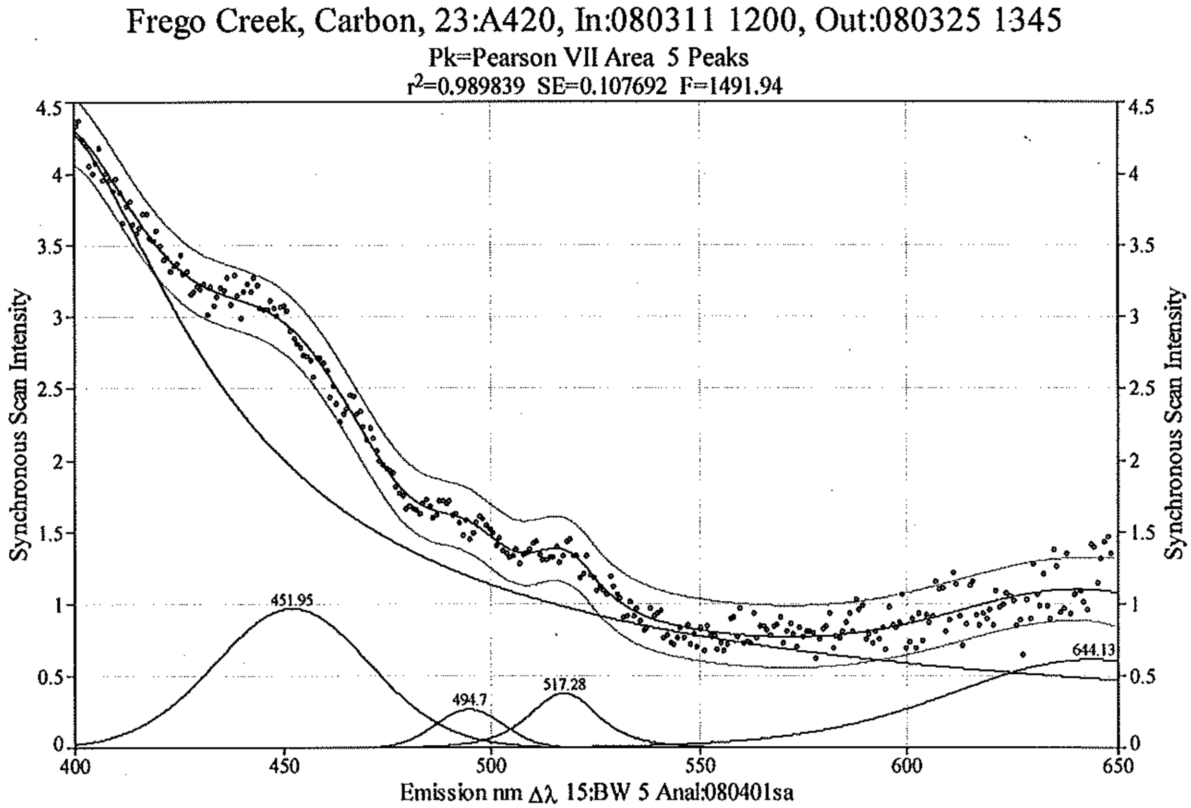
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace



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Y Variable: Synchronous Scan Intensity
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Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98983864	0.98913786	0.10769181	1491.94273

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	8358.98737	393.639068	100.187610	0.51596343
2	Pearson VII Area	45.7169721	451.950975	44.0933291	25.6546179
3	Pearson VII Area	5.52451157	494.696263	19.2375823	167.595402
4	Pearson VII Area	8.91433902	517.281144	19.7244133	2.29738091
5	Pearson VII Area	55.3033015	644.130503	80.7998190	5.21781115

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.38645411	393.692661	100.187830	0.99786261	0.00000000	0.00000000
2	Pearson VII Area	0.96623008	451.950975	44.0933291	0.99999999	89.7174562	0.99999999
3	Pearson VII Area	0.26945528	494.696263	19.2375823	1.00000000	38.6038040	1.00000000
4	Pearson VII Area	0.37878573	517.281144	19.7244133	0.99999995	48.2025464	0.99999998
5	Pearson VII Area	0.61578893	644.130503	80.7998190	1.00000001	175.789854	1.00000001

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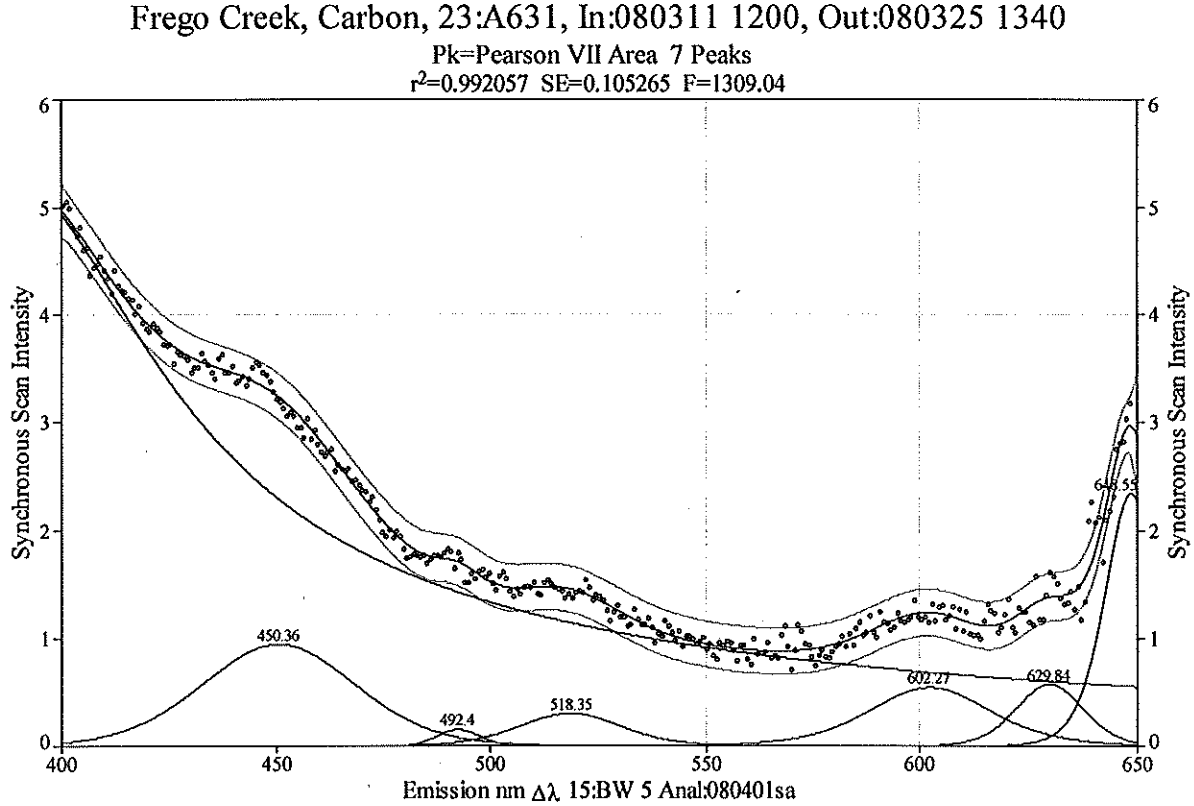
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace



Description: Frego Creek, Carbon, 23:A631, In:080311 1200, Out:080325 1340
X Variable: Emission nm Δλ 15:BW 5 Anal:080401sa
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080311-080325\fc310325

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99205662	0.99126792	0.10526512	1309.04346

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	5487.97693	388.637005	104.031864	0.53181274
2	Pearson VII Area	44.0353525	450.358182	42.4272789	7.32948085
3	Pearson VII Area	1.98570250	492.404600	11.8515454	167.816944
4	Pearson VII Area	9.60204405	518.345699	28.2478729	4.91298804
5	Pearson VII Area	21.0568980	602.273300	33.4098277	3.06555701
6	Pearson VII Area	11.7691092	629.835326	18.3621132	5.35606503
7	Pearson VII Area	38.1596256	648.547457	14.3627846	3.67593080

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.26756636	388.818807	104.034203	0.99303425	0.00000000	0.00000000
2	Pearson VII Area	0.94642931	450.358183	42.4272789	0.99999997	90.0494689	0.99999998
3	Pearson VII Area	0.15721110	492.404600	11.8515454	1.00000000	23.7822625	1.00000000
4	Pearson VII Area	0.30490302	518.345701	28.2478729	0.99999973	61.7899199	0.99999986
5	Pearson VII Area	0.54664377	602.273300	33.4098277	0.99999999	77.3977894	0.99999999
6	Pearson VII Area	0.57736544	629.835325	18.3621132	1.00000014	39.8595667	1.00000007
7	Pearson VII Area	2.34021203	648.547457	14.3627846	1.00000000	32.4288812	1.00000000

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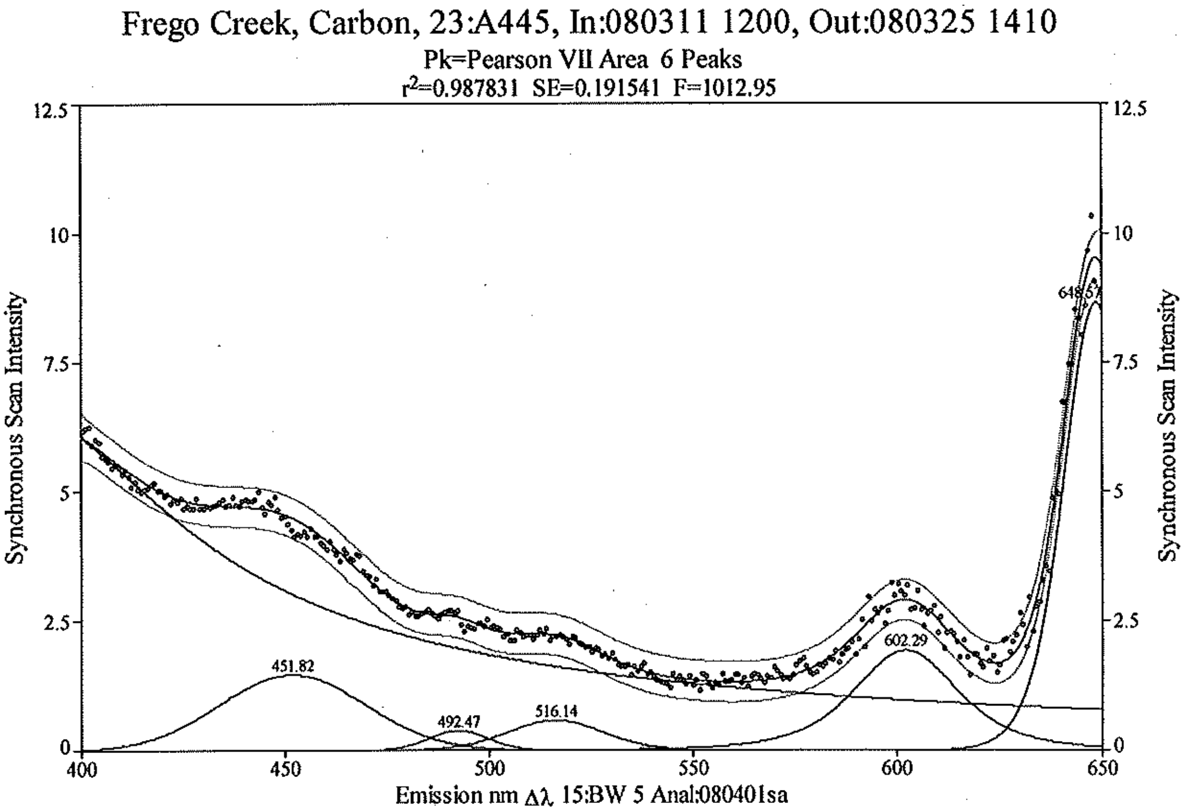
Frego Creek Trace



Description: Frego Creek, Carbon, 23:A445, In:080311 1200, Out:080325 1410
X Variable: Emission nm Δλ 15:BW 5 Anal:080401sa
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080311-080325\fc450325

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98783111	0.98680995	0.19154135	1012.94505

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	8648.71476	386.412980	119.794438	0.52828989
2	Pearson VII Area	66.1608803	451.817904	42.3440308	167.863602
3	Pearson VII Area	7.28621126	492.467553	17.1644090	12.9805602
4	Pearson VII Area	17.7607491	516.140015	27.5960412	8.32580376
5	Pearson VII Area	71.0556088	602.285255	30.1993799	2.01196833
6	Pearson VII Area	180.359344	648.587373	18.8129071	5.54030240

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.47821291	386.811927	119.804306	0.98676818	0.00000000	0.00000000
2	Pearson VII Area	1.46606499	451.817904	42.3440308	1.00000000	84.9708733	1.00000000
3	Pearson VII Area	0.39236113	492.467553	17.1644090	1.00000000	35.4972596	1.00000000
4	Pearson VII Area	0.58911929	516.140015	27.5960412	1.00000000	58.1506745	1.00000000
5	Pearson VII Area	1.93014195	602.285255	30.1993799	1.00000000	76.1434736	1.00000000
6	Pearson VII Area	8.64933413	648.566514	18.8129595	1.00444500	40.7237022	1.00225810

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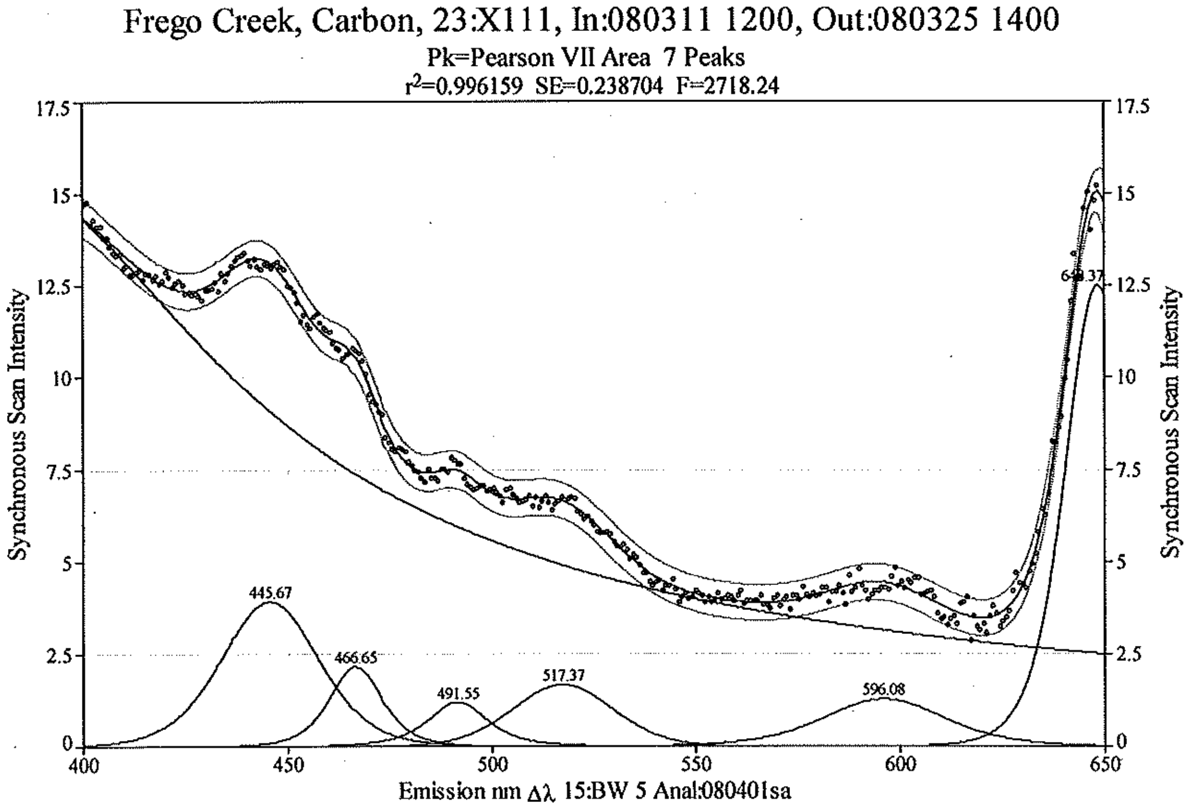
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace



Description: Frego Creek, Carbon, 23:X111, In:080311 1200, Out:080325 1400
X Variable: Emission nm Δλ 15:BW 5 Anal:080401sa
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080311-080325\fcx10325

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99615883	0.99577744	0.23870436	2718.23834

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	33222.1885	383.035581	160.772978	0.52283465
2	Pearson VII Area	124.085460	445.666272	28.2079666	4.21736879
3	Pearson VII Area	39.4413416	466.646562	15.5268380	2.47831110
4	Pearson VII Area	26.1463501	491.552267	17.3605987	1.79917617
5	Pearson VII Area	53.3154463	517.371895	29.3238695	10.1916930
6	Pearson VII Area	51.7969554	596.079240	35.1976065	3.26772787
7	Pearson VII Area	268.194587	648.373964	18.9150013	3.69310094

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	15.2131670	383.944954	160.811705	0.97763339	0.00000000	0.00000000
2	Pearson VII Area	3.91149259	445.666273	28.2079666	0.99999980	62.6612413	0.99999990
3	Pearson VII Area	2.15135277	466.646562	15.5268380	1.00000000	37.3495875	1.00000000
4	Pearson VII Area	1.20862972	491.552268	17.3605987	0.99999968	45.1230802	0.99999986
5	Pearson VII Area	1.67264343	517.371895	29.3238695	0.99999999	61.2001480	1.00000000
6	Pearson VII Area	1.28387803	596.079242	35.1976065	0.99999975	80.7570083	0.99999988
7	Pearson VII Area	12.4935233	648.373963	18.9150013	1.00000007	42.6817297	1.00000004

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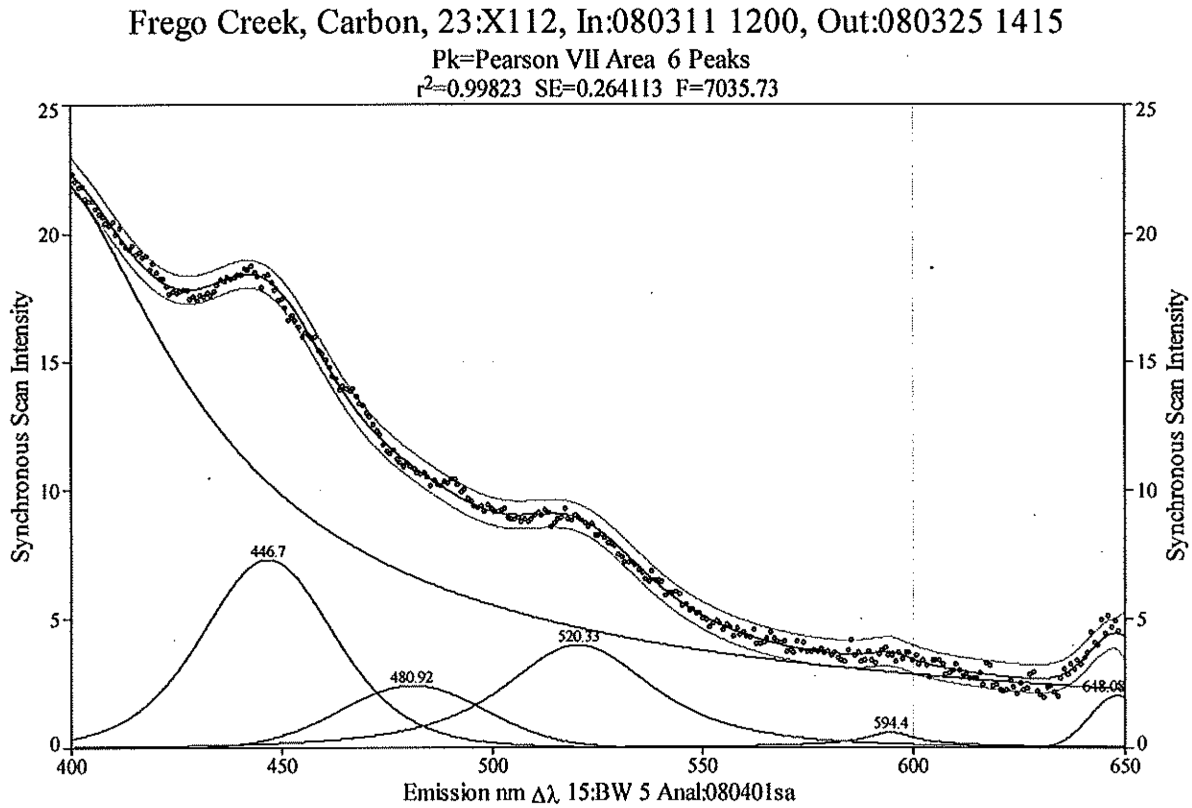
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace



Description: Frego Creek, Carbon, 23:X112, In:080311 1200, Out:080325 1415
X Variable: Emission nm Δλ 15:BW 5 Anal:080401sa
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080311-080325\fcx20325

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99822958	0.99808102	0.26411269	7035.73010

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	36488.2881	393.222011	95.3804014	0.51801865
2	Pearson VII Area	310.351517	446.695843	37.0330622	3.26948092
3	Pearson VII Area	104.776573	480.918817	40.6637413	161.755384
4	Pearson VII Area	222.606765	520.328918	42.3791740	1.45583470
5	Pearson VII Area	332.620248	594.400031	18.1871560	0.51000000
6	Pearson VII Area	33.2803666	648.078346	15.2893941	78.8037563

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	22.5583999	393.222012	95.3804014	0.99999997	0.00000000	0.00000000
2	Pearson VII Area	7.31168355	446.695843	37.0330622	1.00000001	84.9616249	1.00000000
3	Pearson VII Area	2.41758167	480.918817	40.6637413	1.00000000	81.6067257	1.00000000
4	Pearson VII Area	3.98934076	520.328918	42.3791740	1.00000000	118.136100	1.00000000
5	Pearson VII Area	0.61364621	594.400031	18.1871560	1.00000000	113.717369	1.00000000
6	Pearson VII Area	2.03960408	648.078346	15.2893941	0.99999996	30.7672826	0.99999998

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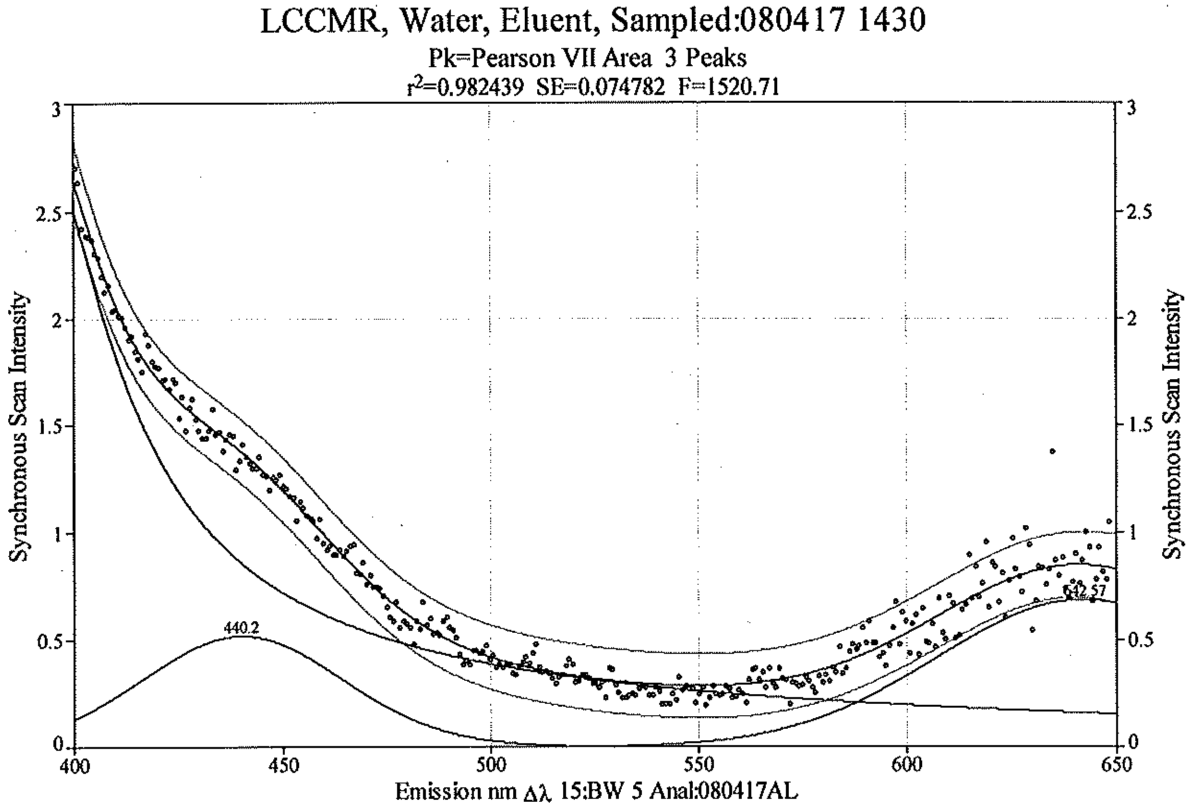
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: LCCMR, Water, Eluent, Sampled:080417 1430
X Variable: Emission nm Δλ 15:BW 5 Anal:080417AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080325-080402\bl080417

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98243947	0.98173233	0.07478199	1520.71100

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1866.35383	390.700069	53.9025533	0.52630966
2	Pearson VII Area	31.8773877	440.200151	56.7780485	13.1218952
3	Pearson VII Area	60.9031137	642.566762	83.1865120	167.872778

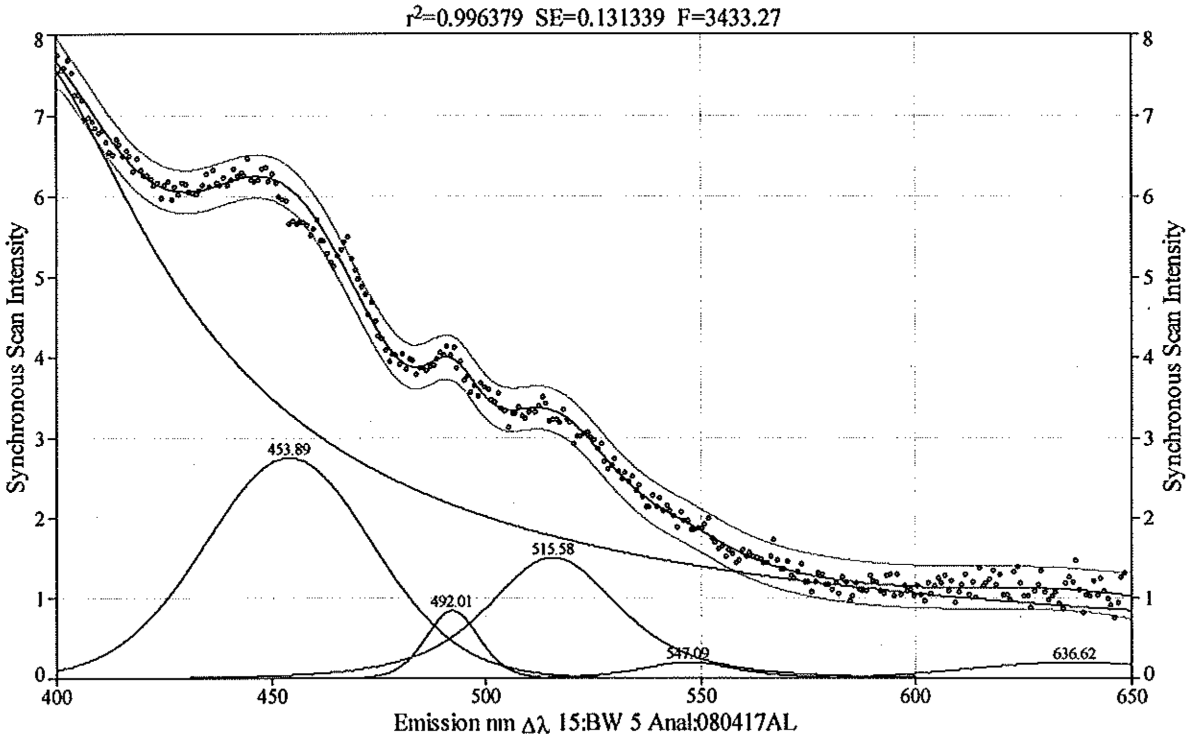
Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	2.89756910	391.972477	54.1262898	0.91018998	0.00000000	0.00000000
2	Pearson VII Area	0.51903265	440.200151	56.7780485	1.00000000	117.379198	1.00000000
3	Pearson VII Area	0.68695890	642.566756	83.1865120	1.00000031	166.928596	1.00000017

Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A400, In:080325 1408, Out:080402 0945

Pk=Pearson VII Area 6 Peaks
r^2=0.996379 SE=0.131339 F=3433.27



Description: Frego Creek, Carbon, 23:A400, In:080325 1408, Out:080402 0945
X Variable: Emission nm Δλ 15:BW 5 Anal:080417AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080325-080402\fc000402

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99637865	0.99607476	0.13133889	3433.27034

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	15979.9588	390.700243	100.680856	0.51514628
2	Pearson VII Area	138.210525	453.886897	46.1243376	8.84347123
3	Pearson VII Area	13.8239328	492.006764	14.8621509	5.77815692
4	Pearson VII Area	66.8038609	515.582769	36.3641922	1.96555505
5	Pearson VII Area	6.49771237	547.091774	25.7700506	1.90782579
6	Pearson VII Area	12.2775355	636.624659	57.1941970	167.916939

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	7.93742525	390.825688	100.682057	0.99502857	0.00000000	0.00000000
2	Pearson VII Area	2.74728474	453.886897	46.1243376	0.99999999	96.8942813	1.00000000
3	Pearson VII Area	0.84071525	492.006764	14.8621509	1.00000000	32.0640568	1.00000000
4	Pearson VII Area	1.50060163	515.582769	36.3641922	1.00000000	92.2405958	1.00000000
5	Pearson VII Area	0.20479279	547.091774	25.7700506	0.99999994	65.8882698	0.99999997
6	Pearson VII Area	0.20142044	636.624659	57.1941970	1.00000000	114.770298	1.00000000

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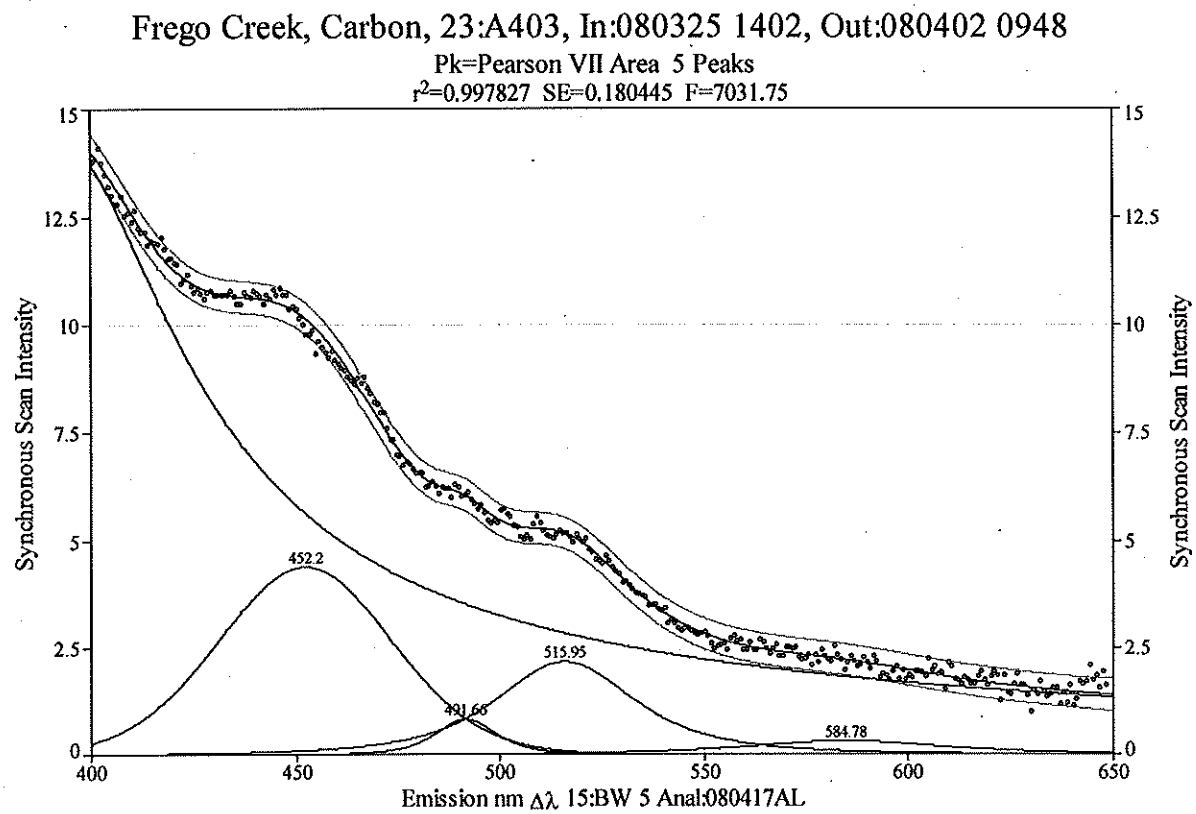
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A403, In:080325 1402, Out:080402 0948
X Variable: Emission nm Δλ 15:BW 5 Anal:080417AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080325-080402\fc030402

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99782664	0.99767676	0.18044453	7031.74966

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	20725.1021	392.941241	89.4463504	0.51877365
2	Pearson VII Area	238.992580	452.204085	50.3702220	15.0553283
3	Pearson VII Area	17.9493522	491.662143	17.5024792	1.93823938
4	Pearson VII Area	110.338226	515.946411	40.0618886	1.66122390
5	Pearson VII Area	23.9082844	584.777450	57.9310372	1.53526502

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	14.2025243	392.941241	89.4463504	0.99999996	0.00000000	0.00000000
2	Pearson VII Area	4.39575200	452.204085	50.3702220	1.00000000	103.694892	1.00000000
3	Pearson VII Area	0.83549359	491.662143	17.5024792	1.00000001	44.5604667	1.00000000
4	Pearson VII Area	2.16997285	515.946412	40.0618886	0.99999989	106.688734	0.99999995
5	Pearson VII Area	0.31844233	584.777449	57.9310372	1.00000006	158.405999	1.00000002

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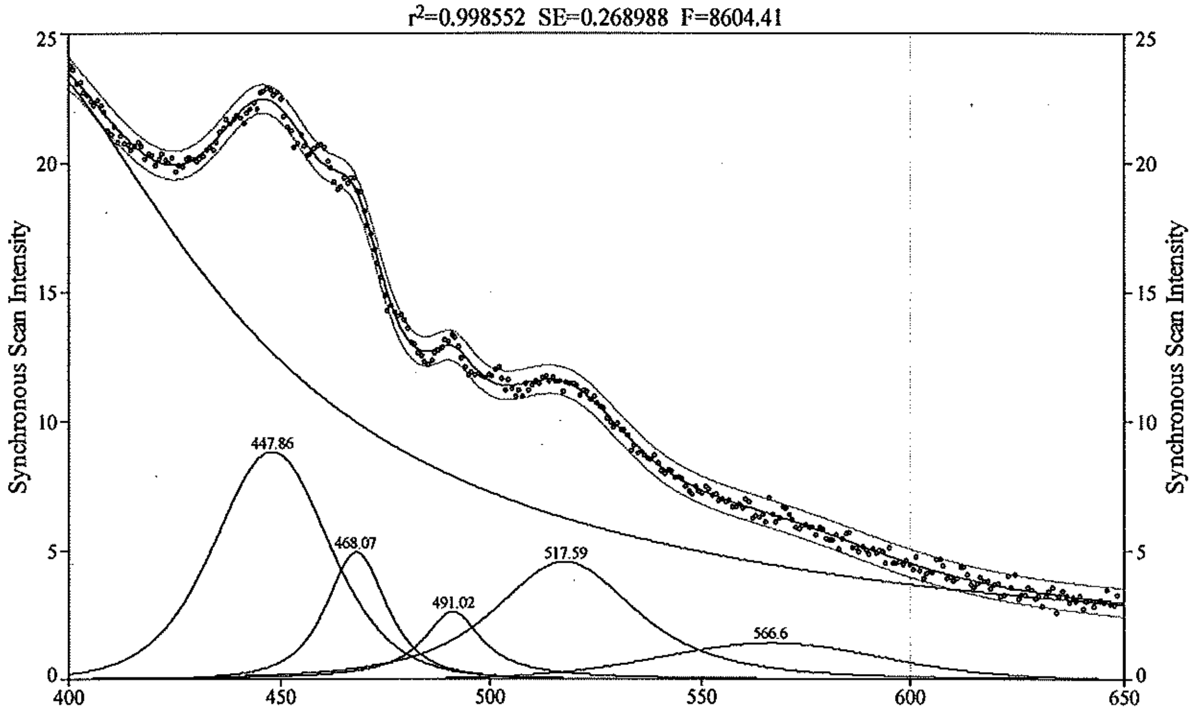
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A420, In:080325 1315, Out:080402 1030

Pk=Pearson VII Area 6 Peaks
r^2=0.998552 SE=0.268988 F=8604.41



Description: Frego Creek, Carbon, 23:A420, In:080325 1315, Out:080402 1030
X Variable: Emission nm Δλ 15:BW 5 Anal:080417AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080325-080402\fc200402

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99855188	0.99843036	0.26898776	8604.41284

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	15027.7440	385.404935	128.938357	0.57668524
2	Pearson VII Area	327.541910	447.862683	32.3898012	3.34996534
3	Pearson VII Area	109.736976	468.065418	17.1576145	1.55190785
4	Pearson VII Area	77.3042763	491.019859	17.0460919	0.90157742
5	Pearson VII Area	236.066019	517.591474	39.7188920	1.53461021
6	Pearson VII Area	99.9693157	566.604343	63.4624450	7.04196128

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	24.6988436	387.385321	129.140570	0.94048486	0.00000000	0.00000000
2	Pearson VII Area	8.84147162	447.862682	32.3898012	1.00000005	74.0500570	1.00000003
3	Pearson VII Area	4.95001024	468.065419	17.1576145	0.99999966	46.7394125	0.99999986
4	Pearson VII Area	2.65955321	491.019857	17.0460919	1.00000042	60.6891836	1.00000013
5	Pearson VII Area	4.58540199	517.591474	39.7188920	1.00000000	108.623185	1.00000000
6	Pearson VII Area	1.43452895	566.604343	63.4624450	1.00000000	135.028440	1.00000000

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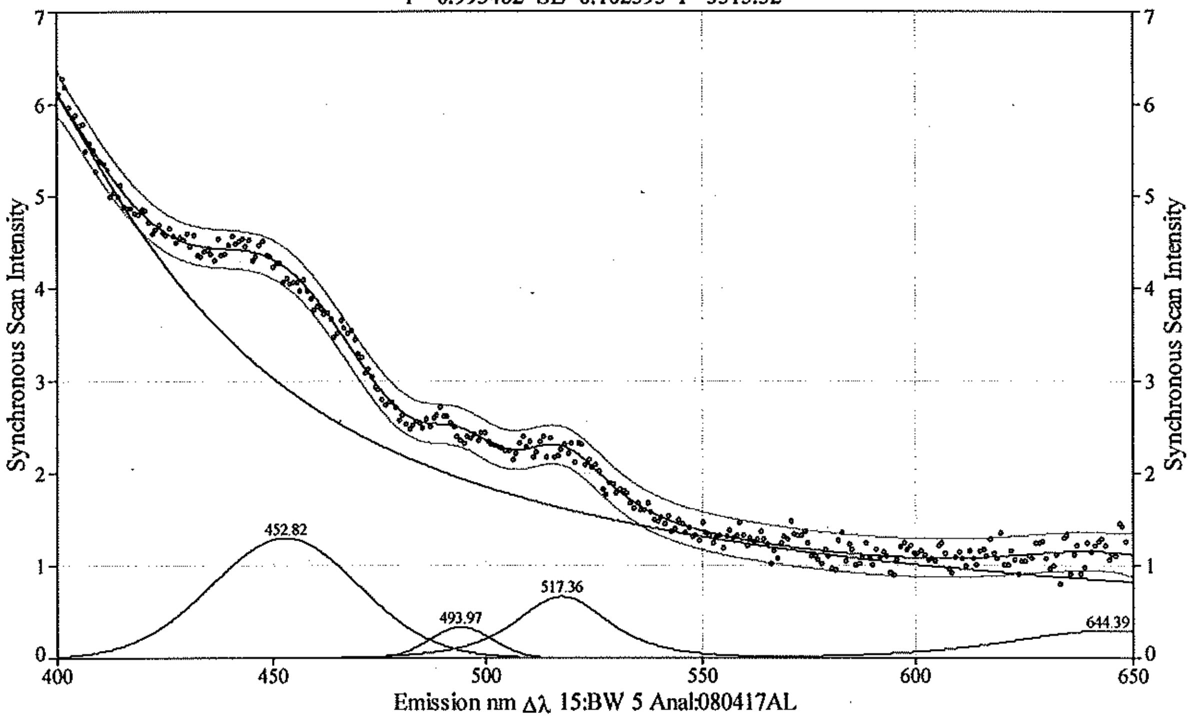
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A631, In:080325 1340, Out:080402 1025

Pk=Pearson VII Area 5 Peaks
r^2=0.995402 SE=0.102393 F=3315.32



Description: Frego Creek, Carbon, 23:A631, In:080325 1340, Out:080402 1025
X Variable: Emission nm Δλ 15:BW 5 Anal:080417AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080325-080402\fc310402

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99540154	0.99508440	0.10239284	3315.31742

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	22936.2959	382.657930	114.143117	0.51023554
2	Pearson VII Area	56.8785919	452.817677	40.7780419	21.8948438
3	Pearson VII Area	6.19944541	493.974498	17.1635976	167.913899
4	Pearson VII Area	21.1657472	517.357259	25.5939841	1.81186727
5	Pearson VII Area	20.6674475	644.391303	55.3720034	1.92369631

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.89592883	382.798165	114.144458	0.99509773	0.00000000	0.00000000
2	Pearson VII Area	1.29802494	452.817675	40.7780419	1.00000015	83.2076742	1.00000008
3	Pearson VII Area	0.33891346	493.974498	17.1635976	1.00000000	34.4418035	1.00000000
4	Pearson VII Area	0.66465437	517.357261	25.5939841	0.99999967	66.3879681	0.99999986
5	Pearson VII Area	0.30364355	644.391303	55.3720034	1.00000000	141.258173	1.00000000

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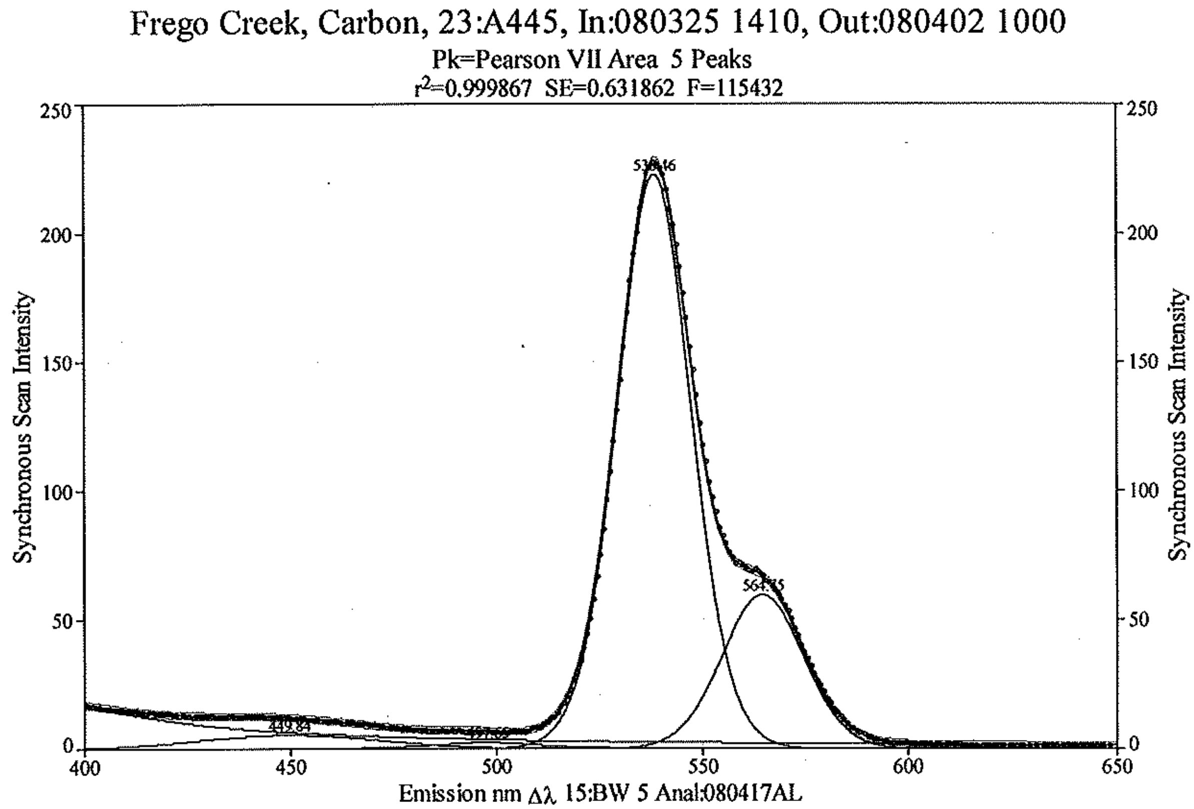
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A445, In:080325 1410, Out:080402 1000
X Variable: Emission nm Δλ 15:BW 5 Anal:080417AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080325-080402\fc450402

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99986734	0.99985819	0.63186229	1.1543e+05

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	34420.2359	390.755835	80.1917536	0.51269433
2	Pearson VII Area	311.088249	449.841539	52.7704906	167.917066
3	Pearson VII Area	111.468266	497.652903	31.1373750	1.26021279
4	Pearson VII Area	5032.36563	538.455606	20.7590468	9.84953412
5	Pearson VII Area	1498.61881	564.749303	23.4063785	20.2614254

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	18.1283678	390.755834	80.1917536	1.00000005	0.00000000	0.00000000
2	Pearson VII Area	5.53142190	449.841539	52.7704906	0.99999999	105.893346	1.00000000
3	Pearson VII Area	2.58094054	497.652903	31.1373750	1.00000000	92.0837762	1.00000000
4	Pearson VII Area	222.844349	538.455607	20.7590468	0.99999982	43.3893672	0.99999991
5	Pearson VII Area	59.5356333	564.749300	23.4063785	1.00000042	47.8355881	1.00000023

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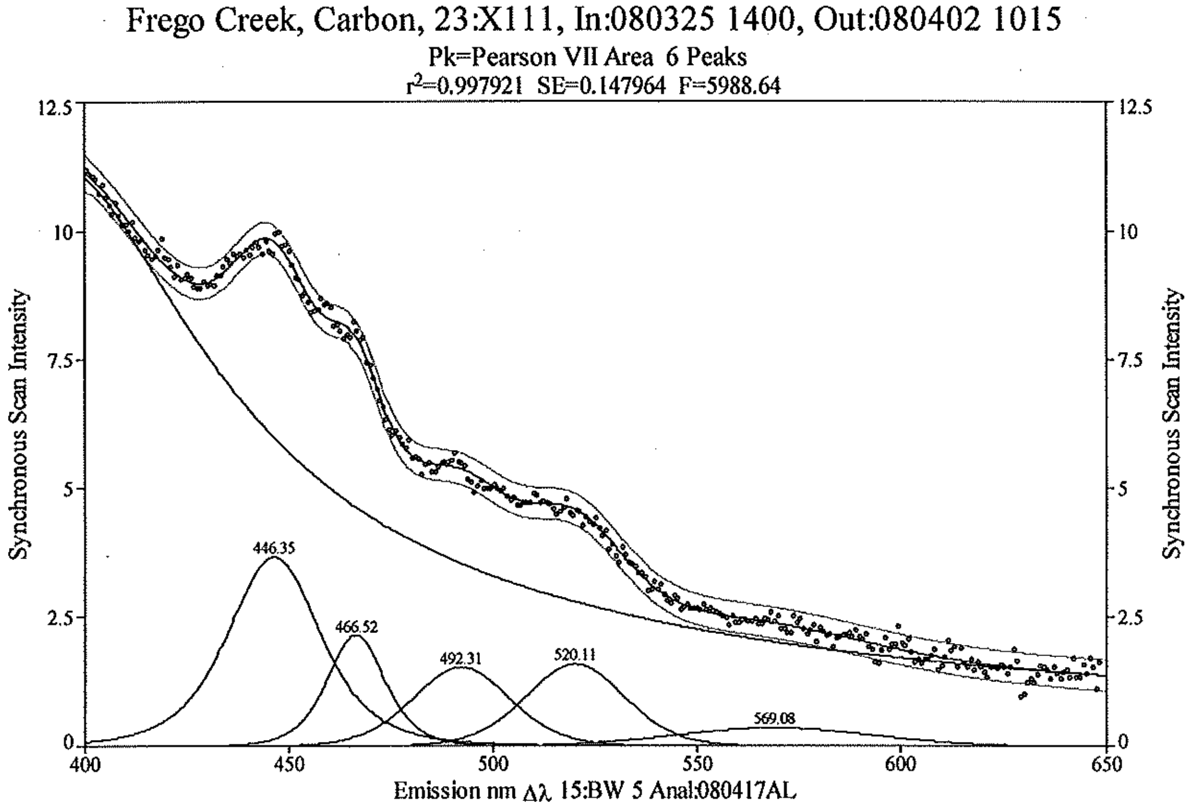
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:X111, In:080325 1400, Out:080402 1015
X Variable: Emission nm Δλ 15:BW 5 Anal:080417AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080325-080402\fcx10402

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99792068	0.99774619	0.14796360	5988.63929

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	14575.7266	392.441481	116.125490	0.52843105
2	Pearson VII Area	118.672672	446.347046	27.0796651	2.25305473
3	Pearson VII Area	42.1815180	466.515946	16.9059833	2.84946905
4	Pearson VII Area	47.2046173	492.311961	28.0931476	6.21120203
5	Pearson VII Area	49.6801100	520.114263	28.5597035	6.80834892
6	Pearson VII Area	21.9322588	569.082922	57.5372323	167.881880

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	11.3148399	392.441480	116.125490	1.00000001	0.00000000	0.00000000
2	Pearson VII Area	3.66238783	446.347046	27.0796651	1.00000007	66.4618890	1.00000003
3	Pearson VII Area	2.14812047	466.515946	16.9059833	0.99999997	39.6344923	0.99999999
4	Pearson VII Area	1.52322338	492.311961	28.0931476	1.00000000	60.2817030	1.00000000
5	Pearson VII Area	1.58228412	520.114263	28.5597035	1.00000000	60.8979137	1.00000000
6	Pearson VII Area	0.35766677	569.082922	57.5372323	1.00000000	115.458719	1.00000000

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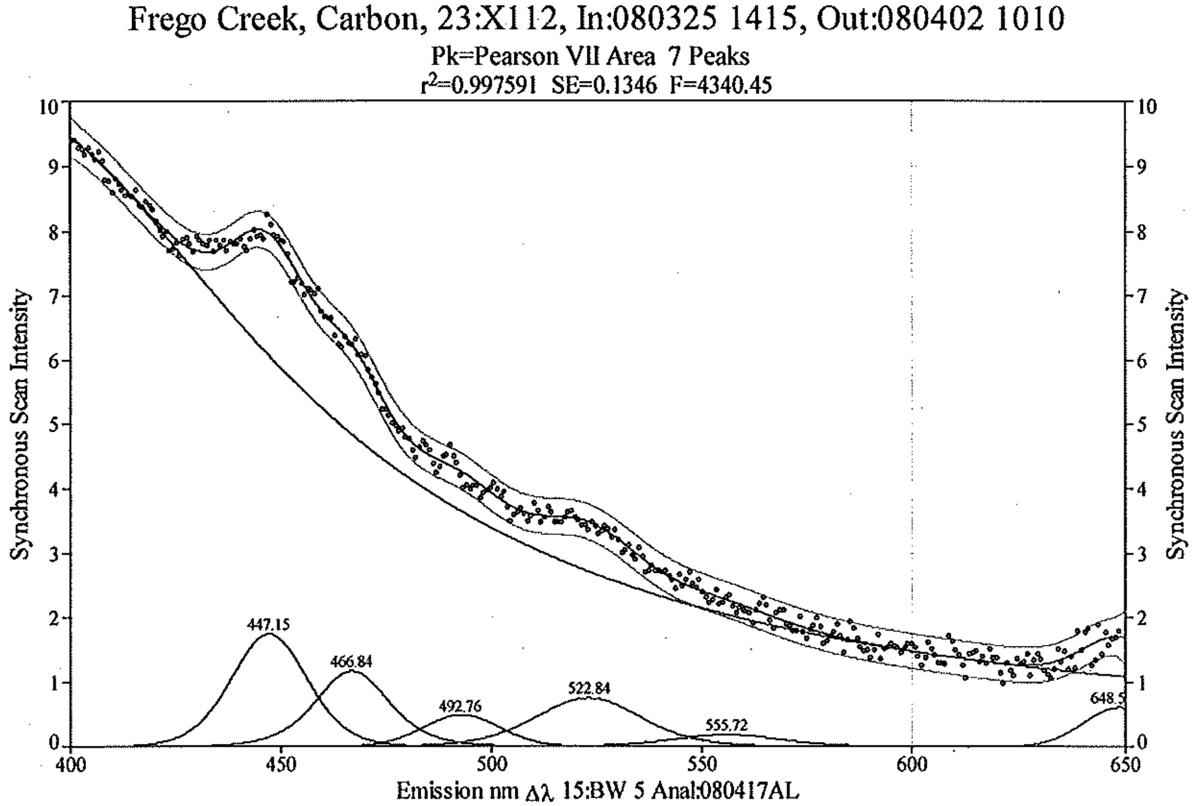
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:X112, In:080325 1415, Out:080402 1010
X Variable: Emission nm Δλ 15:BW 5 Anal:080417AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080325-080402\fcx20402

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99759098	0.99735179	0.13460015	4340.44910

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	3108.70908	383.782009	162.761118	0.80149509
2	Pearson VII Area	41.1166565	447.148994	21.3014354	5.81806841
3	Pearson VII Area	27.6364181	466.841957	20.6164481	3.24738880
4	Pearson VII Area	11.2402054	492.756267	21.2753674	26.1119303
5	Pearson VII Area	24.7025957	522.841160	29.5648754	5.20449916
6	Pearson VII Area	6.14146607	555.715043	30.1031935	5.58917308
7	Pearson VII Area	13.1823363	648.504940	20.1001036	65.3372945

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	9.87076701	383.782009	162.761118	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	1.74515776	447.148995	21.3014354	0.99999972	45.9318282	0.99999986
3	Pearson VII Area	1.16885635	466.841957	20.6164481	1.00000000	47.3453292	1.00000000
4	Pearson VII Area	0.49241998	492.756267	21.2753674	1.00000000	43.2768457	1.00000000
5	Pearson VII Area	0.75163016	522.841160	29.5648754	0.99999999	64.3362952	1.00000000
6	Pearson VII Area	0.18413272	555.715041	30.1031935	1.00000031	65.1169952	1.00000016
7	Pearson VII Area	0.61419932	648.504940	20.1001036	1.00000001	40.4923088	1.00000001

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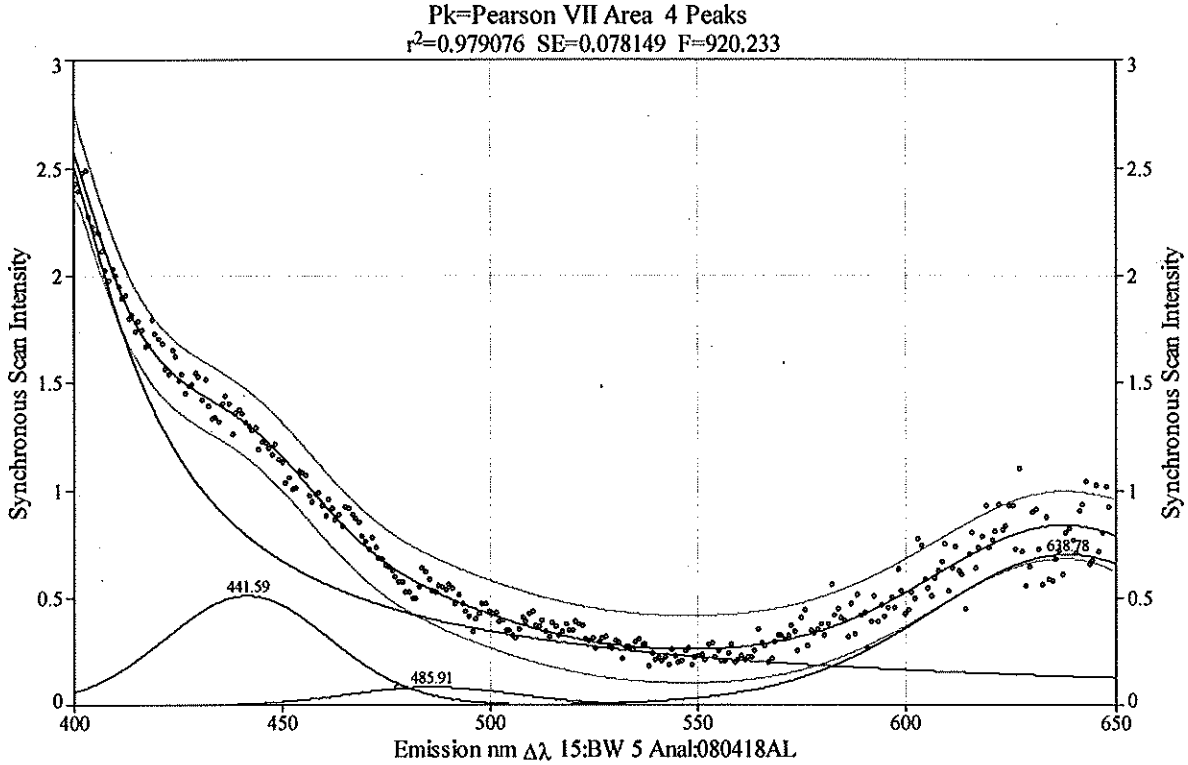
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

LCCMR, Water, Eluent, Sampled:080418 0115



Description: LCCMR, Water, Eluent, Sampled:080418 0115
X Variable: Emission nm Δλ 15:BW 5 Anal:080418AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080402-080409\bl080418

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.97907579	0.97793706	0.07814901	920.233495

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	804.246049	391.891208	52.8823803	0.56492718
2	Pearson VII Area	25.7771869	441.594845	46.7581279	16.5286727
3	Pearson VII Area	4.31291682	485.910285	47.5188506	167.864167
4	Pearson VII Area	60.7373725	638.781754	78.8023099	7.46576540

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	2.82018669	391.972477	52.8832323	0.99387177	0.00000000	0.00000000
2	Pearson VII Area	0.51139766	441.594846	46.7581279	0.99999988	96.0150310	0.99999994
3	Pearson VII Area	0.08516268	485.910285	47.5188506	1.00000000	95.3550743	1.00000000
4	Pearson VII Area	0.70324022	638.781757	78.8023099	0.99999987	167.069160	0.99999993

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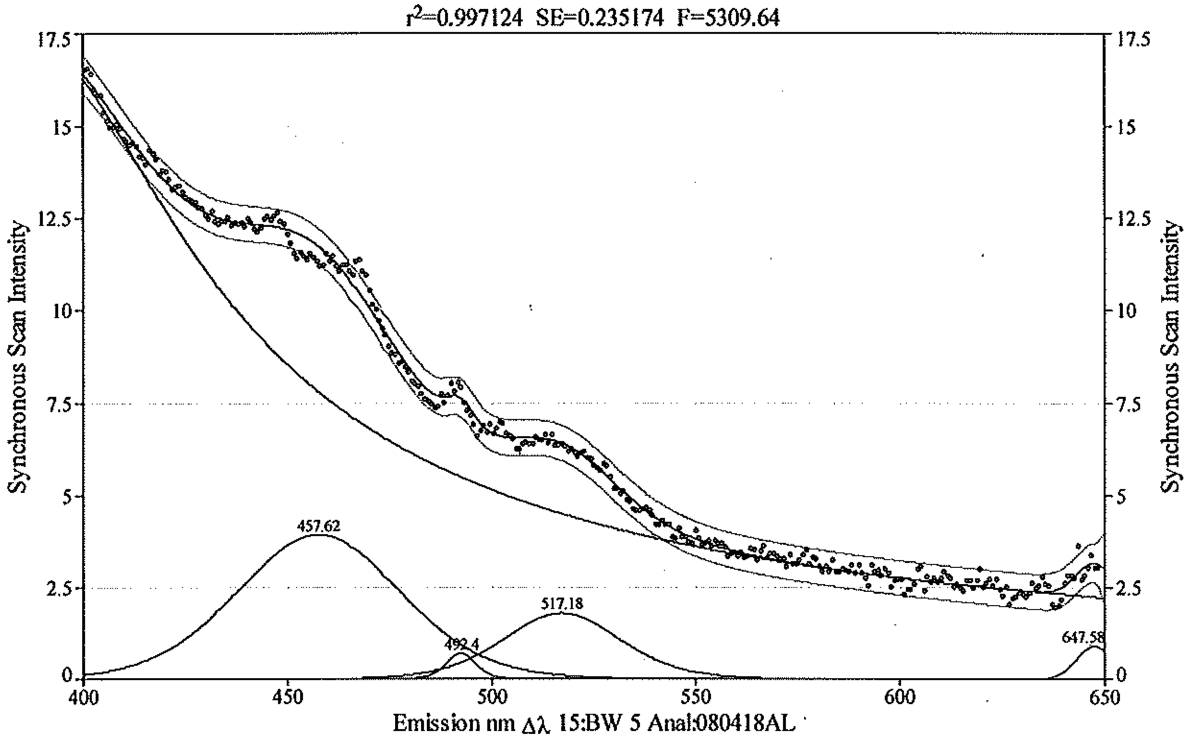
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A400, In:080402 0945, Out:080409 1026

Pk=Pearson VII Area 5 Peaks
r^2=0.997124 SE=0.235174 F=5309.64



Description: Frego Creek, Carbon, 23:A400, In:080402 0945, Out:080409 1026
X Variable: Emission nm Δλ 15:BW 5 Anal:080418AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080402-080409\fc000409

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99712377	0.99692541	0.23517366	5309.63815

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	32540.7451	387.071572	124.011288	0.52026433
2	Pearson VII Area	204.135959	457.616884	47.2795225	7.08867026
3	Pearson VII Area	7.05271019	492.397576	8.52080431	3.26492203
4	Pearson VII Area	68.7323544	517.181163	34.2826510	4.95736942
5	Pearson VII Area	10.1951985	647.580713	10.4821966	167.255006

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	17.2820410	387.098624	124.011332	0.99912782	0.00000000	0.00000000
2	Pearson VII Area	3.93280350	457.616884	47.2795225	1.00000000	100.554428	1.00000000
3	Pearson VII Area	0.72206333	492.397575	8.52080431	1.00000077	19.5524880	1.00000037
4	Pearson VII Area	1.79916972	517.181163	34.2826510	0.99999997	74.9282529	0.99999998
5	Pearson VII Area	0.91261083	647.580714	10.4821966	0.99999990	21.0345928	0.99999995

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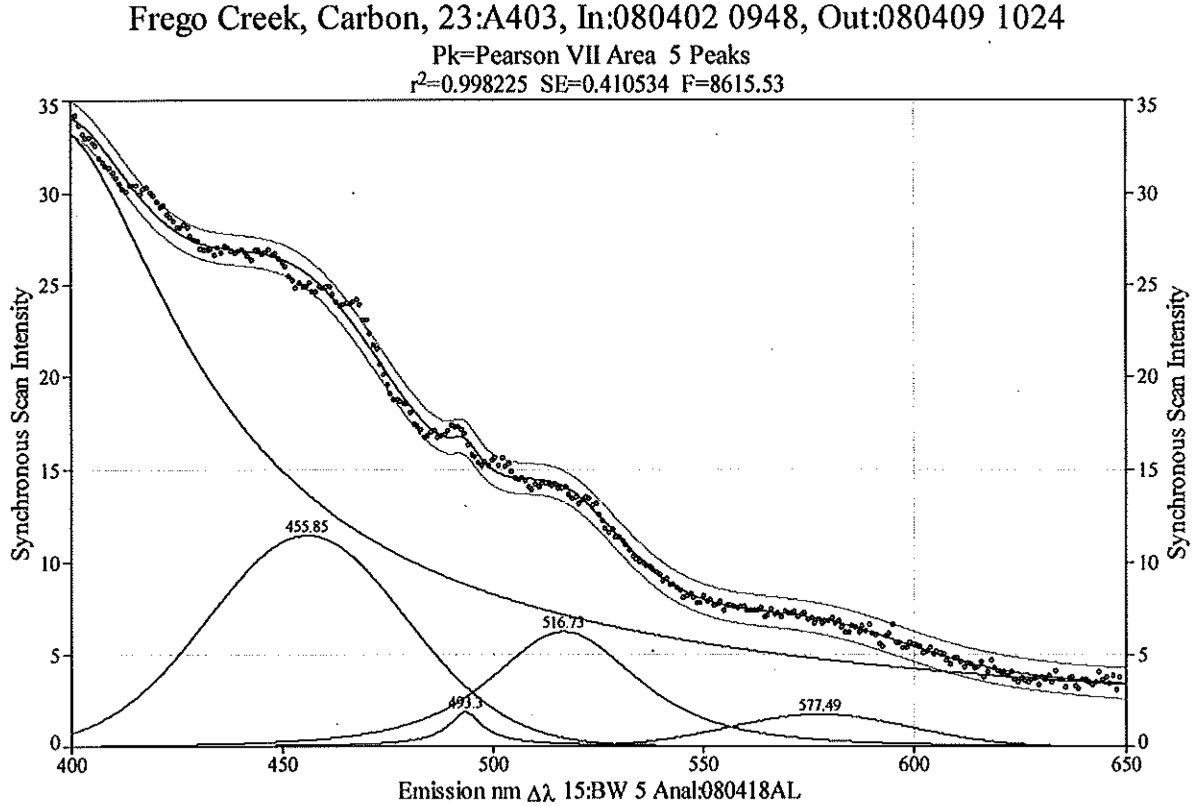
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A403, In:080402 0948, Out:080409 1024
X Variable: Emission nm Δλ 15:BW 5 Anal:080418AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080402-080409\fc030409

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99822546	0.99810308	0.41053374	8615.52531

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	58594.0914	395.862597	93.1007259	0.51623778
2	Pearson VII Area	682.229056	455.850787	55.5953948	27.4851307
3	Pearson VII Area	50.8614918	493.302007	10.8596006	0.68895702
4	Pearson VII Area	330.050632	516.725599	41.5240029	1.63422450
5	Pearson VII Area	94.6619013	577.493243	50.2955286	167.909341

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	33.6284730	395.862597	93.1007259	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	11.4420752	455.850784	55.5953948	1.00000019	112.996691	1.00000010
3	Pearson VII Area	1.87890012	493.302007	10.8596006	1.00000001	48.0262421	1.00000000
4	Pearson VII Area	6.23677149	516.725599	41.5240029	1.00000000	111.168503	1.00000000
5	Pearson VII Area	1.76599770	577.493244	50.2955286	0.99999992	100.926908	0.99999996

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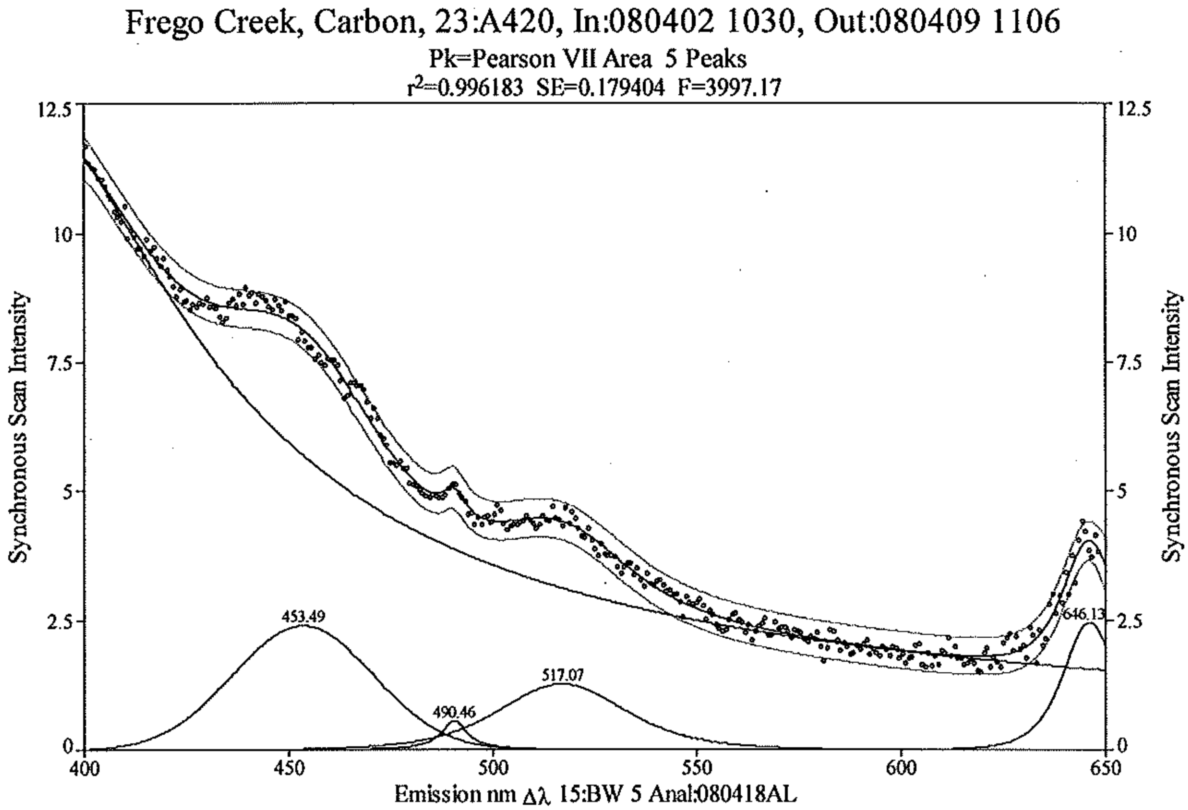
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A420, In:080402 1030, Out:080409 1106
X Variable: Emission nm Δλ 15:BW 5 Anal:080418AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080402-080409\fc200409

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99618297	0.99591972	0.17940384	3997.16834

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	22648.4615	386.616848	121.743575	0.52024081
2	Pearson VII Area	103.519945	453.488862	40.4004040	167.914094
3	Pearson VII Area	7.57293581	490.456911	7.88848433	0.91212924
4	Pearson VII Area	55.6805686	517.066496	37.2825063	2.59866567
5	Pearson VII Area	45.3474140	646.134065	15.3334347	2.22251687

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	12.2379575	387.098624	121.758025	0.98429695	0.00000000	0.00000000
2	Pearson VII Area	2.40426662	453.488862	40.4004040	1.00000000	81.0705778	1.00000000
3	Pearson VII Area	0.56885339	490.456911	7.88848433	1.00000015	27.8662957	1.00000005
4	Pearson VII Area	1.27241606	517.066496	37.2825063	1.00000000	88.8608154	1.00000000
5	Pearson VII Area	2.46644124	646.134065	15.3334347	1.00000002	37.7484853	1.00000001

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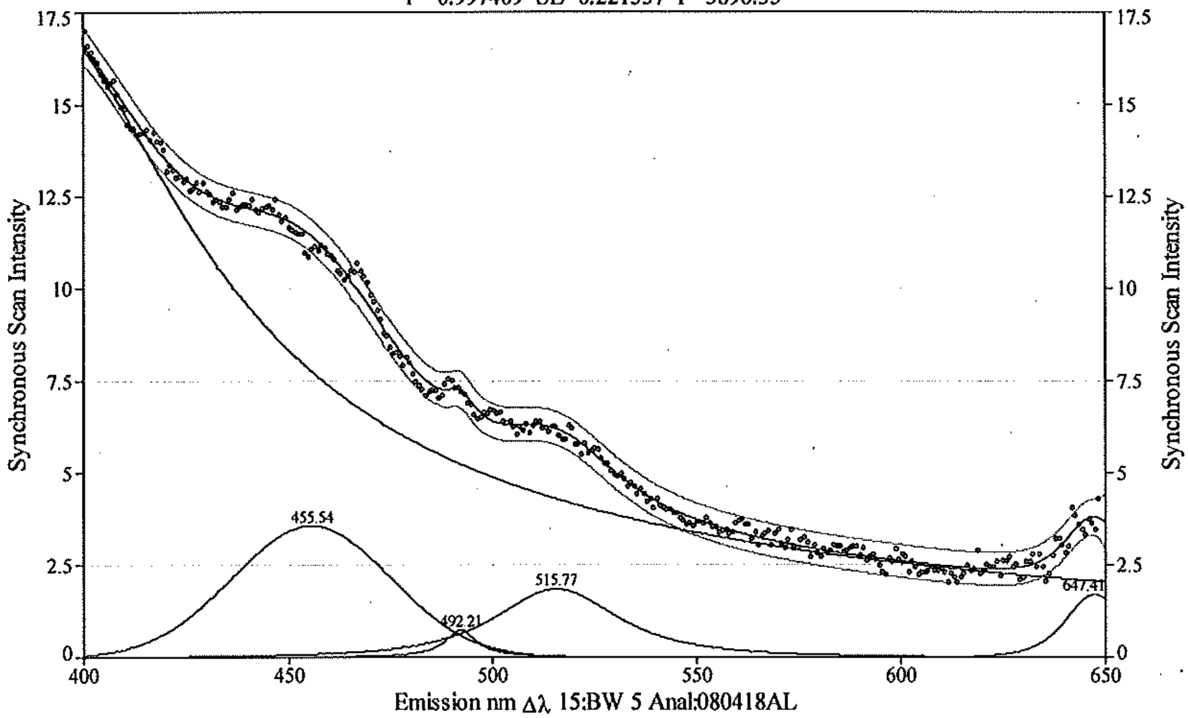
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A631, In:080402 1025, Out:080409 1100

Pk=Pearson VII Area 5 Peaks
r^2=0.997409 SE=0.221337 F=5896.35



Description: Frego Creek, Carbon, 23:A631, In:080402 1025, Out:080409 1100
X Variable: Emission nm Δλ 15:BW 5 Anal:080418AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080402-080409\fc310409

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99740923	0.99723055	0.22133745	5896.35206

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	21621.2804	389.380989	115.509542	0.52920909
2	Pearson VII Area	173.176317	455.540962	45.6881471	147.692621
3	Pearson VII Area	13.0538981	492.207841	9.46101879	0.84329302
4	Pearson VII Area	88.5250047	515.774766	36.0213978	1.40507197
5	Pearson VII Area	33.9518855	647.409784	16.7146018	2.33454033

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	17.2925536	389.965596	115.531467	0.97996215	0.00000000	0.00000000
2	Pearson VII Area	3.55596359	455.540962	45.6881471	0.99999999	91.7125509	1.00000000
3	Pearson VII Area	0.75714400	492.207840	9.46101879	1.00000065	35.3140775	1.00000019
4	Pearson VII Area	1.84514837	515.774766	36.0213978	1.00000000	101.786734	1.00000000
5	Pearson VII Area	1.70639571	647.409781	16.7146018	1.00000063	40.7060146	1.00000029

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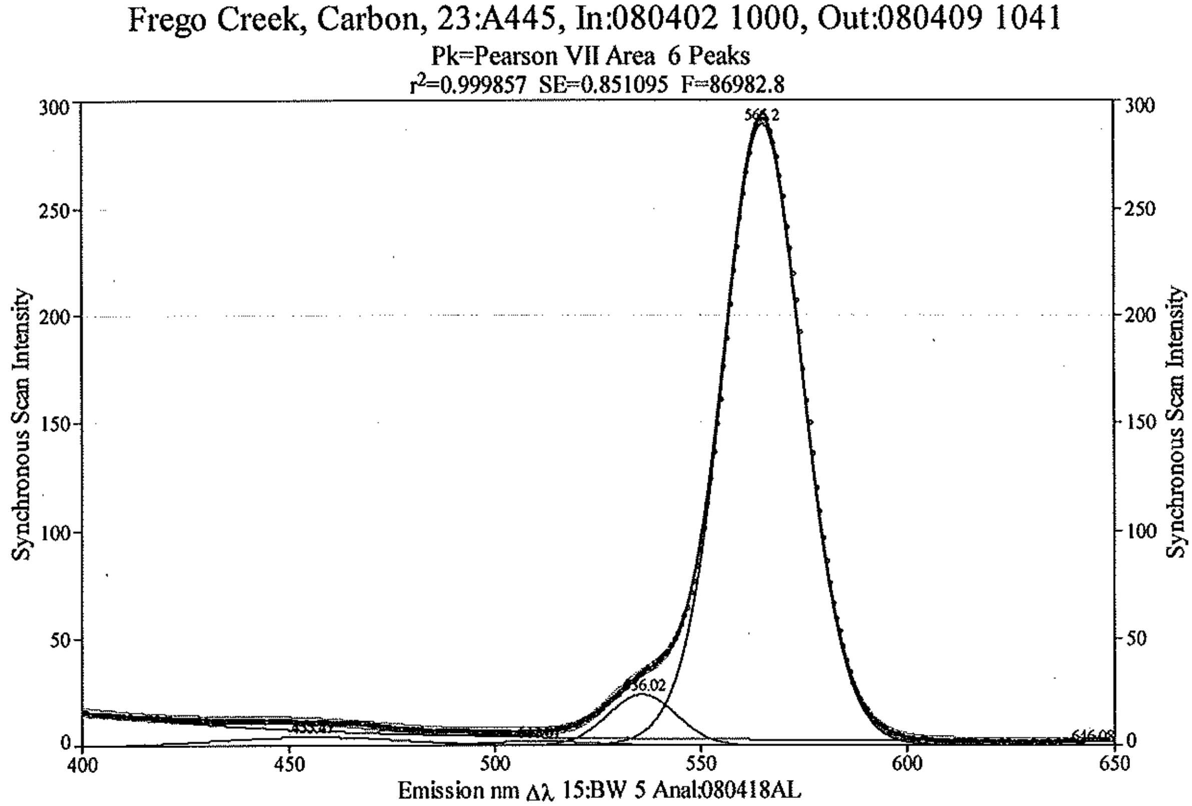
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A445, In:080402 1000, Out:080409 1041
X Variable: Emission nm Δλ 15:BW 5 Anal:080418AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080402-080409\fc450409

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99985656	0.99984453	0.85109505	86982.7927

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	20510.0635	384.630786	109.076178	0.53005432
2	Pearson VII Area	243.074492	455.469718	51.7817265	22.1455214
3	Pearson VII Area	78.5281886	511.012084	31.4069299	3.77690391
4	Pearson VII Area	497.081969	536.019149	19.4493145	37.4934051
5	Pearson VII Area	7112.46625	565.195887	22.5320921	8.54797710
6	Pearson VII Area	24.9034841	646.083580	6.00812293	0.51261596

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	17.8315271	384.632771	109.076178	0.99992718	0.00000000	0.00000000
2	Pearson VII Area	4.36889022	455.469718	51.7817265	0.99999999	105.637514	1.00000000
3	Pearson VII Area	2.20677592	511.012085	31.4069299	0.99999996	70.6706196	0.99999998
4	Pearson VII Area	23.8791628	536.019149	19.4493145	1.00000000	39.3687199	1.00000000
5	Pearson VII Area	289.148352	565.195887	22.5320921	1.00000000	47.4148081	1.00000000
6	Pearson VII Area	0.17402550	646.083580	6.00812293	1.00000056	37.3034684	1.00000010

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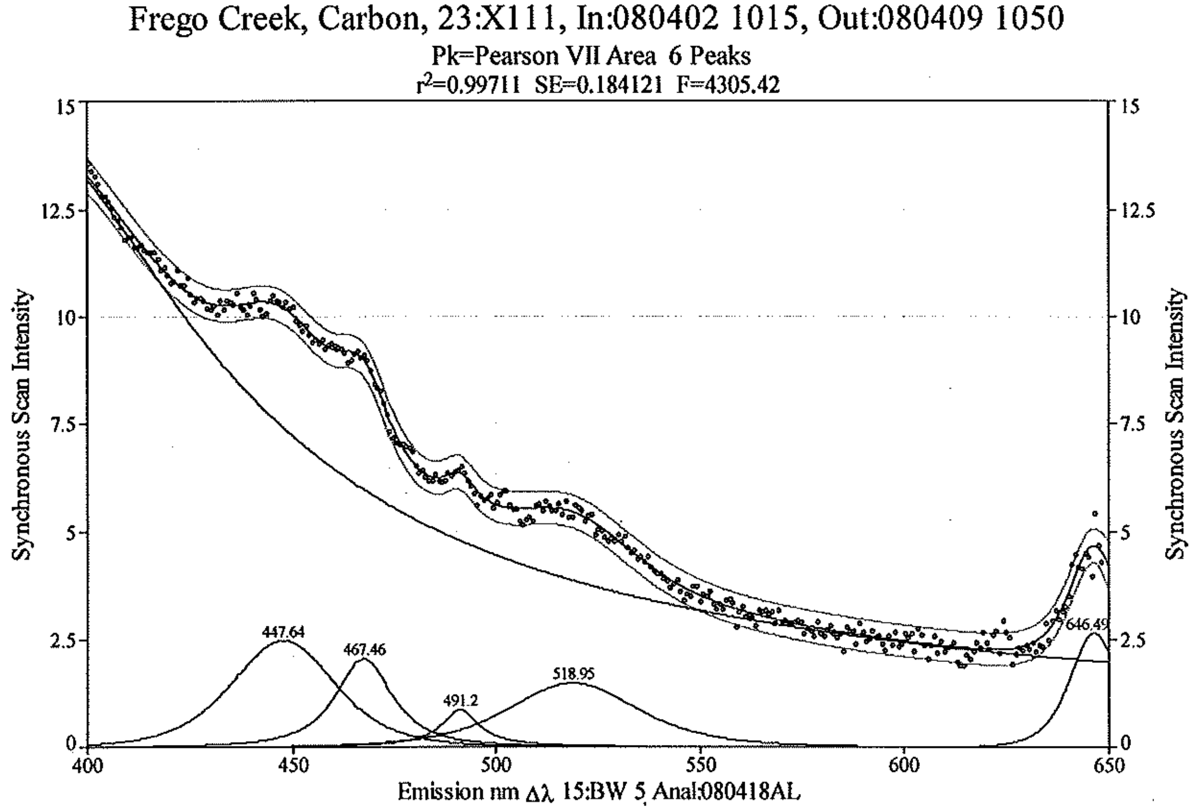
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:X111, In:080402 1015, Out:080409 1050
X Variable: Emission nm Δλ 15:BW 5 Anal:080418AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080402-080409\fcx10409

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99711011	0.99686760	0.18412086	4305.41874

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	48314.5221	385.012232	133.212237	0.51169867
2	Pearson VII Area	87.9532083	447.637232	30.0768018	2.52098340
3	Pearson VII Area	47.9513612	467.462448	16.9432899	1.27633703
4	Pearson VII Area	18.6633698	491.199937	11.6788890	0.84488483
5	Pearson VII Area	67.9097235	518.949453	37.8638879	2.17477960
6	Pearson VII Area	44.4255492	646.492542	14.2018502	2.53339030

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	14.1500660	386.525229	133.345356	0.95562125	0.00000000	0.00000000
2	Pearson VII Area	2.48207780	447.637232	30.0768018	1.00000000	72.1057816	1.00000000
3	Pearson VII Area	2.05103124	467.462447	16.9432899	1.00000016	49.8253437	1.00000006
4	Pearson VII Area	0.87873258	491.199937	11.6788890	0.99999999	43.5319846	1.00000000
5	Pearson VII Area	1.49071354	518.949453	37.8638879	1.00000000	93.6799540	1.00000000
6	Pearson VII Area	2.65676238	646.492545	14.2018502	0.99999917	34.0147714	0.99999962

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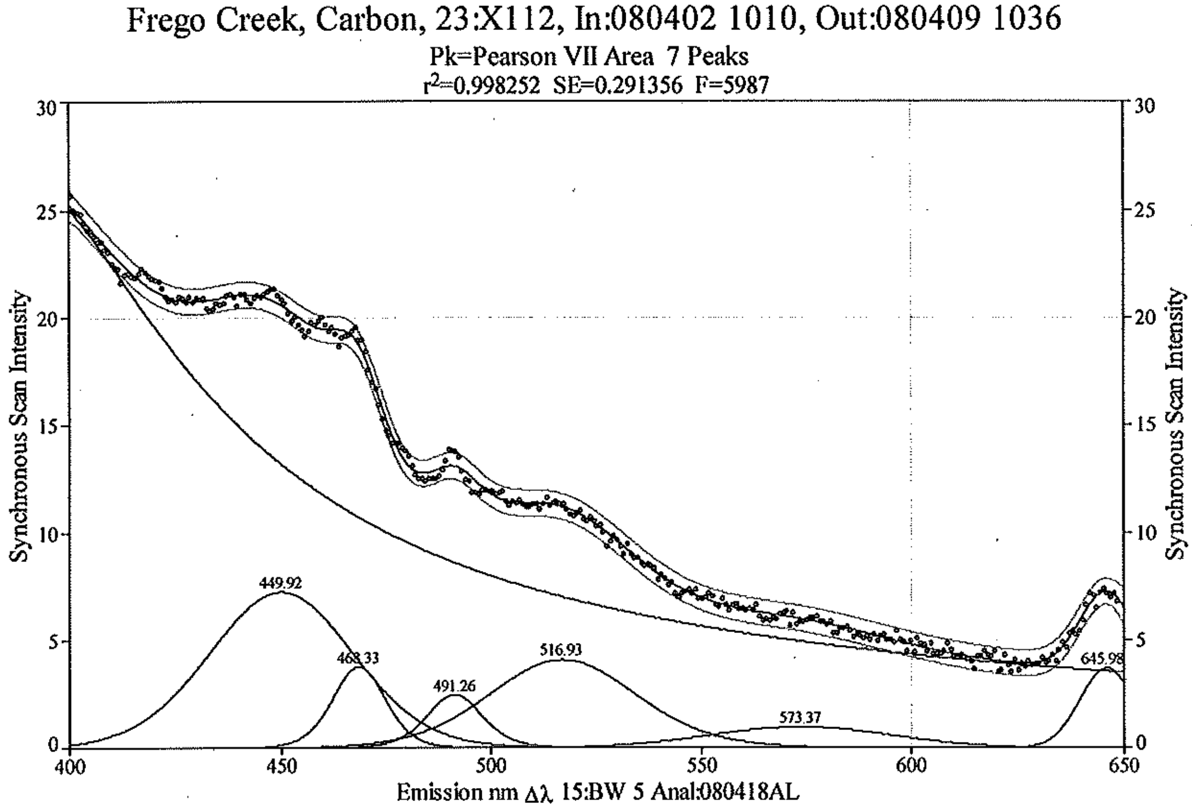
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:X112, In:080402 1010, Out:080409 1036
X Variable: Emission nm Δλ 15:BW 5 Anal:080418AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek\fregocreek080402-080409\fcx20409

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99825235	0.99807883	0.29135575	5987.00064

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	70442.0383	386.459557	124.609948	0.51430347
2	Pearson VII Area	316.681390	449.923911	40.2956408	10.7743003
3	Pearson VII Area	62.7741117	468.334463	14.8662716	4.74990565
4	Pearson VII Area	44.3144205	491.261163	15.6553836	3.57341529
5	Pearson VII Area	184.793246	516.930349	41.1895957	7.36905878
6	Pearson VII Area	52.8579097	573.370648	50.6906497	167.913505
7	Pearson VII Area	59.1431869	645.979860	14.9502367	50.2075021

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	26.7673981	386.525229	124.610214	0.99789413	0.00000000	0.00000000
2	Pearson VII Area	7.23859939	449.923911	40.2956408	1.00000000	83.9049704	1.00000000
3	Pearson VII Area	3.78081511	468.334463	14.8662716	1.00000000	32.6226894	1.00000000
4	Pearson VII Area	2.48788901	491.261163	15.6553836	1.00000001	35.4772573	1.00000000
5	Pearson VII Area	4.09171601	516.930349	41.1895957	0.99999998	87.3942032	0.99999999
6	Pearson VII Area	0.97842249	573.370648	50.6906497	1.00000000	101.719782	1.00000000
7	Pearson VII Area	3.70134572	645.979859	14.9502367	1.00000021	30.1760263	1.00000012

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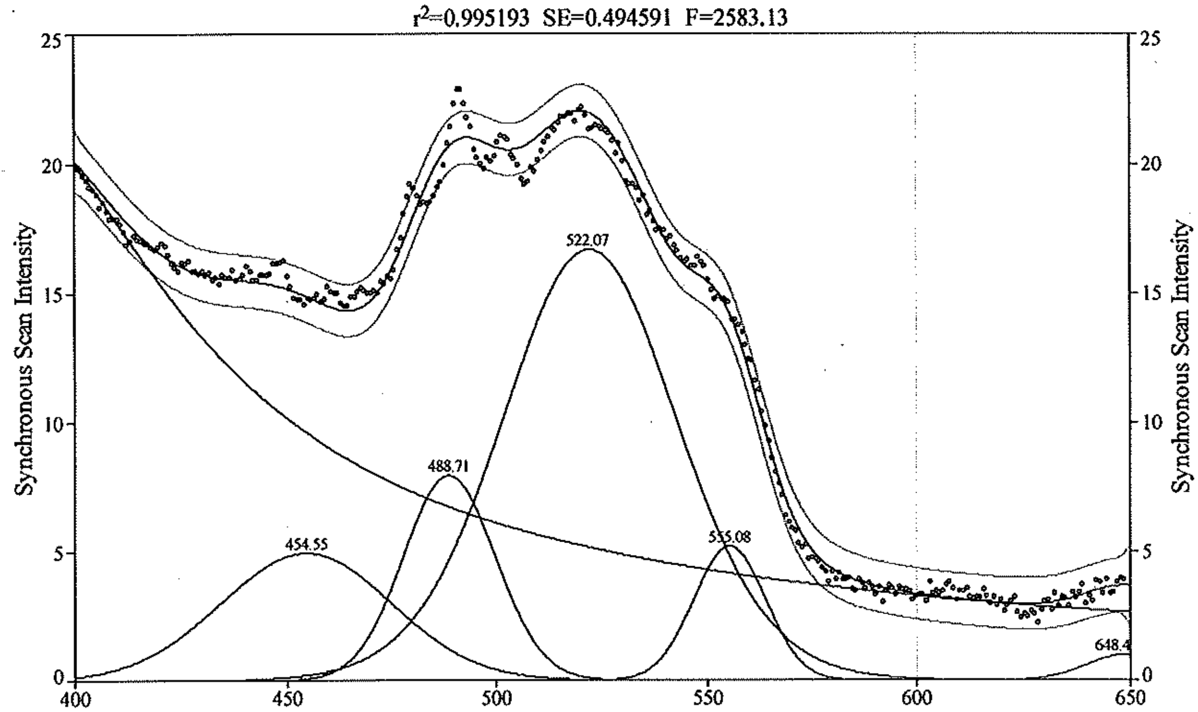
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A400, In:080409 1026, Out:080424 1229

Pk=Pearson VII Area 7 Peaks

r^2=0.995193 SE=0.494591 F=2583.13



Description: Frego Creek, Carbon, 23:A400, In:080409 1026, Out:080424 1229
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080409-080424\fc000424

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99519254	0.99478912	0.49459053	2583.12598

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	42687.0785	386.041119	118.899765	0.51836235
2	Pearson VII Area	254.387003	454.553094	48.0952543	92.6286491
3	Pearson VII Area	220.943539	488.710530	25.9643979	46.3931238
4	Pearson VII Area	883.909146	522.072513	48.6207861	9.05820299
5	Pearson VII Area	112.203390	555.081642	20.1222947	55.4521527
6	Pearson VII Area	24.7885480	649.396155	22.4700854	167.907061

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	21.5493363	386.525229	118.914778	0.98384724	0.00000000	0.00000000
2	Pearson VII Area	4.95802708	454.553094	48.0952543	1.00000000	96.7068452	1.00000000
3	Pearson VII Area	7.95901195	488.710530	25.9643979	1.00000000	52.4433989	1.00000000
4	Pearson VII Area	16.6780490	522.072513	48.6207861	1.00000000	102.018800	1.00000000
5	Pearson VII Area	5.21915400	555.081642	20.1222947	1.00000000	40.5833863	1.00000000
6	Pearson VII Area	1.02948308	648.399991	22.5586019	1.19374694	45.1173205	1.10188481

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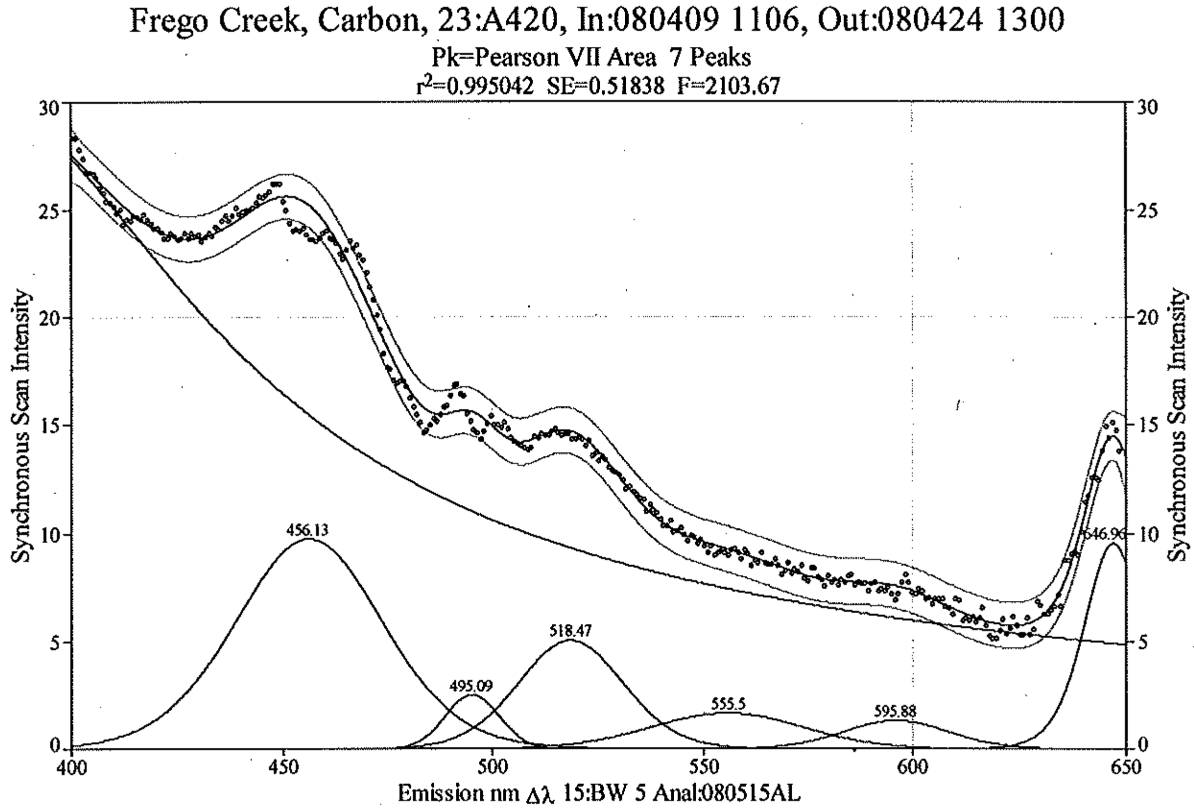
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A420, In:080409 1106, Out:080424 1300
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080409-080424\fc200424

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99504224	0.99454998	0.51837967	2103.67429

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1.0274e+05	380.605414	159.377618	0.51390990
2	Pearson VII Area	444.519575	456.129235	41.6094174	7.60799628
3	Pearson VII Area	41.0288363	495.089152	15.1937618	167.820690
4	Pearson VII Area	161.802027	518.465176	29.3584739	9.21827926
5	Pearson VII Area	77.5314832	555.504592	42.8390350	23.9939398
6	Pearson VII Area	43.4337023	595.879380	29.7915118	10.1920401
7	Pearson VII Area	173.716284	646.957139	16.2097655	4.37361545

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	29.7210396	380.791284	159.379288	0.99534601	0.00000000	0.00000000
2	Pearson VII Area	9.75306953	456.129237	41.6094174	0.99999982	88.1187395	0.99999990
3	Pearson VII Area	2.53377412	495.089153	15.1937618	0.99999971	30.4890206	0.99999984
4	Pearson VII Area	5.05825178	518.465177	29.3584739	0.99999999	61.5499242	0.99999999
5	Pearson VII Area	1.68564812	555.504593	42.8390350	0.99999992	87.2650262	0.99999996
6	Pearson VII Area	1.34123919	595.879380	29.7915118	1.00000000	62.1760467	1.00000000
7	Pearson VII Area	9.55053226	646.957139	16.2097655	0.99999996	35.8678720	0.99999998

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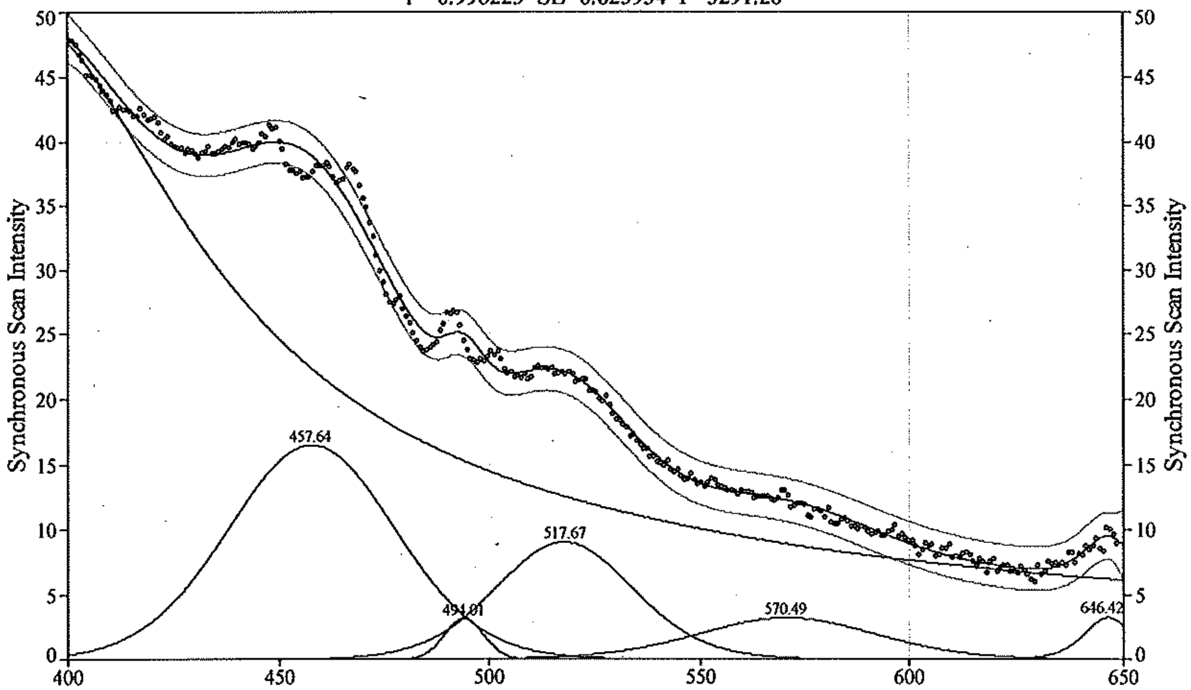
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A631, In:080409 1100, Out:080424 1300

Pk=Pearson VII Area 6 Peaks
r^2=0.996223 SE=0.823934 F=3291.26



Description: Frego Creek, Carbon, 23:A631, In:080409 1100, Out:080424 1300
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080409-080424\fc310424

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99622299	0.99590604	0.82393414	3291.26327

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	96753.3562	391.188991	117.737993	0.51831916
2	Pearson VII Area	841.782784	457.643939	47.3338431	15.5213687
3	Pearson VII Area	36.8965018	494.006552	10.9704225	167.794359
4	Pearson VII Area	379.041253	517.668232	38.3013375	7.52664986
5	Pearson VII Area	177.878629	570.486989	50.7671246	9.23754975
6	Pearson VII Area	52.0928406	646.421465	13.5036640	2.48921334

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	49.2203705	391.188991	117.737993	0.99999998	0.00000000	0.00000000
2	Pearson VII Area	16.4831110	457.643939	47.3338431	0.99999998	97.3607551	0.99999999
3	Pearson VII Area	3.15577307	494.006551	10.9704225	1.00000002	22.0141380	1.00000001
4	Pearson VII Area	9.03170614	517.668232	38.3013375	0.99999999	81.1639581	1.00000000
5	Pearson VII Area	3.21598205	570.486989	50.7671246	1.00000000	106.422545	1.00000000
6	Pearson VII Area	3.26901234	646.421466	13.5036640	0.99999971	32.4545167	0.99999987

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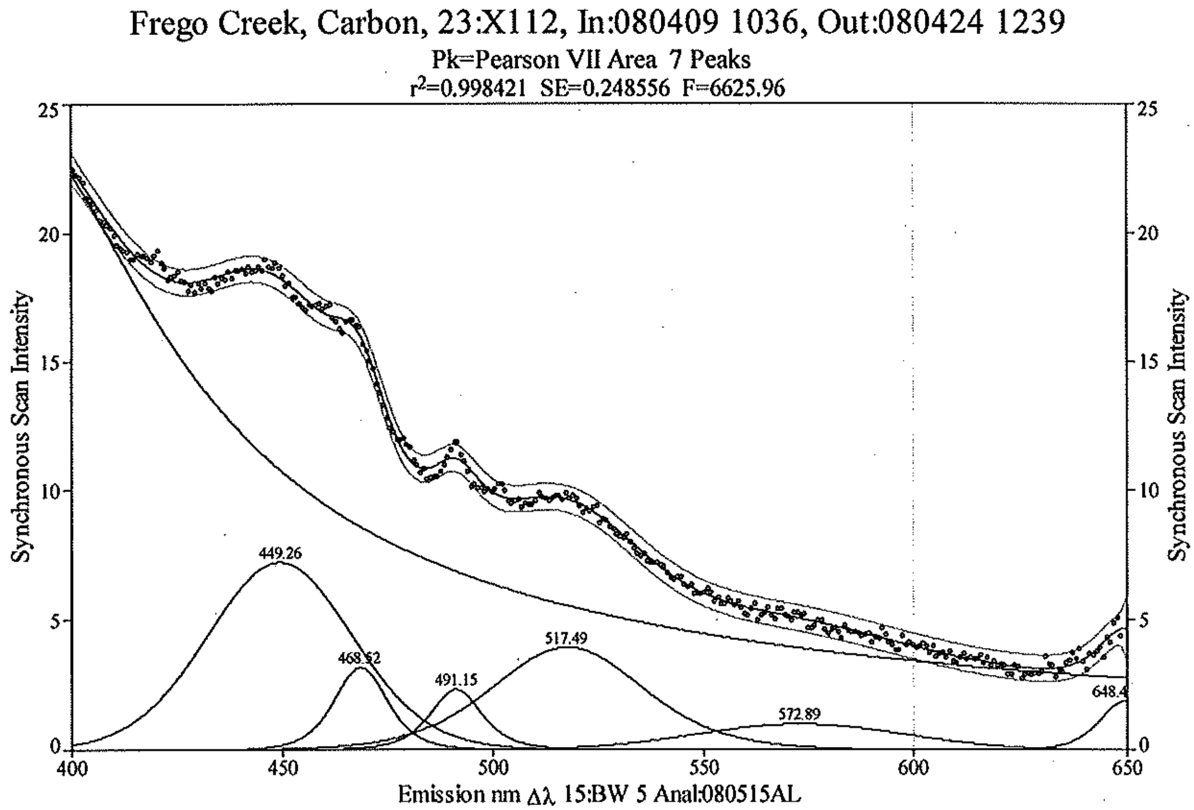
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:X112, In:080409 1036, Out:080424 1239
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080409-080424\fcx20424

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99842062	0.99826380	0.24855626	6625.95700

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	55524.5408	386.357001	108.305539	0.51432392
2	Pearson VII Area	320.690620	449.262238	40.9430546	11.1500551
3	Pearson VII Area	56.0661396	468.523110	15.1043698	2.63118406
4	Pearson VII Area	40.8596574	491.148235	14.5080874	2.10840293
5	Pearson VII Area	187.762722	517.490370	42.3814635	4.23571227
6	Pearson VII Area	61.8872654	572.891502	57.9400863	167.511784
7	Pearson VII Area	31.5938001	649.517112	14.4478450	2.99670971

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	24.3083120	386.357002	108.305539	0.99999998	0.00000000	0.00000000
2	Pearson VII Area	7.21938579	449.262238	40.9430546	1.00000000	85.1374328	1.00000000
3	Pearson VII Area	3.16721859	468.523110	15.1043698	1.00000000	35.9165836	1.00000000
4	Pearson VII Area	2.32908474	491.148235	14.5080874	1.00000000	36.1587791	1.00000000
5	Pearson VII Area	3.94044222	517.490370	42.3814635	0.99999998	94.1015903	0.99999999
6	Pearson VII Area	1.00222492	572.891503	57.9400863	0.99999997	116.267755	0.99999998
7	Pearson VII Area	1.85757663	648.399987	14.6639418	1.35950216	33.7312591	1.15736505

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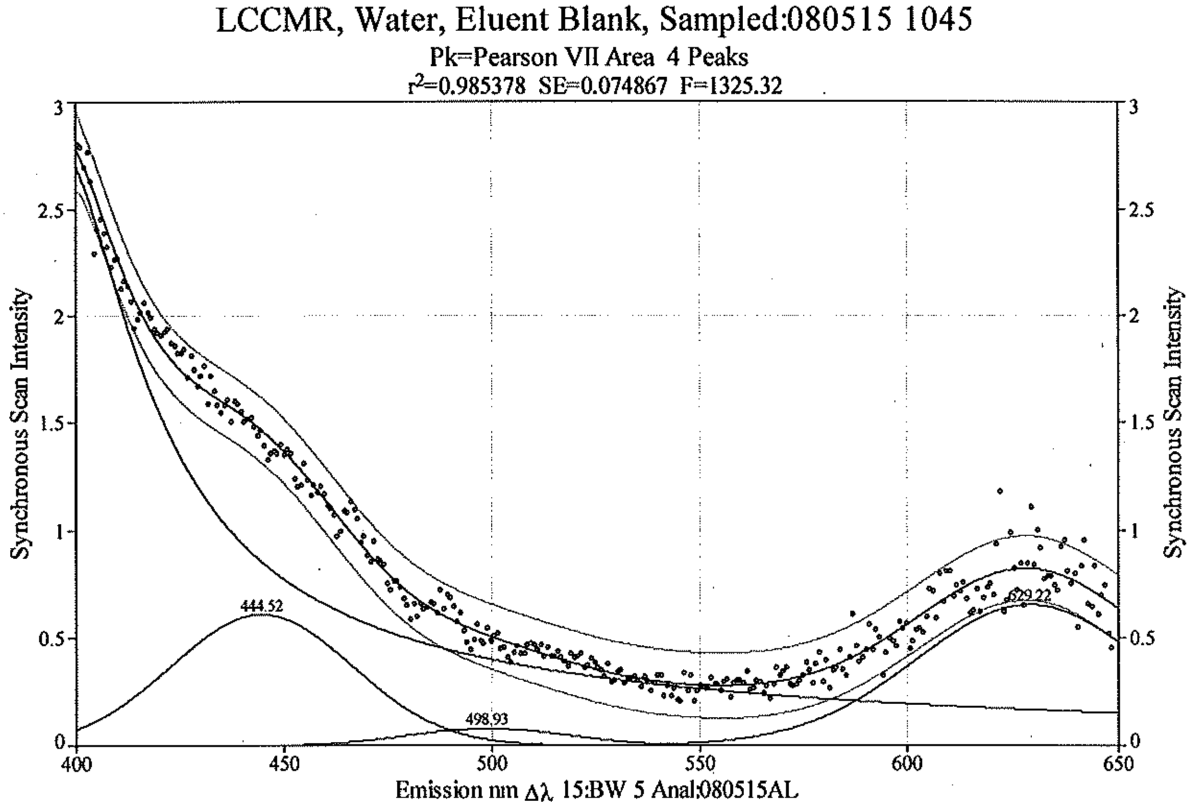
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: LCCMR, Water, Eluent Blank, Sampled:080515 1045
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080409-080424\eb080515

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98537778	0.98458202	0.07486700	1325.31876

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1308.47356	395.316338	56.0314785	0.53915724
2	Pearson VII Area	33.4554083	444.520704	51.4380283	66.0349044
3	Pearson VII Area	3.87348533	498.929293	45.5331986	167.482266
4	Pearson VII Area	45.2625380	629.224810	64.0521137	13.9481380

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	2.80810730	395.699541	56.0504332	0.97302186	0.00000000	0.00000000
2	Pearson VII Area	0.60913236	444.520704	51.4380283	1.00000000	103.616556	1.00000000
3	Pearson VII Area	0.07982092	498.929293	45.5331986	1.00000000	91.3710258	1.00000000
4	Pearson VII Area	0.65392543	629.224810	64.0521137	1.00000000	132.160082	1.00000000

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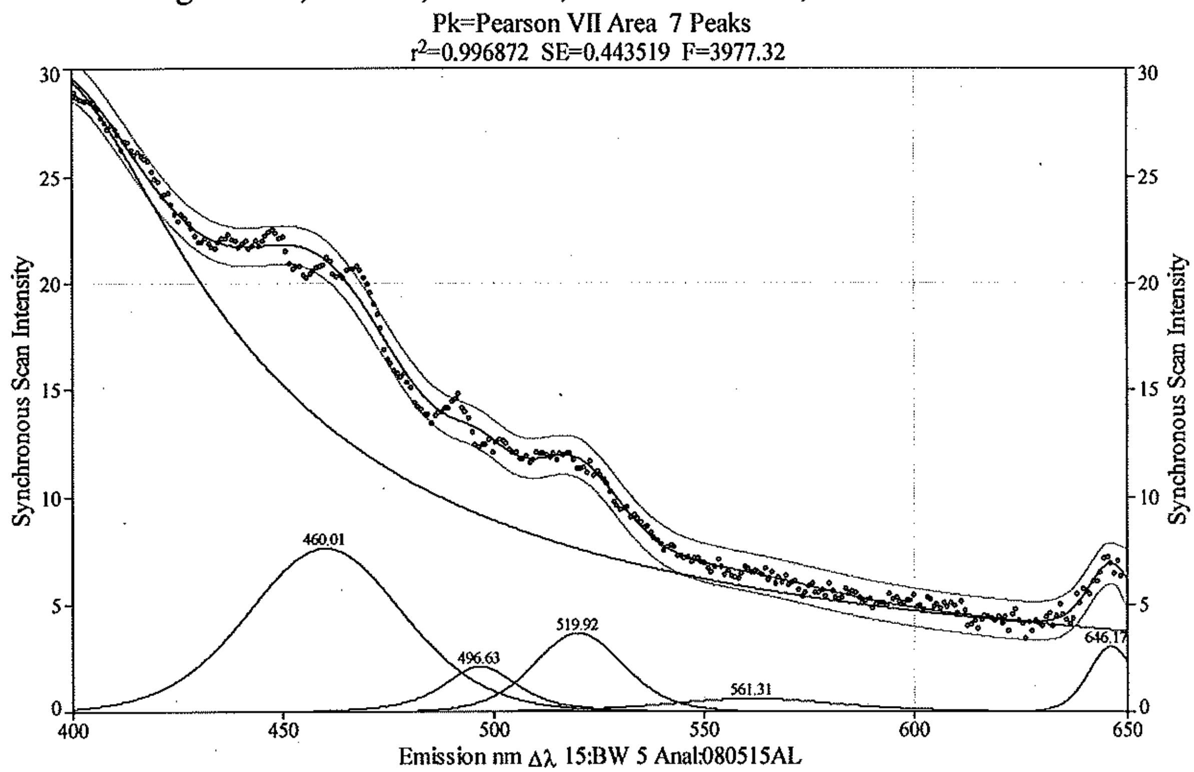
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A400, In:080424 1221, Out:080507 1010



Description: Frego Creek, Carbon, 23:A400, In:080424 1221, Out:080507 1010
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080424-080507\fc000507

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99687246	0.99661001	0.44351863	3977.31934

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	97936.2720	392.986524	116.157082	0.51064112
2	Pearson VII Area	368.355151	460.009365	43.5722133	5.43526437
3	Pearson VII Area	55.9407632	496.633740	20.7859688	1.68351348
4	Pearson VII Area	103.451295	519.915197	25.1661012	4.41499276
5	Pearson VII Area	37.0763945	561.311404	48.6309880	2.16924880
6	Pearson VII Area	43.3952964	646.174757	12.7835424	5.33111579

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	30.0430431	392.986524	116.157082	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	7.62047223	460.009364	43.5722133	1.00000016	94.4680734	1.00000008
3	Pearson VII Area	2.12730420	496.633740	20.7859688	1.00000000	55.1217998	1.00000000
4	Pearson VII Area	3.66545366	519.915197	25.1661012	0.99999991	55.6309091	0.99999996
5	Pearson VII Area	0.63342640	561.311404	48.6309880	1.00000002	120.390340	1.00000001
6	Pearson VII Area	3.05721782	646.174757	12.7835424	1.00000000	27.7608604	1.00000000

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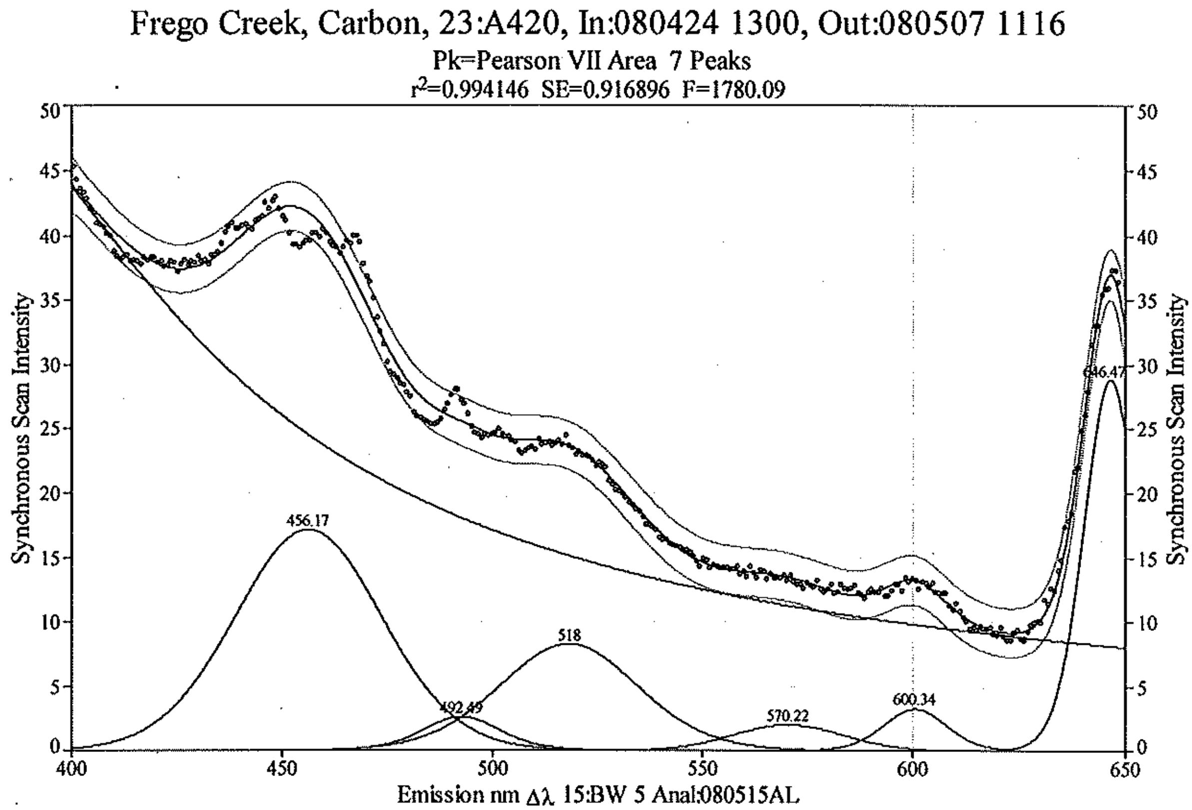
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A420, In:080424 1300, Out:080507 1116
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080424-080507\fc200507

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99414629	0.99356507	0.91689597	1780.08984

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1.8467e+05	374.517787	159.594865	0.51298256
2	Pearson VII Area	763.821888	456.173595	41.1438488	12.6519066
3	Pearson VII Area	65.9059141	492.492093	21.7734328	3.62326364
4	Pearson VII Area	353.981986	518.002928	38.9656109	7.48497167
5	Pearson VII Area	67.6802586	570.222818	31.2145174	167.893751
6	Pearson VII Area	63.6948927	600.336466	17.7004073	6.34646626
7	Pearson VII Area	472.758540	646.470220	15.0208917	8.77820846

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	49.9363981	374.517787	159.594865	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	17.1517554	456.173594	41.1438488	1.00000007	85.1619629	1.00000004
3	Pearson VII Area	2.66325021	492.492093	21.7734328	0.99999998	49.2523242	0.99999999
4	Pearson VII Area	8.28936809	518.002928	38.9656109	1.00000000	82.5986252	1.00000000
5	Pearson VII Area	2.03446219	570.222818	31.2145174	1.00000002	62.6374857	1.00000001
6	Pearson VII Area	3.26483909	600.336466	17.7004073	1.00000002	37.9229275	1.00000001
7	Pearson VII Area	28.8504436	646.470220	15.0208917	0.99999997	31.5663029	0.99999999

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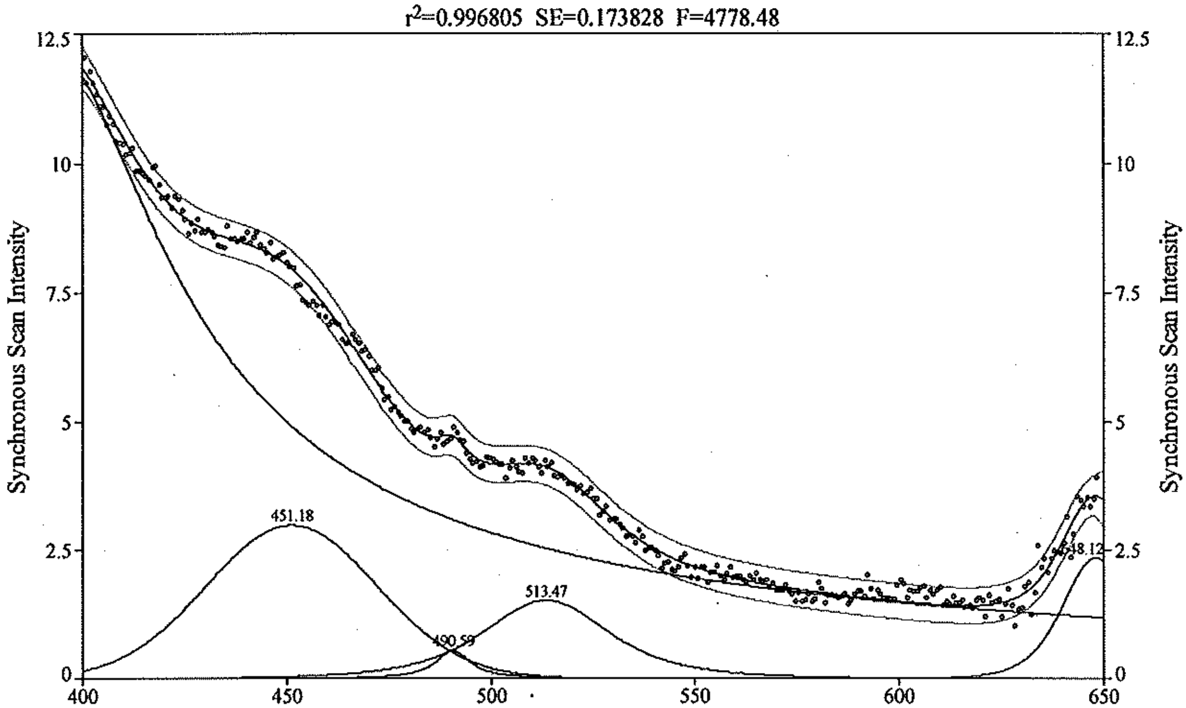
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A631, In:080424 1300, Out:080507 1116

Pk=Pearson VII Area 5 Peaks
r^2=0.996805 SE=0.173828 F=4778.48



Description: Frego Creek, Carbon, 23:A631, In:080424 1300, Out:080507 1116
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080424-080507\fc310507

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99680508	0.99658474	0.17382768	4778.47609

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	28476.0952	391.670812	90.5400362	0.51168714
2	Pearson VII Area	156.921958	451.180714	49.0463556	45.0097693
3	Pearson VII Area	8.84901971	490.594138	10.1984071	0.99701491
4	Pearson VII Area	68.0897673	513.472683	36.7546998	2.01261583
5	Pearson VII Area	52.8520174	648.124120	19.4643677	3.09831187

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	12.2682151	391.685780	90.5400554	0.99933894	0.00000000	0.00000000
2	Pearson VII Area	2.99208262	451.180714	49.0463556	1.00000000	99.0923617	1.00000000
3	Pearson VII Area	0.55123870	490.594138	10.1984071	0.99999998	34.0553748	0.99999999
4	Pearson VII Area	1.51978768	513.472683	36.7546998	0.99999991	92.6642056	0.99999996
5	Pearson VII Area	2.35746510	648.124119	19.4643677	1.00000016	45.0170185	1.00000008

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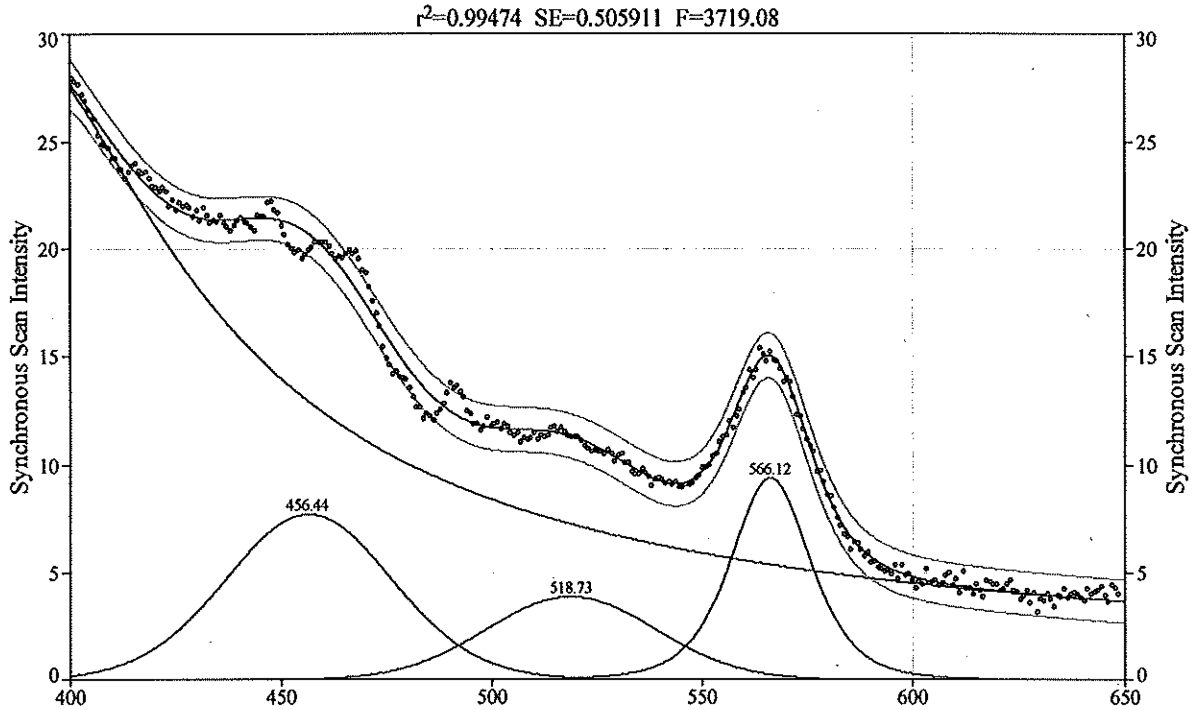
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:A445, In:080424 1242, Out:080507 1057

Pk=Pearson VII Area 5 Peaks
r^2=0.99474 SE=0.505911 F=3719.08



Description: Frego Creek, Carbon, 23:A445, In:080424 1242, Out:080507 1057
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080424-080507\fc450507

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99473977	0.99445350	0.50591051	3719.08338

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	71920.9333	386.595814	118.240865	0.51468733
2	Pearson VII Area	388.988217	456.440652	46.5280213	15.0493060
3	Pearson VII Area	197.137082	518.730425	47.4997379	167.864696
4	Pearson VII Area	246.577351	566.124506	22.3857350	2.63658568

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	29.5391739	386.595814	118.240865	0.99999999	0.00000000	0.00000000
2	Pearson VII Area	7.74536664	456.440652	46.5280213	1.00000000	95.7862194	1.00000000
3	Pearson VII Area	3.89422696	518.730425	47.4997379	1.00000000	95.3167204	1.00000000
4	Pearson VII Area	9.40086449	566.124506	22.3857350	1.00000000	53.2105970	1.00000000

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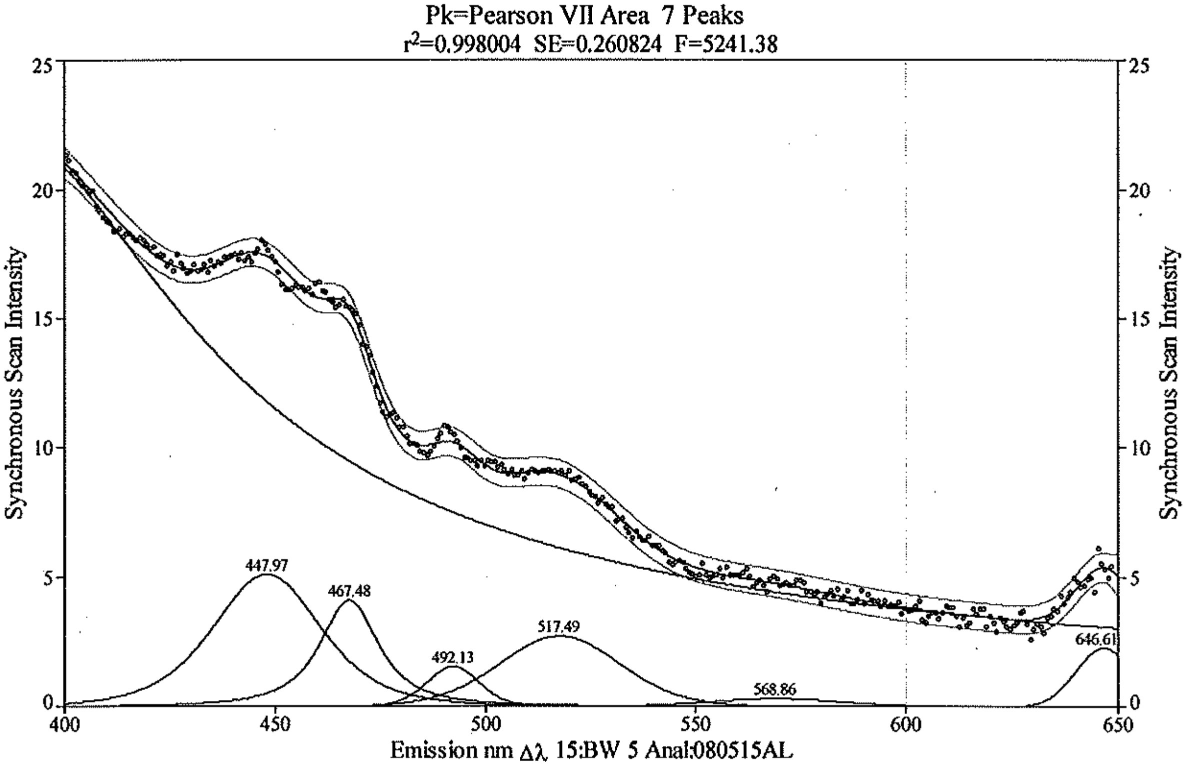
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:X111, In:080424 1250, Out:080507 1106



Description: Frego Creek, Carbon, 23:X111, In:080424 1250, Out:080507 1106
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080424-080507\fcx10507

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99800423	0.99780607	0.26082398	5241.37713

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	38755.3888	386.500885	133.785644	0.52370719
2	Pearson VII Area	182.704243	447.966937	30.4442138	2.61220901
3	Pearson VII Area	94.2563876	467.484596	16.6328471	1.28008353
4	Pearson VII Area	24.8796348	492.127656	14.5508634	7.04476153
5	Pearson VII Area	100.668036	517.489708	33.9412814	10.0000000
6	Pearson VII Area	12.2039017	568.864679	36.6972477	10.0000000
7	Pearson VII Area	38.0200349	646.609857	15.5587960	167.895540

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	22.0872580	386.525229	133.785677	0.99927240	0.00000000	0.00000000
2	Pearson VII Area	5.11619786	447.966937	30.4442138	1.00000000	72.4911285	1.00000000
3	Pearson VII Area	4.11174499	467.484598	16.6328471	0.99999945	48.8494938	0.99999979
4	Pearson VII Area	1.55711416	492.127655	14.5508634	1.00000003	30.9589579	1.00000001
5	Pearson VII Area	2.72740984	517.489708	33.9412814	1.00000000	70.8949121	1.00000000
6	Pearson VII Area	0.30581040	568.864679	36.6972477	1.00000000	76.6514417	1.00000000
7	Pearson VII Area	2.29287705	646.609858	15.5587960	0.99999977	31.2214930	0.99999988

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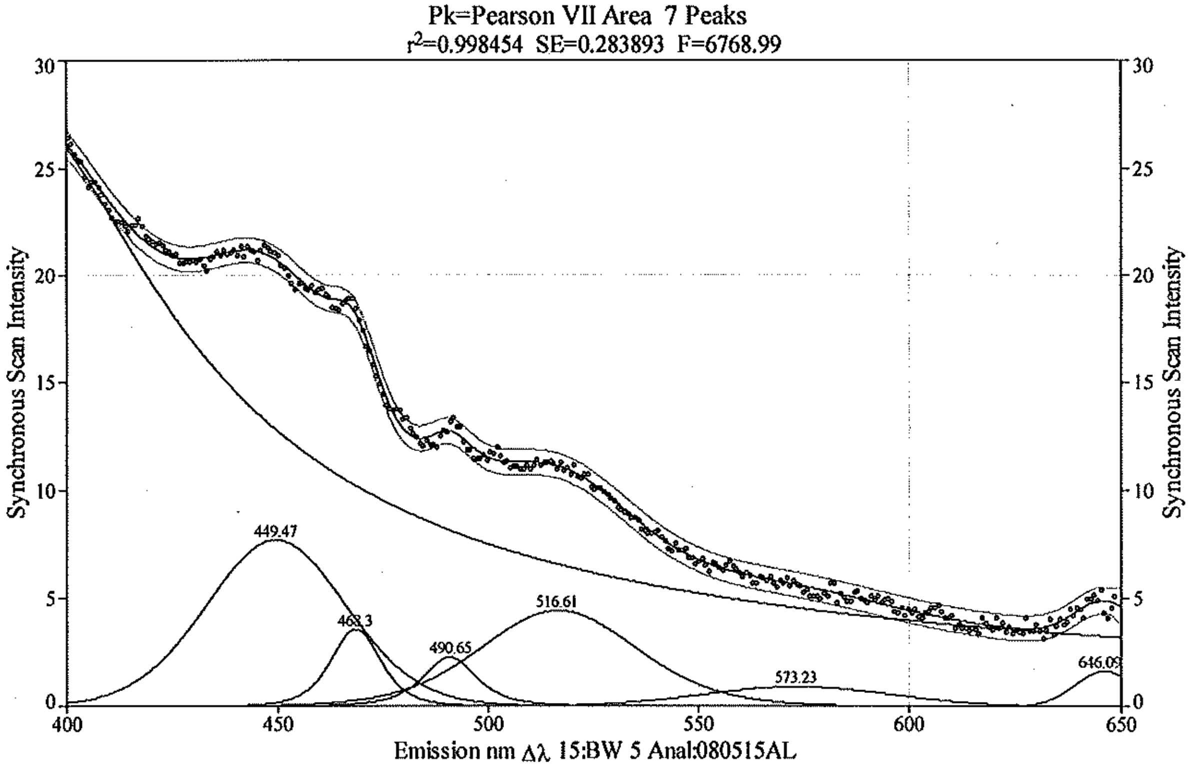
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Carbon, 23:X112, In:080424 1237, Out:080507 1054



Description: Frego Creek, Carbon, 23:X112, In:080424 1237, Out:080507 1054
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080424-080507\fcx20507

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99845394	0.99830043	0.28389295	6768.99122

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	41487.5376	387.869000	111.502864	0.52310168
2	Pearson VII Area	326.351485	449.469021	39.0662086	10.0661329
3	Pearson VII Area	58.6593013	468.299368	13.9424414	2.44979155
4	Pearson VII Area	43.0445609	490.654769	15.1532788	1.78980137
5	Pearson VII Area	216.333795	516.610638	44.1526191	5.46797281
6	Pearson VII Area	51.4756132	573.225804	52.4707813	167.704825
7	Pearson VII Area	29.2093426	646.089975	16.5419318	61.2501114

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	27.6956345	387.958716	111.503407	0.99678676	0.00000000	0.00000000
2	Pearson VII Area	7.68308926	449.469021	39.0662086	1.00000000	81.5762694	1.00000000
3	Pearson VII Area	3.55779986	468.299366	13.9424414	1.00000065	33.6163804	1.00000030
4	Pearson VII Area	2.27702615	490.654769	15.1532788	1.00000001	39.4458578	1.00000000
5	Pearson VII Area	4.41785739	516.610638	44.1526191	0.99999999	95.6788334	1.00000000
6	Pearson VII Area	0.92050816	573.225804	52.4707813	1.00000000	105.292258	1.00000000
7	Pearson VII Area	1.65333057	646.089975	16.5419318	0.99999996	33.3385158	0.99999998

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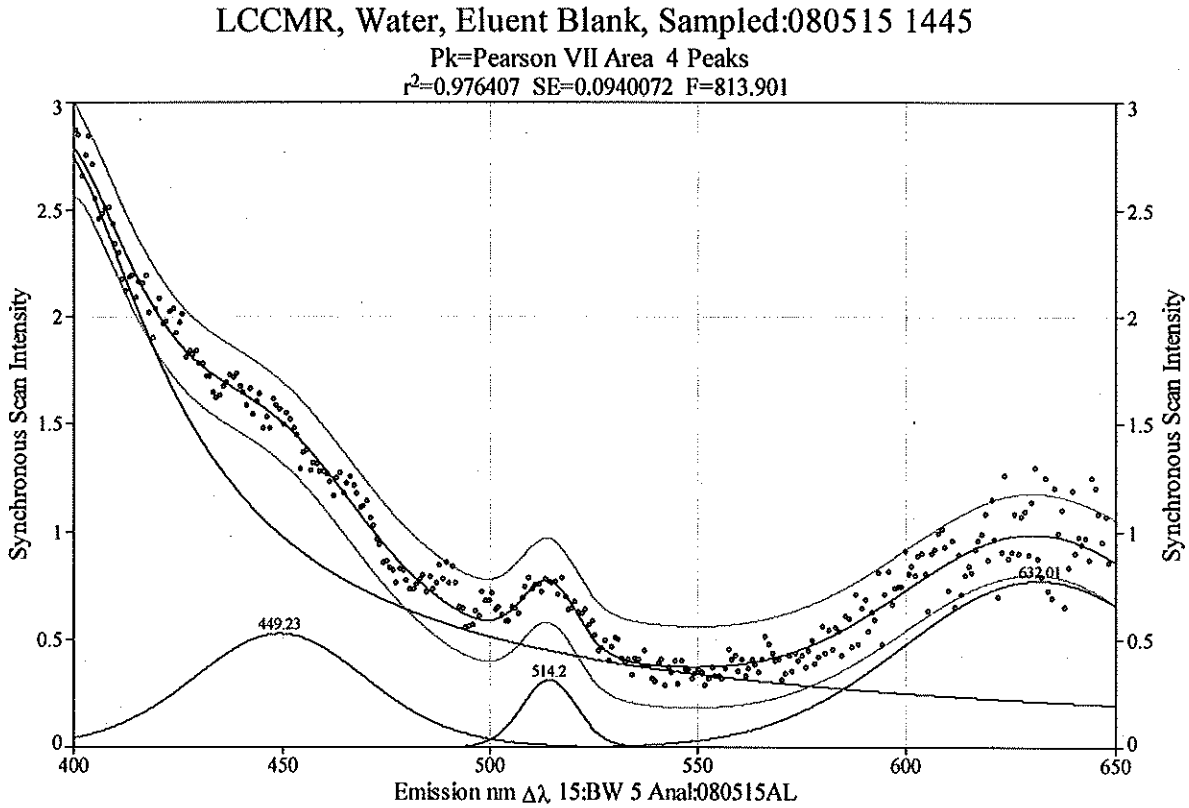

Description: LCCMR, Water, Eluent Blank, Sampled:080515 1445
X Variable: Emission nm Δλ 15:BW 5 Anal:080515AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080424-080507\eb80515b

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.97640663	0.97512263	0.09400718	813.900760

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1500.63895	394.859658	72.0070094	0.54483347
2	Pearson VII Area	28.4542884	449.228674	49.1403022	7.27760803
3	Pearson VII Area	5.32069305	514.201056	15.6727545	10.0000000
4	Pearson VII Area	63.1675875	632.006741	76.6179181	167.892432

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	2.82111463	395.699541	72.0768969	0.95445113	0.00000000	0.00000000
2	Pearson VII Area	0.52788839	449.228674	49.1403022	1.00000000	104.342403	1.00000000
3	Pearson VII Area	0.31218348	514.201056	15.6727545	1.00000000	32.7364940	1.00000000
4	Pearson VII Area	0.77358524	632.006741	76.6179181	1.00000000	153.747494	1.00000000

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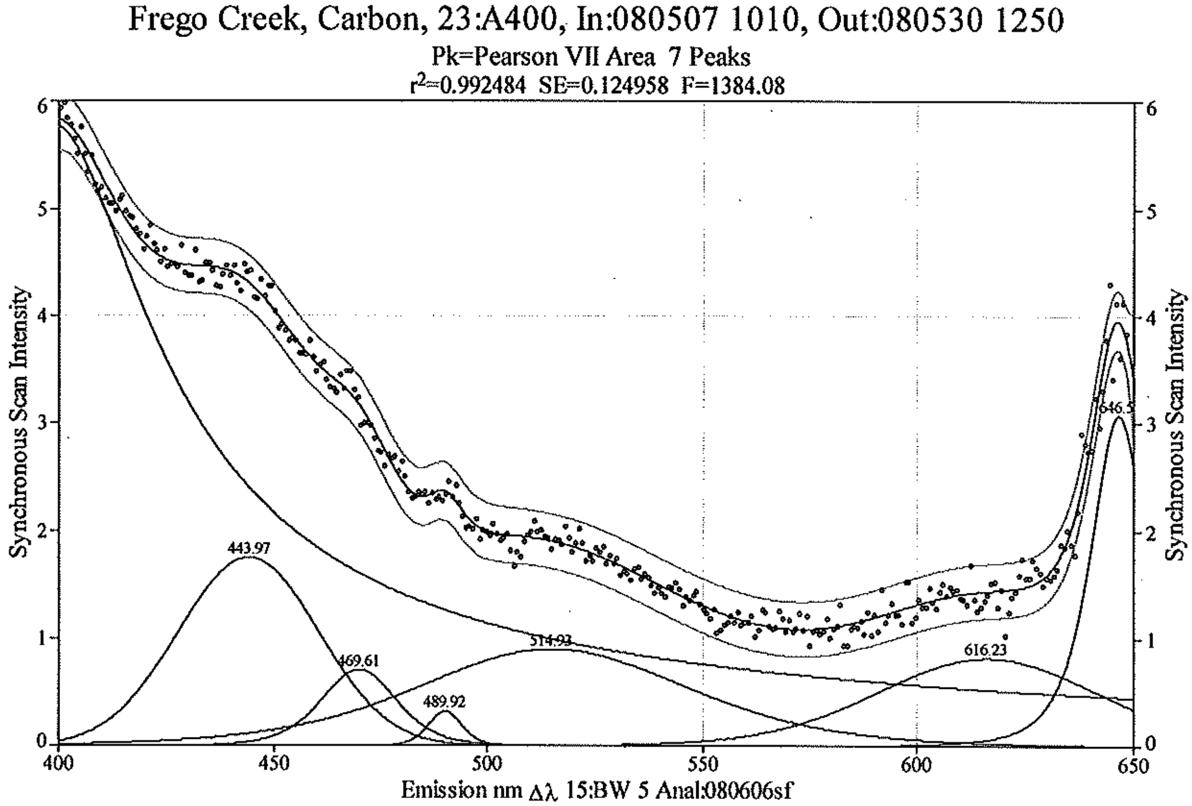
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A400, In:080507 1010, Out:080530 1250
X Variable: Emission nm Δλ 15:BW 5 Anal:080606sf
Y Variable: Synchronous Scan Intensity
File Source: e:\fregocreek080507-080530\fc000530.p

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99248404	0.99173777	0.12495824	1384.08150

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	8001.90743	398.385299	72.2628151	0.51588034
2	Pearson VII Area	71.3937708	443.967319	38.2740569	167.838711
3	Pearson VII Area	16.9661411	469.608485	20.9764940	3.46514074
4	Pearson VII Area	3.48404947	489.920994	9.44924075	4.10674090
5	Pearson VII Area	76.8140055	514.927786	75.1979715	3.68962760
6	Pearson VII Area	54.8877674	616.228374	61.2809354	8.00726924
7	Pearson VII Area	58.1212619	646.499105	15.2133382	1.81590064

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.79293677	398.385301	72.2628151	0.99999992	0.00000000	0.00000000
2	Pearson VII Area	1.75024920	443.967319	38.2740569	0.99999999	76.8037708	1.00000000
3	Pearson VII Area	0.70914694	469.608486	20.9764940	0.99999988	47.7320557	0.99999994
4	Pearson VII Area	0.32729753	489.920994	9.44924075	1.00000000	21.0527463	1.00000000
5	Pearson VII Area	0.90000529	514.927786	75.1979715	1.00000000	169.704626	1.00000000
6	Pearson VII Area	0.81894979	616.228374	61.2809354	1.00000000	129.403612	1.00000000
7	Pearson VII Area	3.07196123	646.499108	15.2133382	0.99999922	39.4364981	0.99999967

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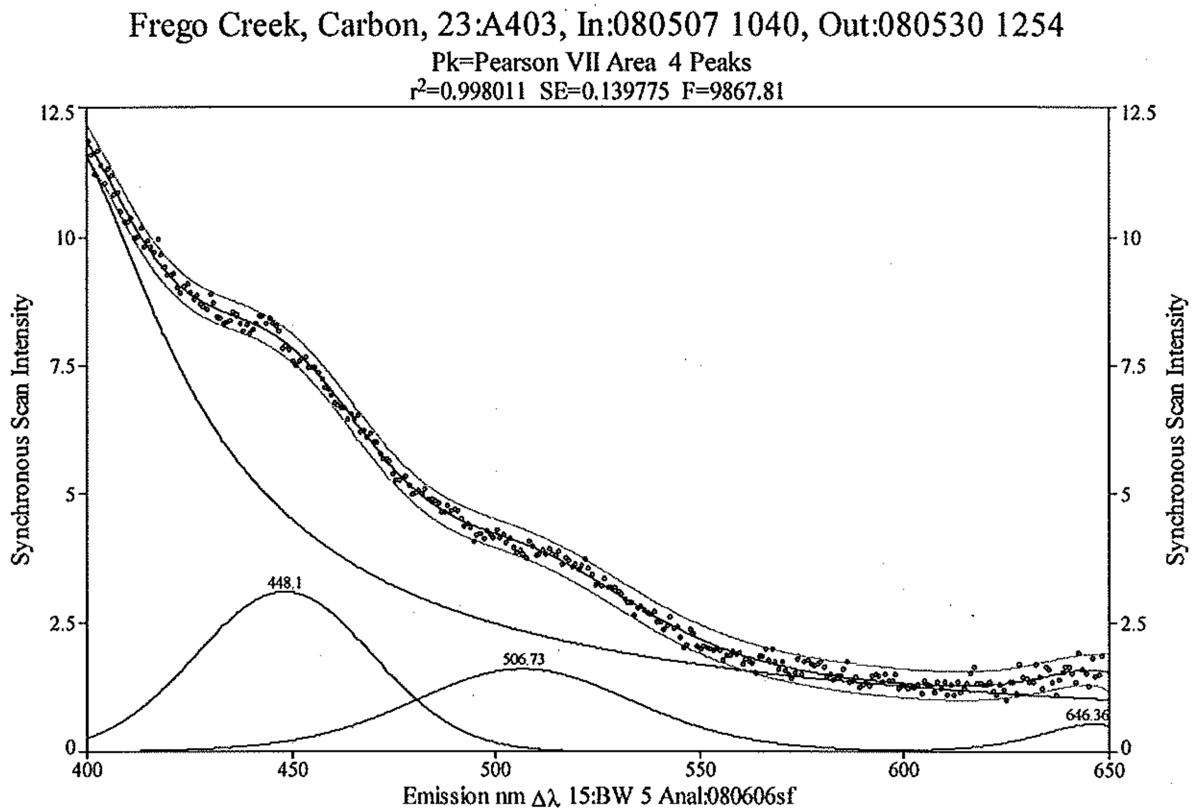
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A403, In:080507 1040, Out:080530 1254
X Variable: Emission nm Δλ 15:BW 5 Anal:080606sf
Y Variable: Synchronous Scan Intensity
File Source: e:\fregocreek080507-080530\fc030530.p

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99801095	0.99790270	0.13977468	9867.80947

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	18358.6700	393.259392	79.8250657	0.51587605
2	Pearson VII Area	169.443521	448.104764	51.1248691	85.1090221
3	Pearson VII Area	114.951129	506.727734	64.4814924	5.54910863
4	Pearson VII Area	22.2096622	646.361131	32.4420511	1.87853067

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	12.0284721	393.259393	79.8250657	0.99999997	0.00000000	0.00000000
2	Pearson VII Area	3.10616355	448.104761	51.1248691	1.00000022	102.839592	1.00000012
3	Pearson VII Area	1.60846104	506.727736	64.4814924	0.99999988	139.562908	0.99999994
4	Pearson VII Area	0.55433672	646.361131	32.4420511	1.00000000	83.2986075	1.00000000

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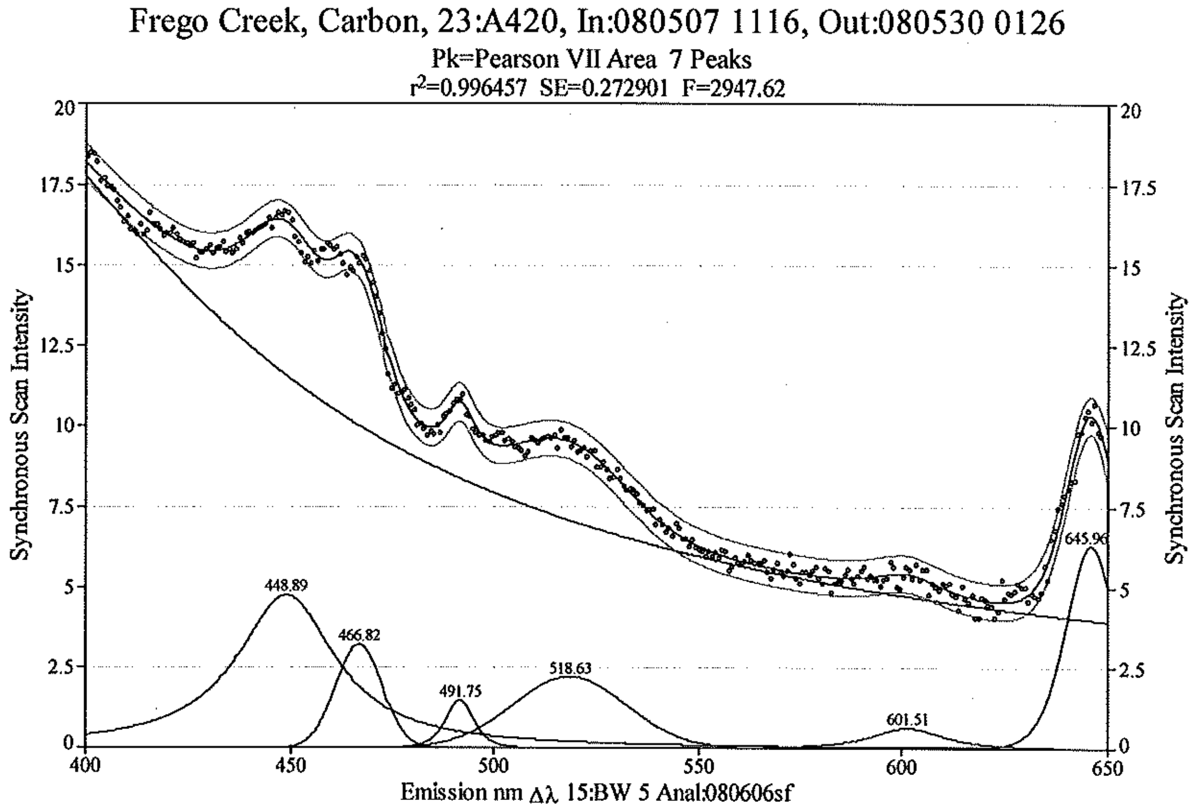
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A420, In:080507 1116, Out:080530 0126
X Variable: Emission nm Δλ 15:BW 5 Anal:080606sf
Y Variable: Synchronous Scan Intensity
File Source: e:\fregocreek080507-080530\fc200530.p

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99645669	0.99610487	0.27290141	2947.62440

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1.1998e+05	364.955259	191.777025	0.51000000
2	Pearson VII Area	227.447391	448.889686	29.5555966	0.95914629
3	Pearson VII Area	46.5999861	466.816399	13.6029239	76.4553797
4	Pearson VII Area	14.8730505	491.745727	8.26080277	2.13280443
5	Pearson VII Area	77.7141718	518.630435	32.8021296	36.4449577
6	Pearson VII Area	19.1233750	601.510415	21.3050968	1.27215347
7	Pearson VII Area	100.077643	645.963101	14.2268762	4.74769959

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	20.9918845	365.349370	460.846924	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	4.75219979	448.889686	29.5555966	1.00000000	101.062864	1.00000000
3	Pearson VII Area	3.20971828	466.816397	13.6029239	1.00000061	27.3780139	1.00000033
4	Pearson VII Area	1.49177283	491.745727	8.26080277	1.00000004	20.5319896	1.00000002
5	Pearson VII Area	2.21321826	518.630435	32.8021296	0.99999996	66.4185452	0.99999998
6	Pearson VII Area	0.64963883	601.510415	21.3050968	0.99999991	62.7429193	0.99999997
7	Pearson VII Area	6.29830259	645.963102	14.2268762	0.99999974	31.2209906	0.99999987

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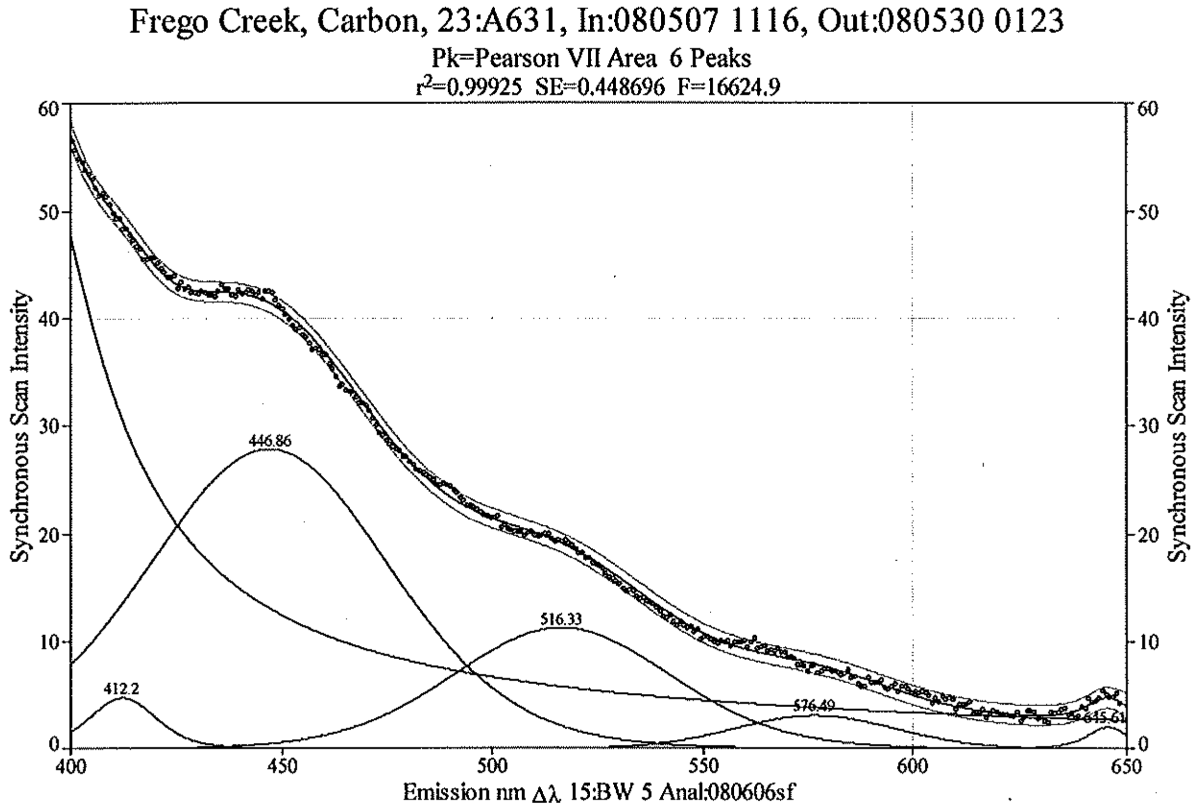
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A631, In:080507 1116, Out:080530 0123
X Variable: Emission nm Δλ 15:BW 5 Anal:080606sf
Y Variable: Synchronous Scan Intensity
File Source: e:\fregocreek080507-080530\fc310530.p

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99924999	0.99918705	0.44869568	16624.9219

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	26569.5939	389.530901	45.9461991	0.53352349
2	Pearson VII Area	102.458071	412.197038	18.7944960	3.26862188
3	Pearson VII Area	2072.12659	446.861719	68.1512837	8.64312130
4	Pearson VII Area	745.705338	516.334660	60.8770972	9.67239158
5	Pearson VII Area	147.995095	576.488316	44.9804017	167.909730
6	Pearson VII Area	29.6012984	645.610235	11.4650874	1.68871623

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	60.5414538	389.530899	45.9461991	1.00000013	0.00000000	0.00000000
2	Pearson VII Area	4.75618347	412.197036	18.7944960	1.00000035	43.1201715	1.00000017
3	Pearson VII Area	27.8594902	446.861720	68.1512837	0.99999991	143.331323	0.99999995
4	Pearson VII Area	11.2555572	516.334661	60.8770972	0.99999993	127.345020	0.99999996
5	Pearson VII Area	3.08722497	576.488316	44.9804017	1.00000000	90.2611616	1.00000000
6	Pearson VII Area	2.04233550	645.610235	11.4650874	1.00000000	30.3745641	1.00000000

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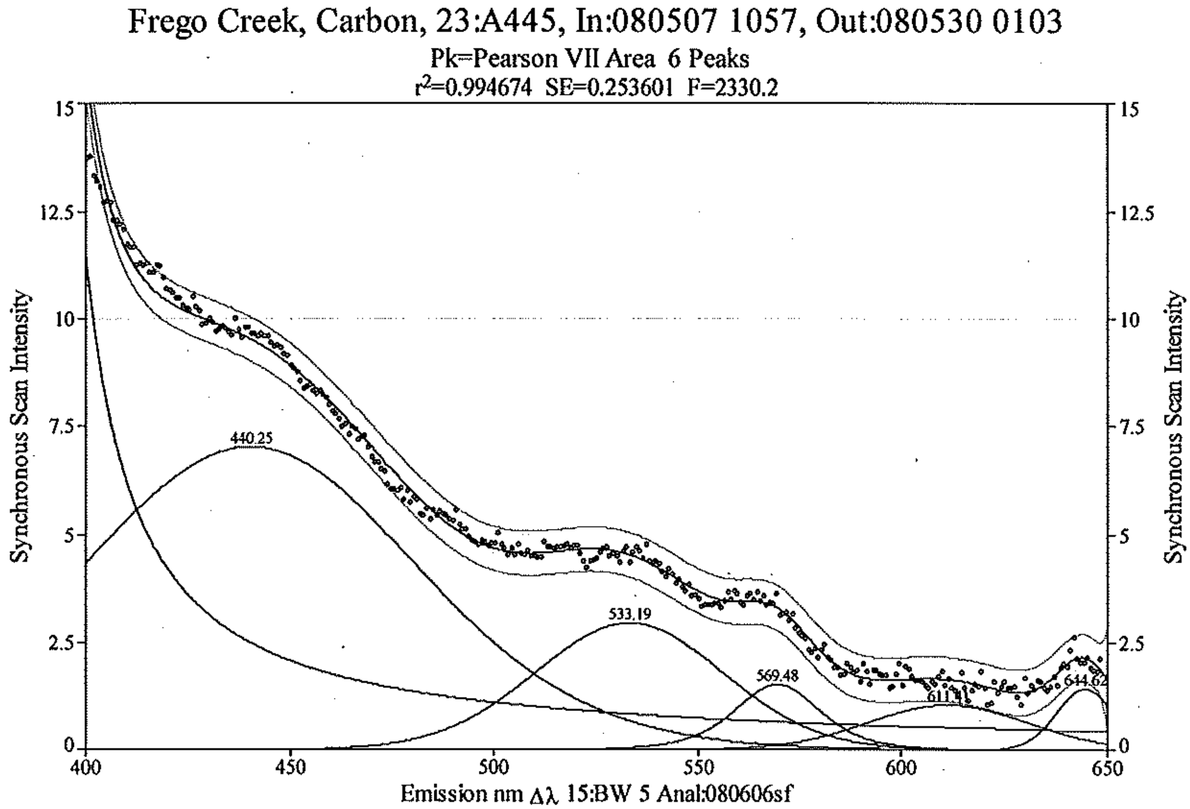
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23:A445, In:080507 1057, Out:080530 0103
X Variable: Emission nm Δλ 15:BW 5 Anal:080606sf
Y Variable: Synchronous Scan Intensity
File Source: e:\fregocreek080507-080530\fc450530.p

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99467350	0.99422652	0.25360117	2330.19847

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	5009.04644	388.289402	13.3660116	0.53190773
2	Pearson VII Area	742.474011	440.245362	97.2073360	10.1117156
3	Pearson VII Area	173.229299	533.193972	54.4132788	16.3137659
4	Pearson VII Area	44.7392009	569.479014	25.1433261	2.77153011
5	Pearson VII Area	52.6653535	611.406592	46.3954956	17.8198255
6	Pearson VII Area	25.2993490	644.618102	16.3525278	13.8519956

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	35.7978611	389.530903	-1.601e-09	-1.0000000	83.1020209	0.93495861
2	Pearson VII Area	7.02550766	440.245360	97.2073360	1.00000005	202.944337	1.00000003
3	Pearson VII Area	2.95271773	533.193972	54.4132788	1.00000000	111.772533	1.00000000
4	Pearson VII Area	1.52734250	569.479014	25.1433261	1.00000000	59.2291738	1.00000000
5	Pearson VII Area	1.05399853	611.406592	46.3954956	1.00000000	95.0920960	1.00000000
6	Pearson VII Area	1.43152822	644.618102	16.3525278	0.99999999	33.7477374	1.00000000

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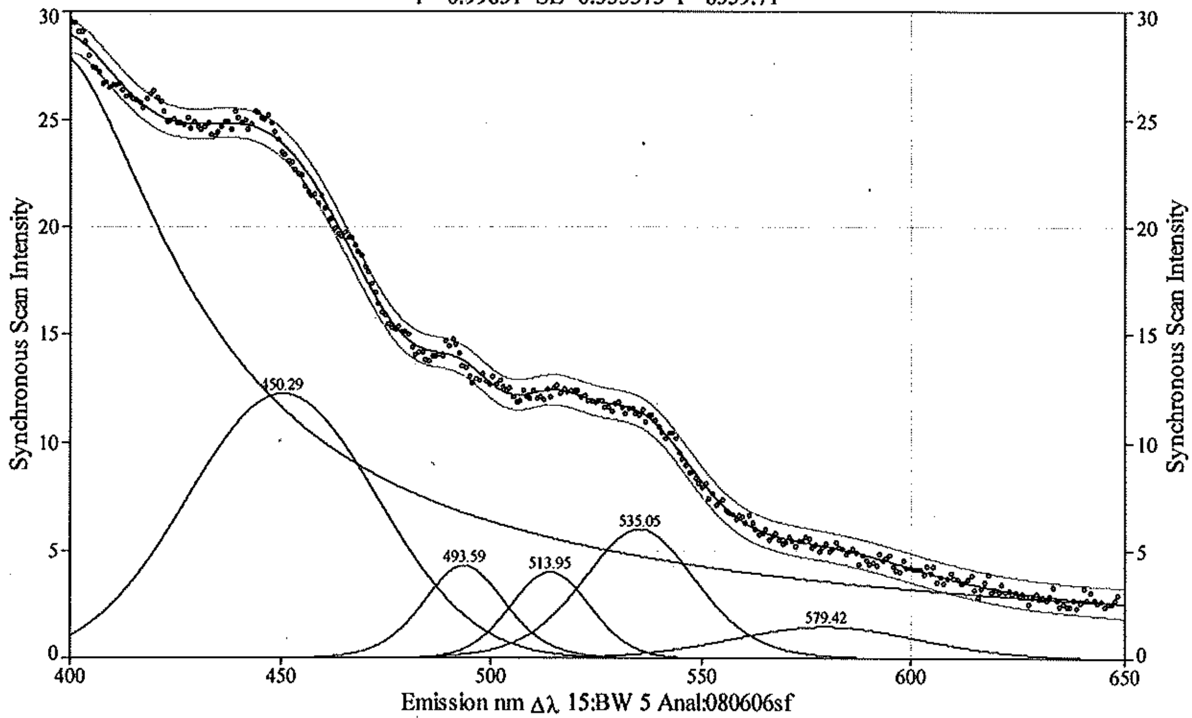
Frego Creek, Carbon, 23:X111, In:080507 1106, Out:080530 0118

Pk=Pearson VII Area 6 Peaks
r^2=0.99851 SE=0.335573 F=8359.71



Description: Frego Creek, Carbon, 23:X111, In:080507 1106, Out:080530 0118
X Variable: Emission nm Δλ 15:BW 5 Anal:080606sf
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080507-080530\fcx10530

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99850956	0.99838449	0.33557341	8359.71021

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	32440.8140	395.555272	85.6222643	0.52318553
2	Pearson VII Area	700.287490	450.292368	53.6668041	167.901224
3	Pearson VII Area	110.897162	493.592957	22.9287478	4.37164104
4	Pearson VII Area	96.7856183	513.954435	22.2750331	10.3460989
5	Pearson VII Area	212.829679	535.052981	31.7693873	4.55479183
6	Pearson VII Area	85.1468358	579.419778	52.7927437	12.3265987

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	28.2970803	395.704467	85.6242201	0.99305444	0.00000000	0.00000000
2	Pearson VII Area	12.2437625	450.292368	53.6668041	1.00000000	107.691984	1.00000000
3	Pearson VII Area	4.31014720	493.592954	22.9287478	1.00000043	50.7375957	1.00000022
4	Pearson VII Area	3.99859556	513.954434	22.2750331	1.00000021	46.4593235	1.00000011
5	Pearson VII Area	5.98436930	535.052981	31.7693873	1.00000007	70.0037089	1.00000003
6	Pearson VII Area	1.48941392	579.419778	52.7927437	0.99999999	109.371958	0.99999999

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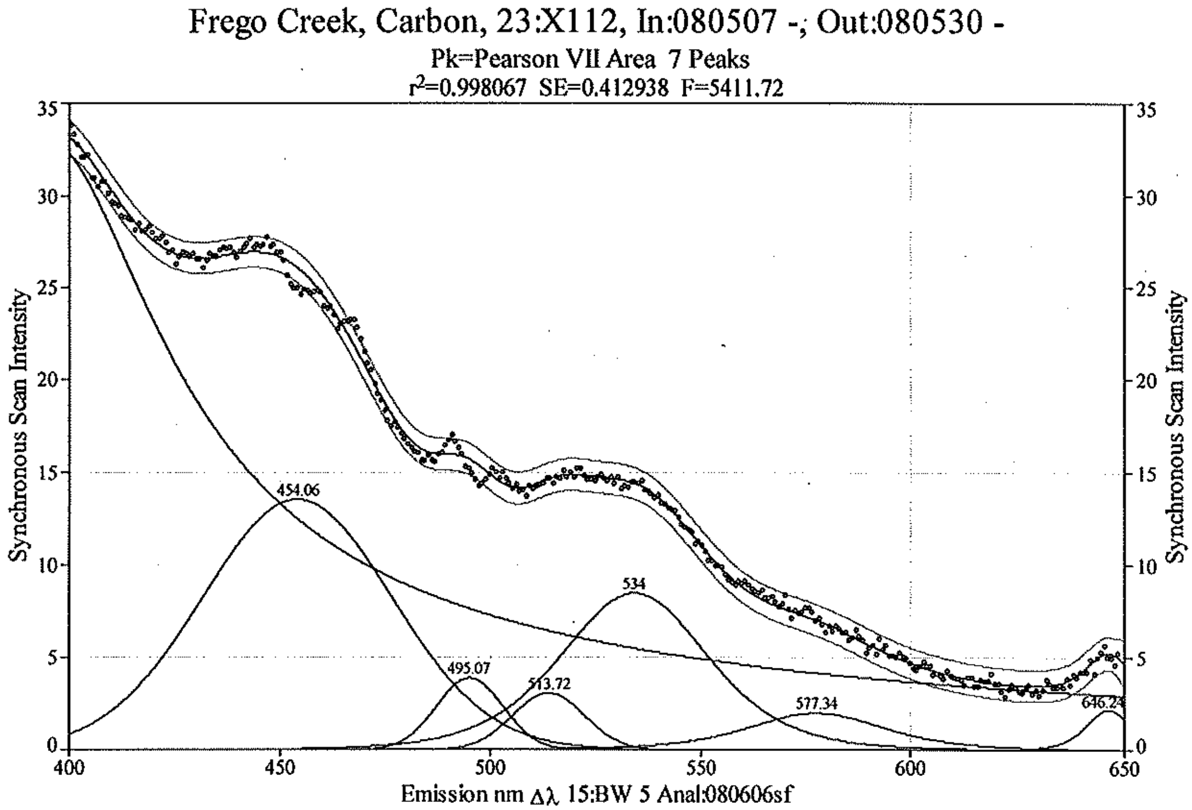

Description: Frego Creek, Carbon, 23:X112, In:080507 -, Out:080530 -
X Variable: Emission nm Δλ 15:BW 5 Anal:080606sf
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080507-080530\fcx20530

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99806693	0.99787500	0.41293840	5411.72312

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	37340.7956	394.836289	84.7099207	0.52323505
2	Pearson VII Area	773.993915	454.057953	53.4126983	28.3192090
3	Pearson VII Area	77.1082433	495.074357	18.6368518	92.4347934
4	Pearson VII Area	65.8507541	513.724154	20.0747813	167.917249
5	Pearson VII Area	401.627921	534.000983	41.2870552	3.15475547
6	Pearson VII Area	93.3097679	577.337583	39.0325735	2.39508135
7	Pearson VII Area	33.2886757	646.240293	12.7665869	2.38214114

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	32.9855908	395.131730	84.7176714	0.98614721	0.00000000	0.00000000
2	Pearson VII Area	13.5146322	454.057953	53.4126983	1.00000000	108.511218	1.00000000
3	Pearson VII Area	3.87830936	495.074359	18.6368518	0.99999955	37.4741381	0.99999976
4	Pearson VII Area	3.07789813	513.724156	20.0747813	0.99999951	40.2836081	0.99999973
5	Pearson VII Area	8.45992230	534.000985	41.2870552	0.99999977	95.2248826	0.99999989
6	Pearson VII Area	2.01540931	577.337584	39.0325735	0.99999989	94.5470902	0.99999995
7	Pearson VII Area	2.19665433	646.240293	12.7665869	0.99999987	30.9588978	0.99999994

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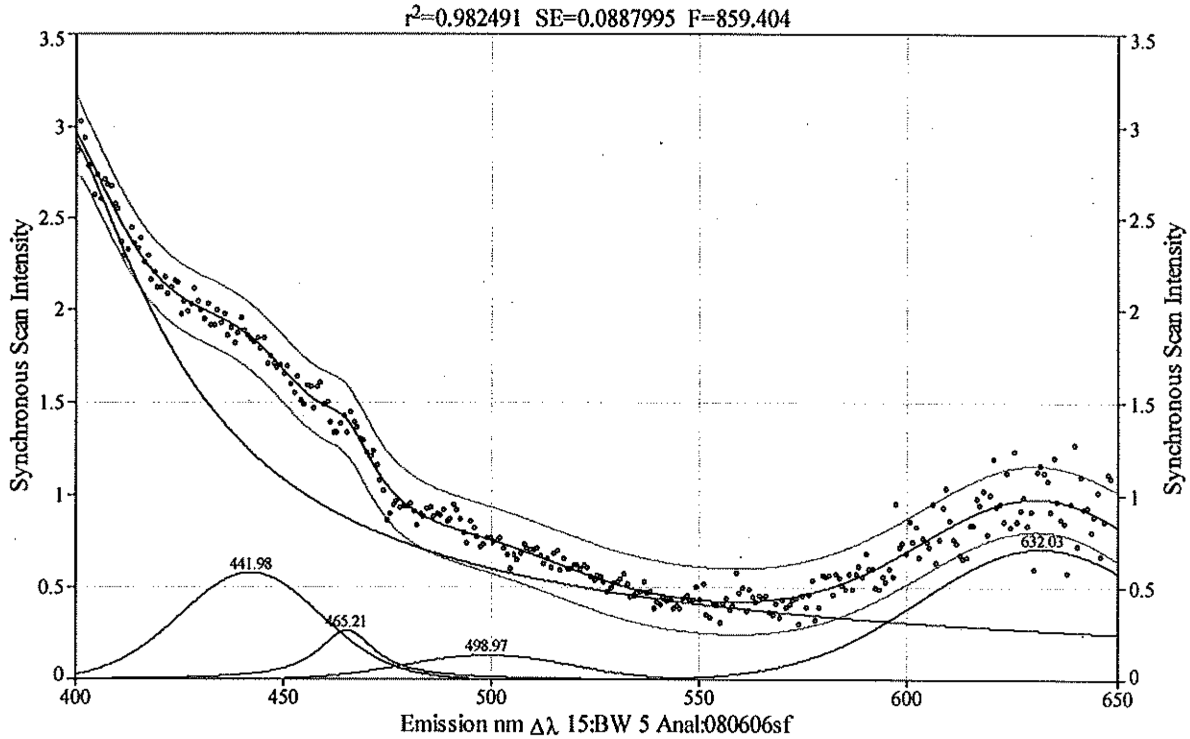
blank, Water, Eluent, Sampled:080606 0334

Pk=Pearson VII Area 5 Peaks
r^2=0.982491 SE=0.0887995 F=859.404



Description: blank, Water, Eluent, Sampled:080606 0334
X Variable: Emission nm Δλ 15:BW 5 Anal:080606sf
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080507-080530\eb080606

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98249063	0.98128309	0.08879946	859.403856

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	5323.37630	391.927777	74.7818325	0.51321634
2	Pearson VII Area	24.8703614	441.981194	39.8683612	21.6312840
3	Pearson VII Area	7.47265656	465.212457	16.9409434	0.93651256
4	Pearson VII Area	6.67624842	498.966331	46.7522107	167.918240
5	Pearson VII Area	51.5466612	632.033676	67.7635181	32.3722951

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	3.12505856	391.981672	74.7821324	0.99712137	0.00000000	0.00000000
2	Pearson VII Area	0.58044745	441.981194	39.8683612	1.00000001	81.3707051	1.00000000
3	Pearson VII Area	0.26728036	465.212457	16.9409434	1.00000000	58.8157920	1.00000000
4	Pearson VII Area	0.13399070	498.966331	46.7522107	1.00000000	93.8165991	1.00000000
5	Pearson VII Area	0.71009755	632.033676	67.7635181	1.00000000	137.409008	1.00000000

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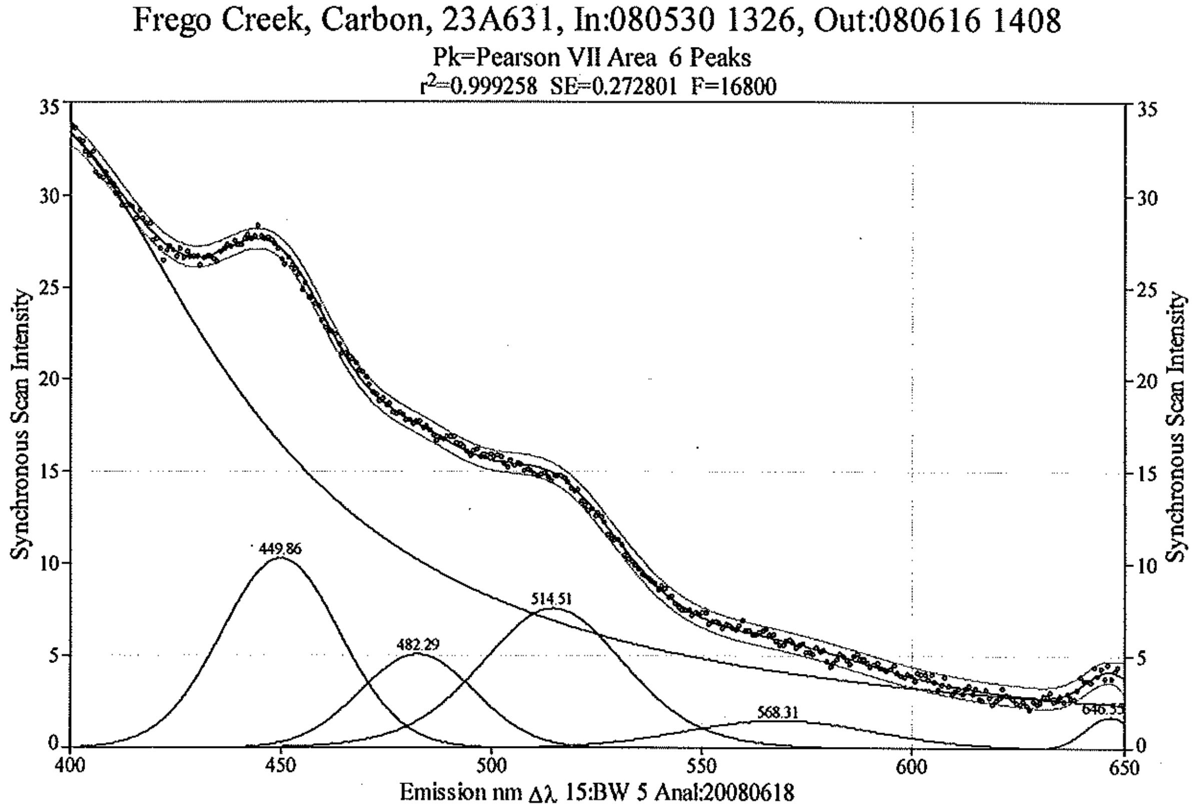
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23A631, In:080530 1326, Out:080616 1408
X Variable: Emission nm Δλ 15:BW 5 Anal:20080618
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080530-080616\fca10616

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99925780	0.99919552	0.27280110	16800.0121

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	7879.09975	391.454722	112.262402	0.76715002
2	Pearson VII Area	367.020227	449.856541	33.2353316	18.4922061
3	Pearson VII Area	173.777704	482.287840	32.0909343	42.4406952
4	Pearson VII Area	337.217281	514.507006	40.3051203	5.42628617
5	Pearson VII Area	86.7169842	568.311228	53.3813825	68.0241033
6	Pearson VII Area	25.0145667	646.551545	13.5664544	167.880183

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	34.1591179	391.695304	112.264947	0.99146465	0.00000000	0.00000000
2	Pearson VII Area	10.2582001	449.856541	33.2353316	1.00000001	68.0597769	1.00000001
3	Pearson VII Area	5.06276027	482.287841	32.0909343	0.99999998	64.8725957	0.99999999
4	Pearson VII Area	7.54121645	514.507008	40.3051203	0.99999983	87.3967802	0.99999991
5	Pearson VII Area	1.52154030	568.311228	53.3813825	1.00000000	107.511305	1.00000000
6	Pearson VII Area	1.73009846	646.551546	13.5664544	0.99999963	27.2235111	0.99999980

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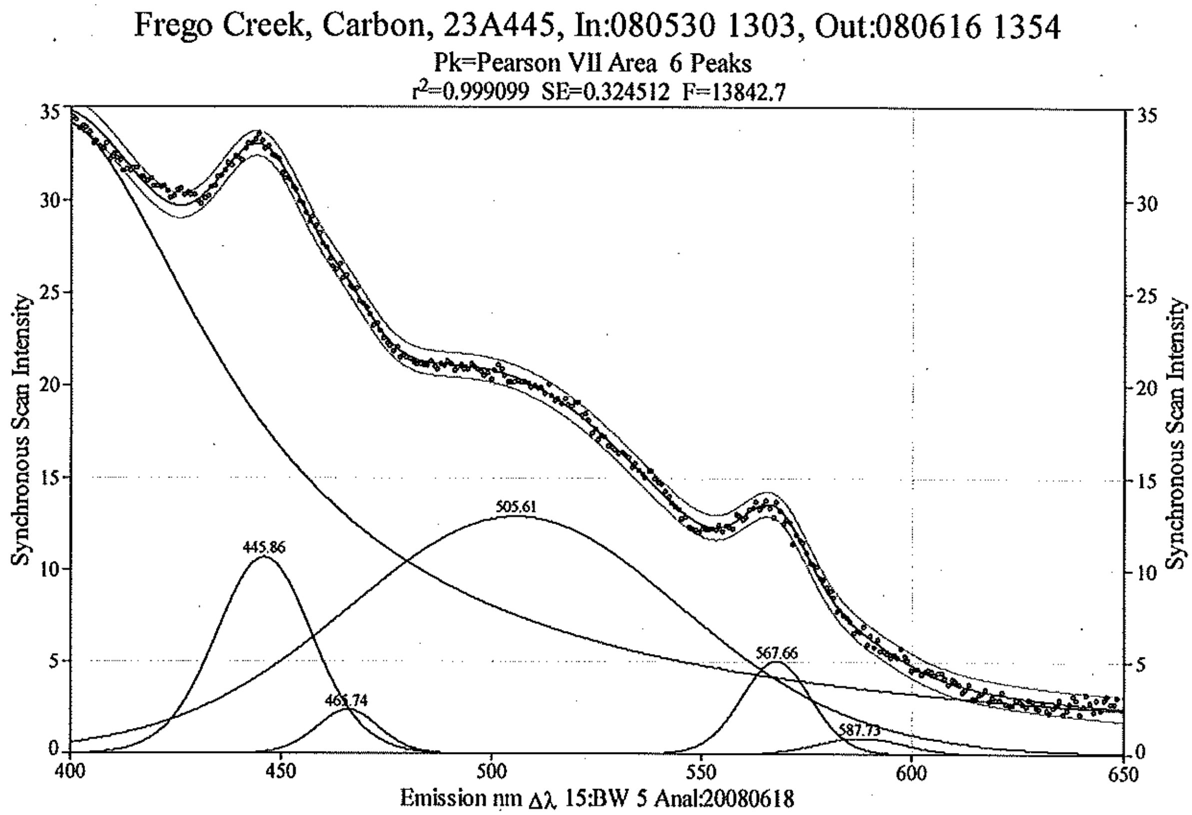
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Carbon, 23A445, In:080530 1303, Out:080616 1354
X Variable: Emission nm Δλ 15:BW 5 Anal:20080618
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreek080530-080616\fca50616

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99909938	0.99902380	0.32451166	13842.6683

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	8097.80540	395.739133	103.744549	0.72268850
2	Pearson VII Area	313.341000	445.856312	26.9588407	8.93109644
3	Pearson VII Area	46.1168019	465.739861	17.5594215	7.85707901
4	Pearson VII Area	1331.38073	505.608185	95.1176024	10.6212710
5	Pearson VII Area	106.722435	567.656707	19.4812296	10.1218806
6	Pearson VII Area	23.0053841	587.731714	24.0247749	167.870406

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	34.4553098	395.739134	103.744549	0.99999998	0.00000000	0.00000000
2	Pearson VII Area	10.6590690	445.856313	26.9588407	0.99999981	56.6054388	0.99999990
3	Pearson VII Area	2.40001762	465.739861	17.5594215	1.00000003	37.1183047	1.00000002
4	Pearson VII Area	12.8884609	505.608183	95.1176024	1.00000009	198.172197	1.00000005
5	Pearson VII Area	5.03900282	567.656706	19.4812296	1.00000013	40.6701229	1.00000007
6	Pearson VII Area	0.89849223	587.731714	24.0247749	1.00000001	48.2100040	1.00000000

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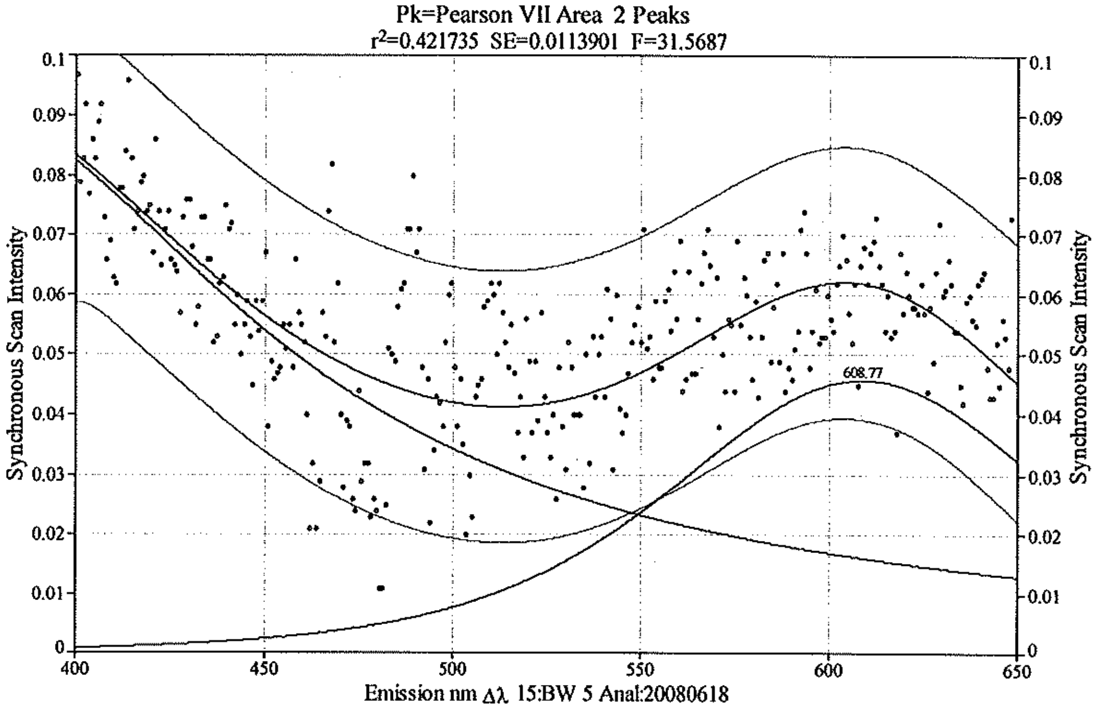
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Blank, Water, Eluent Blank, Sampled:080618 1500



Description: Blank, Water, Eluent Blank, Sampled:080618 1500
X Variable: Emission nm Δλ 15:BW 5 Anal:20080618
Y Variable: Synchronous Scan Intensity
File Source: e:\trace data\elbl0618.p

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.42173487	0.40641659	0.01139012	31.5687287

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	38.1065559	372.630098	193.362892	0.73670446
2	Pearson VII Area	6.51116685	608.767242	120.981930	2.55944744

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	0.08797445	386.254296	471.740636	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	0.04576765	608.767242	120.981930	1.00000000	289.190458	1.00000000

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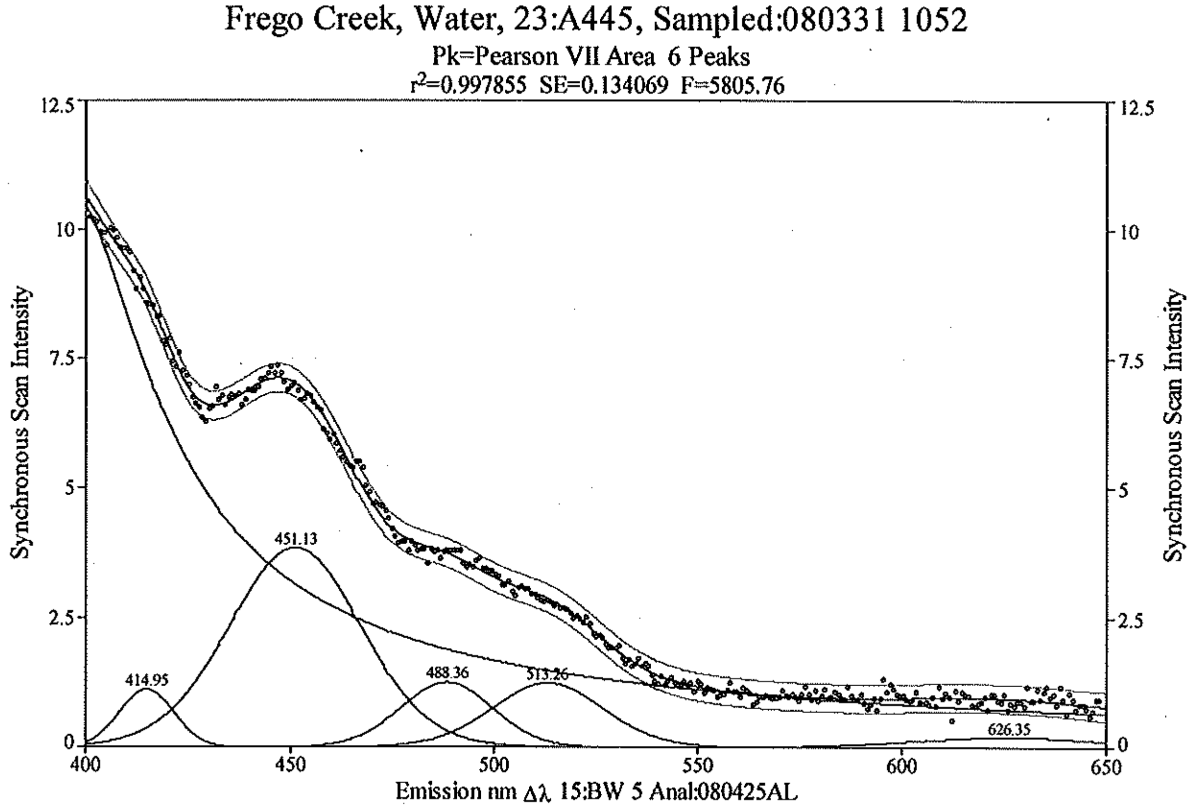
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Water, 23:A445, Sampled:080331 1052
X Variable: Emission nm Δλ 15:BW 5 Anal:080425AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreekwater080331-080409\fcw50331

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99785532	0.99767535	0.13406890	5805.76033

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	8561.27214	395.924712	59.7998997	0.52329269
2	Pearson VII Area	18.8662768	414.947756	15.7797141	167.694010
3	Pearson VII Area	159.181037	451.129507	38.1555044	11.8082723
4	Pearson VII Area	36.4262869	488.362215	26.8675998	21.3114374
5	Pearson VII Area	43.8848629	513.257722	32.3447528	10.2806818
6	Pearson VII Area	12.9606612	626.345915	57.1304291	117.841925

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	10.7384248	395.986239	59.8003758	0.99589302	0.00000000	0.00000000
2	Pearson VII Area	1.12183939	414.947756	15.7797141	1.00000001	31.6648989	1.00000000
3	Pearson VII Area	3.84957037	451.129507	38.1555044	1.00000000	79.1693969	1.00000000
4	Pearson VII Area	1.26133696	488.362216	26.8675998	0.99999981	54.8525248	0.99999990
5	Pearson VII Area	1.24843436	513.257722	32.3447528	1.00000000	67.4799171	1.00000000
6	Pearson VII Area	0.21275533	626.345915	57.1304291	1.00000000	114.763428	1.00000000

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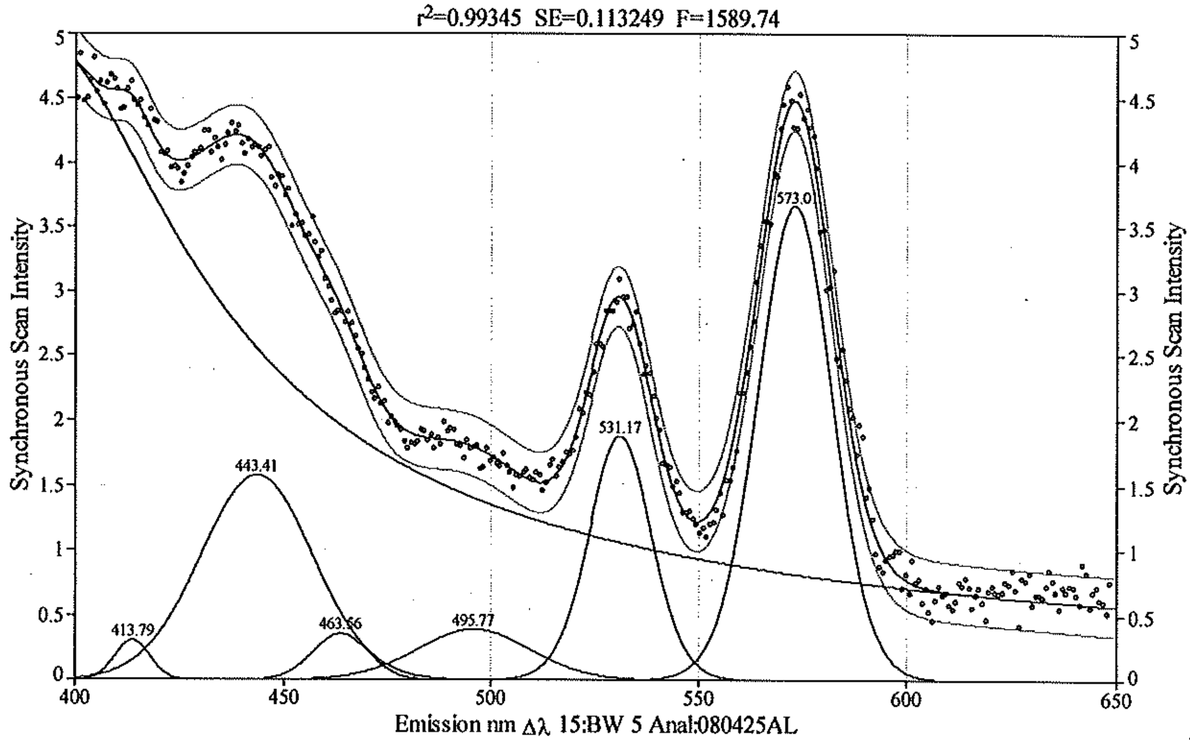
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Water, 23:A445, Sampled:080402 1000

Pk=Pearson VII Area 7 Peaks
r^2=0.99345 SE=0.113249 F=1589.74



Description: Frego Creek, Water, 23:A445, Sampled:080402 1000
X Variable: Emission nm Δλ 15:BW 5 Anal:080425AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreekwater080331-080409\fcw50402

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99344999	0.99279963	0.11324866	1589.74111

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	15135.2838	392.024663	107.508652	0.51044719
2	Pearson VII Area	3.26960645	413.790265	9.95697654	166.612850
3	Pearson VII Area	53.7372004	443.407842	31.6672327	18.1250896
4	Pearson VII Area	6.04677013	463.564033	15.8010247	37.0799146
5	Pearson VII Area	13.6539877	495.774626	32.3999767	17.4360584
6	Pearson VII Area	36.2820485	531.165696	17.7868040	10.1441717
7	Pearson VII Area	82.9566623	573.014979	20.9255999	12.9767523

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.92798999	392.024663	107.508652	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	0.30811170	413.790264	9.95697653	1.00000010	19.9808273	1.00000005
3	Pearson VII Area	1.57595559	443.407842	31.6672327	1.00000001	64.8789087	1.00000000
4	Pearson VII Area	0.35752526	463.564033	15.8010247	0.99999992	31.9879667	0.99999996
5	Pearson VII Area	0.39119219	495.774626	32.3999767	0.99999998	66.4419464	0.99999999
6	Pearson VII Area	1.87637835	531.165696	17.7868040	0.99999991	37.1292346	0.99999996
7	Pearson VII Area	3.66424294	573.014977	20.9255999	1.00000034	43.2761006	1.00000018

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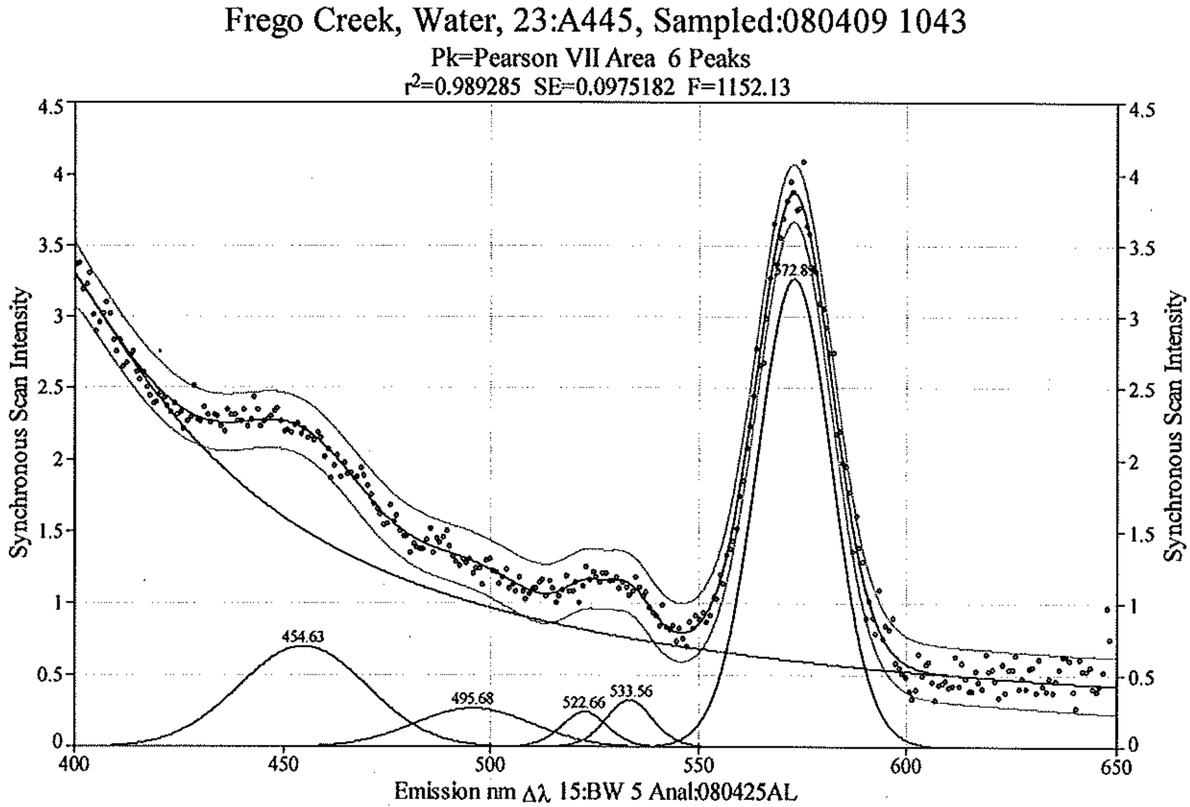
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Water, 23:A445, Sampled:080409 1043
X Variable: Emission nm Δλ 15:BW 5 Anal:080425AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreekwater080331-080409\fcw50409

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98928548	0.98838636	0.09751822	1152.13386

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	11172.3879	383.137913	109.564260	0.51095657
2	Pearson VII Area	27.0136676	454.633745	36.1931795	167.896159
3	Pearson VII Area	9.63899255	495.684823	33.4351058	72.8236556
4	Pearson VII Area	3.55238657	522.664962	13.1181980	7.59602452
5	Pearson VII Area	4.75461534	533.561615	13.2220358	6.47395492
6	Pearson VII Area	74.7067301	572.885266	21.2715351	20.5550933

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	3.68521527	388.532110	111.607568	0.82371323	0.00000000	0.00000000
2	Pearson VII Area	0.70032731	454.633745	36.1931795	0.99999999	72.6280547	1.00000000
3	Pearson VII Area	0.27007496	495.684823	33.4351058	1.00000006	67.3117524	1.00000003
4	Pearson VII Area	0.24721055	522.664962	13.1181980	1.00000000	27.7837312	1.00000000
5	Pearson VII Area	0.32649958	533.561615	13.2220358	0.99999991	28.2888362	0.99999996
6	Pearson VII Area	3.26622610	572.885266	21.2715351	1.00000000	43.4595710	1.00000000

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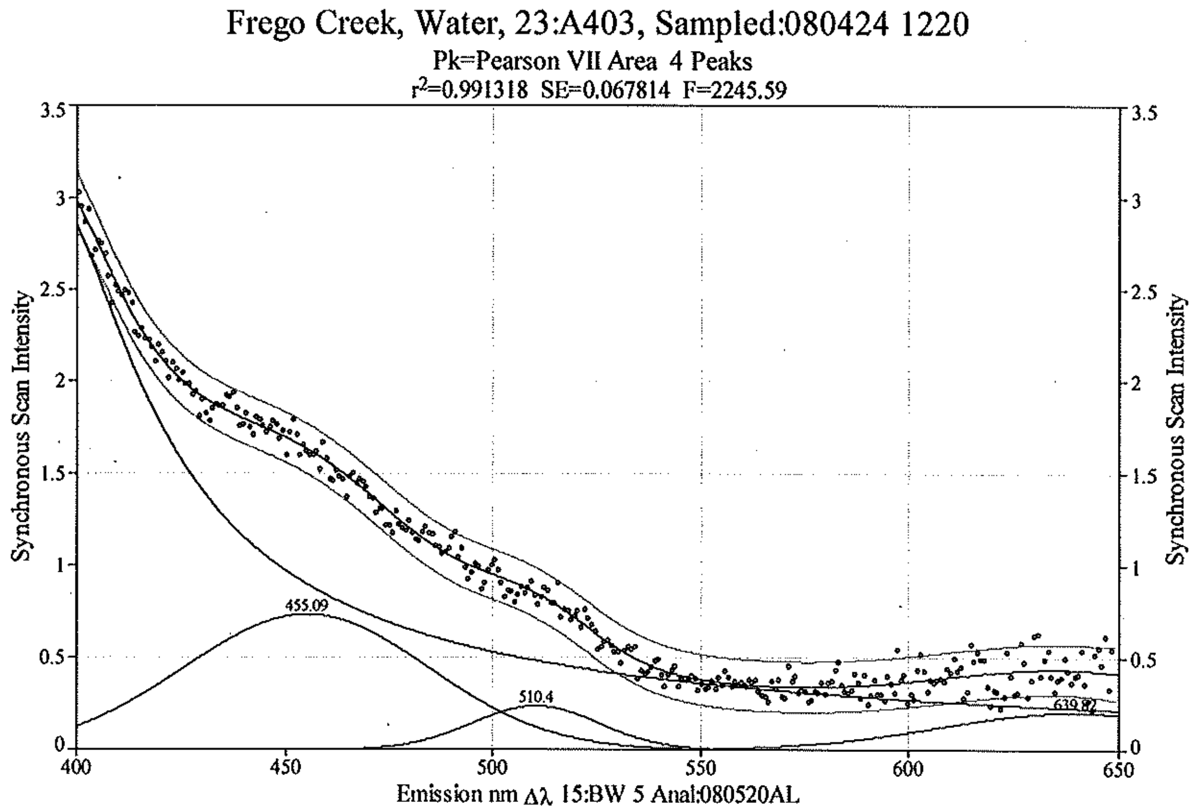
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Water, 23:A403, Sampled:080424 1220
X Variable: Emission nm Δλ 15:BW 5 Anal:080520AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreekwater080424\fcw30424

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99131811	0.99084563	0.06781400	2245.58562

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	5826.70697	393.064592	67.1264458	0.51040546
2	Pearson VII Area	54.1174971	455.085538	69.3429878	167.917467
3	Pearson VII Area	9.27565960	510.403094	36.4067481	70.5431692
4	Pearson VII Area	16.8439692	639.824423	76.4274867	26.2750997

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	3.02515046	393.692661	67.1721325	0.96328599	0.00000000	0.00000000
2	Pearson VII Area	0.73228386	455.085534	69.3429878	1.00000025	139.149000	1.00000014
3	Pearson VII Area	0.23865953	510.403092	36.4067481	1.00000027	73.3078983	1.00000015
4	Pearson VII Area	0.20542586	639.824423	76.4274867	1.00000000	155.447731	1.00000000

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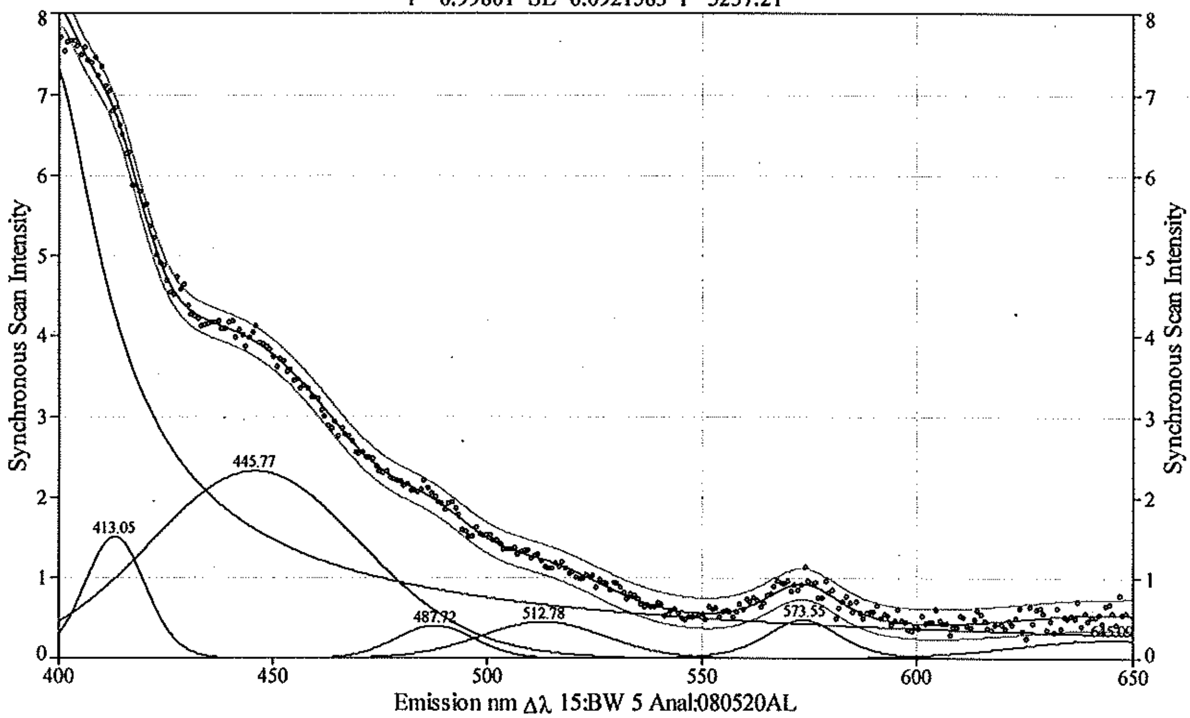
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

Frego Creek, Water, 23:A445, Sampled:080424 1242

Pk=Pearson VII Area 7 Peaks
r^2=0.99801 SE=0.0921583 F=5257.21



Description: Frego Creek, Water, 23:A445, Sampled:080424 1242
X Variable: Emission nm Δλ 15:BW 5 Anal:080520AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreekwater080424\fcw50424

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99801023	0.99781267	0.09215835	5257.20956

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	6626.24829	397.511751	37.0935227	0.51265366
2	Pearson VII Area	27.6244329	413.046799	16.7886961	9.33184098
3	Pearson VII Area	148.248483	445.774407	58.9398846	13.2725988
4	Pearson VII Area	9.42005394	487.715715	21.7233586	167.898275
5	Pearson VII Area	16.9683096	512.776402	34.3875981	13.7592345
6	Pearson VII Area	11.4498190	573.545595	20.2599404	2.82510893
7	Pearson VII Area	13.9241247	645.089644	52.4268151	6.39505069

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	7.52031034	397.706422	37.1014201	0.97922998	230.320379	0.99622516
2	Pearson VII Area	1.51062690	413.046799	16.7886961	1.00000001	35.1771304	1.00000001
3	Pearson VII Area	2.32571269	445.774407	58.9398846	1.00000000	121.803025	1.00000000
4	Pearson VII Area	0.40688405	487.715715	21.7233586	0.99999998	43.5917831	0.99999999
5	Pearson VII Area	0.45652638	512.776402	34.3875981	1.00000000	70.9827006	1.00000000
6	Pearson VII Area	0.48611442	573.545594	20.2599404	1.00000007	47.5672431	1.00000003
7	Pearson VII Area	0.24103518	645.089642	52.4268151	1.00000016	112.263813	1.00000008

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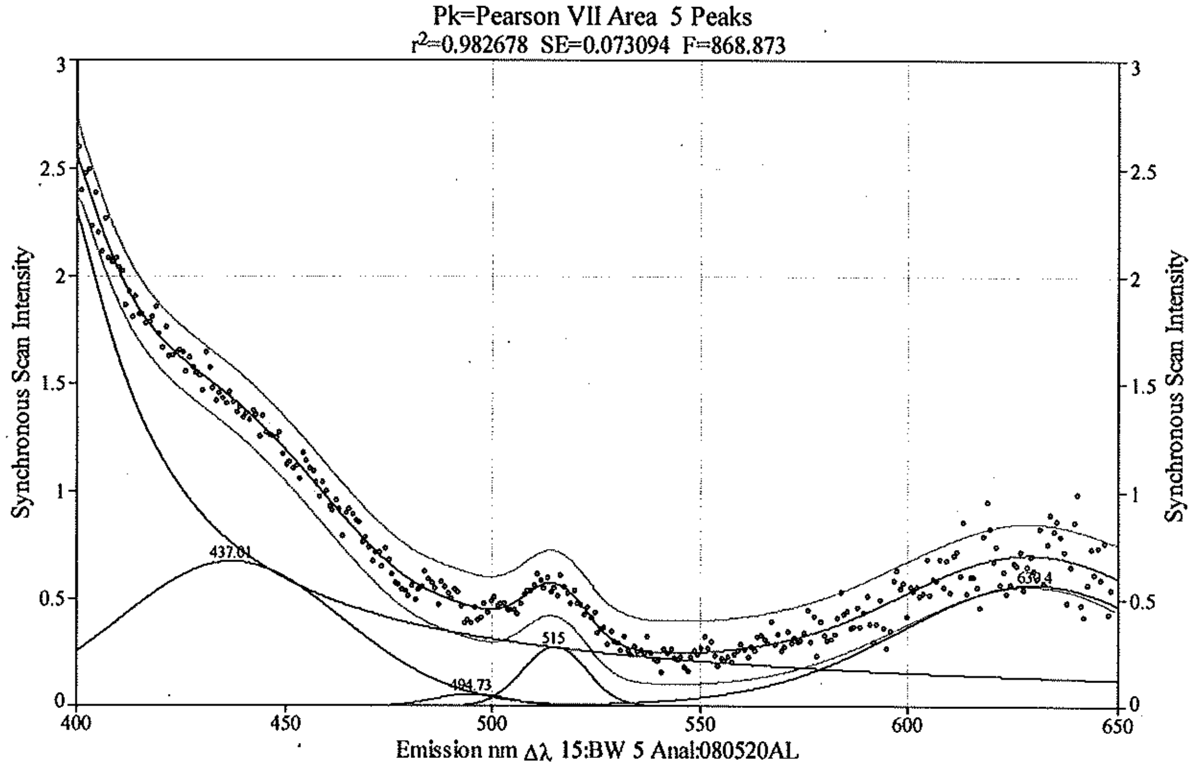
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs

LCCMR, Water, Eluent Blank, Sampled:080520 1550



Description: LCCMR, Water, Eluent Blank, Sampled:080520 1550
X Variable: Emission nm Δλ 15:BW 5 Anal:080520AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreekwater080424\eb80520b

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98267814	0.98148353	0.07309404	868.872537

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1519.47676	392.356471	47.6458722	0.52579602
2	Pearson VII Area	45.1968840	437.007809	62.7923199	57.5757445
3	Pearson VII Area	1.30674108	494.725861	20.9539645	167.514672
4	Pearson VII Area	5.38234931	514.997114	18.2129449	129.808566
5	Pearson VII Area	48.4184752	630.400850	78.0181067	8.30309053

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	2.53232610	396.272936	49.9941157	0.72909114	0.00000000	0.00000000
2	Pearson VII Area	0.67380318	437.007809	62.7923199	0.99999999	126.606557	1.00000000
3	Pearson VII Area	0.05851489	494.725861	20.9539645	1.00000000	42.0480960	1.00000000
4	Pearson VII Area	0.27719262	514.997114	18.2129449	1.00000000	36.5741639	1.00000000
5	Pearson VII Area	0.56803019	630.400850	78.0181067	1.00000000	164.424338	1.00000000

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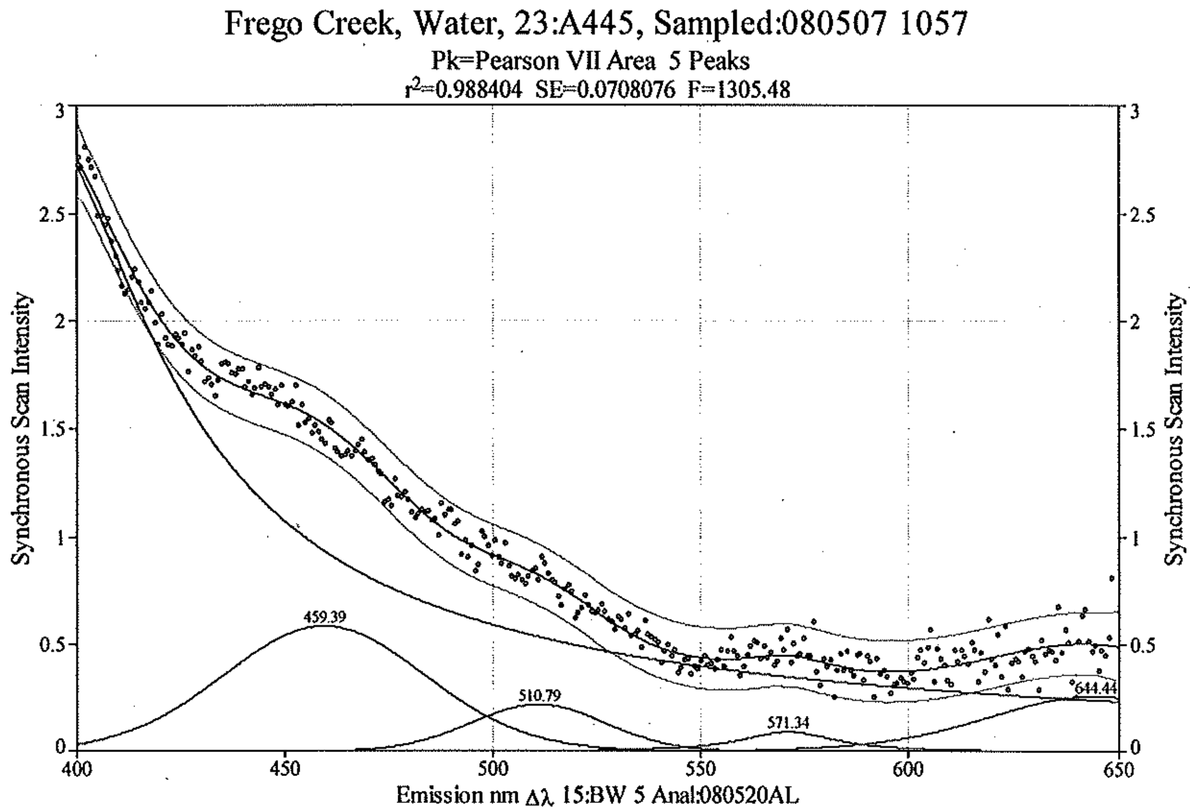
Frego Creek Trace 31 March 2008 Inputs



Description: Frego Creek, Water, 23:A445, Sampled:080507 1057
X Variable: Emission nm Δλ 15:BW 5 Anal:080520AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreekwater080507\fcw50507

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98840416	0.98760445	0.07080760	1305.48460

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1742.90427	390.166970	83.1013181	0.54646252
2	Pearson VII Area	35.9140889	459.390093	57.2285097	22.9313795
3	Pearson VII Area	8.89718239	510.786469	38.2632061	167.743040
4	Pearson VII Area	3.51827357	571.335960	27.1021462	1.16338344
5	Pearson VII Area	17.4892745	644.436940	60.9935081	6.35636018

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	2.93047458	390.538991	83.1131593	0.98225458	0.00000000	0.00000000
2	Pearson VII Area	0.58425616	459.390094	57.2285097	0.99999994	116.672569	0.99999997
3	Pearson VII Area	0.21817998	510.786468	38.2632061	1.00000001	76.7821054	1.00000000
4	Pearson VII Area	0.09027615	571.335960	27.1021462	1.00000000	83.2173409	1.00000000
5	Pearson VII Area	0.26016828	644.436940	60.9935081	1.00000000	130.663596	1.00000000

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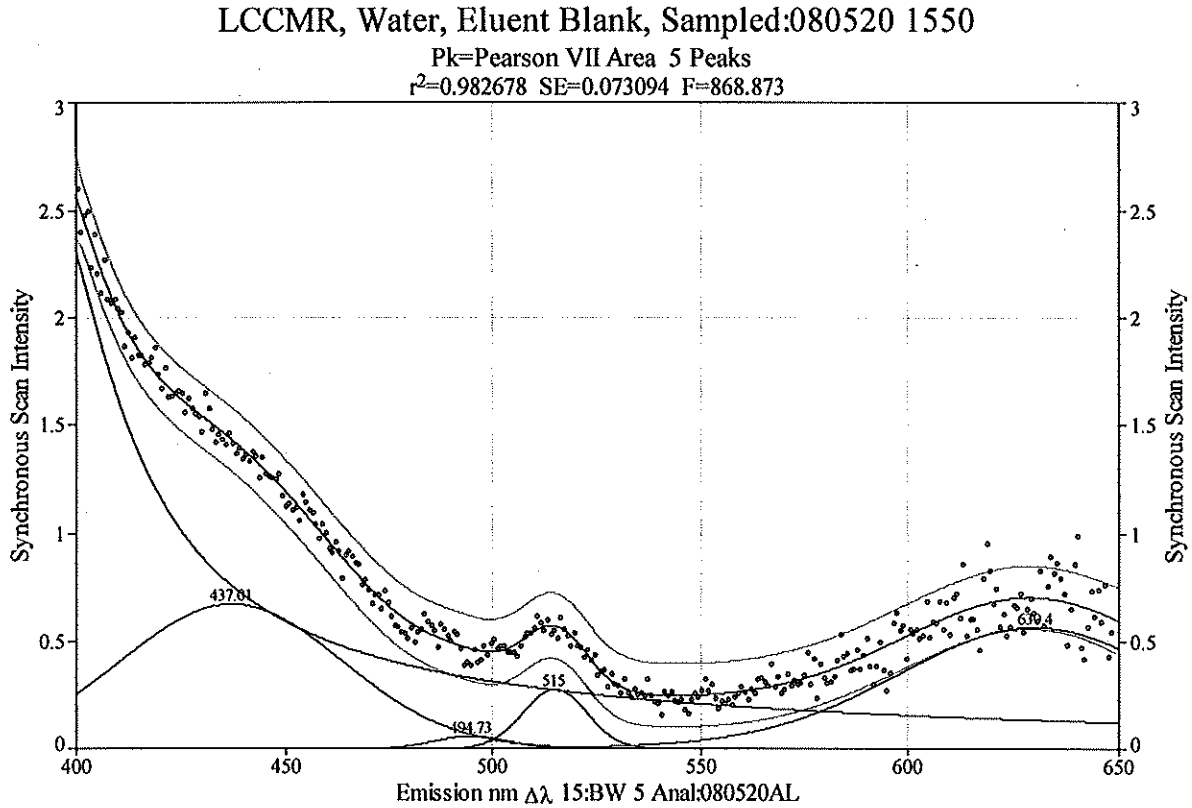
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Frego Creek Trace 31 March 2008 Inputs



Description: LCCMR, Water, Eluent Blank, Sampled:080520 1550
X Variable: Emission nm Δλ 15:BW 5 Anal:080520AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\fregocreek080331\fregocreekwater080507\eb80520b

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98267814	0.98148353	0.07309404	868.872537

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1519.47676	392.356471	47.6458722	0.52579602
2	Pearson VII Area	45.1968840	437.007809	62.7923199	57.5757445
3	Pearson VII Area	1.30674108	494.725861	20.9539645	167.514672
4	Pearson VII Area	5.38234931	514.997114	18.2129449	129.808566
5	Pearson VII Area	48.4184752	630.400850	78.0181067	8.30309053

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	2.53232610	396.272936	49.9941157	0.72909114	0.00000000	0.00000000
2	Pearson VII Area	0.67380318	437.007808	62.7923199	1.00000001	126.606557	1.00000001
3	Pearson VII Area	0.05851489	494.725866	20.9539645	0.99999912	42.0480960	0.99999952
4	Pearson VII Area	0.27719262	514.997114	18.2129449	1.00000000	36.5741639	1.00000000
5	Pearson VII Area	0.56803019	630.400850	78.0181067	1.00000000	164.424338	1.00000000

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Harmony Fall 2008 Dye Trace

October 28, 2008 to May 4, 2009

Jeffrey A. Green, Andrew J. Peters[1], Andrew J. Luhmann[2],
E. Calvin Alexander, Jr.[2] and Scott C. Alexander[2]

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Trace Name: Harmony Fall 2008
Trace Purpose: The sinkholes traced from lie near a springshed divide and were traced from in an effort to better delineate the boundary between three separate springsheds.
County: Fillmore
Cooperators: City of Harmony Fire Department, Earth Systems Class - Fillmore Central High School

Introduction

A dye trace was conducted in an area in the City of Harmony, Minnesota, and an area located just west of the City of Harmony, Minnesota from October 28, 2008 to May 4, 2009 (Figure 1). Numerous dye traces have been completed in this area in the past and this effort was made in order to better delineate the springsheds in this area due to the close proximity of numerous State of Minnesota designated trout streams. Achieving a better understanding of the connection of these sinkholes receiving surface water flow and their connectivity to springs that provide a cold water source for the designated trout streams in the area was the goal of this trace.

Dye tracing entails using fluorescent dyes to track groundwater flow directions and travel times. The dye is poured into a sinkhole or sinking stream; from there, it flows through the karst conduit system until it re-emerges at a spring or springs. For this project, the dye used was Uranine. Both direct water samples and passive dye detectors were used and all the samples were analyzed at the University of Minnesota Geology Department using a scanning spectrofluorophotometer. The trace was designed and executed by Jeff Green and Andrew Peters of MNDNR Waters with help from the City of Harmony Fire Department which provided water for the trace and the Earth Systems Class from Fillmore Central High School. E. Calvin Alexander, Jr., Andrew Luhmann, and Scott Alexander of the University of Minnesota Geology Department performed the sample analysis and interpretation.

Results

Prior to dye injection, dye receptors had been placed at all the sampling points to determine background levels of dyes. The dye trace began on October 28, 2008. Table 1 summarizes the dye input information.

Dye Inputs				
Dye Input Point	Dye (type, quantity)	Time	Water Input (Est.)	Dye Detection Point
Sinkhole 23:D6080	Uranine C, 726 grams	1427 hrs.	450 Gallons	Spring 23:A0024 & Monitoring Point "Quarry Overflow" which monitors waters leaving nearby quarry and Spring 23:A0237
Sinkhole 23:D7963	Rhodamine WT, 758 grams	1500 hrs.	450 Gallons	Spring 23:A0024 & Monitoring Point "Quarry Overflow" which monitors waters leaving nearby quarry and Spring 23:A0237

Table 1: Dye Inputs, Harmony Fall 2008 Dye Trace

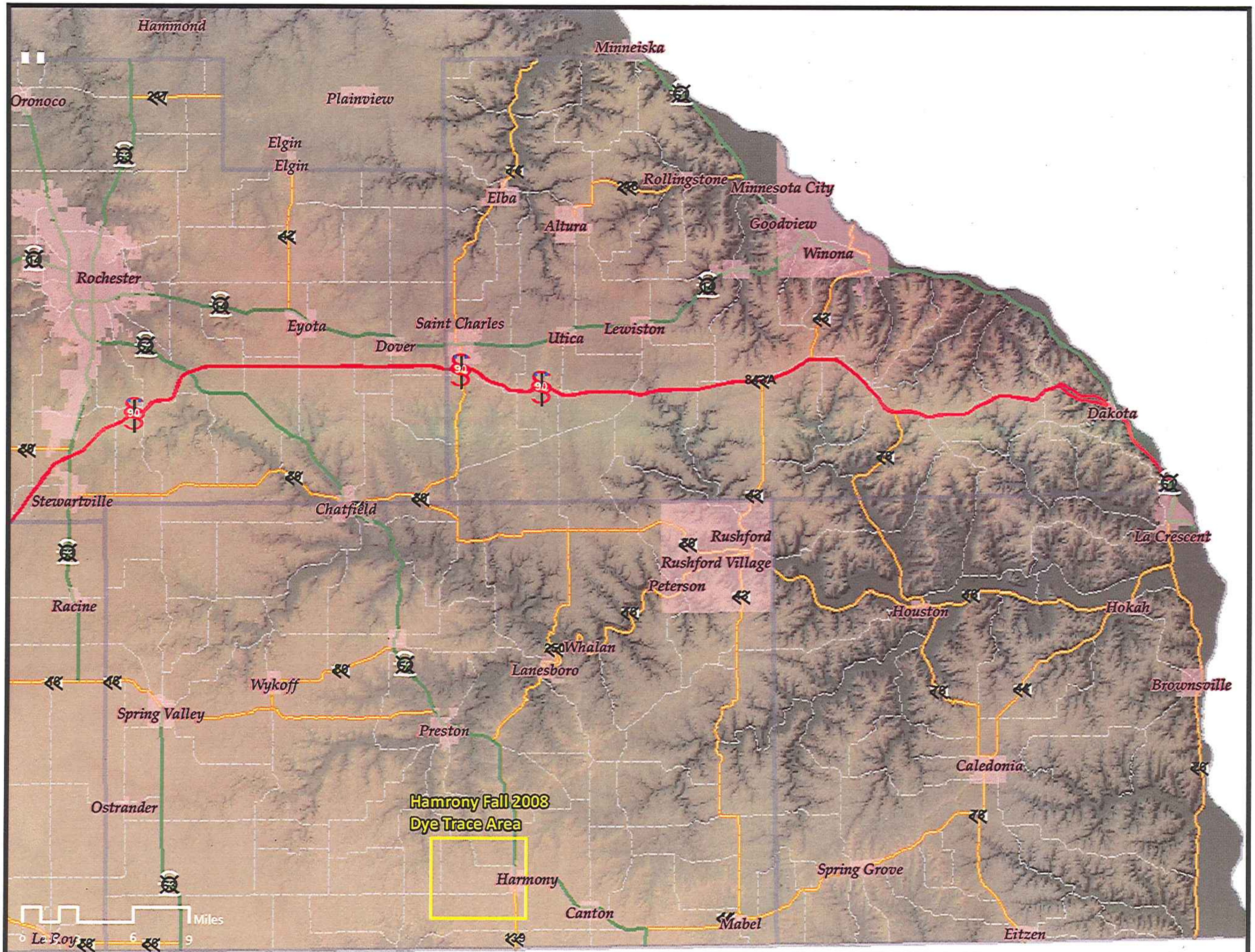
Direct water samples were collected and charcoal dye detectors were in placed at all sampling locations from the start of the trace until early May of 2009. Both dyes were detected at levels high enough for positive identification. The Uranine dye was detected in the carbon samples from Spring 23:A0024 & "Quarry Overflow" no more than 15 days after dye input. This translates to a groundwater flow rate of no greater than approximately 800-feet per day. This rate is consistent with previous traces in this geologic setting (Ordovician Galena limestone).

The Rhodamine WT dye was also detected in the carbon samples from the same locations but later than the Uranine dye, no more than 86 days after dye input. This translates to a groundwater flow rate of no greater than approximately 75 feet per day. This rate is not consistent with previous traces in this geologic setting (Ordovician Galena limestone) which is often much faster. We believe that during the Rhodamine WT dye input there was not enough water introduced to properly flush the dye into the groundwater system. In December of 2008 there were atypically warm winter temperatures that did melt snow cover in the area. We feel the water flow from this runoff event provided enough water to properly flush the dye into the groundwater system. If indeed our conclusions are correct and the dye was introduced into the system in mid-to-late December groundwater flow rates would be estimated at approximately 165 to 248 feet per day. This groundwater flow rate would be more consistent with previous traces in this geologic setting (Ordovician Galena limestone).

The dye input points and their known connection from this dye trace in addition to previously completed traces are shown in Figure 2. Through this trace, we have further delineated the springsheds feeding springs 23:A0237, 23:A0024, 23:A0358 & 23:A0479. This new trace has expanded the known boundaries of the 23:A0237 springshed.

Appendix 1

Figures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Oronoco
Plainview
Elgin
Elgin
Rollingstone
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Elba
Altura
Goodview
Winona
Rochester
Eyota
Saint Charles
Dover
Utica
Lewiston
Dakota
Stewartville
Chatfield
Rushford
Rushford Village
La Crescent
Peterson
Racine
Houston
Hokah
Whalan
Lanesboro
Wykoff
Spring Valley
Preston
Brownsville
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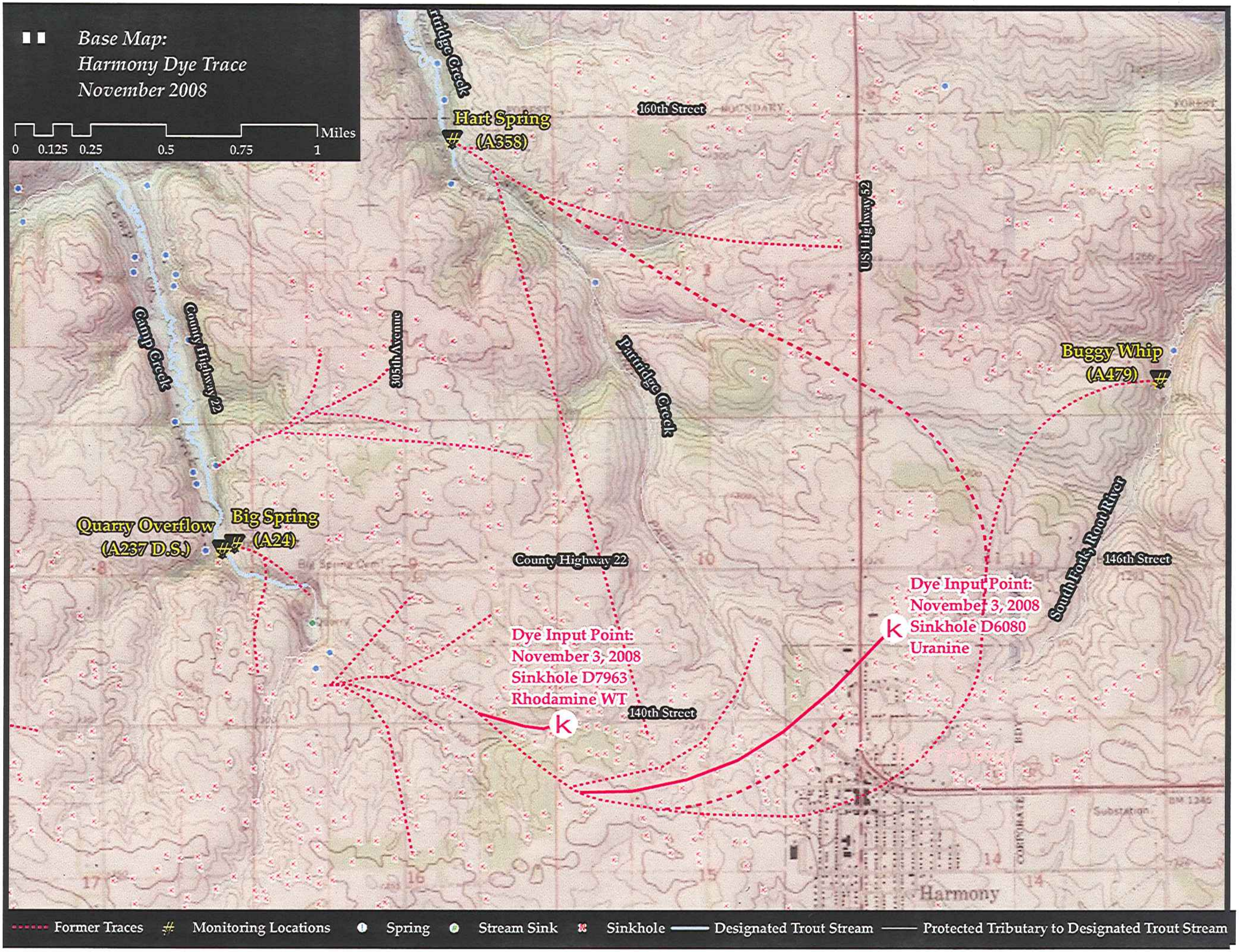
Miles
Le Roy
6
9



Base Map:
Harmony Dye Trace
November 2008
0 0.125 0.25 0.5 0.75 1 Miles
Hart Spring (A358)
160th Street
US Highway 52
Partridge Creek
Camp Creek
County Highway 22
305th Avenue
Partridge Creek
Buggy Whip (A479)
Quarry Overflow (A237 D.S.)
Big Spring (A24)
County Highway 22
146th Street
South Fork Root River
Dye Input Point: November 3, 2008 Sinkhole D6080 Uranine
Dye Input Point: November 3, 2008 Sinkhole D7963 Rhodamine WT
140th Street
Harmony
Former Traces
Monitoring Locations
Spring
Stream Sink
Sinkhole
Designated Trout Stream
Protected Tributary to Designated Trout Stream

Appendix 2

Dye Input

Harmony Fall 2008 Dye Trace: October 28, 2008 to May 4, 2009

Dye Input Points:

Input Point #1:

Sinkhole D6080:	**Minnesota Karst Feature Database Number - MN23:D6080**
UTM:	**580,154 E, 4,823,769 N**
Township, Range, Section:	**SW ¼ of the SW ¼ of Section 11, T101N, R10W**
Elevation:	**~1328 feet**

At 1427 CDT on 28 October 2008, approximately 726 grams of Uranine dye solution was introduced into an open swallow hole in D6080 with approximately 450 gallons of water.

Input Point #2:

Sinkhole D7963:	**Minnesota Karst Feature Database Number - MN23:D7963**
UTM:	**578,335 E, 4,823, 253 N**
Township, Range, Section:	**NE ¼ of the NE ¼ of Section 16, T101N, R10W**
Elevation:	**~1325 feet**

At approximately 1530 CDT on 28 October 2008, approximately 758 grams of Rhodamine WT dye solution was introduced into multiple open swallow holes in D7963 with approximately 450 gallons of water.

Harmony Fall 2008 28 Oct 2008

Set background bugs @ BJ Spring
Quarry overflow, Buggywhip & Hart
Target sinkhole @ Gordons B D7963
BJ Sp- (A24) Quarry overflow (A237)
Hart Sp- (A358) Buggywhip A479
Sinkhole #'s - HECO D6080, Gordon D7963

D6080 450 gal H_2O
dye @ 1427 Chromatint
Orange C lot 0401808C
725.54 gms 35% soln
Slight ponding water
drained rapidly into a
.6m swallow hole
water ended @ 1433
~~[illegible]~~ 9m round sinkhole
4m deep
Sinkhole D7963 Swallow hole
on W. end of sink Harmony F.D.
Dye @ 1500 ~ 450 gal
758.47 gm Rh WT 4m swallet
no ponding 25m long x 25w x
20% soln 5m deep
several swallow holes

D7963
578335/4823253
± 4m
Garmin 76CSx

Appendix 3

Dye Receptors

Harmony Fall 2008 Dye Trace: October 28, 2008 to May 4, 2009

Dye Receptor Locations:

Dye Receptor #1:

Big Spring — Minnesota Karst Feature Database Number - MN23:A0024

UTM: 576,647 E, 4,824,238 N

Notes: Receptor located 10 feet upstream of confluence with Quarry Overflow near steel debris

Dye Receptor #2:

Hart Spring — Minnesota Karst Feature Database Number - MN23:A0358

UTM: 577,803 E, 4,826,382 N

Notes: Receptor located on south side of road on the west bank of the stream just south of bridge

Dye Receptor #3:

Buggy Whip — Minnesota Karst Feature Database Number - MN23:A0479

UTM: 581,549 E, 4,825,118 N

Notes: Receptor located in the culvert discharge on the east side of road

Dye Receptor #4:

Quarry Overflow — Minnesota Karst Feature Database Number - MN23:X???

UTM: 576,581 E, 4,824,208 N

Notes: Receptor located 10 feet upstream from confluence with Big Spring flow

Appendix 4

Summary of Analytical Results

Harmony Fall 2008 Dye Trace: Summary of Analytical Results of Carbon Samples									
Sampling Location	**10/28/08 to 11/3/08**	**11/3/08 to 11/12/08**	**11/12/08 to 11/24/08**	**11/24/08 to 12/8/08**	**12/8/08 to 1/22/09**	**1/22/09 to 3/4/09**	**3/4/09 to 3/16/09**	**3/16/09 to 4/8/09**	**4/8/09 to 5/4/09**
Big Spring	None	Uranine	Uranine	Uranine	Uranine, **RhWT**	Uranine, **RhWT**	Uranine	Uranine, **RhWT**	Uranine, **RhWT**
Quarry Overflow	None	Uranine	Uranine	Uranine	Uranine, **RhWT**	Uranine, **RhWT**	Uranine, **RhWT**	Uranine, **RhWT**	Uranine, **RhWT**
Buggy Whip	None	-	None	None	None	None	None	None	None
Hart Spring	None	None	None	-	Uranine	None	None	None	None

Harmony Fall 2008 Dye Trace: Summary of Analytical Results of Water Samples					
Sampling Location	**11/4/08**	**11/5/08**	**11/6/08**	**11/7/08**	**11/12/08**
Buggy Whip	None	None	None	-	None
Johnson Well	-	-	-	None	-

Appendix 5

Scanning Spectrofluorophotometer Results

The following analytical results were completed by project participants associated with the Geology & Geophysics Department at the University of Minnesota. Analysis of the samples was completed by Andrew J. Luhmann[2] and Scott C. Alexander[2]. Interpretation of the analytical results was completed by Jeffrey A. Green[1], Andrew J. Peters[1], Andrew J. Luhmann[2], E. Calvin Alexander, Jr.[2] and Scott C. Alexander[1].

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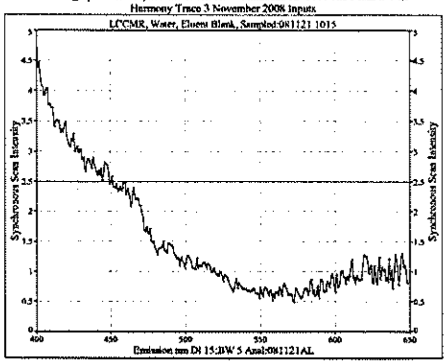
[2] Geology & Geophysics Department, University of Minnesota, 310 Pillsbury Drive. SE., Minneapolis, Minnesota, 55455; Phone (612) 624-3517; Fax (612) 625-3819; emails: luhm0031@umn.edu, alexa001@umn.edu & alexa017@umn.edu

Archived file source: Andrew Peters – D:/Documents/Final Trace Reports/Harmony Fall 2008/HarmonySpringTrace All Curves

Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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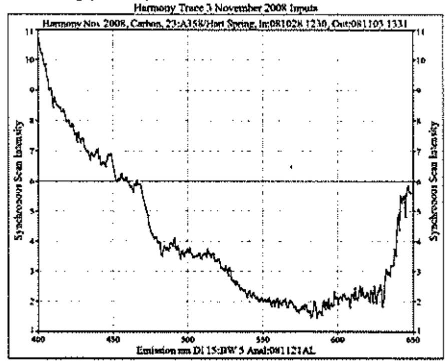

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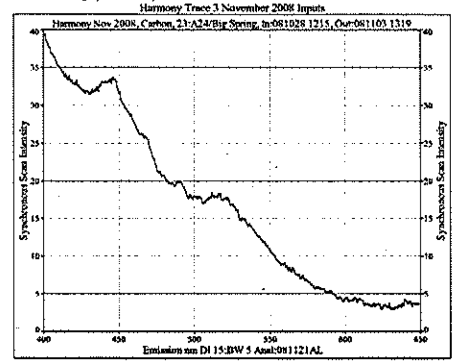

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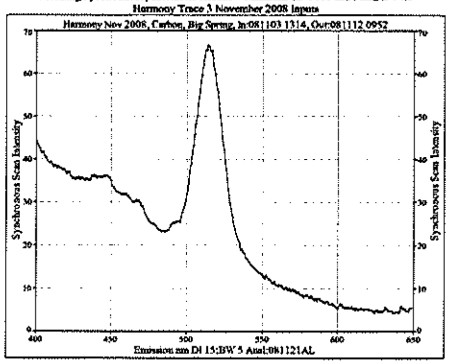

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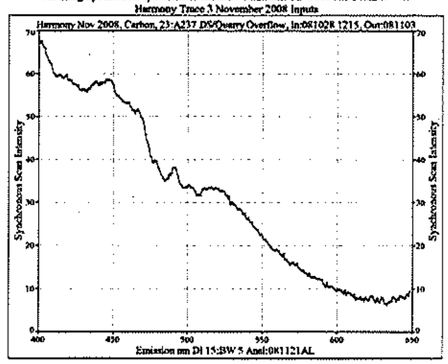

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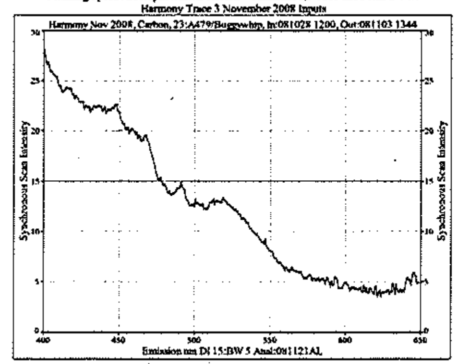

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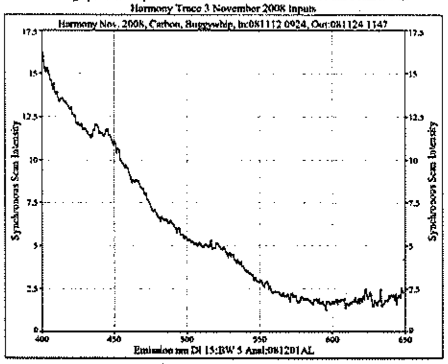

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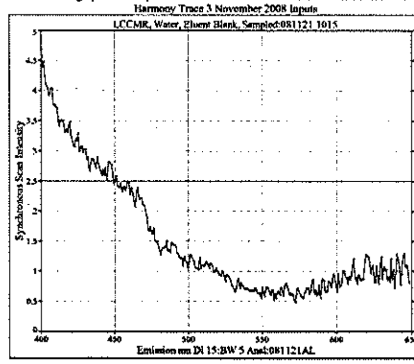

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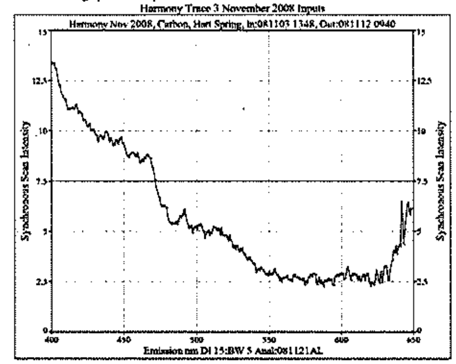

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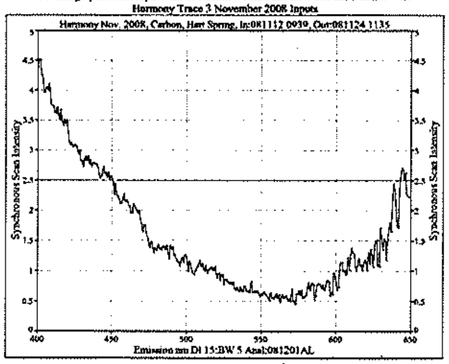

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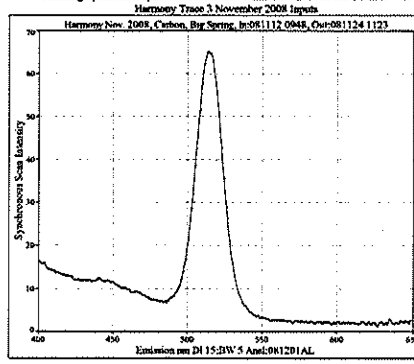

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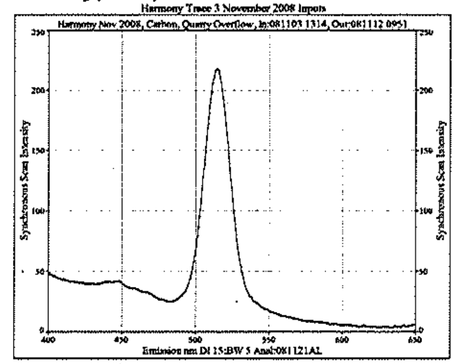

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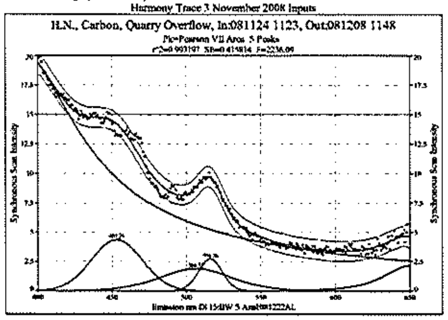

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Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony081124-081208\hnqo1208

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99319723	0.99272807	0.41581433	2236.06830

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	44857.0673	389.607000	119.374138	0.51635622
2	Pearson VII Area	165.236998	453.248897	39.9582102	167.917669
3	Pearson VII Area	119.575759	506.522891	56.6300944	4.44258782
4	Pearson VII Area	54.3047019	516.260632	18.6090944	18.6500837
5	Pearson VII Area	111.511711	650.484281	41.7625819	1.80072864

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	20.2173408	389.606999	119.374138	1.00000002	0.00000000	0.00000000
2	Pearson VII Area	4.34976725	453.248897	39.9582102	1.00000000	80.1832333	1.00000000
3	Pearson VII Area	1.88349055	506.522889	56.6300944	1.00000016	125.102582	1.00000008
4	Pearson VII Area	2.71104063	516.260631	18.6090944	1.00000008	38.1005256	1.00000004
5	Pearson VII Area	2.12525409	648.399987	42.0671966	1.21998633	108.802511	1.08843542

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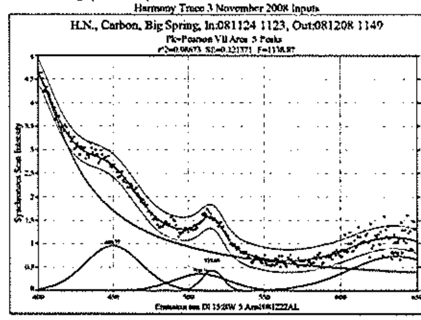
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



Description: H.N., Carbon, Big Spring, In:081124 1123, Out:081208 1149
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Y Variable: Synchronous Scan Intensity
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Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98673028	0.98581513	0.12137104	1138.87497

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	7077.59551	393.217418	74.2808815	0.51545165
2	Pearson VII Area	44.5268474	449.770854	43.5900449	27.1858101
3	Pearson VII Area	16.3084937	508.164368	43.2757070	82.7069061
4	Pearson VII Area	7.50385521	515.651235	16.6551015	167.919233
5	Pearson VII Area	56.3218647	636.898882	72.5984750	103.082839

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.85628892	393.405963	74.2845542	0.98989867	0.00000000	0.00000000
2	Pearson VII Area	0.95242622	449.770854	43.5900449	1.00000000	88.6110362	1.00000000
3	Pearson VII Area	0.35315953	508.164366	43.2757070	1.00000000	87.0631290	1.00000000
4	Pearson VII Area	0.42274679	515.651235	16.6551015	0.99999996	33.4214134	0.99999998
5	Pearson VII Area	0.72728237	636.898882	72.5984750	0.99999999	145.909592	1.00000000

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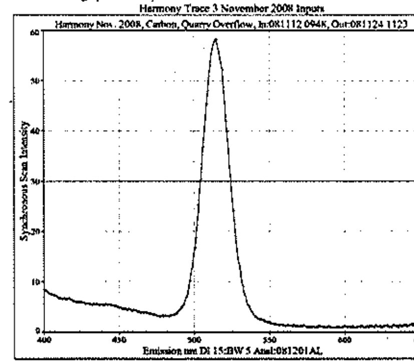
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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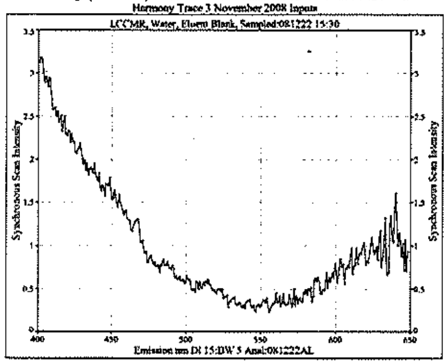
Harmony Trace 3 November 2008 Inputs



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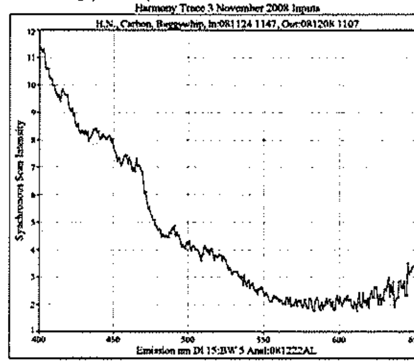

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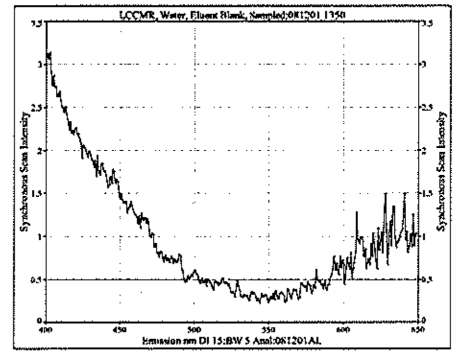
Harmony Trace 3 November 2008 Inputs



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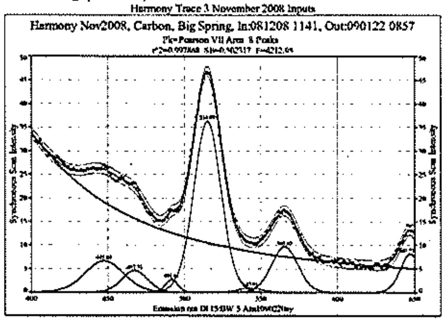
Harmony Trace 3 November 2008 Inputs



Description: Harmony Nov2008, Carbon, Big Spring, In:081208 1141, Out:090122 0857
X Variable: Emission nm Δλ 15:BW 5 Anal:090220sy
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony081208-090122\hsbs0122

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99786828	0.99762291	0.50231659	4212.94952

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	21836.6379	361.247753	142.772809	0.61900308
2	Pearson VII Area	213.959891	447.639504	29.5189648	8.29565936
3	Pearson VII Area	97.7199474	467.510877	19.6846612	10.2727798
4	Pearson VII Area	29.1375754	491.606146	9.27277790	3.87221756
5	Pearson VII Area	818.318144	514.892994	20.7325781	9.67791149
6	Pearson VII Area	18.7626948	542.946177	19.4428007	167.744296
7	Pearson VII Area	210.810776	565.420730	20.0963345	10.3771461
8	Pearson VII Area	136.468519	647.371132	15.4438704	12.4769338

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	45.2364762	361.247753	142.772809	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	6.63400982	447.639504	29.5189648	1.00000000	62.2146146	1.00000000
3	Pearson VII Area	4.56775454	467.510877	19.6846612	1.00000000	41.0688730	1.00000000
4	Pearson VII Area	2.77026466	491.606146	9.27277790	0.99999995	20.8017995	0.99999998
5	Pearson VII Area	36.2683974	514.892994	20.7325781	1.00000001	43.3680775	1.00000000
6	Pearson VII Area	0.90548271	542.946177	19.4428007	1.00000000	39.0155269	1.00000000
7	Pearson VII Area	9.65426592	565.420732	20.0963345	0.99999967	41.9099131	0.99999983
8	Pearson VII Area	8.16190176	647.371132	15.4438704	1.00000000	31.9819268	1.00000000

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Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
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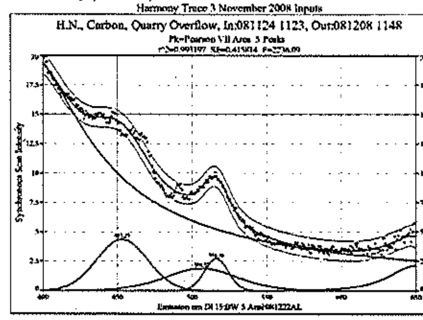

Description: H.N., Carbon, Quarry Overflow, In:081124 1123, Out:081208 1148
X Variable: Emission nm Δλ 15:BW 5 Anal:081222AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony081124-081208\hqo1208

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99319723	0.99272807	0.41581433	2236.08830

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	44857.0673	389.607000	119.374138	0.51635622
2	Pearson VII Area	185.236998	453.248897	39.9582102	167.917669
3	Pearson VII Area	119.575759	506.522891	56.6300944	4.44258782
4	Pearson VII Area	54.3047019	516.260632	18.6090944	18.6300837
5	Pearson VII Area	111.511711	650.484281	41.7625819	1.80072864

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	20.2173408	389.606999	119.374138	1.00000002	0.00000000	0.00000000
2	Pearson VII Area	4.34976725	453.248897	39.9582102	1.00000000	80.1832333	1.00000000
3	Pearson VII Area	1.88349055	506.522989	56.6300944	1.00000016	125.102382	1.00000008
4	Pearson VII Area	2.71104063	516.260631	18.6090944	1.00000008	38.1005256	1.00000004
5	Pearson VII Area	7.12523409	648.399987	42.0671966	1.21998633	108.802511	1.08843542

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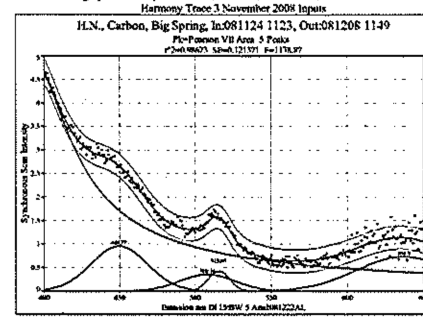
Harmony Trace 3 November 2008 Inputs



Description: H.N., Carbon, Big Spring, In:081124 1123, Out:081208 1149
X Variable: Emission nm Δλ 15:BW 5 Anal:081222AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony081124-081208\hsbs1208

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98673028	0.98581513	0.12137304	1138.87497

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	7077.59551	393.217418	74.2808815	0.51545165
2	Pearson VII Area	44.5280074	449.770854	43.5900449	27.1858101
3	Pearson VII Area	16.3084937	508.164368	43.2757070	82.7069061
4	Pearson VII Area	7.50383521	515.651235	16.6551015	167.919233
5	Pearson VII Area	56.3218647	636.898882	72.5984750	103.082839

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.83628892	393.405963	74.2845542	0.98989867	0.00000000	0.00000000
2	Pearson VII Area	0.95242622	449.770854	43.5900449	1.00000000	88.6110362	1.00000000
3	Pearson VII Area	0.35315953	508.164368	43.2757070	1.00000000	87.0631290	1.00000000
4	Pearson VII Area	0.42274679	515.651235	16.6551015	0.99999996	33.4214134	0.99999998
5	Pearson VII Area	0.72730237	636.898882	72.5984750	0.99999999	145.909592	1.00000000

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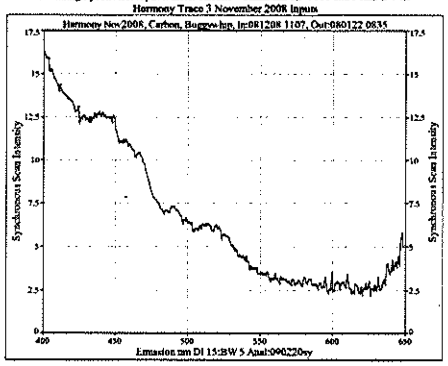
Harmony Trace 3 November 2008 Inputs



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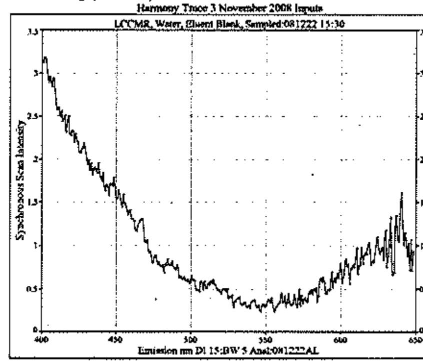
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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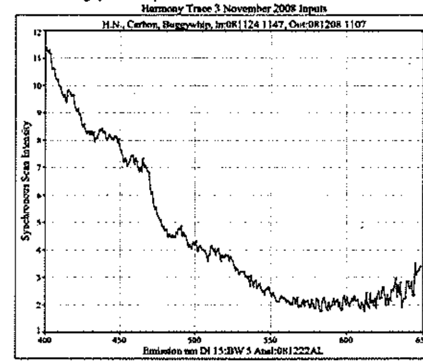
Harmony Trace 3 November 2008 Inputs



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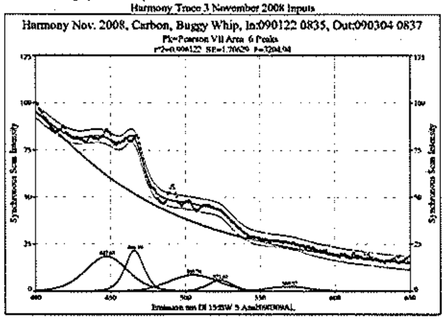
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



Description: Harmony Nov. 2008, Carbon, Buggy Whip, In:090122 0835, Out:090304 0837
X Variable: Emission nm Δλ 15:BW 5 Anal:090309AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090122-090304\hahw0304

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99612165	0.99579619	1.70628501	3204.93717

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	45356.8315	362.190254	191.985044	0.75283012
2	Pearson VII Area	661.975411	447.631570	32.8941904	4.33712347
3	Pearson VII Area	364.264820	466.189345	14.7286522	3.04448723
4	Pearson VII Area	354.535926	505.738088	38.9446201	167.905214
5	Pearson VII Area	130.281934	523.607436	19.6882356	3.69360209
6	Pearson VII Area	98.3058978	569.515151	34.6440585	2.54729359

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	111.743916	362.190255	458.182776	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	18.4668897	447.631569	32.8941904	1.00000016	72.2566194	1.00000008
3	Pearson VII Area	21.4362900	466.189345	14.7286522	0.99999992	34.1576369	0.99999996
4	Pearson VII Area	8.54195054	505.738088	38.9446201	1.00000000	78.1492994	1.00000000
5	Pearson VII Area	5.53075224	523.607436	19.6882356	1.00000006	44.4257686	1.00000003
6	Pearson VII Area	2.41164721	569.515148	34.6440585	1.00000031	82.8677995	1.00000014

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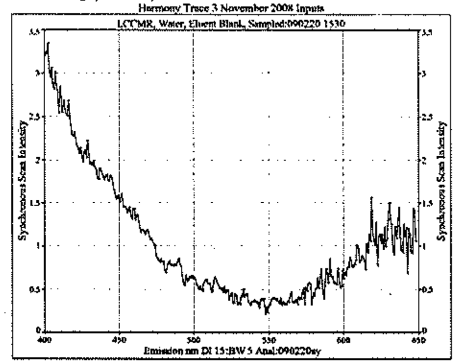
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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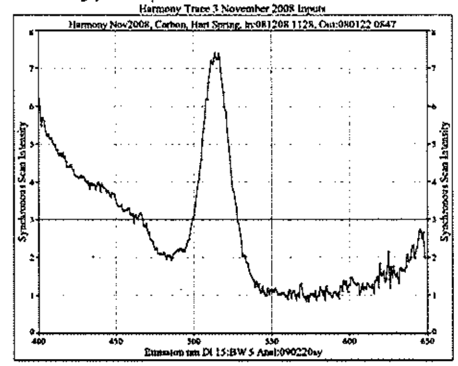
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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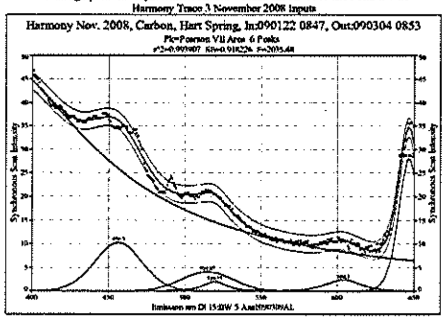
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



Description: Harmony Nov. 2008, Carbon, Hart Spring, In:090122 0847, Out:090304 0853
X Variable: Emission nm ΔλΔ 15:BW 5 Anal:090309AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090122-090304\hahs0304

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99190698	0.99139568	0.91822593	2035.48010

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	20020.7111	368.308294	178.946715	0.73602522
2	Pearson VII Area	398.529528	456.502189	36.3455394	18.6355438
3	Pearson VII Area	170.854340	514.866301	39.2413615	167.352279
4	Pearson VII Area	47.1528727	519.748873	18.0028068	1.38800665
5	Pearson VII Area	76.6532340	604.100039	27.0212534	2.11042427
6	Pearson VII Area	491.860662	646.624868	15.7150996	4.61583757

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	51.0011936	368.308293	178.946715	1.00000003	0.00000000	0.00000000
2	Pearson VII Area	10.1866016	456.502189	36.3455394	1.00000000	74.4157040	1.00000000
3	Pearson VII Area	4.08530501	514.866301	39.2413615	1.00000000	78.7454099	1.00000000
4	Pearson VII Area	1.95876529	519.748873	18.0028068	1.00000000	51.1049434	1.00000000
5	Pearson VII Area	2.35930862	604.100039	27.0212534	1.00000000	66.7925394	1.00000000
6	Pearson VII Area	27.9799500	646.624869	15.7150996	0.99999984	34.5020581	0.99999992

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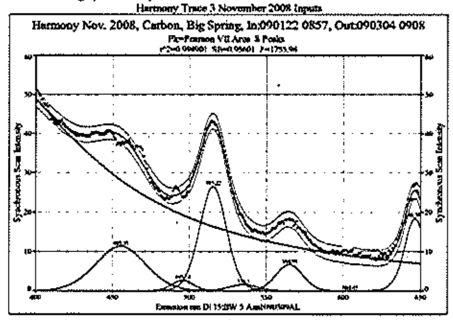
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



Description: Harmony Nov. 2008, Carbon, Big Spring, In:090122 0857, Out:090304 0908
X Variable: Emission nm ΔλΔ 15:BW 5 Anal:090309AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090122-090304\hahs0304

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99490067	0.99431370	0.95600962	1755.93809

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	22209.8544	360.355445	179.242274	0.75883335
2	Pearson VII Area	464.757740	455.346978	38.1199939	12.2523750
3	Pearson VII Area	47.0238226	495.735137	16.5065765	19.9451493
4	Pearson VII Area	588.471284	515.219588	20.4447818	9.82777079
5	Pearson VII Area	38.5359725	535.098809	22.1259598	11.0063007
6	Pearson VII Area	148.552052	564.860516	20.3694544	13.2017290
7	Pearson VII Area	19.5990322	604.445606	11.7994165	0.51000000
8	Pearson VII Area	321.771069	646.381386	15.6489127	4.66100352

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	59.3314499	360.355445	449.976582	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	11.2576485	455.346978	38.1199939	1.00000000	78.9908440	1.00000000
3	Pearson VII Area	2.64855120	495.735139	16.5065765	0.99999952	33.7457096	0.99999974
4	Pearson VII Area	26.4580308	515.219588	20.4447818	1.00000000	42.7566065	1.00000000
5	Pearson VII Area	1.60488771	535.098810	22.1259598	0.99999981	46.0323381	0.99999990
6	Pearson VII Area	6.74272915	564.860537	20.3694544	0.99999967	42.1021087	0.99999982
7	Pearson VII Area	0.05573247	604.445606	11.7994165	0.99999991	73.7772633	0.99999998
8	Pearson VII Area	18.3916422	646.381387	15.6489127	0.99999989	34.4032948	0.99999995

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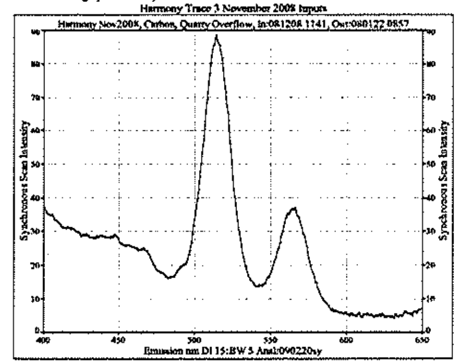
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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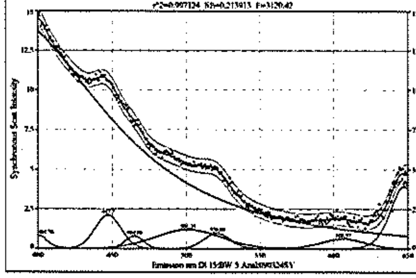
Scanning Spectrofluorophotometer Results -- Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs

Harmony Nov2008, Carbon, Hart Spring, In:090304 0853, Out:090316 0808
Pk=Pearson VII Area 8 Peaks
r^2=0.997124 SE=0.213913 F=3120.42



Description: Harmony Nov2008, Carbon, Hart Spring, In:090304 0853, Out:090316 0808
X Variable: Emission nm Δλ 15:BW 5 Anal:090324SY
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090304-090316\hshs0316

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99712407	0.99679303	0.21391268	3120.42329

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	3322.64231	373.912943	164.123925	1.35462553
2	Pearson VII Area	12.5700766	401.380499	11.5243319	1.42425102
3	Pearson VII Area	46.1692957	447.203551	20.2952724	15.5569897
4	Pearson VII Area	12.3691805	464.875601	14.8450930	167.525934
5	Pearson VII Area	68.1417536	501.345032	53.2759617	15.5714966
6	Pearson VII Area	21.8219848	520.888522	21.1704127	25.2836800
7	Pearson VII Area	25.0640290	606.574763	35.4198537	5.40627992
8	Pearson VII Area	95.3576634	647.414153	21.4658540	4.04485981

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	15.0158421	373.912943	164.123925	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	0.82298533	401.380499	11.5243319	1.00000000	32.3763556	1.00000000
3	Pearson VII Area	2.10854240	447.203551	20.2952724	1.00000000	41.7426098	1.00000000
4	Pearson VII Area	0.78180977	464.875602	14.8450930	0.99999982	29.7894840	0.99999990
5	Pearson VII Area	1.18532980	501.345032	53.2759617	1.00000000	109.573332	1.00000000
6	Pearson VII Area	0.96048042	520.888524	21.1704127	0.99999958	43.0862378	0.99999977
7	Pearson VII Area	0.63770829	606.574761	35.4198337	1.00000023	76.8273604	1.00000012
8	Pearson VII Area	3.93113472	647.414153	21.4658540	1.00000000	47.9083064	1.00000000

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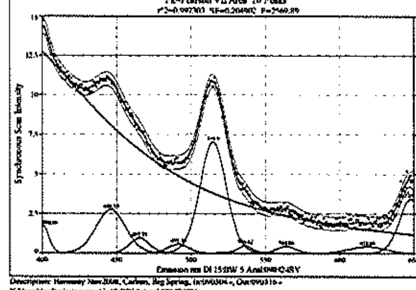
Scanning Spectrofluorophotometer Results -- Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs

Harmony Nov2008, Carbon, Big Spring, In:090304 -, Out:090316 -
Pk=Pearson VII Area 10 Peaks
r^2=0.997303 SE=0.204902 F=2569.89



Description: Harmony Nov2008, Carbon, Big Spring, In:090304 -, Out:090316 -
X Variable: Emission nm Δλ 15:BW 5 Anal:090324SY
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090304-090316\hsbs0316

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99730339	0.99690389	0.20490236	2569.89354

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	4004.06693	361.241430	184.316748	1.13096461
2	Pearson VII Area	16.4421878	400.860274	8.74315123	5.41938865
3	Pearson VII Area	65.5800011	446.176330	22.8043201	9.12412109
4	Pearson VII Area	16.1640058	463.548239	15.4474228	9.75112544
5	Pearson VII Area	10.2167576	491.448434	16.4931727	9.81890902
6	Pearson VII Area	157.353602	514.895955	20.5466511	10.0250964
7	Pearson VII Area	7.77824633	536.421659	10.6282218	1.18599968
8	Pearson VII Area	7.53591714	564.061943	15.0290910	4.14939933
9	Pearson VII Area	13.2786607	618.635668	29.2748044	167.506425
10	Pearson VII Area	67.2662854	647.845028	17.9001668	7.21606085

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	14.9415880	361.241430	453.434404	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	1.69978497	400.860274	8.74315123	0.99999978	18.9043320	0.99999999
3	Pearson VII Area	2.75380353	446.176330	22.8043201	1.00000010	47.8953058	1.00000005
4	Pearson VII Area	0.94938451	463.548239	15.4474228	0.99999999	32.7199571	1.00000009
5	Pearson VII Area	0.56939620	491.448434	16.4931727	0.99999993	34.4778809	0.99999996
6	Pearson VII Area	7.04284000	514.895955	20.5466511	1.00000001	42.9121751	1.00000000
7	Pearson VII Area	0.51373693	536.421660	10.6282218	0.99999965	32.3291787	0.99999987
8	Pearson VII Area	0.44539782	564.061941	15.0290910	1.00000056	33.4459998	1.00000028
9	Pearson VII Area	0.42560169	618.635667	29.2748044	1.00000013	56.7454418	1.00000007
10	Pearson VII Area	3.42495506	647.845028	17.9001668	0.99999997	38.0281788	0.99999999

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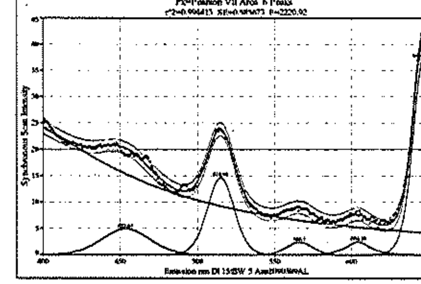
Scanning Spectrofluorophotometer Results -- Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs

Harmony Nov. 2008, Carbon, Quarry Overflow, In:090122 0857, Out:090304 0903
Pk=Pearson VII Area 6 Peaks
r^2=0.994413 SE=0.585673 F=2220.92



Description: Harmony Nov. 2008, Carbon, Quarry Overflow, In:090122 0857, Out:090304 0903
X Variable: Emission nm Δλ 15:BW 5 Anal:090309AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090122-090304\hsqo0304

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99441289	0.99394404	0.58567312	2220.92325

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	12733.5469	361.053699	204.297955	0.73185891
2	Pearson VII Area	194.845216	453.626860	36.6351679	9.30980360
3	Pearson VII Area	324.261580	514.914345	20.3848153	8.62004848
4	Pearson VII Area	51.2733623	566.102038	19.9664565	37.3404395
5	Pearson VII Area	60.1334290	604.175981	18.7872383	1.47080165
6	Pearson VII Area	664.148442	646.705187	16.0518464	5.25757471

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	28.1367276	361.053699	463.202676	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	4.80253611	453.626860	36.6351679	1.00000000	76.7696868	1.00000000
3	Pearson VII Area	14.5743319	514.914345	20.3848153	1.00000000	42.8778354	1.00000000
4	Pearson VII Area	2.39926387	566.102038	19.9664565	0.99999997	40.4173626	0.99999998
5	Pearson VII Area	2.43862814	604.175980	18.7872383	1.00000024	52.1722277	1.00000010
6	Pearson VII Area	37.2302713	646.705187	16.0518464	0.99999995	34.8998018	0.99999997

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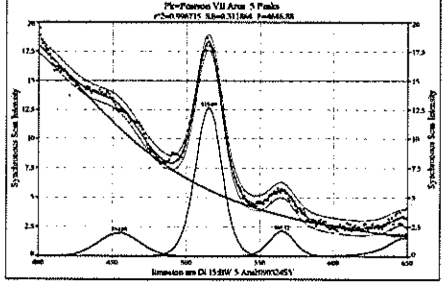
Scanning Spectrofluorophotometer Results -- Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs

Harmony Nov2008, Carbon, Quarry Overflow, In:090304 0903, Out:090316 0816
Pk=Pearson VII Area 5 Peaks
r^2=0.996715 SE=0.311864 F=4646.88



Description: Harmony Nov2008, Carbon, Quarry Overflow, In:090304 0903, Out:090316 0816
X Variable: Emission nm Δλ 15:BW 5 Anal:090324SY
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090304-090316\hsqo0316

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99671490	0.99648034	0.31186443	4646.87873

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	5449.19421	368.028721	189.069552	1.15870128
2	Pearson VII Area	68.2199422	454.678612	32.4693192	167.720997
3	Pearson VII Area	290.253308	515.091804	20.8722734	6.87165370
4	Pearson VII Area	46.4878587	565.123455	19.9382718	8.57226009
5	Pearson VII Area	54.8393031	647.623762	26.2053064	1.32571232

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	20.0030125	368.028723	462.543498	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	1.97143227	454.678612	32.4693192	1.00000001	65.1556355	1.00000000
3	Pearson VII Area	12.6532830	515.091803	20.8722734	1.00000006	44.4792198	1.00000003
4	Pearson VII Area	2.13593111	565.123455	19.9382718	0.99999995	41.9504694	0.99999997
5	Pearson VII Area	1.53916821	647.623762	26.2053064	0.99999999	75.8150312	1.00000000

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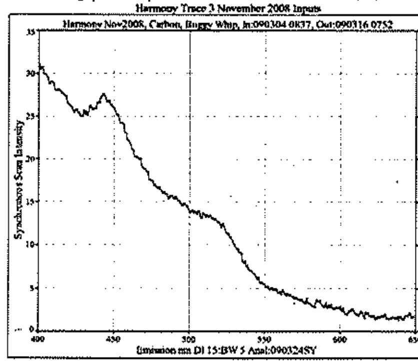
Harmony Trace 3 November 2008 Inputs



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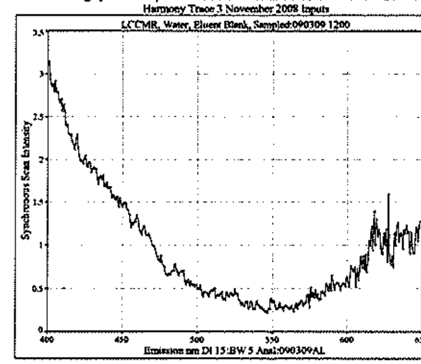
Scanning Spectrofluorophotometer Results -- Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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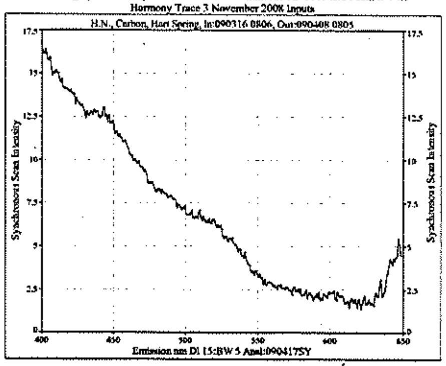
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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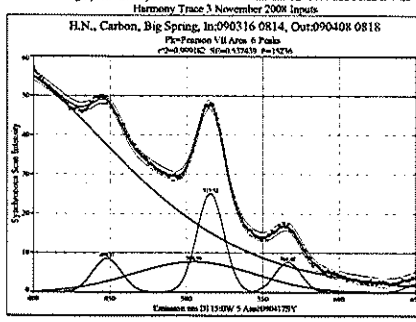
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



Description: H.N., Carbon, Big Spring, In:090316 0814, Out:090408 0818
X Variable: Emission nm ΔΛ 15:BW 5 Anal:090417SY
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090316-090408\hnb20408

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99918167	0.99911300	0.53743938	15235.9714

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	13898.6491	364.604792	204.369118	3.86464149
2	Pearson VII Area	199.052158	448.110872	21.9130286	167.890211
3	Pearson VII Area	765.909658	504.937215	93.0207323	109.559625
4	Pearson VII Area	553.738890	515.517085	20.7419612	59.2812488
5	*Pearson VII Area	165.433348	566.420164	20.2781234	31.2084955
6	Pearson VII Area	40.6862692	650.363233	18.4328704	11.3093621

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	60.0619229	364.942529	466.890019	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	8.52331839	448.110872	21.9130286	1.00000000	43.9723949	1.00000000
3	Pearson VII Area	7.72079132	504.937210	93.0207323	1.00000021	186.909807	1.00000012
4	Pearson VII Area	24.9937222	515.517084	20.7419612	1.00000022	41.8127307	1.00000012
5	Pearson VII Area	7.61384844	566.420164	20.2781234	1.00000000	41.1394171	1.00000000
6	Pearson VII Area	2.02779935	649.712644	18.4816339	1.15147205	38.3270912	1.07752323

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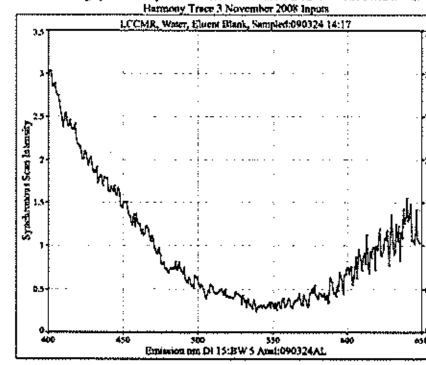
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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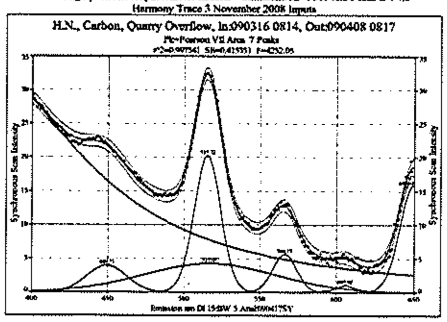
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



Description: H.N., Carbon, Quarry Overflow, In:090316 0814, Out:090408 0817
X Variable: Emission nm ΔΛ 15:BW 5 Anal:090417SY
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090316-090408\hnqo0408

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99754102	0.99729687	0.41535094	4252.04942

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	9192.58294	358.648478	168.648146	1.04070454
2	Pearson VII Area	130.356963	449.309196	30.7376243	159.481862
3	Pearson VII Area	440.959883	515.316390	20.2485953	20.0812659
4	Pearson VII Area	465.624166	517.074669	102.534966	167.916379
5	Pearson VII Area	110.129122	566.150957	18.4036526	102.465369
6	Pearson VII Area	23.8669514	605.919158	14.2572178	0.97269745
7	Pearson VII Area	353.783126	649.612013	20.6976412	14.9749704

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	35.6242119	359.482759	442.980585	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	3.97905974	449.309196	30.7376243	1.00000004	61.6885945	1.00000002
3	Pearson VII Area	20.2460476	515.316389	20.2485953	1.00000014	41.3895290	1.00000008
4	Pearson VII Area	4.26096365	517.074673	102.534966	0.99999985	205.754593	0.99999992
5	Pearson VII Area	3.61056001	566.150958	18.4036526	0.99999969	36.9888624	0.99999983
6	Pearson VII Area	1.04491671	605.919158	14.2572178	1.00000000	48.3220528	1.00000000
7	Pearson VII Area	15.8345307	649.612010	20.6976412	1.00000059	42.6158105	1.00000032

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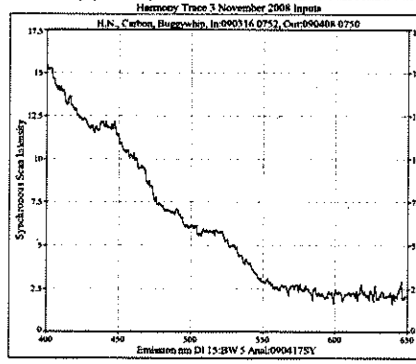
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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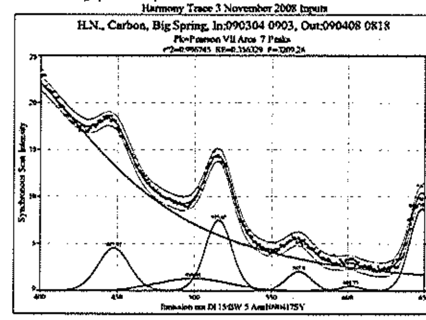
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



Description: H.N., Carbon, Big Spring, In:090304 0903, Out:090408 0818
X Variable: Emission nm ΔΛ 15:BW 5 Anal:090417SY
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090316-090408\hnb10408

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99674462	0.99642139	0.33632852	3209.26194

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	6149.18934	366.394589	171.677648	1.19884088
2	Pearson VII Area	116.650445	447.814233	23.7789236	12.2535949
3	Pearson VII Area	76.4804470	499.412934	54.9520305	39.7197848
4	Pearson VII Area	163.580489	515.673663	20.3501233	16.9487192
5	Pearson VII Area	41.6520024	567.899242	19.1738821	32.7314625
6	Pearson VII Area	13.5914117	601.728403	15.8241501	0.92237759
7	Pearson VII Area	174.294733	648.382834	18.4494028	11.3628209

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	25.2663654	366.394589	171.677648	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	4.52969390	447.814233	23.7789236	1.00000006	49.2736347	1.00000003
3	Pearson VII Area	1.30075935	499.412932	54.9520305	1.00000014	111.162297	1.00000008
4	Pearson VII Area	7.45908281	515.673663	20.3501233	1.00000004	41.7609928	1.00000002
5	Pearson VII Area	2.02800960	567.899242	19.1738821	1.00000001	38.8747146	1.00000001
6	Pearson VII Area	0.51388338	601.728403	15.8241501	1.00000002	35.4864394	1.00000001
7	Pearson VII Area	8.71082014	648.382834	18.4494028	1.00000007	38.3359792	1.00000004

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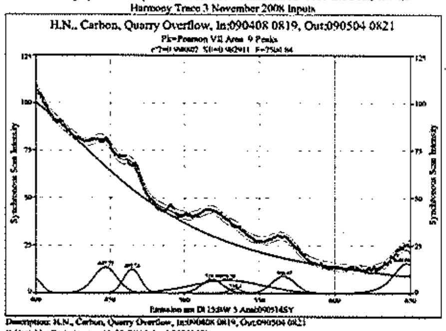
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



Description: H.N., Carbon, Quarry Overflow, In:090408 0819, Out:090504 0821
X Variable: Emission nm Δλ 15:BW 5 Anal:090514SY
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090408-090504\hnqo0504

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99880221	0.99866434	0.98291134	7504.84389

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	29366.8761	369.385887	190.225466	1.22752236
2	Pearson VII Area	84.8085134	399.845649	10.7583061	121.039549
3	Pearson VII Area	272.725873	447.267641	18.3880647	9.27815727
4	Pearson VII Area	177.876502	465.236693	13.3406792	167.878249
5	Pearson VII Area	136.092840	518.880200	17.2614675	8.98773019
6	Pearson VII Area	429.943483	529.281529	56.6922376	9.53171389
7	Pearson VII Area	28.6447580	534.195400	10.9195400	10.0000000
8	Pearson VII Area	177.391163	566.421644	18.5376220	70.0554899
9	Pearson VII Area	406.716918	648.058901	21.3255989	2.15128883

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	110.061306	369.385887	464.498420	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	7.33222815	400.287336	10.7947234	0.84870635	21.6204334	0.91413704
3	Pearson VII Area	13.6147508	447.267641	18.3880647	1.00000002	38.5387077	1.00000001
4	Pearson VII Area	12.5107927	465.236693	13.3406792	0.99999999	26.7706537	1.00000000
5	Pearson VII Area	7.23154445	518.880200	17.2614675	0.99999999	36.2326833	1.00000000
6	Pearson VII Area	6.96411837	529.281529	56.6922376	1.00000000	118.669965	1.00000000
7	Pearson VII Area	2.41228076	534.195402	10.9195400	0.99999916	22.8082087	0.99999936
8	Pearson VII Area	8.97379404	566.421645	18.5376220	0.99999977	37.3285260	0.99999987
9	Pearson VII Area	15.8242922	648.058901	21.3255989	0.99999999	52.8962059	1.00000000

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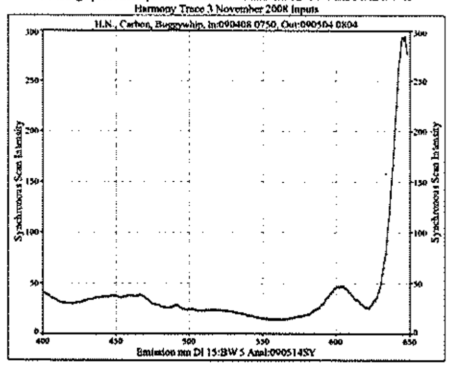
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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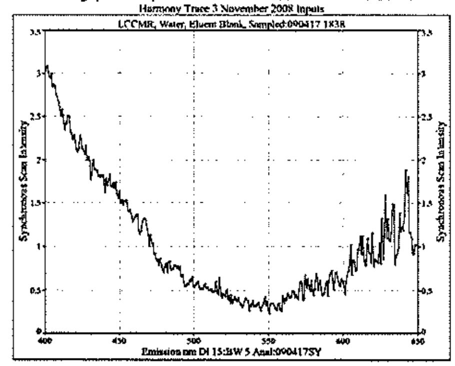
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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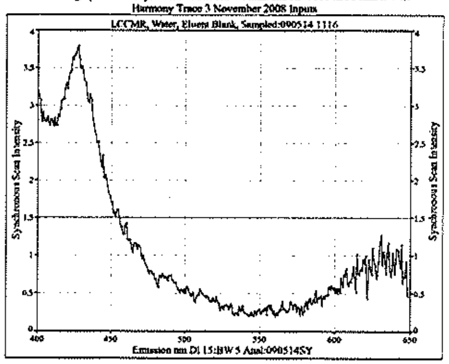
Harmony Trace 3 November 2008 Inputs



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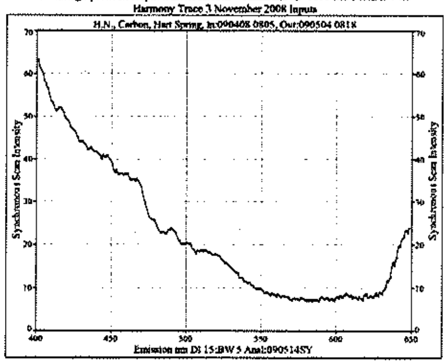
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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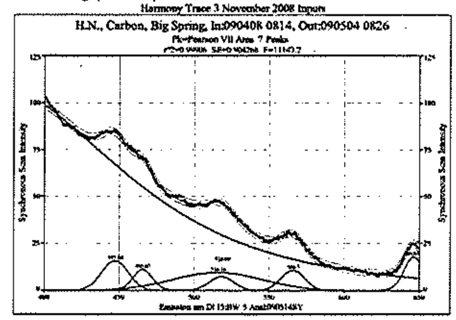
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Trace 3 November 2008 Inputs



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X Variable: Emission nm Δλ 15:BW 5 Anal:090514SY
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmony081103\harmony090408-090504\hnbs0504

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99906026	0.99896696	0.90426829	11143.3700

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	29402.3247	361.085496	209.025643	1.80906719
2	Pearson VII Area	353.800585	447.643018	21.0382626	163.798082
3	Pearson VII Area	188.903885	466.069896	15.2593052	5.05947245
4	Pearson VII Area	735.436379	516.157548	71.2694956	27.8222002
5	Pearson VII Area	155.424077	518.888542	19.1526272	12.9543648
6	Pearson VII Area	215.587980	566.297138	18.6435285	41.2144120
7	Pearson VII Area	292.259498	646.633425	14.9743979	7.88287958

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	110.989109	361.206897	465.098420	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	15.7790002	447.643017	21.0382626	1.00000007	42.2196994	1.00000004
3	Pearson VII Area	11.1256143	466.069896	15.2593052	0.99999998	33.2890386	0.99999999
4	Pearson VII Area	9.62266108	516.157548	71.2694956	1.00000000	144.827033	1.00000000
5	Pearson VII Area	7.50046358	518.888542	19.1526272	1.00000004	39.6117007	1.00000002
6	Pearson VII Area	10.8095842	566.297140	18.6435285	0.99999962	37.6994529	0.99999980
7	Pearson VII Area	17.8372102	646.633425	14.9743979	0.99999996	31.6480921	0.99999998

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Harmony Spring 2008 Dye Trace

May 6, 2008 to June 13, 2008

Jeffrey A. Green, Andrew J. Peters[1], Andrew J. Luhmann[2], E. Calvin Alexander, Jr.[2] and Scott C. Alexander [2]

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[2] Geology & Geophysics Department, University of Minnesota, 310 Pillsbury Drive. SE., Minneapolis, Minnesota, 55455; Phone (612) 624-3517; Fax (612) 625-3819; emails: luhm0031@umn.edu, alexa001@umn.edu & alexa017@umn.edu

Trace Name: Harmony Spring 2008
Trace Purpose: The sinkhole traced from lies near a springshed divide and was traced from in an effort to better delineate the boundary between three separate springsheds.
County: Fillmore
Cooperators: City of Harmony Fire Department, Earth Systems Class - Fillmore Central High School, Kwik Trip of Harmony

Introduction

A dye trace was conducted in an area in the City of Harmony, Minnesota from May 6, 2008 to June 13, 2008 (Figure 1). Numerous dye traces have been completed in this area in the past and this effort was made in order to better delineate the Buggywhip, Hart, and the Big Spring springsheds in this area due to the close proximity of numerous State of Minnesota designated trout streams. Achieving a better understanding of the connection of these sinkholes receiving surface water flow and their connectivity to springs that provide a cold water source for the designated trout streams in the area was the goal of this trace.

Dye tracing entails using fluorescent dyes to track groundwater flow directions and travel times. The dye is poured into a sinkhole or sinking stream; from there, it flows through the karst conduit system until it re-emerges at a spring or springs. For this project, the dye used was Uranine. Both direct water samples and passive dye detectors were used and all the samples were analyzed at the University of Minnesota Geology Department using a Shimadzu scanning spectrofluorophotometer. The trace was designed and executed by Jeff Green and Andrew Peters of MNDNR Waters with help from the City of Harmony Fire Department (which provided water for the trace) and the Earth Systems Class from Fillmore Central High School (Darrin Ellsworth, teacher). E. Calvin Alexander, Jr., Andrew Luhmann, and Scott Alexander of the University of Minnesota Geology Department performed the sample analysis and interpretation.

Results

Prior to dye injection, dye receptors had been placed at all the sampling points to determine background levels of dyes. The dye trace began on May 6, 2008. Table 1 summarizes the dye input information.

Dye Inputs				
Dye Input Point	Dye (type, quantity)	Time	Water Input (Est.)	Dye Detection Point
Sinkhole 23:D6526	Uranine C, 881 grams	1649 hrs.	1,500 Gallons	Spring 23:A0237

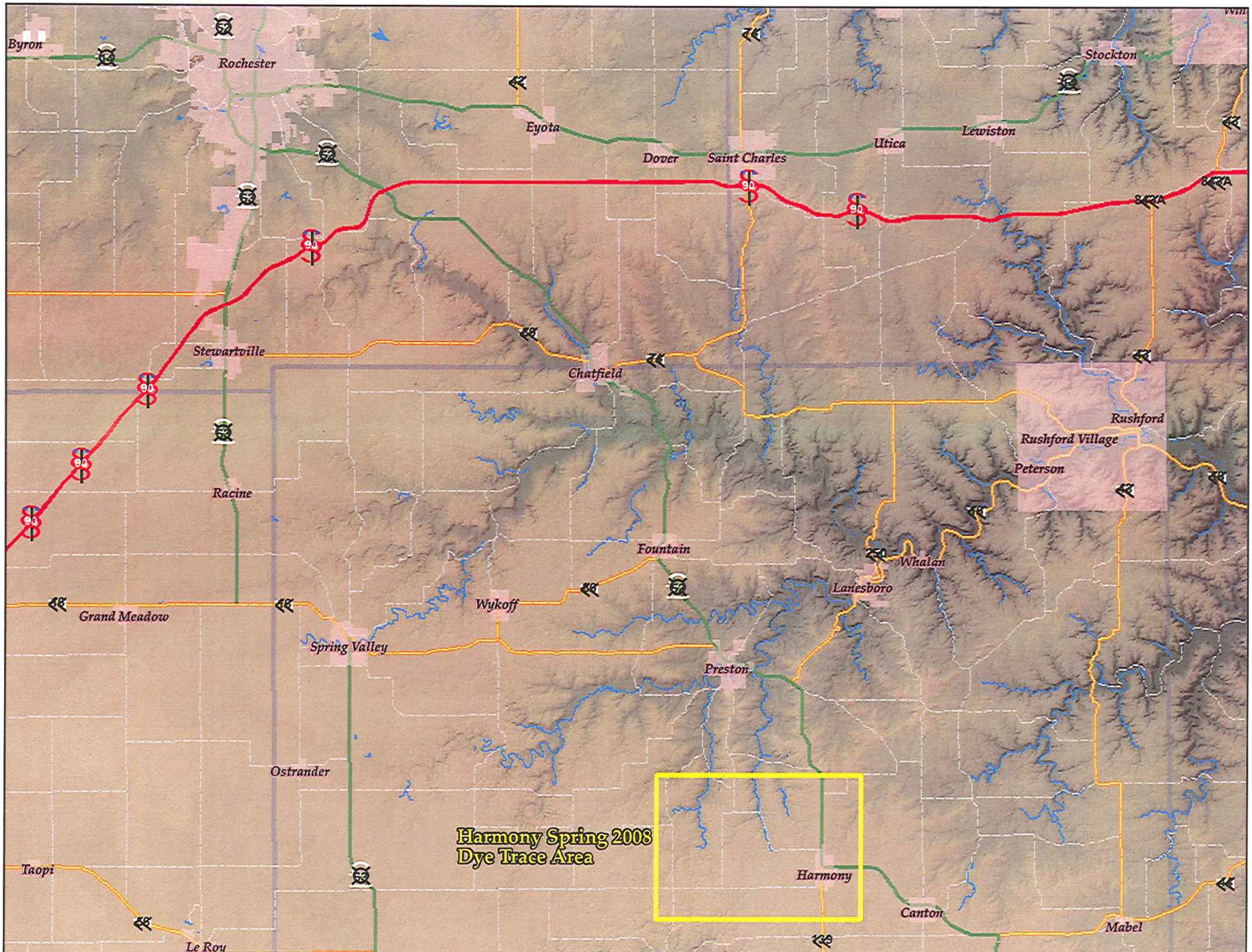
Table 1: Dye Inputs, Harmony Spring 2008 Dye Trace

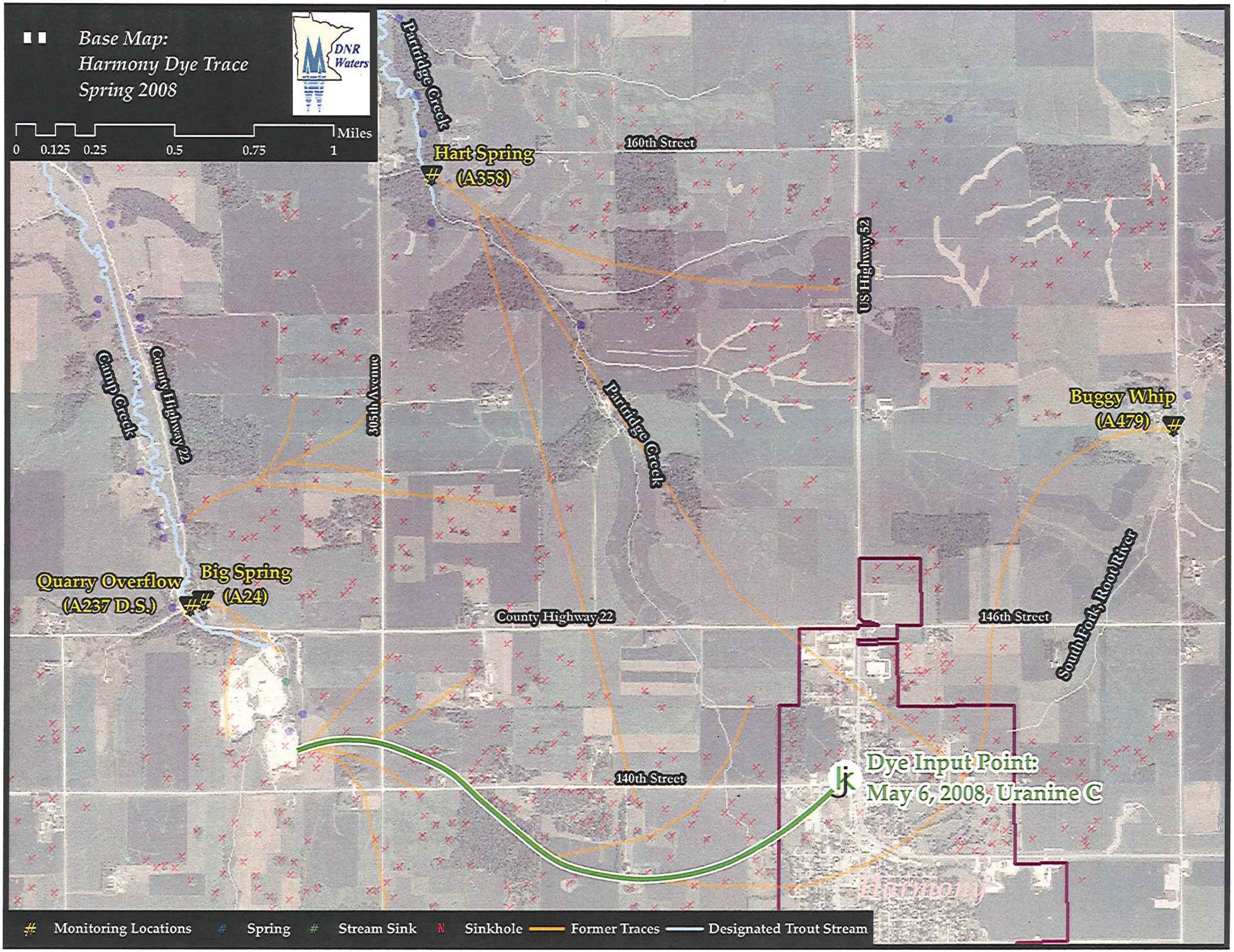
Direct water samples were collected and charcoal dye detectors were in placed at all sampling locations from the start of the trace until mid-June of 2008. The dye was detected at levels high enough for positive identification. The dye, Uranine C, was detected in the water sample from spring 23:A0237 no more than 23 hours later. This translates to a groundwater flow rate of no greater than approximately 1.8-miles per day. This is consistent with previous traces in this geologic setting (Ordovician Galena limestone).

The dye input point and its known connection from this dye trace in addition to previously completed traces are shown in Figure 2. Through this trace, we have further delineated the springsheds feeding springs 23:A0237, 23:A0358 & 23:A0479. This new trace has expanded the known boundaries of that springshed.

Appendix 1

Figures


Byron
Rochester
Stockton
Eyota
Lewiston
Dover
Saint Charles
Utica
Stewartville
Chatfield
Rushford
Rushford Village
Peterson
Racine
Fountain
Whalan
Lanesboro
Wykoff
Grand Meadow
Spring Valley
Preston
Ostrander
Harmony Spring 2008
Dye Trace Area
Taopi
Harmony
Canton
Mabel
Le Roy


Base Map:
Harmony Dye Trace
Spring 2008
DNR Waters
0 0.125 0.25 0.5 0.75 1 Miles
Partridge Creek
Hart Spring (A358)
160th Street
US Highway 52
Camp Creek
County Highway 22
305th Avenue
Partridge Creek
Buggy Whip (A479)
Quarry Overflow (A237 D.S.)
Big Spring (A24)
County Highway 22
146th Street
South Fork, Root River
140th Street
Dye Input Point:
May 6, 2008, Uranine C
Harmony
Monitoring Locations
Spring
Stream Sink
Sinkhole
Former Traces
Designated Trout Stream

Appendix 2

Dye Input

Harmony Spring 2008 Dye Trace: May 6, 2008 to June 13, 2008

Dye Input Points:

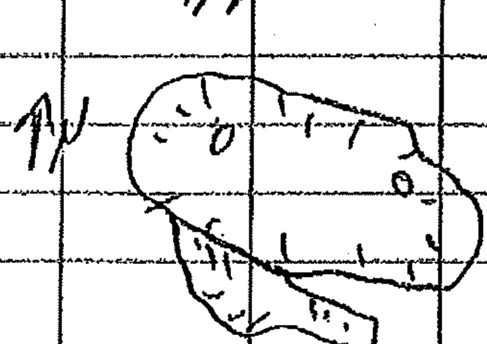
Input Point #1:

Sinkhole D6526:	**Minnesota Karst Feature Database Number - MN23:D6526**
UTM:	**579,853 E, 4,823,346 N**
Township, Range, Section:	**SE ¼ of the SE ¼ of Section 10, T101N, R10W**
Elevation:	**~1330 feet**

At 1649 CDT on 6 May 2008, approximately 881 grams of Uranine dye solution was introduced into an open swallow hole in D6526 with approximately 1,500 gallons of water.

Harmony Dye Trace
6 May 2008
Background water samples at
Buggyshop, Hart, Quarry Overflow
Big Spring, Big Spring East
Background bugs @ these sites

Kwik Trip Sinkhole 579853/4823346
Organic C Chromatech 082207-C
554.2 gm + 051807-C
Chromatech 326.62 gm
554.2
326.6
880.8 gm
Water @ 1643
Dye @ 1649
Water @ 1651
Dye into swallow hole on W-side
of sink, ponding, drainage
thru this hole & 1 on east side
~~Sink~~ approx 1500 gal water



Appendix 3

Dye Receptors

Harmony Spring 2008 Dye Trace: May 6, 2008 to June 13, 2008

Dye Receptor Locations:

Dye Receptor #1:

Big Spring — Minnesota Karst Feature Database Number - MN23:A0024
UTM: 576,647 E, 4,824,238 N
Notes: Receptor located 10 feet upstream of confluence with Quarry Overflow near steel debris

Dye Receptor #2:

Big Spring East — Minnesota Karst Feature Database Number - MN23:A0237
UTM: 577,080 E, 4,823,582 N
Notes: Receptor located in riffle just downstream of main spring discharge point

Dye Receptor #3:

Hart Spring — Minnesota Karst Feature Database Number - MN23:A0358
UTM: 577,803 E, 4,826,382 N
Notes: Receptor located on south side of road on the west bank of the stream just south of bridge

Dye Receptor #4:

Buggy Whip — Minnesota Karst Feature Database Number - MN23:A0479
UTM: 581,549 E, 4,825,118 N
Notes: Receptor located in the culvert discharge on the east side of road

Dye Receptor #5:

Quarry Overflow — Minnesota Karst Feature Database Number - MN23:X???
UTM: 576,581 E, 4,824,208 N
Notes: Receptor located 10 feet upstream from confluence with Big Spring flow

Appendix 4

Summary of Analytical Results

Harmony Spring 2008 Dye Trace: Summary of Analytical Results of Carbon Samples				
Sampling Location	**4/9/08 to 5/6/08**	**5/6/08 to 5/14/08**	**5/14/08 to 5/22/08**	**5/22/08 to 6/13/08**
Big Spring	None	Uranine	Uranine	-
Quarry Overflow	-	Uranine	None	Uranine
Buggy Whip	-	None	None	-
Hart Spring	-	-	None	-
Big Spring East	-	-	Uranine	-

Harmony Spring 2008 Dye Trace: Summary of Analytical Results of Water Samples							
Sampling Location	**5/6/08**	**5/7/08**	**5/8/08**	**5/9/08**	**5/14/08**	**5/22/08**	**6/13/08**
Big Spring	-	Uranine	Uranine	Uranine	None	None	-
Quarry Overflow	None	Uranine	Uranine	None	None	None	None
Buggy Whip	-	-	-	-	-	-	None
Hart Spring	None	None	None	None	-	-	None
Big Spring East	None	Uranine	Uranine	Uranine	None	None	None

Appendix 5

Scanning Spectrofluorophotometer Results

The following analytical results were completed by project participants associated with the Geology & Geophysics Department at the University of Minnesota. Analysis of the samples was completed by Andrew J. Luhmann[2] and Scott C. Alexander[2]. Interpretation of the analytical results was completed by Jeffrey A. Green[1], Andrew J. Peters[1], Andrew J. Luhmann[2], E. Calvin Alexander, Jr.[2] and Scott C. Alexander[1].

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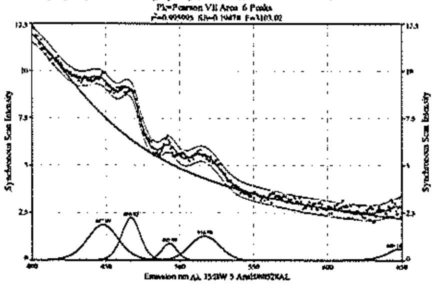
[2] Geology & Geophysics Department, University of Minnesota, 310 Pillsbury Drive. SE., Minneapolis, Minnesota, 55455; Phone (612) 624-3517; Fax (612) 625-3819; emails: luhm0031@umn.edu, alexa001@umn.edu & alexa017@umn.edu

Archived file source: Andrew Peters – D:/Documents/Final Trace Reports/Harmony Spring 2008/HarmonySpringTrace All Curves

Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Big Spring (23:A24), In:080409 0942, Out:080506 1343

Pk=Pearson VII Area 6 Peaks
r²=0.995995 SE=0.19478 F=3103.02



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Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspring080409-080506\haba0506

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99599478	0.99565868	0.19478046	3103.01978

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	62765.3411	384.683872	168.509870	0.51000000
2	Pearson VII Area	50.1717317	447.892744	24.2886757	5.81808926
3	Pearson VII Area	36.2487215	466.823172	14.7203881	6.77669196
4	Pearson VII Area	11.6360222	492.934486	12.0411500	9.15648621
5	Pearson VII Area	32.2348720	516.987707	23.6679311	167.655963
6	Pearson VII Area	15.7645590	648.139194	18.9200232	1.33884133

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	12.4973726	385.039033	168.515698	0.99160506	0.00000000	0.00000000
2	Pearson VII Area	1.86758806	447.892744	24.2886757	1.00000000	52.3731359	1.00000000
3	Pearson VII Area	2.23953514	466.823172	14.7203881	1.00000001	31.3978960	1.00000000
4	Pearson VII Area	0.89830011	492.934486	12.0411500	0.99999995	25.2523065	0.99999997
5	Pearson VII Area	1.27793612	516.987707	23.6679311	1.00000000	47.4940841	1.00000000
6	Pearson VII Area	0.61507975	648.139194	18.9200232	1.00000000	34.5133350	1.00000000

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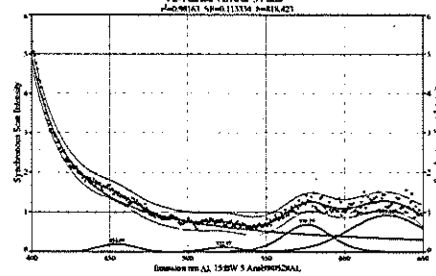
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

LCCMR, Water, Eluent Blank, Sampled:080528 1500

Pk=Pearson VII Area 5 Peaks
r²=0.98163 SE=0.113334 F=818.423



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Y Variable: Synchronous Scan Intensity
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Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.98163000	0.98036310	0.11333391	818.423496

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	4081.04534	387.581706	48.1837893	0.52416463
2	Pearson VII Area	6.11781857	454.682297	27.7944195	167.930640
3	Pearson VII Area	3.45339190	522.967895	26.8892658	17.7495339
4	Pearson VII Area	26.8020516	576.191331	35.1952604	6.21539203
5	Pearson VII Area	57.4321126	627.138692	57.1103396	10.6348345

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.57336125	387.582342	48.1837893	0.99994720	0.00000000	0.00000000
2	Pearson VII Area	0.19592827	454.682298	27.7944195	0.99999979	55.7744209	0.99999989
3	Pearson VII Area	0.11924412	522.967896	26.8892658	0.99999986	55.1174018	0.99999993
4	Pearson VII Area	0.69035867	576.191331	35.1952604	1.00000000	75.3176120	1.00000002
5	Pearson VII Area	0.92600096	627.138692	57.1103396	1.00000000	118.979997	1.00000000

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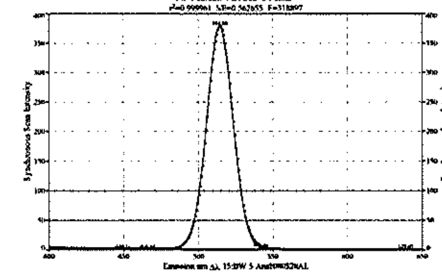
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Big Spring East (23:A237), In:080506 1615, Out:080514 12

Pk=Pearson VII Area 6 Peaks
r²=0.999961 SE=0.562655 F=318897



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Y Variable: Synchronous Scan Intensity
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Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99996067	0.99995759	0.56265486	3.189e+05

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	12339.6997	378.324590	144.794734	0.51896641
2	Pearson VII Area	12.6762208	449.306234	26.9290920	10.1790601
3	Pearson VII Area	6.11293408	465.943975	11.4796089	6.27112560
4	Pearson VII Area	8065.67362	514.677064	19.7264373	13.3705347
5	Pearson VII Area	27.1441923	541.477429	15.3208780	167.827690
6	Pearson VII Area	17.9663756	639.054466	59.1390034	9.23671016

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.27427181	378.324589	144.794734	1.00000004	0.00000000	0.00000000
2	Pearson VII Area	0.43303973	449.306234	26.9290920	1.00000000	56.2051253	1.00000000
3	Pearson VII Area	0.48203660	465.943975	11.4796089	0.99999998	24.6157605	0.99999999
4	Pearson VII Area	378.111385	514.677064	19.7264373	1.00000000	40.7562519	1.00000000
5	Pearson VII Area	1.66240677	541.477429	15.3208781	1.00000021	30.7440991	1.00000011
6	Pearson VII Area	0.27884303	639.054466	59.1394034	1.00000001	123.973791	1.00000000

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Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Big Spring (23:A24), In:080506 1343, Out:080514 1303

Pk=Pearson VII Area 4 Peaks
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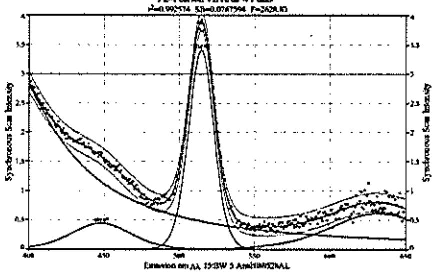

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Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99257441	0.99217030	0.07675942	2628.83334

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	693.764885	373.612388	94.5700076	0.79727098
2	Pearson VII Area	22.6199298	448.072994	46.5663879	6.30900118
3	Pearson VII Area	73.7133639	514.578957	19.7729126	7.84746502
4	Pearson VII Area	51.4783390	632.265892	74.9133699	4.54031162

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	3.76489042	374.197248	94.5880625	0.97556921	0.00000000	0.00000000
2	Pearson VII Area	0.44059768	448.072994	46.5663879	1.00000000	99.8139971	1.00000000
3	Pearson VII Area	3.40663206	514.578957	19.7729126	1.00000000	41.8002074	1.00000000
4	Pearson VII Area	0.61373546	632.265892	74.9133699	1.00000000	165.124365	1.00000000

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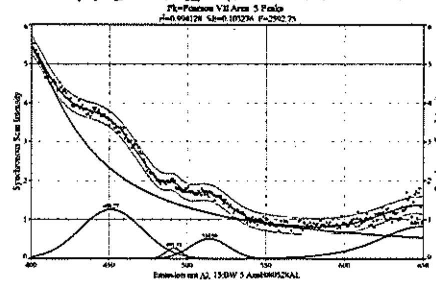
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Buggy Whip, In:080506 1230, Out:080514 1333

Pk=Pearson VII Area 5 Peaks
r²=0.994128 SE=0.103276 F=2592.75



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Y Variable: Synchronous Scan Intensity
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Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99412752	0.99372252	0.10327650	2592.74605

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	4827.69250	389.317578	92.0502680	0.53602325
2	Pearson VII Area	62.0174907	451.267566	46.4575394	167.893330
3	Pearson VII Area	3.51601341	491.234966	11.9090407	5.64394886
4	Pearson VII Area	15.6343187	514.058716	28.6905522	27.6415994
5	Pearson VII Area	60.5037400	648.910867	63.2955161	2.87011104

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.85683963	389.392202	92.0507090	0.99676252	0.00000000	0.00000000
2	Pearson VII Area	1.25257063	451.267566	46.4575394	1.00000000	93.2253233	1.00000000
3	Pearson VII Area	0.26630264	491.234965	11.9090407	1.00000022	25.7405902	1.00000011
4	Pearson VII Area	0.50812699	514.058716	28.6905522	1.00000000	58.3079787	1.00000000
5	Pearson VII Area	0.82343433	648.399991	63.3060148	1.03280929	148.216045	1.01532640

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Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Quarry Overflow, In:080506 1347, Out:080514 1303

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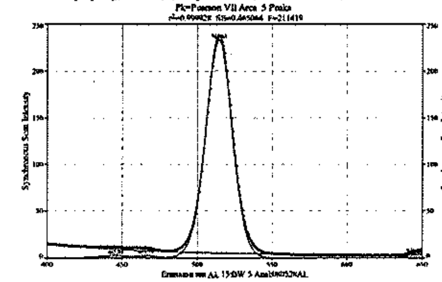

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Y Variable: Synchronous Scan Intensity
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Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99992756	0.99992257	0.46506387	2.1142e+05

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	77333.8915	371.934098	148.549577	0.51053666
2	Pearson VII Area	72.9271765	445.838615	25.3421367	6.31449628
3	Pearson VII Area	46.7686280	465.786690	15.5267099	166.021031
4	Pearson VII Area	4997.87389	514.632105	19.6731789	9.42508376
5	Pearson VII Area	76.8878090	648.370956	15.4134957	13.7602523

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	18.4214276	372.026867	148.550027	0.99750513	0.00000000	0.00000000
2	Pearson VII Area	2.61037453	445.838615	25.3421367	1.00000000	54.3146131	1.00000000
3	Pearson VII Area	2.82626906	465.786690	15.5267099	1.00000000	31.1579800	1.00000000
4	Pearson VII Area	233.290201	514.632104	19.6731789	1.00000026	41.2038616	1.00000014
5	Pearson VII Area	4.61515187	648.370956	15.4134957	1.00000000	31.8163038	1.00000000

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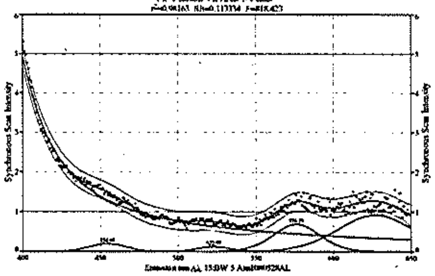
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

LCCMR, Water, Eluent Blank, Sampled:080528 1500

Pk=Pearson VII Area 5 Peaks
r²=0.98163 SE=0.113334 F=818.423



Description: LCCMR, Water, Eluent Blank, Sampled:080528 1500
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Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspring080506-080514\eb080528

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.98163000	0.98036310	0.11333391	818.423496

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	4081.04534	387.581706	48.1837893	0.52416463
2	Pearson VII Area	6.11781857	454.682297	27.7944195	167.930640
3	Pearson VII Area	3.45339190	522.967895	26.8892658	17.7495539
4	Pearson VII Area	26.8020516	576.191331	35.1952604	6.21538203
5	Pearson VII Area	57.4321126	627.138692	57.1103396	10.6348145

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.57336125	387.582342	48.1837893	0.99994720	0.00000000	0.00000000
2	Pearson VII Area	0.19592827	454.682298	27.7944195	0.99999979	55.7744200	0.99999989
3	Pearson VII Area	0.11924412	522.967896	26.8892658	0.99999986	55.1174018	0.99999993
4	Pearson VII Area	0.69035867	576.191331	35.1952604	1.00000003	75.5176120	1.00000002
5	Pearson VII Area	0.92600096	627.138692	57.1103396	1.00000000	118.979997	1.00000000

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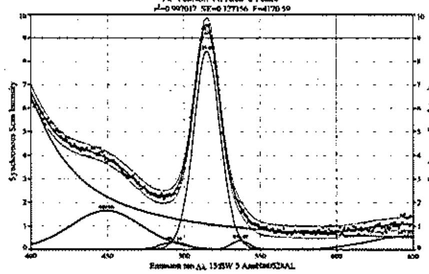
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Big Spring East (23:A237), In:080514 1243, Out:080522 14

Pk=Pearson VII Area 6 Peaks
r²=0.99701 SE=0.127156 F=4170.59



Description: Harmony Spring, Carbon, Big Spring East (23:A237), In:080514 1243, Out:080522 14
X Variable: Emission nm Δλ 15:BW 5 Anal:080528AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspring080514-080522\bsbe0522

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99701696	0.99676664	0.12715577	4170.59071

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	7762.34372	388.504619	66.8339487	0.51992455
2	Pearson VII Area	99.2137970	449.060001	55.5687038	11.8641446
3	Pearson VII Area	6.90653669	493.144700	20.5612856	167.858150
4	Pearson VII Area	185.255257	515.085537	20.1679411	9.53601672
5	Pearson VII Area	5.80452741	536.972738	14.1259200	13.3251215
6	Pearson VII Area	38.4093366	647.028398	61.6895087	15.6917439

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	7.52895762	388.532110	66.8340345	0.99835606	0.00000000	0.00000000
2	Pearson VII Area	1.64762518	449.060001	55.5687038	1.00000000	115.280405	1.00000000
3	Pearson VII Area	0.31317676	493.144700	20.5612856	1.00000000	41.2599013	1.00000000
4	Pearson VII Area	8.43755718	515.085538	20.1679411	0.99999984	42.2152927	0.99999991
5	Pearson VII Area	0.38193757	536.972738	14.1259200	1.00000002	29.1083801	1.00000001
6	Pearson VII Area	0.57716813	647.028398	61.6895087	1.00000000	126.850830	1.00000000

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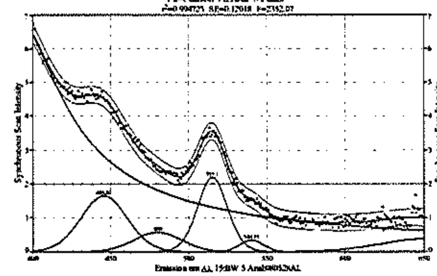
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Big Spring (23:A24), In:080514 1303, Out:080522 1430

Pk=Pearson VII Area 6 Peaks
r²=0.99472 SE=0.12018 F=2352.07



Description: Harmony Spring, Carbon, Big Spring (23:A24), In:080514 1303, Out:080522 1430
X Variable: Emission nm Δλ 15:BW 5 Anal:080528AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspring080514-080522\bsbs0522

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99472278	0.99427994	0.12018045	2352.07499

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	9983.29074	390.075207	86.0817405	0.51825567
2	Pearson VII Area	62.0578311	445.668443	34.9127205	14.3645123
3	Pearson VII Area	22.1591651	479.997227	36.1026082	49.4092937
4	Pearson VII Area	53.2417195	515.103872	22.3419558	8.87439289
5	Pearson VII Area	6.54040426	540.151258	17.8845435	167.502854
6	Pearson VII Area	27.4108508	649.922614	64.8321851	5.49456270

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.92348185	390.252294	86.0645160	0.99180524	0.00000000	0.00000000
2	Pearson VII Area	1.64563330	445.668443	34.9127205	1.00000001	71.9718488	1.00000000
3	Pearson VII Area	0.57423409	479.997227	36.1026082	0.99999999	72.8804775	0.99999999
4	Pearson VII Area	2.18505748	515.103872	22.3419558	1.00000004	46.9260745	1.00000005
5	Pearson VII Area	0.34313873	540.151258	17.8845435	1.00000000	35.8887282	1.00000000
6	Pearson VII Area	0.38081130	648.566514	64.8965123	1.08723100	140.465660	1.04343114

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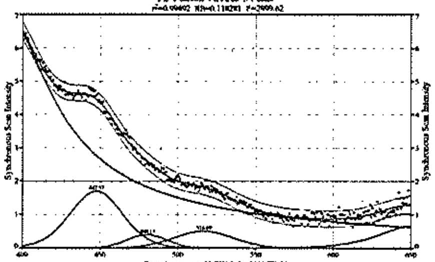
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Buggy Whip, In:080514 1333, Out:080522 1447

Pk=Pearson VII Area 5 Peaks
r²=0.99492 SE=0.118281 F=2999.62



Description: Harmony Spring, Carbon, Buggy Whip, In:080514 1333, Out:080522 1447
X Variable: Emission nm Δλ 15:BW 5 Anal:080528AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspring080514-080522\hsbw0522

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99492002	0.99456968	0.11828086	2999.61626

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	12062.0406	390.939202	86.3679681	0.51486336
2	Pearson VII Area	73.0830940	447.522535	39.4102601	8.02960706
3	Pearson VII Area	12.7620765	480.134530	29.8824751	167.660920
4	Pearson VII Area	24.3369782	516.686166	45.0471985	58.5833988
5	Pearson VII Area	40.2203770	651.074730	51.4835807	2.41412533

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.83986112	390.939202	86.3679681	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	1.69570318	447.522534	39.4102601	1.00000001	83.2077651	1.00000000
3	Pearson VII Area	0.40072671	480.134527	29.8824751	1.00000032	59.9647129	1.00000017
4	Pearson VII Area	0.50577417	516.686164	45.0471985	1.00000019	90.8161481	1.00000010
5	Pearson VII Area	0.65786051	649.713303	51.5794415	1.11146312	124.573281	1.04944949

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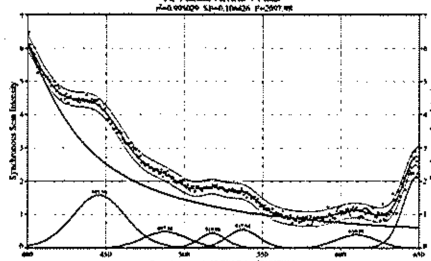
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Hart Spring (23:A358), In:080514 1318, Out:080522 1437

Pk=Pearson VII Area 7 Peaks
r²=0.99503 SE=0.10643 F=2097.98



Description: Harmony Spring, Carbon, Hart Spring (23:A358), In:080514 1318, Out:080522 1437
X Variable: Emission nm Δλ 15:BW 5 Anal:080528AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspring080514-080522\hsha0522

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99502886	0.99453527	0.10642605	2097.98444

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	8127.67291	386.945435	86.9022014	0.52271539
2	Pearson VII Area	67.7590910	445.563218	39.5298580	9.50920355
3	Pearson VII Area	17.2206016	487.840879	33.3050039	32.5416306
4	Pearson VII Area	9.03257204	518.056549	19.6215926	3.87754768
5	Pearson VII Area	13.8731484	537.543013	23.5900863	9.22073855
6	Pearson VII Area	12.7717287	610.013610	30.5759976	167.730598
7	Pearson VII Area	47.8635270	648.660007	20.6055932	7.24817840

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.85323661	387.098624	86.9042354	0.99297384	0.00000000	0.00000000
2	Pearson VII Area	1.57442125	445.563218	39.5298580	1.00000001	82.7540747	1.00000001
3	Pearson VII Area	0.40264837	487.840879	33.3050039	0.99999996	67.5303965	0.99999998
4	Pearson VII Area	0.44310314	518.056548	19.6215926	1.00000022	44.0102034	1.00000011
5	Pearson VII Area	0.53975706	537.543014	23.5900863	0.99999984	49.4558967	0.99999992
6	Pearson VII Area	0.39193385	610.013611	30.5759976	0.99999986	61.3563301	0.99999992
7	Pearson VII Area	2.11633276	648.399987	20.6131498	1.05298911	43.7670666	1.02711130

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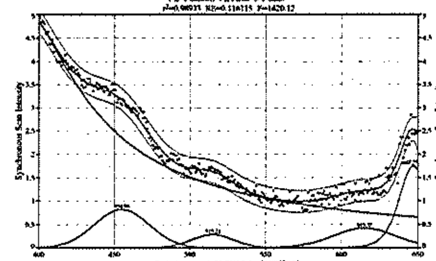
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Carbon, Quarry Overflow, In:080514 1303, Out:080522 1429

Pk=Pearson VII Area 5 Peaks
r²=0.98933 SE=0.116115 F=1420.12



Description: Harmony Spring, Carbon, Quarry Overflow, In:080514 1303, Out:080522 1429
X Variable: Emission nm Δλ 15:BW 5 Anal:080528AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspring080514-080522\hsqo0522

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.98933024	0.98859440	0.11611508	1420.12327

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	9079.14398	385.434889	121.490140	0.52167563
2	Pearson VII Area	37.1426409	454.958559	42.5135897	146.614215
3	Pearson VII Area	9.98405449	515.214003	33.3104205	73.2800332
4	Pearson VII Area	22.0731718	615.320341	47.7085114	7.80406629
5	Pearson VII Area	43.0923192	647.269252	21.6304943	3.43547101

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.24191502	385.663138	121.493435	0.99244805	0.00000000	0.00000000
2	Pearson VII Area	0.81962077	454.958559	42.5135897	1.00000000	85.3418447	1.00000000
3	Pearson VII Area	0.28079529	515.214003	33.3104205	1.00000000	67.9503353	1.00000000
4	Pearson VII Area	0.42271532	615.320341	47.7085114	1.00000000	100.887388	1.00000000
5	Pearson VII Area	1.74547763	647.269252	21.6304943	0.99999995	49.2782538	0.99999998

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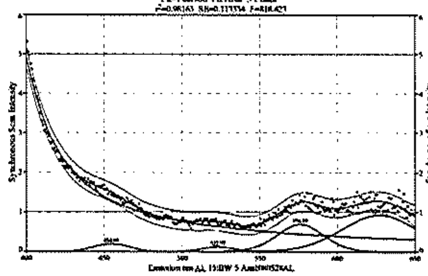
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

LCCMR, Water, Eluent Blank, Sampled:080528 1500

Pk=Pearson VII Area 5 Peaks



Description: LCCMR, Water, Eluent Blank, Sampled:080528 1500
X Variable: Emission nm Δλ 15:BW 5 Anal:080528AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspring080514-080522\ch080528

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.98163000	0.98036310	0.11333391	818.423496

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	4081.04534	387.581706	48.1857893	0.52416463
2	Pearson VII Area	6.11781857	454.682297	27.7944195	167.930640
3	Pearson VII Area	3.45339190	522.967895	26.8892658	17.7495539
4	Pearson VII Area	26.8020516	576.191331	35.1952604	6.21538203
5	Pearson VII Area	57.4321126	627.138692	57.1103396	10.6348145

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.57336125	387.582342	48.1857893	0.99994720	0.00000000	0.00000000
2	Pearson VII Area	0.19992827	454.682298	27.7944195	0.99999979	55.7744200	0.99999989
3	Pearson VII Area	0.11954412	522.967896	26.8892658	0.99999986	55.1174018	0.99999995
4	Pearson VII Area	0.69035867	576.191331	35.1952604	1.00000003	75.5176120	1.00000002
5	Pearson VII Area	0.92600096	627.138692	57.1103396	1.00000000	118.979097	1.00000000

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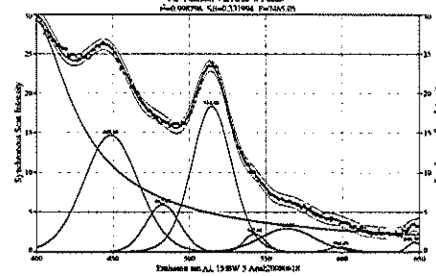
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony creek, Carbon, Quarry Overflow, In:080522 1426, Out:080613 1324

Pk=Pearson VII Area 8 Peaks



Description: Harmony creek, Carbon, Quarry Overflow, In:080522 1426, Out:080613 1324
X Variable: Emission nm Δλ 15:BW 5 Anal:20080618
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspring080522-080613\hcqo0613

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99879583	0.99865722	0.33199446	7465.04775

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	20184.4004	398.037960	71.4527165	0.53341082
2	Pearson VII Area	667.723573	448.626423	42.0053513	12.6122548
3	Pearson VII Area	165.656311	482.472093	26.1621359	49.2783292
4	Pearson VII Area	620.121869	514.482322	30.7986470	7.31811471
5	Pearson VII Area	40.1634503	542.613844	16.6437495	167.917744
6	Pearson VII Area	133.741863	564.030451	41.7974370	11.7417237
7	Pearson VII Area	12.5150379	598.486302	18.4484918	34.1501214
8	Pearson VII Area	14.3115554	646.961726	10.8923606	59.6615277

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	29.4647384	398.037959	71.4527165	1.00000006	0.00000000	0.00000000
2	Pearson VII Area	14.6855307	448.626424	42.0053513	0.99999992	86.9544735	0.99999996
3	Pearson VII Area	5.92040597	482.472094	26.1621359	0.99999977	52.8772494	0.99999987
4	Pearson VII Area	18.3426173	514.482322	30.7986470	0.99999999	65.4850294	1.00000000
5	Pearson VII Area	2.26424886	542.613844	16.6437495	0.99999999	33.3986343	1.00000000
6	Pearson VII Area	2.95222540	564.030451	41.7974370	1.00000000	86.7441031	1.00000000
7	Pearson VII Area	0.63337529	598.486302	18.4484918	1.00000001	37.3839858	1.00000001
8	Pearson VII Area	1.23012758	646.961726	10.8923606	1.00000000	21.9564012	1.00000000

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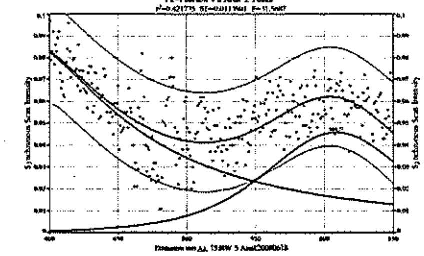
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Blank, Water, Eluent Blank, Sampled:080618 1500

Pk=Pearson VII Area 2 Peaks



Description: Blank, Water, Eluent Blank, Sampled:080618 1500
X Variable: Emission nm Δλ 15:BW 5 Anal:20080618
Y Variable: Synchronous Scan Intensity
File Source: e:\trace data\elN0618.p

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.42173487	0.40641659	0.01139012	31.5687287

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	38.1065559	372.630098	193.362892	0.73670446
2	Pearson VII Area	6.31116683	608.767242	120.981930	2.55944744

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	0.08797445	386.254296	471.740636	0.00000000	0.00000000	0.00000000
2	Pearson VII Area	0.04576765	608.767242	120.981930	1.00000000	289.190458	1.00000000

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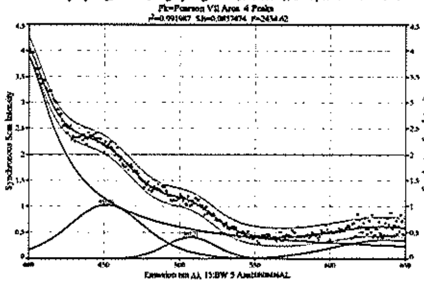
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring East (23:A237), Sampled:080506 1614

Pk=Pearson VII Area 4 Peaks



Description: Harmony Spring, Water, Big Spring East (23:A237), Sampled:080506 1614
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\habc0506

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99198681	0.99155071	0.08574743	2434.61910

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	3181.21469	395.705633	57.3866284	0.52252961
2	Pearson VII Area	67.9924880	451.559021	59.1329320	4.64937745
3	Pearson VII Area	16.9448303	507.208361	39.0188659	41.0100127
4	Pearson VII Area	31.2925080	637.968311	81.7710652	167.919889

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.03115348	395.705635	57.3866284	0.99999986	0.00000000	0.00000000
2	Pearson VII Area	1.02032176	451.559021	59.1329320	1.00000001	130.032933	1.00000001
3	Pearson VII Area	0.40594224	507.208361	39.0188659	1.00000000	78.9048443	1.00000000
4	Pearson VII Area	0.35907489	637.968304	81.7710652	1.00000031	164.098135	1.00000017

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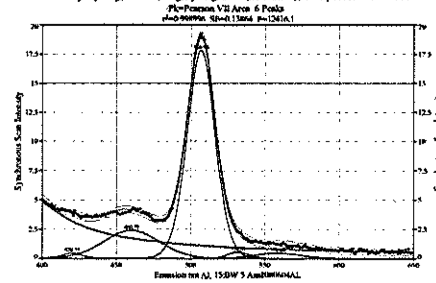
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring East (23:A237), Sampled:080507 1530

Pk=Pearson VII Area 6 Peaks



Description: Harmony Spring, Water, Big Spring East (23:A237), Sampled:080507 1530
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\habc0507

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99899601	0.99891175	0.13864029	12416.1350

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	8900.01021	376.240874	64.9422591	0.51816655
2	Pearson VII Area	9.64947199	420.327051	16.4360933	1.59351743
3	Pearson VII Area	113.299185	460.391428	43.3616859	11.0714344
4	Pearson VII Area	423.815486	506.956121	21.7776316	8.64832677
5	Pearson VII Area	10.4739591	532.608068	18.0063392	167.919490
6	Pearson VII Area	19.3621942	558.837797	37.5887742	7.30670455

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	8.14384715	376.240874	64.9422591	0.99999999	0.00000000	0.00000000
2	Pearson VII Area	0.45765586	420.327051	16.4360933	1.00000006	44.3715159	1.00000003
3	Pearson VII Area	2.40798078	460.391428	43.3616859	1.00000000	90.1918633	1.00000000
4	Pearson VII Area	17.8200095	506.956122	21.7776316	0.99999983	45.8549519	0.99999991
5	Pearson VII Area	0.54579527	532.608068	18.0063392	1.00000000	36.1329111	1.00000000
6	Pearson VII Area	0.46966123	558.837797	37.5887742	1.00000001	79.7950454	1.00000001

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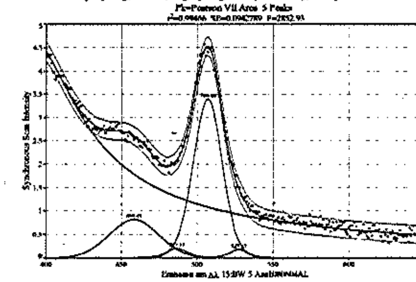
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring East (23:A237), Sampled:080508 1610

Pk=Pearson VII Area 5 Peaks



Description: Harmony Spring, Water, Big Spring East (23:A237), Sampled:080508 1610
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\habc0508

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99466022	0.99429196	0.09427893	2852.92853

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	8447.26432	389.627798	98.5792680	0.51663737
2	Pearson VII Area	33.2770341	458.425734	38.4515075	87.7918072
3	Pearson VII Area	4.12888535	487.119100	16.4716421	1.70766543
4	Pearson VII Area	82.4578634	506.883789	22.2445217	8.98670321
5	Pearson VII Area	3.21787670	527.665767	14.6398105	1.77487671

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.68520200	389.965596	98.5881235	0.98638784	0.00000000	0.00000000
2	Pearson VII Area	0.81113796	458.425732	38.4515075	1.00000021	77.3350408	1.00000012
3	Pearson VII Area	0.19881108	487.110102	16.4716421	0.99999942	43.4872650	0.99999976
4	Pearson VII Area	3.40001817	506.883789	22.2445217	1.00000000	46.6926231	1.00000000
5	Pearson VII Area	0.17587130	527.665767	14.6398105	1.00000011	38.2030425	1.00000005

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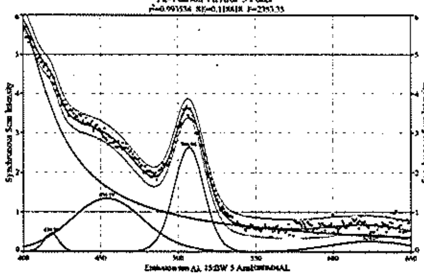
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring East (23:A237), Sampled:080509 1605

Pk=Pearson VII Area 5 Peaks
r^2=0.993534 SE=0.118818 F=2353.35



Description: Harmony Spring, Water, Big Spring East (23:A237), Sampled:080509 1605
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\habe0509

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99353401	0.99308808	0.11881786	2353.35445

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	8863.87563	397.165600	57.7296065	0.51140095
2	Pearson VII Area	5.73812671	418.061927	11.4678899	10.0000000
3	Pearson VII Area	80.4255840	454.185780	55.0458716	10.0000000
4	Pearson VII Area	65.0797562	506.938073	22.7385763	10.0000000
5	Pearson VII Area	17.7771168	624.087824	62.8136365	167.905252

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.84775581	397.165628	57.7296065	0.99999806	0.00000000	0.00000000
2	Pearson VII Area	0.46012270	418.061927	11.4678899	1.00000000	23.9535755	1.00000000
3	Pearson VII Area	1.34335828	454.185780	55.0458716	1.00000000	114.977163	1.00000000
4	Pearson VII Area	2.63190184	506.938073	22.7385763	1.00000000	47.4952418	1.00000000
5	Pearson VII Area	0.26535328	624.087824	62.8136365	1.00000000	126.046721	1.00000000

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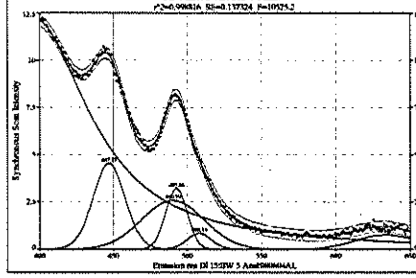
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring East (23:A237), Sampled:080514 1243

Pk=Pearson VII Area 6 Peaks
r^2=0.998816 SE=0.137324 F=10525.2



Description: Harmony Spring, Water, Big Spring East (23:A237), Sampled:080514 1243
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\habew514

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99881584	0.99871647	0.13732363	10525.1861

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1761.35346	395.772290	91.7792399	1.00188611
2	Pearson VII Area	123.755803	447.147626	25.2711030	12.5104986
3	Pearson VII Area	136.381516	490.287596	49.5042958	48.8028712
4	Pearson VII Area	58.3343770	492.677896	17.1288655	79.0874412
5	Pearson VII Area	17.7381812	508.126440	19.0945769	7.03880783
6	Pearson VII Area	39.2018040	633.572370	47.8392557	167.917176

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	12.2284764	396.555683	91.8059481	0.96644020	0.00000000	0.00000000
2	Pearson VII Area	4.52352559	447.147625	25.2711030	1.00000016	52.3277870	1.00000009
3	Pearson VII Area	2.57729563	490.287594	49.5042958	1.00000000	99.9450677	1.00000000
4	Pearson VII Area	3.19115653	492.677894	17.1288655	1.00000024	34.4682429	1.00000013
5	Pearson VII Area	0.84596401	508.126440	19.0945769	1.00000001	40.6284967	1.00000000
6	Pearson VII Area	0.76889308	633.572370	47.8392557	1.00000000	95.9979491	1.00000000

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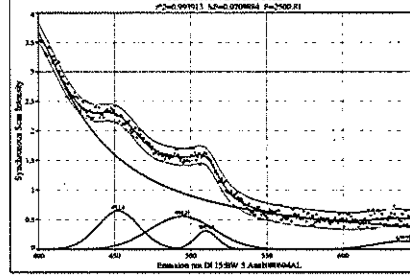
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring East (23:A237), Sampled:080522 1420

Pk=Pearson VII Area 5 Peaks
r^2=0.993913 SE=0.070984 F=2500.81



Description: Harmony Spring, Water, Big Spring East (23:A237), Sampled:080522 1420
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\habew522

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99391294	0.99349314	0.07098838	2500.80583

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	3759.66976	390.184370	94.2760600	0.53093308
2	Pearson VII Area	22.4039563	452.404145	32.1268249	16.0897346
3	Pearson VII Area	29.2803474	494.210855	49.4837824	167.828064
4	Pearson VII Area	5.83123412	509.944298	17.1749510	8.15634439
5	Pearson VII Area	6.42696006	639.973881	42.9793528	15.4223510

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	3.88220351	390.184370	94.2760600	0.99999999	0.00000000	0.00000000
2	Pearson VII Area	0.64660917	452.404145	32.1268249	1.00000001	66.0171306	1.00000000
3	Pearson VII Area	0.55521011	494.210855	49.4837824	1.00000000	99.2981144	1.00000000
4	Pearson VII Area	0.31060075	509.944298	17.1749510	1.00000001	36.2309809	1.00000001
5	Pearson VII Area	0.13858545	639.973882	42.9793528	0.99999998	88.4196980	0.99999999

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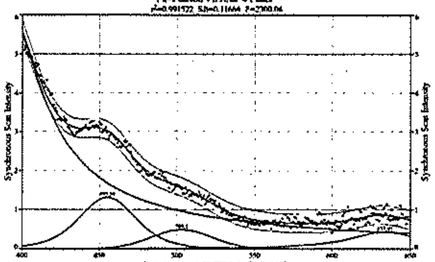
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring (23:A24), Sampled:080506 1600

Pk=Pearson VII Area 4 Peaks
r^2=0.991522 SE=0.11664 F=2300.04



Description: Harmony Spring, Water, Big Spring (23:A24), Sampled:080506 1600
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\haba0506

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99152192	0.99106052	0.11664011	2300.03995

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	4076.38587	391.282153	65.1218690	0.52653109
2	Pearson VII Area	64.8433011	455.138094	43.1807614	3.24267643
3	Pearson VII Area	23.9978682	503.103749	45.9974897	167.824961
4	Pearson VII Area	36.1400229	633.911494	55.6187520	1.08631132

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.07533886	391.282153	65.1218689	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	1.30921831	455.138094	43.1807614	0.99999999	99.1850325	1.00000000
3	Pearson VII Area	0.48953366	503.103749	45.9974897	1.00000000	92.3022450	1.00000000
4	Pearson VII Area	0.43577891	633.911496	55.6187520	0.99999984	176.912461	0.99999994

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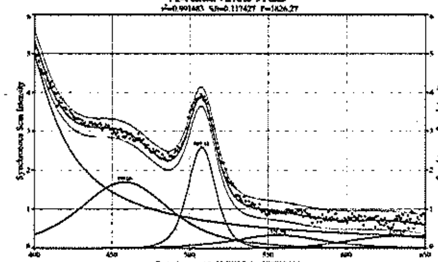
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring (23:A24), Sampled:080507 1540

Pk=Pearson VII Area 5 Peaks
r^2=0.991663 SE=0.117427 F=1826.27



Description: Harmony Spring, Water, Big Spring (23:A24), Sampled:080507 1540
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\haba0507

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99166336	0.99116980	0.11742651	1826.26728

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	3725.11652	391.249630	54.8355026	0.52612633
2	Pearson VII Area	140.062009	458.060851	68.3337623	2.08761891
3	Pearson VII Area	61.9673195	507.511468	20.6422018	2.86352663
4	Pearson VII Area	27.8104022	556.536697	65.6842596	1.81697076
5	Pearson VII Area	24.1647668	632.136015	73.0438900	167.901429

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.66629898	391.390083	54.8383444	0.98915779	0.00000000	0.00000000
2	Pearson VII Area	1.69224870	458.060851	68.3337623	1.00000000	170.718489	1.00000000
3	Pearson VII Area	2.58588957	507.511468	20.6422018	1.00000000	48.3533519	1.00000000
4	Pearson VII Area	0.34049080	556.536697	65.6842596	1.00000000	170.240032	1.00000000
5	Pearson VII Area	0.31041520	632.136015	73.0438900	1.00000000	146.575351	1.00000000

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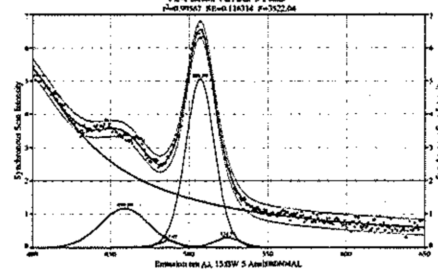
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring (23:A24), Sampled:080508 1710

Pk=Pearson VII Area 5 Peaks
r^2=0.99567 SE=0.116314 F=3522.04



Description: Harmony Spring, Water, Big Spring (23:A24), Sampled:080508 1710
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\haba0508

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99567027	0.99537167	0.11631440	3522.03931

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	4345.58104	389.295858	107.509443	0.54487840
2	Pearson VII Area	45.6180726	459.077935	36.3688163	19.6599939
3	Pearson VII Area	6.81161170	487.467463	14.4710699	0.74848974
4	Pearson VII Area	118.727792	506.888103	21.4344314	7.88124551
5	Pearson VII Area	7.03636680	524.746630	20.2813758	2.72413333

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.69211381	389.392202	107.510057	0.99642188	0.00000000	0.00000000
2	Pearson VII Area	1.16597094	459.077935	36.3688163	1.00000000	74.3746933	1.00000000
3	Pearson VII Area	0.22060195	487.467463	14.4710699	1.00000000	59.3873632	1.00000000
4	Pearson VII Area	5.06227137	506.888102	21.4344314	1.00000004	45.3017697	1.00000002
5	Pearson VII Area	0.29722363	524.746629	20.2813758	1.00000011	47.9223643	1.00000005

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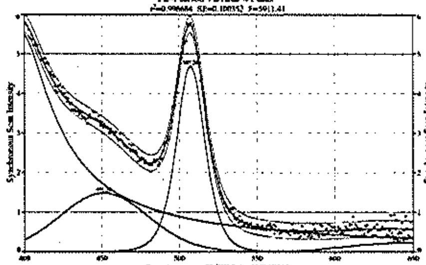
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring (23:A24), Sampled:080509 1612

Pk=Pearson VII Area 4 Peaks
r²=0.996684 SE=0.100352 F=5911.41



Description: Harmony Spring, Water, Big Spring (23:A24), Sampled:080509 1612
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\haba0509

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99664433	0.99650368	0.10035359	5911.40757

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	2848.15482	396.413527	61.9736600	0.53982373
2	Pearson VII Area	106.772786	451.279196	67.2369042	23.7874933
3	Pearson VII Area	116.489054	507.255122	21.5772303	3.07635926
4	Pearson VII Area	18.9405603	642.093289	76.5422126	167.454737

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.61097758	396.413527	61.9736600	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	1.47893175	451.279196	67.2369042	1.00000001	136.985584	1.00000001
3	Pearson VII Area	4.68432345	507.255122	21.5772303	1.00000000	49.9536807	1.00000000
4	Pearson VII Area	0.23218527	642.093289	76.5422126	1.00000000	153.596575	1.00000000

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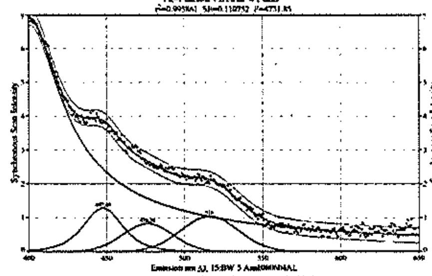
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring (23:A24), Sampled:080514 1303

Pk=Pearson VII Area 4 Peaks
r²=0.995861 SE=0.110752 F=4731.85



Description: Harmony Spring, Water, Big Spring (23:A24), Sampled:080514 1303
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\habsw514

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99586097	0.99563571	0.11075239	4731.84576

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	10733.5084	400.148517	62.2412407	0.51200520
2	Pearson VII Area	44.9504534	447.484413	29.6614460	2.37855753
3	Pearson VII Area	33.3269932	476.243321	37.9401062	167.920113
4	Pearson VII Area	47.9453871	515.999784	43.0296738	48.7757488

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	6.91579810	400.148517	62.2412408	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	1.27641367	447.484413	29.6614460	0.99999997	71.9514645	0.99999998
3	Pearson VII Area	0.82520528	476.243321	37.9401062	1.00000000	76.1335470	1.00000000
4	Pearson VII Area	1.04238790	515.999784	43.0296738	1.00000000	86.8737585	1.00000000

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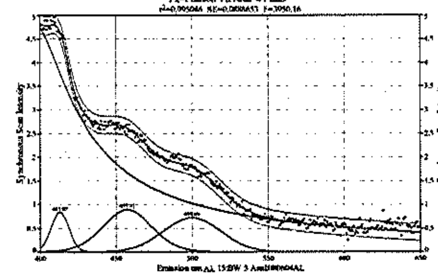
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring (23:A24), Sampled:080522 1426

Pk=Pearson VII Area 4 Peaks
r²=0.995046 SE=0.088653 F=3950.16



Description: Harmony Spring, Water, Big Spring (23:A24), Sampled:080522 1426
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\habsw522

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99504597	0.99477636	0.08886535	3950.16221

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	5771.83336	393.565565	80.5900909	0.52122877
2	Pearson VII Area	12.3038035	413.018971	13.7900980	167.876756
3	Pearson VII Area	36.2832579	457.412863	37.3377922	8.36921953
4	Pearson VII Area	34.1960551	499.892323	44.3427341	46.4009779

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.92613722	393.979358	80.6061532	0.97967465	0.00000000	0.00000000
2	Pearson VII Area	0.83717494	413.018972	13.7900980	0.99999953	27.6722933	0.99999974
3	Pearson VII Area	0.88962916	457.412863	37.3377922	1.00000000	78.6570559	1.00000000
4	Pearson VII Area	0.72128969	499.892323	44.3427341	1.00000000	89.5641845	1.00000000

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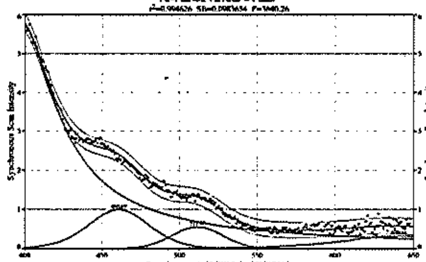
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Hart Spring (23:A358), Sampled:080506 1550

Pk=Pearson VII Area 4 Peaks
r²=0.996626 SE=0.090365 F=3640.26



Description: Harmony Spring, Water, Hart Spring (23:A358), Sampled:080506 1550
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\haha0506

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99462649	0.99433405	0.09036536	3640.26024

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	1029.09615	396.326712	62.9065138	0.65723717
2	Pearson VII Area	50.6689280	460.692129	46.3525747	5.96834448
3	Pearson VII Area	22.7318787	511.416384	38.2601006	167.918213
4	Pearson VII Area	33.9965944	640.984386	86.1274700	2.07355657

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	5.84744973	396.846330	62.9311538	0.96750884	0.00000000	0.00000000
2	Pearson VII Area	0.98935996	460.692129	46.3525747	1.00000000	99.7549067	1.00000000
3	Pearson VII Area	0.55748545	511.416385	38.2601006	0.99999995	76.7756748	0.99999997
4	Pearson VII Area	0.32551732	640.984386	86.1274700	1.00000000	215.528424	1.00000000

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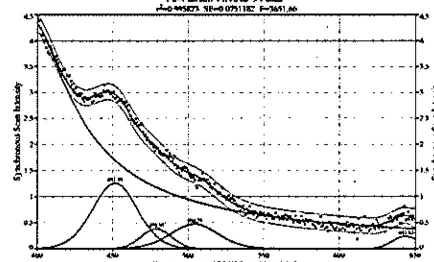
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Hart Spring 23:A358, Sampled:080507 1515

Pk=Pearson VII Area 5 Peaks
r²=0.995823 SE=0.0751182 F=3651.66



Description: Harmony Spring, Water, Hart Spring 23:A358, Sampled:080507 1515
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: e:\harmonyspringwater080506-080522\haha0507.p

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99582332	0.99553527	0.07511822	3651.66196

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	4903.69137	394.306319	81.8816294	0.52271935
2	Pearson VII Area	47.6945919	451.577406	34.8021856	8.52333207
3	Pearson VII Area	9.73666301	478.927408	23.8887445	28.3034654
4	Pearson VII Area	19.5129486	504.297237	37.2800270	5.46445922
5	Pearson VII Area	5.19402958	643.825136	20.2745521	167.614460

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.46070295	394.306319	81.8816294	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	1.25525150	451.577406	34.8021856	1.00000001	73.2459275	1.00000001
3	Pearson VII Area	0.38090585	478.927410	23.8887445	0.99999977	48.5318165	0.99999988
4	Pearson VII Area	0.47193020	504.297237	37.2800270	1.00000000	80.7902026	1.00000000
5	Pearson VII Area	0.24037899	643.825136	20.2745521	1.00000000	40.6846662	1.00000000

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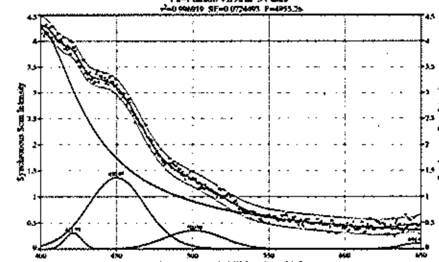
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Hart Spring (23:A358), Sampled:080508 1700

Pk=Pearson VII Area 5 Peaks
r²=0.996919 SE=0.0724493 F=4955.26



Description: Harmony Spring, Water, Hart Spring (23:A358), Sampled:080508 1700
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: e:\harmonyspringwater080506-080522\haha0508.p

Fitted Parameters

r² Coef Det	DF Adj r²	Fit Std Err	F-value
0.99691871	0.99670621	0.07244928	4955.26180

Peak	Type	a0	a1	a2	a3
1	Pearson VII Area	4224.48448	398.953698	79.3979925	0.53496574
2	Pearson VII Area	4.47509285	421.545701	13.5376069	33.0401045
3	Pearson VII Area	66.3130512	450.067478	44.5706037	8.74187575
4	Pearson VII Area	17.1456788	500.982076	45.2863393	167.907475
5	Pearson VII Area	3.38751222	649.388239	29.1221851	49.8372534

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.25539243	398.953699	79.3979925	0.99999994	0.00000000	0.00000000
2	Pearson VII Area	0.30862437	421.545701	13.5376069	1.00000000	27.4439604	1.00000000
3	Pearson VII Area	1.36367867	450.067476	44.5706037	1.00000016	93.6842662	1.00000008
4	Pearson VII Area	0.35524809	500.982076	45.2863393	1.00000000	90.8750827	1.00000000
5	Pearson VII Area	0.10844018	648.399969	29.1901170	1.14525811	58.8065223	1.07664906

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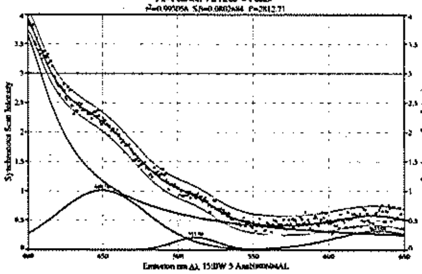
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Hart Spring (23:A358), Sampled:080509 1620

Pk=Pearson VII Area 4 Peaks
r²=0.99305648 SE=0.08026838 F=2812.71



Description: Harmony Spring, Water, Hart Spring (23:A358), Sampled:080509 1620
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\hahs0509

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99305648	0.99267860	0.08026838	2812.70959

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	2597.52279	393.565382	63.1617867	0.52978320
2	Pearson VII Area	78.3143809	449.743885	71.6296988	11.0484673
3	Pearson VII Area	7.86071118	511.982942	35.5603234	167.694925
4	Pearson VII Area	24.5948231	633.083388	70.3383385	5.39093255

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	3.86787450	393.565388	63.1617867	0.99999961	0.00000000	0.00000000
2	Pearson VII Area	1.00754060	449.743884	71.6296988	1.00000004	149.000832	1.00000002
3	Pearson VII Area	0.20741480	511.982941	35.5603234	1.00000005	71.3583291	1.00000003
4	Pearson VII Area	0.31507393	633.083388	70.3383385	1.00000000	152.603573	1.00000000

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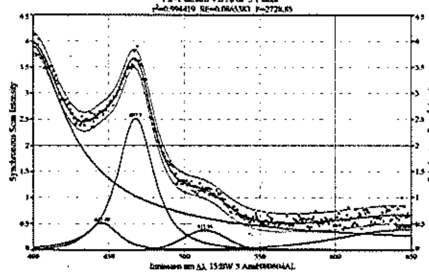
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Quarry Overflow, Sampled:080506 1600

Pk=Pearson VII Area 5 Peaks
r²=0.99441877 SE=0.0865383 F=2728.85



Description: Harmony Spring, Water, Quarry Overflow, Sampled:080506 1600
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: c:\harmonyspringwater080506-080522\haqo0506.p

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99441877	0.99403386	0.08653831	2728.84565

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	2758.79448	398.975962	66.6226462	0.52991917
2	Pearson VII Area	16.2679987	445.477809	25.0941024	1.69195467
3	Pearson VII Area	93.7615724	467.703228	27.9084742	1.39468131
4	Pearson VII Area	13.5902944	513.548858	34.2752046	167.833175
5	Pearson VII Area	45.3048234	645.838078	101.431322	2.99465361

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	3.91080963	398.975962	66.6226462	1.00000000	0.00000000	0.00000000
2	Pearson VII Area	0.51304270	445.477809	25.0941024	1.00000000	66.4425813	1.00000000
3	Pearson VII Area	2.51610112	467.703228	27.9084742	1.00000000	79.0921427	1.00000000
4	Pearson VII Area	0.37204276	513.548858	34.2752046	0.99999993	68.7793610	0.99999996
5	Pearson VII Area	0.38651400	645.838077	101.431322	1.00000000	235.851032	1.00000000

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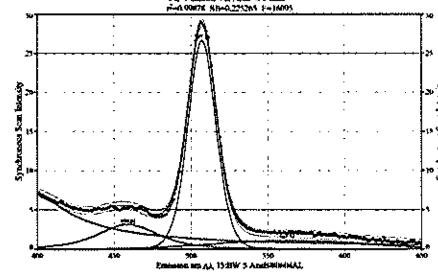
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Quarry Overflow, Sampled:080507 1540

Pk=Pearson VII Area 4 Peaks
r²=0.99878 SE=0.225265 F=16095



Description: Harmony Spring, Water, Quarry Overflow, Sampled:080507 1540
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: c:\harmonyspringwater080506-080522\haqo0507.p

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99877958	0.99871316	0.22526516	16095.0071

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	5422.62019	395.683792	75.1189983	0.53103830
2	Pearson VII Area	180.745263	459.011440	46.6734162	1.39459869
3	Pearson VII Area	621.547150	507.138349	21.1412014	6.04709388
4	Pearson VII Area	134.148510	562.318137	113.527505	167.908675

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	7.04901109	395.683790	75.1189983	1.00000007	0.00000000	0.00000000
2	Pearson VII Area	3.14303846	459.011440	46.6734162	1.00000000	119.559472	1.00000000
3	Pearson VII Area	26.6207538	507.138348	21.1412014	1.00000014	45.4532467	1.00000007
4	Pearson VII Area	1.10873829	562.318142	113.527505	0.99999980	227.813098	0.99999989

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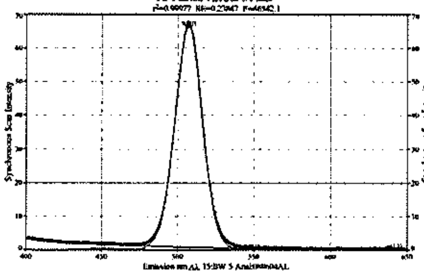
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Quarry Overflow, Sampled:080508 1710

Pk=Pearson VII Area 5 Peaks
r²=0.99977 SE=0.23847 F=66542.1



Description: Harmony Spring, Water, Quarry Overflow, Sampled:080508 1710
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\haqo0508

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99976089	0.99975402	0.23846973	66542.1116

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	4297.82123	379.602962	90.8910582	0.53100005
2	Pearson VII Area	20.5741676	453.770846	35.8910092	50.0796079
3	Pearson VII Area	1463.02036	507.111324	20.2638548	9.56679427
4	Pearson VII Area	14.9926668	549.106155	48.8276785	167.890358
5	Pearson VII Area	5.12363326	642.268041	31.5005727	10.0000000

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.61220491	379.667812	90.8913996	0.99715012	0.00000000	0.00000000
2	Pearson VII Area	0.53633365	453.770846	35.8910092	0.99999999	72.4450841	1.00000000
3	Pearson VII Area	66.3237964	507.111324	20.2638548	1.00000000	42.4098125	1.00000000
4	Pearson VII Area	0.28810914	549.106155	48.8276785	1.00000000	97.9814336	1.00000000
5	Pearson VII Area	0.14057073	642.268041	31.5005727	1.00000000	65.7968776	1.00000000

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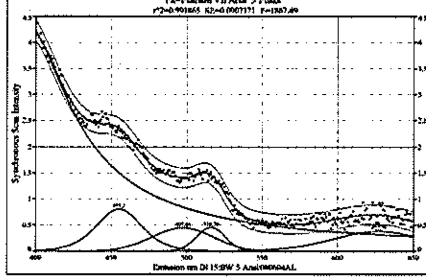
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Quarry Overflow, Sampled:080509 1609

Pk=Pearson VII Area 5 Peaks
r^2=0.991865 SE=0.0907171 F=1867.49



Description: Harmony Spring, Water, Quarry Overflow, Sampled:080509 1609
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\haqo0509

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99186545	0.99130444	0.09071715	1867.49085

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1144.29375	392.094099	84.0465470	0.43506564
2	Pearson VII Area	32.1175862	455.195152	35.2811123	3.89016343
3	Pearson VII Area	22.7523302	497.457719	47.3610234	167.828341
4	Pearson VII Area	10.8573213	516.264440	22.2265014	113.611542
5	Pearson VII Area	29.9695339	627.762150	70.9770503	6.45612370

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.39848232	392.537313	84.0606695	0.97912963	0.00000000	0.00000000
2	Pearson VII Area	0.80513956	455.195152	35.2811123	1.00000002	79.1028217	1.00000001
3	Pearson VII Area	0.45076360	497.457719	47.3610234	1.00000000	95.0384160	1.00000000
4	Pearson VII Area	0.45808325	516.264440	22.2265014	1.00000000	44.6544167	1.00000000
5	Pearson VII Area	0.30333807	627.762146	70.9770503	1.00000018	151.805879	1.00000009

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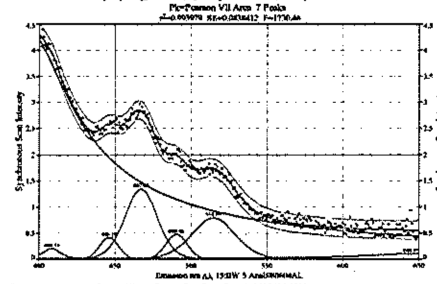
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Quarry Overflow, Sampled:080514 1303

Pk=Pearson VII Area 7 Peaks
r²=0.993979 SE=0.0838412 F=1730.46



Description: Harmony Spring, Water, Quarry Overflow, Sampled:080514 1303
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: c:\harmonyspringwater080506-080522\haqow514.p

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99397942	0.99338164	0.08384119	1730.46149

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	7109.46168	389.669728	93.5175269	0.51812675
2	Pearson VII Area	3.67828130	408.428469	13.9072472	1.50964037
3	Pearson VII Area	6.49402252	446.188815	14.6800579	167.587765
4	Pearson VII Area	36.6131785	467.078533	24.8563282	7.31446333
5	Pearson VII Area	8.40156950	490.456353	16.3518185	28.0022073
6	Pearson VII Area	29.3121576	514.892219	33.6038527	6.96004485
7	Pearson VII Area	61.5542516	644.954028	86.2341930	0.54867581

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	4.30827863	389.678899	93.5175337	0.99960778	0.00000000	0.00000000
2	Pearson VII Area	0.20309083	408.428469	13.9072472	1.00000000	38.2556211	1.00000000
3	Pearson VII Area	0.41448957	446.188814	14.6800579	1.00000031	29.4582830	1.00000017
4	Pearson VII Area	1.34308544	467.078534	24.8563282	0.99999981	52.7626765	0.99999990
5	Pearson VII Area	0.47914736	490.456353	16.3518185	1.00000000	33.2253509	1.00000000
6	Pearson VII Area	0.79216006	514.892219	33.6038527	0.99999999	71.7220183	1.00000000
7	Pearson VII Area	0.10393668	644.954026	86.2341939	1.00000009	0.00000000	0.00000000

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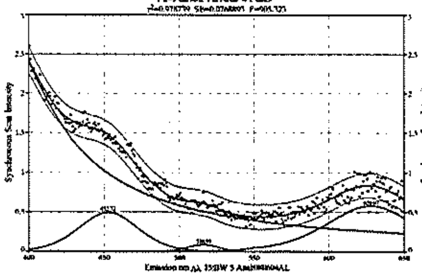
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

LCCMR, Water, Eluent Blank, Sampled:080604 1130

Pk=Pearson VII Area 4 Peaks
r²=0.978779 SE=0.0768893 F=905.323



Description: LCCMR, Water, Eluent Blank, Sampled:080604 1130
X Variable: Emission nm Δλ 15:BW 5 Anal:080604AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080506-080522\ch080604

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.97873850	0.97758141	0.07688931	905.322958

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1251.77559	380.487020	92.5773739	0.57897667
2	Pearson VII Area	24.8958611	452.719638	45.9468453	6.52883168
3	Pearson VII Area	2.35612996	516.048440	26.1445371	167.629753
4	Pearson VII Area	46.0160906	628.069026	69.6304872	3.31524559

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	2.93621322	381.077982	92.6023498	0.97479485	0.00000000	0.00000000
2	Pearson VII Area	0.49212192	452.719638	45.9468453	1.00000000	-98.2473562	1.00000000
3	Pearson VII Area	0.08455936	516.048440	26.1445371	1.00000000	52.4638728	1.00000000
4	Pearson VII Area	0.57720313	628.069026	69.6304872	1.00000000	139.426672	1.00000000

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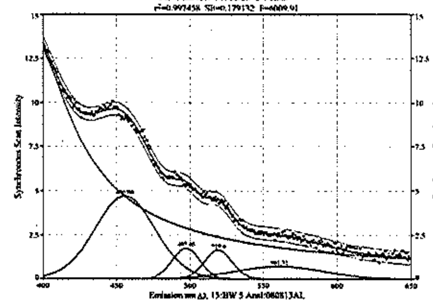
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring-A24-Quarry Overflow, Sampled:080613 1131

Pk=Pearson VII Area 5 Peaks
r²=0.997458 SE=0.179132 F=6009.91



Description: Harmony Spring, Water, Big Spring-A24-Quarry Overflow, Sampled:080613 1131
X Variable: Emission nm Δλ 15:BW 5 Anal:080813AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080613\hsws0613

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99745806	0.99728275	0.17913175	6009.91470

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	16777.9250	392.610183	80.1168078	0.52028721
2	Pearson VII Area	244.382268	456.036149	48.0166450	13.6031215
3	Pearson VII Area	41.3685099	497.654245	22.1627381	167.906822
4	Pearson VII Area	38.6372939	519.603271	21.5505758	9.81768874
5	Pearson VII Area	56.1331431	561.308691	71.2774897	7.27141026

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	13.8063076	392.863297	80.1229644	0.98734447	0.00000000	0.00000000
2	Pearson VII Area	4.70790385	456.036149	48.0166450	1.00000000	99.1512826	1.00000000
3	Pearson VII Area	1.75142176	497.654245	22.1627381	0.99999993	44.4734706	0.99999996
4	Pearson VII Area	1.64798122	519.603272	21.5505758	0.99999988	45.0902421	0.99999996
5	Pearson VII Area	0.71793836	561.308691	71.2774897	1.00000000	151.355406	1.00000000

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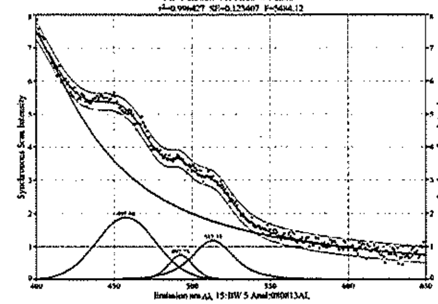
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Big Spring East-A237, Sampled:080613 1110

Pk=Pearson VII Area 4 Peaks
r²=0.996427 SE=0.123407 F=5484.12



Description: Harmony Spring, Water, Big Spring East-A237, Sampled:080613 1110
X Variable: Emission nm Δλ 15:BW 5 Anal:080813AL
Y Variable: Synchronous Scan Intensity
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Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99642670	0.99623224	0.12340746	5484.12234

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	3070.54871	386.076438	111.528483	0.61821990
2	Pearson VII Area	89.1165877	457.882666	44.4934872	167.910928
3	Pearson VII Area	15.3259616	492.726047	18.6477529	4.16043610
4	Pearson VII Area	45.0343898	513.332107	31.2688340	1.97691662

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	8.10076301	387.157534	111.592778	0.96198509	0.00000000	0.00000000
2	Pearson VII Area	1.87942908	457.882666	44.4934872	1.00000000	89.2800557	1.00000000
3	Pearson VII Area	0.73016394	492.726047	18.6477529	0.99999998	41.6864111	0.99999999
4	Pearson VII Area	1.17769823	513.332107	31.2688340	1.00000000	79.1968147	1.00000000

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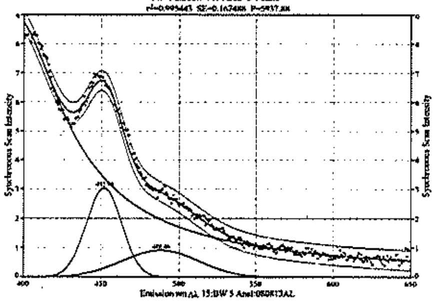
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Buggy Whip, Sampled:080613 1155

Pk=Pearson VII Area 3 Peaks
r²=0.995443 SE=0.167488 F=5937.88



Description: Harmony Spring, Water, Buggy Whip, Sampled:080613 1155
X Variable: Emission nm Δλ 15:BW 5 Anal:080813AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080613\hswb0613

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99544317	0.99525967	0.16748753	5937.88090

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	2149.12126	394.089557	85.5612790	0.65683126
2	Pearson VII Area	85.4025926	452.080451	26.4379581	80.5448680
3	Pearson VII Area	55.8652396	488.458529	57.4554290	167.881120

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	8.96616873	394.089557	85.5612790	1.00000002	0.00000000	0.00000000
2	Pearson VII Area	3.02702194	452.080451	26.4379581	1.00000002	53.1957517	1.00000001
3	Pearson VII Area	0.91233596	488.458529	57.4554290	1.00000000	115.294567	1.00000000

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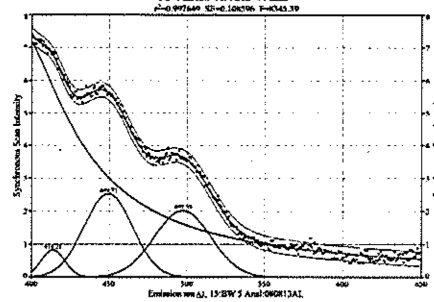
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Hart Spring, Sampled:080613 1142

Pk=Pearson VII Area 4 Peaks
r²=0.997649 SE=0.108596 F=8345.39



Description: Harmony Spring, Water, Hart Spring, Sampled:080613 1142
X Variable: Emission nm Δλ 15:BW 5 Anal:080813AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080613\hswh0613

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99764895	0.99752100	0.10859565	8345.38819

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	2170.26156	387.520478	93.7846269	0.64537025
2	Pearson VII Area	15.6838254	414.205767	17.8455669	25.0083886
3	Pearson VII Area	98.3407817	449.708539	36.5821868	167.906528
4	Pearson VII Area	91.6967704	497.575558	42.7070421	119.757987

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	7.85788138	387.520479	93.7846269	0.99999995	0.00000000	0.00000000
2	Pearson VII Area	0.81083184	414.205767	17.8455669	0.99999999	36.3261773	0.99999999
3	Pearson VII Area	2.52236697	449.708539	36.5821868	1.00000000	73.4086559	1.00000000
4	Pearson VII Area	2.01366557	497.575558	42.7070421	1.00000000	85.7849109	1.00000000

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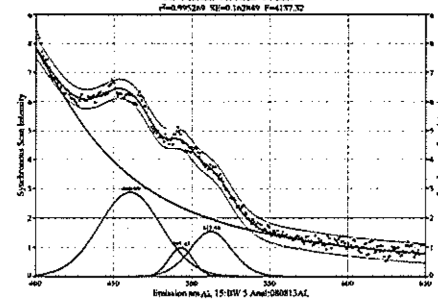
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

Harmony Spring, Water, Quarry Overflow, Sampled:080613 1124

Pk=Pearson VII Area 4 Peaks
r²=0.995269 SE=0.162849 F=4137.32



Description: Harmony Spring, Water, Quarry Overflow, Sampled:080613 1124
X Variable: Emission nm Δλ 15:BW 5 Anal:080813AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080613\hswq0613

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99526901	0.99501154	0.16284913	4137.31765

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	2729.84026	378.001192	125.811477	0.69712997
2	Pearson VII Area	145.053783	460.886553	46.7964651	13.1968450
3	Pearson VII Area	19.1135095	493.427434	18.2876289	167.917967
4	Pearson VII Area	52.5101238	512.479925	31.1464206	6.94395896

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	8.92745133	378.319502	125.815588	0.99021436	0.00000000	0.00000000
2	Pearson VII Area	2.86582581	460.886554	46.7964651	0.99999991	96.7258924	0.99999995
3	Pearson VII Area	0.98068007	493.427434	18.2876289	0.99999999	36.6973695	0.99999999
4	Pearson VII Area	1.53458769	512.479925	31.1464206	0.99999999	66.3277242	0.99999999

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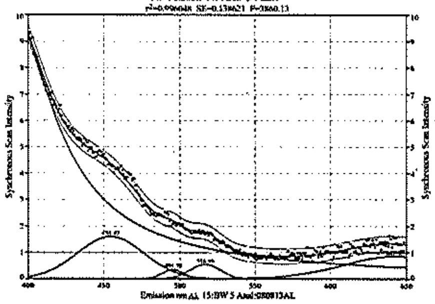
Scanning Spectrofluorophotometer Results – Shimadzu RF-5000 and PeakFit V4.0
Harmony Spring Trace 6 May 2008 Inputs

LCCMR, Water, Tap Water Blank, Sampled:080813 1630

Pk=Pearson VII Area 5 Peaks
r^2=0.996048 SE=0.138621 F=3860.13



Description: LCCMR, Water, Tap Water Blank, Sampled:080813 1630
X Variable: Emission nm Δλ 15:BW 5 Anal:080813AL
Y Variable: Synchronous Scan Intensity
File Source: g:\dyetracing\harmonyspring080506\harmonyspringwater080613\cb080813

Fitted Parameters

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.99604800	0.99577344	0.13862125	3860.13380

Peak	Type	a_0	a_1	a_2	a_3
1	Pearson VII Area	1814.34656	390.415393	72.0678952	0.68531110
2	Pearson VII Area	86.5345905	454.416022	51.6599052	41.1522870
3	Pearson VII Area	6.28486602	495.383077	16.7811580	167.836899
4	Pearson VII Area	14.1984506	516.861587	23.8094739	30.9210285
5	Pearson VII Area	77.2100347	642.419746	80.3487701	5.85615685

Measured Values

Peak	Type	Amplitude	Center	FWHM	Asym50	FW Base	Asym10
1	Pearson VII Area	9.98091183	390.582192	72.0790581	0.99078506	0.00000000	0.00000000
2	Pearson VII Area	1.60202258	454.416022	51.6599052	1.00000000	104.464140	1.00000000
3	Pearson VII Area	0.35141443	495.383077	16.7811580	1.00000000	33.6744090	1.00000000
4	Pearson VII Area	0.35650991	516.861587	23.8094739	1.00000006	48.3097492	1.00000003
5	Pearson VII Area	9.86903924	642.419745	80.3487701	1.00000006	173.167361	1.00000003

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North-Central Section - 43rd Annual Meeting (2-3 April 2009)
Paper No. 10-5

Presentation Time: 2:30 PM-2:50 PM

HOLY GRAIL CAVE, FILLMORE COUNTY, MINNESOTA

ACKERMAN, John G., 26455 Galaxy Ave, Farmington, MN 55024, john@karstpreserve.com, KRAUS, Clayton T., 8543 County 7 Rd, Chatfield, MN 55923, GERBOTH, David W., 13961 Falcon Ave, Apple Valley, MN 55124, DORNINK, Daniel S., Box 12, Harmony, MN 55939, and ALEXANDER, E. Calvin Jr, Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455

Dye traces (Alexander et al., 1995, plate 9, Springsheds) demonstrated that water sinking in the York Blind Valley (the biggest blind valley in MN) resurges 11 miles away at Odessa Spring (the biggest spring in MN). Cavers and karst hydrologists have been searching for an entrance to the conduit/cave system that connects York and Odessa for decades. That search was unsuccessful until August 2008. On 7-8 Jun 2008 a thunderstorm dumped 11-12 inches of rain on southern Fillmore Co., MN in about 12 hours and a new sinkhole MN23:D5160 opened in a grassed waterway in section 19 of Bristol Township in Fillmore County. When first visited by one of us (DSD) on 5 Aug 2008, D5160 proved to be the Dome Collapse Entrance to a new cave MN23:C0158. The explored passages are in the Ordovician Dubuque and Stewartville Formations. C0158 was named Holy Grail Cave (HGC) and purchased by the Minnesota Karst Preserve (). A temporary 24 inch culvert was sealed into D5160. A permanent 30 inch shaft entrance will be installed in 2009. As of 14 Dec 2008 HGC's mapped length is 2.55 miles (4.1 km). HGC is currently the 4th or 5th longest cave in MN and exploration and mapping is actively expanding the surveyed length. The explored passages in HGC underlie a 1/4 by 1/8 mile rectangle. Typical passages are often 15 ft wide by 10 ft tall. HGC is a strongly joint-controlled maze cave. Several of the passages are partially or completely blocked by debris cones from sinkholes. Many passages contain pits that lead to lower, usually water-filled levels. HGC is about midway between York Blind Valley and Odessa Spring and may prove to provide access to the largest cave system in the Upper Mississippi Valley.

The discovery of the HGC cave system further emphasizes the ubiquity of conduit drainage systems in carbonate aquifers with active flow systems and the vulnerability of these important aquifers to surface pollutants. Until D1560 opened there were no mapped sinkholes on the property. Active sinkholes on a property do indicate the presence of conduit system below. However, the absence of an active sinkhole on the surface is neither sufficient nor adequate evidence that the site does not overlie a vulnerable karst aquifer.

North-Central Section - 43rd Annual Meeting (2-3 April 2009)
General Information for this Meeting

Session No. 10
Water Resources in Karst Terranes of the Midwestern U.S.
Northern Illinois University Rockford: 201
1:00 PM-5:00 PM, Thursday, 2 April 2009

Geological Society of America *Abstracts with Programs*, Vol 41, No. 4, p. 18

August 2008

Peptidoglycan Degradation Fluorescence: Applications to Karst Groundwater Mapping

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*Brown University, Department of Geological Sciences;
**University of Minnesota, Department of Geology and Geophysics;
***Michigan Technological University, Department of Environmental Engineering

Abstract: Natural fluorescence groundwater tracing is extremely useful in karst groundwater flow investigations, as there is no artificial dye being introduced to the system and therefore there is no limit on the geographical or chronological spacing of dye traces. However, the fluorescence properties of individual microbiological materials that would impact this tracing method have not been investigated in a pH-controlled lab setting. Through this investigation, we have found that the pH of groundwater will have an enormous impact on the fluorescence of the microbial cell wall materials found in it, and therefore an impact on the analysis of those samples. We have also found cursory evidence that the path that a groundwater flow takes through a karst system (conduit flow, flow through porous media or fractured flow, or a combination) has an impact on that water's fluorescence peak's location and intensity. Further work in this area will have to take pH into account.

Introduction

Conducting fluorescent dye traces through karst groundwater systems has yielded invaluable information about the path of flow through these difficult-to-model features. However, using artificial dye for these traces can create problems for future traces. Highly fluorescent artificial dyes commonly used for tracing can reside in a karst system for an extended period of time, limiting the turnaround between dye traces. Also, the number of fluorescent dyes that can be used for these traces is limited, restricting the number of paths that can be traced at one time in a single area. Using the natural fluorescence from the groundwater itself eliminates both of these issues. Because no dye is being introduced, natural fluorescence analysis is not limited by time or geographical proximity to other traces.

Natural fluorescence can also provide insight into the type of path followed by groundwater. Interactions between groundwater and microbiological colonies would increase the ratio of microbial organic materials to surficial organic materials in that groundwater and change the peak location of the fluorescence. Different fluorescence could indicate more interaction between the water and the microbiology, and suggest that the groundwater flow was not purely through karst conduit, but also through a porous bedrock system.

To be able to link the water's increased fluorescence with microbiological interactions, we must identify the DOM as a known compound in microbiological cells. Microbial cell wall materials make up a significant portion (~11.4%) of DOM in terrestrial rivers (Jorgensen et al 2003). Identifying some of these common materials and testing them for fluorescence peaks would allow us to extrapolate our results to analysis of natural waters.

Present in almost all eubacteria, the common cell wall material peptidoglycan is a major contributor to DOM and appears as both the complete compound and as degradation product molecules (Van Heijenoort 2001). Gram-negative bacterial cell walls contain structures that seem to shield their peptidoglycan from breakdown by other bacteria, leaving the complete compound as DOM, while Gram-positive bacterial cell walls are almost completely peptidoglycan, which is easily broken down by other organisms and therefore can be seen as its constituent molecules (Jorgensen et al 2003). These components include N-Acetylglucosamine, N-Acetylmuramic acid and the pentapeptide chain containing D-Alanine. The fluorescence of the whole compound and the several molecules in the peptidoglycan degradation sequence can be tested.

As peptidoglycan is only common in eubacterial cell walls, the sample set was expanded to include amino sugars found commonly in all cell materials, including both phototropic and heterotrophic bacteria, as well as some methanogenic Archaea (Benner and Kaiser 2003). To include these other organisms' cell materials in our data, galactosamine and glucosamine were added. These two amino sugars are abundant in marine organic material and also occur in close conjunction with each other.

Previously, standards used for natural water fluorescence tracings in marine and estuarine settings have been derived from natural water samples themselves (Coble, 1996). These standards for fluorescence analysis unintentionally incorporate numerous environmental variables that could dramatically alter the excitation/emission spectra, such as incorporation of multiple fluorophores into one sample, differences in salinity and alterations due to proximity to marine plants (Coble, 1996). Analysis of lab-created samples of common microbial cell wall materials eliminates the unwanted variability found in the field. Therefore, lab-mixed DOM under controlled conditions (such as pH, salinity, and elimination of outside organisms) will yield more accurate, repeatable and usable results for future natural water analysis of the organic compounds.

Method:

Peptidoglycan (a common microbial cell wall material) and its constituent materials N-acetylmuramic acid, N-acetylglucosamine and D-Alanine were diluted in DI water to ppm levels, then diluted to ppb levels in four pH buffers from pH 6.5 to pH 8.0. For more complete details on the mixing of the buffers, or the dilutions, see Appendix A.

Each of the vials of diluted material was run through a Shimzu RF-5000 Spectrofluorophotometer scanning for fluorescence intensity. The scans were performed from 200nm to 800nm on both excitation and emission scales for each $\Delta\lambda$ in 5nm intervals from 10nm to 400nm.The data was then run through a Matlab program to eliminate the Raman scattering peak and to create a contour plot. The plots for each material were normalized in scale to a maximum 8.5, 15 or 38 fluorescence intensity.

Results:

The fluorescence peaks for peptidoglycan (fig. 1) appear to be the sum of the compound's major components. The N-acetylmuramic acid (fig. 3) has a less intense peak than the peptidoglycan that sits higher in both excitation and emission than the N-acetylglucosamine (fig. 2) . However, the elongated peak of the N-acetylmuramic corresponds with the elongated peak region in the peptidoglycan scan and the rounder peak of the N-acetylglucosamine also appears in the peptidoglycan. The alanine peak (fig. 4) appears as a connecting region between the other two.

Figure 1

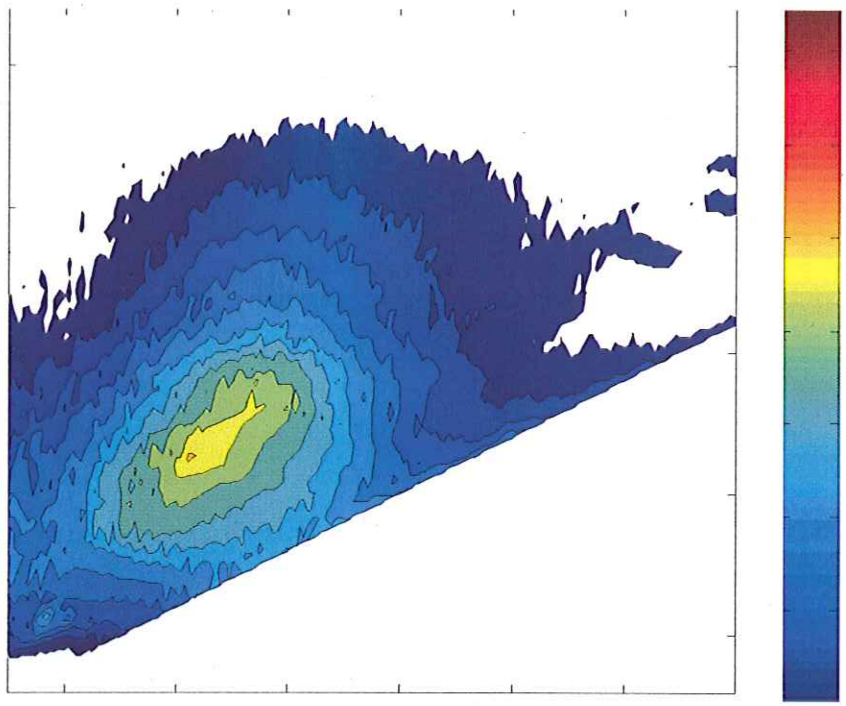


Figure 2

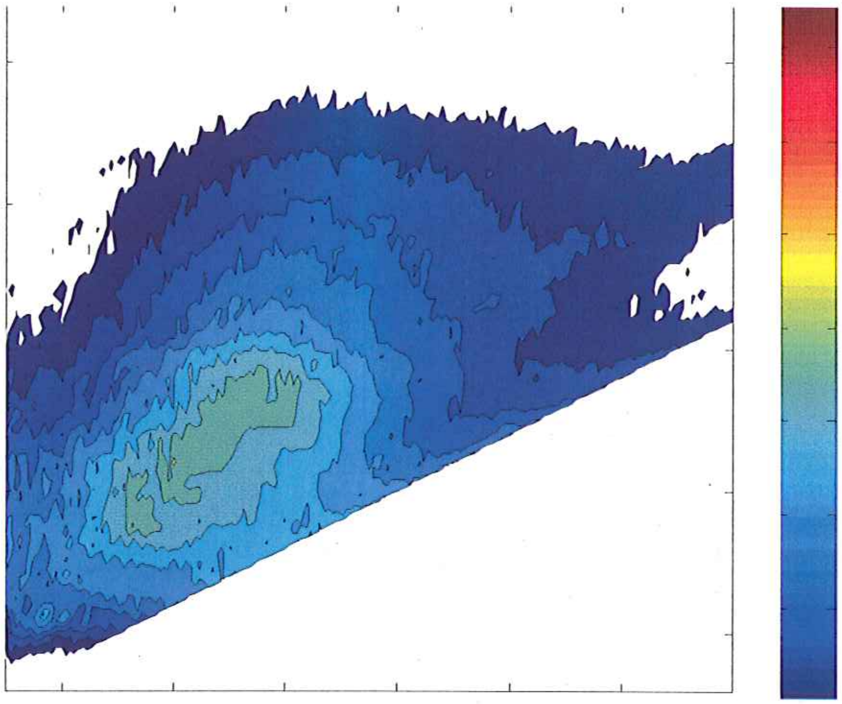


Figure 3

N-Acetylmuramic Acid

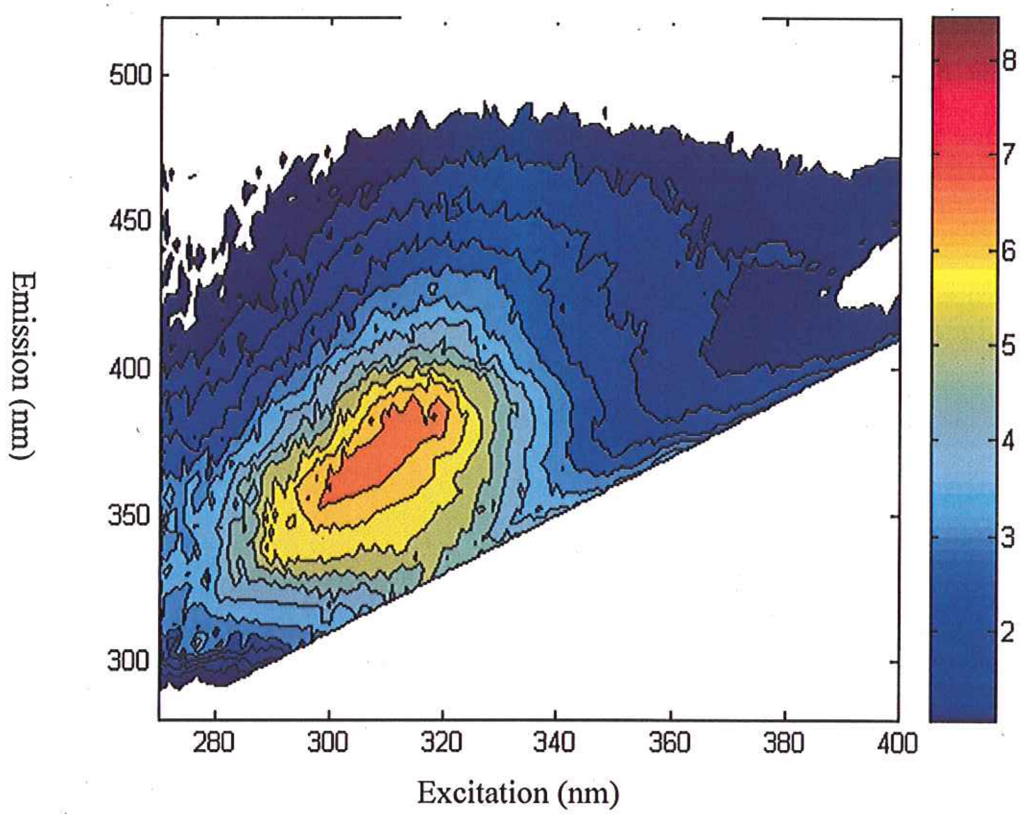


Figure 4

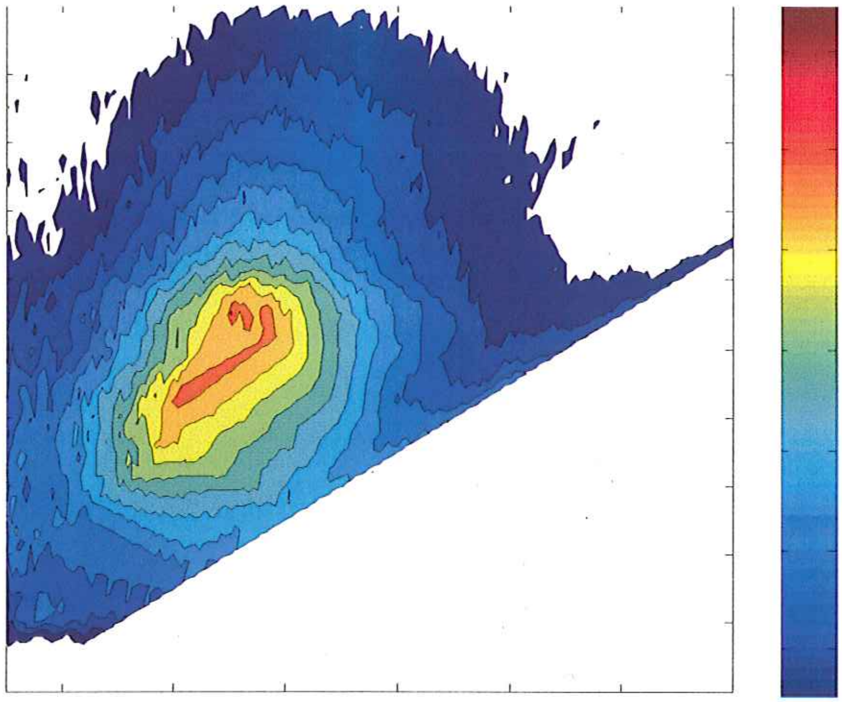
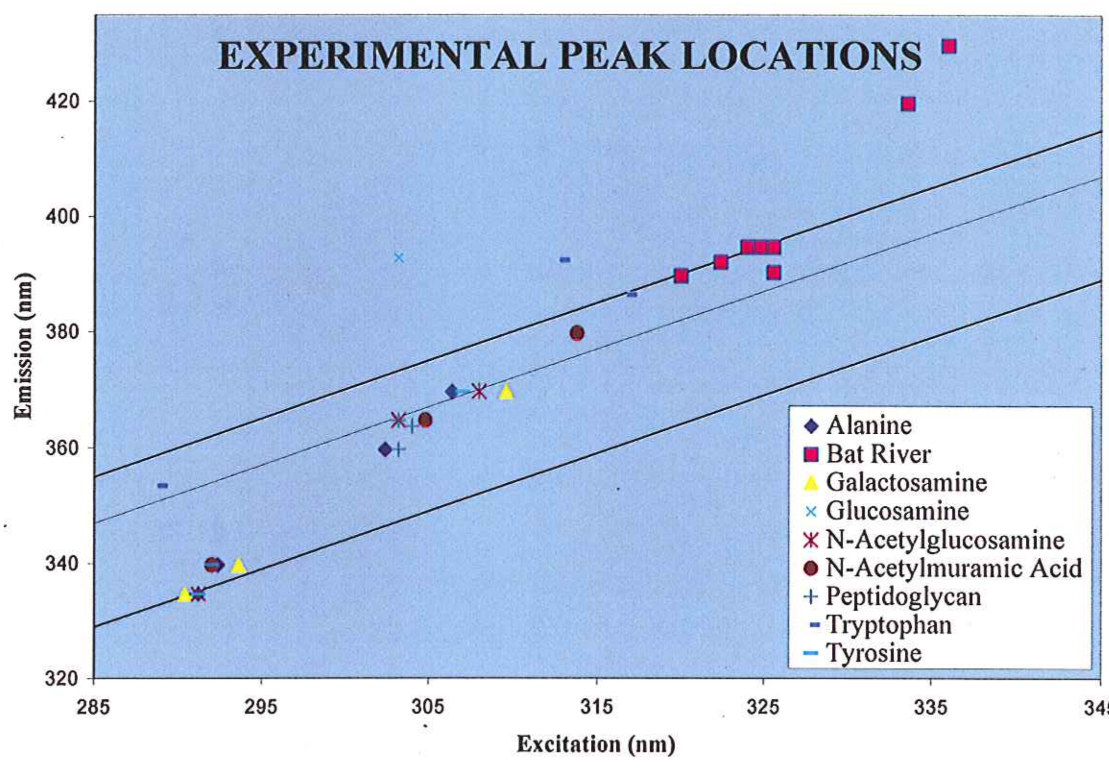
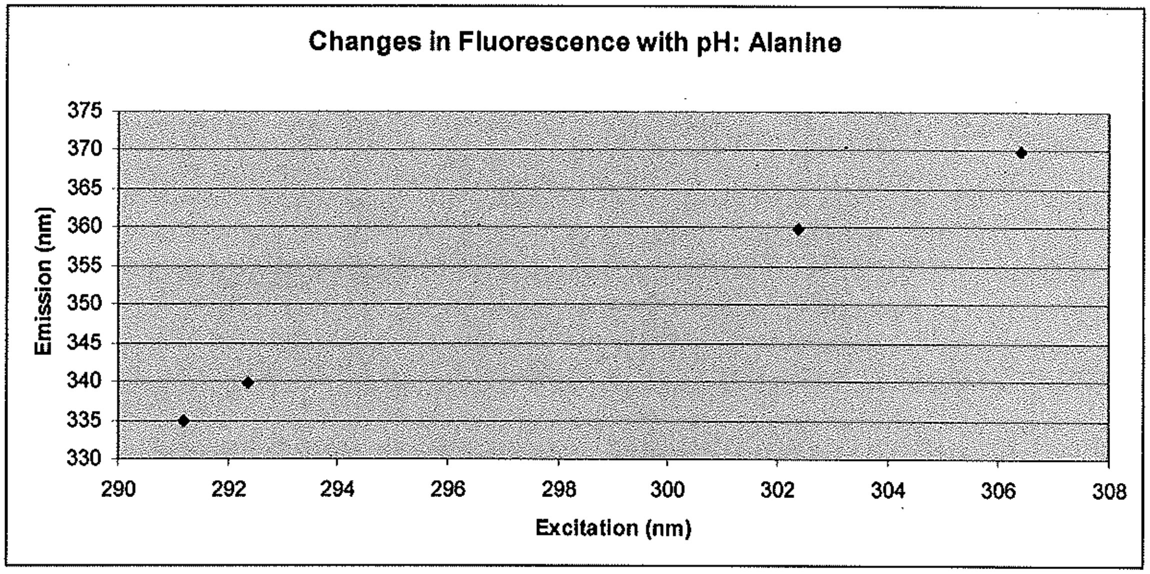


Figure 5



As shown in the "Experimental Peak Locations" graph above (fig. 5), the locations of the fluorescence peaks seem to shift up in both excitation and emission, but this is not with higher pH. Also outlined in the "Experimental Peak Locations" (above), both the test materials and the natural water samples aligned along three major $\Delta\lambda$ lines, at 44, 62 and 70.

As seen in "Changes in Fluorescence with pH: Alanine" (fig. 6, below), the linear-looking trend in changing fluorescence with different pH is not actually linear, as excitation and emission do not increase with increased pH. In the graph below, the progression going up in both excitation and emission wavelengths is pH 7.0, pH 8.0, pH 6.5, pH 7.5, which reflects that the fluorescence is not changing directly with the pH increasing.



The materials tested that were not directly associated with peptidoglycan degradation also showed results in the same region of the excitation-emission spectra.

Looking at the natural water samples from Bat River Cave, we cannot identify the materials in the karst groundwater samples from Bat River Cave (scans shown on schematic drawing) without enough information about the impact of pH on the fluorescence peaks of DOM. However, the peaks from various water samples were very different (see fig. 7, below), indicating that the water did interact with different parts of the karst system, and different amounts and/or types of organic material.

Comparisons with Others?

The fluorescence peaks we identified also do not correspond with the widely accepted B,T,A,M, and C regions published in Coble et al 1996. For example, the tyrptophan pH 7.5 is close, but not exactly the same as the T-region, but the other pH-buffered tryptophans are much different. Other compounds listed below are closer to the T-region than the other tryptophan scans. The fluorescence peaks' ranges used as a benchmark for most organic fluorescence analysis do not directly correspond with any of our experimental materials. Our natural water samples also do not align with published standards

Discussion:

The dramatic changes in a material's fluorescence peak with changing pH suggests that taking pH of natural water samples into account when testing for fluorescence is much more important than previously thought. Future work on pH-dependent fluorescence will yield much more information about how to identify organic materials in natural waters. The impact that pH has on a material's fluorescence also could explain the discrepancies between published fluorescence peaks (Coble et al, 1996; Biers et al, 2007). Without controlling for pH in water samples, the fluorescence peaks are not usable outside the pH at which they were mixed. Further examination of the impact of pH on fluorescence on much finer pH intervals should be able to more precisely characterize a material's fluorescent properties at a range of pH levels.

Finally, with many of the material's main fluorescence peaks lying on or very near the $\Delta\lambda$ 44, 62 and 70, scanning for their presence becomes much quicker and easier than running a full excitation-emission scan, which enables us to analyze more unique water samples and better understand karst systems.

Acknowledgements: I would like to extend my thanks to the National Science Foundation - Research Experience for Undergraduates program for funding this project. I would also like to thank John Ackerman for the use of Bat River Cave, and the local residents for their help and cooperation.

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Appendix A

Before the dilution of the organic materials could begin, pH buffers in the range of typical Minnesota groundwater had to be mixed. The two chemicals KH_2PO_4 and NaOH were mixed into a solution to serve later as components for the pH buffers needed. For the KH_2PO_4, this required a solution of 13.60912g KH_2PO_4 into 1000g DI water and for the NaOH, the solution was 4.00122g NaOH into 1000g DI water. These two solutions were then combined, based on (PAPER ON BUFFERS) guidelines to create 400g of pH buffer solution of each pH 6.5, pH7.0, pH7.5, and pH8.0. The calculated amounts needed of each material follow.

Planned pH	KH_2PO_4 (g)	NaOH (g)	DI H_2O (g)	Total (g)
6.5	200	55.6	144.4	400
7.0	200	116.4	83.6	400
7.5	200	163.6	36.4	400
8.0	200	184.4	15.6	400

The actual amounts of each material used (due to human inaccuracy) to create each buffer are listed below. After each buffer was mixed, its pH was tested with an Accumet pH/Conductivity meter calibrated just previous to measurement with a three buffer (pH4.0, pH7.0 and pH10.0) sequence. The actual pH of each buffer also listed.

Planned pH	KH_2PO_4 (g)	NaOH (g)	DI H_2O (g)	Total (g)	**Actual pH**
6.5	200.00	55.61	144.42	400.03	**6.44**
7.0	200.00	116.40	83.61	400.01	**6.98**
7.5	200.00	163.67	36.33	400.00	**7.49**
8.0	200.00	184.39	15.60	400.03	**7.93**

After the initial dissolution of the organic materials to be tested for fluorescence down to ppm levels, the final dilution down to the 100ppb level was done in each of the four pH buffers. This was done for two reasons. First, using a buffer with a known pH would standardize the pH level of each diluted material as opposed to dilution in DI water, which could yield virtually any pH, due to the different material introduced. Second, using four pH buffers of levels commonly found in Minnesota groundwater could yield different levels of fluorescence for a given material in waters of different overall pH levels. Hopefully, looking at the differences in fluorescence between different pH levels of a given material will provide some insight into how these materials appear in natural water samples of varying pH.

To mimic the approximate range of concentration of our organic compounds in natural waters, the compounds needed to be diluted down to approximately 100ppb in solution. This was completed in three dilutions. First, between 0.02g and 0.03g of a given material was dissolved into approximately 8g DI water. Next, between 0.02g and 0.03g of the solution was mixed into another 8g DI water. This yielded concentrations in the ppm range. From here, differing amounts of the second solution were added to 8g of each of the four pH buffers to produce four solutions containing around 100ppb of the original material. For example, a solution with a concentration of 7.74172ppm after the second dilution would require 0.1033362g to be mixed with 8g of the pH buffer to yield 100ppb, which would vary with the actual amounts of material and solvent in the first two dilutions. While DI water would be used for all materials in a perfect world, in reality the different organic compounds required different methods to completely dissolve them into solution. The different methods used will be discussed in conjunction with each material.

Salicylic acid dissolved readily into deionized water, so there was no need to look for alternative solvent material. Following the process outlined above, the salicylic acid was diluted to approximately 100ppb in three steps. First, the approximately 0.02g of salicylic acid was measured into an 8ml glass vial with cap. The 8g of DI water was poured into the vial onto the material while sitting on a scale. The vial was then capped and shaken to mix. Using a repeating pipette, a small amount of the solution was drawn off the top and dripped into a second glass vial replacing the first on the scale. Again, 8g DI water was added to the vial, it was capped and shaken. The equation used to find the amount of the second solution necessary for the third (into the four pH buffers) is shown below. The same method was used to pipette a small amount of solution off the top, which was then added to a third 8ml glass vial (replacing the second) on the scale. Finally, 8g of the pH buffer was added. This final step was repeated for the other three pH buffers. The salicylic acid used was Sigma Aldrich 105910 batch 00530JH.

Dilution	1		2
Salicylic Acid (g)	0.020286g	Solution 1	0.023360g
DI water (g)	7.72417g	DI water	7.92464g
Concentration (gSA/gDI)	2.62630*10^-3	Concentration	7.74172*10^-6

(Concentration 1)(Volume 1)=(Concentration 2)(Volume 2)
(concentration of second dilution)(volume needed for third)=(100*10^-9)(8g)
(7.74172*10^-6)V_1=(800*10^-9)
V_1=0.1033362g second solution into third

pH buffer	Solution 2 (g)	Buffer (g)	**Concentration**
6.5	0.10331	8.23872	**97.07783ppb**
7.0	0.10280	8.16070	**97.52213ppb**
7.5	0.10081	7.88507	**98.97778ppb**
8.0	0.10357	7.95104	**100.84340ppb**

Glucosamine hydrochloride also dissolved into DI water, so the same procedure used for the salicylic acid was used. The needed amount of solution 2 for four buffered solutions is also the same, so it will not be outlined in its entirety. The glucosamine hydrochloride used was Sigma Aldrich 64875-25G 047K0129.

Dilution	1		2

Glucosamine (g)	0.02487	Solution 1	0.04906
DI water (g)	8.28866	DI water	7.55888
Concentration (gGl/gDI)	3.00049*10^-3	Concentration	15.8786*10^-6

$$(15.8786*10^{-6})V_1=(800*10^{-9})$$
V_1=0.050382g second solution into third

pH buffer	Solution 2 (g)	Buffer (g)	**Concentration**
6.5	0.07105	7.75574	**145.463ppb**
7.0	0.05001	8.24081	**96.3605ppb**
7.5	0.05166	7.91369	**103.6543ppb**
8.0	0.06309	8.06415	**125.309ppb**

Galactosamine dissolved as easily as the salicylic acid and the glucosamine. It required no alternative methods of dilution and followed the same procedure as above.

Dilution	1		2
Galactosamine (g)	0.01945	Solution 1	0.13692
DI water (g)	8.33362	DI water	8.12672
Concentration (gGl/gDI)	2.333919*10^-3	Concentration	39.32216^10^-6

$$(39.32216*10^{-6})V_1=(800*10^{-9})$$
V_1=0.020344g second solution into third

pH buffer	Solution 2 (g)	Buffer (g)	**Concentration**
6.5	0.02710	8.26747	**128.8944ppb**
7.0	0.02401	8.29331	**113.8418ppb**
7.5	0.01816	8.17641	**87.3355ppb**
8.0	0.02660	8.11092	**128.9582ppb**

The L-Tyrosine did not dissolve easily when mixed into DI water as outlined with the salicylic acid and the glucosamine. Several different solvents were tried, including 10%, 50% and 100% methyl alcohol (CH_3OH), as well as isopropyl alcohol and directly into the pH6.5 and pH7.0 buffer solutions. No solvent worked completely without heating and stirring, but after heating to 90°C, the tyrosine did dissolve into the DI water. Pipetting a small amount of the heated liquid off quickly (to prevent reprecipitation), the same procedure was followed as with the salicylic acid and glucosamine.

Dilution	1		2

L-Tyrosine (g)	0.02326	Solution 1	0.04432
DI water (g)	8.10595	DI water	8.04473
Concentration (gGl/gDI)	2.86949*10^-3	Concentration	15.80862*10^-6

$$(15.80862*10^{-6})V_1=(800*10^{-9})$$
V_1=0.050605g second solution into third

pH buffer	Solution 2 (g)	Buffer (g)	**Concentration**
6.5	0.06042	8.19447	**116.5612ppb**
7.0	0.06620	8.25793	**126.7304ppb**
7.5	0.05283	8.08376	**103.3145ppb**
8.0	0.05951	8.12729	**115.7546ppb**

The tryptophan also did not dissolve into 25°C DI water. It did, however, dissolve into 10% methyl alcohol (CH_3OH). The methyl alcohol solution used consisted of 30g Mallinckrodt lot 3016 KXNT methyl alcohol dissolved into DI water to yield 300.03g of total solution. The Sigma Aldrich T0254-256 tryptophan dissolved into this 10% concentration by mass solution fairly readily. The amounts used for each step of solution are listed below.

Dilution	1		2
Tryptophan (g)	0.01907	Solution 1	0.02109
10% CH_3OH (g)	7.88393	DI water	7.78220
Concentration (gGl/gDI)	2.41884*10^-3	Concentration	6.553446*10^-6

$$(6.553446*10^{-6})V_1=(800*10^{-9})$$
V_1=0.122073g second solution into third

pH buffer	Solution 2 (g)	Buffer (g)	**Concentration**
6.5	0.13144	7.86780	**109.48ppb**
7.0	0.15263	8.09790	**123.52ppb**
7.5	0.16283	8.30899	**128.43ppb**
8.0	0.13544	8.13487	**109.11ppb**

Peptidoglycan Degradation Fluorescence: Applications to Karst Groundwater Mapping

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Conducting fluorescent dye traces through karst groundwater systems has yielded invaluable information about the path of flow through these difficult-to-model features. However, highly-fluorescent artificial dye can reside in a karst system for an extended period of time and the number of fluorescent dyes used for these traces is limited, restricting the number of traces that can be conducted in one area during a certain time frame. Using the natural fluorescence from the groundwater itself eliminates both of these issues. Because no dye is being introduced, natural fluorescence analysis is not limited by time or geographical proximity to other traces.

Natural fluorescence can also provide insight into the type of path followed by groundwater. Interactions between groundwater and microbiological colonies would increase the ratio of microbial organic materials to surficial organic materials in that groundwater and change the peak location of the fluorescence. Different fluorescence could indicate more interaction between the water and the microbiology, and suggest that the groundwater flow was not purely through karst conduit, but also through a porous bedrock system.

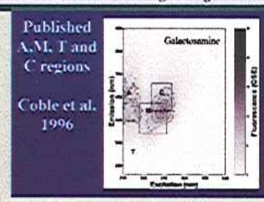
To be able to link the water's changing fluorescence with microbiological interactions, we must identify the DOM (dissolved organic material) as a known compound in microbiological cells. Microbial cell wall materials make up a significant portion (~11.4%) of DOM in terrestrial rivers (Jorgensen et al 2003). Identifying some of these common materials and testing them for fluorescence peaks would allow us to extrapolate our results to analysis of natural waters.

Method: Peptidoglycan (a common microbial cell wall material) and its constituent materials N-acetylmuramic acid, N-acetylglucosamine and D-Alanine were diluted in DI water to ppm levels, then diluted to ppb levels in four pH buffers from pH 6.5 to pH 8.0.

Each sample was scanned for fluorescence in a Shimazu R-5000 spectrofluorometer from 200nm to 800nm on both excitation and emission scales for each Δλ in 5nm intervals from 10nm to 400nm. The data was then run through a Matlab program to eliminate the Raman scattering peak and to create a contour plot. These plots were then normalized to 8.5, 15 or 38 intensity.

Comparisons with Others?

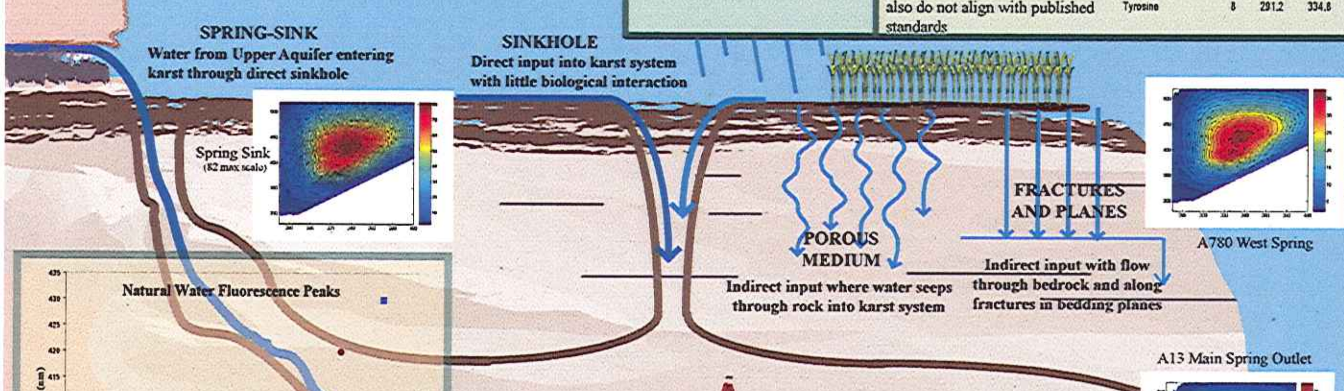
The fluorescence peaks we identified also do not correspond with the widely accepted B,T,A,M, and C regions published in Coble et al 1996. For example, the tyrptophan pH 7.5 is close, but not exactly the same as the T-region, but the other pH-buffered tryptophans are much different. Other compounds listed below are closer to the T-region than the other tryptophan scans. The fluorescence peaks' ranges used as a benchmark for most organic fluorescence analysis do not directly correspond with any of our experimental materials. Our natural water samples also do not align with published standards

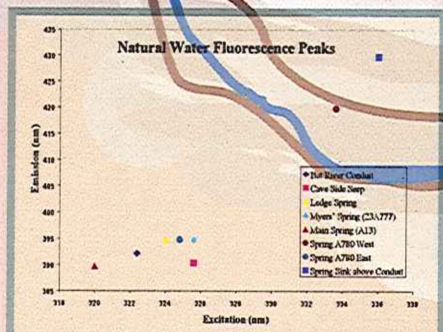


Coble et al, 1996

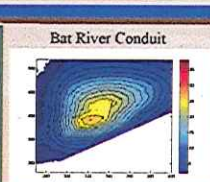
Peak	Ex_{max} (nm)	Em_{max} (nm)	
B	275	310	Tyrosine-like, protein-like
T	275	340	Tryptophan-like, protein-like
A	260	380–460	Humic-like
M	312	380–420	Marine humic-like
C	350	420–480	Humic-like

Our Scans	pH	Excitation	Emission
Tryptophan	7.5	288.8	353.6
Galactosamine	7	290.4	334.8
Alanine	7	291.2	334.8
N-Acetylglucosamine	7	291.2	334.8
Tyrosine	7	291.2	334.8
Tyrosine	8	291.2	334.8



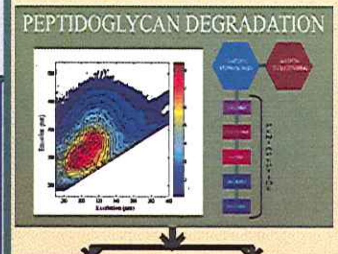


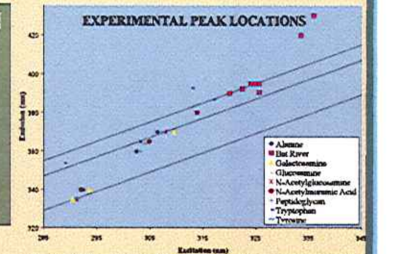
Without enough information about the impact of pH on the fluorescence peaks of DOM, it would be impossible to identify the materials in the karst groundwater samples from Bat River Cave (scans shown on schematic drawing). However, the peaks from various water samples were very different (see graph left), indicating that the water did interact with different parts of the karst system, and different amounts and/or types of organic material



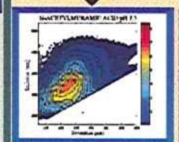
Acknowledgements: I would like to extend my thanks to the National Science Foundation - Research Experience for Undergraduates program for funding this project. I would also like to thank John Ackerman for the use of Bat River Cave, and the local residents for their help and cooperation.

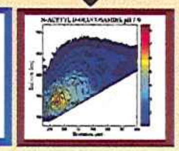
RESULTS: PEPTIDOGLYCAN DEGRADATION AND EXPERIMENTAL PEAKS

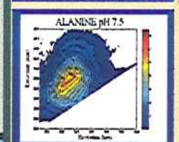




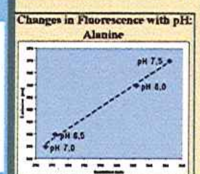
Maximum peak locations of the organic materials at pH levels between pH 6.5 and pH 8.0







Organic Material	pH	Excitation (nm)	Emission (nm)
Peptidoglycan	7.5	303.2	364.8
N-Acetylmuramic	7.5	313.8	379.8
N-Acetylglucosamine	7	291.2	334.8
Alanine	7.5	306.4	369.8
Galactosamine	7.5	309.6	369.8
Glucosamine	6.5	303.2	393



Results: The fluorescence peaks for peptidoglycan appear to be the sum of the compound's major components. The N-acetylmuramic acid has a less intense peak than the peptidoglycan that sits higher in both excitation and emission than the N-acetylglucosamine. However, the elongated peak of the N-acetylmuramic corresponds with the elongated peak region in the peptidoglycan scan, and the rounder peak of the N-acetylglucosamine also appears in the peptidoglycan. The alanine peak appears as a connecting region between the other two.

As shown in the "Experimental Peak Locations" graph above, the locations of fluorescence peaks seems to shift up in both excitation and emission, but this is not with higher pH. As seen in "Changes in Fluorescence with pH: Alanine", the linear-looking trend in changing fluorescence with different pH is not, excitation and emission do not increase with increased pH.

Materials not directly associated with peptidoglycan degradation also showed results in the same region of the excitation-emission spectra. As outlined in the "Experimental Peak Locations" (above), both the test materials and the natural water samples aligned along three major Δλ lines, at 44, 62 and 70.

Discussion: The dramatic changes in a material's fluorescence peak with changing pH suggests that taking pH of natural water samples into account when testing for fluorescence is much more important than previously thought. Future work on pH-dependent fluorescence will yield much more information about how to identify organic materials in natural waters. The impact that pH has on a material's fluorescence also could explain the discrepancies between published fluorescence peaks (Coble et al, 1996; Biers et al, 2007). Without controlling for pH in water samples, the fluorescence peaks are not usable outside the pH at which they were mixed. Further examination of the impact of pH on fluorescence on much finer pH intervals should characterize this fluorescence.

Finally, with many of the material's main fluorescence peaks lying on or very near the Δλ 44, 62 and 70, scanning for their presence becomes much quicker and easier than running a full excitation-emission scan, which enables us to analyze more unique water samples and better understand karst systems.

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[illegible]

A Quantitative Dye Trace in the Bat River System

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ABSTRACT: While in resent years a significant amount of work has been done to delineate the karst spring sheds of southeastern Minnesota. There has been little work done to document the characteristics of the spring sheds such as the resonance time of water with in the system. Bat River Cave and spring were the focal point for this trace, the spring being the sampling location. Four dyes were released, one in a drilled access shaft and three others into near by sinkholes. All four dyes were detected in Bat River Spring within twenty-four hours of there releases. The velocity of the system was found to be 651 ft/hr relative to cave passage and 258 ft/hr compared to the surface distance. This goes to highlight the Galena group's vulnerabilities and the difficulty of contamination containment.

INTRODUCTION

Little is know about Bat River Cave and the karst system in which it is located. The first know explorations into the cave, according to Ron Spong, were done in the mid 1950's and lasted until 1976. The cavers were stopped by a terminal sump at that time an estimated third to half mile of passage had been discovered. Interested in the cave reignited when in 2006 John Ackerman led a cave diving trip that pushed past the sump and discovered an open walking passage that stretched before them(Spong 2007). The cave has since been mapped to 2.2 miles and a shaft entrance has been drilled past the terminal sink opening up the cave to further exploration. Bat River Cave and Spring are located in the Galena Group which is composed of limestone and dolomites. The system travels west to east before emerging in the spring.

It is nearly impossible to predict the flow of groundwater in a karst region since groundwater boundaries often do not match the surface water boundaries; tracer testing is often the best tool to gain insight in the behavior of the system (Baedke 2000). A quantitative approach was chosen in the Bat River trace since a dye could be released at the base of the drilled shaft and then be sampled at the spring to produce an accurate breakthrough curve (BTC). The curve is the most valuable piece of data garnered from a quantitative trace, BTC give allow hydrologist to understand the aquifer, groundwater flow, contaminate transport and conduit networks with in the area (Pronk, 2008). Given that one good BTC was likely additional inputs were investigated with in the area.

The data gained from a quantitative trace within a delineated aquifer is the most useful information for scientists trying to mitigate contamination flow in a karst system. Knowledge of groundwater velocities and conduit networks can help determine the size of the area contaminated and the directions in which the contamination is moving. The BTC can help save time, money and additional areas from being contaminated by indicating the best mitigation strategy and remediation sight. Previous studies such as Baedke and Krothe's in the Beech Creek Aquifer have help develop an effective cleanup plan for groundwater contamination where previous pump and treat test have failed (Baedke 2000).

Do to the lack of accurate knowledge of the Galena groups conduit flow characteristics even one quantitative trace and BTC give an important starting point for clean up of spills within the region.

Fig. 1. Bat River Spring with ISCO 3700 auto samplers in place

METHODS

Bat River Cave and Spring were selected for a quantitative trace do to the knowledge a dye released in the passage below the drilled shaft entrance would reach Bat River Spring. On June 17, 2008, passive charcoal detectors were placed in springs radiating out from Bat River spring for background information. While in the area a survey was undertaken to identify sinkholes that could be used as additional dye inputs(fig. 2). At Bat River Spring(A13) a staff gage was put in place to monitor flow fluctuations.

The trace was initiated on June 26, 2008, three ISCO 3700 auto samplers were place at Bat River Spring and set at staggered 20 minute intervals for the first 24 hours before the dye was released. In addition to the collection of background bugs and placement of a new set. The first dye released was 300g of 91 wt % Phloxine(Lot #AJ7526 Warner-Jenkinson, K7054 1105 D&C Red No. 28) an estimated 100ft down stream of the drilled entrance shaft at 13:55. A previously identified spring and sinkhole were chosen as the second input do to the system being primed by the spring water and its ability to flush the dye. In this sinkhole 436.6g of 17.7 wt % Sulforhodamine B(Lot #082207D Chromatint, M93010X Red 0551) was released at 14:21. The next input was a grassy sinkhole at the edge of a corn field. The system was primed by pouring approximately 1000 gallons of water from a fire trunk. This was followed by 479.4g 33 % wt Eosine(Lot #020706 Chromatint, D13802, Red 0143) which was flushed with an additional 1000 gallons at 14:34. The final sinkhole was primed with 1000 gallons of water before 478.9g Uranine Hs(Lot #082207C Chromatint, D11006) was dump followed by 1000 gallons of water to flush the dye into the system.

The first 71 water samples were collected on June 27, 2008 at 13:00 and the auto samplers were reset so a sample would be taken every 40 minutes. The next set of water samples was collected at 12:00 on June 29, 2008 and also at this time the bugs were collected form the near by springs and new bugs were placed. The samplers were reset to take a sample every hour. Another set was collected on July 2, 2008 at 11:00 and the auto samplers were reset to sample every 3 hours. The final set was collected July 12, 2008 in addition to the removal of all the bugs in the area.

All water and carbon samples were run as they were collected on a Shimadzu RF5000U Spectrofuorophotomter and analyzed using Peakfit software. The carbon samples were eluted in a liter solution of 70% isopropyl, 30% deionized water and 10 grams NaOH. Some of the water samples were found to be off chart and there for had to be systematically diluted. Standards of each dye were made to find a relationship between area and ppb. This original curve was found to be incorrect for the sulforhodamine b this is suspect to have been do to the dyes highly responsive changes due to temperature. A temperature equilibrated standard was made and a multiplication factor of .6964 was found to correct for the temperature.

Flow measurements were taken throughout the trace. Unfortunately due to an error in a data logger only two relevant flow measurements were available. There was a declining trend in the water levels during the trace noted through staff gage measurements. It was found that an exponentially decline in water levels best represented the flow for the period of the trace.

RESULTS

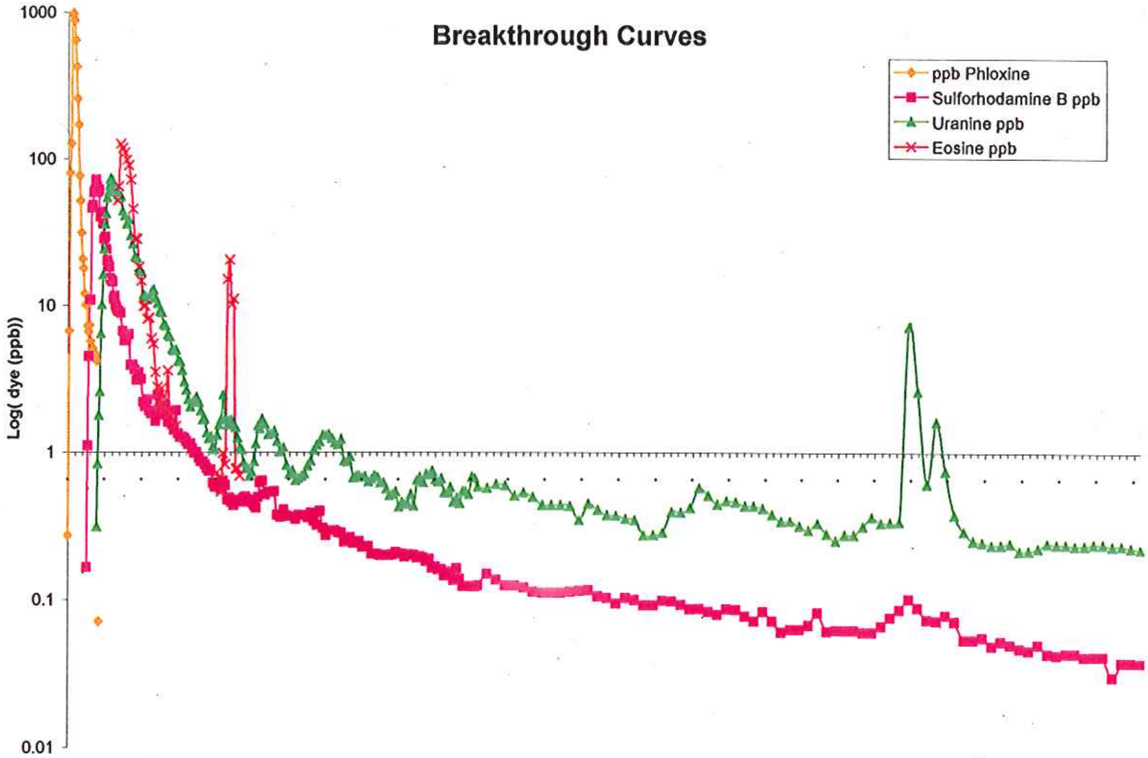

Fig. 2 Breakthrough curves for Bat River Dye Trace

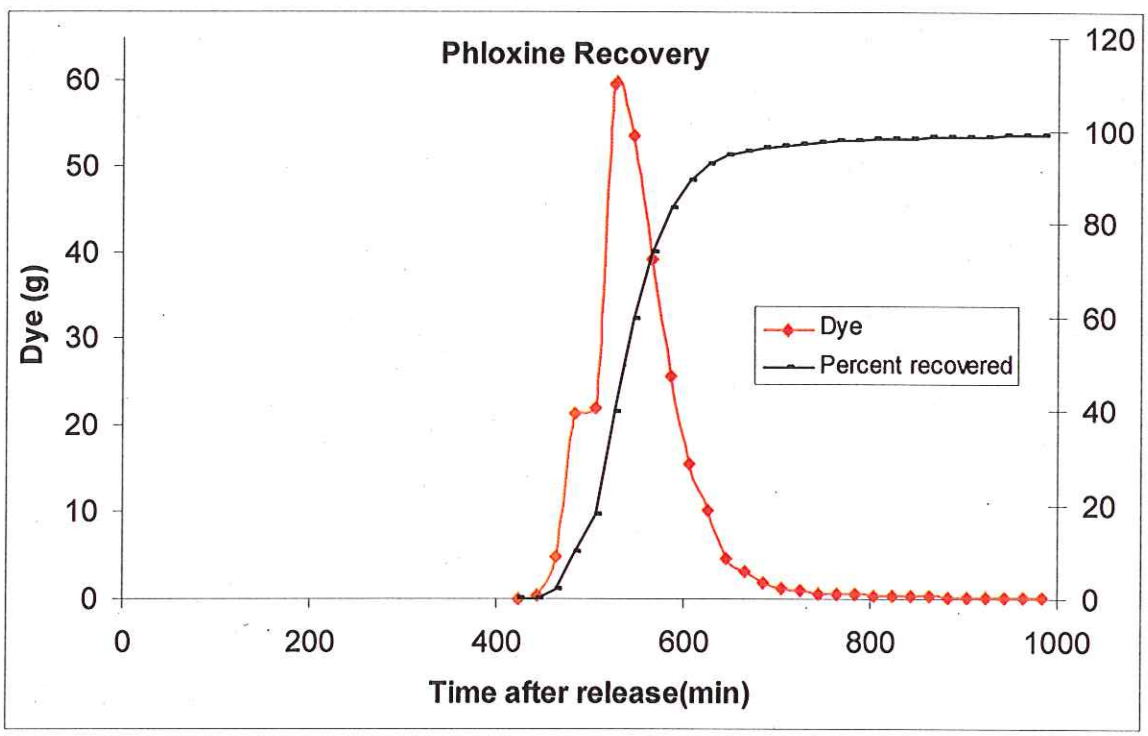

Fig. 3

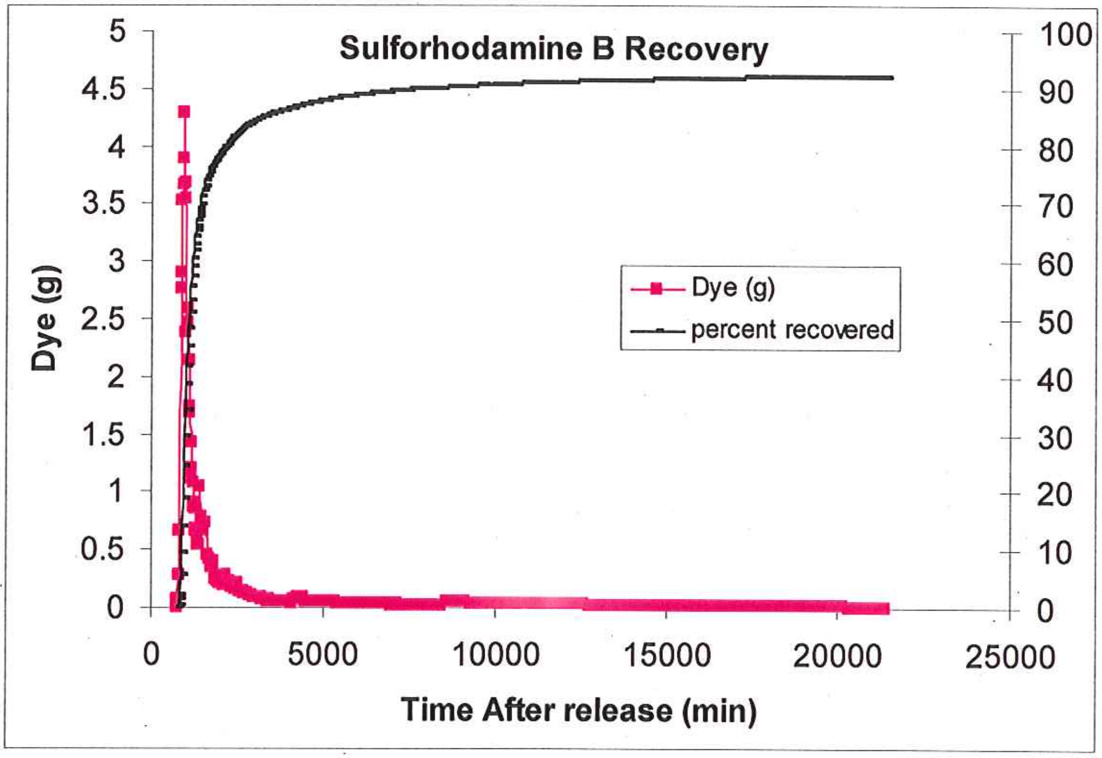
Sulforhodamine B Recovery
Dye (g)
percent recovered
Time After release (min)
0
5000
10000
15000
20000
25000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60
70
80
90
100

Fig. 4

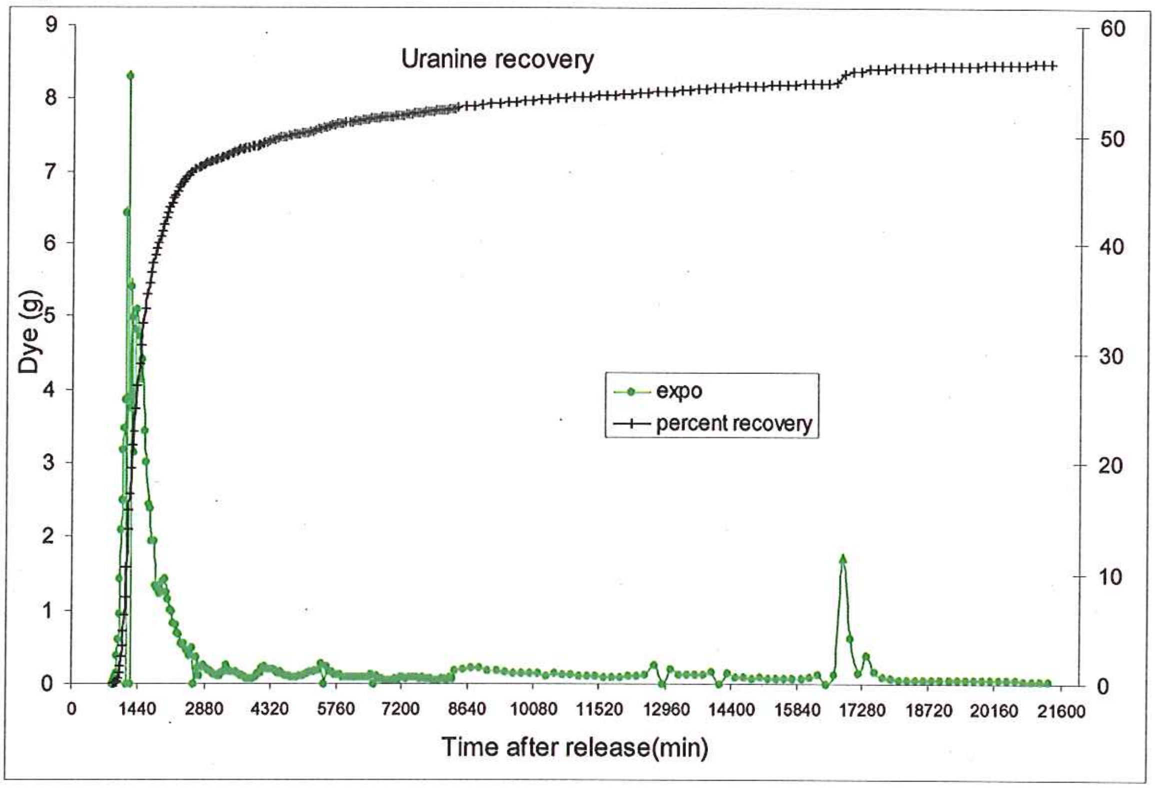
Uranine recovery
expo
percent recovery
Dye (g)
Time after release(min)
0
1440
2880
4320
5760
7200
8640
10080
11520
12960
14400
15840
17280
18720
20160
21600
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60

Fig. 5

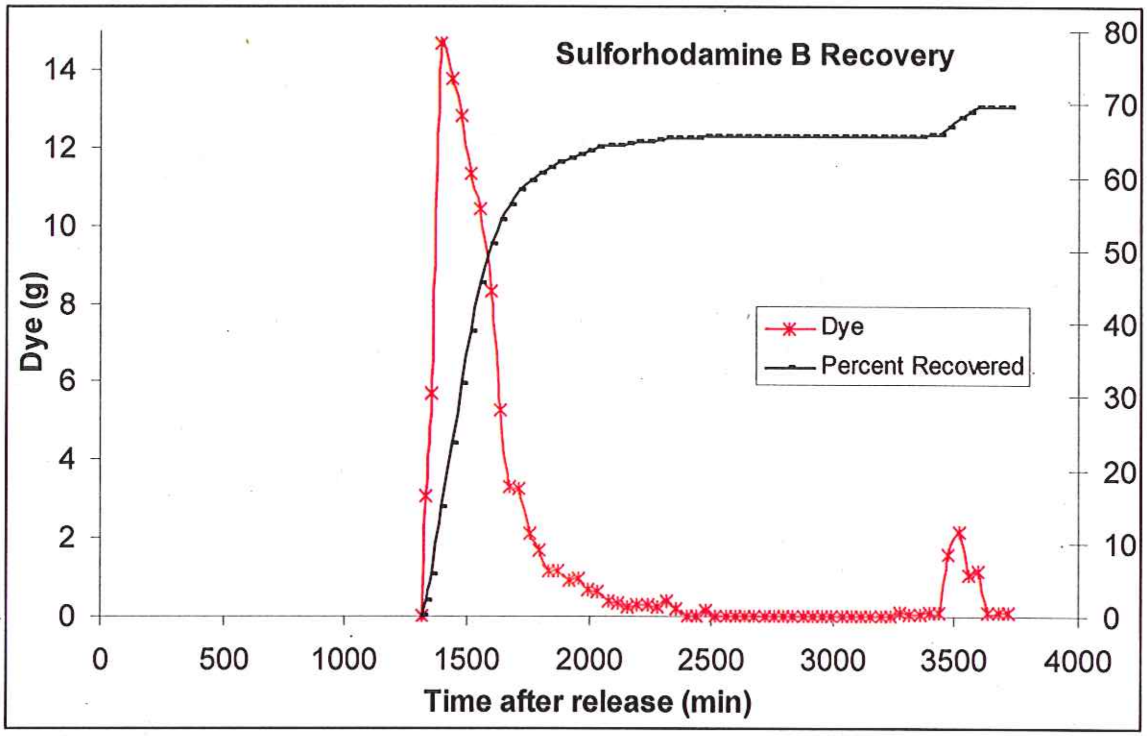

Fig. 6

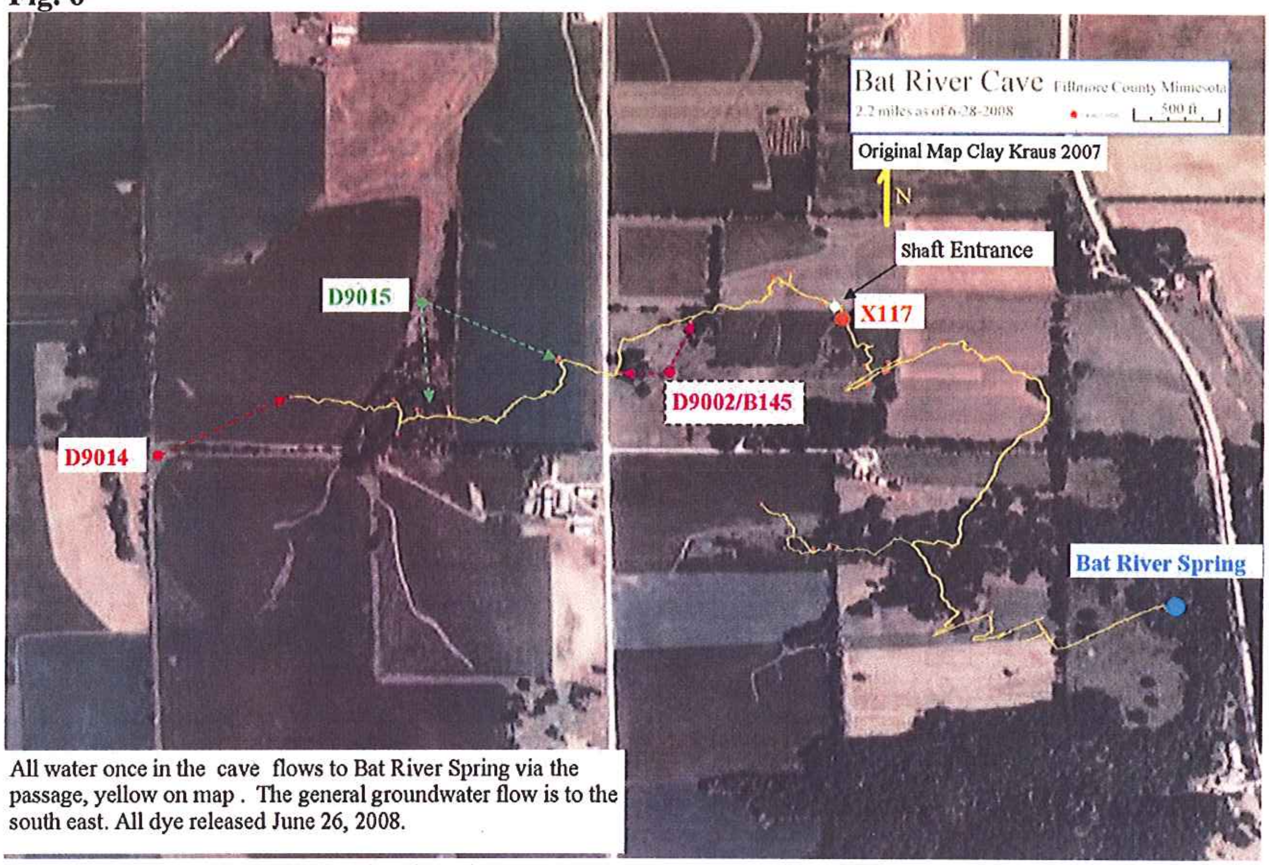

Fig. 7 Map of Dye Input Distributions and Suspected Subsurface Dye Flows

	Percent Recovered	Breakthrough(hr)	Peak(hr)	Half Mass(hr)	Surface Distance (ft)	Subsurface Distance (ft)	Suface Velocity(ft/hr)	Subsurface Velocity(ft/hr)
Phloxine	99.07	7.08	8.75	8.91	2553	5802	258.27	650.69
Sulforhodamine B	92.17	12.65	16.65	17.31	3201	7302	184.92	421.84
Uranine	56.55	15.18	19.51	23.85	4674	7757	195.97	325.24
Eosine	69.61	22.38	25.28	24.95	6049	9952	242.45	398.88

Table 1

DISCUSSION

The flow data indicates that flow in minor /side conduits is significantly slower than in the main passage. Given how close the surface flow velocity of the Eosine is to the Phloxine it indicates that D9014 is very close to if not on top of the main cave passage. The Bat River Trace data shows the speed and irregularities that are found in karst systems. This trace could provide a useful tool in: future traces, showing the conduit flow properties of the Galena Group and working with contamination mitigation efforts.

ACKNOWLEGMENTS

The help of many individuals was required to conduct this trace especially time frame that was available. An acknowledgement of these individuals is the least we can do. John Ackerman for his access and continued efforts to preserve and map the karst lands of Southern Minnesota through the Minnesota Karst Preserve. Duane Schmidt, Carolyn Meyer and the Gladys for letting us access the various sinkholes and springs on their properties. The Chatfield Fire Department for providing a tanker truck to help flush dyes. Clay Kraus for his help, maps and knowledge of the cave. The National Science Foundation for generous funding. Finally Calvin Alexander, Scott Alexander and Andrew Luhmann, whom all took time out of their busy summer schedules to help with this trace. Their patients was immeasurable as they answered the same simple questions over and over for me.

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Spong Ronald Craig, 2007- *Early spelean history of bat river cave,* Book FLW001.01

A Quantitative Dye Trace in the Bat River Cave System: Shannon Flynn [1], E. Calvin Alexander Jr. PHD[2], Scott Alexander PHD[3]

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ABSTRACT: While in resent years there has been much work done to delineate the karst spring sheds of southeastern Minnesota. There has been little work done to document the characteristics of the spring sheds such as the resonance time of water with in the systems. Bat River Cave and spring were chosen the focal point for this trace both are located in the Cummingsville formation (Spong 2007). This trace illustrated the Galena group's vulnerabilities and the potential difficulty of contamination, containment.

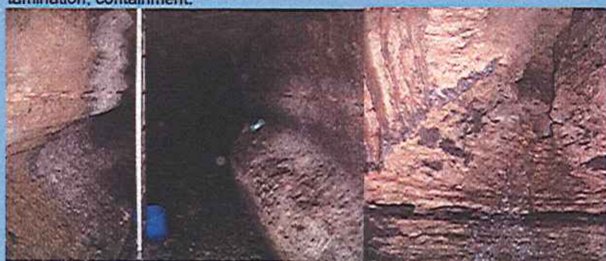


Fig. 1: Right a Stream passage Typical of the Bat River Cave System
Left: Side conduit entering and eroding into the main passage

Quantitative Tracing:

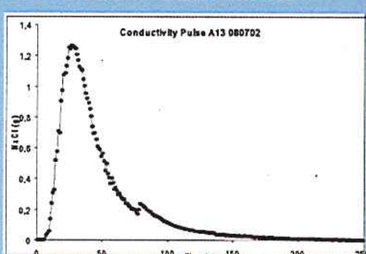
Quantitative traces are a more in depth and labor intensive than a qualitative trace. They are often under taken in areas which have already been delineated. In quantitative trace auto samplers are placed in the spring is know to be the systems outlet to take frequent sample. These samplers are started before the dye is released to get a background and complete breakthrough curve(BTC). The BTC is a combinations of flow and dye concentrations(ppb) in comparison to the time past since the dye has been released. The curve is the most valuable piece of data garnered from a quantitative trace, BTC give allow hydrologist to understand the aquifer, groundwater flow, contaminate transport and conduit networks with in the area (Pronk, 2008).

Dye Recovery= $\sum Flow*PPB(dye)*dt$

Flow

Flow was calculated using NaCl pulses measured with data logging conductivity probes recording at one second intervals. Mass is found from regression curve of know samples with know concentrations of NaCl and measured conductivities.

Mass recovered= $\sum mass*dt$
Flow=Mass recovered/Mass Released



Mass passing Probe During Conductivity Pulse

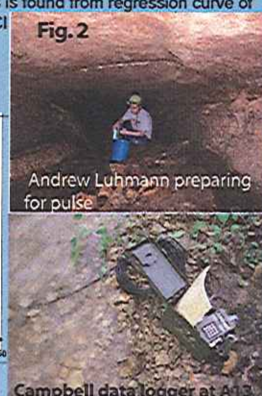


Fig. 2

Andrew Luhmann preparing for pulse

Campbell data logger at A13

Fig. 3

Bat River Spring with ISCO 3700 Auto Samplers

Bat River Spring Green from Uranine

Bat River Trace:

For the Bat River Trace four dye inputs were selected. The first was at the base of the drilled shaft entrance to the cave, it is the reference since the distance and path to the spring are know. Three sinkholes were selected as additional dye input sights through field work done in the weeks proceeding the trace(fig. 1).

On June 26, 2008 at 13:00 the auto samplers were put in place and set to sample every 20 minutes over the first 24 hours(fig. 3). Passive charcoal detectors were placed in near by springs to see if all the dye went through Bat River Spring or was diffused through multiple springs.

Dye Releases went as follows:

X117/Shaft Entrance: 300g of 91 wt % Phloxine at 13:55
D9002/B145/Sinkhole Spring: 436.6g of 17.7 wt % Sulforhodamine B(SRB) at 14:21
D9014/Grassy Sinkhole: 479.4g 33 % wt Eosine at 14:34
D9015/Pasture: 478.9g 50% wt Uranine Hs at 15:09

At locations without a natural water flow the system was initially primed with 1000 gallons of water before and then flushed with 1000 gallons of water after the release: D9014 and D9015(fig. 5).

Fig. 5

Fig. 4

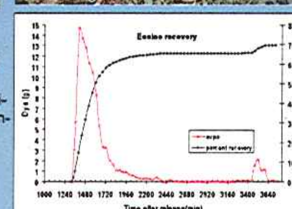
Releasing uranine into D9015

A special thanks is due to: John Ackerman for cave access. The land owners; Duane Schmidt, Carolyn Meyer and the Gladys. Clay Kraus for his maps and knowledge of the cave. The Chatfield Fire Department for providing a pumper truck. The National Science Foundation for funding. Most importantly the individuals who guided me through this Andrew Luhmannn, Calvin Alexander and Scott Alexander.

References:

Pronk Michiel, Meiman Joe, Smart Christopher & Goldscheider Nico, 2008- Tracer tests in karst hydrology and speleology. International Journal of Speleology 37(1) 27-40

Spong Ronald Craig, 2007- Early spelean history of bat river cave, Book FLW001.01



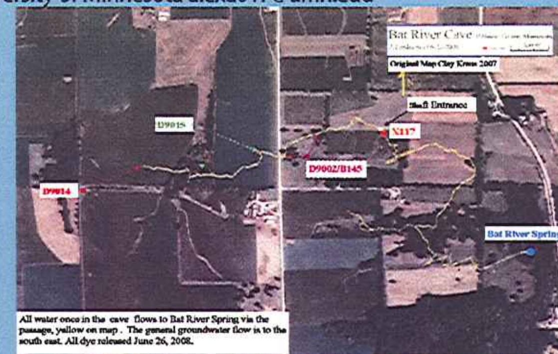
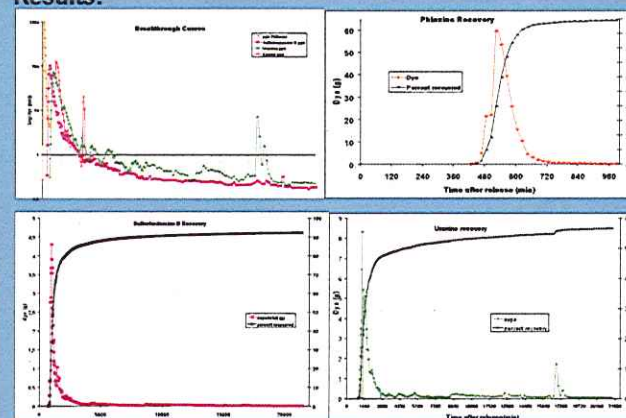


Fig. 6 The Bat River Trace dye input distribution and suspected dye flow.

Results:



Dye	Recovery	Time(hr)	Velocity(ft/hr) (relative to surface)	Velocity(ft/hr) (relative to passage)
Phloxine	99.07	8.92	258	650.7
SRB	92.17	17.98	178.05	389.43
Uranine	56.55	23.85	195.97	352.28
Eosine	69.61	24.95	242.45	398.88

Discussion:

The flow data indicates that flow in minor /side conduits is significantly slower than in the main passage. Given how close the surface flow velocity of the Eosine is to the Phloxine it indicates that D9014 is very close to if not on top of the main cave passage. The Bat River Trace data shows the speed and irregularities that are found in karst systems. This trace could provide a useful tool in showing the conduit flow proporties of the Galena Group, especially when working with contamination clean up efforts.

North-Central Section - 43rd Annual Meeting (2-3 April 2009)
Paper No. 10-4
Presentation Time: 2:10 PM-2:30 PM

SINKS AND RISES OF THE SOUTH BRANCH ROOT RIVER, FILLMORE CO., MN

ALEXANDER, E. Calvin Jr[1], ALEXANDER, Scott C.[2], LUHMANN, Andrew J.[3], ANGER, Cale T.[4], GREEN, Jeffrey A.[5], and PETERS, Andrew J.[5], (1) Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455, alexa001@umn.edu, (2) Geology & Geophysics Department, University of Minnesota, 310 Pillsbury Dr. SE, Minneapolis, MN 55455, (3) Department of Geology and Geophysics, University of Minnesota, 310 Pillsbury Dr. SE, Minneapolis, MN 55455, (4) Geology & Geophysics Dept, University of Minnesota, 108 Pillsbury Hall, 310 Pillsbury Dr. SE, Minneapolis, MN 55455, (5) Division of Waters, Minnesota Department of Natural Resources, 2300 Silver Creek Rd. NE, Rochester, MN 55906

When the South Branch of the Root River (SBRR) reaches Mystery Cave I in Forestville Twp in Fillmore County, MN, its flow starts to sink underground at ~ 1225 ft elevation. At that point the SBRR is flowing on the Ordovician Dubuque Fm. in entrenched bedrock meanders. Under all but flood conditions the SBRR sinks in the next 0.25 to 2 miles of its channel. The terminal sinking point varies depending upon the river's stage. Perennial flow in the SBRR resumes at Seven Springs (MN23:A001) at ~1160 ft. Leveling surveys in Mystery Cave (Palmer and Palmer, 1995) document that most of that 65-foot head loss occurs close to the sinking points. The straight line distance between the Mystery I entrance and Seven Spring is about 1.5 miles. The distance along the SBRR channel between Mystery I and Seven Springs is about 5.5 miles. The river flows in two large entrenched meander loops that cross the Ordovician Stewartville Fm. The lower stream levels in Mystery Cave currently act as an underground meander cutoff for the SBRR.

A series of dye traces over the last 3+ decades have demonstrated that much of the water that sinks from the SBRR resurges in three major spring systems, Seven, Crayfish (MN23:A0080), and Saxifrage (MN23:A0113) Springs. These springs form the head of the perennial flow along a ~0.25 mile reach of the SBRR. The SBRR is a warm water stream above Mystery I, a coldwater stream below Seven Springs and typically dry inbetween.

Mohring (1983) found that water sinking at MN23:B0110 traced both to Seven and to Moth (MN23:A0002) and Grabau (MN23:A003) Springs. Moth and Grabau Springs are the source springs for Forestville Creek, a coldwater stream north of the SBRR in Forestville Twp. Moth and Grabau rise at ~1115 ft from the lower Ordovician Cummingsville Fm. An 18 Nov 2008 dye trace from sink MN23:B0061 found that the dye resurged in Crayfish, Seven and Saxifrage and in Moth and Grabau Springs confirming Mohring's results. Moth and Grabau are about 3.5 miles from B61.

The Sinks of the SBRR feed at least 3 identified springsheds and at least 5 major spring groups that are the source springs for 2 trout streams in 2 different watersheds. In a complex, stage-dependent fashion, Moth and Grabau are pirating flow from the SBRR into Forestville Creek.

North-Central Section - 43rd Annual Meeting (2-3 April 2009)
General Information for this Meeting

Session No. 10
Water Resources in Karst Terranes of the Midwestern U.S.
Northern Illinois University Rockford: 201
1:00 PM-5:00 PM, Thursday, 2 April 2009

Geological Society of America *Abstracts with Programs*, Vol 41, No. 4, p. 18

Spring Characterization Methods & Springshed Mapping

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E. Calvin Alexander, Jr.[1], Jeffrey A. Green[2] and Andrew J. Peters[2]

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[2]Minnesota Department of Natural Resources, Division of Waters, 2300 Silver Creek Road NE, Rochester, MN 55906.

ABSTRACT: Southeastern Minnesota's karst lands support numerous trout streams created by coldwater springs emanating from Paleozoic bedrock. While trout streams have been traditionally managed as surface water resources they are fundamentally supported by clear, relatively constant temperature groundwater. In karst areas this groundwater resource is as vulnerable as surface waters to human activities. Designing Best Management Practices (BMPs) to protect groundwater fed springs should improve the overall protection of Minnesota's trout streams. Dye tracing has been the tool of choice for mapping the recharge area or groundwater basin that feed a particular spring. These karst groundwater basins have been termed "springsheds". In order to accelerate springshed mapping, a two-year study was funded by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR). To improve the effectiveness of dye tracing we are applying a variety of new tools to increase our knowledge of the underlying karst systems

Techniques being investigated include temperature and discharge monitoring, detailed structural mapping of the aquifers, unit hydrographs, chemical and isotopic studies. These new methods to define the size and geometry of springsheds can be tested against basins previously defined by dye tracing. In previously untraced basins these predictive tools can be used to design more efficient tracing programs. The following paper demonstrates the application of structural mapping to dye tracing.

INTRODUCTION

Trout streams depend on a steady supply of clean, cool and constant temperature water to exist. Water management associated with the increasing human impacts of intensive agriculture, new water demands, climate change, and landscape alteration requires more efficient means of defining the springsheds that support and define trout fisheries. Over the past three decades twenty-four springsheds have been defined which feed just twelve of the 173 designated trout streams in southeastern Minnesota. Figure 1 shows the correlation of trout streams with active karst regions of Minnesota. Additional large groundwater withdrawals for energy production and other development loom in the future. Delineation of the recharge areas or springsheds of the trout springs is a crucial first step in the protection of the trout fisheries and the restoration of those that have been degraded.

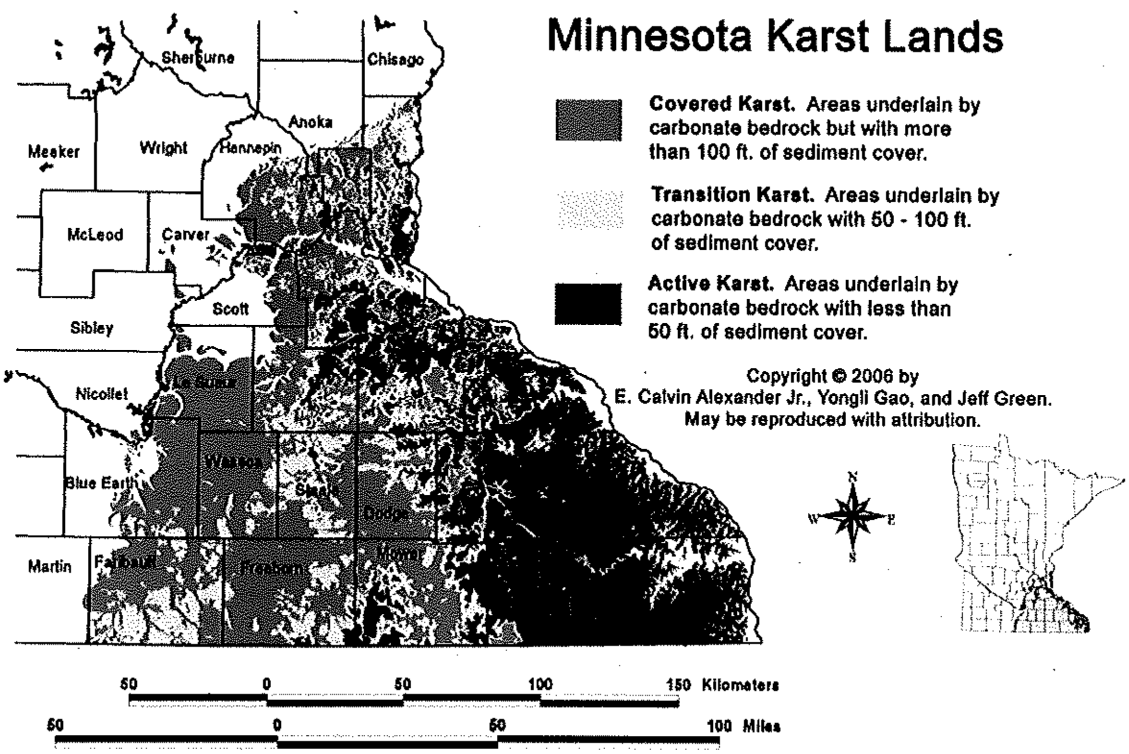


Fig. 1. Minnesota Karst Lands with designated trout streams (heavy lines).

Paleozoic bedrock aquifer systems serve as the primary water supply source for southeast Minnesota trout stream springs. The primary tool for delineating springsheds in Minnesota has been dye tracing (Alexander, 2005, Hötzl, 1998 and Ozark Underground Laboratory, 2002). Despite the use of multiple tracers, dye tracing is time and labor intensive. Most of these trout stream springshed delineation efforts have been conducted in the upper Ordovician Galena limestone (Alexander et al., 1995 and Green et al., 2005). Numerous major springs and related trout streams emanate from throughout the Ordovician and Cambrian aquifer systems. The hydrology of the lower Ordovician and Cambrian springs has been studied only to a limited extent despite their importance for trout streams and relationship to municipal water supply wells (Runkel et al., 2003). See Green et al. in this proceedings volume for a report of initial dye tracing efforts in this part of the section.

Significant work on the hydrostratigraphy of the bedrock underlying southeastern Minnesota is reported in Runkel et al. (2003). Beyond traditional lithographic and chronologic based stratigraphic methods, hydrostratigraphy encompasses lithologically controlled primary permeability as well as secondary fracture and solution enhanced permeabilities.

GALENA KARST SYSTEM

One promising technique to improve springshed delineation combines gamma logs of a few water wells with conventional driller's logs to construct detailed structural contour maps. Groundwater flow in karst regions is generally independent of surface topography, but is largely influenced by underlying geological formations and structures (Goldscheider and Andreo, 2007). Conduits present in southeastern Minnesota karst systems generally run parallel to the local, sub-horizontal bedding planes, and multiple joint systems enable water to move down-dip within and along local bedrock units (Runkel et al., 2003). Therefore, in these relatively flat lying strata, structural contour maps of underlying rock formations may allow the prediction of groundwater flow direction. The working hypothesis is that this method will work best with upper aquifer systems of southeastern Minnesota that are well above base-level rivers. The corollary hypothesis would be that structural control on groundwater flow direction is less significant when dealing with aquifers at greater depths or with greater saturated aquifer thickness.

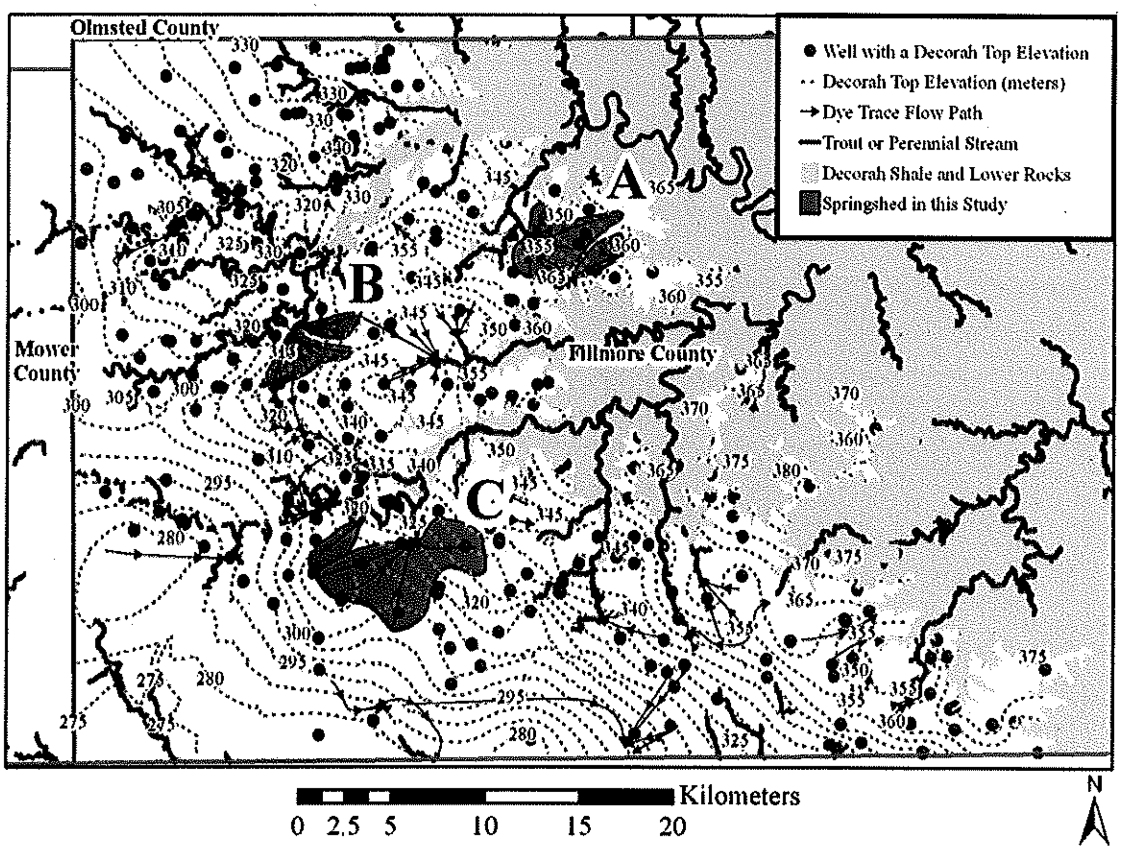
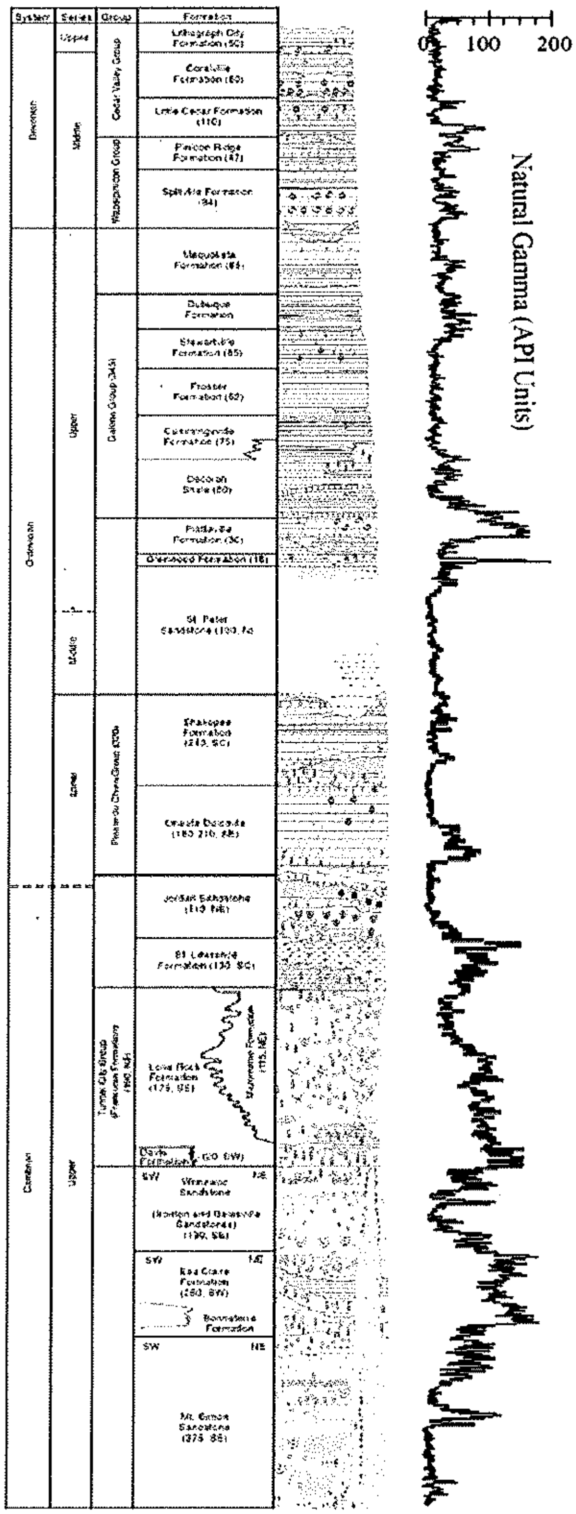


Fig. 2. Structural contours of the top of the Decorah Shale for Fillmore County, Minnesota with groundwater flow paths as defined by dye tracing. Highlighted springsheds "A" are Fountain and Mahoney (Fig. 4), "B" are Waterhole and Wykoff springsheds (Fig. 5), and "C" are Starless River and Cold Spring springsheds (Fig. 6).

Fig. 3. Stratigraphic column for southeastern Minnesota with representative natural gamma log (after Mossler, 2008).



To investigate the application of structural mapping in dye trace interpretation we started our investigation in the Minnesota County with the richest record of dye tracing. Figure 2 portrays the Decorah shale top elevation across Fillmore County, Minnesota. The Decorah shale is a regionally important aquitard that separates the two major Ordovician carbonate systems in Minnesota. The upper aquifer includes the Maquoketa Formation, and Galena Group as depicted in Figure 3. The lower major carbonate unit is the Prairie du Chien Group which is bounded by the St. Peter and Jordan Sandstones.

The Minnesota County Well Index (CWI) contains driller's records for water wells throughout Minnesota and is maintained by the Minnesota Department of Health. Over 2,500 CWI records from Fillmore County were compared with fifteen gamma logs recorded by the Minnesota Geological Survey. Gamma logs record the emission of natural gamma radiation produced primarily from potassium (K) in minerals. Shales are often rich in K-feldspar minerals while quartz sandstones have almost no potassium (Runkel et al., 2003). In Figure 3 increasing gamma radiation, and correlated shale content, is depicted on the right side of the figure. Higher potassium produces a stronger signal shifting the natural gamma signal to the right. Representative stratigraphic thicknesses for individual units within a given area were determined from gamma log records.

This detailed stratigraphic information was then used to interpret CWI well logs in greater detail than based on driller's records alone. In particular, the top of the Decorah shale is a gradational contact with the Cummingville Formation which is composed of shales interbedded with carbonates. The top of the Decorah is therefore very difficult for well drillers to consistently pick and record. However, the Cummingsville/Decorah contact shows up clearly on gamma logs where continuous shales are observed. Drillers, however, are very adept at identifying the Glenwood/St. Peter contact where they drill through shale into clean sandstone. By adding the thickness of Glenwood, Platteville and Decorah to the Glenwood/St. Peter elevation we can determine the top of Decorah elevation for the selected well.

Determinations of the Decorah shale top elevation for 293 wells in Fillmore County are represented by the dots in Figure 2. The contours were generated by kriging interpolation in ArcMap™, v. 9.1. The groundwater flow path lines are from dye traces conducted over the past thirty years (Alexander et al., 1995).

STRUCTURALLY CONTROLLED SPRINGSHEDS

Two Fillmore County study areas exhibiting structural control of groundwater movement in the upper carbonate aquifer are used as an example of the structural method. The Fountain and Mahoney Springsheds of north-central Fillmore County are shown in Figure 4. In this portion of Fillmore County the Galena Group is found high on ridges separated by deeply entrenched bedrock valleys. The valley floors cut well into the Prairie du Chien Group and Jordan Sandstones. This creates aquifers with thin saturated thickness near the bottom of the Galena. The boundaries of the springsheds were drawn based on past dye traces.

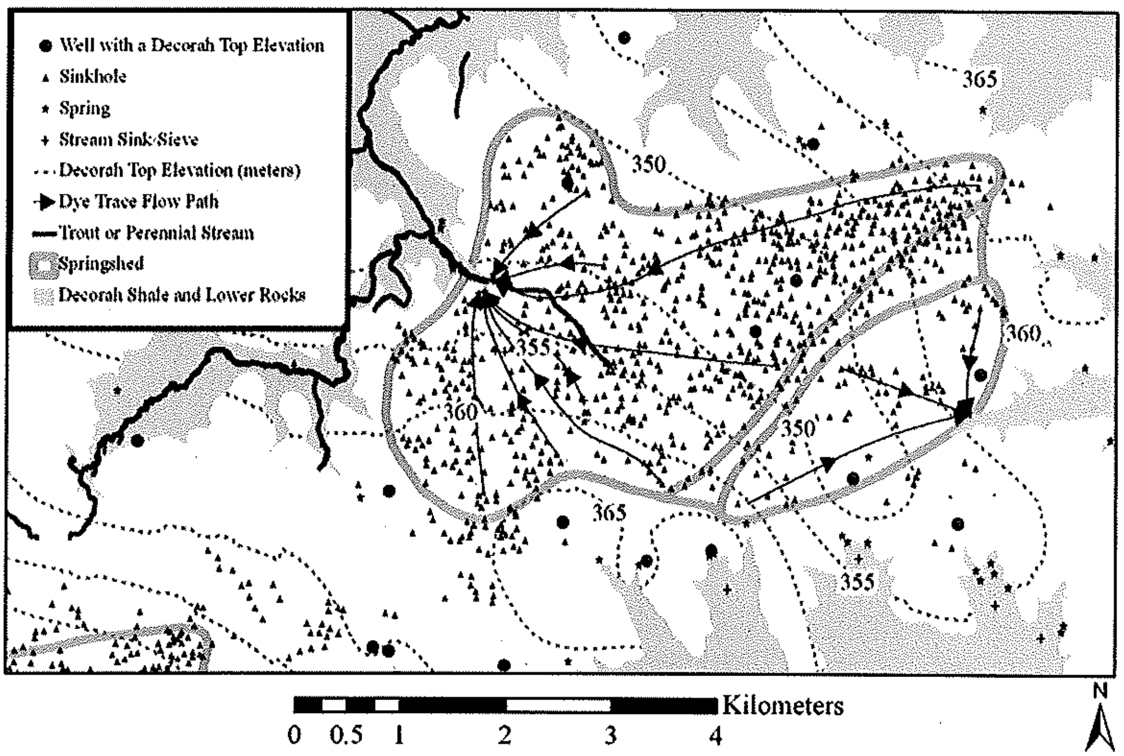


Fig. 4. Fountain (west) and Mahoney (east) springsheds.

Flow paths and springshed boundaries appear to follow structural controls within the rock formations for these basins. In the Fountain springshed flow originates from a structural high on the south side of the basin at 365 meters flowing north and west to a discharge point at Fountain Big Springs. However the northern portion of the Fountain basin appears to flow up dip to the same springs. This anomaly may be due to the groundwater flow paths in Galena systems which typically follow high gradient paths initially (including free fall waterfalls) to lower level, very low gradient paths that terminate in springs just above the Decorah shale. Alternatively, the density of data points constraining the structural mapping is low suggesting that flow on the sub-springshed scale may be controlled by small scale structural features. This knowledge then enables us to extend springshed boundaries and to better design future dye traces in adjacent basins.

A second example of structural control can be found a few kilometers southwest of the Fountain and Mahoney springsheds near the town of Wykoff (Figure 5). The Waterhole and Wykoff springsheds show perhaps an even stronger structural control. Water in both basins flows from a structural high of about 340 meters in the eastern portion of Figure 5 towards Mahoods Valley. Large springs found on the west side of Mahoods Valley are fed by the Waterhole springshed to the south. Springs on the east side of Mahoods Valley capture water from the Wykoff springshed to the east.

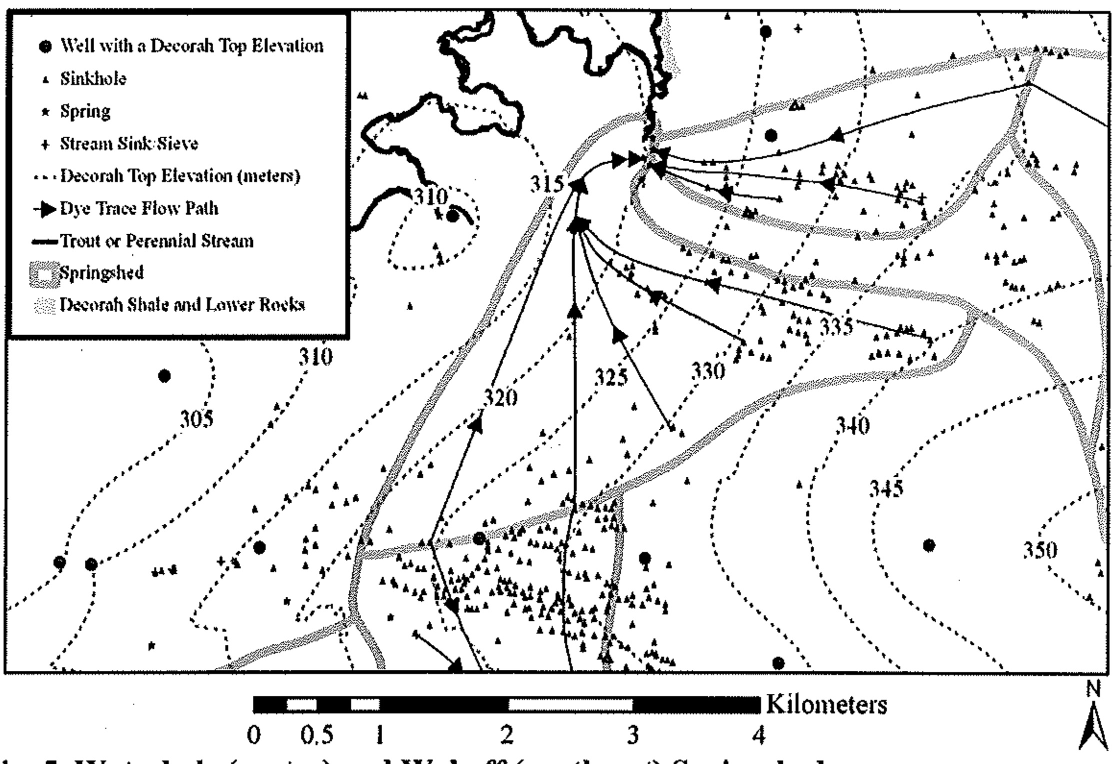


Fig. 5. Waterhole (center) and Wykoff (northeast) Springsheds.

While there is generally good agreement of dye trace vectors with structural control there are some discrepancies. In particular, as flow approaches the west side of Mahoods Valley in the Waterhole springshed it makes a sharp turn to the east flowing apparently up dip. Since the bottom of Mahoods Valley cuts into the Decorah shale aquitard we know the springs on the west side of the valley have to make a loop to the south. A simple explanation may be found in the density of data used to construct the structural contours. Note the round circles in Figure 5 which denote wells that had top of Decorah elevation. While there are eleven wells within Figure 5 none of them are immediately in Mahoods Valley. Additional, detailed mapping of surface outcrops in Mahoods Valley could be used to add additional structural information.

HYDRAULICALLY CONTROLLED SPRINGSHEDS

The Cold Spring and Starless River springsheds of southwestern Fillmore County are shown in Figure 6. The larger Starless River springshed flows to the northeast almost perfectly against the structural dip. Similarly the smaller Cold Spring springshed flows up dip. In this southwest area of Fillmore County the regional base-level river, the Root River, is not incised through the Galena Group creating thicker saturated aquifer conditions in the Galena. Thick saturated conditions may reduce the sensitivity of groundwater flow to underlying bedrock structures. The flow paths are therefore more dependent on the regional water table than on subsurface structures. Both the structurally controlled and hydraulically controlled Galena springsheds typically yield groundwater flow velocities of kilometers per day and dye pulses that are a few hours to a day wide with a small but characteristic exponential tail.

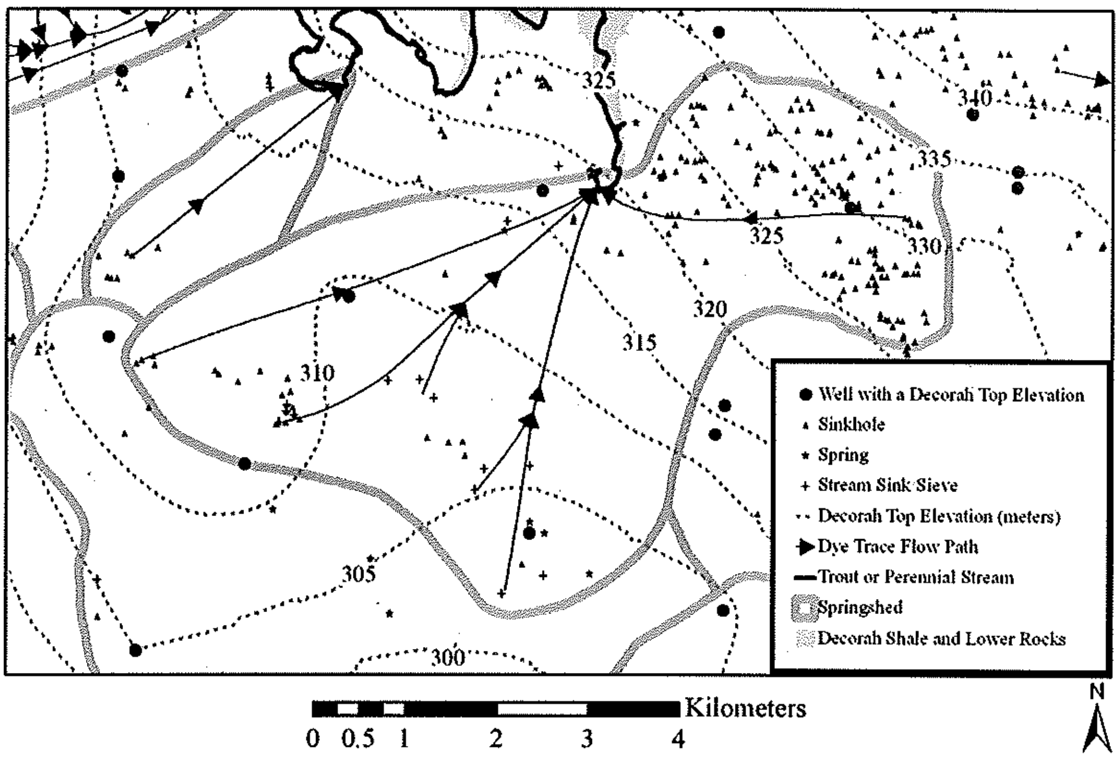


Fig. 6. Starless River (center) and Cold Spring (northwest) hydraulically controlled springsheds.

FUTURE WORK

Of the hundreds of Minnesota dye traces conducted over the last thirty years only six, including a new trace by Green et al. (in this proceedings volume), have been conducted in the lower Ordovician/upper Cambrian aquifer system. This lower portion of the stratigraphic section exhibits distinctly fewer surficial karst features than the Galena karst. However, the lower aquifer feeds significantly more trout streams, and several fish hatcheries. The lower aquifer is hydrologically more complex than the Galena since it encompasses interbedded sequences of coarse clastics (sandstones), fine clastics (shales) and carbonates while the Galena lacks coarse clastics (Runkel et al., 2003).

The logistics of dye tracing in these stratigraphically lower units and the resulting dye breakthrough curves are more complex. The leading edges of the dye pulses have been observed to travel with speeds ranging from kilometers per day to kilometers per year. The dye pulses are complex, often weeks to months wide, often contain multiple peaks and some respond to recharge events with repeated dye pulses.

Dye tracing becomes logistically more difficult as transit times of kilometers per day in the Galena increase to kilometers per year in the Prairie du Chien. The result is that it will be difficult to conduct hundreds of dye traces in the lower aquifer system. Future dye tracing efforts in this part of the geologic section will have to be conducted with significantly more planning and forethought. Individual tracing dyes may take years to flush out of the aquifer system severely limiting the number of dye traces that can be conducted in a given area to number of different tracing materials available. By applying supplemental geologic and hydrologic tools dye traces can be conducted more efficiently and be better designed to answer relevant questions on the first dye tracing attempt.

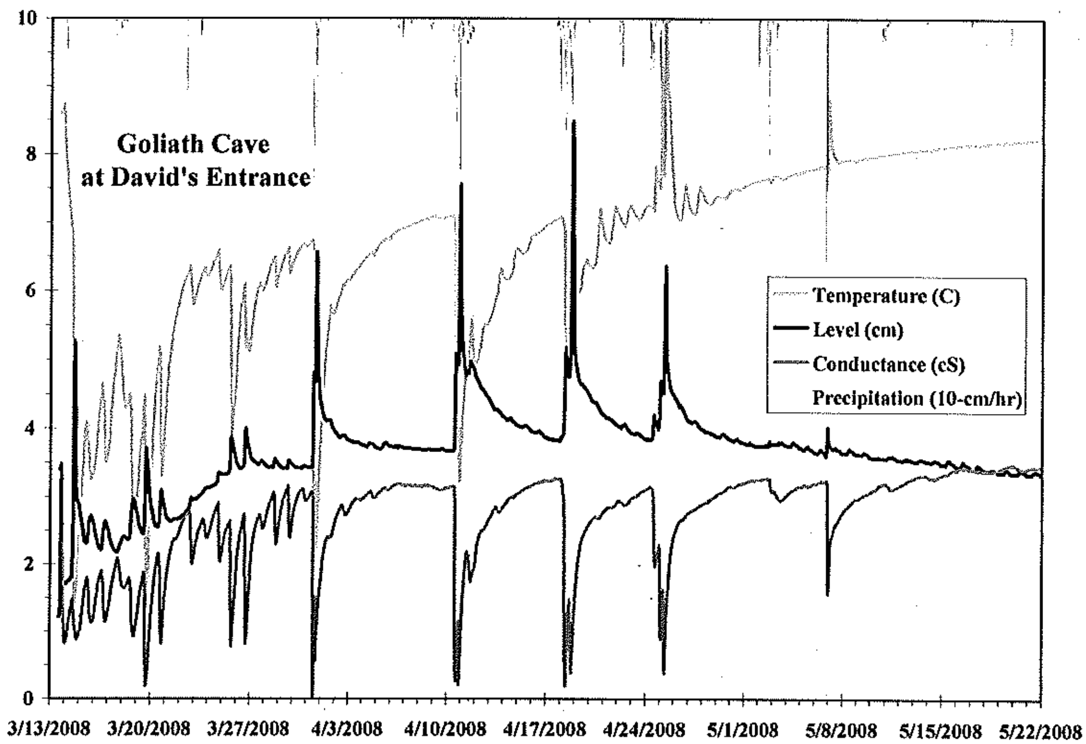


Fig. 7. Stream hydrograph (black line) from Goliath Cave, Minnesota with temperature (light gray), conductance (dark gray) and precipitation (thin gray).

Additional tools beyond structural mapping include temperature and conductivity monitoring in addition to traditional hydrographs. High resolution measurements, at the scale of minutes or seconds, allow separation of the hydrograph. Figure 7 is a hydrograph from a conduit passage in Goliath Cave, Minnesota. The spring snowmelt started in mid-March with a daily freeze thaw cycle that produces a strong daily signal in temperature, conductance and water level. Spring rain storms generate spike inputs with normal recession curves. As plant growth begins to pick up a small scale sinusoidal fluctuation appears in early May. Each of these three hydrologic effects provide information on the connectivity and rate of movement between surficial and soil waters as they recharge the groundwater system. Estimated recharge rates combined with total spring discharge can also be used to estimate basin area (Peters et al., 2006). The estimated basin area can then be compared to structural mapping to help define springsheds which can then be tested by dye tracing.

SUMMARY

Previous studies of southeastern Minnesota karst had focused almost entirely on dye tracing. While an invaluable tool for springshed delineation, dye tracing alone cannot be extended across the area of interest in a timely fashion. As pressures on our natural resources, including trout streams, have grown exponentially our knowledge of how to protect these resources have grown only at a slow linear pace.

The results presented here for the Galena karst system leverage existing dye trace data with water well driller's records and down hole gamma logging. The combination of these tools should lead to a better understanding of the overall flow system and greatly facilitate future dye tracing efforts in the Galena karst.

Springs originating from Lower Aquifer System including the St. Peter, Prairie du Chien, Jordan and St. Lawrence are a much less understood but even more important resource with regard to trout streams. At only six dye traces to date we are many years behind efforts in the overlying Galena karst. Tools and techniques that we have used to define the Galena karst system can be extended to the lower aquifer system, hopefully greatly accelerating the pace of springshed delineation.

ACKNOWLEDGEMENTS

Funding for this project was provided by Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR) and the Minnesota Department of Natural Resources - Division of Waters.

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2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Intra-Lake Zoning to Protect Sensitive Lakeshore Areas
PROJECT MANAGER: Paul Radomski
AFFILIATION: Minnesota DNR
MAILING ADDRESS: 1601 Minnesota Drive
CITY/STATE/ZIP: Brainerd, MN 56401
PHONE: 218-833-8643
FAX: 218-828-6043
E-MAIL: paul.radomski@state.mn.us
WEBSITE: http://www.dnr.state.mn.us/eco/sli
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 5(h).
Appropriation Language: $110,000 is from the trust fund to the commissioner of natural resources in cooperation with Cass County to identify sensitive shorelines of the highest priority lakes to protect water quality and near-shore habitat through improved shoreland zoning by Cass County.

APPROPRIATION AMOUNT: $110,000

Overall Project Outcome and Results
Minnesota's lakes are one of its most valuable resources. In particular, naturally vegetated shorelines provide feeding, nesting, and breeding habitat for many species. These areas, defined by natural and biological features that provide unique or critical ecological habitat, are known as sensitive lakeshores. Increasing development pressure within shorelands may have negative impacts on these sensitive areas – and Minnesota's shorelands are being developed at a rapid rate.

With this in mind, the Minnesota Department of Natural Resources developed a protocol for identifying sensitive lakeshores. The project focused on seventeen high priority lakes, identified by Cass County. These lakes represent some of the county's most valuable waters – large lakes with significant undeveloped shorelands. Protocol to identify sensitive lakeshores consists of several components.

- Field surveys evaluate the distribution of high priority plant and animal species.
- An ecological spatial model, based on scientific data, ranks lakeshore areas for sensitive area designation. The model provides objective, repeatable results that can be used as the basis for regulatory action.

Field surveys were conducted on all seventeen high priority lakes as well as three connecting lakes. Sensitive lakeshore area assessments were completed on nine high priority lakes. Reports summarizing these assessments were delivered to Cass County and interested organizations that could use the information to maintain high quality environmental conditions. To date, 48 miles of shoreline (approximately 36 percent of total surveyed shoreline miles) have been identified as sensitive lakeshore. Cass County is working to develop provisions in their land use ordinance that will require conservation-oriented development standards for sensitive areas. They will then propose and implement resource protection zoning districts. These resource protection districts will help promote healthy near-shore communities and protect critical fish and wildlife habitat.

Project Results Use and Dissemination
Nine Sensitive Lakeshore Reports were produced, and these reports are posted on the project's website. Public presentations were made explaining the project and the details of the sensitive lakeshore reports to the Cass County Board of Commissioners, the Cass County Planning Commission, the Association of Cass County Lake Associations, U.S. Forest Service, seven lake associations, and several interested groups and organizations. Cass County will hold public hearings on shoreland ordinance revisions and reclassifications in an effort to protect identified sensitive lakeshores, and all required processes for public input, review, and comment will be adhered to, including the rights afforded to challenge such ordinance and zoning district changes.

Trust Fund 2007 Work Program Final Report

Date of Report: August 17, 2009 (final report)
Date of Work program Approval: 2007 5(h) 6/5/07
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Intra-Lake Zoning to Protect Sensitive Lakeshore Areas

Project Manager: Paul Radomski
Affiliation: Minnesota DNR
Mailing Address: 1601 Minnesota Drive
City / State / Zip : Brainerd, MN 56401
Telephone Number: 218-833-8643
E-mail Address: paul.radomski@dnr.state.mn.us
Fax Number: 218-828-6043
Web Page address: http://www.dnr.state.mn.us/eco/sli
Location: Cass County

Total Trust Fund Project Budget: 2007
Trust Fund Appropriation: $110,000
Minus Amount Spent: $110,000
Equal Balance: $0

Legal Citation:
ML 2007, Chap. 30, Sec. 2, Subd. 5(h).
Appropriation Language: $110,000 is from the trust fund to the commissioner of natural resources in cooperation with Cass County to identify sensitive shorelines of the highest priority lakes to protect water quality and near-shore habitat through improved shoreland zoning by Cass County.

II. and III. FINAL PROJECT SUMMARY:

Minnesota's lakes are one of its most valuable resources. In particular, naturally vegetated shorelines provide feeding, nesting, and breeding habitat for many species. These areas, defined by natural and biological features that provide unique or critical ecological habitat, are known as sensitive lakeshores. Increasing development pressure within shorelands may have negative impacts on these sensitive areas – and Minnesota's shorelands are being developed at a rapid rate.

With this in mind, the Minnesota Department of Natural Resources developed a protocol for identifying sensitive lakeshores. The project focused on seventeen high priority lakes, identified by Cass County. These lakes represent some of the county's most valuable waters – large lakes with significant undeveloped shorelands. Protocol to identify sensitive lakeshores consists of several components.

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Field surveys were conducted on all seventeen high priority lakes as well as three connecting lakes. Sensitive lakeshore area assessments were completed on nine high priority lakes. Reports summarizing these assessments were delivered to Cass County and interested organizations that could use the information to maintain high quality environmental conditions. To date, 48 miles of shoreline (approximately 36 percent of total surveyed shoreline miles) have been identified as sensitive lakeshore. Cass County is working to develop provisions in their land use ordinance that will require conservation-oriented development standards for sensitive areas. They will then propose and implement resource protection zoning districts. These resource protection districts will help promote healthy near-shore communities and protect critical fish and wildlife habitat.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Identify and Map Sensitive Shorelands

Description: Conduct comprehensive field surveys of aquatic and near-shore habitat and animal presence using Minnesota's Lakeshore Sensitive Area Survey Protocol. Surveys will be completed for 17 of the highest priority lakes in Cass County. Ecological models will be used to assist in the determination of sensitive areas. Criteria in a spatial ecological model will come from the science-based surveys, and the value of the shoreland with regard to aquatic habitat and vulnerability to water quality degradation will be objectively assessed. Lake-specific reports and digital GIS files will be produced and delivered to Cass County.

Summary Budget Information for Result 1:

	2007
Trust Fund Budget:	**$110,000**
Amount Spent:	**$110,000**
Balance:	**$0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. 4 lakes surveyed & mapped	Jun 2008	$58,000	complete
2. 5 lakes surveyed & mapped	Jun 2009	$60,000	complete
3. map critical habitat on Leech Lake	Jun 2010	$37,000	
4. 7 lakes surveyed & mapped	Jun 2010	$70,000	

Final Report Summary: Nine lake survey surveys were completed (Ada, Birch, Little Boy, Long, Pine Mountain, Pleasant, Ten Mile, Woman, and Wabedo lakes). Sensitive lakeshore maps were made for all lake surveyed. Summaries for each lake follow.

Ada Lake: Plant surveys documented 48 native aquatic plant taxa within Ada Lake, including eight unique species of high conservation importance. Aquatic plants occurred around the entire shoreline of Ada Lake, and included 29 submerged, two free-floating, four floating-leaved, and 13 emergent taxa. Within the shore to 20 feet depth zone, 93 percent of the sample sites contained vegetation. Surveyors mapped over 40 acres of waterlily beds and 10 acres of emergent bulrush.

Twenty-seven fish species were identified during the nongame fish surveys, including four species not previously documented within Ada Lake. No fish species of greatest conservation need were detected. Both green and mink frogs were documented, with the majority found in North Bay and Little Ada Bay.

Bird surveyors documented 61 species of birds, 12 of which were species of greatest conservation need. Red-eyed vireos were the most commonly documented species, whereas the veery was the most commonly found species of greatest conservation need. The bays, in particular, provided good habitat for the bird species of greatest conservation need.

An ecological model based on major conservation principles was used to assess lakeshore sensitivity. The ecological model identified one primary sensitive lakeshore area to be considered for potential resource protection districting by Cass County. The inlet of Ada Lake was also identified as an important ecological connection.

Birch Lake: Aquatic plants occurred around the entire perimeter of Birch Lake, with the greatest concentrations in shallow areas, such as the southeast basin and small bays. A total of 48 native aquatic plant taxa were recorded in Birch Lake and included 11 emergent, six floating-leaved and 31 submerged and free-floating plant taxa. Submerged plants occurred to a depth of 29 feet but were most common in the shore to 15 feet depth zone, where 87 percent of the sample sites contained vegetation. Floating-leaf plants occupied about 50 acres and were mostly located in protected bays of the northwest basin. Emergent plants occupied about 47 acres and were located mainly along shallow sandy shorelines. Seven unique plant species were documented during the surveys.

One fish species of greatest conservation need (pugnose shiner) was identified at Birch Lake. Seven fish species previously undocumented in this lake were identified during this study, bringing the total historical observed fish community to 30 species. Bluegills were the most abundant fish species found. Both mink and green frogs were detected; they were closely associated with the presence of waterlily beds.

Surveyors documented 72 species of birds, including 13 species of greatest conservation need. Song sparrows were the most abundant bird species overall, whereas the veery was the most commonly detected species of greatest conservation need. Although distribution of several species was restricted to the bays, others were found along the shoreline of the main basin as well.

An ecological model based on major conservation principles was used to assess lakeshore sensitivity. The ecological model identified two primary sensitive lakeshore areas to be considered for potential resource protection districts by Cass County. The Boy River between Birch Lake and Ten Mile Lake was identified as an important ecological connection.

Little Boy, Wabedo, and Louise Lakes: Plant surveyors recorded a total of 39 aquatic plant taxa in Little Boy, Wabedo, and Louise Lakes. Plants occurred to a maximum depth of 19 feet (in Louise Lake), but were most common in the shore to 10 feet depth zone, where 90 percent of the sample sites contained vegetation. Common submerged aquatic plants included large algae and several pondweed species. Surveyors also mapped approximately 308 acres of emergent and floating-leaf plants and common plants were bulrush, wild rice and waterlilies. Unique plant species included both submerged and emergent aquatic plants.

Two fish species of greatest conservation need, the pugnose shiner and greater redhorse, were identified on this group of lakes. A number of previously undocumented fish species were identified at each of the lakes; surveyors documented 11 new species at Little Boy Lake and 8 new species at Wabedo Lake. The nongame fish surveys conducted on Louise Lake were the first fish surveys on that lake, and surveyors documented 11 species. In total, 35 fish species were documented during the nongame fish surveys. Green frogs were identified at numerous locations on both Little Boy and Wabedo Lakes.

Surveyors documented 87 species of birds on the three lakes, including 19 species of greatest conservation need. Wabedo Lake had the highest species count (80 species), followed by Little Boy Lake (64 species) and Louise Lake (34 species). Ovenbirds were the most commonly detected species of greatest conservation need, whereas red-eyed vireos were most abundant overall.

An ecological model based on major conservation principles was used to assess lakeshore sensitivity. The ecological model identified four primary sensitive lakeshore areas to be considered for potential resource protection districts by Cass County. The major inlets and outlets, as well as Louise Lake and the channel connecting the three lakes, were identified as important ecological connections.

Long Lake: Aquatic plants occurred around the entire shoreline. A total of 45 native aquatic plant taxa were recorded in Long Lake, including 29 submerged, five floating-leaved and 11 emergent taxa. Submerged plants occurred to a depth of 30 feet but were most common in the shore to 15 feet depth zone where 96 percent of the sample sites contained vegetation. Rooted submerged plants were most common in water depths of 15 feet and less, while large algae and moss were frequent in the 16 to 25 feet depth zone. Emergent and floating-leaf plants were abundant in most bays and covered approximately 34 acres. Several unique plants and a rare (Special Concern) submerged plant were documented during the surveys, and indicate a relatively undisturbed native plant community in Long Lake.

Twenty-two different fish species were identified during the survey, including nine species not previously documented in the lake. No fish species of greatest conservation need were observed, but surveyors did find three proxy species (blackchin shiner, blacknose shiner, and banded killifish). Both mink and green frogs were detected, with the majority located within or near protected bays.

Surveyors documented 66 species of birds, including 13 species of greatest conservation need. Song sparrows were the most frequently detected species overall, whereas ovenbirds were the most commonly detected species of greatest conservation need. Bird species were distributed both within the bays and along the shoreline of the main basins.

An ecological model based on major conservation principles was used to assess lakeshore sensitivity. The ecological model identified three primary sensitive lakeshore areas to be considered for potential resource protection districts by Cass County.

Pine Mountain Lake: Forty native aquatic plant species were recorded in Pine Mountain Lake, including 13 emergent, five floating-leaved, two free-floating and 20 submerged plants. Submerged plants were found to a depth of 20 feet but were most common from shore to the 10 feet depth where 95 percent of the sample sites contained vegetation. Emergent and floating-leaf plant beds ringed the lake and covered about 303 acres, or about 20 percent of the lake. Approximately 153 acres of bulrush (Schoenoplectus spp.), 105 acres of wild rice (Zizania palustris) and 45 acres of white and yellow waterlilies (Nymphaea odorata and Nuphar variegata) were mapped. Two unique aquatic plants, water arum (Calla palustris) and wiregrass sedge (Carex lasiocarpa), were documented during the surveys.

Eleven fish species previously not documented on Pine Mountain Lake were identified during the nongame fish surveys. These species were blackchin shiner, brook stickleback, central mudminnow, emerald shiner, golden shiner, Iowa darter, mimic shiner, mottled sculpin, spotfin shiner, spottail shiner, and tadpole madtom. Twenty-eight fish species were identified during the surveys, bringing the total historical observed fish community to 33 species. Mink frogs and green frogs were both documented on Pine Mountain Lake.

Seventeen bird species of greatest conservation need were identified at Pine Mountain Lake. Sixty additional species were documented, for a total of 77 bird species. Swamp sparrows and common loons were the most commonly documented species of greatest conservation need. Yellow warblers, red-winged blackbirds, and song sparrows were the most commonly identified species overall; surveyors documented each of these species at over 75 percent of the sample sites.

An ecological model based on major conservation principles was used to assess lakeshore sensitivity. The ecological model identified one primary sensitive lakeshore area to be considered for potential resource protection districts by Cass County. Several rivers and streams near Pine Mountain Lake were identified as important ecological connections.

Pleasant Lake: Plant surveyors documented 46 native aquatic plant taxa within Pleasant Lake. These aquatic plants occurred around the entire shoreline of Pleasant Lake and included 11 emergent, five floating-leaved, and 30 submerged and free-floating taxa. Plants were found to a water depth of 20 feet. This vegetated zone includes about two-thirds of the lake and within this area 88 percent of the survey sites contained vegetation. Surveyors mapped over 25 acres of waterlilies and seven acres of emergent plants such as wild rice and bulrush. Six unique plant species were documented during the surveys.

Four fish species not previously recorded in Pleasant Lake were identified during the fish surveys. These newly documented species were central mudminnow, mottled sculpin, pugnose shiner, and tadpole madtom. Twenty-nine species were identified during the nongame fish surveys, bringing the total observed historical fish community to 35 species. Both mink frogs and green frogs were documented on Pleasant Lake.

Surveyors documented 73 species of birds, including 13 species of greatest conservation need. Song sparrows were the most abundant bird species overall, whereas common loons were the most commonly detected species of greatest conservation need. Bird species were distributed both within the bays and along the shoreline of the main basin.

An ecological model based on major conservation principles was used to assess lakeshore sensitivity. The ecological model identified two primary sensitive lakeshore areas to be considered for potential resource protection districts by Cass County. The Boy River as it enters and exits Pleasant Lake was identified as an important ecological connection.

Ten Mile Lake: Plant surveys revealed a rich, diverse plant community. A total of 48 native aquatic plant taxa were recorded, making Ten Mile Lake among the richest lake plant communities in the state. Eleven plant species previously undocumented in this lake were collected for this survey. Plants occurred around the entire perimeter of Ten Mile Lake but were more concentrated within the bays where 84 percent of the survey sites contained vegetation compared to 54 percent of the sites in the main basin. Submerged plants occurred to a depth of 29 feet and included rooted flowering plants and large algae. Approximately 90 acres of bulrush and 50 acres of waterlilies occurred within the bays and along protected shorelines. Unique plant species included both emergent and submerged plants. Seven of these species were documented for the first time in Ten Mile Lake.

Five fish species previously undocumented in the lake were collected for this survey, bringing the total historical observed fish community to 38 species. The new species recorded included blackchin shiner, pugnose shiner, brook stickleback, least darter, and longear sunfish. Both mink and green frogs were observed, with the vast majority found in the sheltered bays.

Surveyors documented 82 species of birds, including 17 species of greatest conservation need. Red-eyed vireos were the most abundant bird species overall, whereas the veery was the most commonly detected species of greatest conservation need. Although distribution of several species was restricted to the bays, others were found along the shoreline of the main basin as well.

An ecological model based on major conservation principles was used to assess lakeshore sensitivity. The ecological model identified five primary sensitive lakeshore areas to be considered for potential resource protection districts by Cass County.

Woman Lake: Plant surveys revealed a rich, diverse plant community. A total of 41 native aquatic plant taxa were recorded, making Woman Lake among the richest lake plant communities in the state. Plant growth was sparse in the main lake but within Broadwater Bay, Lantern Bay and Bungey Bay, 70% of the sites were vegetated. Common submerged plants included muskgrass, narrow-leaf and broad-leaf pondweeds, wild celery, Canada waterweed, and coontail. Approximately 180 acres of wild rice, 17 acres of bulrush and 16 acres of mixed waterlily beds occurred within Lantern Bay and Broadwater Bay. Unique aquatic plants were identified at 18 sampling stations. Plants included small bladderwort species (Utricularia intermedia, U. gibba, and U. minor), water arum (Calla palustris), and wiregrass sedges (Carex oligosperma and C. lasiocarpa). Five of these species were documented for the first time in Woman Lake.

Two fish species of greatest conservation need (pugnose shiner and longear sunfish) were documented in Woman Lake. A total of 30 fish species were found during the 2006 surveys, bringing the total documented fish community at Woman Lake to 39 species. Surveyors identified four species (blacknose shiner, pugnose shiner, spotfin shiner, and central mudminnow) not previously documented at Woman Lake. Both mink and green frogs were observed, with the vast majority found in the sheltered bays. Surveyors documented 62 species of birds, including 11 species of greatest conservation need. Red-eyed vireos were the most abundant bird species overall, whereas the veery was the most commonly detected species of greatest conservation need. Although distribution of several species was restricted to the bays, others were found along the shoreline of the main basin as well.

An ecological model based on major conservation principles was used to assess lakeshore sensitivity. The ecological model identified several primary sensitive shoreland areas to be considered for a potential resource protection district by Cass County. Two rivers were also identified as important ecological connections.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $79,000; one unclassified Natural Resource Specialist (Nongame Wildlife Biologist)
Equipment: $31,000
Development: $ 0
Restoration: $ 0
Acquisition, including easements: $ 0

TOTAL TRUST FUND PROJECT BUDGET: $110,000

Explanation of Capital Expenditures Greater Than $3,500: From the 2007 appropriation, $16,000 for one watercraft suitable for electrofishing, seining and trap deployment -- This equipment will continue to be used for its useful life within the DNR for comprehensive field surveys of aquatic and near-shore habitat and animal presence.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: Cass County, Environmental Services Department, John Sumption, Director. Leech Lake Reservation, Division of Resources Management (LLRDRM), John Ringle

B. Other Funds Proposed to be Spent during the Project Period: Four other funds will likely be spent to complete the project. Federal funding via a State Wildlife Grant (SWG) for FY09 in the amount of about $150,000 was used. State funding to the Minnesota Department of Natural Resources, Division of Ecological Resources for FY09 and FY10 was also used. Cass County funded their activities related to this project ($25,000 to $35,000 per year in inkind value), and LLRDRM funded their activities ($5,000 to $10,000 in inkind value for field surveys).

C. Past Spending: SWG: $115,000 in FY09 state match; SWG: $150,000 in FY08; State: $150,000 in FY08. SWG: $135,000 in FY07; State: $150,000 in FY07 used to develop survey protocol. DNR staff provided additional technical advice to Cass County in FY06.

D. Time: This is a multi-year project ending on June 30, 2011 (includes appropriation from ML 2008, Chap. 367, Sec. 2, Subd. 4(e)). Several openwater seasons are needed to complete field surveys. Implementation of revised zoning ordinances in Cass County extends through FY11.

VII. DISSEMINATION: Nine Sensitive Lakeshore Reports were produced (Ada, Birch, Little Boy, Long, Pine Mountain, Pleasant, Ten Mile, Woman, and Wabedo lakes), and these reports are posted on the project's website. Public presentations were made explaining the details of these reports. Cass County will hold public hearings on shoreland reclassifications, and all required processes for public input, review and comment will be adhered to, including the rights afforded to challenge such ordinance and zoning district changes.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than January 2008, November 2008, March 2009, November 2009, March 2010, and November 2010. A final work program report and associated products will be submitted by August 2011.

Exhibit A. Intra-lake Zoning to Protect Sensitive Lakeshore Areas. List of lakes and completed survey work using Minnesota's Lakeshore Sensitive Area Survey Protocol.

LAKE	DOWLKNUM	ACRES	% Shoreline that is Private and is in Large Parcels	Grid Aquatic Plant Survey	Emergent & Floating-leaf Beds Delineated from aerial photos	Bulrush Beds Mapped	Shoreline Habitat Plots	Frog Survey	Fish Survey	Bird Survey	Potential Sensitive Areas fowarded to County	Sensitive Area District established County
Leech	11020300	109415		2002-2005	yes	2008-*10*		2007-*09*			2011	
Woman	11020100	5360	16	2006	yes	AF	2006-07	2006	2006	2007	2008	
Ten Mile	11041300	4640	26	2006	yes	AF	2006-07	2006	2006	2007	2008	
Birch	11041200	1262		2006	yes	2006	2006-07	2007	2007	2008	2009	
Long	11014200	926		2007	yes	2007	2007	2007	2007	2008	2009	
Little Boy	11016700	1396	32	2007	yes	2007	2007	2007	2007	2008	2009	
Louise*	11057300	22		2007	yes				2007	2008	2009	
Wabedo	11017100	1272	32	2007	yes	2007	2007	2007	2007	2008	2009	
Ada	11025000	1044	7	2007	yes	2007	2007	2007	2007	2008	2009	
Pine Mountain	11041100	1657	41	2007	yes	2007	2008	2008	2007	2008	2009	
Pleasant	11038300	1038	38	2007	yes	2008	2008	2008	2007	2008	2009	
Washburn	11005900	1768		2006	yes	AF - 2008	2007	2007	2007	2009	2010	
Thunder	11006200	1316	42	2008	yes	2008	2008	2008	2008	2009	2010	
Boy	11014300	3404		2008	yes	2008		2008	2008	2009	2010	
Roosevelt	11004300	1561	9	2008	yes	2008	2008	2009	2008	2009	2010	
Lawrence*	11005300	224		2008	yes	2008		2009	2008	2009	2010	
Deep Portage*	11023700	129		2008	yes	2008	2008	2009	2008	2009	2010	
Sylvan	11030400	882		2008	yes	2008		2009	2008	2009	2010	
Big Portage	11030800	956		2008	yes	2008		2009	2008	2009	2010	
Steamboat	11050400	1761	38	2008	yes	2008	2008	2009	2008	2009	2010	

KEY (with year completed, in progress, or planned noted):		
		completed
		sampled this year
		future survey work
		not completed or planned
	AF	DNR Fisheries data
	yes	non-field work that was completed
	*	Added lakes

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: *Intra-Lake Zoning to Protect Sensitive Lakeshore Areas, [2007: Subd. 5(h)]*

Project Manager Name: *Paul Radomski*

Trust Fund Appropriation: $ *110,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet
2) Remove any budget item lines not applicable

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent (06/30/2009)	Balance (06/30/2009)	Result 2 Budget:	Amount Spent (06/30/2009)	Balance (06/30/2009)	Result 3 Budget:	Amount Spent (06/30/2009)	Balance (06/30/2009)	TOTAL BUDGET	TOTAL BALANCE
	Identify and Map Sensitive Shorelands			*Cass County Ordinance Development and Adoption for Sensitive Shorelands*			*Propose and Implement Zoning Districts for Sensitive Areas*				
BUDGET ITEM			0			0			0	0	0
PERSONNEL: wages and benefits	84,000	91,989	-7,989			0	0		0	84,000	-7,989
Other direct operating costs *(fleet expenses)*	4,000	3,403	597			0			0	4,000	597
Capital Equipment (watercraft suitable for electrofishing, seining and trap deployment)	16,000	12,571	3,429			0			0	16,000	3,429
Equipment / Tools *(sampling equipment and biological supplies)*	6,000	2,037	3,963			0			0	6,000	3,963
Office equipment & computers - NOT ALLOWED unless unique to the project			0			0			0	0	0
Printing			0	0		0	0		0	0	0
Other Supplies *(education material and mailing)*			0			0			0	0	0
Travel expenses in Minnesota			0			0			0	0	0
Travel outside Minnesota *(where?)*			0			0			0	0	0
Other *(Describe the activity and cost)*						0			0	0	0
COLUMN TOTAL	**$110,000**	**$110,000**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$110,000**	**$0**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Water Resources Sustainability
Project Manager: John L. Nieber
Affiliation: Department of Bioproducts and Biosystems Engineering, University of Minnesota
Mailing Address: 1390 Eckles Ave.
City / State / Zip : St. Paul, MN 55045
Telephone Number: 612-625-6724
E-mail Address: nieber@umn.edu
FAX Number: 612-624-3005
WEBSITE: www.bbe.umn.edu
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, [Chap._30___], Sec.[__2__], Subd._5(i)____.

Appropriation Language: $292,000 is from the trust fund to the University of Minnesota to quantify sustainable supplies of surface and groundwater by integrating surface water, vadose zone, and groundwater systems into defined hydrologic units.

APPROPRIATION AMOUNT: $292,000

Overall Project Outcome and Results

To assure that our use of freshwater within Minnesota is sustainable into the indefinite future it is necessary to know beforehand the rate of renewal of our freshwater supplies on an annual basis. The rate of renewal of freshwater supplies is a measure of the limits of the natural system to sustain both human needs as well as the needs of nature (ecological services). This project quantified this rate of renewal across the state and related the rate to various characteristics of the local landscape. This quantification was achieved using streamflow records for gauged watersheds located throughout Minnesota. The final result is in the form of atlases of mean minimum annual groundwater recharge (the rate of annual renewal of the freshwater resource) at three different geographical scales; statewide, regional, and county. Regional atlases were developed for the east central, southeast, and south central regions of the state. County atlases were created for Pope, Lac Qui Parle and Olmsted counties. Based on these atlases and the MNDNR water permits a database was produced that will allow the quantitative comparison of renewable freshwater supply and the water demand for human use down to the scale of individual township sections. The database provides the information needed to assess freshwater sustainability on any desired geographical scale. The atlases and the database supplied by this project will be of value to water planners at all geographical levels. One limitation of the current results provided is that they do not account for changes that occur in time, and therefore do not account for possible effects of future climate change. This aspect is needed to provide additional information to water planners for consideration of the risks posed by climate change.

Project Results Use and Dissemination

1. To date the project results have been used for an assessment of siting of a gas-fired power plant in Chisago County. In this case John Nieber was requested by 'The Friends of the Sunrise' to speak to their group, and other interested citizens regarding to the availability of groundwater resources for projected use by the power plant. The Minnesota Environmental Quality Board used results from the precursor study in helping to formulate the EQBs 2008 report on water resources sustainability, and it is expected that the results of the current study will be used for similar statewide assessments in the future. Of course it is the hope of the PI and co-PI of the project that the results will be used by the MNDNR, the MPCA, and by other agencies in conducting water resource planning activities.
2. A website for the project exists at https://wiki.umn.edu/view/Water_Sustainability.
3. Many presentations have been made regarding this project every since the project began in 2007. A list of the presentations, both oral presentations and poster presentations, is given below.

J. Nieber, R. Kanivetsky, B. Shmagin, B. Wilson, and D. Mulla, Multi-scale quantitative mapping of recharge/discharge to ground water systems as related to freshwater sustainability in Minnesota, 2007 Minnesota Waters Conference, October 23-24. Results presented as a poster.

J. Nieber, Quantifying Water Resources Sustainability, Texas A&M University, Distinguished Speakers Series in the Department of Biological and Agricultural Engineering, October 16-18, 2007. No cost to project as TAMU provided complete funding for the trip.

J. Nieber, R. Kanivetsky, B. Shmagin, B. Wilson, and D. Mulla, Quantification of Water Resources Sustainability in Minnesota, 52nd Annual South Dakota Water Resources Conference, Sioux Falls, October 28-30, 2007. *This meeting provided the opportunity for us to present the methodology to a broader group of water resource managers and hydrogeologist coming from the upper Midwest region. Discussions stimulated by the presentations provided us with a means to further fine-tune the message regarding the methodology and justification for the work. An important presentation at the meeting given by Bill Allie (USGS, Reston, VA) was valuable to our effort since he spoke about the effects of mining of groundwater on flows in surface waters connected to aquifers. Cost to the project was $800. Roman Kanivetsky and John Nieber also met with Boris Shmagin (project partner) at the meeting to discuss the ongoing work.*

J. Nieber, R. Kanivetsky, B. Shmagin, B. Wilson, and D. Mulla, Regional hydrologic synthesis using a system model of watersheds: a new integrative tool to advance knowledge and predictability of hydrologic systems, 2007 Fall meeting of the American Geophysical Union, December 11-15. *At this meeting we were able to present to a national audience the conceptual development of the ideas of sustainability, and also a description of the methodology used for the project for quantifying water resource sustainability. The meeting also provided the opportunity for John Nieber to meet with Boris Shmagin (project partner) to discuss progress on the project. A presentation by a scientist from Sweden (Anders Worman) also gave some new ideas that we could use in the modeling the physical basis for hydrogeologic units. The cost was for John Nieber's travel, coming to $1,200.*

J. Nieber, R. Kanivetsky, B. Shmagin, D. Mulla, H. Peterson, and B. Wilson, Regional hydrologic synthesis using system model of watersheds; a new integrative tool to advance knowledge and predictability of hydrologic systems, presented at the 1st International Conference on

Hydropedology, Pennsylvania State University, State College, PA, July 28 – July 31, 2008. Given as an oral presentation by John Nieber and a poster presentation by Heidi Peterson. Total cost of travel for Nieber and Peterson was $1,850 - no cost to the project.

H. Peterson, J. Nieber, R. Kanivetsky, D. Mulla, F. Lahoud, B. Wilson, and B. Shmagin, Multi-scale quantitative hydrologic analysis of water resources sustainability: An integration of vadose zone, ground water and surface water systems. Oral presentation at the 2008 Fall meeting of the American Geophysical Union, San Francisco, December 14-19. This was an invited presentation. Total cost for Nieber and Peterson was $1,655 – no cost to project.

J. Nieber, R. Kanivetsky, H. Peterson, F. Lahoud, D. Mulla, and B. Shmagin, 2008. Atlases of Minnesota water sustainability: Creation from models, analytical methods, and databases of watershed characteristics, Midwest Groundwater Association, Dubuque, IA, 9/29/08-10/02/08. $450 – no cost to project.

H. Peterson, J. Nieber, R. Kanivetsky, B. Shmagin, and J. Wells, 2009. Atlases of water resources for Minnesota as a tool for sustainable community planning, 52nd Annual Great Lakes Research Conference, Toledo, OH, May 18-22. $1,030 – no cost to project.

J. Nieber, H. Peterson, R. Kanivetsky and B. Shmagin. Water resources sustainability and climate change in the Twin Cities Metropolitan Area. Oral presentation at the annual meeting of the University Council on Water Resources, July 7-9, 2009. Total cost for Nieber was $530 – no cost to project.

J.Nieber, H. Peterson, R. Kanivetsky, B. Shmagin, Assessment of the renewable flux for water resource sustainability with the watershed characterization method, Water Resources Center, University of Minnesota, June 30, 2009

J. Nieber, R. Kanivesky and B. Shmagin. Map of ground water recharge in the Twin Cities Metropolitan Area. Poster presentation at the annual meeting of the University Council on Water Resources, July 7-9, 2009. Total cost for Nieber was $530 – no cost to project.

J.Nieber, H. Peterson, R. Kanivetsky, B. Shmagin, Assessment of the renewable flux for water resource sustainability with the watershed characterization method, Minnesota Department of Natural Resources, September 9, 2009

H. Peterson, J. Nieber, R. Kanivetsky, B. Shmagin, Water resources sustainability and climate change in the Twin Cities Metropolitan Area, 2009 Minnesota Water Conference, October 26, 2009. No cost to project.

J. Nieber, H. Peterson, R. Kanivetsky, and B. Shmagin. Quantifying biophysical constraints of nature: Measuring renewable freshwater resources at multiple scales. Oral presentation at the International Workshop on International Cooperation for Data Acquisition, 90th American Meteorological Society (AMS) Annual Meeting, Atlanta, GA, January 16-21, 2010. Invited presentation. All travel expenses paid by the American Meteorological Society.

Trust Fund 2007 Work Program Final Report

Date of Report: originally submitted September 11, 2009 – revised March 15, 2010

Trust Fund 2007 Work Program Final Report

Date of Work program Approval:
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Water Resource Sustainability

Project Manager: John L. Nieber
Affiliation: Department of Bioproducts and Biosystems Engineering, University of Minnesota
Mailing Address: 1390 Eckles Ave.
City / State / Zip : St. Paul, MN 55045
Telephone Number: 612-625-6724
E-mail Address: nieber@umn.edu
FAX Number: 612-624-3005
Web Page address: https://wiki.umn.edu/view/Water_Sustainability

Location: University of Minnesota, St. Paul campus

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$** 292,000
	Minus Amount Spent:	**$** 292,000
	Equal Balance:	**$** 0

Legal Citation: ML 2007, [Chap._30___], Sec.[__2__], Subd._5(i)____.

Appropriation Language: $292,000 is from the trust fund to the University of Minnesota to quantify sustainable supplies of surface and groundwater by integrating surface water, vadose zone, and groundwater systems into defined hydrologic units.

II. and III. Final Project Summary.

To assure that our use of freshwater within Minnesota is sustainable into the indefinite future it is necessary to know beforehand the rate of renewal of our freshwater supplies on an annual basis. The rate of renewal of freshwater supplies is a measure of the limits of the natural system to sustain both human needs as well as the needs of nature (ecological services). This project quantified this rate of renewal across the state and related the rate to various characteristics of the local landscape. This quantification was achieved using streamflow records for gauged watersheds located throughout Minnesota. The final result is in the form of atlases of mean minimum annual groundwater recharge (the rate of annual renewal of the freshwater resource) at three different geographical scales; statewide, regional, and county. Regional atlases were developed for the east central, southeast, and south central regions of the state. County atlases were created for Pope, Lac Qui Parle and Olmsted counties. Based on these atlases and the MNDNR water permits a database was produced that will allow the quantitative comparison of renewable freshwater supply and the water demand for human use down to the scale of individual township sections. The database provides the information needed to assess freshwater sustainability on any desired geographical scale. The atlases and the database supplied by this project will be of value to water planners at all geographical levels. One limitation of the current results provided is that they do not account for changes that occur in time, and therefore do not account for possible effect of future climate change. This aspect is needed to provide additional information to water planners for consideration of the risks posed by climate change.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Development of hierarchical hydrologic units and estimation of associated ground water recharge

Description: Compilation of an hierarchy of flow fields based on ecological (surface water system), agroecological (vadose zone) and hydrogeological units (ground water system). Computation and analysis of runoff rates and ground water recharge/discharge rates and preparation of atlases of stream runoff and ground water recharge/discharge. Prepare state-wide maps of flow fields at the 1:3,000,000 scale, and similar maps for Southeastern Minnesota and the Twin Cities – St. Cloud Corridor at the 1:500,000 scale, and for Olmsted, Pope and Lac Qui Parle counties at the 1:100 000 to 1:200 000 scales. Using these flow field results we will develop estimates of surface runoff and ground water recharge/discharge at the same spatial scales. From these estimates we will develop atlases of stream runoff and ground water recharge/discharge at the same spatial scales. The developed atlases will be basic information for assessment of water resource sustainability. Note that detailed maps and atlases for other regions and counties of the state cannot be produced within the scope of the proposed budget. The counties selected for analysis in the present work will be used to demonstrate that the proposed approach does work as expected. It will require additional follow-up work (and funding) to complete maps for other counties and other regions of the state.

Summary Budget Information for Result 1: Trust Fund Budget: **$** 202,000
Amount Spent: **$** 202,000
Balance: **$** 0

Deliverable	Completion Date	Budget	Status
1.Statewide atlas	03/31/08	$ 55,000	$0
2.Regional atlases	09/30/08	$ 95,000	$0
3.County scale atlases	03/31/09	$ 52,000	$0

The statewide map for minimum recharge was produced by considering the variables including bedrock geology, quaternary geology, soil order, drainage density, as well as a number of other variables. Of these variables the ones that show a significant effect on the minimum recharge are the bedrock geology and quaternary geology. This is similar to the result that was found in the previous study by Kanivetsky and Shmagin (2001) where only 75 watersheds were used to derive the statewide map of minimum groundwater recharge. The atlas showing the statewide map is illustrated in Attachment 1. The recharge rates are given in $l/s/km^2$.. We note that there is also a climate effect manifested in this atlas but that effect has not been separated out within the overall distribution of recharge. The annual precipitation variability varies significantly across the state with the strongest trend being from the southeast (33 inches/year) to the northwest (20 inches/year), but this climate effect has not been separated out from the effect of geology. The geology effect is very strong however. We can see this by comparing the recharge for the very southeast part of Minnesota to the southwest part. The total precipitation changes by about 5 inches/year across that distance, but yet the recharge varies by an order of magnitude. The procedure for deriving the statewide atlas for recharge is described in Attachment 2.

The atlases for the East Central Minnesota region, the Southeast Region (karst region), and the Southcentral region are presented in Attachment 1 along with tables of estimates of recharge rates for various HHUs. The procedures for deriving the estimates of recharge for the region scale level are described in Attachment 2.

The atlases for the three counties, Olmsted, Lac Qui Parle and Pope, are presented in Attachment 1 along with tables of estimates of recharge rates for various HHUs. The procedure for deriving the estimates of recharge at the county scale level is fairly straight forward. Due to the fact that there are so few gauged watersheds within a given county, the estimates of recharge were taken from the HHU recharge characteristics derived from the analyses of the regions, ECM, Karst, and South Central. The procedure is described in more detail in Attachment 2.

A manuscript for publication in a scientific journal of the results developed for the regional scale analysis results has been prepared in a format to be submitted to the journal Water Resource Research, the premier journal of water resources. We hope to prepare a manuscript on the state-wide analysis for future submission.

Result 2: Development of materials for quantitative information system for freshwater sustainability.

Description: It is desirable to develop a Quantitative Information System (QIS) which will be an expert information and decision support system to compare sustainable supply with water use. To support the future development of this QIS, the water resources sustainability atlases will be converted as overlays onto GIS databases that will also include the spatial distribution of water use/demand.

Summary Budget Information for Result 2: Trust Fund Budget: $ 42,500
Amount Spent: $ 42,500
Balance: $ 0

Deliverable	Completion Date	Budget	Status
1. GIS databases on CD	08/19/09	$42,500	$0

Using the atlases of HHUs, the estimates minimum recharge rates associated with the individual HHUs, and data from the DNR permits for the entire State of Minnesota we developed a database that can be used to quantify the minimum renewable flux and the permitted water demand for any area within the boundaries of the state. The minimum size of the area for estimation of water availability and permitted water demand is the area of a township section, one square mile.

The database for water availability and permitted water demand was derived by using township sections as the basis for the area of query. The idea being that anyone wishing to gain an estimate of water availability and water demand within specified boundaries, the township section would be the basic unit most easily identified. For instance, one could easily determine what townships and what portions of townships lie within a bounty boundary, or within the boundaries of a watershed. Given that the data on water availability and permitted water demand are organized by township sections, the cumulative water available and the cumulative water demand can be determined by summing the corresponding amounts for the sections contained within the boundaries of interest.

The database created for this project is in the form of a Microsoft Access file with a memory size of 28 megabytes. This file is available on CD but also at the freshwater sustainability website (https://wiki.umn.edu/view/Water_Sustainability) for internet download. Other pertinent data generated by GIS analysis will also be available upon request.

The procedures used to create the database files are described in Attachment 3. The created database file can be queried by a QIS, a program that can read the data, extract the required information, and summarize the results in a report format. Presumably this QIS program would also be capable of updating the information in the database as information become available. For example, if a new water use permit is added, or one is deleted from use, the user would be able to enter the information about the permitted use and update the database as a result. Likewise, if new information is gained that helps to improve the accuracy of the estimates of water availability, this information could also be added by the user.

Result 3: County level test of the sustainable supply estimation methodology.

Description: The water use and the estimated sustainable supply of water in Olmsted, Pope and Lac Qui Parle counties will be compared as case study tests of the methodology used here to estimate sustainable supply.

Summary Budget Information for Result 3: Trust Fund Budget: $ 32,500
Amount Spent: $ 32,500
Balance: $ 0

Deliverable	**Completion Date**	**Budget**	**Status**
1.Report detailing the test of the methodology	08/19/09	$32,500	$0

Once the water availability and the permitted water use database was created, as in Result 2, that database could be applied to estimate the water use and water availability for the county level to demonstrate its use. This demonstration was conducted for the counties of Olmsted, Lac Qui Parle and Pope. The method was also demonstrated for selected watersheds to show that the method can be used for general areas and not only for areas bounded by political boundaries. The methodology for this application and the results are outlined in Attachment 4. It should be noted that we did not develop the QIS that would be used to query the database. However the logical steps used in doing the query are essentially identical to the algorithmic steps that would be incorporated into the QIS. We should add that anyone with basic knowledge of Microsoft Access should be able to query the databases created to do a sustainability assessment.

Result 4: Compare recharge estimates from alternative methodologies

Description: Compare the estimates of ground water recharge obtained with our regionalization procedure to estimates obtained with the regionalization reported by Delin et al. (2007). This comparison will be conducted for selected watersheds representing the breadth of variability within the state.

Summary Budget Information for Result 4: Trust Fund Budget: $15,000
Amount Spent: $ 15,000
Balance: $ 0

Deliverable	**Completion Date**	**Budget**	**Status**
1. Report detailing the comparison of our method with alternative methods	08/31/09	$15,000	$0

Estimated minimum mean annual recharge for selected watersheds in Olmsted County and Lac Qui Parle County was determined using the results of the regional atlases and county atlases developed within this project, and these estimates are compared to mean annual recharge derived from the regional regression recharge (RRR) method developed by the USGS. The procedures for estimating the minimum mean annual recharge from the developed atlases are outlined in Attachment 5. The estimates are compared to estimates using the RRR method.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services:

Dr. Roman Kanivetsky, UofM, $67,666. 33%. Responsible for hierarchical conceptualization of the terrestrial hydrologic system resulted in creation of units and subsequent quantification of these units. Worked in concert with Boris Shmagin as well as John Nieber, David Mulla and Bruce Wilson to develop and quantify hierarchical units of vadose zone to compile the multi-scale maps showing sustainable water resources.

Dr. Boris Shmagin, SDSU, $38,000. 28%. The developer of the original statistical analyses used to develop multi-scale maps, he was primarily responsible to develop the statewide atlas of mean annual minimum groundwater recharge, and provided guidance to Heidi Peterson in learning the statistical analysis procedures for development of the regional and county level atlases.

Jason Ulrich, Research Associate, GIS specialization. $19,195. 33%. Developed the the Microsoft Access database for the QIS concept.

Graduate Research Assistants(2), Heidi Peterson and Francisco Lahoud. $82,859. 50%. Assisted with acquisition of data bases used for analyses and also provided substantial. Both students are studying at the Ph.D. level so they were expected to help with the regular project activities such as data acquisition, data processing, etc., but will also be required to develop an off-shoot project for their Ph.D. theses that will augment the proposed outcomes of the project. Since the project ended being closely related to the Ph.D. research of Heidi Peterson she took primary responsibility to learn the statistical methods for development of the regional and the county level atlases of recharge.

Undergrad Research Assistant, $9,194. Several undergraduate research assistants assisted with routine data acquisition, and also prepare GIS maps and other summary charts and illustrations needed for analysis and report presentation.

Fringe Benefits: Explanation for the fringe benefit charges.
32.8% of salary for Research Associate (GIS specialist), $6,296
13.4% of salary for Kanivetsky, $9,067
70% of salary for Graduate Research Assistants, $52,615
7.7% of salary for Undergrad Research Assistant, $708

TOTAL TRUST FUND PROJECT BUDGET: $292,000

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: Dr. Boris Shmagin, Research Associate Professor, Water Resources Institute and Dept of Agricultural & Biosystems Engineering, South Dakota State University; $38,000

B. Other Funds Proposed to be Spent during the Project Period: During the project period and after the project final date of June 30 the work was also supported by Minnesota Agricultural Experiment Station project, MN-12-046, “Characterizing Mass and Energy Transport at Different Scales”. From July 1, 2007 until June 30, 2009 the 12-046 project provided support (salary and supplemented travel) for Nieber at about $11,500 per year. Additional work was conducted following the June 30, 2009 deadline to revise the final report and to do additional analyses to address review comments. Project MN-12-046 also supported those activities for Nieber, Peterson and Ulrich for an amount of approximately $10,550.

C. Past Spending: NA

D. Time: NA

VII. DISSEMINATION: Throughout the period of the project the results of the project were presented at scientific and professional society meetings, at other institutions (by invitation), and at public forums within Minnesota (the PI has given three such presentations even before the project began). At least one scientific article will be prepared and submitted to a scientific journal. A web site was established to highlight the results of the project. This web site will be maintained to update results even as the project has come to a close.

Presented results of the research at the following venues:

J. Nieber, R. Kanivetsky, B. Shmagin, B. Wilson, and D. Mulla, Multi-scale quantitative mapping of recharge/discharge to ground water systems as related to freshwater sustainability in Minnesota, 2007 Minnesota Waters Conference, October 23-24. Results presented as a poster.

J. Nieber, Quantifying Water Resources Sustainability, Texas A&M University, Distinguished Speakers Series in the Department of Biological and Agricultural Engineering, October 16-18, 2007. No cost to project as TAMU provided complete funding for the trip.

J. Nieber, R. Kanivetsky, B. Shmagin, B. Wilson, and D. Mulla, Quantification of Water Resources Sustainability in Minnesota, 52nd Annual South Dakota Water Resources Conference, Sioux Falls, October 28-30, 2007. *This meeting provided the opportunity for us to present the methodology to a broader group of water resource managers and hydrogeologist coming from the upper Midwest region. Discussions stimulated by the presentations provided us with a means to further fine-tune the message regarding the methodology and justification for the work. An important presentation at the meeting given by Bill Allie (USGS, Reston, VA) was valuable to our effort since he spoke about the effects of mining of groundwater on flows in surface waters connected to aquifers. Cost to the project was $800. Roman Kanivetsky and John Nieber also met with Boris Shmagin (project partner) at the meeting to discuss the ongoing work.*

J. Nieber, R. Kanivetsky, B. Shmagin, B. Wilson, and D. Mulla, Regional hydrologic synthesis using a system model of watersheds: a new integrative tool to advance knowledge and predictability of hydrologic systems, 2007 Fall meeting of the American Geophysical Union, December 11-15. *At this meeting we were able to present to a national audience the conceptual development of the ideas of sustainability, and also a description of the methodology used for the project for quantifying water resource sustainability. The meeting also provided the opportunity for John Nieber to meet with Boris Shmagin (project partner) to discuss progress on the project. A presentation by a scientist from Sweden (Anders Worman) also gave some new ideas that we could use in the modeling the physical basis for hydrogeologic units. The cost was for John Nieber's travel, coming to $1,200.*

J. Nieber, R. Kanivetsky, B. Shmagin, D. Mulla, H. Peterson, and B. Wilson, Regional hydrologic synthesis using system model of watersheds; a new integrative tool to advance knowledge and predictability of hydrologic systems, presented at the 1st International Conference on Hydropedology, Pennsylvania State University, State College, PA, July 28 – July 31, 2008. Given as an oral presentation by John Nieber and a poster presentation by Heidi Peterson. Total cost of travel for Nieber and Peterson was $1,850 - no cost to the project.

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J. Nieber, H. Peterson, R. Kanivetsky, and B. Shmagin. Quantifying biophysical constraints of nature: Measuring renewable freshwater resources at multiple scales. Oral presentation at the International Workshop on International Cooperation for Data Acquisition, 90th American Meteorological Society (AMS) Annual Meeting, Atlanta, GA, January 16-21, 2010. Invited presentation. All travel expenses paid by the American Meteorological Society.

Project webpage, pamphlet.

A project web site at the U of M is operational and is currently being updated with the final project results. The website provides information about project results and outreach efforts. The website address is

https://wiki.umn.edu/view/Water_Sustainability

A pamphlet which describes the need for sustainability of water resources, and also provides information on the general concepts underlying the methodology. This pamphlet gives a layman's explanation for the research. A number of copies of the pamphlet have been distributed at professional meetings. A copy of the pamphlet is shown as Attachment 6**.**

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports were due on December 31, 2007, June 30, 2008, December 31, 2008. A final work program report and associated products was due on August 17, 2009.

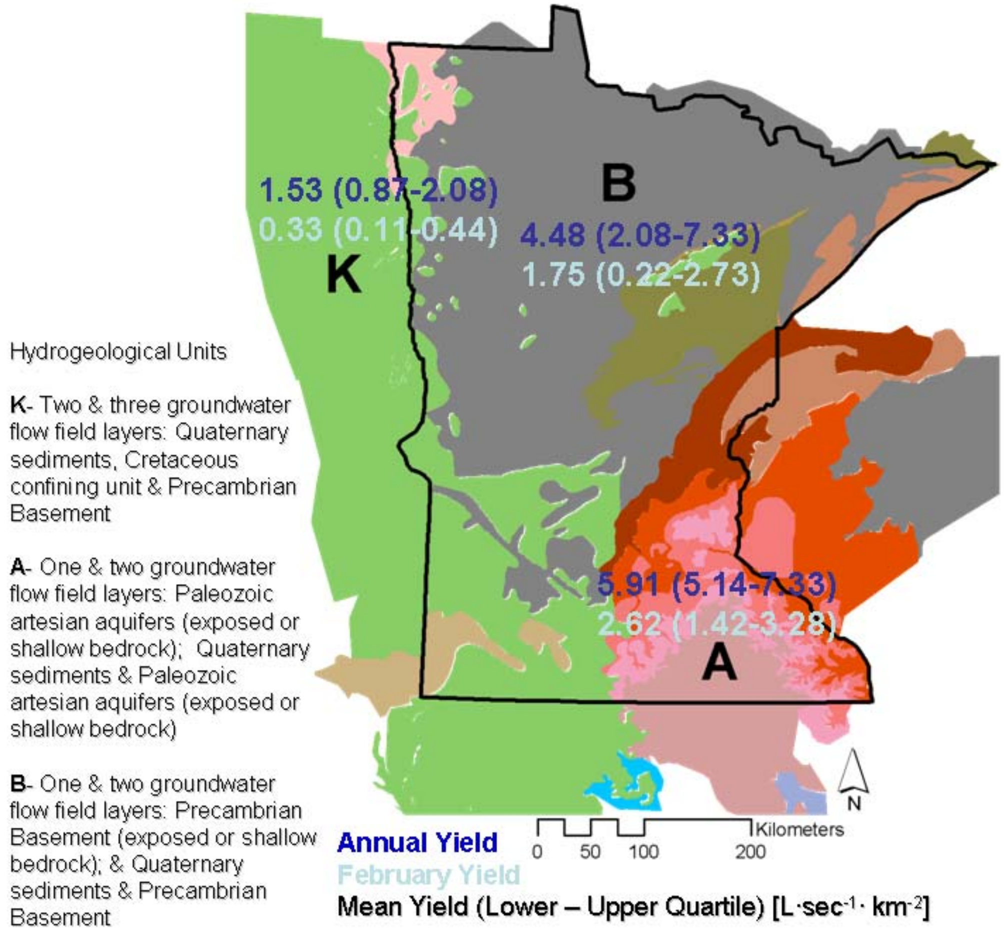
IX. RESEARCH PROJECTS:

1. Two research documents that show methods for estimating ground water recharge similar to the approach used in the current research are given in Attachment 7.
2. The graduate students, Heidi Peterson and Francisco Lahoud, both supported by this project are currently working on their Ph.D. research activities. Heidi's work is closely related to this project as she will be quantifying the relationship between recharge and landscape features, that is, she will be deriving equations to predict the relationships. Francisco's project will involve the use of remote sensing techniques to monitor baseflow in streams, and as such is not directly related to the objectives of the Water Resources Sustainability project, but is an offshoot of it.

Attachment 1

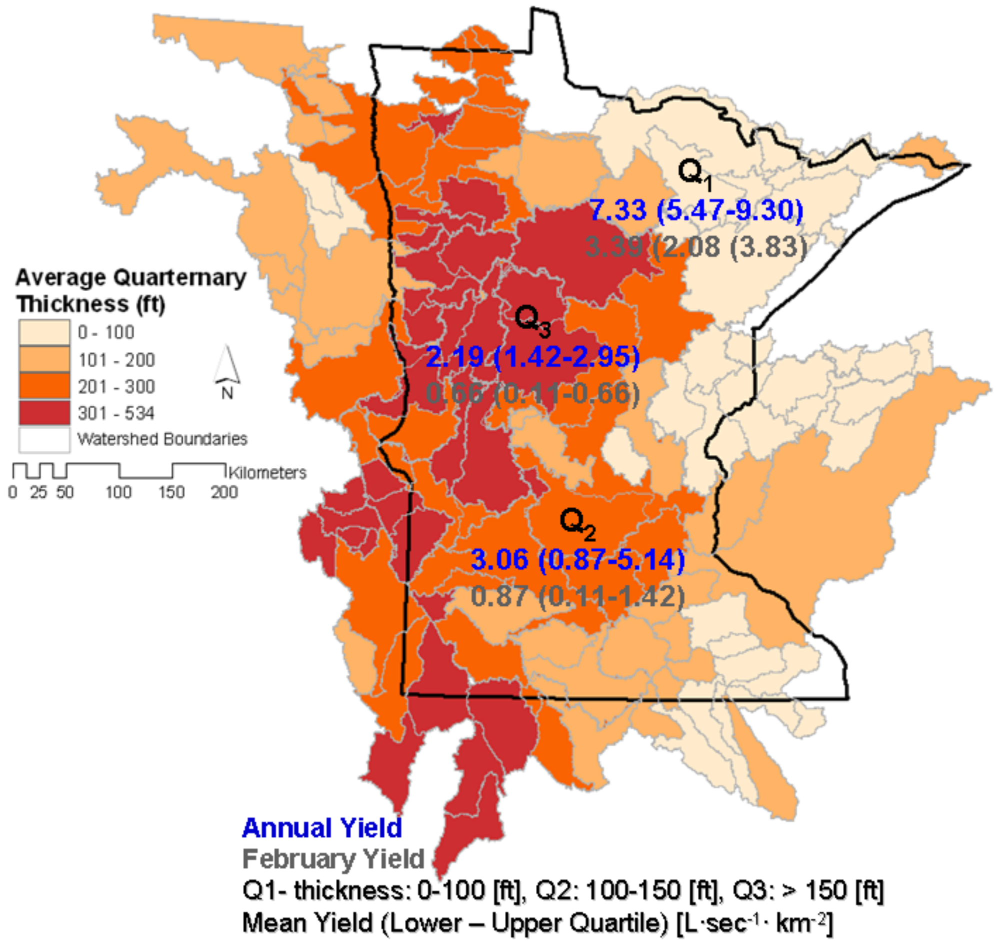
Recharge atlases, hierarchical hydrogeologic units, recharge tables

Variables for Initial Analysis of Basin Characteristics			
Variables	**Regionalization Level**	**Data Use**	**Data Source**
Soil			
Available Water Capacity	Regional	Watershed average	Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. U.S. General Soil Map (STATSGO2) for IA, MN, ND, SD & IA. [Available online at http://soildatamart.nrcs.usda.gov]
Available Water Storage (AWS)	Regional	Watershed average	STATSGO2
AWS 0-25 cm			
AWS 0-50 cm			
AWS 0-100 cm			
AWS 0-150 cm			
Drainable Porosity	Regional	Watershed average	Calculated using total porosity and field capacity data layers.
Drainage Class	State	Composition by category	STATSGO2
Field Capacity	Regional	Watershed average	STATSGO2
Hydrologic Soil Class	State	Composition by category	STATSGO2
Permeability	State	Composition by category	STATSGO2
Slope	State	Composition by category	STATSGO2
Soil Order	State, Regional	Composition by category	STATSGO2
Soil Texture	Regional	Composition by category	STATSGO2
Total porosity	Regional	Watershed average	Miller, D.A. and R.A. White. 1998: A Conterminous United States Multi-Layer Soil Characteristics Data Set for Regional Climate and Hydrology Modeling. Earth Interactions, 2. [Available online at http://EarthInteractions.org]
Ecoregions			
Agroecoregions	State	Compotition by category	Data obtained from Professor David Mulla, University of Minnesota, 2007.
Bailey	State	Compotition by category	USDA Forest Service, 200403, Bailey's Ecoregions and Subregions of the United States, Puerto Rico, and the U.S. Virgin Islands: National Atlas of the United States, Reston, VA.
Sections			
Provinces			
Omernik Level III Ecoregions	State	Composition by category	U.S. Environmental Protection Agency, 200506, Omernik's Level III Ecoregions of the Continental United States: National Atlas of the United States, Reston, VA.
Elevation			
Altitude	State, Regional	Watershed average	Calculated from a 30-meter USGS Digital Elevation Mode (DEM)l. [Available online at http://edc2.usgs.gov/geodata/index.php]
Slope	State, Regional	Watershed average	Calculated from a 30-meter USGS DEM.
Geology			
Bedrock	State, Regional	Composition by category	Kanivetsky, R. 1978. Hydrogeologic Map of Minnesota: Bedrock Hydrogeology (Digital Version). Map S-2. 1:500,000. Minnesota Geological Survey. Digitized by: Land Management Information Center, 1985. [Available online at http://www.lmic.state.mn.us/chouse/metadata/bdrkhydr.html]
Depth to Bedrock	State, Regional	Watershed average	50-meter grid supplied by Richard Lively, Minnesota Geological Survey, 2007. Iowa Department of Natural Resources. 1993. Quaternary Isopach of Iowa. [Available online at http://www.igsb.uiowa.edu/nrgislibx/] North Dakota Geological Survey. 1980. Surficial Geology. [Available online at http://web.apps.state.nd.us/hubdataportal/srv/en/main.home] South Dakota Geological Survey. Contours for Bedrock - Eastern SD. [Available online at http://arcgis.sd.gov/IMS/sdgis/Data.aspx] Schoephoester, P.R. 2001. Wisconsin Depth to Bedrock Map. 1:250,000. Wisconsin Geological and Natural History Survey.
Quaternary	State, Regional	Composition by category	Kanivetsky, R. 1979. Hydrogeologic Map of Minnesota: Quaternary Hydrogeology (Digital Version). Map S-3. 1:500,000. Minnesota Geological Survey. Digitized by: Land Management Information Center, 1985. [Available online at http://www.mngeo.state.mn.us/chouse/metadata/hydgeo.html] *Additional data layers used for extending bedrock and quaternary data outside of Minnesota:* U.S. Geological Survey. 200209. Aquifers of Alluvial and Glacial Origin: U.S. Geological Survey, Reston, VA. [Available online at http://nationalatlas.gov/atlasftp.html] U.S. Geological Survey, 200310. Principal Aquifers of the 48 Conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands: U.S. Geological Survey, Madison, WI, USA. [Available online at http://nationalatlas.gov/atlasftp.html] Olcott, Perry. 1992. Ground water atlas of the United States: Iowa, Michigan, Minnesota, Wisconsin. U.S. Geological Survey. HA 730-J. [Available online at http://pubs.usgs.gov/ha/ha730/ch_j/index.html] Whitehead, R.L. 1996. Ground water atlas of the United States: Montana, North Dakota, South Dakota, Wyoming. U.S. Geological Survey. HA 730-I. [Available online at http://pubs.usgs.gov/ha/ha730/ch_i/index.html]
Land Use			
2001 Land Cover	State	Composition by category	Homer, C. C. Huang, L. Yang, B. Wylie and M. Coan. 2004. Development of a 2001 National Landcover Database for the United States. Photogrammetric Engineering and Remote Sensing, Vol. 70, No. 7, July 2004, pp. 829-840. [Available online at http://www.mrlc.gov/index.php]
Drainage			
Drainage Density	State, Regional	Watershed total	Calculated using flowline database from: U.S. Geological Survey and the U.S. Environmental Protection Agency. 2004. National Hydrography Dataset (NHD) Medium Resolution. [Available online at http://www.horizon-systems.com/nhdplus/data.php]
Intermittent			
Perennial			
Total			



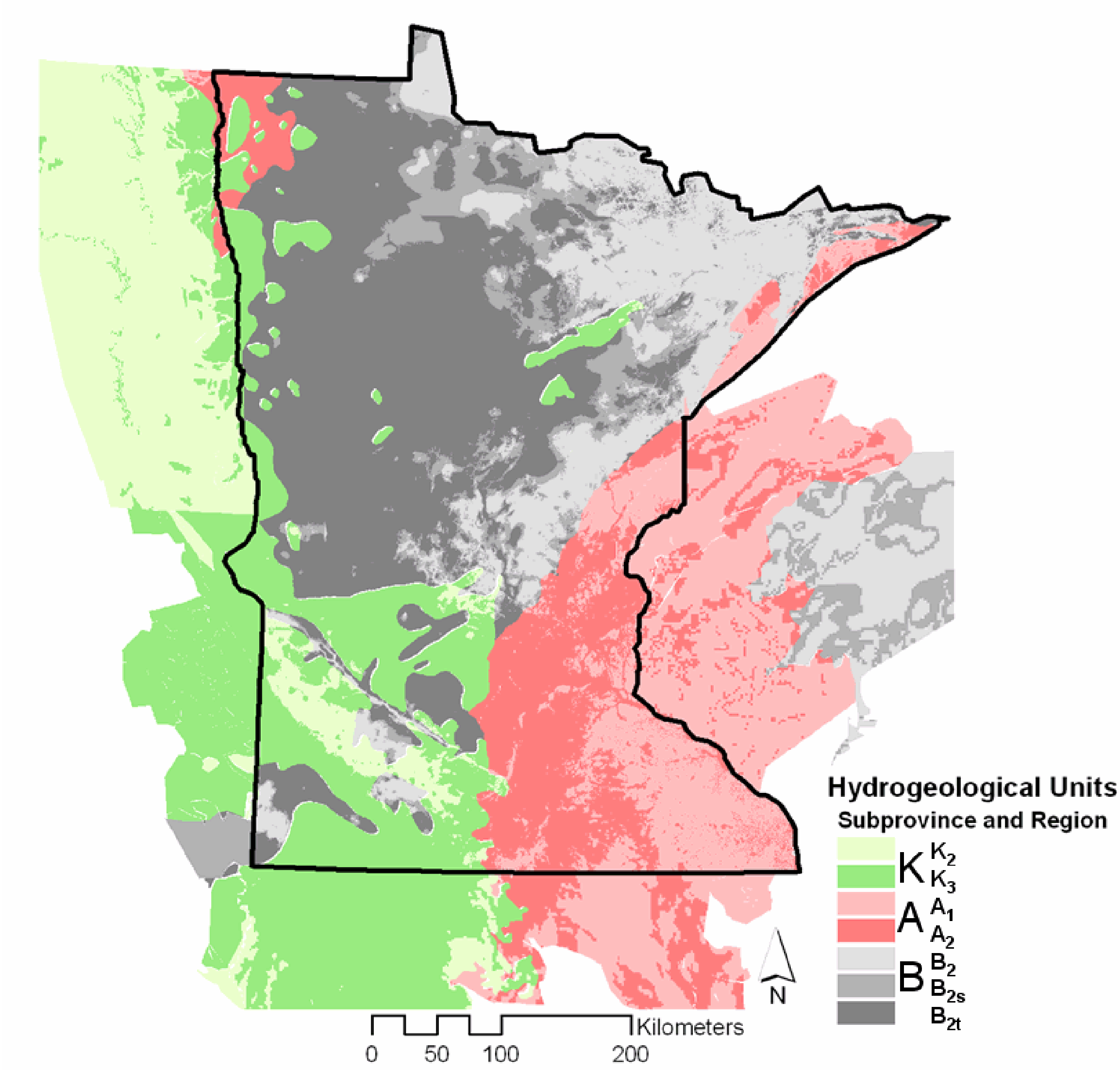
Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24

Distribution of mean minimum annual groundwater recharge for the state scale given by the February yield values as affected by bedrock geology.



Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24

Distribution of mean minimum annual groundwater recharge for the state scale given by the February yield values as affected by bedrock and quaternary geology.



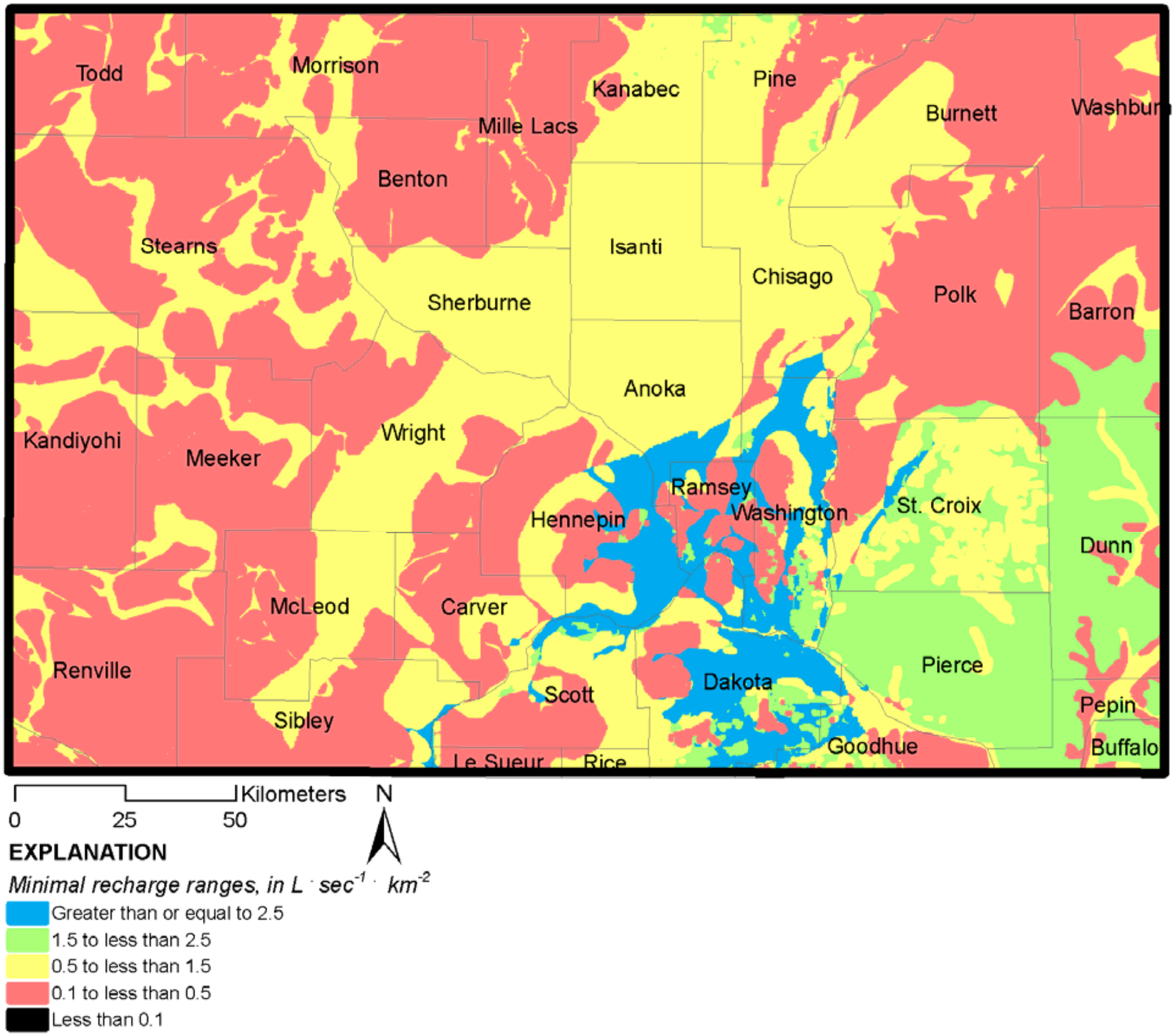
State scale map for minimum annual groundwater recharge. Hydrogeological units are shown on the map and are defined by the bedrock geology and the thickness of quaternary material. The values for each unit are given in the table for the statewide results.

Table of average rates of annual and monthly (February) stream flow for units of hydrogeological hierarchical regionalization for Minnesota and surrounding areas.

Symbol - Subprovince	Mean Annual Stream Flow (L/s/km^2)	Mean February Recharge (L/s/km^2)	Symbol - Region	Mean Annual Stream Flow (L/s/km^2)	Mean February Recharge (L/s/km^2)
K - Two & three ground water flow field layers: Quaternary sediments, Cretaceous deposits & Precambrian Basement	1.53 (0.88 - 2.08)[a]	0.33 (0.11 - 0.44)	**K_2** (9)[b] - Two ground water flow field layers: Quaternary sediments < 130 ft thick (till, sand, silt, gravel, peat), Cretaceous deposits (shale, sandstone) & Precambrian Basement (crystalline, magmatic, metamorphic & volcanic rocks)	0.798 (0.22-0.88)	0.12 (0.00-0.11)
			K_3 (22) - Three ground water flow field layers: Quaternary sediments > 130 ft thick (till, sand, silt, gravel, peat), Cretaceous deposits (shale, sandstone) & Precambrian Basement (crystalline, magmatic, metamorphic & volcanic rocks)	1.85 (1.31-2.30)	0.36 (0.11 - 0.44)
A - One & two ground water flow field layers: Paleozoic artesian aquifers (exposed or shallow bedrock); Quaternary sediments & Paleozoic artesian aquifers	5.91 (5.14-7.33)	2.62 (1.42 - 3.28)	**A_1** (12) - One ground water flow field layer: Quaternary sediments <100 ft thick (till, sand, silt, gravel, peat), Paleozoic artesian aquifers (sandstone, dolomite, limestone, shale)	6.93 (5.47-8.64)	3.43 (2.35-3.77)
			A_2 (7) - Two ground water flow field layers: Quaternary sediments > 100 ft thick (till, sand, silt, gravel, peat) & Paleozoic artesian aquifers	4.04 (1.09-5.36)	1.19 (0.44-1.86)
B - One & two ground water flow field layers: Precambrian Basement (exposed or shallow bedrock); Quaternary sediments & Precambrian Basement	4.48 (2.08 - 7.33)	1.75 (0.22 - 2.73)	**B_1** (13) - One ground water flow field layer: crystalline, magmatic, metamorphic & volcanic rocks (Quaternary sediments <100 ft thick (till, sand, silt, gravel, peat)	8.17 (7.33-9.62)	3.70 (1.86-3.83)
			B_{2s} (4) - Two ground water flow field layers: Quaternary sediments 100-150 ft thick (till, sand, silt, gravel, peat) & Precambrian Basement (crystalline, magmatic, metamorphic & volcanic rocks)	5.72 (4.10-7.33)	1.64 (1.09-2.19)
			B_{2t} (26) - Two ground water flow field layers: Quaternary sediments > 150 ft thick (till, sand, silt, gravel, peat) & Precambrian Basement (crystalline, magmatic, metamorphic & volcanic rocks)	2.53 (1.75-3.06)	0.85 (0.11-0.98)

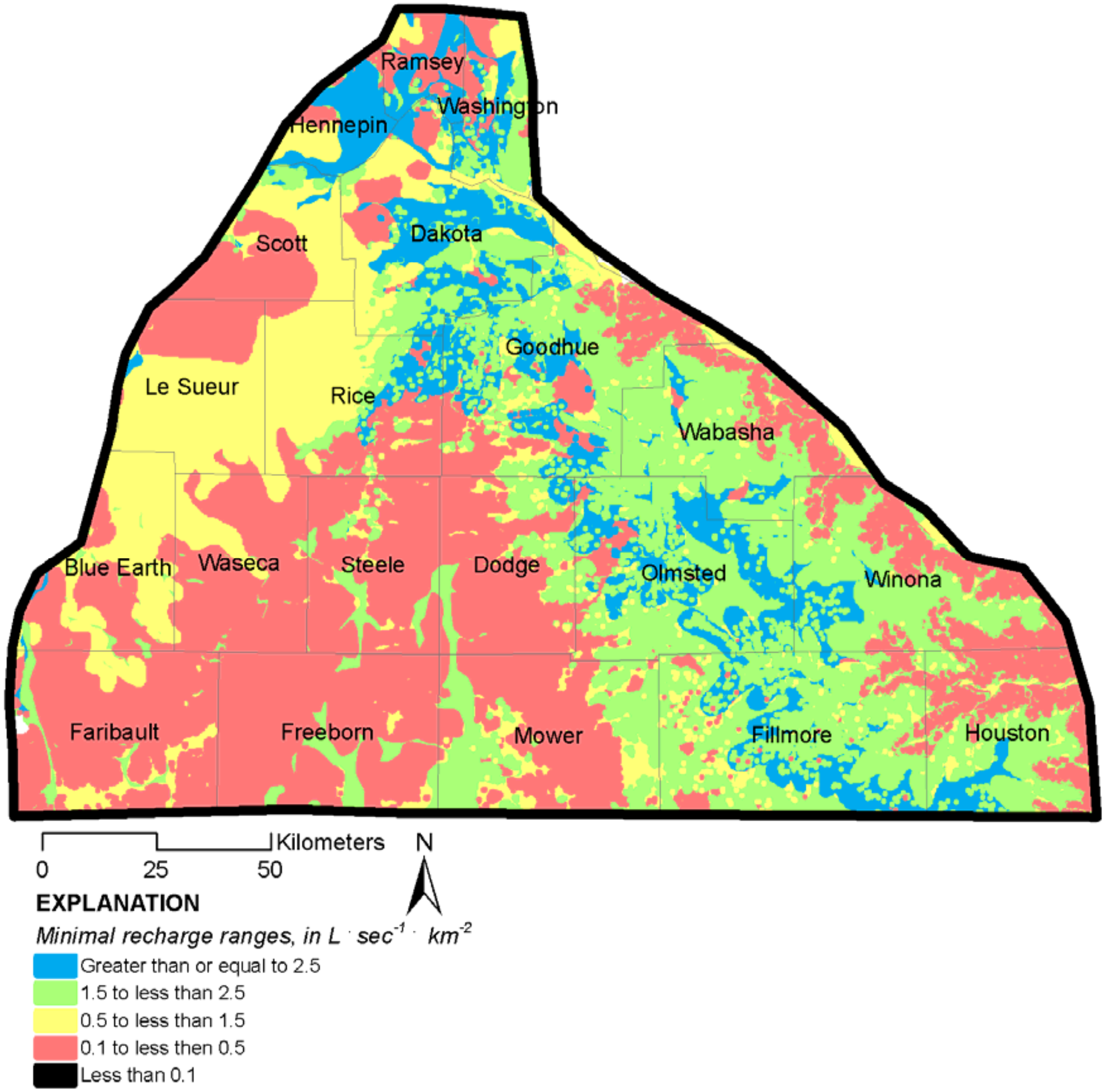
[a] *Range of the lower and upper quartile.*
[b] *(#) refers to the number of watersheds included in analysis.*

Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24



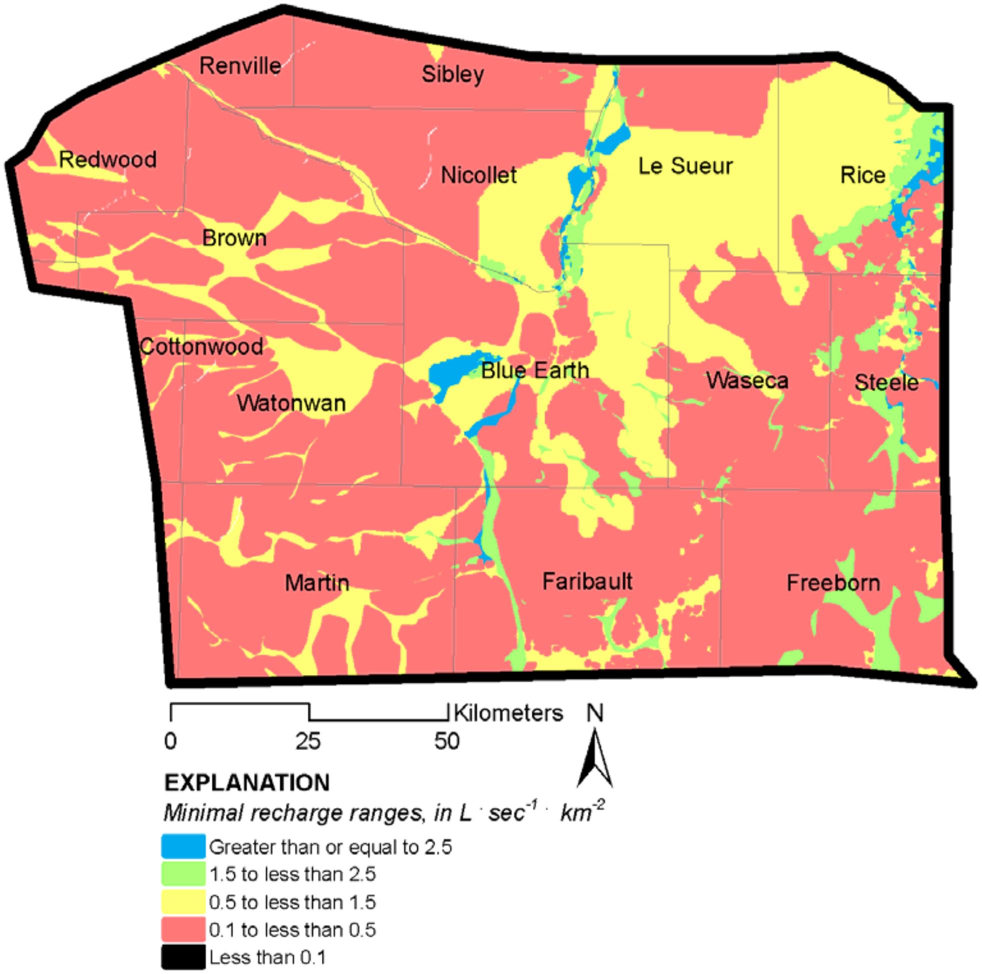
Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24

Recharge distribution atlas for the East Central Minnesota region.



Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24

Recharge distribution atlas for the Southeast Minnesota region.



Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24

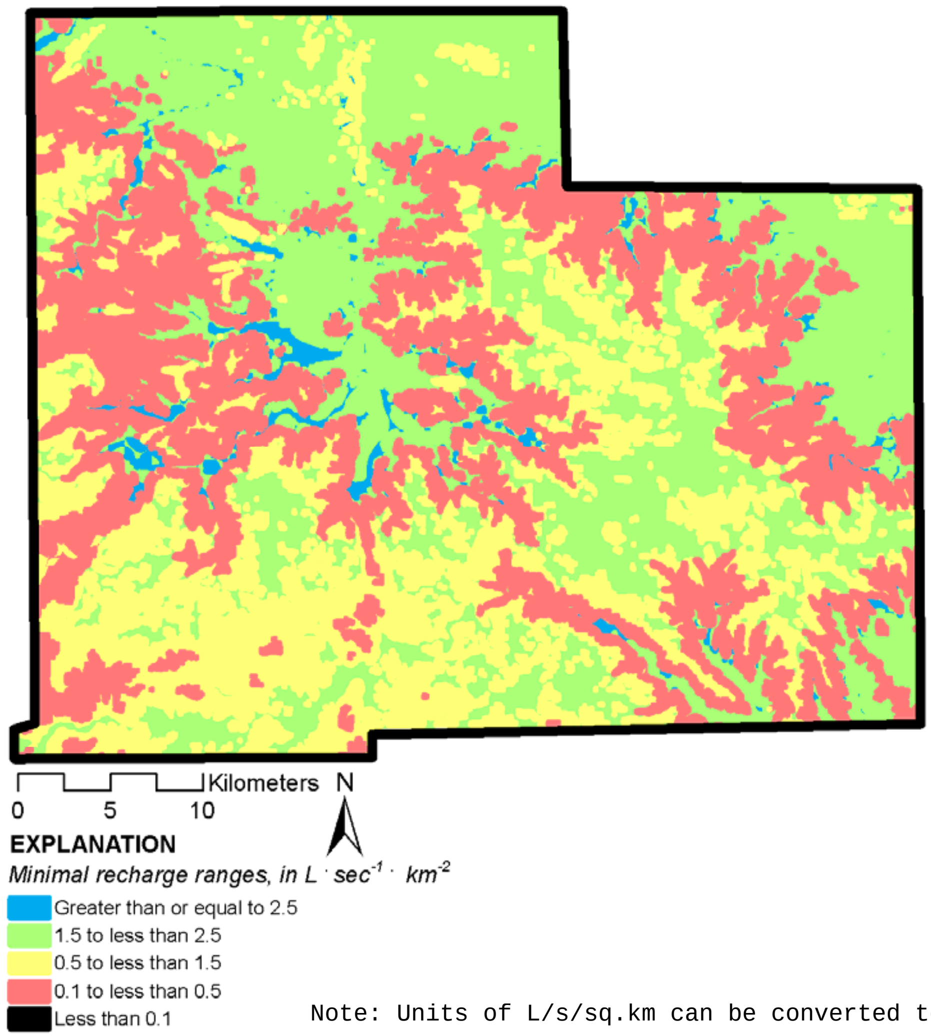
Recharge distribution atlas for the South Central Minnesota region.

Table of average rates of minimal ground water discharge/recharge for units of hydrologic regionalization for Southern Minnesota.

Symbol - Subprovince	Mean Recharge (L/s/km^2)	Symbol - Region	Mean Recharge (L/s/km^2)	Symbol - Subregion	Mean Recharge (L/s/km^2)	Symbol - District	Mean Recharge (L/s/km^2)	Symbol - Subdistrict	Mean Recharge (L/s/km^2)
K - Two & three ground water flow field layers: Quaternary sediments, Cretaceous deposits & Precambrian Basement		**K_3/Q** (38) - Three ground water flow field layers: Quaternary sediments > 50 ft thick (till, sand, silt, gravel, peat), Cretaceous deposits (shale, sandstone) & Precambrian Basement (crystalline, magmatic, metamorphic & volcanic rocks)	0.37 (0.02-0.26)					**$K_3/Q2$** - gravel and sand quaternary sediment	0.90*
								$K_3/Q3$ - sand and gravel quaternary sediment	0.60*
								$K_3/Q6$ (37) - till quaternary sediment	0.33 (0.02-0.24)
A (79[a]) - One & two ground water flow field layers: Paleozoic artesian aquifers (exposed or shallow bedrock); Quaternary sediments & Paleozoic artesian aquifers	1.33 (0.28-2.08)[b]	**A_1** (27) - One ground water flow field layer: Quaternary sediments < 50 ft thick (till, sand, silt, gravel, peat), Paleozoic artesian aquifers (sandstone, dolomite, limestone, shale)	2.00 (0.92-3.05)	**A_1^1** (2) - Cedar Valley-Maquoketa-Dubuque-Galena aquifer (limestone, dolomite)	2.40 (1.00-3.80)				
				A_1^2 (6) - St. Peter aquifer (sandstone)	3.38 (2.76-3.29)				
				A_1^3 (8) - Prairie du Chien Jordan aquifer (sandstone, limestone)	2.07 (1.04-3.05)				
				A_1^4 (6) - Franconia-Ironton-Galesville aquifer (mixed shale, sandstone, some shaly carbonates)	1.65 (0.28-2.42)				
				A_1^5 - Mt. Simon-Hinckley-Fond du Lac aquifer (sandstone)	1.85*				
				A_1^6 (5) - Keweenawan Volcanic Rocks aquifer (basaltic lava flows)	0.50 (0.29-0.66)				
		A_2/Q (52) - Two ground water flow field layers: Quaternary sediments > 50 ft thick (till, sand, silt, gravel, peat) & Paleozoic artesian aquifers	0.98 (0.20-1.47)	**$A_2/Q1$** - Primarily gravel quaternary sediment	2.15*			**$A_2^2/Q1$** - St. Peter aquifer (sandstone) within Mississippi River Valley	2.80*
								$A_2^3/Q1$ - Prairie du Chien Jordan aquifer (sandstone, limestone) within Mississippi River Valley	2.60*
								$A_2^4/Q1$ - Franconia-Ironton-Galeville aquifer (mixed shale, sandstone, some shaly carbonates) within Mississippi River Valley	1.15*
				$A_2/Q2$ (6) - Gravel and sand quaternary sediment	1.59 (0.80-2.66)			**$A_2^1/Q2$** - Cedar Valley-Maquoketa-Dubuque-Galena aquifer (limestone, dolomite)	2.15*
								$A_2^2/Q2$ - St. Peter aquifer (sandstone)	2.60*
								$A_2^3/Q2$ - Prairie du Chien Jordan aquifer (sandstone, limestone)	2.50*
								$A_2^4/Q2$ - Franconia-Ironton-Galesville aquifer (mixed shale, sandstone, some shaly carbonates)	0.90*
								$A_2^5/Q2$ - Mt. Simon-Hinckley-Fond du Lac aquifer (sandstone)	1.40*
								$A_2^6/Q2$ - Keweenawan Volcanic Rocks aquifer (basaltic lava flows)	0.45*
				$A_2/Q3$ (1) - Sand and gravel quaternary sediment	1.50*			**$A_2^1/Q3$** - Cedar Valley-Maquoketa-Dubuque-Galena aquifer (limestone, dolomite)	1.95*
								$A_2^2/Q3$ - St. Peter aquifer (sandstone)	2.40*
								$A_2^3/Q3$ - Prairie du Chien Jordan aquifer (sandstone, limestone)	2.30*
								$A_2^4/Q3$ - Franconia-Ironton-Galesville aquifer (mixed shale, sandstone, some shaly carbonates)	0.60*
								$A_2^5/Q3$ - Mt. Simon-Hinckley-Fond du Lac aquifer (sandstone)	1.25*
								$A_2^6/Q3$ - Keweenawan Volcanic Rocks aquifer (basaltic lava flows)	0.40*
				$A_2/Q5$ - Silt and sand quaternary sediment	1.15*			**$A_2^4/Q5$** - Franconia-Ironton-Galesville aquifer (mixed shale, sandstone, some shaly carbonates)	0.50*
								$A_2^6/Q5$ - Keweenawan Volcanic Rocks aquifer (basaltic lava flows)	0.35*
				$A_2/Q6$ (45) - Till quaternary sediment	0.84 (0.19-1.15)	**A_2/Q_s6** (16) - Quaternary sediment thickness < 100 feet	1.55 (0.71-2.07)	**A_2^1/Q_s6** (8) - Cedar Valley-Maquoketa-Dubuque-Galena aquifer (limestone, dolomite)	1.33(0.44-2.08)
								A_2^2/Q_s6 (3) - St. Peter aquifer (sandstone)	1.77 (1.45-2.05)
								A_2^3/Q_s6 (2) - Prairie du Chien Jordan aquifer (sandstone, limestone)	1.60 (1.14-2.08)
								A_2^4/Q_s6 (1) - Franconia- Ironton Galesville aquifer (mixed shale, sandstone, some shaly carbonates)	0.30*
								A_2^5/Q_s6 (1) - Mt. Simon-Hinckley-Fond du Lac aquifer (sandstone)	1.20*
								A_2^6/Q_s6 (1) - Keweenawan Volcanic Rocks (basaltic lava flows)	0.30*
						A_2/Q_t6 (29) - Quaternary sediment thickness > 100 feet	0.45 (0.12-0.60)	**A_2^1/Q_t6** (14) - Cedar Valley-Maquoketa-Dubuque-Galena aquifer (limestone, dolomite)	0.38 (0.06-0.50)
								A_2^2/Q_t6 (4) - St. Peter aquifer (sandstone)	0.23 (0.17-0.28)
								A_2^3/Q_t6 (5) - Prairie du Chien Jordan aquifer (sandstone, limestone)	0.85 (0.25-1.49)
								A_2^4/Q_t6 (2) - Franconia- Ironton-Galesville aquifer (mixed shale, sandstone, some shaly carbonates)	0.12 (0.06-0.17)
								A_2^5/Q_t6 (4) - Mt. Simon-Hinckley-Fond du Lac aquifer (sandstone)	0.58 (0.42-0.74)
								A_2^6/Q_t6 - Keweenawan Volcanic Rocks (basaltic lava flows)	0.25*
B - One & two ground water flow field layers: Precambrian Basement (exposed or shallow bedrock); Quaternary sediments & Precambrian Basement		**B_2/Q** (38) - Two ground water flow field layers: Quaternary sediments > 50 ft thick (till, sand, silt, gravel, peat) & Precambrian Basement (crystalline, magmatic, metamorphic & volcanic rocks)	0.45 (0.04-0.62)			**B_2/Q_s** (26) Quaternary sediment thickness < 200 feet	0.59 (0.09-0.74)	**B_2/Q_s1** - gravel quaternary sediment	1.60*
								B_2/Q_s2 (1) - gravel and sand quaternary sediment	1.05*
								B_2/Q_s3 (1) - sand and gravel quaternary sediment	0.85*
								B_2/Q_s6 (24) - till quaternary sediment	0.48 (0.07-0.65)
						B_2/Q_t (12) - Quaternary sediment thickness > 200 feet	0.16 (0.02-0.18)	**B_2/Q_t1** - gravel quaternary sediment	0.90*
								B_2/Q_t2 - gravel and sand quaternary sediment	0.60*
								B_2/Q_t3 (1) - sand and gravel quaternary sediment	0.50*
								B_2/Q_t6 (11) - till quaternary sediment	0.11 (0.01-0.17)

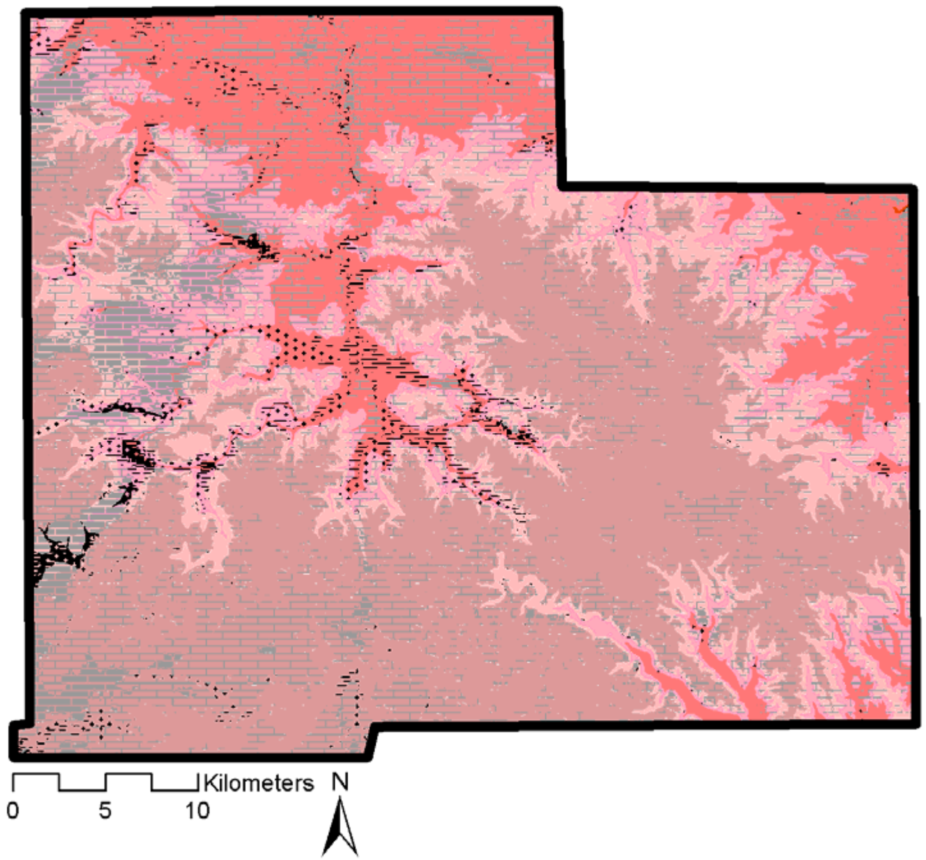
[a] (#) refers to the number of watersheds included in analysis.
[b] Range of the lower and upper quartile.
** Mean recharge estimated through expert judgement, not statistical analysis, due to insufficient set of study watersheds falling within unit.*

Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24



Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24

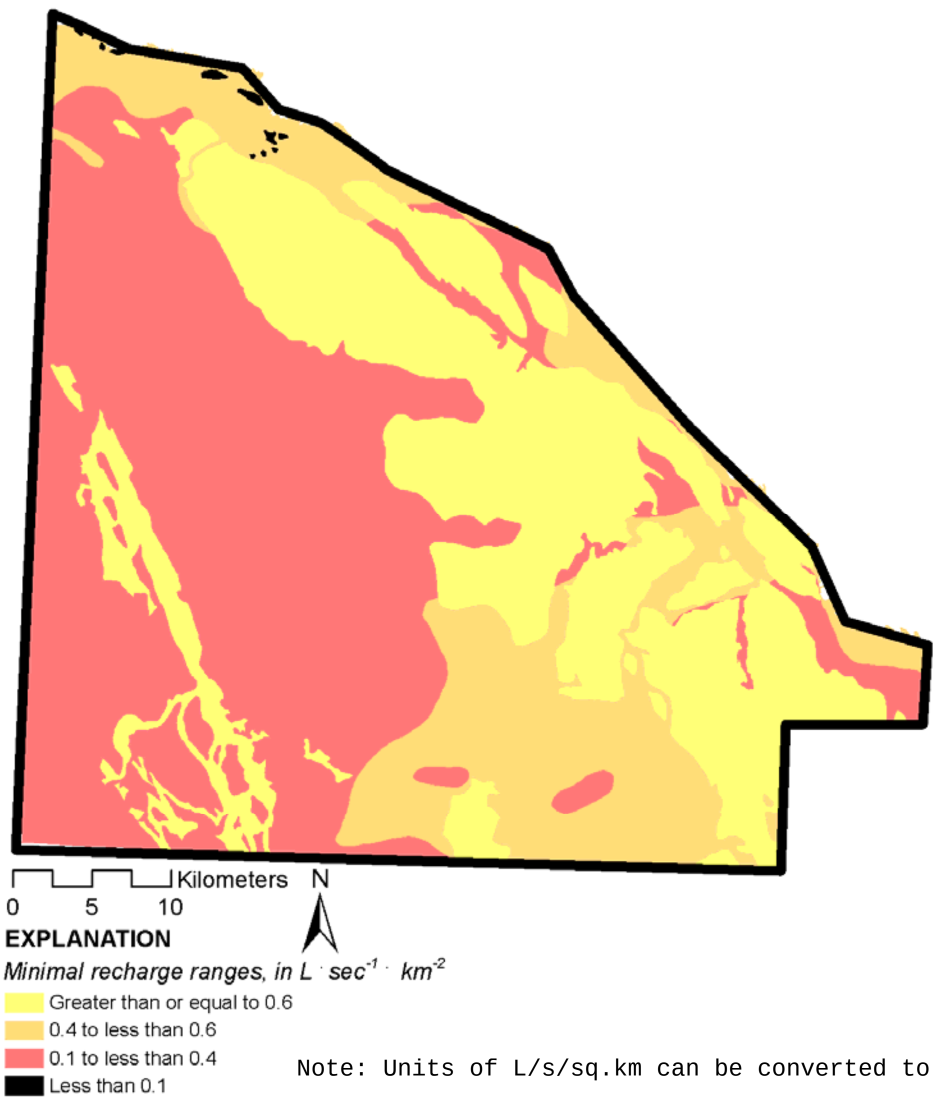
Recharge distribution atlas for Olmsted County.



Hierarchical Hydrogeologic Units for Olmsted County. The recharge table goes with this map.

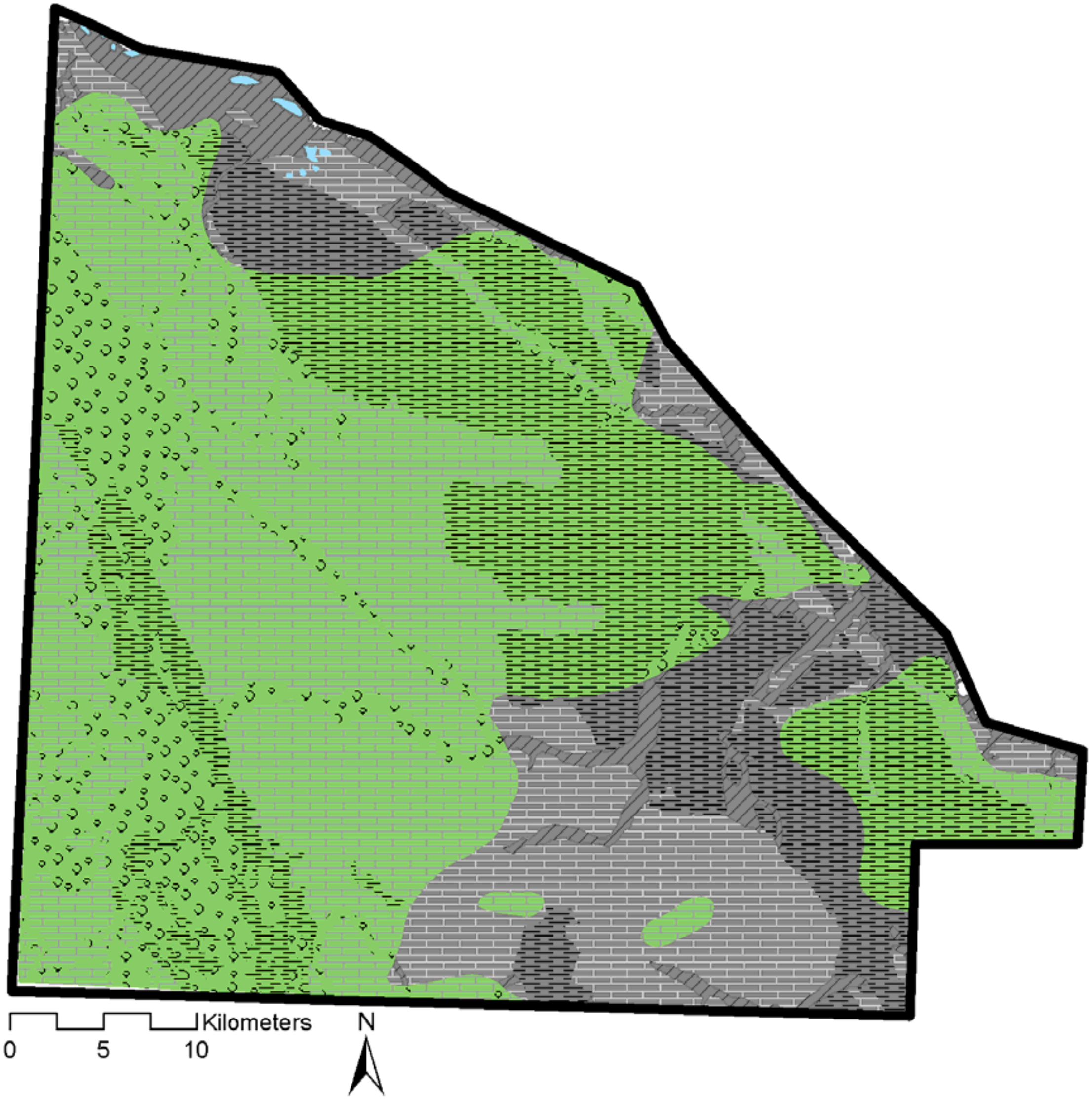
Olmsted County Minimal Ground-Water Recharge Based on February Monthly Discharge Mean Measurements Period 1955-1978			
Subregion	**Symbol**	**Unit Description**	**Recharge [L/s/km^2]**
A_1^1		Exposed or less than 30 feet quaternary material over Cedar Valley - Maquoketa - Dubuque - Galena Aquifer	2.40
A_2^1/Q2		Cedar Valley - Maquoketa - Dubuque - Galena Aquifer overlain by gravel and sand	2.15
A_2^1/Q3		Cedar Valley - Maquoketa - Dubuque - Galena Aquifer overlain by sand and gravel	1.95
A_2^1/Q6		Cedar Valley - Maquoketa - Dubuque - Galena Aquifer overlain by till	1.33
A_1^2		Exposed or less than 30 feet of quaternary material over St. Peter Aquifer	3.39
A_2^2/Q2		St. Peter Aquifer overlain by gravel and sand	2.60
A_2^2/Q3		St. Peter Aquifer overlain by sand and gravel	2.40
A_2^2/Q6		St. Peter Aquifer overlain by till	1.77
A_1^3		Exposed or less than 30 feet of quaternary material over Prairie du Chien - Jordan Aquifer	2.07
A_2^3/Q2		Prairie du Chien - Jordan Aquifer overlain by gravel and sand	2.50
A_2^3/Q3		Prairie du Chien - Jordan Aquifer overlain by sand and gravel	2.30
A_2^3/Q6		Prairie du Chien - Jordan Aquifer overlain by till	1.60
A_1^4		Exposed or less than 30 feet of quaternary material over Franconia - Ironton - Galesville Aquifer	1.65
A_2^4/Q2		Franconia - Ironton - Galesville Aquifer overlain by gravel and sand	0.90
A_2^4/Q6		Franconia - Ironton - Galesville Aquifer overlain by till	0.30
A_1c1		Exposed of less than 30 feet of quaternary material over Decorah - Platteville - Glenwood	0.10
A_2c1/Q2		Decorah - Platteville - Glenwood overlain by gravel and sand	0.35
A_2c1/Q3		Decorah - Platteville - Glenwood overlain by sand and gravel	0.25
A_2c1/Q6		Decorah - Platteville - Glenwood overlain by till	0.10
Q2/A_2^1		Sand and gravel predominant over Cedar Valley - Maquoketa - Dubuque - Galena Aquifer	2.00
Q2/A_2c1		Sand and gravel predominant over Decorah - Platteville - Glenwood	0.30
Q2/A_2^2		Sand and gravel predominant over St. Peter Aquifer	2.50
Q2/A_2^3		Sand and gravel predominant over Prairie du Chien - Jordan Aquifer	2.40
Q2/A_2^4		Sand and gravel predominant over Franconia - Ironton - Galesville Aquifer	0.50
Q3/A_2^1		Gravel and sand predominant over Cedar Valley - Maquoketa - Dubuque - Galena Aquifer	2.20
Q3/A_2c1		Gravel and sand predominant over Decorah - Platteville - Glenwood	0.55
Q3/A_2^2		Gravel and sand predominant over St. Peter Aquifer	2.70
Q3/A_2^3		Gravel and sand predominant over Prairie du Chien - Jordan Aquifer	2.60
Q6/A_2^1		Till predominant over Cedar Valley - Maquoketa - Dubuque - Galena Aquifer	0.30
Q6/A_2c1		Till predominant over Decorah - Platteville - Glenwood	0.10
Q6/A_2^2		Till predominant over St. Peter Aquifer	0.20
Q6/A_2^3		Till predominant over Prairie du Chien - Jordan Aquifer	0.80
Q6/A_2^4		Till predominant over Franconia - Ironton - Galesville Aquifer	0.10

Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24



Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24

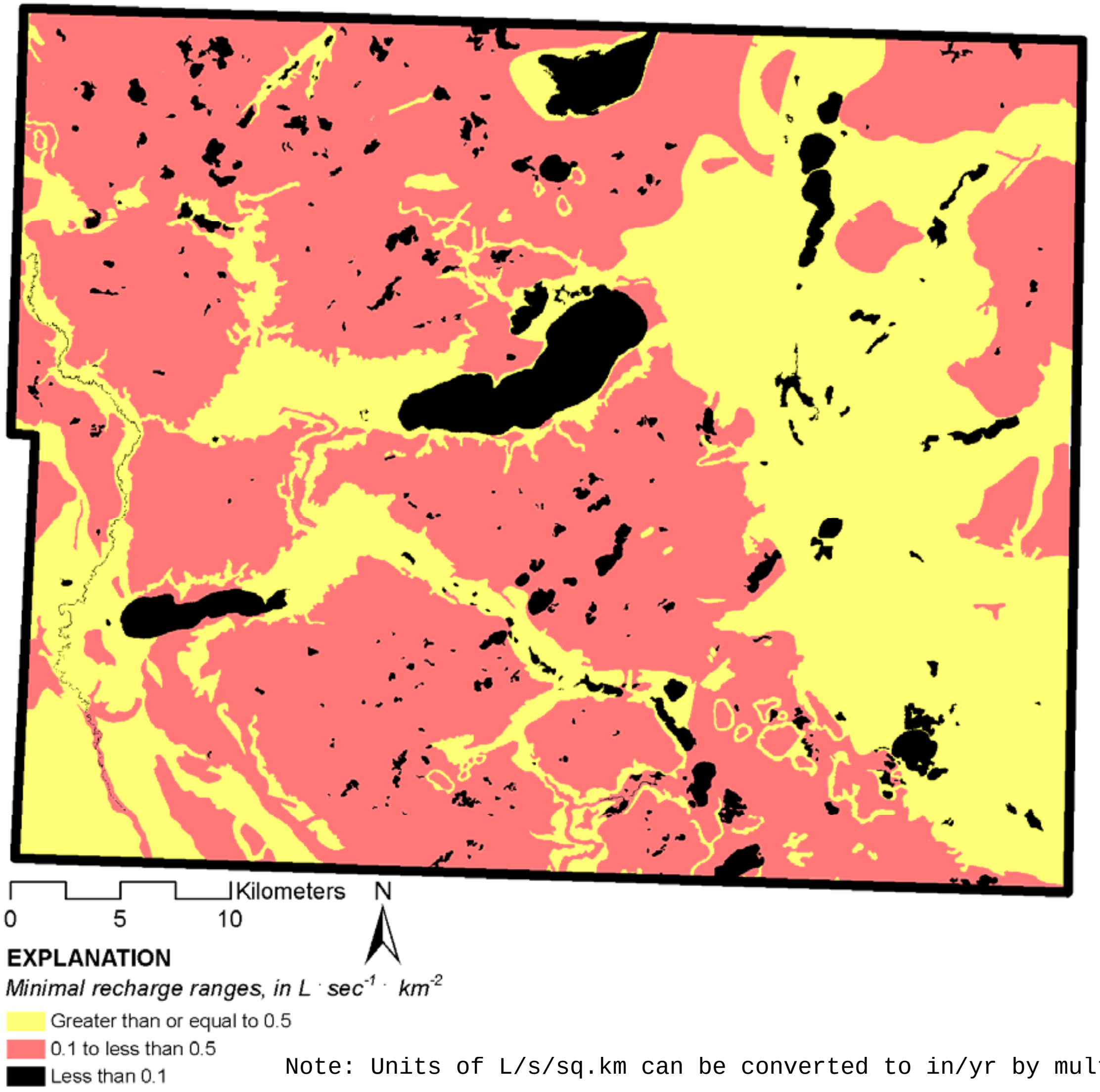
Recharge distribution atlas for Lac Qui Parle County.



Hierarchical Hydrogeologic Units for Lac Qui Parle County. The recharge table goes with this map.

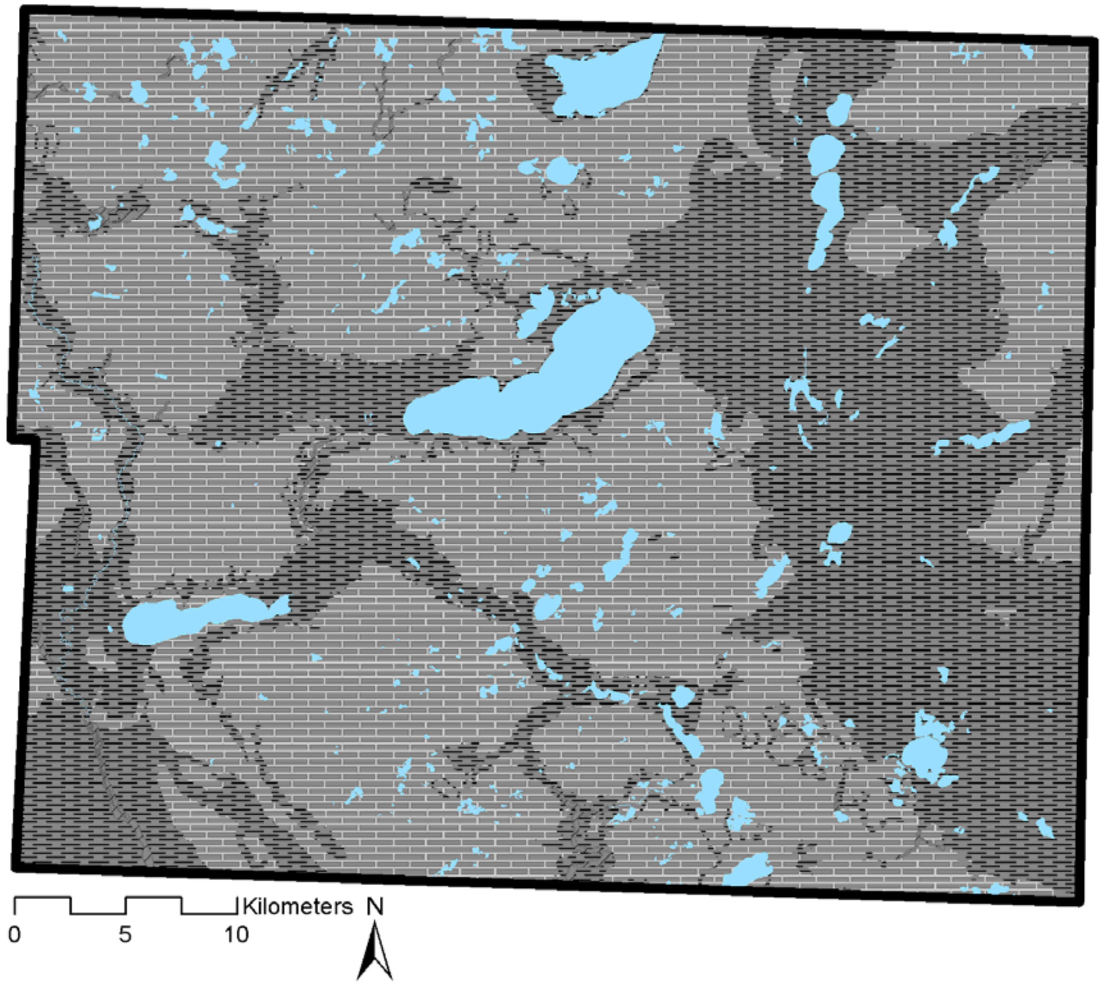
Lac Qui Parle County Minimal Ground-Water Recharge Based on February Monthly Discharge Mean Measurements Period 1955-1978			
Subregion	**Symbol**	**Unit Description**	**Recharge $[L/s/km^2]$**
B_2/Q3		Precambrian Igneous and Metamorphic Rocks overlain by sand and gravel	0.85
B_2/Q6		Precambrian Igneous and Metamorphic Rocks overlain by till	0.48
B_2/Q10		Precambrian Igneous and Metamorphic Rocks overlain by sandy till	0.40
K_3/Q3		Cretaceous Aquifer overlain by sand and gravel	0.60
K_3/Q6		Cretaceous Aquifer overlain by till	0.33
K_3/Q10		Cretaceous Aquifer overlain by sandy till	0.28

Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24



Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24

Recharge distribution atlas for Pope County.



Hierarchical Hydrogeologic Units for Pope County. The recharge table goes with this map.

Pope County Minimal Ground-Water Recharge Based on February Monthly Discharge Mean Measurements Period 1955-1978			
Subregion	**Symbol**	**Unit Description**	**Recharge [L/s/km^2]**
B_2/Q3		Precambrian Igneous and Metamorphic Rocks overlain by sand and gravel	0.85
B_2/Q6		Precambrian Igneous and Metamorphic Rocks overlain by till	0.48
B_2/Q10		Precambrian Igneous and Metamorphic Rocks overlain by sandy till	0.44

Note: Units of L/s/sq.km can be converted to in/yr by multiplying by 1.24

Attachment 2

Methods for deriving estimates of minimum groundwater recharge for Minnesota at state, regional and county scales.

General concepts for all spatial scales.

The methodology underlying the analysis used in this study is called the Watershed Characterization (WC) method. Previous applications of this method to groundwater recharge mapping have been presented by Shmagin and Kanivetsky (2002, 2006) and Kanivetsky and Shmagin (2005). The method is founded in the hydrogeological regionalization concepts described by Pinneker (1984) and the geophysical systems analysis described by Krcho (1978). Factor analysis, cluster analysis, and non-parametric statistical testing procedures play the part for the quantitative implementation of the basic concepts.

The basic idea underlying the WC method is that we can describe the landscape by various landscape characteristics and that within a whole landscape domain one can define subareas that appear to have relatively homogeneous landscape characteristics at some specified spatial scale. Examples of landscape characteristics that could be used include bedrock geology, quaternary geology, soil order, topographic slope, drainage density, vegetation, and landuse. With respect to defining hydrologic responses these subareas then are defined as being hydrologic response units. If the hydrologic responses or hydrologic response units are quantified at locations where hydrologic monitoring data are available, and those responses are related to the landscape characteristics of those response units, then it is possible to use those relations to predict the response of areas where no hydrologic data are available. In the present application the hydrologic response units are referred to as Hierarchical Hydrologic Units (HHUs) and the hydrologic response of interest is the minimum annual groundwater recharge.

The WC method can be applied at multiple scales, and is applied starting at the largest area of interest (e.g., global scale or continental), and then moving down to the smallest area for which data are available to quantify the responses of the HHUs. In the present application the largest area has boundaries extending outside the State of Minnesota, and the smallest area is the scale of an individual county.

Application of the WC method to Minnesota.

USGS gauging station locations and real time stream flow data (annual and monthly) for sites throughout MN and surrounding states were downloaded from the USGS Real-Time Water Data for the Nation website (http://waterdata.usgs.gov/nwis/rt). Data was sorted and sites were selected based on consistent consecutive available data and gauging station location.

To conduct the watershed characterization, a digital landscape database was constructed. The latitudinal and longitudinal coordinates for each gauging station were georeferenced in ArcGIS®, a Geographic Information System (GIS) database. Using Arc Hydro, GIS mapping software for water resources, catchment boundaries were delineated for each gauging station (e.g., at the statewide scale we have Figure 1) (Maidment, 2002). NHDPlus data, which is a compilation of the National Hydrography Dataset (NHD), National Elevation Dataset (NED), National Land Cover Dataset (NLCD) and Watershed Boundary Dataset (WBD) were formatted for the Arc Hydro delineations. Although the NHDPlus data were initially based on a 1:100,000-scale, most of the data incorporated into the database were developed at a higher resolution (USGS, 2009).

Soil data from the US General Soil Map (STATSGO2) Database, downloadable through the National Resources Conservation Service (NRCS), were formatted and compiled into the landscape database. STATSGO2 is a state-wide map at a scale of 1:250,000 (Soil Survey Staff, 2009). Some of the soil characteristics pertinent to this research, either in this NRCS database or derived from this database, include available water capacity, drainable porosity, field capacity, available water storage, particle-size and taxonomic soil order.

Bedrock hydrogeology, quaternary hydrogeology and depth to bedrock data layers from the MGS were formatted and incorporated into the landscape database. It should be noted that while this study was specific to Minnesota, whenever a delineated watershed crossed the boundaries between adjacent states, the data for this watershed lying within the adjacent state were acquired (LMIC, 2009).

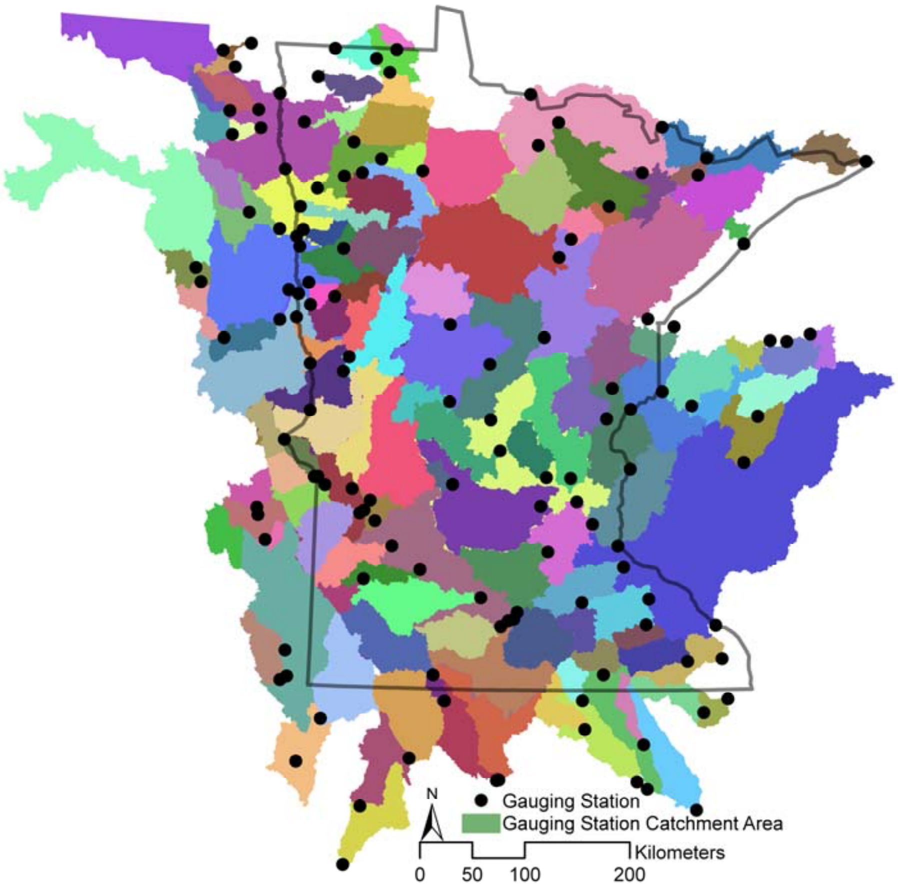


Figure 1. Minnesota regional map illustrating gauging station location and corresponding delineated watersheds.

A seamless, 30-meter resolution digital elevation model (DEM) was used for various topographic analyses. This DEM was compiled from the USGS National Map Seamless Server (2009b) and covers Minnesota and adjacent states. A number of additional data layers were acquired for the digital landscape database, and are summarized in a table included in Attachment 1. Some of these data layers include, landuse (MRLC, 2009), hydrologic soil group, and drainage classification. More than 80 characteristics were derived in total and maps are included on the project website (https://wiki.umn.edu/view/Water_Sustainability).

A watershed characterization for each watershed included in the hydrologic database was conducted using a compilation of the data layers discussed. The characterization involves overlaying the watershed boundaries that correspond to the stream gauge stations on the landscape characteristics and summarizing the fraction of each watershed that consists of a specific characteristic. A conceptualization of this overlay process showing the correspondence between the watershed boundaries, the gauging stations, and the landscape features is illustrated in Figure 2. These data were compiled into a set of matrices, to be used in a non-parametric analysis to facilitate segregation of the watersheds into distinct groups and thereby distinguish the hydrologic responses of the HHUs associated with the watersheds. This separation of the HHUs comprises the regionalization process.

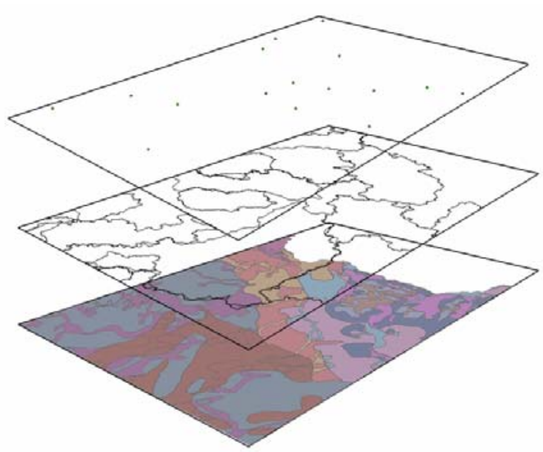


Figure 2. Diagram illustrating the overlay of GIS layer to extract values for the initial matrix used in the factor analysis.

Non-parametric statistical analysis, specifically the Kruskal-Wallis analysis of variance (ANOVA), was used to determine if streamflow was statistically different between basins, given different watershed characteristics. This analysis was used since the characteristics are not normally distributed, as basic parametric statistical analyses assume. In addition, non-parametric statistical analyses can be used with small data sets to identify differences between independent groups.

Minimum groundwater recharge from stream discharge.

Numerous methods have been used by hydrologist to estimate groundwater recharge. These methods are represented in the review by Scanlon et al. (2002). The method adopted in this project is to use the minimum flow in the month of February, which is known in Minnesota to be composed only of groundwater discharge to the surface stream system. Using streamflow to estimate groundwater recharge is not new but a recent advocacy was expressed by Bredehoeft (2007). Other methods using streamflow use baseflow recessions (e.g., Rorabaugh, 1964) and are not limited to time of year. However, we select to use the minimum flow in February because then the flow is known to be composed only of groundwater discharge and will not be affected by processes such as bank storage recession.

Using the minimum flow in February as the surrogate for minimum annual groundwater recharge is sensible because it is known that the water balance requires that groundwater discharge back to the surface at some point in the landscape, unless the water that does recharge is already completely allocated to human use or to ecological processes. The streamflow is therefore the signal for the groundwater recharge, and the minimum recharge can be viewed as being the stable baseflow, the part that is not affected by short-term events.

The groundwater discharge that occurs as part of the water balance of a watershed is illustrated in Figure 3 where there is a recharge area and a discharge area for the watershed. The net between the infiltration of precipitated water and evapotranspiration is the recharge to the groundwater shown in the figure as R. It is this quantity that we estimate with the streamflow gauging data.

The calculation of the aerial groundwater recharge from the minimum February flow is based on the assumption that the groundwater divide is approximated by the topographic divide (surface water divide) for the watershed associated with the streamflow measurement. The assumption of correspondence between the groundwater divide and the topographic divide is not flawless, but all reference books covering the topic of regional groundwater flow systems state that topography is an important driver of groundwater flow, at lease in humid areas.

An illustration of the multiscale nature of groundwater recharge and discharge is presented in Figure 4. Here we see that the scale of the groundwater flow field is related to the surface topography, and the scale of the surface topography relates to the size of watersheds. So for small watersheds the flow pathways are short, and for large watersheds the flow pathways are long, with intermediate sized watersheds and pathways in between. Even though the flow pathways operate over different length and time scales for the different size watersheds, the recharge through the surface is gradual and there is a link between the flows recharging the shallow groundwater system (local groundwater recharge and discharge) and the deeper groundwater system (regional groundwater recharge and discharge).

With the assumption that the groundwater divide corresponds to the surface water divide, the minimum groundwater recharge can be calculated by simply dividing the annual discharge volume associated with the minimum discharge by the watershed area. This recharge can be expressed in various common units such as inches/year, cfs/mi^2 or l/sec/km^2 .

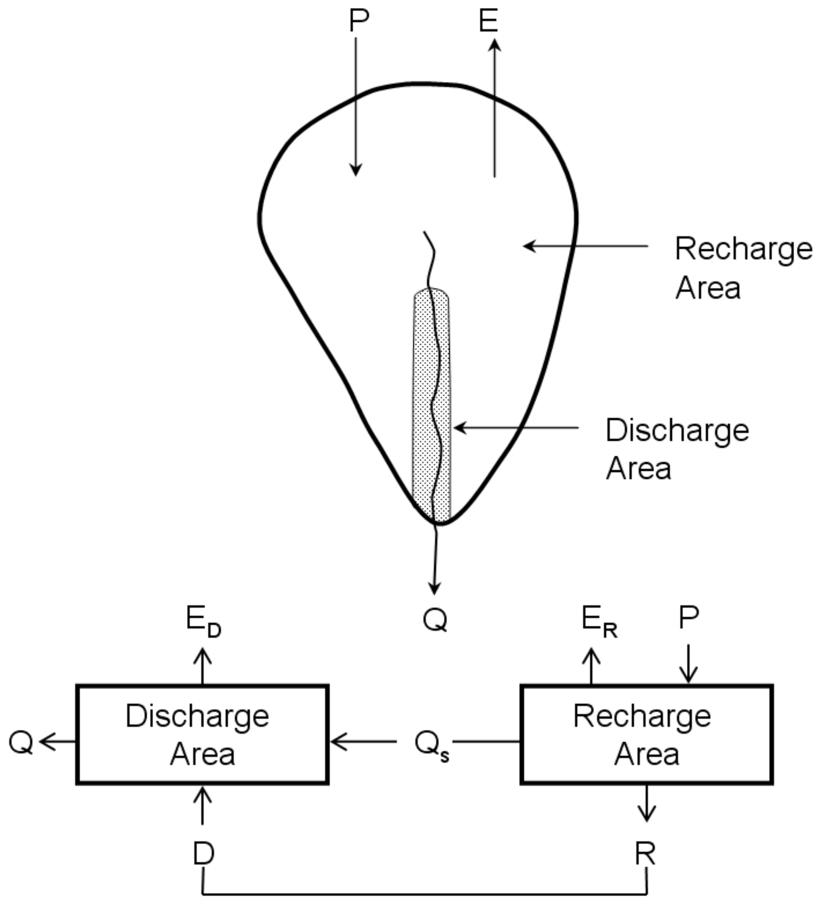


Figure 3. The water balance of a watershed showing the components of the balance and the recharge to the groundwater as a result of the excess between infiltrated water and evapotranspired water (from Freeze and Cherry, 1979).

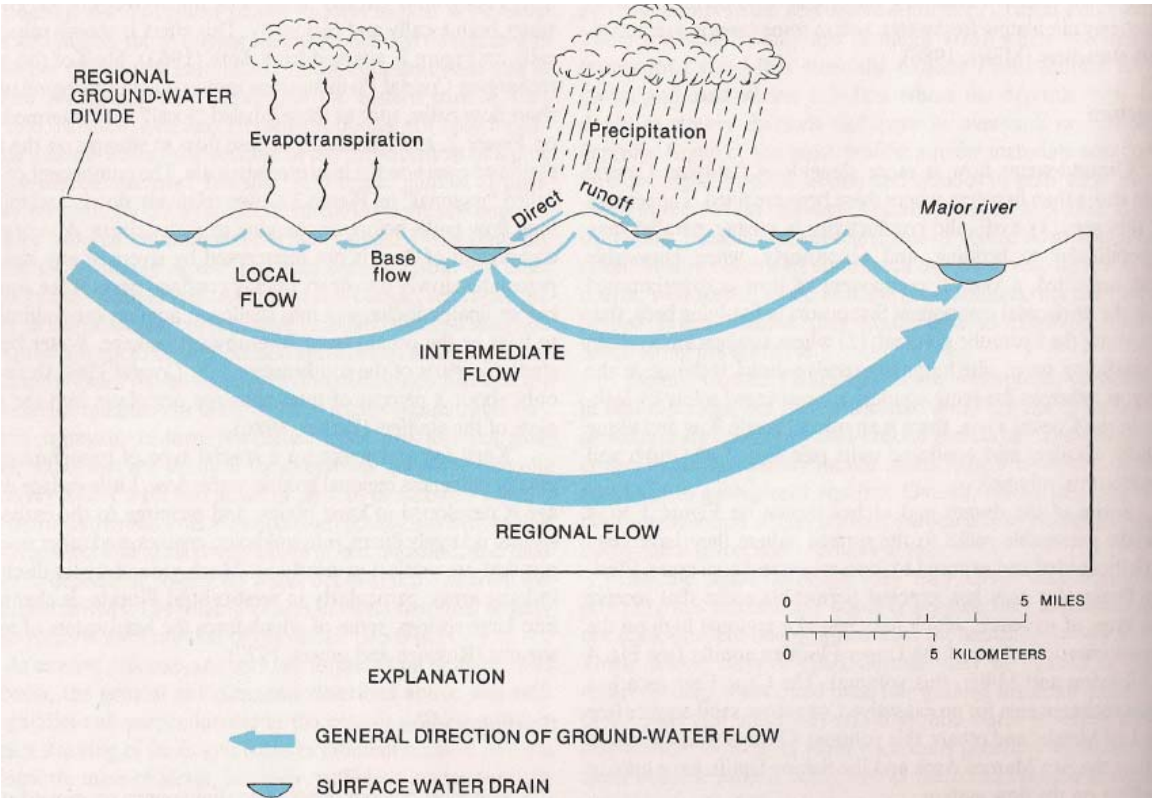


Figure 4. Illustration of groundwater flow fields in a vertical plane showing different spatial scales of flow ranging from local flow to regional flows. Local flow have to do with small watersheds, while regional flow are associated with large watersheds. (from Miller, 1988)

Multivariate statistical analysis.

Multivariate statistical analysis is commonly used to complete stream flow regionalization (Bartlein, 1982; Lins, 1985, 1997; Sophocleous, 1992; Mauer et al., 2004; Shmagin and Kanivetsky, 2002, 2006; and Kahya, et. al., 2008). It explains correlations in a large set of variables by reducing the number of underlying independent components or variables. In these studies regional stream flow behaviors were delineated to identify homogeneous hydrologic regions. These hydrologic regimes had distinct patterns of seasonality and persistence (Lins, 1985, 1997; Kahya et. al., 2008).

In the present research project we used factor analysis for completion of the regionalization of state-wide hydrologic units (watersheds). Factor analysis is a multivariate analysis technique used for data reduction or structure detection by reducing the number of variables and detecting structure in the relationships between variables (*classifying variables) (*Thurstone, 1931; StatSoft, 2007). It allowed us to indicate watersheds that fell within five specific hydrologic regimes representing similar flow trends. By looking at the boundaries of these regimes with the boundary of landscape characteristics across Minnesota, an initial understanding of the data is established.

When a factor analysis is performed, the correlation between two or more variables is summarized in a scatterplot. A regression line with the maximum variance is then fit to represent a linear relationship between the variables. This correlation is called the factor load. After this first factor has been extracted additional lines are drawn to maximize the remaining variability extracting consecutive factors.

Variance maximizing rotation is the method used to extract the additional factors. In essence, the maximum variance of each additional factor is obtained by rotating the original factor regression line to represent the X-axis. This maximizes the variability of the new factors, while minimizing the variance around the new variable. Since each consecutive factor is defined to maximize the variability that is not indicated by the preceding factor, consecutive factors are independent of each other, making them uncorrelated or orthogonal. Varimax rotation is the most common orthogonal method (Haan, 1977; Kahya et al., 2008).

State scale.

It is recognized that a number of factors control the recharge rate to groundwater systems. These factors include, but are not necessarily limited to, climate (precipitation and evapotranspiration potential), geology (both bedrock and quaternary layer characteristics), surface topography, vegetation (landuse), and soil type. As such, using GIS methodology we derived statewide maps of parameters that represent these characteristics. Examples of these maps are available on the project website (https://wiki.umn.edu/view/Water_Sustainability), and a summary of all data layers used to produce these maps are summarized in the table found in Attachment 1. . Figure 5 is an example of a state-wide data map representing the distribution of Soil Orders overlain by the watershed boundaries.

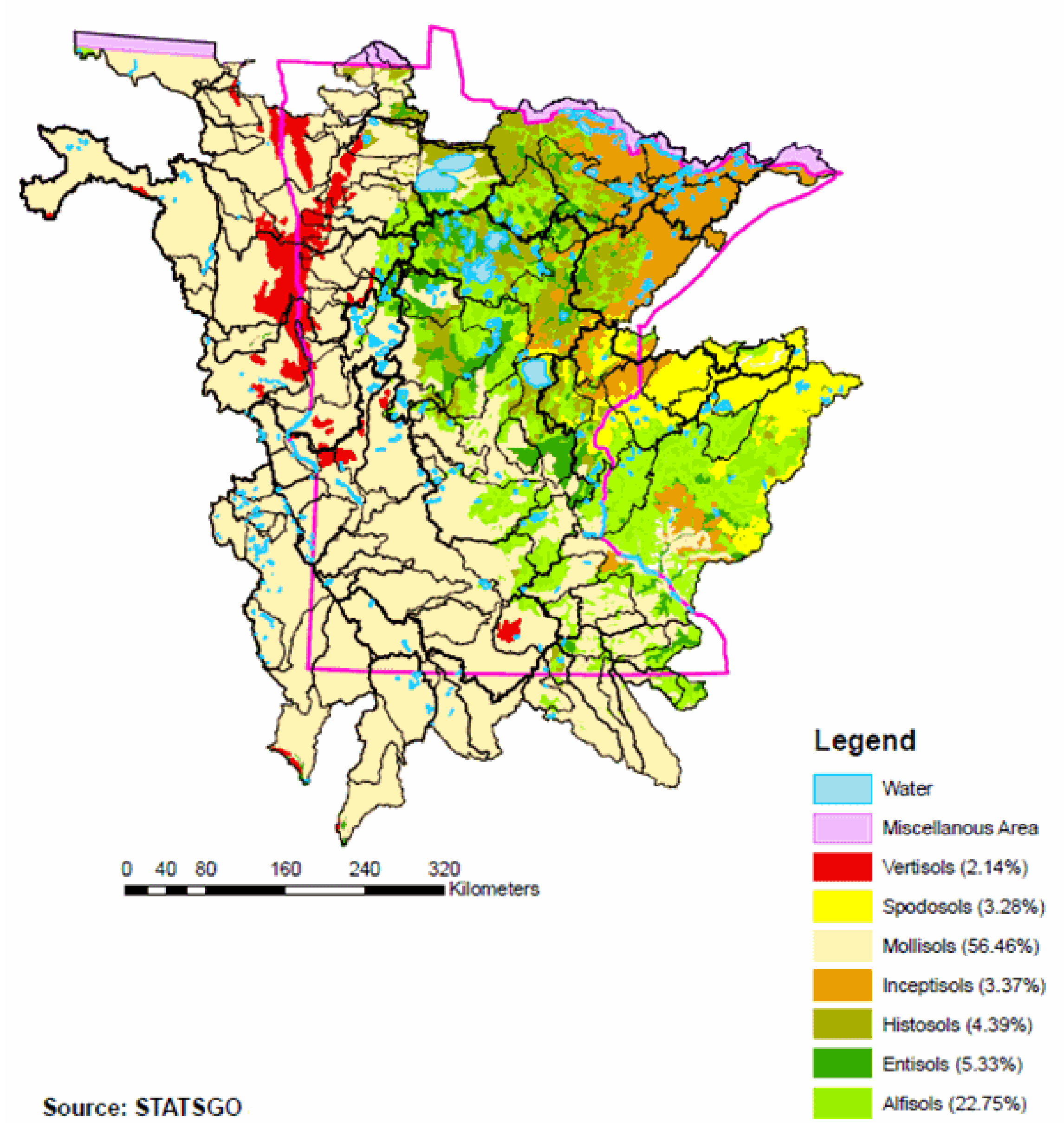


Figure 5. State-wide GIS map of Soil Orders overlain by watershed boundaries.

These maps could then be coordinated with the hydrologic characteristics derived for the watersheds outlined in Figure 1 in a fashion similar to the illustration given in Figure 2. That is, we identify the landscape characteristics that exist within the boundaries of a watershed, and correlations are then sought between the landscape characteristics and corresponding hydrologic characteristics. It is this identification of significant correlations that leads to the delineation of HHUs. By definition, HHUs are delineated landscape units that contain distinct landscape characteristics and distinct hydrologic response. The hydrologic response of interest to us at the state-wide scale is the minimum annual groundwater recharge. To quantify this recharge we use as a surrogate the minimum flow that occurs in February.

Before analyzing the recharge characteristics of different HHUs we first establish the fact that there are differences in hydrologic characteristics across the state, and that these characteristics can be regionalized. An analysis was conducted using the within-year distribution of monthly streamflows for all 129 watersheds. The monthly flow data for each of the 129 watersheds was entered into spreadsheets for application of factor analysis. The data ranged over the period from 1936 to 2006. Analyses were performed for three periods within the hydrologic record. The number of watersheds used in the analyses for these periods depended on the time period itself. The factor analyses distinguished watersheds lying within a given region of the state from watersheds lying within other regions as illustrated in Figure 6. Each of these regions has a distinct hydrologic regime in terms of the distribution of the annual flows and of the within-year distribution of flows. The distinctions shown in Figure 6 were found to be consistent among the three time periods analyzed, for both monthly and annual flow. Similar analysis of the annual minimum flows for the month of February showed that the behavior of those flows were similar to those for the annual and monthly hydrologic regimes.

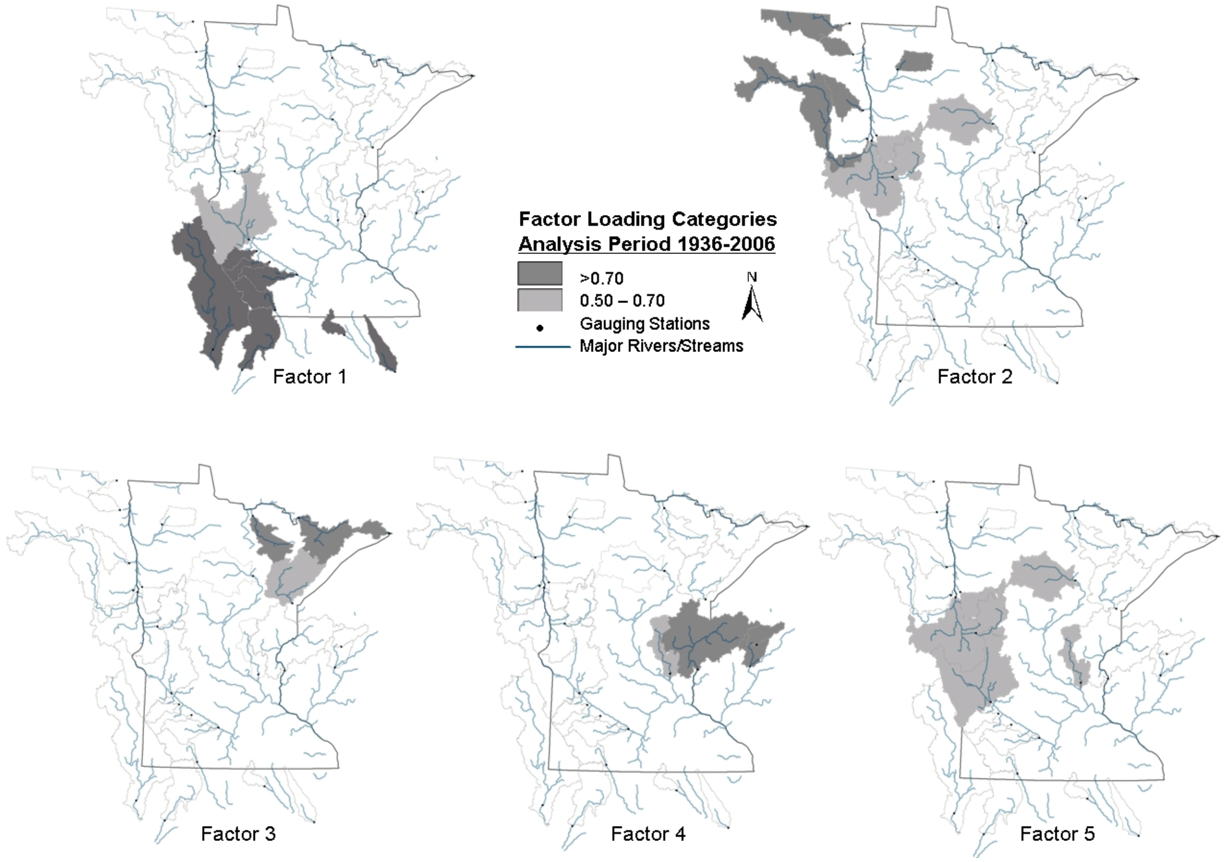


Figure 6. Illustration of the identification of the various regions of the state where the hydrologic regime is distinguished.

This result is then used as a visual guide to determine what areas of the state might divide up into regions of similar mean minimum annual groundwater recharge. For this the mean minimum February flows from the records for 129 watersheds were entered into tables along with coded landscape characteristics, such characteristics include but are not limited to, bedrock geology, quaternary geology, and soil order.

It was discovered from this analysis that the bedrock characteristics and the presence/absence of Quaternary layer were the variables that provide distinction in mean minimum annual groundwater recharge at the state scale. Other variables, such as soil order for instance, were not found to be significant. A map showing the spatial distribution of the mean minimum annual groundwater recharge at the state scale based on hydrogeologic boundaries is presented as the image on page 1-2 in Attachment 1, and in Figure 7. This map shows that there are three areas of the state with distinct recharge characteristics and those are identified as being Paleozoic Artesian Basin (referred to as A), Precambrian Basement (B), and Cretaceous Deposits (K). Further subdivision of this map was completed by overlaying Quaternary thickness on top of hydrogeologic boundaries (Figure 8). Although the thickness intervals which resulted in statistically significant recharge variations do not correspond directly to the coloration of the map used for Figure 8, this illustration provides a representation of the Quaternary distribution across the State of Minnesota. The final atlas (Figure 9) corresponds to the state-wide recharge table included on page 1-5 in Attachment 1.

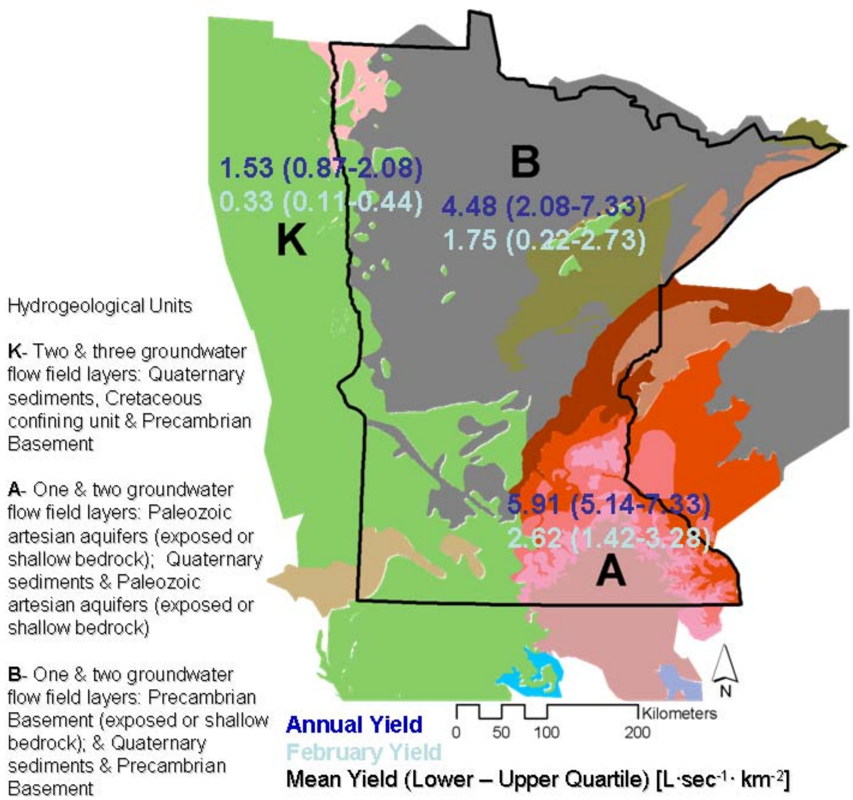


Figure 7. Distribution of mean minimum annual groundwater recharge for the state scale given by the February yield values. The regions are distinguished by the three hydrogeologic regimes, A, B, and K as defined in the legend. The recharges are given as mean values and the lower and upper 25% quartiles. To convert $L/s/km^2$ to in/yr multiply by 1.24.

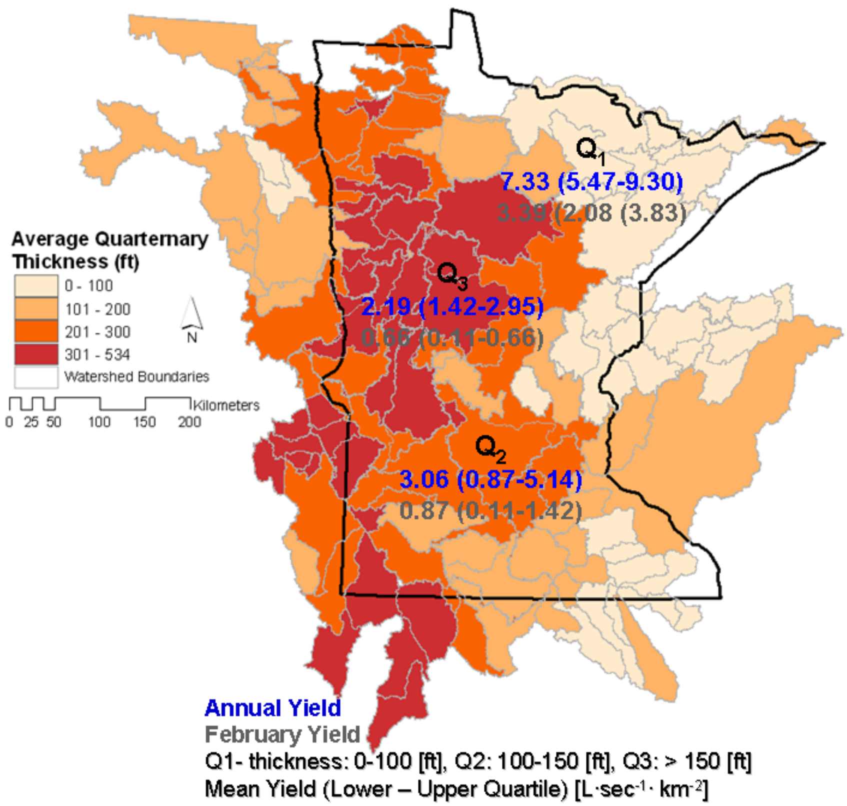


Figure 8. Distribution of mean minimum annual groundwater recharge for the state scale depicted by Quaternary thickness. Results of the non-parametric analysis indicated recharge variations for thicknesses of <100 ft, 100-150 feet and >150 ft. To convert $L/s/km^2$ to in/yr multiply by 1.24.

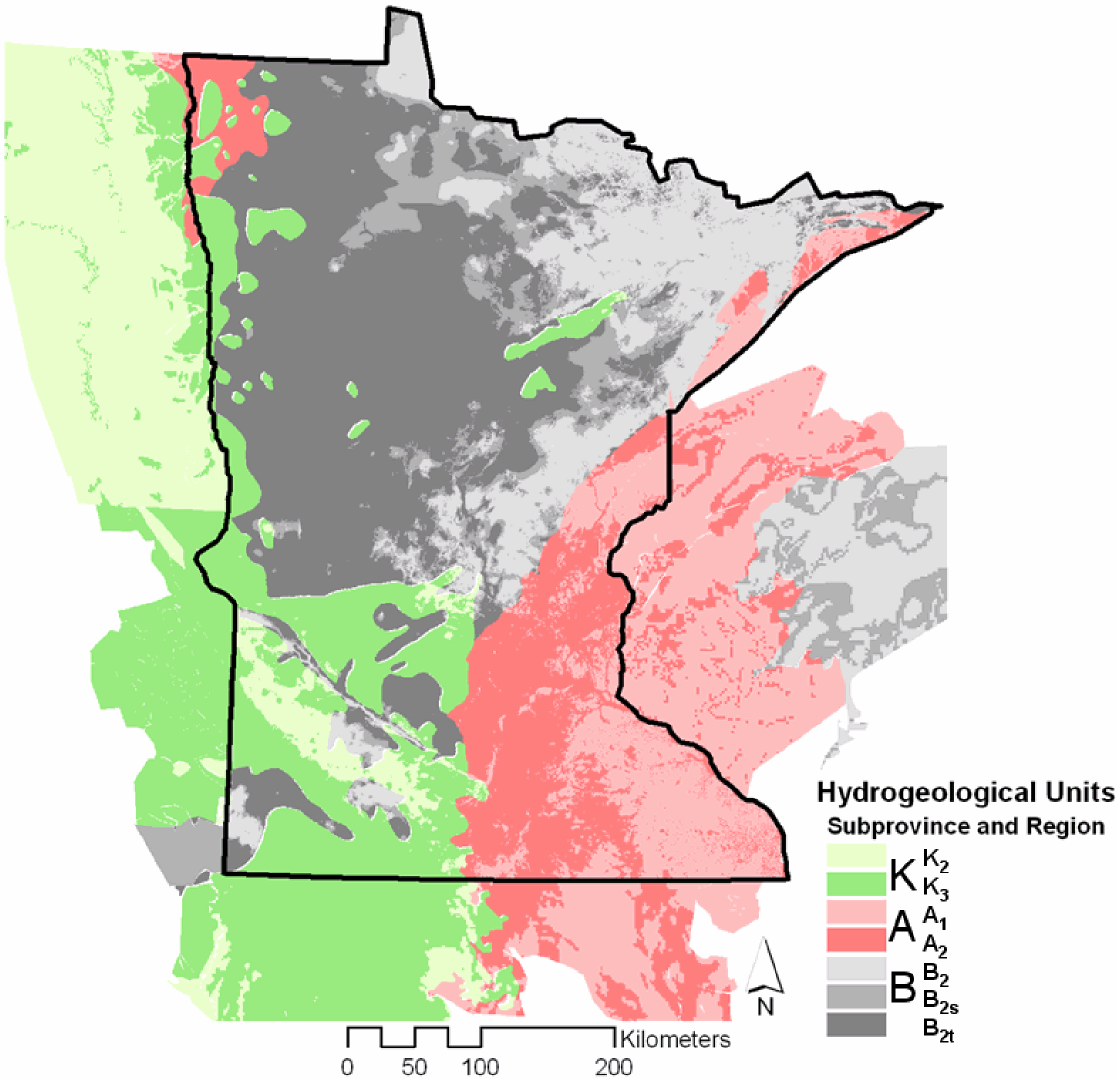


Figure 9. Final state-wide atlas created by overlaying hydrogeologic boundaries with Quaternary thickness.

Region scale.

We conducted analysis for three regional locations, the East Central Minnesota (ECM) region, the South East region (Karst), and the South Central (SC) region. The method for developing the atlases of mean minimum annual groundwater recharge for each of these regions will now be presented.

For the region scale a total of 176 gauging stations were used to analyze the minimal monthly stream runoff.. These locations were selected based on data summarized in

Lindskov [1977], which contains an extensive summary of low-flow characteristic data for Minnesota streams prior to the period of anthropogenic influences. GIS procedures were used to delineate the catchment boundaries (watershed) corresponding to each gauging station.

Various combinations of landscape characteristics were derived for these watersheds by the overlaying the spatial distribution of individual landscape characteristics onto each of the watersheds. One could then determine the fraction of a given watershed that is composed of a given characteristic. These characteristics are then entered into a table that has the watershed identifier along with the fraction of watershed composed of a given characteristics.

The next step is to derive the estimates of mean minimum February flow to be used in the analysis. For larger watersheds, such as those used at the state level scale the periods of record are much longer and complete than those records for the regional scale analysis. It is unfortunate that this is the case, but this is the reality of hydrologic monitoring at the present time.

To address this problem we use the idea of benchmark watersheds. These are defined as watersheds having relatively long-term records that exist in a given region and can presumably be used to represent the hydrologic characteristics of smaller watersheds within the same region that have short-term records.

From the 129 watersheds analyzed for the state scale analysis we selected four_ benchmark watersheds, these being the Elk River near Big Lake (5275000), the Yellow Medicine River near Granite Falls (5313500), the Root River near Lanesboro (5384000) and the Root River near Houston, MN (5385000). The records used were those from 1955 to 1976. The Root River data near Lanesboro was used as a benchmark for some of the ECM watersheds, while the Root River data near Houston was used as a benchmark watershed for some of the Karst and the SC watersheds. _The procedure for deriving the mean minimum February flow for a watershed from the regional scale using the benchmark watersheds is now explained briefly.

Average long-term characteristics of minimal monthly (February) discharge for the period of 1958-1976 were recorded for each of these watersheds were calculated for these benchmark watersheds. Each watershed was assigned to a corresponding benchmark based on proximity to the benchmark and the results of a state-wide streamflow regionalization. The February monthly runoff values for the 176 regional watersheds were obtained by determining the linear proportion between the discharge of the specific corresponding benchmark watershed and the regional watershed's observed February discharge value.

The available data for a given regional scale watershed is selected for analysis. Using an example, let us say that a given watershed in the ECM has but one year of flow data available, and that those data exist within the period of record of the Elk River watershed. The minimum February flow (in $L \cdot s^{-1} \cdot km^{-2}$) for the Elk River for the year corresponding to that one year of record for the ECM watershed is identified, and that flow is then divided into the flow that occurred for the ECM watershed for the same date in February. This ratio is then multiplied by the mean minimum February flow for Elk River to obtain the estimate of the mean minimum February flow for the ECM watershed. This procedure is then applied to all of the watersheds, and the resulting estimated mean minimum February flows are then entered into the tables along with the derived watershed characteristics.

These calculated minimal monthly discharge values represent the sustainable groundwater recharge rate for each regional watershed. The watershed characteristics approach uses these values together with the corresponding watershed's landscape characteristics to determine the hydrologic drivers.

A matrix table like the one created for the state-wide analysis was also created for the regional scale using the 176 watersheds. A detailed, simplified, step-by-step description is given in Appendix A of this attachment. This matrix table was used to conduct the non-parametric statistical analysis, specifically the Kruskal-Wallis analysis of variance (ANOVA). Using this analysis, it was determined whether minimal monthly streamflow (February yield) was statistically different between catchment groups having different watershed characteristics.

Based on the results of the ANOVA, characteristics exhibiting a significant statistical difference ($p \leq 0.05$) were used to establish the final HHUs. A statistically significant difference in minimum February flows between various groups of watersheds each containing a specific landscape characteristic (such as watersheds with a Quaternary thickness <100 ft or >100 ft) means that the specific HHU characteristic does play a role in determining the flows. If the difference is not significant, than one can conclude that the HHUs behave similarly and therefore cannot be separated, or distinguished, by way of the value of the recharge. These characteristics, specifically bedrock material, Quaternary sediment, and depth to bedrock, represented the primary hydrologic drivers. A list of all evaluated characteristics is included in Attachment 1. Some of these characteristics may have been statistically significant at one hierarchical level but could not be further subdivided into additional units; therefore, they were not included in the final regionalization.

With the combination of these characteristics HHUs at a subprovince, region, subregion, district, and subdistrict hierarchical level within the regional atlas were established. At each level moving from subprovince down to subdistrict, recharge values were refined. For example, at the subprovince level, three HHUs are identified within boundaries of the ECM (Figure 10) based on the hydrogeologic boundaries of K, B and A. However, at the region hierarchical level, these units are further refined into an additional HHU created by applying Quaternary thickness to subprovince HHU denoted by symbol A (Figure 11). The means test showed that the recharge values for these two units are significantly different and therefore A was subdivided into two distinct units with respect to their recharge characteristics. Further subdivisions continue to develop by refining the bedrock features, the type of Quaternary material, and the thickness of the Quaternary material.

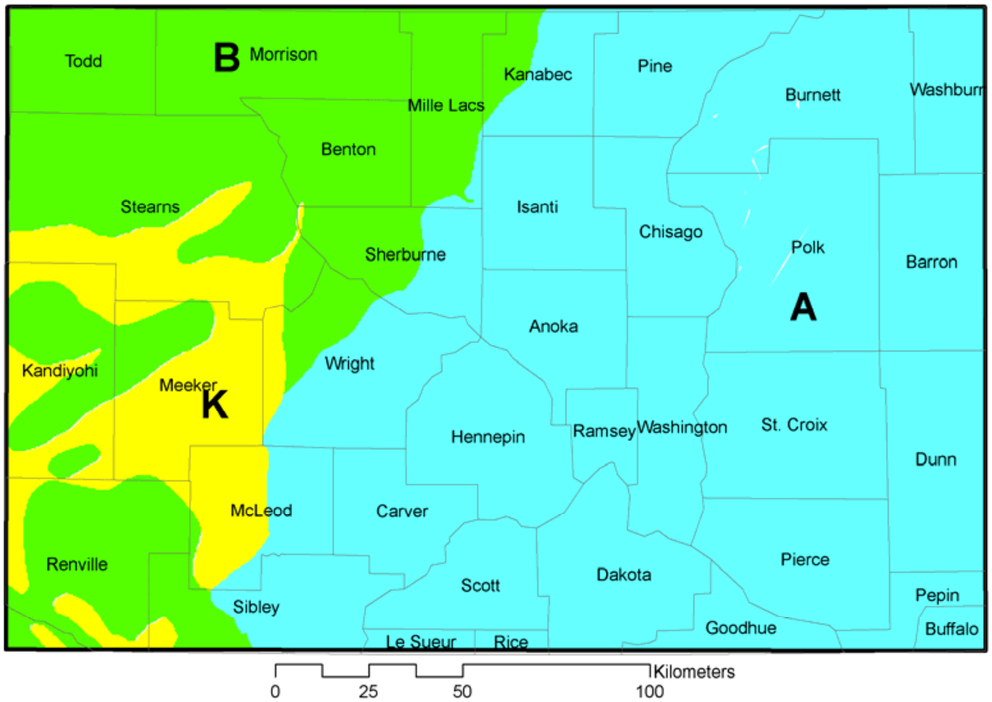


Figure 10. Subprovince hierarchical units boundaries for the ECM.

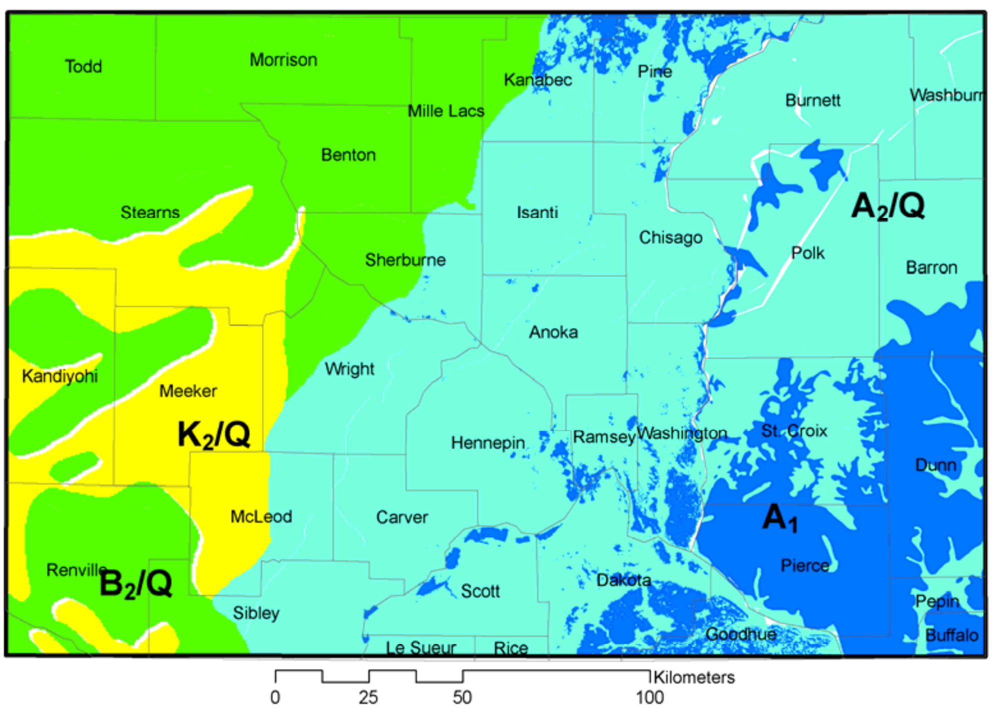


Figure 11. Region hierarchical unit boundaries for the ECM.

Basic descriptive statistics were conducted to compute the mean minimum annual recharge values along with upper and lower quartiles for each HHU. We note that the quartiles were computed only when sufficient watershed data was available to represent a given HHU at the corresponding scale. As the level of analysis decreases in scale, that is, as the number of HHUs increases, the number of watersheds available for a given HHU decreases, and eventually only one or two watersheds are available to estimate the recharge associated with each HHU. At that level, especially when there is only one watershed for an HHU the assignment of the recharge rate is made by expert judgment. Some background information on the approach to derive expert judgment estimates of recharge is provided in Appendix B of this attachment.

Atlases for spatial distribution of mean minimum annual recharge are presented for each of the regions (East Central Minnesota, South East Minnesota, South Central Minnesota) in Attachment 1. Also given is the table that summarizes the details of the estimated recharges for each level of HHU.

County scale.

Our objective was to derive atlases of minimum annual groundwater recharge for the counties of Olmsted, Pope and Lac Le Parle. There is not sufficient watershed gauging station data at the county scale to allow for the same type of statistical analysis possible at the statewide and region scales. Therefore, for the present condition it is necessary to extrapolate/interpolate the recharge results derived from the state scale analysis and from the region scale analyses to the county scale. This is done by transferring the estimates of minimum groundwater recharge for the individual HHUs derived from the state scale and the region scale to those same units where they occur at the county scale. The resulting county scale atlases are presented in Attachment 1 for the counties of Olmsted, Lac Qui Parle and Pope. Also given in the attachment are the maps of the HHUs for each county and the associated tables for the HHUs in each county.

It is hoped that in future efforts by federal, state and county agencies, that streamflow records will be collected at the smaller scale and that these data will be used along with the analyses derived for the larger scale (like that derived in this project) to provide estimates of recharge at county level and even at higher resolutions. Evidence that such will be possible is suggested in the article by Eng and Milly (2007).

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Appendix A.

Step-By-Step Regional Procedure Documentation

A matrix of watershed characteristics is generated with watersheds listed as the rows and characteristics as the columns. The first characteristics included are the watershed area and yield.

Qualitative characteristics are listed as a percentage (decimal) of the watershed containing the specific attribute, each listed as an independent matrix column (**Figure** Figure A.1 and Figure A.2).

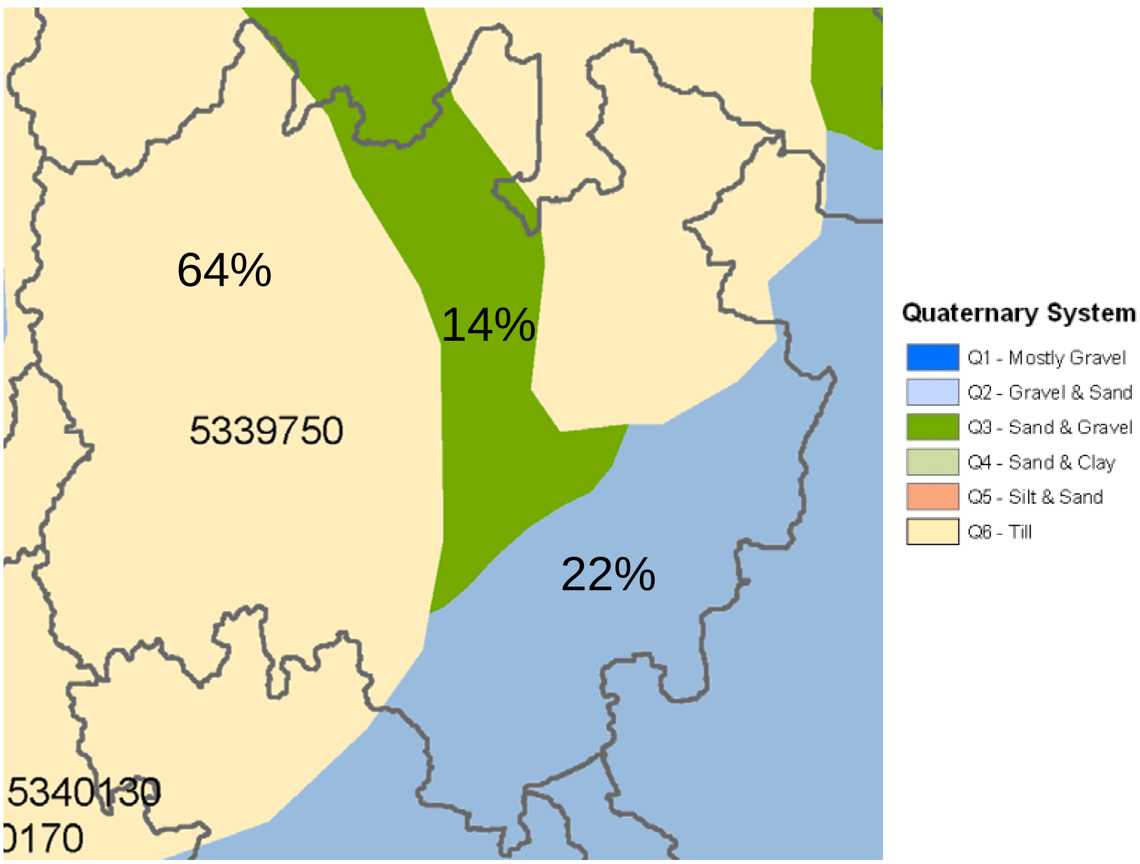


Figure A.1. Percentage of watershed #5339750 which falls within each type of quaternary sediment.

				Quaternary Sediment Material						
Name	Area (km2)	FebY (L/s/km^2)	Quat Thickness (Ft)	Q1	Q2	Q3	Q6	Q7	Q8	Quat Code
5339750	175.8	0.60	129.62	0.00	0.22	0.14	0.64	0.00	0.00	6
5339800	134.8	0.19	192.70	0.00	0.59	0.00	0.41	0.00	0.00	2
5339950	138.8	0.80	180.31	0.00	1.01	0.00	0.00	0.00	0.00	2
5340110	69.0	0.04	97.97	0.00	0.40	0.18	0.42	0.00	0.00	6
5340130	134.8	2.84	114.50	0.00	0.43	0.23	0.35	0.00	0.00	2
5340170	181.7	3.86	141.75	0.00	0.35	0.40	0.26	0.00	0.00	2
5341540	77.5	1.49	115.03	0.00	0.10	0.00	0.90	0.00	0.00	6
5345000	328.3	1.74	143.20	0.00	0.43	0.00	0.57	0.00	0.00	6
5352010	863.2	0.71	185.83	0.00	0.00	0.05	0.95	0.00	0.00	6
5352810	108.1	0.06	137.30	0.00	0.09	0.05	0.85	0.00	0.00	6
5352850	528.6	1.13	130.50	0.00	0.07	0.22	0.70	0.00	0.00	6
5352900	104.4	0.52	126.39	0.00	0.07	0.00	0.93	0.00	0.00	6

Figure A.2. Example of matrix development using quantitative and qualitative characteristics.

Compiling the data into a matrix enables statistical analyses to be conducted on the entire dataset to get a preliminary understanding of connections. For example, a factor analysis (varimax normalized) was completed on the regional watersheds to see if any characteristics are linked directly to February yield throughout the dataset. Unfortunately, the results shown below do not indicate that solely one characteristic is controlling the yield (Figure A.3). Therefore, it will be necessary to continue the analysis to uncover the relationships.

Variable	Factor Loadings (Varimax normalized) (FullRegionalData_Revised.sta) Extraction: Principal components (Marked loadings are >.700000) Factor 1	Factor 2	Factor 3	Factor 4
FebY (l/s/km2)	-0.495789	0.467276	0.108654	0.424980
Area (km2)	0.608301	0.002356	0.051363	0.163292
Quat Thickness (Ft)	0.694142	-0.329705	0.131974	-0.254688
Perennial Drainage Density (km/km^2)	0.065646	-0.145551	-0.132125	0.908187
Intermittent Drainage Density (km/km^2)	0.051849	0.915910	0.025722	-0.314510
Total Drainage Density (km/km^2)	0.086949	0.935427	-0.032578	0.073427
Average Slope	-0.457696	0.649316	-0.043096	-0.024292
Average Altitude (ft)	0.744477	0.207379	-0.017656	-0.224613
Available Water Capacity	0.104778	0.197694	-0.885955	0.012524
Total Porosity	-0.340475	-0.253962	-0.726397	0.150010
CO	0.644855	-0.064328	0.040097	0.099291
Expl.Var	2.418700	2.634494	1.367386	1.284810
Prp.Totl	0.219882	0.239499	0.124308	0.116801

Figure A.3. Results of factor analysis for regional study; no preliminary connection to February yield was determined.

Next, non-parametric statistical analyses (specifically, Kruskal-Wallis ANOVA by ranks) were conducted. To use the Kruskal-Wallis test, characteristics must be assigned a "Code". This code is based on the predominant characteristic within the watershed. Based on the data summarized in Figure A.2 for watershed 5339750, 64% of the watershed is listed as Q6-till so this watershed would be coded "6" for quaternary sediments (Figure A.2). The Kruskal-Wallis test evaluates whether there is a statistical difference between mean values within each "Code". A p-value less than 0.05, was considered significant (Figure A.4).

Depend.: FebY (l/s/km2)	Kruskal-Wallis ANOVA by Ranks; FebY (l/s/km2) (BQ.sta) Independent (grouping) variable: CQt Kruskal-Wallis test: H (1, N= 38) =6.000000 p =.0143 Code	Valid N	Sum of Ranks
1	1	26	585.0000
2	2	12	156.0000

Figure A.4. Result output for Kruskal-Wallis ANOVA by Ranks test; result indicates a significant difference ($p<0.05$) between quaternary thickness in the B_2/Q Region.

This approach can be time consuming and involves trial and error to evaluate which characteristic combinations can refine units and remain statistically significant. Once it is determined if there is a significant difference in each characteristic, then descriptive statistics are calculated to determine the mean for each characteristic, as well as the lower and upper quartiles (Figure A.5). Providing the quartile range summarizes the variation within each unit.

	All Groups Descriptive Statistics (BQ.sta)				
Variable	**Valid N**	Mean	Lower Quartile	Upper Quartile	Std.Dev.
FebY (l/s/km2)	38	0.454580	0.036574	0.621334	0.650835

Figure A.5. Descriptive statistics for B_2/Q Region; summary of mean and lower and upper quartiles.

Appendix B.

Description of Expert Judgment for Assigning Recharge Rates to Units

The quantification of recharge values for hierarchical hydrogeologic units (HHUs) using the statistical quantification method becomes problematic when the number of gauging stations representing a unit becomes too small to draw statistical inferences. This problem occurs when the size of the HHUs reach a lower limit because gauging station data are generally available only for larger watersheds.

To partially overcome this limitation for estimating of recharge rates for small HHUs a procedure using expert judgment was employed. The procedure is based on the interpretation of the dominant character of flow fields using landscape descriptors (in the immediate case, bedrock and quaternary geology) for the area of interest and uses inferences about those flow field characteristics for the (larger) spatial scales where sufficient data was available to draw statistically significant results. In that way the estimates are essentially derived as extrapolations from the larger scale to the smaller scale, and therefore can be derived by any analyst familiar with the steps in the statistical data analysis and the regionalization procedure. This part of the assigning the flow to the HHU is rather objective.

There is however a significant amount of subjectivity in the interpretation of the physical setting for any given HHU, and this subjectivity comes from having extensive experience in understanding the workings of the hydrogeologic systems of interest. Thus the final interpretation and assigning of the recharge rates to HHUs that have insufficient data requires significant background knowledge from the field of hydrogeology and familiarity with the region (e.g., Kanivetsky, 1979).

As an example let's consider an HHU, call it HHU-small that is dominated by carbonate bedrock (fractured media) for which we want to derive an estimate of the minimum annual recharge. Within the same region and at a larger scale let us say that an HHU, call it HHU-large, exists that contains both the same carbonate bedrock feature, but also sandstone feature as well. Let us also say that HHU-large is large enough such that enough flow data was available to derive a statistically significant estimate of recharge for the unit, and let us say that the mean value for the estimate is 2.5 l/s/km^2 and the range (lower and upper 25% values) is 1.25 l/s/km^2 to 3.5 l/s/km^2. Since HHU-large contains both carbonate and sandstone units, the lower value of the range presumably is for measured flows associated with sandstone dominated features and the upper value is for measured flows dominated by the carbonate features. Thus since HHU-small is dominated by carbonate features the expert judgment would be that the recharge rate would be from the upper part of the range, or 3.5 l/s/km^2.

Attachment 3

Result 2. Freshwater Sustainability Database – for use in a Quantitative Information System (QIS)

Purpose

The *Freshwater Sustainability* database is designed to quantify sustainability for a desired area of interest by comparing permitted water use to available groundwater recharge volumes by way of a MS Access database (db) queries or manipulation in MS Excel. The db is intended to allow querying of spatially referenced data without the need of a GIS. Areas of interest are queried by using references to the different areal extents (county, major and minor watershed) that are associated with each row of sustainability data.

Methodology

The db was created using ArcGIS 9.2 and MS Access 2003. Fundamentally, it is formed by the intersection of three geospatial layers for Minnesota (MN): bedrock-quaternary (BQ) spatial unit polygons, DNR permitted-use points, and Section level public land survey polygons. As such, the db is composed of three tables:

1. *Recharge_units_12_09*: consists of groundwater recharge rates for each BQ spatial unit in Minnesota. The data were generated from dissolution of BQ polygons at three different spatial resolutions (State-wide, Southern MN "zone" and county [Lac Qui Parle, Olmsted and Pope]) to produce a master list of 80 unique BQ units.
2. *Sections_final*: stores all MN Sections and the dominant BQ spatial unit for each as well as the associated county, and major- and minor watersheds. The data were generated by intersecting publically available MN Section polygons with BQ, county, and watershed polygons.
3. *DNR_wateruse_permits_new*: consists of volume and location data for surface- and groundwater use permits issued in Minnesota from 1988 through 2007. The data were generated by taking the permit point data available from the MN-DNR

http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html) and intersecting it with the MN Section polygons.

Tables 1 through 3 for provide descriptions of table columns.

Table 1. Column descriptions for *Recharge_units_12_09* db table

ID	Subdistrict code that uniquely identifies BQ Subdistrict unit and links *Recharge_units_12_09* table to *Sections_final* table
zone_subdist	Combination of BQ resolution "zone" and Subdistrict
subprovince	BQ Subprovince (non-unique)
Region	BQ Region (non-unique)
subregion	BQ Subregion (non-unique)
District	BQ District (non-unique)
subdistrict	BQ Subdistrict (unique)
Yield	Recharge rate of BQ unit (L/s/km^2); this value is converted to inches/year for query calculations
Shape_Area	Total area of BQ unit in Minnesota (m^2)

Table 2. Column descriptions for *Sections_final* db table

Column Name	**Column Description**
Objectid	Unique identifier for each section row
Area	Area of the section (m^2)
Town	Township number
Rdir	Range direction
Rang	Range number
Sect	Section number
Cty_name	County name where geographic center of section is located
Cty_fips	County FIPS code
Majorws	Major watershed number
Majwsname	Major watershed where geographic center of section is located
Minorws5	Minor watershed number
Minwsname	Minor watershed where geographic center of section is located
Subdist_code	Code linking the section with the BQ spatial data

Table 3. Column descriptions for *DNR_wateruse_permits_new* db table

Column Name	Column Description
PERMIT	Permit code
INST	Installation (note: the combination of PERMIT and INST that creates a unique permit ID)
PERMITTEE	Name of permit holder
USE_CODE	ID associated with designated use
USENAME	Designated use name
CATEGORY	Designated use category
PERMIT_VOL	Maximum permitted volume (Mgallons/year)
PERMIT_GPM	Maximum permitted volume (gallons/minute)
PERMIT_ACR	Permit acres
STATUS	Status code (1, 2, or 99)
RES_CODE	ID associated with permit resource
RES_NAME	Permit resource name (surface water body or aquifer name)
PWI_ID	Public Waters Inventory ID
WELL_NUM	Well number
WELL_DEPTH	Well depth (feet)
COUNTY_ID	ID associated with permit county
COUNTY	Permit county
WATERSHED	Watershed code ID
TWP	Township
RNG	Range
SECTION_	Section
TWPRNGSEC1	Section code consisting of township+range+section; used to link this table to *Sections_final* table
SUB_SECT	Sub-section
XUTM	X-coordinates for permit location (UTM NAD1983 Region 15)
YUTM	Y-coordinates for permit location (UTM NAD1983 Region 15)
ACCURACY	Estimated accuracy of reported use volumes
USE_2007	Reported volume by year (Mgallons/year)
USE_2006	
USE_2005	
USE_2004	
USE_2003	
USE_2002	
USE_2001	
USE_2000	
USE_1999	
USE_1998	
USE_1997	
USE_1996	
USE_1995	
USE_1994	
USE_1993	
USE_1992	
USE_1991	
USE_1990	
USE_1989	
USE_1988	

Recharge rates for *Recharge_units_12_09* were determined by deriving BQ units defined at three different resolutions (i.e., "zones"); listed from lowest to highest they are State-wide, Southern MN, and County. High resolution County level BQ units have been defined for Lac Qui Parle, Olmsted and Pope Counties. All three resolution sets of polygons were merged together in ArcGIS with the highest resolution polygon taking precedence at any given point. This resulted in a mosaic-like BQ polygon map with significantly varying resolution state wide (See Figure 1).

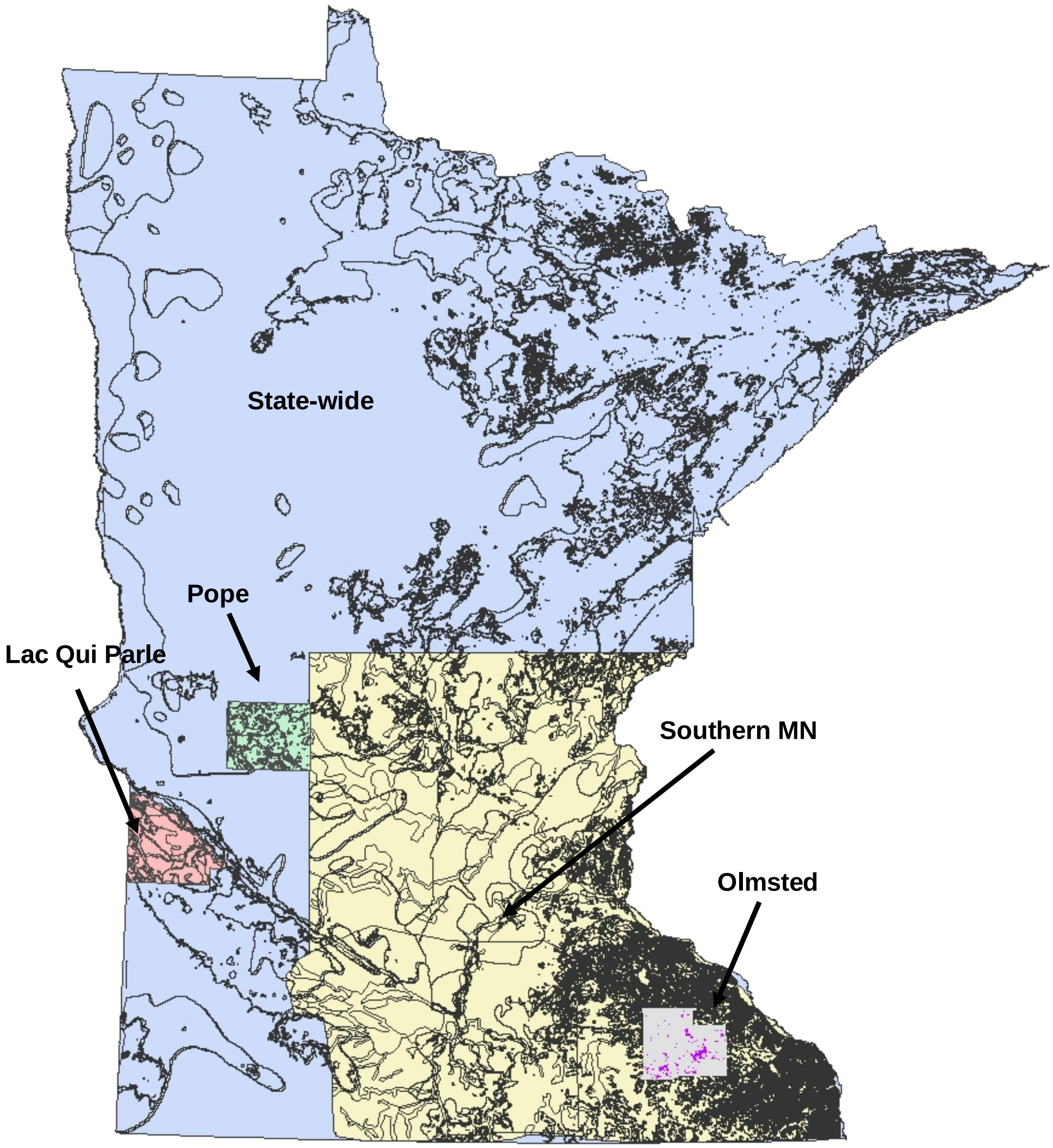


Figure 1. Resulting map from merging bedrock-quaternary unit polygons of different scales.

Each section was intersected by one or more BQ units. The dominant BQ Subdistrict for a given section was determined as that with the highest areal proportion in the section.

Water use was quantified by intersecting the BQ-Section map with MN-DNR water permit points. The annual permits are a mix of ground- and surface withdrawals with groundwater comprising the vast majority of permitted volumes. Currently, annual water use data is available from 1988 to 2007.

Attachment 4

Result 3. Assessment of water resources sustainability with the constructed database

The freshwater sustainability database (db) is meant to be browsed or queried using MS Access 2003 or higher. Sustainability calculations are performed by db queries which are required to pull together the necessary data from the three db tables. Sections are used as the elementary units of analysis in the db; that is, for purposes of calculating sustainability, an area of interest is defined as a set of Sections. County and watershed are coded for each section allowing querying by these areal boundaries.

Three queries are included with the db to provide examples of how it can be used to evaluate sustainability for an area of interest: *All_Sections*, *County_sustainability* and *Majwatershed_sustainability*. These queries can be modified and expanded upon by anyone with intermediate knowledge of MS Access. The queries require entering a county or watershed name exactly as they appear in the *Sections_final* table (although they are not case-sensitive). Consequently it may be necessary to browse the db table first to see how a particular county or watershed is spelled and formatted.

Output from the queries are nearly identical in that they all group results by BQ Subdistrict (i.e., BQ Subdistrict recharge – permitted use = sustainability). *All_sections* queries data for all sections in MN. *County_sustainability* and *Majwatershed_sustainability* query data for all sections in a user-defined county or watershed, respectively. Maximum permitted and 2007 reported use volumes were arbitrarily selected for the queries as they provided the most conservative and most recently reported use scenarios, respectively. Query results can be easily exported into MS Excel for further analysis and manipulation by copy/pasting (see Table 1 for description of query results).

Table 1. Column descriptions for db query results

Column Name	Column Description
County[1]	County that was inputted into the query
Watershed[2]	Watershed that was inputted into the query
Subprovince	Bedrock-quaternary Subprovince associated with dominant Subdistrict
Region	Bedrock-quaternary Region associated with dominant Subdistrict
Subregion	Bedrock-quaternary Subregion associated with dominant Subdistrict
District	Bedrock-quaternary District associated with dominant Subdistrict
Subdistrict[3]	Dominant bedrock-quaternary Subdistrict within section as determined by highest areal percentage
Yield	Recharge rate (inches/year) associated with the dominant Subdistrict
TotArea	Total area (square miles) for sections associated with the dominant Subdistrict
Recharge_totvol	Total recharge (Mgallons/year) for sections associated with the dominant Subdistrict
Permit_totvol	Maximum permitted volume (Mgallons/year) for permits in sections associated with the dominant Subdistrict
Permit_2007vol	2007permitted volume (Mgallons/year) for permits in sections associated with the dominant Subdistrict
Recharge_TotPermit_Diff	Difference (Mgallons/year) between Total recharge and Max permitted volume (Recharge_totvol - Permit_totvol)
Recharge_2007Permit_Diff	Difference (Mgallons/year) between Total recharge and 2007 permitted volume (Recharge_totvol - Permit_2007vol)

[1] Column present in County_sustainability query only
[2] Column present in MajWatershed_sustainability query only
[3] All query results are aggregated by Subdistrict

The queries mentioned above were applied to three counties where high resolution BQ data was available as well as three major watersheds that intersected the counties to illustrate how the db can be used.

(1) Open db, click *Queries* on the left navigator pan, and double-click *County_sustainability* (See Figure 1)

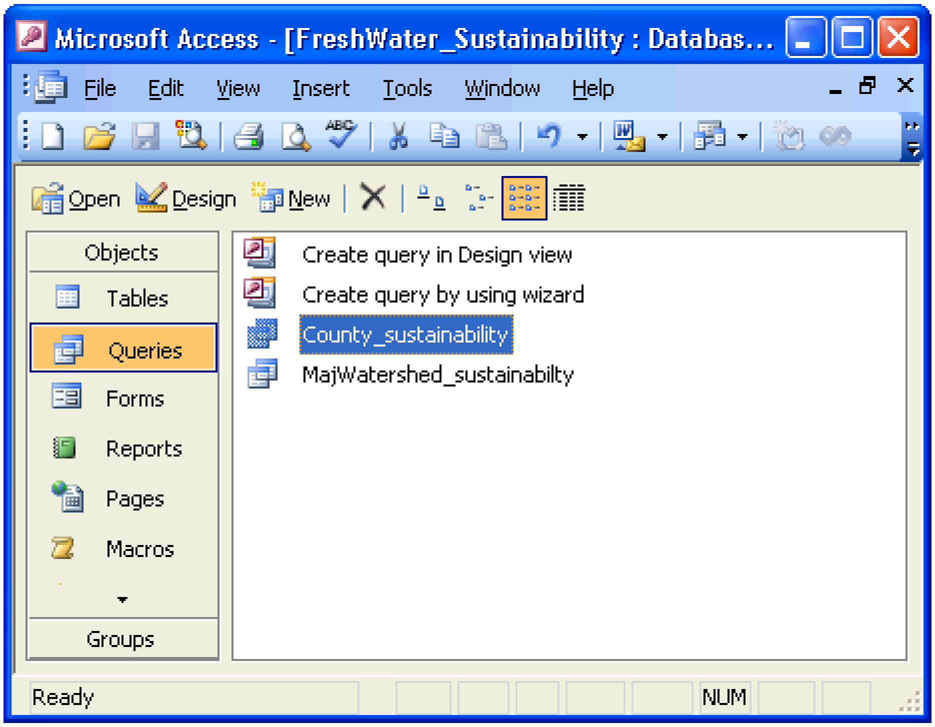


Figure 1. Opening db and selecting an example query.

(2) Enter name of county—Olmsted, in this example (Figure 2) – and click OK

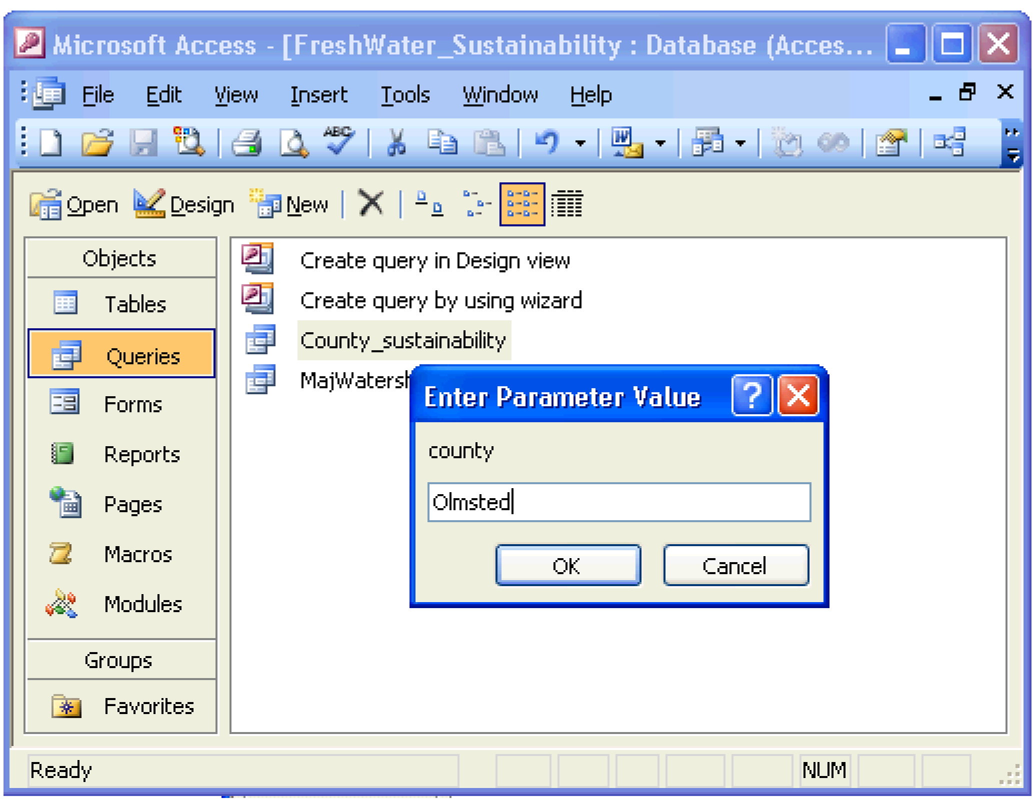


Figure 2. Entering County value for query argument

The resulting query-table (See Table 2) shows the distribution of the dominant Subdistricts for all the sections within Olmsted county as well as annual recharge, max permitted volume and 2007 volume used as well as the differences between annual recharge and max and 2007 volumes. Note: the sum totals comprising the last row of the table were added using MS Excel.

Table 2. Results of sustainability query for Olmsted county

sub-province	region	subregion	district	Subdistrict	yield	TotArea	Rchrg_totvol	Permit_totvol	Permit_2007vol	Rchrg_TotPermit_Diff	Rchrg_2007Permit_Diff
A	A_1	A_1^1	A_1^1	A_1^1	2.4	220.3	11484.1	15931.7	860	-4447.6	10624.1
A	A_2/Q	A_2/Q2	A_2/Q2	A_2^1/Q2	2.15	1	46.3	0	0	46.3	46.3
A	A_2/Q	A_2/Q6	A_2/Q6	A_2^1/Q6	1.33	96.3	2782.1	20416.4	705.8	-17634.3	2076.3
A	A_1	A_1^2	A_1^2	A_1^2	3.38	49.4	3628.9	20286	740.8	-16657.1	2888.1
A	A_2/Q	A_2/Q2	A_2/Q2	A_2^2/Q2	2.6	4	228.5	0	0	228.5	228.5
A	A_2/Q	A_2/Q3	A_2/Q3	A_2^2/Q3	2.4	3	155	0	0	155	155
A	A_2/Q	A_2/Q6	A_2/Q6	A_2^2/Q6	1.77	28.7	1105.4	15000	416.5	-13894.6	688.9
A	A_1	A_1^3	A_1^3	A_1^3	2.07	89	4002.2	27200.9	1354.8	-23198.7	2647.4
A	A_2/Q	A_2/Q2	A_2/Q2	A_2^3/Q2	2.5	6	323.5	10193.3	360	-9869.8	-36.5
A	A_2/Q	A_2/Q3	A_2/Q3	A_2^3/Q3	2.3	7.9	395.7	36865	10123	-36469.3	-9727.5
A	A_2/Q	A_2/Q6	A_2/Q6	A_2^3/Q6	1.6	44.6	1549.6	21184	4378.7	-19634.4	-2829.1
A	A_1	A_1	A_1	A_1c1	0.1	53.5	116.3	20146	1104.1	-20029.7	-987.8
A	A_2/Q	A_2/Q	A_2/Q	A_2c1/Q6	0.1	26.7	58.1	4.8	0.6	53.3	57.5
A	A	A	A	Q2/A_2c1	0.3	2	13.1	0	0	13.1	13.1
A	A	A	A	Q6/A_2^1	0.3	5	32.4	0	0	32.4	32.4
A	A	A	A	Q6/A_2^2	0.2	11.9	51.6	100	46.2	-48.4	5.4
A	A	A	A	Q6/A_2^3	0.8	1	16.8	0	0	16.8	16.8
A	A	A	A	Q6/A_2c1	0.1	4	8.7	0	0	8.7	8.7
					SUM	654.3	25998.3	187328.1	20091	-161329.8	5907.6

The following examples further illustrate use of the included queries with Zumbro Watershed, Lac Qui Parle County, Lac Qui Parle Watershed, Pope County, and Chippewa Watershed, respectively.

Table 3. Results of sustainability query for Zumbro Watershed

sub-province	region	subregion	district	subdistrict	Yield	TotArea	Rchrg_totvol	Permit_totvol	Permit_2007vol	Rchrg_TotPermit_Diff	Rchrg_2007Permit_Diff
A	A_1	A_1^1	A_1^1	A_1^1	3	194.8	10154.8	15928.3	813.1	-5773.5	9341.7
A	A_2/Q	A_2/Q2	A_2/Q2	A_2^1/Q2	2.69	20.7	967.9	131.4	27.7	836.5	940.2
A	A_2/Q	A_2/Q3	A_2/Q3	A_2^1/Q3	2.44	24	1016.7	0	0	1016.7	1016.7
A	A_2/Q	A_2/Q6	A_2/Q6	A_2^1/Q6	1.66	49.5	1430.7	20373.4	705.8	-18943	724.9
A	A_1	A_1^2	A_1^2	A_1^2	4.22	88.1	6472.1	20496	775.2	-14024	5696.9
A	A_2/Q	A_2/Q2	A_2/Q2	A_2^2/Q2	3.25	10	564.3	0	0	564.3	564.3
A	A_2/Q	A_2/Q3	A_2/Q3	A_2^2/Q3	3	3	155	0	0	155	155
A	A_2/Q	A_2/Q6	A_2/Q6	A_2^2/Q6	2.21	24.7	951.5	15000	416.5	-14049	535
A	A_1	A_1^3	A_1^3	A_1^3	2.59	255.6	11495.2	28140.1	1616.3	-16645	9878.9
A	A_2/Q	A_2/Q2	A_2/Q2	A_2^3/Q2	3.12	24.8	1346.8	10235.7	384.9	-8888.9	961.9
A	A_2/Q	A_2/Q3	A_2/Q3	A_2^3/Q3	2.88	9.9	495.5	36865	10123.2	-36370	-9627.7
A	A_2/Q	A_2/Q6	A_2/Q6	A_2^3/Q6	2	40.6	1410.4	21184	4378.7	-19774	-2968.3
A	A_1	A_1^4	A_1^4	A_1^4	2.06	35.6	1275.8	0	0	1275.8	1275.8
A	A_2/Q	A_2/Q1	A_2/Q1	A_2^4/Q1	1.44	2	49.6	0	0	49.6	49.6
A	A_2/Q	A_2/Q2	A_2/Q2	A_2^4/Q2	1.12	12.8	250.8	0	0	250.8	250.8
A	A_1	A_1	A_1	A_1c1	0.12	24.7	53.7	20100	1090.3	-20046	-1036.6
A	A_2/Q	A_2/Q	A_2/Q	A_2c1/Q6	0.12	16.8	36.6	4.8	0.6	31.8	36
A	A_2/Q	A_2/Q6	A_2/Q_s6	A_2^1/Q_s6	1.66	131.3	3793.2	183	76.5	3610.2	3716.7
A	A_2/Q	A_2/Q6	A_2/Q_s6	A_2^2/Q_s6	2.21	40.7	1566.2	695.5	266.7	870.7	1299.5
A	A_2/Q	A_2/Q6	A_2/Q_s6	A_2^3/Q_s6	2	45.7	1586.8	14.6	6.9	1572.2	1579.9
A	A_2/Q	A_2/Q6	A_2/Q_s6	A_2^4/Q_s6	0.38	4	25.8	0	0	25.8	25.8
A	A_2/Q	A_2/Q6	A_2/Q_t6	A_2^1/Q_t6	0.48	283.6	2340.7	1175.8	300.6	1164.9	2040.1
A	A_2/Q	A_2/Q6	A_2/Q_t6	A_2^2/Q_t6	0.29	35.6	177.8	0	0	177.8	177.8
A	A_2/Q	A_2/Q6	A_2/Q_t6	A_2^3/Q_t6	1.06	4	74.5	0	0	74.5	74.5
A	A_2/Q	A_2/Q6	A_2/Q_t6	A_2^4/Q_t6	0.15	12.8	33.5	0	0	33.5	33.5
A	A	A	A	Q2/A_2c1	0.38	2	13.1	0	0	13.1	13.1
A	A	A	A	Q6/A_2^1	0.38	2	13	0	0	13	13
A	A	A	A	Q6/A_2^2	0.25	11.9	51.6	100	46.2	-48.4	5.4
A	A	A	A	Q6/A_2^3	1	1	16.8	0	0	16.8	16.8
A	A	A	A	Q6/A_2c1	0.12	4	8.7	0	0	8.7	8.7
A	A_2	A_2	A_2	A_2	1.49	4	103.5	43	22.4	60.5	81.1
					SUM	1420.2	47932.6	190670.6	21051.6	-142738	26881

Table 4. Results of sustainability query for Lac Qui Parle County

sub-province	region	subregion	district	subdistrict	yield	TotArea	Rchrg_totvol	Permit_totvol	Permit_2007vol	Rchrg_TotPermit_Diff	Rchrg_2007_Permit_Diff
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q10	0.55	43.3	414.1	2598	689.3	-2184	-275.2
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q3	1.06	79.8	1472.8	381.7	84.1	1091.1	1388.7
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q6	0.6	104.3	1087.2	10	4.9	1077.2	1082.3
K	K_2/Q	K_2/Q	K_2/Q	K_2/Q10	0.35	92.9	564.9	921.3	346.3	-356.4	218.6
K	K_2/Q	K_2/Q	K_2/Q	K_2/Q3	0.75	188.5	2456.9	494.3	155.3	1962.6	2301.6
K	K_2/Q	K_2/Q	K_2/Q	K_2/Q6	0.41	258.7	1854.6	549.3	166.1	1305.3	1688.5
Water	Water	Water	Water	Water	0	9.8	0	0	0	0	0
B	B_1	B_1	B_1	B_1	4.62	3.9	317.3	46.8	16	270.5	301.3
B	B_2s	B_2s	B_2s	B_2s	2.05	1	34.4	0	0	34.4	34.4
					SUM	782.2	8202.2	5001.4	1462	3200.8	6740.2

Table 5. Results of sustainability query for Lac Qui Parle Watershed

sub-province	Region	subregion	district	subdistrict	Yield	TotArea	Rchrg_totvol	Permit_totvol	Permit_2007vol	Rchrg_TotPermit_Diff	Rchrg_2007Permit_Diff
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q10	0.55	18.1	172.8	2548	689.3	-2375	-516.5
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q3	1.06	48.1	888.7	381.7	84.1	507	804.6
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q6	0.6	81.4	848.5	10	4.9	838.5	843.6
K	K_2/Q	K_2/Q	K_2/Q	K_2/Q10	0.35	62.9	382.7	869.3	322	-486.6	60.7
K	K_2/Q	K_2/Q	K_2/Q	K_2/Q3	0.75	101.1	1317.2	92.3	45.3	1224.9	1271.9
K	K_2/Q	K_2/Q	K_2/Q	K_2/Q6	0.41	197.4	1414.8	549.3	166.1	865.5	1248.7
K	K_2	K_2	K_2	K_2	0.15	96.9	252.7	490	171.9	-237.3	80.8
K	K_3	K_3	K_3	K_3	0.45	155.2	1213.7	1760	375.5	-546.3	838.2
					SUM	761.1	6491.1	6700.6	1859.1	-209.5	4632

Table 6. Results of sustainability query for Pope County

sub-province	region	subregion	district	subdistrict	yield	TotArea	Rchrg_totvol	Permit_totvol	Permit_2007vol	Rchrg_TotPermit_Diff	Rchrg_2007Permit_Diff
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q3	0.85	261.2	4822.4	23874.2	10475	-19051.8	-5652.8
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q6	0.48	427.2	4454.2	2734	1254.3	1720.2	3199.9
Water	Water	Water	Water	Water	0	28.8	0	74.2	48.8	-74.2	-48.8
					SUM	717.2	9276.6	26682.4	11778	-17405.8	-2501.7

Table 7. Results of sustainability query for Chippewa Watershed

Sub-province	region	subregion	district	subdistrict	Yield	TotArea	Rchrg_totvol	Permit_totvol	Permit_2007vol	Rchrg_TotPermit_Diff	Rchrg_2007Permit_Diff
K	K_3/Q	K_3/Q	K_3/Q	K_3/Q3	0.75	2.9	38.4	0	0	38.4	38.4
K	K_3/Q	K_3/Q	K_3/Q	K_3/Q6	0.41	4.9	35.1	0	0	35.1	35.1
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q3	1.06	196.4	3627	15379.4	6603.3	-11752	-2976.3
B	B_2/Q	B_2/Q	B_2/Q	B_2/Q6	0.6	389.2	4058.7	1945.5	875.5	2113.2	3183.2
B	B_2/Q	B_2/Q	B_2/Q_s	B_2/Q_s3	1.06	1	18.6	0	0	18.6	18.6
B	B_2/Q	B_2/Q	B_2/Q_s	B_2/Q_s6	0.6	1	10.5	0	0	10.5	10.5
B	B_2/Q	B_2/Q	B_2/Q_t	B_2/Q_t3	0.62	31.4	341.6	115	77	226.6	264.6
B	B_2/Q	B_2/Q	B_2/Q_t	B_2/Q_t6	0.14	10	23.9	0	0	23.9	23.9
Water	Water	Water	Water	Water	0	28.8	0	74.2	48.8	-74.2	-48.8
B	B_1	B_1	B_1	B_1	4.62	7.9	635.7	327	33.6	308.7	602.1
B	B_2s	B_2s	B_2s	B_2s	2.05	7.9	281.9	0	0	281.9	281.9
B	B_2t	B_2t	B_2t	B_2t	1.06	493.1	9104.8	8724.2	2976.4	380.6	6128.4
K	K_2	K_2	K_2	K_2	0.15	7	18.2	128	19.9	-109.8	-1.7
K	K_3	K_3	K_3	K_3	0.45	886.2	6930.3	10932.1	2187.4	-4002	4742.9
					SUM	2067.7	25124.7	37625.4	12821.9	-12501	12302.8

Attachment 5

Result 4. Estimate of mean minimum annual groundwater recharge and comparison to the RRR method

The results derived from the watershed characteristics (WC) method are used here to estimate the mean minimum groundwater recharge for three selected watersheds in Olmsted County, and those estimates are then compared to the estimated mean annual groundwater recharge derived from the regional regression recharge (RRR) method developed by the USGS (Lorenz and Delin, 2007).

The watersheds considered for analysis are the South Fork of the Zumbro River on Belt Line near Rochester (5372800; 155 sq. miles), Bear Creek at Rochester (5372930; 78 sq. miles), and the South Fork of the Zumbro River at Rochester (5372995; 303 sq. miles).

To implement the results from the WC method the Hierarchical Hydrogeologic Units (HHUs) for the watersheds were outlined on each of the watersheds using GIS with the bedrock and the quaternary overlay data. These units are shown in Attachment 1 for the Olmsted County map. The estimated mean minimum recharge flux into each of the HHUs is given in the tables for Olmsted County, and the corresponding tables for the Karst Region in Attachment 1. Here we used the tables derived for Olmsted County.

The summary of the analysis is presented in Table 1. The predicted mean minimum recharge is determined by taking the area weighted average of the HHU fluxes. Table 1 presents the summary for each watershed of the percentage of area that each HHU comprises in each watershed, and also presents the estimated recharge rate for each of the HHUs (see the Olmsted County table in Attachment 1). The area weighted average recharge is derived from these figures. The totaled results give the recharge rate in inches/year for each watershed, and in addition the predicted mean minimum February flow is presented in cubic feet per second.

For the three watersheds, the mean minimum annual recharge rate are 1.6 inches/year, 2.1 inches/year, and 1.3 inches/year for watersheds 5372930, 5372930 and 5372995, respectively.

The mean annual recharge rate for these watersheds using the RRR method is essentially the same for all of the watersheds because they are nested and therefore exist in the same area of the state. According to the chart given by Lorenz and Delin (2007) the recharge rate for the watershed ranges between 10 and 20 cm/year or 3.9 to 7.9 in/year.

The estimates of mean annual recharge given by the RRR method are higher than those estimated by the WC method because in the current application of the WC method the quantity estimated is the mean minimum annual groundwater recharge. Since most of the runoff generated in the southeast part of Minnesota is from groundwater, the estimate of groundwater recharge by the RRR method is closer to the mean annual flow for streams in the region. As such, the RRR estimate for that region should be similar to the regionalized estimates of mean annual flow provided within the scope of our project.

For the region surrounding Olmsted County the estimate of mean annual flow is about 5 l/s/sq. km, or about 6.5 in/year.

The types of results shown in Table 1 are currently being replicated for other selected watersheds within several locations around the state. The selected watersheds are ones that have some record of streamflow measurement but were not included in the original set of data used to derive the estimates of recharge for HHUs. The reason for doing this analysis is to provide a measure of the predictive accuracy of the watershed characterization method for ungauged watersheds. Since this work is currently being done it is not available for this report, but will be reported in manuscripts being prepared for publication.

Table 1. Calculation of the mean minimum recharge rate for three watersheds in Olmsted County

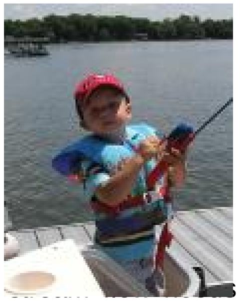
Watershed	Watershed Area (sq.mi)	HHU	HHU Area (m^2)	HHU Area %	HHU flux (l/s/sqkm)	recharge (l/s/sqkm)	recharge (in/yr)	predicted minimum flow (cfs)
5372800	154.6	A2/Q2	79761	0.02	1.85	0.0004	0.0005	
		A1/Q3	30576279	7.62	1.95	0.1487	0.1858	
		A2/Q3	33674829	8.40	1.8	0.1511	0.1889	
		A1/Q6	316957714	79.03	1.15	0.9089	1.1361	
		A2/Q6	19433101	4.85	1.62	0.0785	0.0981	
		Totals	**400721684**			**1.2876**	**1.6095**	**18.3**
5372930	78.1	A2/Q2	2210546	1.09	1.85	0.0202	0.0252	
		A1/Q3	80569484	39.78	1.95	0.7758	0.9697	
		A2/Q3	40560680	20.03	1.8	0.3605	0.4506	
		A1/Q6	50964180	25.17	1.15	0.2894	0.3617	
		A2/Q6	28065008	13.86	1.62	0.2245	0.2806	
		Totals	**202369898**			**1.6704**	**2.0880**	**12.0**
5372995	303	A2/Q2	18831029	1.93	1.85	0.0358	0.0447	
		A3/Q2	1652119	0.17	3.4	0.0058	0.0072	
		A1/Q3	165070519	16.94	1.95	0.3304	0.4130	
		A2/Q3	146942994	15.08	1.8	0.2715	0.3393	
		A3/Q3	57621	0.01	3.2	0.0002	0.0002	
		A1/Q6	543503002	55.78	1.15	0.6415	0.8019	
		A2/Q6	97239005	9.98	1.62	0.1617	0.2021	
		A3/Q6	283696	0.03	0.85	0.0002	0.0003	
		Totals	**788026318**			**1.0751**	**1.3438**	**30.1**

Attachment 6

Water Resources Sustainability

Why is Water Resources Sustainability a Concern in Minnesota?

Water resources sustainability is the key to Minnesota's economy, healthy ecosystem functioning and well-being of its citizens. Yet, presently, the State is managing water resources unsustainably. This unsustainable management of water resources is a concern for the State, educators, businesses and general public and must be transformed toward sustainable management. It is exhibited by stream flow depletion and lake desiccation;



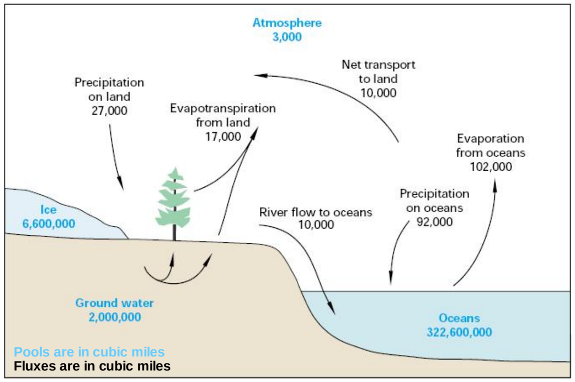
falling water levels of ground water systems; loss and degradation of wetlands, water bodies and associated wildlife habitats; contamination of surface and ground waters; competition for in-stream uses for recreation, navigation, waste assimilation and aquatic habitat; land use changes; etc. As our water resources become depleted and degraded, so is the natural resource base that sustains the economy (Nelson, 1998). Water resources include ground water, rivers, lakes, wetlands, etc. The label of Minnesota as water rich does not fit as well as once thought. In areas of the State, the demands on renewable water resources are a special concern for water supply management (VanBuren and Wells, 2007). In portions of Minnesota, there has been a decline, depletion or pollution of surface and ground water resources. To address this concern, the LCCMR funded a Water Resources Sustainability project to the University of Minnesota.

Addressing the Issue

The challenge of meeting human development needs while protecting natural ecosystems and water resources for future generations, confronts this and all generations to come. The Minnesota Legislature has established the legal and institutional framework to ensure that water supplies meet human and environmental needs for present and future generations. *Minnesota Statutes*, section 103G.265, assigns the Department of Natural Resources (DNR) the task of managing water resources to meet long-range needs for a variety of economic, social and ecological purposes. Although the DNR (2005) stated the needs for sustainable water use, it does not have a quantitative base to compare a growing demand with the supply of the natural hydrologic system. It is becoming clear that traditional approaches dealing with only one part of the hydrologic system (i.e. ground or surface water) are not able to address the water resources sustainability issue. This project will develop a new approach and tool to quantify the renewable water resources supply at multiple scales and demonstrate it at the State, regional, and county levels. Once the limit of the hydrologic system as a renewable (i.e. sustainable) water resource is determined, the State will be able to move toward sustainable water use by developing a framework for managing water resources based on comparison of human and environmental needs with the quantitative tool developed in this project.

Review of the Hydrologic Cycle

The hydrologic cycle provides the basis of water resources sustainability. The hydrologic cycle is the continuous movement of water on, above, and below the surface of the earth, generally with a "*minimal*" overall fluctuation of water (near equilibrium state). **Water resources sustainability is ensuring that this overall fluctuation of water within the hydrologic cycle remains near equilibrium**. The hydrologic cycle explains why the depletion of ground water affects surface water. Surface and ground water systems are linked components of the hydrologic continuum and it is imperative to characterize them together to address the complex issue of water resources sustainability. For example, if water will be withdrawn from the ground water system at a rate that will deplete that system, less water will be discharged back into the surrounding rivers/streams, lowering water levels and



From: Ground water and surface water: a single resource / by Thomas C. Winter et al., 1998. (U.S. Geological Survey circular: 1139)

potentially affecting stream flow or drying up wetlands and water bodies. To understand water resources sustainability, it is necessary to grasp the relationship within the hydrologic cycle between the atmosphere, hydrosphere, lithosphere, pedosphere, biosphere and anthroposphere.

The New Paradigm for Quantification

Researchers at the University of Minnesota are quantifying freshwater sustainability by addressing the key scientific question: How does landscape heterogeneity control spatial and temporal variability of stream runoff, ground water flux (recharge/discharge) and vadose zone flux, across spatial scales. The principle water balance characteristic used for integrating surface water, ground water and vadose zone fluxes is stream runoff. This new paradigm parameterizes and quantifies the relationships between landscape components and water balance characteristics. The method will not only quantify the water balance characteristics, but will provide a practical mapping tool. The key indicator in freshwater sustainability is the ratio of renewable water supply to water use by humans and the environment (Kanivetsky and Shmagin, 2005). Sustainable water use by humans and the environment ***should not cause a decline or depletion*** of freshwater resources.

Explanation of Water Resources Sustainability Terms:

Discharge: Any water that exits the ground water system (Jyrkama and Sykes, 2006).

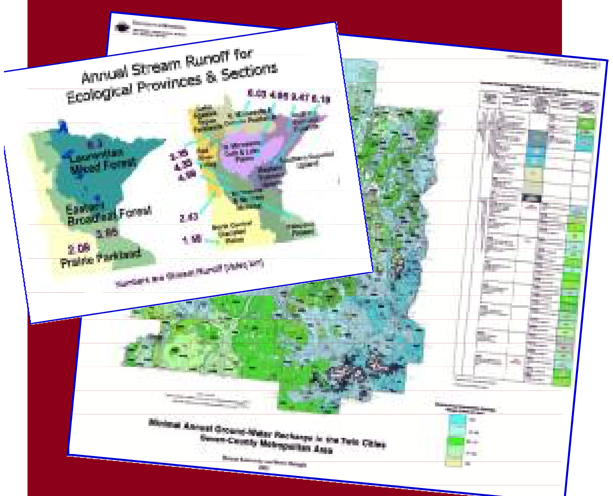
Hydrologic unit: A parcel of land surface defined and quantified by association of hydro-climate characteristics (stream run-off, ground water levels, precipitation, air temperature, etc.) with landscape components (climate, soil, vegetation, topography and geology) (Kanivetsky and Shmagin, 2005).

Recharge: Any water that is added as an input to the ground water system (Jyrkama and Sykes, 2006).

Spatio-temporal: Relationship of space and time together.

Vadose Zone: The portion of Earth between the land surface and the zone of saturation, extending from the top of the ground surface to the water table.

Watershed: Area of land drained by a single stream or river (catchment area).



For more information on water resources sustainability in Minnesota, and to learn about current research projects, please visit:

https://wiki.umn.edu/twiki/bin/view/Water_Sustainability/WebHome

A complete list of references included in this publication can also be found on the website.

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WATER RESOURCES SUSTAINABILITY
Minnesota Project

*Genuine "sustainability" requires that consumption **will not cause a decline** or depletion of freshwater.*

The Legislative and Citizens Commission on Minnesota Resources (LCCMR) has provided the University of Minnesota with funding to quantify sustainable supplies of surface and ground water by integrating surface water, vadose zone, and ground water systems into defined hydrologic units. *The purpose of this publication is to provide a general overview of water resources sustainability.*

Attachment 7

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ORIGINAL ARTICLE

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Estimation of groundwater recharge using water balance coupled with base-flow-record estimation and stable-base-flow analysis

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Abstract In this paper, the long-term mean annual groundwater recharge of Taiwan is estimated with the help of a water-balance approach coupled with the base-flow-record estimation and stable-base-flow analysis. Long-term mean annual groundwater recharge was derived by determining the product of estimated long-term mean annual runoff (the difference between precipitation and evapotranspiration) and the base-flow index (BFI). The BFI was calculated from daily streamflow data obtained from streamflow gauging stations in Taiwan. Mapping was achieved by using geographic information systems (GIS) and geostatistics. The presented approach does not require complex hydrogeologic modeling or detailed knowledge of soil characteristics, vegetation cover, or land-use practices. Contours of the resulting long-term mean annual *P*, BFI, runoff, groundwater recharge, and recharge rates fields are well matched with the topographical distribution of Taiwan, which extends from mountain range toward the alluvial plains of the island. The total groundwater recharge of Taiwan obtained by the employed method is about 18 billion tons per year.

Keywords Groundwater recharge · Water balance · Base-flow-record estimation · Stable-base-flow analysis · Base-flow index

Introduction

Estimating groundwater recharge is an important issue in hydrogeologic studies. In most cases, recharge is estimated by multiplying the magnitude of water-level fluctuations in wells by the specific yield of the aquifer material or by applying the water budget model or using the water-balance method. While other parts of the water-balance equation, such as precipitation and runoff, are relatively easy to measure, recharge remains an elusive process to quantify. This is especially so because it depends not only on precipitation but also on meteorological conditions, as well as on soil type, soil–moisture status, vegetation cover and condition, slope, cultivation practices, and most of all, on evapotranspiration, which is a function of the previously noted factors.

Currently, standard techniques of estimating regional recharge most often involve (1) applying a water-balance model, where the moisture content of the soil is tracked through time (Finch 1998; Simmons and Meyer 2000; Chen et al. 2005), or (2) parameter-value adjustment of groundwater flow models (Lee et al. 2000; Jyrkama et al. 2002; McDonald and Harbaugh 2003). Application of the first approach, while generally less intensive computationally, requires knowledge of the vegetation and soil types within the study area, in addition to a number of basic meteorological variables such as air temperature and precipitation. The second approach is more taxing of computer resources because a potentially complex groundwater flow model may have to be run repeatedly in search of a multidimensional parameter-value optimum.

With the purpose of inspecting recharge, estimating the groundwater component of streamflow has been a research focus for more than a century. Following the work of Boussinesq (1877), numerous studies (Bevans 1986; Moore 1992; Rutledge 1992; Rutledge and Daniel 1994; Mau and Winter 1997; Chen and Lee 2003) have investigated the recession of streamflow, particularly baseflow, and have estimated the contribution of groundwater to streamflow. In some cases, the value of baseflow is assumed to be equal to groundwater recharge. The primary purpose of most researches is to determine the groundwater component of streamflow. Nevertheless, only a handful of researchers, including Meyboom (1961), Rorabaugh (1964), and Rutledge (1992), have focused on groundwater recharge through analyzing the streamflow data. Rutledge (2005) further summarizes constraints involved with the application of the Rorabaugh model for estimating groundwater recharge. Mau and Winter (1997) have provided the instantaneous recharge method and the constant recharge method of hydrograph analysis to estimate recharge.

Although several methods have been used to estimate the groundwater discharge and recharge from streamflow records, the most commonly used are the techniques of baseflow separation. These methods aim at estimating a continuous or daily record of baseflow under the streamflow hydrograph. In other words, it requires an extended period of recording efforts in estimating the long-term groundwater discharge, as well as the exercise of a variety of manual methods (Horton 1933; Barnes 1939; Olmsted and Hely 1962; Dzhamalov 1973; Zektser 1977) or a rapid analysis and that introduces some elements of subjectivity in the research for the base-flow-record estimation (Rutledge 1992; Mau and Winter 1997). One study employed a water-balance approach and digital filter method to estimate base recharge to groundwater in Nebraska (Szilagyi et al. 2003).

To increase the speed of analysis and reduce the subjectivity inherent in manual analysis, Rutledge (1993) proposes several computer programs: RECESS, RORA, and PART, and newer versions have been proposed (Rutledge 1998, 2000). The research of this paper is accomplished using an automated analysis procedure by the programs described above.

To prevent overestimation caused by rainstorm events, several studies (Rutledge 1993, 1998, 2000; Zektser 2002; Chen and Lee 2003) indicate that the baseflow in the dry season should be chosen to be the average value of the year. For this purpose, the stable-base-flow analysis is developed in this study to obtain a more reliable result.

Based on our previous research (Chen and Lee 2003), the proposed approach in this paper offers an estimate of total recharge for regions where groundwater evaporation is negligible, i.e., for areas where the water table is not so close to the surface that the vegetation can use it through its root system. The approach combines the water-balance model, base-flow-record estimation, and stable-base-flow analysis. It is computationally simple, requires minimal optimization, and does not need information on vegetation and soil types. The technique is mainly a collection of existing methods which, to the best knowledge of the authors, have not yet been combined in a similar fashion for recharge estimation. It is expected to be most practical for regional-scale studies where the long-term mean annual value of the spatially variable recharge is of interest. The approach was applied using data from Taiwan to demonstrate the utility of the technique.

Methodology

The water balance of a geographic region can, in general, be written as

$$P = \mathrm{ET} + q_\mathrm{s} + q_\mathrm{b} + q_\mathrm{N} + \Delta S, \quad (1)$$

where P is the precipitation (LT^{-1}); ET is the evapotranspiration (LT^{-1}); q_s is the surface runoff (LT^{-1}); q_b is the groundwater contribution to runoff (LT^{-1}), which is the definition of baseflow; q_N is the net flux (LT^{-1}) of any water entering or leaving the region other than precipitation (e.g., water diversions, groundwater flux across the basin boundaries, and irrigation); and ΔS is the change in stored water (LT^{-1}) within the area. Generally, evapotranspiration is by far the largest loss term in Eq. 1, amounting to 70% of precipitation (including evaporation from open water surfaces) on a global basis (Brutsaert 1982). Long-term ET measurements are practically nonexistent, and the available ET estimation methods may differ by as much as 10–20% on an annual basis (Vorosmarty et al. 1998). In light of these uncertainties, the general assumption that ΔS is negligible in most cases on a long-term basis may be well justified. For our purposes, this assumption is employed, acknowledging that for some watersheds where hydraulic heads have changed significantly in the past, it may lead to biased recharge estimates. It is further assumed that q_N in Eq. 1 can be neglected as well, at least on a regional scale.

With regard to the stated assumptions, Eq. 1 simplifies to

$$P - E = q_\mathrm{s} + q_\mathrm{b} \quad (2)$$

which states that the difference between precipitation and ET emerges as surface runoff and baseflow. If the change in the stored water volume is negligible, as was assumed, then on a long-term basis, baseflow must represent a lower bound to groundwater recharge within a given watershed. By quantifying q_b, one obtains an estimate of recharge, provided that the portion of the areal ET originating from the groundwater is negligible when compared to the total ET of the watershed.

Flow as completely groundwater discharge (while the surface runoff is negligible) can be based on the antecedent recession. Linsley et al. (1982) proposed the empirical relation that

$$N = A^{0.2}. \quad (3)$$

This relation gives the time base of surface runoff (N [d]) as a function of the drainage area (A) upstream from a streamflow-gauging station, in square miles. The time base of surface runoff is the number of days after a peak in the hydrograph of streamflow while the component of flow attributed to surface runoff (including the bulk of interflow) is considered negligible. A part of the streamflow hydrograph may thus be considered completely groundwater discharge, if it is preceded by a period of recession equal to or greater than N.

Various techniques have been used to estimate a record of groundwater discharge under the streamflow hydrograph. The base-flow-record estimation employed here is a form of streamflow partitioning. Rutledge (1992) developed this method first based on the antecedent streamflow recession. The principles of this method are as follows: (1) Daily data of streamflow are required. (2) Linear interpolation is used to estimate groundwater discharge during the period of surface runoff.

Figure 1 shows a flow diagram of the steps analyzed by the method of base-flow-record estimation. The requirement of the antecedent recession is met for the day in question if, for the part of the daily mean streamflow record that includes all days that precede the day in question by N days or less, the streamflow on each of these days is greater than or equal to the streamflow on the day that follows where N is the time base of surface runoff.

Steps of the base-flow-record estimation are as follows (see Fig. 1). First, a one-dimensional array of the daily mean streamflow data is filled. This array is searched for days that fit the requirement of the antecedent recession. On each of these days, groundwater discharge is designated equal to streamflow, as long as it is not followed by a daily decline of more than 0.1 log cycle. According to Barnes (1939), a daily decline more than 0.1 log cycle could indicate interflow (stormflow) or surface flow. The array is searched again, and it is determined by linear interpolation of the groundwater discharge on remaining days. For some streamflow records, this interpolation can cause the calculated groundwater discharge to exceed streamflow for a few days on the record. The last step of the procedure is to correct this error.

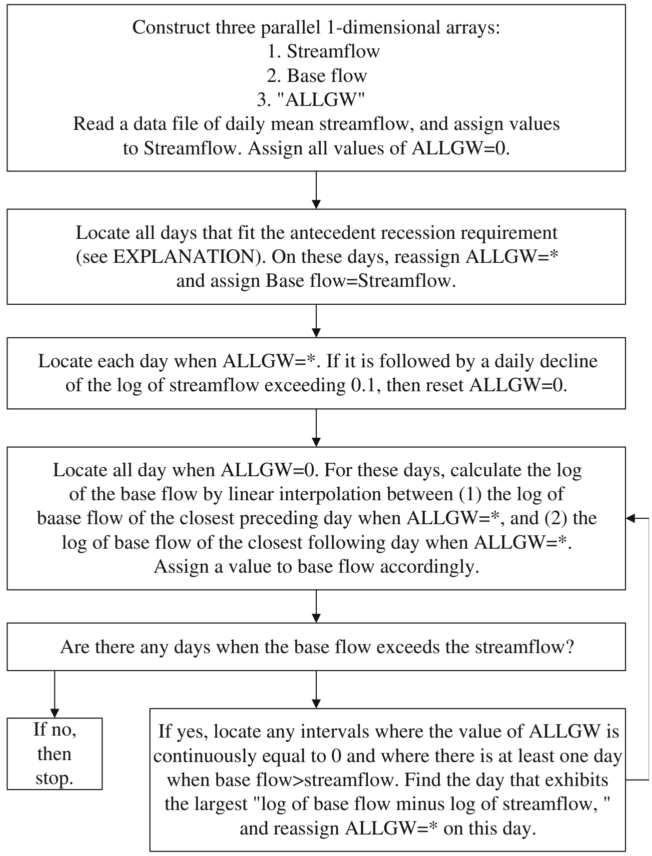


Fig. 1 Flow diagram showing the procedure of streamflow partitioning [baseflow is considered to be groundwater discharge. Referenced from Rutledge (1993)]

To prevent overestimation caused by rainstorm events, Rutledge (1993, 1998, 2000) suggests that the wintertime recession data are chosen to represent the behavior of the recession characteristic. Zektser (2002) indicates that the lowest two monthly baseflows should be chosen to be the average value of the year in some cases. For this purpose, an alternative method, the stable-base-flow analysis, is developed in this study to obtain a more reliable result.

The diagram of the stable-base-flow analysis according to our previous study is shown in Fig. 2 (Chen and Lee 2003). The procedure of the stable-base-flow analysis is as follows:

1. Obtain monthly baseflow from the base-flow-record estimation.
2. Obtain long-term mean monthly baseflow.
3. Perform data processing by sorting and accumulating the long-term mean monthly baseflow, and then a new series of long-term mean monthly accumulated baseflows is obtained.
4. Choose the most stable (near-linear) segment and obtain the slope of the stable baseflow. To avoid

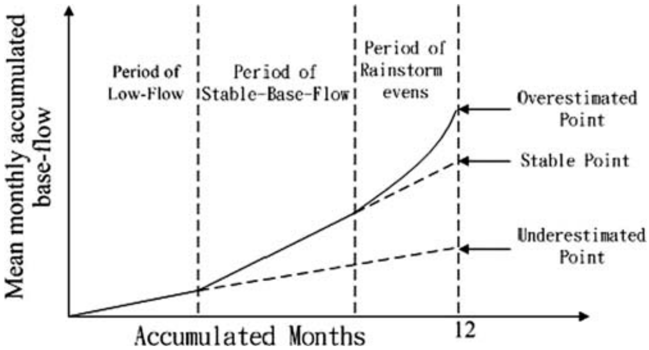


Fig. 2 The diagram of the stable-base-flow analysis

overestimating the results, the largest several monthly values (minimally adjusted requirements for each gauging station) will not be chosen.

5. Use linear interpolation on the remaining months, and finally the mean annual baseflow is obtained.

Baseflow (Q_b) is obtained by employed the base-flow-record estimation and the stable-base-flow analysis. As a consequence, the drainage area value of the gauging station is used for the calculation of N, and Eq. 2 is employed through the introduction of the dimensionless base-flow index (BFI), which is the ratio of baseflow and total stream runoff ($Q = Q_b + Q_s$) over time:

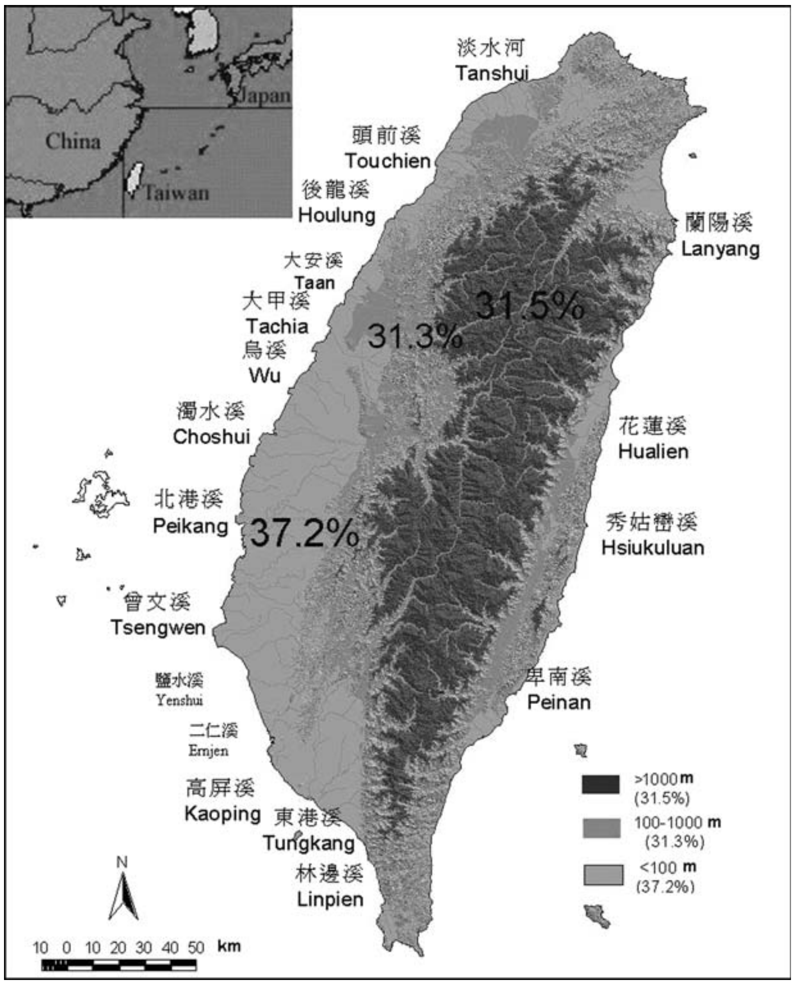
$$\mathrm{BFI} = \frac{Q_b}{Q_b + Q_s}. \tag{4}$$

Inserting Eq. 4 into Eq. 2 yields

$$\mathrm{BFI} \times (P - ET) = \mathrm{BFI} \times q = q_b \approx R, \tag{5}$$

where R (LT^{-1}) is the yet unknown groundwater recharge, and $q = Q/A_d$, with A_d denoting the contributing drainage area. Note that the base-flow-record estimation and the stable-base-flow analysis are only used to calculate BFI, but neither q nor q_b were used in Eq. 5 because they require the extent of the contributing drainage area, A_d, whereas BFI does not. When the two

Fig. 3 Topography of Taiwan



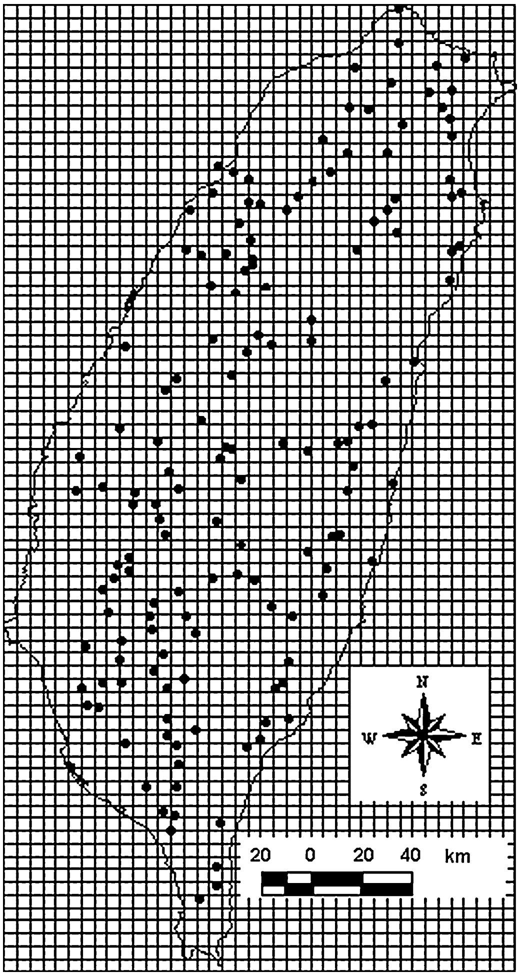


Fig. 4 Distribution of the climatic stations in Taiwan with long-term daily precipitation records

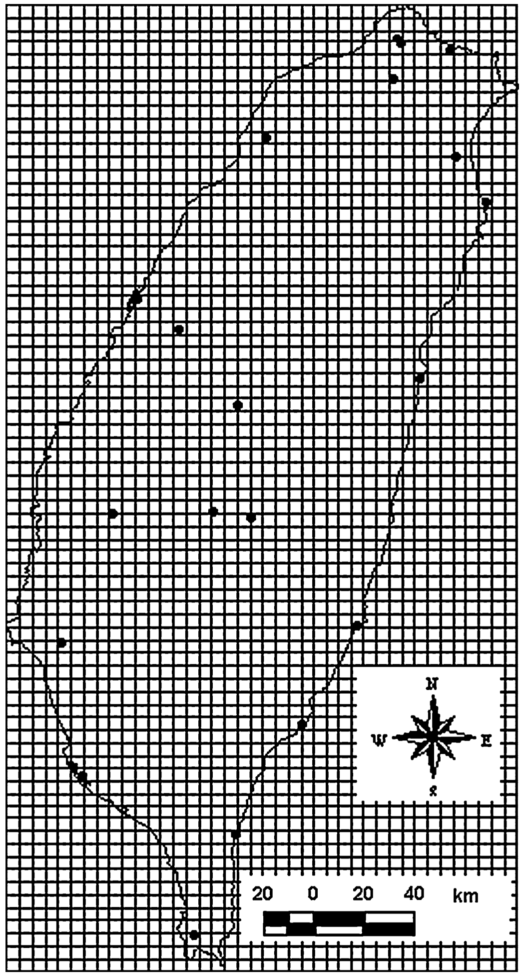


Fig. 5 Distribution of the climatic stations in Taiwan with long-term daily evapotranspiration records

contributing areas for surface runoff and groundwater are known to be fairly close, then q can be used in Eq. 5, eliminating the need for the P and ET measurements.

Results and discussion

The island of Taiwan is in the Western Pacific between Japan and the Philippines off the southeast coast of China, from which it is separated by the Taiwan Strait. With a total area of about 36,179 km^2, Taiwan is 394 km long and 144 km wide at its widest point.

High mountains over 1,000 m constitute about 31% of the island's land area; hills and terraces between 100 and 1,000 m above sea level make up 31%; and alluvial plains below 100 m in elevation, where most communities, farming activities, and industries are concentrated, account for the remaining 38%. Taiwan's most prominent geographic feature is its 270-km central mountain range, which has more than 200 peaks over 3,000 m high. Foothills from the central mountain range lead to tablelands and coastal plains in the west and south. The eastern shoreline is relatively steep, and mountains over 1,000 m high dominate the island in the north. The topography of Taiwan is shown in Fig. 3.

Taiwan is between the world's largest continent (Asia) and largest ocean (the Pacific). The Tropic of Cancer (23.5° N) running across its middle section divides the island into two climates, the tropical monsoon climate in the south and subtropical monsoon climate in the north. High temperature and humidity, massive rainfall, and tropical cyclones in summer characterize the climate of Taiwan. The latitude and topography, ocean currents, and monsoons are the main contributing factors. According to Köppen's climate classification, the four climate types in Taiwan are a monsoon and trade-wind coastal climate (Am) in the south, mild, humid climate (Cfa) in the north, wet–dry tropical climate (Cwa) in the west, and temperate rainy climate with dry winter (Cw) in mountain areas.

Figures 4 and 5 show the distribution of the climatic stations with long-term daily precipitation and evapotranspiration values used respectively in the study. From the long-term mean annual values of the point measurements of *P* and ET, surfaces were generated using universal kriging with a linear drift. Contours of the resulting long-term mean annual *P* and ET fields are shown in Figs. 6 and 7, respectively.

The main stream of the northward-moving Kuroshio Current passes up the eastern coast of Taiwan, thus bringing in warm and moist air. Summer and winter monsoons also bring intermittent rainfall to Taiwan's hills and central mountains. As a result, more than 2,300 mm of rain fall every year. The northeastern corner is the rainiest place in Taiwan, receiving 4,000–5,000 mm of rain per year. The coast of the western plain of the island is the driest spot, with less than 1,000 mm per year. Some characteristics of Taiwan's rainfall are as follows. (1) Spatial distribution of rain: More rain falls in the mountains than in the plains, on the east coast than the west coast, and at the windward side of hills than the leeward (sheltered) side. (2) Seasonal distribution of rain: The north has rain all year round while the south is rainy in summer and dry in winter. In winter, when the northeastern monsoon system is active, the north is constantly visited by drizzle while the south remains dry. However, in summer when the southwestern monsoon comes in force, afternoon thunderstorms and typhoons carry heavy rain to central and southern Taiwan. This intensive and concentrated summer rainfall, which constitutes up to 80% of annual precipitation, often causes flooding and landslides. (3) Variability of rainfall: As northern Taiwan has more rainy days than the south, the variability of rainfall increases as we move toward the south.

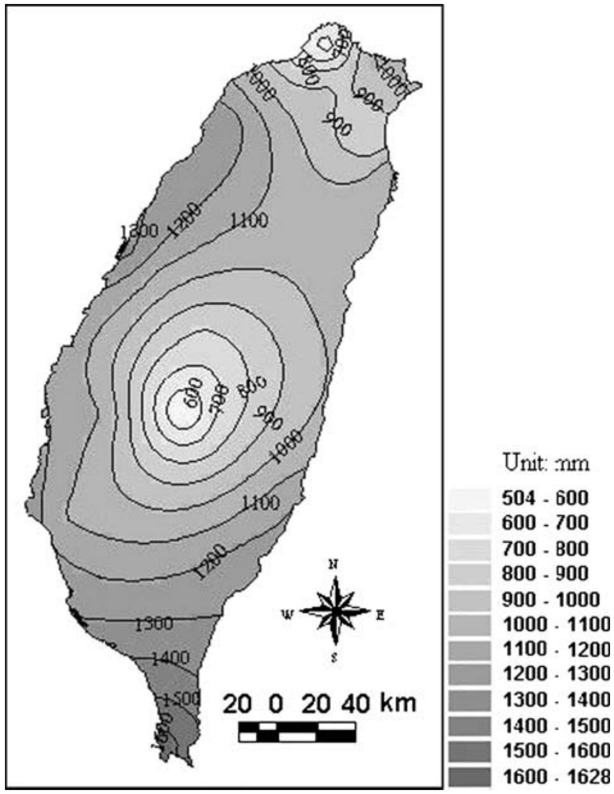


Fig. 7 Long-term mean annual evapotranspiration (mm) in Taiwan. The contour interval is 100 mm

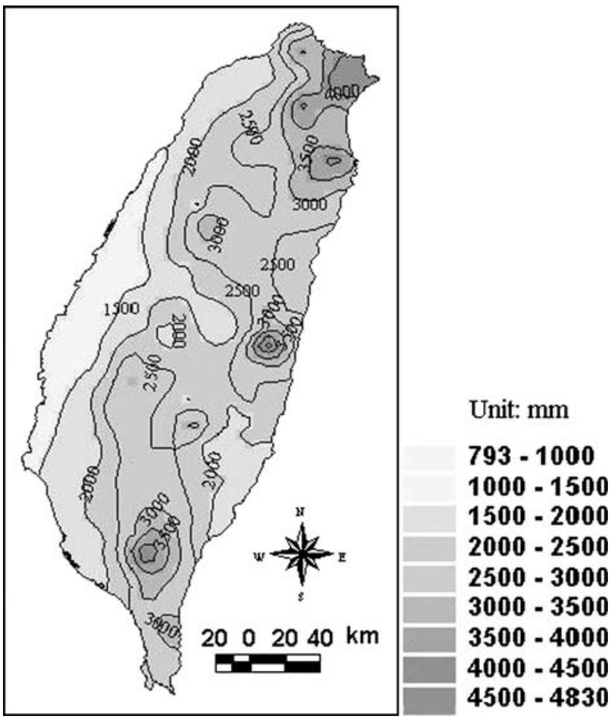


Fig. 6 Long-term mean annual precipitation (mm) in Taiwan. The contour interval is 50 mm

The evaporative behavior is mainly related to sunshine in Taiwan. The number of hours of sunshine has an inverse relationship with the degree of cloudiness. That is, the accumulation of clouds shortens the daylight. Less sunshine is seen in the mountains than on the plains, and less on the east coast than the west. While rainy days prevent the northeastern corner from getting much sunshine, the western and southern areas of Taiwan enjoy more hours of sunshine a year.

The spatial distribution (Fig. 8) of long-term mean annual runoff is obtained by subtracting the ET map values from those of the precipitation map, in accordance with Eq. 5. Runoff is about 0–1,000 mm in the western area, and above 3,000 mm in the northeastern corner. This significant difference in runoff is mostly due to the general distribution in annual precipitation and

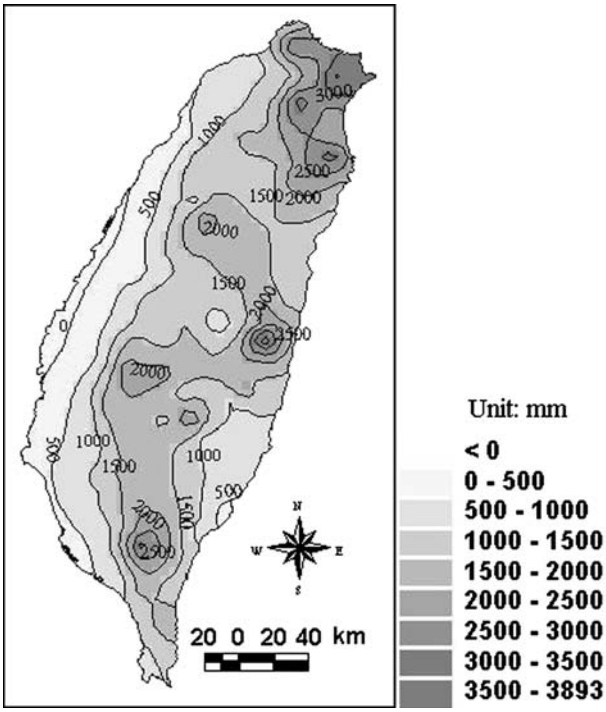


Fig. 8 Estimated long-term mean annual runoff (mm) in Taiwan, estimated as the difference between precipitation and evaportranspiration. The contour interval is 500 mm

the aridity of the environment around the island. The degree of aridity can expressed as the ratio of ET and precipitation (Fig. 9). The closer the value to unity (i.e., 100%), the more arid the environment. Note the extremely high aridity value of the western edge of Taiwan. A long-term mean runoff ratio of 55.5% for Taiwan can be obtained by dividing the spatial mean (1,304 mm/year) of the runoff values of Fig. 8 by the long-term mean precipitation (2,348 mm/year, from Fig. 6) of the island.

There are 129 rivers in Taiwan, most of which flow toward the east or west. Because of the major watershed, the drainage area of western Taiwan is larger than that in the east. Taiwan's rivers have the following characteristics: (1) They are fast flowing due to their short length and steep grade. Even Taiwan's longest river, the Choshui River, is only 186 km long but its degree of steepness of slope is 1/55. (2) They have a limited water flow in dry seasons, and they even became wildbachs unsuitable for sailing. (3) Their peak flow is enormous; a catchment area of 2,000–3,000 km^2 often receives peak flows of up to 10,000 m^3/s.

According to the watershed division of the Water Resource Agency, Ministry of Economic Affairs, Taiwan, can be divided into 61 catchments in total. The first step is to collect and establish a complete daily streamflow database, and the streamflow gauging stations collected in this paper, total 191. The distribution of the daily streamflow gauging stations used in this study is shown in Fig. 10.

The daily streamflow of each gauging station is used to calculate BFI by employing the base-flow-record estimation and the stable-base-flow analysis. To avoid overestimating results due to rainstorm events which mostly occur in the typhoon season, the largest three monthly values (minimally adjusted requirements for each gauging station) will not be chosen when the stable-base-flow analysis is employed. From the long-term mean annual values of the estimations of BFI, surfaces were generated using ordinary kriging where no apparent spatial drift in the values could be detected. The contour of the resulting long-term mean annual BFI field is shown in Fig. 11.

Finally, the spatial distribution of the naturally occurring long-term mean annual groundwater recharge (Fig. 12) is obtained by multiplying the runoff map values (Fig. 8) with those of the BFI map (Fig. 11). The highest rates (> 1,000 mm/year) occur in the northeastern part and the central-eastern part of Taiwan, primarily due to more abundant precipitation and a less severe aridity index. High mountain areas (over 1,000 m) express a rate of 800–2,000 mm/year annually, the areas of hills and terraces (between 100

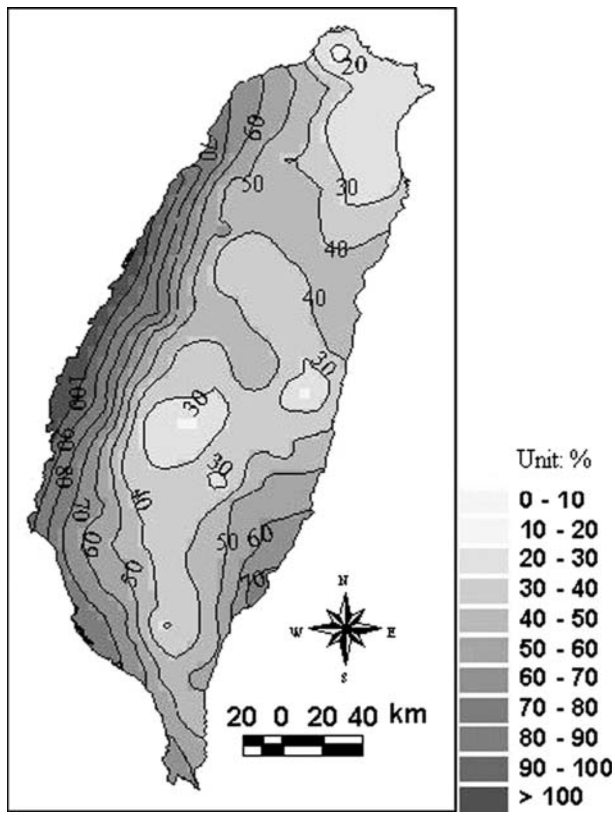


Fig. 9 Aridity (%) of the environment in Taiwan. The closer the value to 100%, the more arid the environment becomes

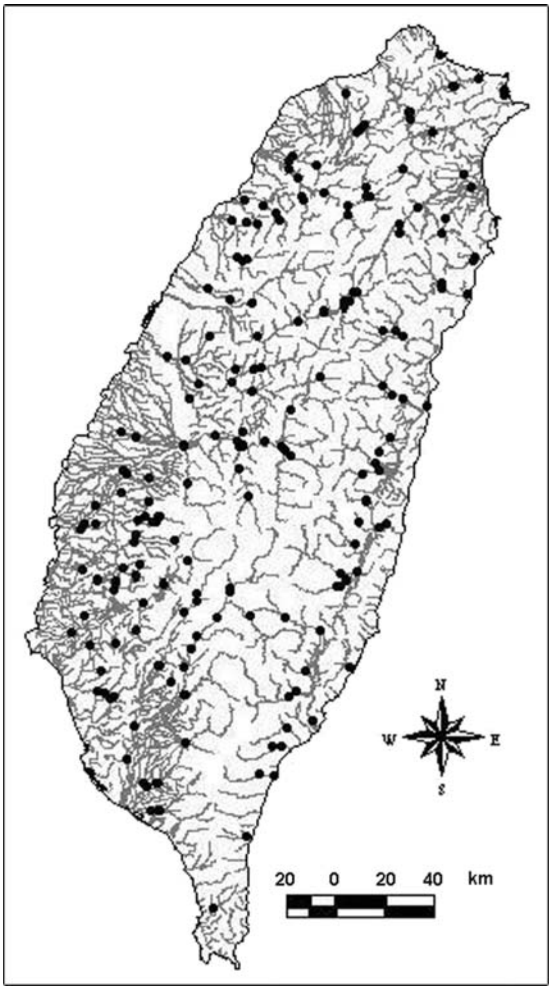


Fig. 10 Distribution of the gauging stations in Taiwan, used in the study

and 1,000 m above sea level) express a rate of 200–600 mm/year annually, and the areas of alluvial plains (below 100 m in elevation) receive an annual groundwater recharge of 0–200 mm. Note that the mean annual groundwater recharge is below 0 mm at the western edge of Taiwan, which is the most serious land subsidence area in Taiwan. The total groundwater recharge of Taiwan is obtained by multiplying the long-term mean annual groundwater recharge map values by the area of each grid. The total groundwater recharge of Taiwan is about 18 billion tons per year. The value compares well with the long-term mean groundwater recharge provided by the Water Resource Agency (2003). They obtained a long-term mean annual groundwater recharge of 17.3 billion tons for Taiwan.

The central mountain range of Taiwan has long been considered the main recharge area for groundwater due to the region's highly permeable gravelly/sandy aquifers. The high recharge rates are reflected in the high values of the BFI map (Fig. 11) and in the increased recharge rates in Fig. 12 when compared to the areas of hills, terraces, and alluvial plains. Because aridity increases and precipitation decreases from the mountain range toward its alluvial plains, groundwater recharge decreases as well. Note that at the western edge of Taiwan below 0% of the long-term mean annual precipitation recharges the groundwater (Fig. 13), while this recharge is larger than 20% of the annual precipitation in the mountain range of the island. This mainly due to greater precipitation and a less arid climate in the mountain range of Taiwan.

Conclusions

Naturally occurring long-term mean annual groundwater recharge on a regional scale can be estimated using a water-balance approach coupled with an automated baseflow separation technique and a procedure of adjustment. The water balance uses meteorological and discharge measurements. Geostatistics are used to generate surfaces of variables from point measurements. An objective automated baseflow separation technique (the base-flow-record estimation) and a procedure of adjustment (the stable-base-flow analysis) are applied to estimate the BFI. Finally, geographic information

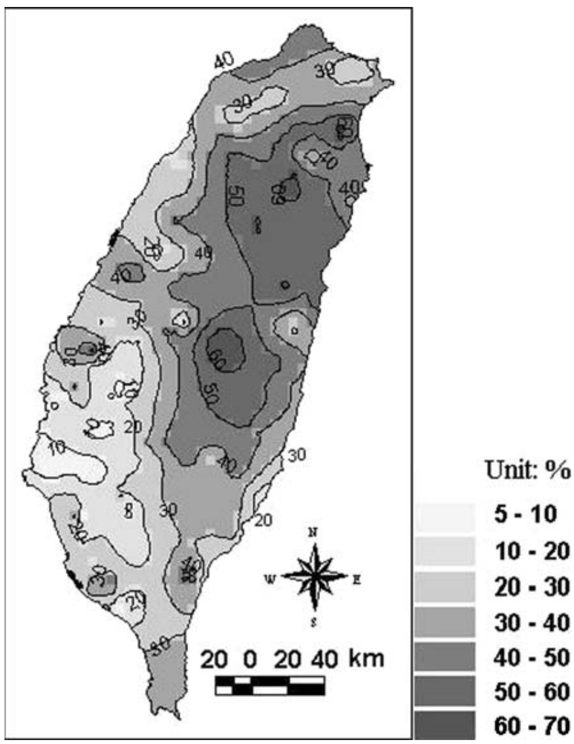


Fig. 11 Estimated long-term mean annual baseflow index, BFI (%) in Taiwan

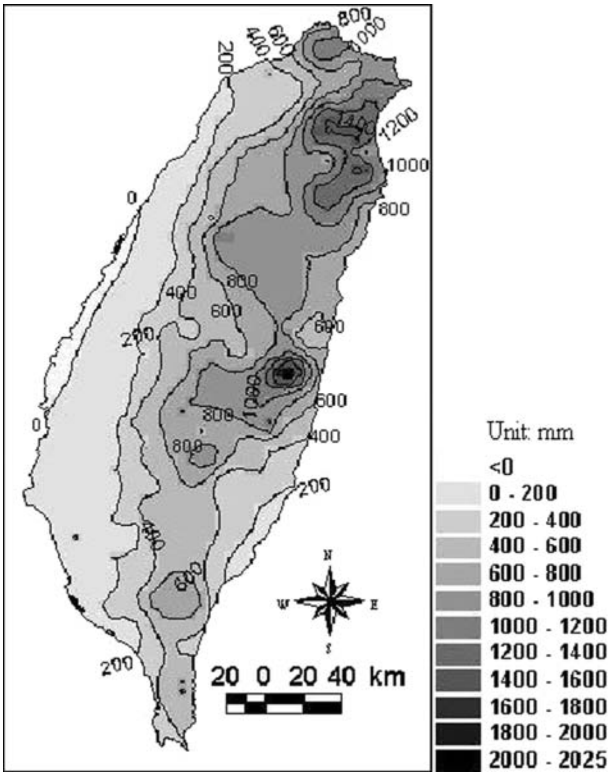


Fig. 12 Estimated long-term mean annual groundwater recharge (mm) in Taiwan. The contour interval is 200 mm

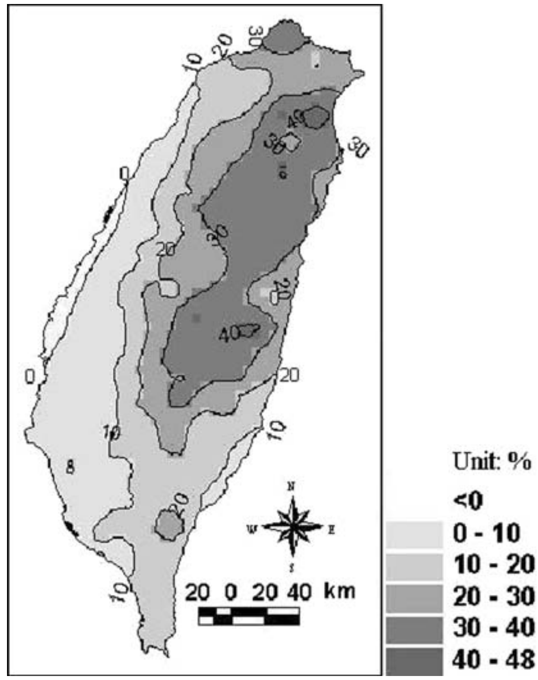


Fig. 13 Estimated long-term mean annual groundwater recharge as a percentage of long-term mean annual precipitation in Taiwan

system (GIS) is used to manipulate the maps of the different variables in the water balance.

Contours of the resulting long-term mean annual *P*, BFI, runoff, groundwater recharge, and recharge rates fields are well matched with the topographical distribution of Taiwan, which spans from the mountain range toward the alluvial plains of the island. Note that the mean annual groundwater recharge is below 0 mm at the western edge of Taiwan, which is the most serious land subsidence area due to overdrawing groundwater in Taiwan. The total groundwater recharge of Taiwan is about 18 billion tons per year as obtained by the employed method. The value compares well with long-term mean groundwater recharge estimates from related research.

The techniques used are easy to implement, widely available and do not require complex hydrogeologic modeling or detailed knowledge of soil characteristics, vegetation cover, or land-use practices. The technique can also provide input to complex groundwater flow models or validate their recharge estimates obtained through parameter optimization.

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Principles of regional assessment and mapping of natural groundwater resources

Igor S. Zektser

Abstract The modern state of scientific investigations for regional assessment and mapping of the natural groundwater resources is characterized. The main methods for regional assessment of the natural groundwater resources (river hydrograph separation by genetic recharge species for a long-term period, hydrodynamic methods, methods for perennial water-balance assessment for water recharge or discharge areas), their advantages and limitations are discussed. It is noted that the use of these methods for regional assessment of natural groundwater resources and groundwater runoff is based on analyzing and processing available hydrological and hydrogeological information and does not demand special expensive drilling and pumping tests. It is suggested to assess specific groundwater discharge modules, characterizing groundwater flow in 1 l/s per 1 km^2, the coefficient of groundwater discharge, characterizing groundwater recharge by infiltration in percent from the precipitation volume, and the coefficient of river recharge by groundwater, indicating the contribution of groundwater in the total river runoff, as the main quantitative characteristics of natural groundwater resources. The above-mentioned methods and quantitative characteristics of natural groundwater resources were used for compiling different scale maps of groundwater discharge for separate large regions, countries, central and eastern Europe, as well as the map of hydrogeological conditions and groundwater discharge of the world.

Keywords Investigations · Regional assessment · Mapping methods

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Introduction

This paper is dedicated to the memory of my great friend and prominent scientist Valery Mironenko. Valery Mironenko did not study spontaneously problems of regional assessment of groundwater resources alone. However, being a man of encyclopedic knowledge and an outstanding many-sided researcher, he was very interested in many problems of modern hydrogeological science. In our private conversations we discussed some methodological approaches for assessing and mapping groundwater resources, and debated about advantages and disadvantages of some scientific approaches and methods.

In recent decades there have been many investigations of regional assessments of natural groundwater resources and flow. This has happened for two main reasons. First, there is the necessity and ever-increasing need for determining groundwater use perspectives in different regions, which must be considered in regional schemes and projects for the complex use and protection of groundwater resources. Second is the development of techniques for regional assessment of groundwater flow which will make it possible to objectively and economically assess natural groundwater resources by analyzing and handling the available hydrological and hydrogeological materials without undertaking special expensive and labor-consuming explorations.

Methodology

Natural resources are defined as rechargeable groundwater flow, characterizing the amount of recharge by infiltration of atmospheric precipitation, inflow from rivers and leakage from adjacent aquifers. Natural groundwater resources occur and are continuously renewed in the process of a total hydrological cycle. Making a regional assessment, we can equate the average long-term value of groundwater recharge with the deduction of the evaporation from the groundwater level to the groundwater discharge value. Hence, main quantitative groundwater discharge characteristics can serve as indicator for natural groundwater resources in the territory being studied. In other words, natural resources characterize the natural productivity (groundwater discharge) of main aquifers in the intensive water-change zone. In practice, natural groundwater

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resources indicate the higher level for possible use of constantly rechargeable groundwater on withdrawals with the indefinite exploitation (but for coastal withdrawals, functioning mainly due to river discharge). Generally, natural groundwater resources are expressed by following quantitative characteristics of groundwater discharge: modules and coefficients of groundwater flow and coefficients of river recharge with groundwater.

A module of groundwater flow is defined as groundwater flow discharge from a unit of catchment area, given in liters per second per 1 km^2. The coefficient of groundwater flow is the ratio of groundwater flow to atmospheric precipitation. It demonstrates (usually on a percentage basis) which part of atmospheric precipitation recharges the groundwater. The coefficient of river recharge with groundwater is the ratio of groundwater flow being drained by the river to total river runoff, and it characterizes a portion of groundwater in the river runoff. This shows (usually on a percentage basis) which part of the total river runoff is formed by the groundwater.

Given quantitative characteristics (modules, coefficient of groundwater flow and river recharge with groundwater) make it possible not only to show natural groundwater resources, but also to consider them as important water-balance characteristics, allowing us to compare different components of total water balance and total water resources for different regions.

To cite one example: on the average 600 mm of atmospheric precipitation falls yearly in the area of Moscow. A mean annual module of total river runoff for a multiyear period is about 6 l/s per 1 km^2 (equivalent to a layer about 190 mm/year). The groundwater flow module, calculated by the method of genetic stream hydrograph separation for a multiyear period, is about 2 l/s per 1 km^2, which is equivalent to a layer of 63 mm/year. Thus, it is clearly seen that the groundwater flow coefficient (ratio of groundwater recharge 63 mm/year to precipitation 600 mm/year) is about 10% in the area of Moscow. Therefore, one tenth of atmospheric precipitation contributes to groundwater recharge. The groundwater portion in total river runoff or, in other words, the relationship between groundwater resources (groundwater flow) and total water resources (river runoff), is 30% on the average.

Regional assessments are aimed to determine natural groundwater resources in large territories, for example, river basins or artesian basins or parts thereof, and to calculate relative quantitative characteristics (modules and coefficients of groundwater discharge) as well as total natural groundwater resources. At present, the main and most widely used methods for regionally assessing groundwater resources are:

1. genetic stream hydrograph separation for a multiyear period;
2. hydrodynamic method for calculating groundwater discharge (modeling included);
3. computation of changes in the river low-water runoff between two stations;
4. calculating a long-term water balance of groundwater recharge or discharge areas (Table 1).

Having no way of considering in detail methods for regionally assessing groundwater flow and groundwater natural resources and, as extensive literature is devoted to them (see below), the principal aspects of the two most commonly used methods will be given, namely, the method of stream hydrograph separation and the hydrodynamic method for calculating groundwater flow discharge.

The method for stream hydrograph separation according to genetic types of recharge used to estimate flow, is based on the commonly held assumption that groundwater flow for a zone with intensive water exchange in areas with a constant river system is formed mainly because of the draining impact of the river. Singling out groundwater components in a total river runoff allows for assessing the amount of regional groundwater flow.

Table 1
The main methods for regional assessments of natural groundwater resources

Methods	Advantages	Disadvantages
River hydrograph separation	Possibility of obtaining average long-term groundwater flow characteristics Possibility of evaluating groundwater flow variability	Need for long-term observations of a river runoff under disturbed conditions Applicable only to the upper hydrodynamic zone where groundwater discharges into rivers
Computation of changes in the river low-water runoff between two hydrometric stations	Possibility of obtaining both average long-term and annual and seasonal groundwater flow characteristics	Difference in the river flow between two section lines should exceed the total error in the river flow measurement.
Hydrodynamic method of computing a specific groundwater flow (analytical approach or modeling)	Possibility of evaluating groundwater discharge in individual aquifers	Need for good aquifer parameters, difficulty in averaging them Impossibility to evaluate long-term groundwater flow variability
Method for determining a long-term water balance in groundwater recharge or discharge areas	Possibility of evaluating a discharge of deep aquifers not drained by rivers	Need for determining the main water-balance components by independent methods Estimated groundwater flow value should exceed the error in determining main water-balance components
Computation of infiltration values using groundwater level regime data	Possibility of evaluating groundwater discharge of individual aquifers	Difficulties in areal extension of groundwater recharge values computed for a point (well) Need for numerous observation wells

At present, there are many scientifically proven methods and technical procedures for genetic hydrograph separation. In this case, most authors proceed from the fact that base-flow water level is formed only due to the groundwater flow (excluding rivers with prevailing lacustrine or swamp recharge). The main difference of the available techniques concerns hydrograph separation during floods and high water. The approaches used here can be conditionally subdivided into three groups:

1. not considering the effect of coastal regulation during a flood, e.g., not considering possible decrease or increase in groundwater discharge during floods;
2. reducing the effect of coastal regulation to insignificant lowering of the river recharge with groundwater;
3. increasing groundwater discharge into the river as a result of augmentation of groundwater recharge.

The experience in genetic hydrograph separation speaks for a necessity to consider concrete hydrogeological conditions of interaction between surface and groundwater, that is, a degree of their hydraulic connection. Some methods for separation of the common river runoff hydrographs characterizing river basin peculiarities are given in the hydrogeological literature (Linsley and others 1962; Chow 1964; Freeze and Cherry 1979).

To obtain reliable data on river recharge with groundwater, it is necessary to jointly consider the surface and groundwater regime of runoff within a catchment area, and prove the character and degree of their interaction. The processes of coastal control during floods cause a considerable decrease or increase of river recharge with groundwater, which should be considered under hydrograph separation.

Russian specialists have developed a complex hydrologic-hydrogeologic method for hydrograph separation which was successfully used for regional assessment of groundwater discharge in the USSR territories and countries of central and eastern Europe (Kudelin 1960; Anonymous 1965; Lebedeva 1972; Dzhamalov 1973; Zektser 1977; Anonymous 1982, 1983; Vsevolozhsky 1983; Zektser 1986). The main feature of this method is to consider the character and degree of interconnection between groundwater and surface water in the river basin, which is determined as a result of careful study of the available geologic-hydrogeological data. In difficult cases, a reconnaissance or special investigation of the river valley is carried out. A typical scheme of draining for different parts of the river basin is made based on literature and field data. Drained aquifers and their lithological composition, and also levels of groundwater and river water for different seasons are given in these schemes. The different character of hydraulic connection between a river and aquifers, depending on the relationship between levels of groundwater and river water, determines different schemes for hydrograph separation.

The simplest way to assess groundwater flow drained by the river is to calculate low-water runoff changes for a multiyear period at the river site between two gauging stations.

A hydrodynamic method for assessing groundwater discharge is based on studying hydrogeological parameters of the main aquifers. Here, maps of the level surface and transmissivity are compiled for every aquifer. Total groundwater discharge is determined by the main Darcy dependence for flow paths singled out. This traditional method, being very simple, gives the possibility of obtaining a reliable enough value of groundwater flow for each aquifer. Here, special attention should be paid to the reliability and accuracy of the initial hydrogeological parameters (transmissivity and permeability), compiled on the basis of hydrodynamic maps. Flow discharge is calculated by flow paths, taking into account all the main parameters. Initial hydrodynamic parameters are not averaged for large territories, but are used and given in detail for calculated sites and flow paths.

Under complex hydrogeological conditions, with enough available data characterizing regional conditions of groundwater filtration, different methods of modeling are applicable for groundwater flow assessment. Methods for assessing the interconnection between aquifers of an artesian basin should be considered the most suitable for this kind of calculations. Under a known areal distribution of head and transmissivity, this allows the gathering of horizontal and vertical components for groundwater flow at every point of calculations (Ogilvi and Semendyaeva 1972; Dzhamalov 1973; Zektser and others 1984).

Groundwater flow within a water catchment described by the models of total river runoff formation is of great practical value (Kutchment and others 1983; Khublaryan and others 1990). There are approaches proposing a complex consideration and solution of differential equations for moisture transport, groundwater filtration, and water flow above the river bed (San Venant equation).

The main methods for regional assessment of groundwater flow, their advantages and disadvantages are given in Table 1. Thus, for instance, a widely used method, primarily in the territories of sufficient humidity, for determining groundwater flow by genetic stream hydrograph separation along with important advantages (the possibility of obtaining mean perennial data to characterize groundwater flow variability for a long-term period), is essentially restricted. It is most important to use data for an undisturbed river runoff regime, the assumption of coincidence between water catchment areas for surface water and groundwater (which is impossible for areas of intensive karst and fissured rocks distribution), and to use data for a long-term observation. Each of the methods mentioned has both advantages and disadvantages. This is why the right choice will depend on concrete geologic-hydrogeological and hydrologic conditions of investigated regions, and also on the aims and scale (details) of the investigations made. The given methods are not competing; they supplement each other very well. This is why the most reliable result is obtained using a combination of different methods to assess regional groundwater flow (Zektser and Dzhamalov 1988; Zektser 2000).

It must be noted that there are enough methodological problems of regional evaluation of groundwater natural resources to be solved. Thus, the researcher gets the value of groundwater discharge of all drainage zone using the method of river hydrograph separation, but the way of evaluating the recharge of every aquifer of this zone is not clear yet. The problem of this method applicable to river basins with very disturbed river flow is not enough developed. While using the hydrodynamic method of calculation of ground flow rate, the problem of hydrogeological parameters averaging also is not enough developed. There are several other methodological problems to be examined.

Results

It should be noted that the first studies for regional assessment and mapping of natural groundwater resources and groundwater flow were made in the former USSR territory at the beginning of the 1960s under the initiative and guidance of Professor B.I. Kudelin. This work resulted in compiling and editing in 1964 of the "Maps of groundwater flow of the USSR area" at a scale of 1:5,000,000, and a monograph entitled "Groundwater flow of the USSR area" in 1966, which is actually a detailed explanation note to this map. Later, in the early 1970s, the maps of groundwater flow in the USSR at a scale of 1:2,500,000 were compiled by a large group of hydrogeologists and hydrologists. At the same time, many years of work went into assessing and mapping groundwater flow in central and eastern Europe. This work was carried out in accordance with the UNESCO International Hydrological Program and resulted in compiling and editing "The international map of groundwater flow in central and eastern Europe" at a scale of 1:1,500,000, and a monograph entitled "Groundwater flow in central and eastern Europe" in 1983. Here, values of groundwater flow for large regions have been obtained, the main regularities of groundwater flow formation, depending on physical geographical and geologic-hydrogeological conditions, have been revealed, and time and space peculiarities of changes for specific values and coefficients characterizing groundwater flow have been defined. Considering the positive experience of international cooperation in the field of regional assessment and mapping of groundwater resources in the period from 1987 to 1992, in accordance with UNESCO's Project for the International Hydrological Program, investigations have been made for regional assessment and mapping of groundwater flow of the whole world. A large group of scientists from many countries (former USSR, USA, France, Australia, India, Brazil, Argentina, Thailand, etc.) participated in this work. As a result of their joint effort, the "The world map of hydrogeological conditions and groundwater flow", at a scale of 1:10,000,000, was compiled, then edited and published by an international group of experts in the USA in 1999 (Anonymous 1999). Among other works on the problem under consideration, studies made in different years for the regional assessment and mapping of groundwater flow and groundwater resources of the Russian Nechernozemie, Moscow and Baltic artesian basins, eastern Siberia, Cis-Caucasus and other regions of the former USSR territory should be noted. The "Map of groundwater flow in California" at a scale of 1:2,000,000, published in 1991 and jointly compiled by Russian and American specialists, should also be noted.

One most important point should be noted. Regional quantitative characteristics of the main aquifers (groundwater modules and coefficients of the river recharge with groundwater), characterizing their natural productivity and groundwater recharge in natural conditions, are given in these maps. These maps contain quantitative information on groundwater and its resources, which makes them different from other hydrogeological maps. Besides natural conditions, factors (mainly geologic-hydrogeologic) causing groundwater resources formation are given in the maps of groundwater flow.

Maps of groundwater flow are widely used in practice (hydrologic-hydrogeologic and water-management works), allowing practical problems for the complex use and protection of water resources to be solved on a quantitative basis. Such problems incorporate determining fresh groundwater natural resources for characterizing water supply of separate areas, determining and predicting changes of groundwater component for the river runoff, assessing the amount of groundwater recharge when characterizing its safe yield, quantitative assessment of groundwater flow as an element of water balance for the territories, etc.

Tasks for further investigations

Main tasks for further investigation are:

1. to improve the available and to develop new methods for assessing groundwater resources, accounting for natural measures;
2. to develop and put into practice nature-protecting criteria, determining the acceptable impact of groundwater withdrawal on other components of the environment, and also the acceptable effect of anthropogenic activities on groundwater resources and quality;
3. to perfect the available methods and to develop new methods for predicting changes in groundwater resources and quality under intensive anthropogenic activities and possible climate changes;
4. to substantiate the principles of conducting groundwater monitoring under different natural climatic and anthropogenic conditions as a component of the general monitoring of water resources and the environment;
5. to assess the function of groundwater discharge in the water-salt balance of large regions, including separate seas and large lakes.

Acknowledgements This article was written under support of the Russian Fond for Fundamental Investigations, grant number 01-05-64173.

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Attachment A

Attachment A: Budget Detail for 2007 Projects

Project Title: Water Resource Sustainability

Project Manager Name: John L. Nieber

Trust Fund Appropriation: $ *292,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(06/30/09)*	**Balance** *(06/30/09)*	**Result 2 Budget:**	**Amount Spent** *(06/30/09)*	**Balance** *(06/30/09)*	**Result 3 Budget:**	**Amount Spent** *(06/30/09)*	**Balance** *(06/30/09)*	**Result 4 Budget**	**Amount Spent (06/30/09)**	**Balance** *(06/30/09)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Development of hierarchical hydrologic units and estimation of associated ground water recharge			*Development of materials for quantitative information system for freshwater sustainability*			*County level test of the sustainable supply estimation methodology.*			*Compare recharge estimates from alternative methodologies*				
BUDGET ITEM						0			0				0	0
PERSONNEL: wages and benefits	169,600	169,600	0	42,500	42,500	0	24,100	24,100	0	15,000	15,000	0	251,200	0
Contracts			0			0			0	0		0	0	0
Professional/technical: Boris Shmagin; hydrological/statistical analysis	30,000	30,000	0	0		0	8,000	8,000	0	0		0	38,000	0
Travel outside Minnesota; Brookings, SD	1,200	1,200	0	0		0	400	400	0	0		0	1,600	0
Travel outside Minnesota; San Francisco	1,200	1,200	0	0		0	0		0	0		0	1,200	0
Other *(Describe the activity and cost) be specific*			0			0	0		0	0		0	0	0
COLUMN TOTAL	**$202,000**	**$202,000**	**$0**	**$42,500**	**$42,500**	**$0**	**$32,500**	**$32,500**	**$0**	**$15,000**	**$15,000**	**$0**	**$292,000**	**$0**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: COUNTY GEOLOGIC ATLAS PROGRAM ACCELERATION
PROJECT MANAGER: Dale R. Setterholm
AFFILIATION: Minnesota Geological Survey, University Of Minnesota
MAILING ADDRESS: 2642 University Ave W.,
CITY/STATE/ZIP: St. Paul, MN 55114
PHONE: 612-627-4780 EXT. 223
FAX: 612-627-4778
E-MAIL: sette001@umn.edu
WEBSITE: http://www.geo.umn.edu/mgs
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 5(j).

APPROPRIATION AMOUNT: $400,000

Overall Project Outcome and Results

The County Geologic Atlas program creates geologic maps and associated databases at scales appropriate for resource management, especially ground water management, at the local scale. This grant funded progress on such mapping for Benton and Chisago counties. The counties qualified for participation by establishing accurate digital locations for water wells with construction records that are used as a basic data element in creating the maps. For each county the following products have been constructed:

- Database of well record information with geologic interpretations and a location map;
- Map of the glacial materials occurring at the land surface;
- Map of the bedrock types occurring at the surface of the bedrock;
- Closely-spaced cross-sectional views of the distribution of glacial materials between the land surface and the bedrock surface;
- Map of the elevation of the bedrock surface;
- Map of the thickness of glacial materials above the bedrock surface.

Tasks remaining include:

- Map or maps of the distribution of aquifers within the glacial materials;
- Digital surfaces for multiple sedimentary bedrock formations;
- CD or DVD with digital files of all the maps and databases and a GIS project to display and manipulate those maps and data;
- Printed copies of all the maps. These unfinished products will be created under our 2008 LCCMR grant.

The final outcome of completed county geologic atlases is an understanding of the distribution of aquifers and wells including how the aquifers are connected with each other, how they are connected to the land surface, and how they are connected to surface water features. Hydrologic maps and databases will be created by DNR Waters. The LCCMR funds were augmented with a matching grant of $41,110 from the United States Geological Survey under the STATEMAP program.

Project Results Use and Dissemination

When the additional products for Benton and Chisago counties are complete (expected December 2009 using M.L. 2008 appropriation from the Environment and Natural Resources Trust Fund) a workshop will be arranged to present this work to local users, and to explain how it was created and how it might be applied to resource management. The MGS provides ongoing support of these products as well. Logical applications that have arisen already include the search for municipal well sites for the City of Foley, evaluation of the effects of quarrying on local ground water in Benton County, and an evaluation of the ground water implications of a proposed power plant in Chisago County. Draft versions of some products have already been distributed to parties involved in these issues. The digital versions of the products will be available on CD or DVD and from the website of the Minnesota Geological Survey, and 1,000 printed copies will be distributed to each county. The County Geologic Atlases are a well-known and well-used source of data and geologic interpretations for state and local agencies, consultants, well construction contractors, and citizens. Many of the elements of the atlases are specifically named in the data needs identified in sustainable ground water management plans under development in Minnesota. They are provided in formats appropriate for the complete spectrum of users, including those who don't use computers through users that require digital files appropriate for modeling and simulation of the ground water system.

Trust Fund 2007 Work Program Final Report

Date of Report: August 15, 2009
Trust Fund 2007 Work Program Final Report
Date of Work program Approval: June 5, 2007
Project Completion Date: June 30, 2009

I. PROJECT TITLE: County Geologic Atlas Program Acceleration

Project Manager: Dale R. Setterholm
Affiliation: Regents of the University of Minnesota
Dept: Minnesota Geological Survey
Mailing Address: Regents: 450 McNamara Center
200 Oak Street SE
City / State / Zip : Minneapolis MN 55455
Mailing Address: Geological Survey: 2642 University Ave. W.
City / State / Zip : St. Paul MN 55114

Telephone Number: 612-627-4780 Geological Survey
E-mail Address: sette001@umn.edu
FAX Number: 612-627-4778
Web Page address: http://www.geo.umn.edu/mgs

Location: Benton and Chisago counties

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	400,000
	Minus Amount Spent:	**$**	400,000
	Equal Balance:	**$**	0

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 5(j).

Appropriation Language:
$400,000 is from the trust fund to the University of Minnesota, Minnesota Geological Survey to accelerate the production of county geologic atlases which describe location, size, boundaries and vulnerability of aquifers to enhance the protection and use of ground water.

II. and III. FINAL PROJECT SUMMARY

The County Geologic Atlas program creates geologic maps and associated databases at scales appropriate for resource management, especially ground water management, at the local scale. This grant funded progress on such mapping for Benton and Chisago counties. The counties qualified for participation by establishing accurate digital locations for water wells with construction records that are used as a basic data element in creating the maps. For each county the following products have been constructed:

- Database of well record information with geologic interpretations and a location map;
- Map of the glacial materials occurring at the land surface;
- Map of the bedrock types occurring at the surface of the bedrock;
- Closely-spaced cross-sectional views of the distribution of glacial materials between the land surface and the bedrock surface;
- Map of the elevation of the bedrock surface;
- Map of the thickness of glacial materials above the bedrock surface.

Tasks remaining include:

- Map or maps of the distribution of aquifers within the glacial materials;
- Digital surfaces for multiple sedimentary bedrock formations;
- CD or DVD with digital files of all the maps and databases and a GIS project to display and manipulate those maps and data;
- Printed copies of all the maps. These unfinished products will be created under our 2008 LCCMR grant.

The final outcome of completed county geologic atlases is an understanding of the distribution of aquifers and wells including how the aquifers are connected with each other, how they are connected to the land surface, and how they are connected to surface water features. Hydrologic maps and databases will be created by DNR Waters. The LCCMR funds were augmented with a matching grant of $41,110 from the United States Geological Survey under the STATEMAP program.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1 Geologic Mapping and Databases, Benton County **Budget: $**199,786

- Produce geologic maps and associated databases for Benton County.
- A completed atlas will include maps of bedrock geology, surficial geology, database, bedrock topography, depth-to-bedrock, and subsurface Quaternary geology in GIS formats. This project will not complete all of those products (see deliverables).
- Benton County will contribute effort, and possibly funding to this project.

Summary Budget Information for Result 1:

Trust Fund Budget:	**$199,786**
Amount Spent:	**$199,786**
Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. County Well Index database	6/30/08	$48,696.50	complete
2. Revised surficial geology map	6/30/08	$50,196.50	complete
3. Bedrock topography / drift thickness	6/30/08	$ 3,500.00	complete
4. Bedrock geology map	6/30/09	$53,696.50	draft
5. Progress on subsurface geology	6/30/09	$43,696.50	underway

Final Report Summary:
Approximately 75% of the products typically included in a county geologic atlas have been completed for Benton County. This is a positive outcome considering a typical atlas costs about $330,000 and this work has been completed for less than $200,000. Completing the atlas with the funds allocated to that purpose in the 2008 grant will be a challenge, but I am hopeful we will achieve that. It would be helpful to identify candidate counties in advance of the grant period, and have them qualify for the program by establishing well locations before the grant starts. However, until the grant is in place I cannot promise to do the work, and they will not likely participate without that promise. Conducting their work within the grant period somewhat delays MGS work, and compresses the project schedule. The award of less than full funding for an atlas is also a challenge. The products are all essential, and the project scope cannot realistically be changed. Less than full funding requires finishing the project on a subsequent grant, or with alternative funding, and it is not easily coordinated.

Result 2 Geologic Mapping and Databases, Chisago County **Budget: $**200,214

- Produce geologic maps and associated databases for Chisago County.
- A completed atlas will include maps of bedrock geology, surficial geology, database, bedrock topography, depth-to-bedrock, and subsurface Quaternary geology in GIS formats. This project will not complete all of those products (see deliverables).
- Chisago County will contribute effort, and possibly funding to this project.

Summary Budget Information for Result 2:		
	Trust Fund Budget:	**$200,214**
	Amount Spent:	**$200,214**
	Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. County Well Index database	6/30/08	$40,651.75	complete
2. Revised surficial geology map	6/30/08	$25,651.75	complete
3. Bedrock topography / drift thickness	9/30/08	$ 3,500.00	complete
4. Bedrock geology map	6/30/09	$61,303.50	complete
5. Progress on subsurface geology	6/30/09	$69,107.00	underway

Final Report Summary:
Approximately 75% of the products typically included in a county geologic atlas have been completed for Chisago County. This is a positive outcome considering a typical atlas costs about $330,000 and this work has been completed for less than $200,000. Completing the atlas with the funds allocated to that purpose in the 2008 grant will be a challenge, but I am hopeful we will achieve that.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: MGS salaries and fringes $329,182
(several permanent staff at less than full time, students)
MGS travel, vehicle rentals $ 10,769

Contract drilling services $ 52,509

Equipment: $ 7,540
(includes supplies, repairs, and services, no equipment greater than several hundred dollars)
Development: $ 0
Restoration: $ 0
Acquisition, including easements: $ 0

TOTAL TRUST FUND PROJECT BUDGET: $ 400,000

Explanation of Capital Expenditures Greater Than $3,500: none

VI. OTHER FUNDS & PARTNERS:
A. Project Partners: The MGS works with county staff create and deploy the atlases. Each county has contributed labor to this effort. When the geologic portions of these atlases are complete it is anticipated that DNR Division of Waters will undertake hydrologic studies to augment the geologic work. This proposal only funds the MGS portion of the work.

B. Other Funds Proposed to be Spent during the Project Period: The Minnesota Geological Survey State Special Appropriation does not fund the County Geologic Atlas Program.
DNR Waters currently funding the MGS at $200,000 per year.
Selected counties contribute $108,000 or less (based on tax capacity) or contributions of labor and in-kind spending will be accepted.
A matching contribution of $41,110 from the USGS STATEMAP program was applied to the bedrock geologic mapping effort in Chisago County.

C. Past Spending: In the period 7/1/05 to 7/1/07 MGS will receive $400,000 from DNR Waters, $29,423 from Todd County, $28,647 from Carlton County, and $34,729 from McLeod County.

D. Time: $400,000 over a 2 year period would bring the rate of funding back to levels achieved in 1995-2000 and roughly twice the current funding rate. This can be achieved efficiently and will allow MGS to begin mentoring some new staff in anticipation of the retirement of some experienced mapping staff. The two year time frame will not likely allow for a complete geologic atlas to be completed in any county. More likely, progress will be made in one or more counties and the work will be completed as funding allows.

VII. DISSEMINATION: The map files and associated databases are made available on the MGS web page http://www.geo.umn.edu/mgs/ in multiple formats to accommodate the preferences of users. These files are also made available to affected counties and they may also further distribute the results. The County Well Index database, including data from this project is available at http://mdh-agua.health.state.mn.us/cwi/cwiViewer.htm.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than Dec. 31, 2007, June 30, 2008, and December 31, 2008. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: 5(j) County Geologic Atlas Program Acceleration

Project Manager Name:Dale R. Setterholm

Trust Fund Appropriation: $ *400,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent (*06/30/2009*)**	**Balance** *(date)*	**Result 2 Budget:**	**Amount Spent** *(06/30/2009)*	**Balance** *(date)*	**Result 3 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Geologic Mapping and Databases, Benton County, FY 08 and 09			*Geologic Mapping and Databases, Chisago County, FY 08 and 09*			*Fill in your result title here.*				
BUDGET ITEM			0			0			0	0	0
PERSONNEL: wages and benefits	150,187	156,269	-6,083	150,703	172,913	-22,209			0	300,890	-28,292
Contracts			0			0			0	0	0
Professional/technical *(Drilling Services)*	38,000	32,186	5,814	20,000	20,323	-323			0	58,000	5,492
Other Supplies (Lab Services and supplies, printing, general supplies and services, repairs and maintenance)	6,200	4,607	1,593	6,112	2,933	3,179			0	12,312	4,772
Travel expenses in Minnesota	5,399	6,724	-1,325	23,399	4,045	19,354			0	28,798	18,029
COLUMN TOTAL	**$199,786**	**$199,786**	**$0**	**$200,214**	**$200,214**	**$0**	**$0**	**$0**	**$0**	**$400,000**	**$0**

2007 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Minnesota's Water Resources: Impacts of Climate Change - Phase II
PROJECT MANAGER: Lucinda B. Johnson
AFFILIATION: Natural Resources Research Institute, University of Minnesota Duluth
MAILING ADDRESS: 5013 Miller Trunk Highway
CITY/STATE/ZIP: Duluth, MN 55811-1442
PHONE: (218) 720-4251
FAX: (218) 720-4328
E-MAIL: ljohnson@d.umn.edu
WEBSITE: http://www.nrri.umn.edu/staff/ljohnson.asp
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2007, Chp. 30, Sec. 2, Subd. 5k

APPROPRIATION AMOUNT: $300,000

<u>Overall Project Outcome and Results</u>
Minnesota's climate has become increasingly warmer, wetter, and variable, resulting in unquantified economic and ecological impacts. Our team assessed future climate scenarios, quantified hydrologic responses to past climate, conducted an economic analysis to assess implications of changing climate to water resources, and identified water quality and fish indicators of response that could be used for future monitoring. Specific products included:

- Data tools to extract and summarize historic climate data from the State Climatology Office database,
- A water quality reporting tool,
- Climate predictions to the end of the century,
- Assessment of economic impacts of climat change on fisheries and water resources,
- Recommendations of indicators for inclusion in future monitoring programs.

Our findings include the following:

- Temperature increases are projected to be greatest in the latter half of this century, with temperatures generally above 2°C above the average from 1950-1999.
- Precipitation is projected to increase on an annual basis, but will decrease or be unchanged during the growing season, resulting in drier growing conditions.
- Overall, water temperatures in streams are projected to increase between 3 and 5°C.
- Ice out dates were found to be occuring about 1.44 days earlier per decade since the 1950's, and trends for increasing air temperatures in the future imply further declines in ice-free days.
- Historic data were utilized to identify climate periods in the record that were extreme (either due to temperature or precipitation). These extreme periods were then used to assess possible water quality and fish responses during those periods. Indicators of water quality responses were identified (e.g., water clarity, surface water temperature, conductivity); no specific fish responses were detected.
- Walleye spawning dates are changing with ice out dates, and there is evidence that some fish species are expanding their distributions (especially largemouth bass, bluegill and black bullhead). Cisco (tullibee) abundance is declining in northern lakes.
- Water quality and biological indicators were recommended for future monitoring.

Individual project components show detailed analyses and results.

Project Results Use and Dissemination

Project team members and their collaborators have made numerous presentations to general audiences, to agencies, and at professional conferences. Additional outreach and communications products include:

- Data from Kristal Schneider's Master's thesis regarding the relationship between walleye spawning and ice out has been published in the Transactions of the American Fisheries Society 139(4):1198-1210.. http://afsjournals.org/doi/abs/10.1577/T09-129.1. Further publications are planned.
- A mapping tools was created to display trends for lakes having between 5 to >18 years of data. Because of the large number of options for analyzing this broad data set, a comprehensive subproject website was constructed to make the trend results available to other project scientists and ultimately others: (http://mnbeaches.org/gmap/trendswebsite). The website includes "processed raw" data, complete metadata, summary tables, links to Google Maps that identify sites with descriptive statistics, and graphs (box and whisker and regressions). The data are also incorporated into the larger project database that is now being used for more detailed examinations of climatic associations, geographic patterns, size and depth patterns, and associations with fish, and ice cover data.
- The climate data retrieval tool, developed by the State Climatology Office, was essential to all climatic research undertaken in this project. The climate data retrieval tool enabled project participants to extract climate variables important to their own specific questions, at time and space scales they deem relevant. While the climate data retrieval tool is available to project investigators only at the present time, the Office of the State Climatologist plans to make it available widely to Minnesota resource managers and researchers at the conclusion of this project.
- A third product is an annotated bibliography for the economics of climate change and environmental quality.

Trust Fund 2007 Work Program Final Report

Date of Report: January 4, 2011
Trust Fund 2007 Work Program Final Report

I. PROJECT TITLE: Minnesota's water resources: impacts of climate change - Phase II – SN 13
Project Manager: Lucinda B. Johnson
Affiliation: Natural Resources Research Institute, University of Minnesota Duluth
Mailing Address: 5013 Miller Trunk Highway
City/State/Zip: Duluth, MN 55811-1442
Telephone Number: (218) 720-4251
E-mail Address: ljohnson@d.umn.edu
FAX Number: (218) 720-4328
Web Page Address: http://www.nrri.umn.edu/staff/ljohnson.asp

Location: Entire state of Minnesota

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	**300,000**
	Minus Amount Spent:	**$**	**300,000**
	Equal Balance:	**$**	**0**

Legal Citation: ML 2007, [Chap. 30], Sec.[1], Subd. 5(k)

Appropriation Language: $300,000 is from the trust fund for the second biennium to the University of Minnesota's Natural Resources Research Institute, to quantify climate, hydrologic, and ecological variability and trends, along with economic impacts of environmental fluctuation on water resources, and to identify indicators of future climate change effects on aquatic systems. This appropriation is available until June 30, 2010, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. AND III. FINAL PROJECT SUMMARY
Minnesota's climate has become increasingly warmer, wetter, and variable, resulting in unquantified economic and ecological impacts. Our team assessed future climate scenarios, quantified hydrologic responses to past climate, conducted an economic analysis to assess implications of changing climate to water resources, and identified water quality and fish indicators of response that could be used for future monitoring. Specific products included:

- Data tools to extract and summarize historic climate data from the State Climatology Office database,
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- Climate predictions to the end of the century,
- Assessment of economic impacts of climat change on fisheries and water resources,
- Recommendations of indicators for inclusion in future monitoring programs.

Our findings include the following:

- Temperature increases are projected to be greatest in the latter half of this century, with temperatures generally above 2°C above the average from 1950-1999.
- Precipitation is projected to increase on an annual basis, but will decrease or be unchanged during the growing season, resulting in drier growing conditions.
- Overall, water temperatures in streams are projected to increase between 3 and 5°C.
- Ice out dates were found to be occuring about 1.44 days earlier per decade since the 1950's, and trends for increasing air temperatures in the future imply further declines in ice-free days.
- Historic data were utilized to identify climate periods in the record that were extreme (either due to temperature or precipitation). These extreme periods were then used to assess possible water quality and fish responses during those periods. Indicators of water quality responses were identified (e.g., water clarity, surface water temperature, conductivity); no specific fish responses were detected.
- Walleye spawning dates are changing with ice out dates, and there is evidence that some fish species are expanding their distributions (especially largemouth bass, bluegill and black bullhead). Cisco (tullibee) abundance is declining in northern lakes.
- Water quality and biological indicators were recommended for future monitoring.

Individual project components show detailed analyses and results.

Result 1: Economic and Engineering Assessment of Potential Impacts on Water Resource Infrastructure.

Description: Recent changes in precipitation patterns, combined with urbanization, wetland loss, and increased tile drainage have resulted in higher riverine base flows in Minnesota, compared to historic averages. These changes are associated with increased flood frequency and intensity. The economic impact of such floods has been substantial. We will use data from our Phase I LCCMR funded Climate Change project, along with the outcome of Result 2 (i.e., future MN climate predictions) to estimate the economic cost of flooding and degraded water quality and assess infrastructure changes needed to meet future climate projections. Outcome: An economic analysis of floods and the cost of water quality protection and infrastructure needs under changing climatic conditions. The analysis will include estimates of flood damages to physical and natural assets, including costs due to increased sedimentation and nutrient enrichment of surface waters using market valuation techniques. Damages to water quality will also be estimated using benefits transfer based on evidence from the literature on the public values of water quality. Costs to mitigate damages from flooding and reduced water quality will also be determined using current and projected engineering costs and market values.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$ 85,458**
	Amount Spent:	$ **85,458**
	Balance:	**$** 0

Deliverable	Completion Date	Budget	Status
1. Engineering analysis	September 2008	$25,458	Complete
2. Categorization of economic impacts by market and non-market values	June 2009	$16,000	Complete
3. Finalize economic estimates for infrastructure and water quality impacts	June 2010	$44,000	Complete

Completion Date: *June 30, 2010*

Final Report Summary:

Potential Impacts of Climate Change on Minnesota's Water Resources: An Economic Analysis (see Appendix A).

Patrick G. Welle, Rabi Vandergon
Bemidji State University

Conceptual Framework for Inferring Economic Impacts

Potential economic impacts of climate change must be understood within the conceptual framework about what people value. Environmental economics identifies two major conceptual components of value: use values and passive-use value. The theory and practice has developed toward the conventional wisdom that only recognizing use values in evaluating environmental effects would lead to substantial underestimation of value to the public.

It is also worthwhile to relate conceptual components of value to the benefits estimation techniques available to measure them. Benefits estimation must be grounded in measurement of market and non-market values. Market values ideally measure willingness-to-pay (WTP) based on derivation of the market demand curve. Actual expenditures are a lower-bound estimate of WTP in that consumer surplus would be missed. Non-market values are not directly revealed in market transactions. Purchases of items, such as bird-watching equipment, can indicate people's values for these activities. Existence values are most often measured through direct statements rather than being revealed through market choices.

The focus of the overall project leads to emphasis on the three categories of environmental impacts below. The major mechanisms for economic impacts to occur are included.

1. Lake and stream levels: flood damages, especially to infrastructure
2. Water temperatures: shorter ice duration, changes in fish populations, habitat, winter and summer kills
3. Water quality: multiple values of clean water

Potential Economic Effects of Changes in Minnesota's Water Resources

Empirical economic analyses were performed on two impacts to MN water resources: 1) magnitudes and types of infrastructure damages due to weather-related events, particularly floods, and 2) the trend toward shorter ice duration on MN lakes. This is likely to affect recreational fishing which is extremely important to MN.

Infrastructure Damage: The longest yearly record for weather-related damages in MN comes from figures reported in a NOAA study (2002). From 1955-2000 occasional weather events caused damages (in constant 1995 dollars) in the tens of millions of dollars. Damages in the hundreds of millions of dollars also occurred over this time period. By far the two years with the highest damages were 1997 and 1993. The floods of 1993 caused damages in excess of $1 billion in constant 1995 dollars. During the 1990s there were 14 presidential declarations of major disasters. Most of the damages were the result of flooding, ice storms, snow removal, straight-line winds, tornadoes, and heavy rain (MN Department of Public Safety's Division of Homeland Security and Emergency Management). From the disasters of the 1990s, Minnesota taxpayers spent $827 million and the cost to insurance companies was more than $2 billion.

Water Quality: There is a great deal of evidence that water quality is extremely important to Minnesota. The value of water quality is manifested in recreational and tourism activities, property values for lakeshore, investments in policies to protect water, and other ways in which citizens demonstrate WTP and the role of water in the MN quality of life. The evidence of historical trends on water quality in MN lakes yields mixed results, with general trends toward improving water quality measures (see Appendix F, LCCMR 2005 report). It is difficult to isolate potentially negative impacts of climate change on lake water quality from the backdrop of other complex processes that are having a net positive effect.

If climate change has a negative impact on thousands of lakes within the state, the loss of economic value would be substantial. These assets (natural capital) would be much less valuable to MN than they otherwise could be under static climatic conditions. For a thousand lakes that might be degraded from climate change, the loss could be in the tens of billions of dollars. (Krysel, et al. 2003). It is difficult to predict the exact trajectory of water quality changes across all lakes due to complex, often non-linear responses to multiple and interacting stressors; however, the evidence in the literature indicates climate change is likely to have a negative net effect (See Appendix C).

Ice Duration: Ice duration is getting shorter in the state (Appendix F, this report). The trend analysis indicated that ice-duration has on average been getting shorter by a third of a day in a typical year, or 3.3 days over the course of a decade for the past 35 years, and 1.44 days per decade over the past 60 years. A direct socio-economic impact of shorter ice duration will be the switch of recreational days for ice-related activities to open-water activities. Certainly activities such as ice fishing and skiing which are dependent on ice and snow are likely to suffer based on climate evidence. Changes in fish species distribution and abundance will enhance the fishing experience for some anglers and detract for others. In addition, there is an important linkage between ice-on/ice-off periods, limnological conditions/water quality, fish habitat and species distribution/abundance (Appendices K, L, M).

Creel survey data includes variables on the time respondents spent fishing, catch rates and other aspects of the fishing experience. Shorter ice duration can reasonably be expected to diminish the benefits the public enjoys from ice fishing. Since some MN lakes, most notably Upper Red Lake, see higher use in winter months, the onset of climate change through decreasing lake ice will likely have a net negative impact on recreational benefits from use of these lakes.

Seasonal patterns of use were examined for other large walleye lakes in the state. These generate a very large portion of the overall fishing activity in the state. In contrast to Upper Red Lake, other large walleye lakes (and statewide data for smaller lakes) show that summer effort significantly exceeds effort in the winter. A higher amount of angler effort in the open-water season is likely to lead to a net positive impact from the onset of climate change, unless water quality is degraded to the extent that fish communities are negatively impacted.

An additional empirical question investigates whether changes already occurring in species distribution and abundance are leading to changing patterns of fishing effort. The results from the multiple regressions (see Appendix B) did not show significant results for a change in yield per unit of effort in response to change in species abundance over certain regions of the state over time (Appendix B; this report). Nor did they indicate increasing effort thus far in areas where yields might be expected to increase in the future as certain species become more abundant. As mentioned in the literature (Johnston, et al 2006) certain species, such as trout, have a higher WTP than walleye and panfish. Therefore, a change in these species abundances could have a significant impact on the WTP by anglers. For example, fewer trout (which are predicted to decline from climate change) would be detrimental to recreational benefits. The net impact from these changes in species abundance and the economic consequences cannot be estimated given current limitations of available data.

Further Conclusions

The relative emphases of the economic analyses and the empirical estimation are dependent upon the findings of the other environmental components of this research effort. To a certain extent, the findings on environmental impacts at this juncture are predicated on available data that are constrained in both temporal and spatial scale. So while evidence is mounting that Minnesota's water resources are vulnerable to the effects described in this report (higher surface water levels/streamflow, increased sedimentation, degraded water quality, infrastructure implications) some of the more extreme impacts anticipated at the global or regional scale are difficult to detect statistically at the smaller statewide scale. This is due in part to lack of small spatial scale data over the length of time needed to detect statistically meaningful trends.

MN should adopt a two-pronged approach to risk management to the degree that MN can inventory watersheds for the combination of two groups of characteristics. A convergence of two characteristics that cause greatest vulnerability to damages from flash floods should be inventoried. Watersheds most vulnerable to transportation infrastructure damages have:1) geomorphology conducive to flash floods and 2) human and natural environments that put highly valued assets and human life in harm's way.

See Appendix A for a the complete report on the economic impacts of climate change due to changes in water levels and flows and shorter duration of ice cover in Minnesota's lakes.

Johnston, R. J., M. Ranson, E. Besedin, and E. Helm. 2006. What determines willingness to pay per fish? A meta-analysis of recreational fishing values. Marine Resource Economics 21(1): 1-32.

Categorization of economic impacts by market and non-market values (see Appendix B).
Rabi J. Vandergon
Bemidji State University

Global climate change has recently come into popular light and is becoming widely accepted as a problem that must be addressed for a wide variety of reasons. This study provides an in-depth analysis into the impacts that global climate change may pose to Minnesota fisheries and recreational anglers. The literature review covers a range of topics from biological impacts on recreational fisheries to economic impacts. **The main goal of this study is to determine what impact climate change may pose to recreational benefits provided by the activity of angling.** Creel surveys from the Minnesota Department of Natural Resources Creel Database were utilized to determine statewide angler effort and preferences for certain species. Lake ice duration observations were gathered to determine current trends and future projections. These data were utilized and combined with fishing valuation literature to determine an economic impact from climate change. Lake ice duration is significantly decreasing statewide (Appendix F), extending the open water fishing season. Since more anglers fish during the summer months, this could lead to a net economic gain. On the other hand, bodies of water such as East Upper Red Lake seeing more anglers during the ice-fishing season could potentially see an economic loss. The project also utilized creel surveys to test the hypothesis indicating a statewide decline of trout species and northeastern shift of largemouth bass and sunfish from the onset of climate change (Appendix I). A multiple regression was performed on historical creel data to determine if there was a change in effort over time across different climate regions by species group. These variables were tested to determine their influence on the amount of fish caught. The regression indicated a positive relationship between the amount of effort and the amount of yield, but effort does not yet appear to be shifting regionally in response to climate change predictions. See Appendix B for a full description of this set of analyses.

Rabi Vandergon completed his masters of science in Environmental Studies in April 2010 at Bemidji State University with his thesis titled “Economic Impacts of Global Climate Change on Minnesota Fisheries through Decreases in Lake Ice” (see Appendix B).

Literature Review: Economic estimates for infrastructure and water quality impacts (see Appendix C).
Rabi Vandergon, Patrick G. Welle
Bemidji State University

An annotated bibliography for the economics of climate change and environmental quality was completed December 2008 (see Appendix C).

Result 2: Future Climate Projections for Minnesota.

Description: We propose to construct a database of possible climate scenarios (including temperature and precipitation patterns, frequency of extreme events, drought and flood episodes) that Minnesota may experience over the next 50 years. Scenarios will be constructed from observed episodes including cooler and wetter conditions at the end of the last century, warmer and drier conditions from the 1930s, and drier conditions from the 1950s. Trend and frequency analyses of historical data will guide the scenario selection. From climate projections we will develop projections of hydrologic and water quality responses of lakes and streams. Outcome: A database of temperatures, extreme events, flood and drought episodes, and physical responses likely to determine the character of Minnesota's water resources over the next 50 years.

Summary Budget Information for Result 2:		
	Trust Fund Budget:	**$ 47,017**
	Amount Spent:	**$ 47,017**
	Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. Climate data access system	December 2007	$14,672	Complete
2. Definition and analysis of climate regimes	June 2008	$14,672	Complete
3. Projection of climate regime scenarios to 2050	December 2008	$14,673	Complete
4. Model ice-out dates	December 2009	$ 3,000	Complete

Completion Date: *June 30, 2010*

Final Report Summary:

Climate data access system (see Appendix D, part 1).

Richard Skaggs[1], Kenneth Blumenfeld[1], James Zandlo[2]
[1]University of Minnesota, [2]Minnesota Department of Natural Resources, State Climatology Office

The climate data retrieval tool, developed by the State Climatology Office, was essential to all climatic research undertaken in this project, because relating climate data to aquatic ecosystems and hydrology is a complex undertaking: different species have different critical and optimal climate conditions that vary geographically and through time, and the hydrologic implications of climate vary with the local topography. Thus, climate summaries must be tailored to the specific questions and locations of interest. The climate data retrieval tool enabled project participants to extract climate variables important to their own specific questions, at time and space scales they deem relevant. While the climate data retrieval tool is available to project investigators only at the present time, the Office of the State Climatologist plans to make it available widely to Minnesota resource managers and researchers at the conclusion of the second phase of this project.

The climate data retrieval tool has two major components—a climate scenario visualizer and a climate time-series generator. The climate scenario visualizer uses monthly climate data and allows researchers to examine two climate variables of interest simultaneously, over an area or spatial unit of the investigator's choosing, including point locations, lakesheds, major and minor ecoregions, river basins, counties, climate divisions, and the entire state. Data can be viewed in the native monthly form, or aggregated into user-defined "seasons," such as November through March, or the "water year" of October through September.

For the spatial unit and month or season selected, the visualizer ranks the climate variables from lowest to highest and plots them on a graph. This allows to the investigator to determine which years match some important combination of the two climate variables for a particular location or area. For example, the investigator can isolate the years that were in the warmest and driest 10 percent during May through September over the Cottonwood River basin. Further details on using the visualizer, including example queries and the resulting images, are included in Appendix D.

The time-series generator extracts climate time series data for point locations in the state. The location is specified by the user, and the data can be summarized in many different ways. Once again, a user-defined season can be specified, along with the starting and ending years if the entire record is not wanted. For example, the cooling degree days for Roseville can be obtained by asking for the total or average degree days above 65 Fahrenheit for ZIP code 55113 from 1890 to the present. More detailed examples are provided in Appendix D.

Definition and analysis of climate regimes (see Appendix D, part 2)
Kenneth Blumenfeld, Richard Skaggs
University of Minnesota

Identification of historical climatic episodes was obtained by statistical analyses of monthly temperature and precipitation values for climatological divisions of Minnesota. Over the past 100 years, approximately half the years have experienced at least one multiple-month period of extreme temperature and/or precipitation. Here, an "extreme" is defined as a value of temperature and/or precipitation that is at least one standard deviation above or below the average during the season of interest. More specific results include the following:

- simultaneous wet/warm, and also cool/dry regimes are uncommon, especially during the growing season and summer
- warm regimes tend to be dry or have near-normal precipitation
- wet periods tend to be cool or near-normal
- dry periods tend to have warm or near-normal temperatures

Detailed statistics and results for a variety of seasons over Minnesota's nine climatic divisions are given in Appendix E.

Projection of climate regime scenarios to 2050 (see Appendix E).
Richard H. Skaggs
University of Minnesota

Introduction: Projections the climate of Minnesota for the remainder of this century must be rather general and include rather large uncertainties. In light of the resources available this report presents two projections. The first is of temperature, precipitation, and soil moisture on a monthly time scale for four points representing the northwest, northeast, southwest, and southeast climatological division of Minnesota. The data are part of the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset and are bias-corrected and spatially downscaled climate projections, which were obtained from the CMIP3 data The specific GCM used is the GFDL CM2.1 as run under the A2 (business as usual) scenario for CO_2 change over the century.

The second projection uses the GFDL CM2.1 A2 and B1 (rapid control of CO_2) scenarios but for daily data for a grid point that is located close to the Twin Cities metropolitan area. These data are used to estimate projected changes in maximum daily precipitation, annual maximum daily temperature, and annual minimum daily temperature for 10-year and 100-year return periods. The results are based on the generalized extreme value (GEV) distribution. The daily data are not bias-corrected. And it is likely that there is residual bias in the monthly data. Therefore, projected changes and not absolute values are presented for both the monthly and daily data analyses. The monthly temperature and precipitation data are time averaged over three periods: 1950-99, 2000-49, and 2050-99.

Results: It is clear that the temperature change will be greatest in the second half of the 21st century. Monthly temperature increases in the 2000-49 period are generally less than 2 degrees Celsius and generally well above 2 degrees Celsius in the second half of the century. There is an annual cycle of the monthly temperature increases with the largest increases occurring in the late summer and in the winter. The late summer temperature increases are larger than the winter increases in the southern part of the state but in the northern part of the state the two increases are comparable in magnitude. The late summer peak in temperature increase is very important when combined with the projected changes in precipitation.

Changes in precipitation are shown as percent change. Precipitation is projected to increase in most months with peaks of increase occurring in the late fall and early winter and in the spring. However, the months of July, August, and September are projected to have precipitation decreases or little change, which is crucial when combined with the temperature increase peak in the same months. In general, the projected precipitation changes are larger in the second half of the 21st century. Also the projected precipitation changes appear to be more erratic than the projected temperature changes. It is likely that using percent change is partially responsible, but it also the case that GMCs have a much harder time projecting precipitation.

The combination of the projected late summer increases in temperature and decreases in precipitation is crucial for soil moisture. The higher temperatures imply larger amounts of water loss (evapotranspiration) at the same time water supply is reduced. With rare exceptions, soil moisture is projected to decrease throughout the year. And the soil moisture decreases in the late summer are projected to be very large. In general, the soil moisture results demonstrate that the projected increases in precipitation are well short of what are required to offset the projected temperature increases and the associated projected increases in evapotranspiration. The soil moisture changes are shown as constant for four to six months depending on the location, scenario, and time averaging period, as the result of frozen soil.

While these monthly analyses are instructive, they do not provide insight into combinations of months into important seasons. For a look at seasons, we analyzed mean seasonal temperature and total seasonal precipitation for each year, for the two seasons of summer (June, July, and August) and winter (November through March), for the four climatological divisions, and for two carbon dioxide scenarios A2 (business as usual) and B1 (rapid emissions reductions). Twentieth century means and standard deviations were then calculated. Five categories of temperature and precipitation were constructed for each climatological division and season based on standard deviations from the mean as indicated in table 1.

Table 1. Five categories of temperature and precipitation.

Limits	Temperature	Precipitation
-2 sds or greater below the mean	very cold	very dry
-1 to -2 sds below the mean	cold	dry
-1 to +1 sds around the mean	normal	normal
1 to 2 sds above mean	warm	wet
2 sds or more above the mean	very warm	very wet

For each division and season the value of the boundaries of these categories were determined and the output of the A2 and B1 scenarios results were compared with the critical values to produce a frequency count of seasons in each category, season, and division in 50 year increments from 1950 through 2100

Conclusions drawn from analyses include:

- After removing the bias the models reproduce the 20th century temperature and precipitation regimes, as the second half of the century is well known to have been slightly warmer and wetter.
- The summer temperatures in the 21st century, especially in the last half, are projected to be much warmer for all divisions with most of the summer seasons being in the 20th century category of very warm.
- The winter temperature also are projected to be warmer but not to the degree of summer temperatures.
- Precipitation will not change to the degree that temperature changes; the changes are toward slightly wetter conditions but not significantly so.
- The largest changes in both temperature and precipitation occur in the second half of the current century.
- The combination of much high temperatures and little change in precipitation imply that summers will be much drier than was experienced in the 20th

century leading to a reduction in lake volume and stream flow and an increase in moisture stress for plants.

Daily Data Analyses: The GFDL CM2.1 daily data are for the period 1961 through 2099. Daily time series of maximum temperature, minimum temperature, and precipitation were acquired for the A2 and the B1 scenarios. The total time period was divided into segments: 1961-2000, 2000-49, and 2050-99. Within each time segment and each scenario, time series of the maximum temperature each year, the minimum temperature each year, and maximum daily precipitation each year were extracted. The GEV distribution was fit to each of the 18 time series. Results are expressed as changes rather than absolute values because the input data from the models are biased. The 24-hour, 10-year and 100-year return period maximum daily precipitation for the A2 and B1 scenarios are presented. But it is clear that the absolute values for the 1961-2000 base period are underestimates by nearly 50 percent. Thus it is necessary to focus attention on the percent increases, which range from about 1 percent for the B1 10 year return period to about 24 percent for the B1 100 year return period. The full 20th century records for annual maximum temperature, annual minimum temperature, and annual daily precipitation were analyzed by fitting the GEV to the appropriate annual time series. The differences were then applied to the results for the observed 20th century.

Summary

The broad outlines of the likely climate of Minnesota over the remainder the 21st century as projected by a particular GCM (GFDL CM2.1) seem relatively clear. The temperature will be warmer especially in the second half of the century and the late summer and winter. Precipitation will increase marginally except in the late summer. The combined temperature and precipitation changes likely will lead to decreases in available soil moisture and a general drying of the climate. The magnitude of maximum temperature extremes will increase while the coldest days are likely to be warmer. Precipitation in extreme events such as the 100 year storm will be larger.

Details of these analyses are presented in Appendix E.

Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy (2007). Fine-resolution climate projections enhance regional climate change impact studies', *Eos Trans. AGU, 88*(47), 504.

Model ice-out dates
Virginia Card
Metropolitan State University

Modeling of lake ice cover was completed in August 2009, and thus the results for both the LCCMR Climate Change Phase I and LCCMR Climate Change Phase II (LCCMR2007: this project) were reported in the final report for LCCMR2005 project: Impacts on Minnesota's aquatic resources from climate change Phase I - W-12. Below is a description of the ice-out modeling completed and available for use in other results. These data have been used for economic analyses, fish community and spawning responses, more in-depth analysis of statewide trends in ice-out date, and development of indicators.
Observational records of lake ice-cover were collected from across the state from a variety of sources including observers, newspapers, the Minnesota Department of Natural Resources, the Minnesota State Climatology Office, and the Minnesota Pollution Control Agency Citizens Lake Monitoring Programs, assembled into database form, checked for errors, and analyzed. This data set now includes more than ten thousand individual reports of ice-cover break-up, from 65 of Minnesota's 87 counties, from more than 1,400 lakes– approximately 1% of all lakes in Minnesota. Most of the ice-cover records are short, spanning an average of 6 or fewer years per lake, but many of the records are long or very long, including more than 120 lakes with records 21 years long or longer.

A set of 106 lakes was selected for further analysis, each of which had, in addition to ice-cover data, both long-term water quality and gill-net fish data, including at least 15 years of water quality data with at least 1 record in 1970s or before, and at least 8 years of gill-net fish data including at least 1 record in 1970s. This set includes 29 lakes with fisheries data from 1948-50 or earlier, and 23 lakes with water quality data from 1948-50 or earlier. From this set of 106 lakes, 75 lakes had either complete ice-out records for the period 1948-2008, or sufficient observational ice-out data to permit a complete record to be re-constructed for the period 1948-2008.

Ice-out records were checked and reconstructed using an empirical numerical model. Many ice-out records include occasional missing years in an otherwise continuous record. The empirical neighbor-comparison model used for this project is based on the principal that for any pair of neighboring lakes in the state, the ice tends to go out later on one than the other; in general, for any two lakes of similar depth and size, the lake to the north goes out later. This model compares the ice-out records from pairs of lakes are compared, calculates the exact relationship for years in which there are ice-out observations for both lakes, and uses this relationship to predict the ice-out date for each year in which the neighboring lake has an ice-out report. These predictions are made using a selected set of 6-10 lakes, generally with 50 km of the target lake, and the average of those predictions is used as the final modeled date. For the target lakes in this study, the dates produced by the model have average difference of less than 2-3 days, when compared to observational dates.

Error rates in historical records of lake ice-cover, due to observational, typographical and other sources, are within this same range or 2-3 days. Error rates in the ice-out records were assessed in three ways: by comparison of ice-out records from one lake by two or more independent observers; by comparison of multiple redactions of the same record; and by comparison of each year of a very long ice-out record to contemporary reports of ice-out dates from archival record at the Minnesota Historical Society. Overall, error rates in historical ice-out reports were found to be very low: untrained individual observers tend to differ in their report of ice-out date by an average of 1-2 days each year, and errors introduced during transcription tend to occur at a rate of about 1 per 20 dates, with an average error of about 2-3 days. The data set collected by the CLMP program of the MPCA has a very low error rate overall, the result of efforts that include providing a program definition of 'ice-out' and 'ice-in', regular annual collection of observations, and provision of a mechanisms for observers to do their own checking of the data entered into the CLMP data set.

The trend in ice out has been towards earlier dates, with the average loss of ice cover being 3-4 days earlier than 35 years ago. These ice-out records and the results of the modeled and error analysis were provided to other project- members, for use in analysis with regard to climate scenarios, fish populations, water quality, and economic impacts.

Ice-out timing trend analysis for Minnesota lakes 1948-2008 (see Appendix F)

David Staples[1], Lucinda Johnson[2], Dan Breneman[2], Virginia Card[3]
[1]Minnesota Department of Natural Resources, [2] Natural Resources Research Institute, University of Minnesota Duluth, [3] Metropolitan State University

One of the most obvious changes that can be attributed to changing climate is the shift in the seasonal patterns associated with lake ice formation and disappearance. Ices out dates are captured from a range of sources, including citizen monitoring in recent years. Virginia Card has assembled the historic ice out data for Minnesota lakes (see above), and has developed regression models to predict ice out records for neighboring lakes. A detailed examination of the observed and modeled ice out data are presented below, in an attempt to establish patterns in the geographic distribution of ice out patterns across the state, and with respect to lake characteristics (area and depth). Details of analyses are presented in Appendix G.

Methods: Data from 71 lakes in MN were used to show trends in both observed and modeled ice out dates. To account for repeated measures of lakes over time and correlated annual variation in ice out date among lakes, we used a mixed model (Venables and Ripley, 2002) to estimate the temporal trend in ice out date using the *lmer* function from the lme4 package in version 2.8.1 of the R statistical program (R Development Core Team, 2008).

The model was fit with the observed and modeled data separately, both models had practically identical trend estimates and very similar variance estimates as the model fit to the full data set, confirming no differences between the observed and modeled ice out data; all results shown below reflect the full data set with observed and modeled data combined.

Results: There was a significantly negative estimate of the fixed trend in ice out date; ice out dates were 0.144 days earlier per year, which translates to ice out happening about 1.4 days earlier per decade (Figure 1). The average ice out date, excluding random year effects, for the earliest measurements (1948-1950) was approximately the 111th day of the year. There was large variation among lakes (σ_L = 7.29 days) which represent the large variation in climate and lake morphologies across the state; however, when compared to spatial location (UTM coordinates) there did not appear to be a spatial pattern in the random lake effects.

There was a slight difference in the geographic pattern of the predictions in which more southerly points tended to ice out earlier than predicted and northerly points tended to be a little later than predicted. When accounting for north-south variation, the North-South predictor variable was highly significant suggestions that going North 1 km makes ice out tend to be .6 days later per decade. Over the course of the study period this would mean that southern lakes now lose their ice an average of 3.6 days earlier than southern lakes. No significant trends were apparent in the ice out patterns with respect to lake area or depth when geographic trends were also included in the models.

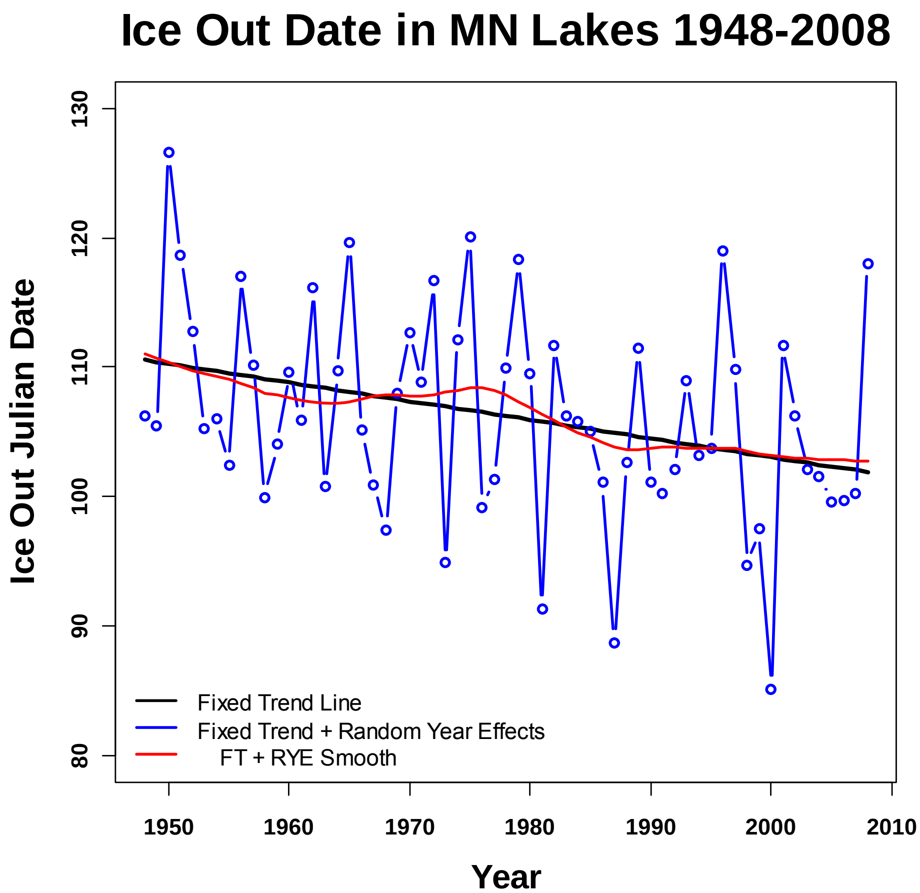

Figure 1. The fixed ice-out trend and year effects (added to show the annual deviations about the trend), in additional to a smooth fit of the trend plus year effects. This trend represents a decline in cie cover of 1.44 days per decade since 1950.

Result 3: Projecting Biological Responses to Changing Climate

Description: Fish populations and other biological communities will be affected by warmer water temperatures, and altered thermal regimes, changes in flow regimes, total flows, water level, and water quality. These changes will affect the health of aquatic ecosystems, with impacts on productivity, species diversity, and species and predict biological responses to climate change. However, data for physical properties such as hydrology and water quality are more abundant, and their responses to future climate scenarios can be modeled**.** We will use the historic trend data for biological communities, stream hydrology, lake level, and lake water quality data from our Phase I LCCMR Climate Change project and Result 2 (future MN climate predictions) of this proposal to predict invertebrate and fish population responses in Minnesota's rivers and lakes and make generalized projections across the state. Outcome: Projections of aquatic invertebrate and fish community responses to climate change scenarios from Result 2 using appropriate physical models.

Summary Budget Information for Result 3:	**Trust Fund Budget:**	**$ 94,931**
	Amount Spent:	**$ 94,931**
	Balance:	**$** 0

Deliverable	Completion Date	Budget	Status
1. Hydrologic and physical models predicting responses to future climate scenarios	June 2009	$19,879	Complete
2. Fish community responses to future climate	December 2009	$25,934	Complete
3. Water quality responses to future climate	June 2009	$24,558	Complete
4. Invertebrate responses to future climate	December 2009	$24,560	Complete

Completion Date: *June 30, 2010*

Final Report Summary:

HYDROLOGIC AND PHYSICAL MODELS

Annual stream runoff and climate in Minnesota's river basins (see Appendix G).
Todd R. Vandegrift, Heinz G. Stefan
St. Anthony Falls Hydrologic Laboratory, University of Minnesota

Stream flows recorded by the USGS from 1946 to 2005 at 42 gauging stations in the five major river basins of Minnesota and tributaries from neighboring states were analyzed and related to associated climate data. Goals of the study were (1) to determine the strength of the relationships between annual and seasonal runoff and climatic variables in these river basins, (2) to make comparisons between the river basins of Minnesota, and (3) to determine trends in stream flows over time. Climatic variables were air temperature, precipitation, the Palmer Drought Severity Index (PDSI), and the Palmer Hydrological Drought Index (PHDI); the latter are common indices of soil moisture.

Results: Water year averages showed stronger correlations than calendar year averages. Precipitation was a good predictor of stream flow, but the PDSI was the best predictor and slightly better than PHDI when linear regressions at the annual timescale were used. With an exponential regression PDSI gave a significantly better fit to runoff data than PHDI. Five-year running averages made precipitation almost as good a predictor of stream flow (runoff) as PDSI.

A seasonal time scale analysis revealed a logical stronger dependence of stream flow on precipitation during summer and fall than during the winter and spring, but all relationships for seasonal averages were weaker than for annual (water year) averages. Dependence of stream runoff on PDSI did not vary significantly by season. On a monthly timescale the strength of correlation between precipitation and runoff dropped off significantly, while PDSI was still a decent predictor in all months but the spring.

Annual stream flow in the Upper Mississippi River basin, including the Minnesota River basin, had the strongest dependence on precipitation and PDSI. The Red River of the North basin showed lower than average dependence on precipitation and average dependence on PDSI. The Rainy River basin and the Lake Superior basin showed the weakest dependence of annual stream flow on precipitation and PDSI.

The relationship between stream flow and precipitation can be expressed most easily by an annual average runoff coefficient, i.e., the ratio of runoff to precipitation in a year. Runoff coefficients vary significantly across the state of Minnesota, from more than 0.4 in the northeast to less than 0.1 in the northwest. Trends in runoff coefficients were estimated from averages for 20-year periods from 1926-1945 to 1986-2005, although data for 1926-1945 were sparse. According to our analysis, runoff coefficients in some of the major river basins of Minnesota have increased significantly during the last 40 years.

The Lake Superior and Rainy River basins have high and invariant characteristic runoff coefficients around 0.35. The Red River basin has the lowest characteristic runoff coefficient at ~0.14 but its value has consistently increased from the beginning of the record. The Mississippi Headwaters basin characteristic runoff coefficient has increased to ~0.24. The Minnesota River basin runoff coefficient (from the Minnesota River at Jordan, MN station) has also increased significantly and consistently to 0.19. The largest increases in runoff coefficients were found in the Red River and the Minnesota River basins, the two basins with the lowest runoff coefficients; runoff coefficients in some tributary or sub-watersheds have doubled. In the Lake Superior and Rainy River basins, and in the St. Croix River watershed, little change in runoff coefficients was found.

Overall runoff coefficients drop significantly from east to west in Minnesota. This distribution does not seem to have changed over time. Increases in runoff coefficients over time have been highest in the west, and lowest in the east of Minnesota. One can hypothesize that changes in stream flow in Minnesota's west are mainly due to land use changes that have lead to faster and easier surface runoff from the land since the beginning of European settlement. An explanation based on climatological factors can, however, also be offered. Precipitation has increased in all of the river basins of Minnesota over the time period of 1926 to 2005, but the largest changes have occurred in the south and west and little change in the northeast of Minnesota.

Changes in total annual runoff (in/yr) between 1946 - 1965 and 1986 – 2005 increased at 38 of 42 stream gaging stations analyzed. Only 4 gaging stations, 3 in the Lake Superior and Rainy River basins showed decreases, with all being less than 3%. The largest increases in average annual runoff were at 19 gaging stations in the Red River and Minnesota River basins; at 17 of these, increases were from 60% to 132%, and at the remaining two stations the increases were 19% and 20%. The southern Minnesota watersheds with the largest increases in runoff also had the largest increases in precipitation.

Overall, stream flow, expresses as annual runoff (in/yr), has increased since the beginning of stream gaging in Minnesota and the Upper Midwest, although periods of substantially lowered stream flows have occurred, e.g., in the drought period of the 1930s. Not only has the runoff (cm/yr) increased, but runoff coefficients, i.e., the ratio of runoff to precipitation, have also increased. When viewed as a percent change of annual runoff, the largest stream flow changes have occurred in the western part and the lowest in the eastern part of Minnesota. Increases in absolute values of annual runoff, percent of runoff, and runoff coefficients have been quantified in this study.

Projecting the impact of climate change on coldwater stream temperatures in Minnesota using equilibrium temperature models (see Appendix H)
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Coldwater streams are valued because they provide unique habitat for coldwater fish such as trout, and other animal species. Water temperature is the most important characteristic of coldwater stream habitat. Stream temperature is controlled by the balance of the heat fluxes across the water surface and the heat fluxes across the sediment surface (groundwater inflow and conduction to the sediment). In this study, a modified equilibrium temperature model was developed for coldwater streams, including the effects of both climate and groundwater inflow on stream temperature. It gives an upper bound, and in some cases, good prediction of, daily average temperature based on climate conditions, riparian shading, stream width, and groundwater inputs.

The modified equilibrium temperature models developed in this study are intended to be applicable to stream-average (generic) analyses with minimal in-situ data on stream geometry, rather than for detailed analyses of individual stream reaches. Additional expressions are derived and tested for distances and times required to reach thermal equilibrium, and for diurnal temperature amplitude. For a small tributary stream with relatively uniform riparian shading (South Branch), the modified equilibrium temperature gave good predictions of daily average stream temperature. The modified equilibrium temperature model also gave good estimates of daily average stream temperature for the main stem of the Vermillion when riparian shading was averaged over sufficiently long distances.

The stream temperature models were then used to characterize the response of water temperatures in three Minnesota coldwater stream basins to two projected climate change scenarios. Two of the study streams, Miller Creek and Chester Creek, are located in Duluth, Minnesota and are primarily fed by upland wetlands. The third stream, the South Branch of the Vermillion River, is located south of the Twin Cities, Minnesota, and is primarily fed by shallow groundwater. Two climate change scenarios were run: the Canadian Global Climate Model (CGCM) version 2.0 for a doubling of atmospheric CO_2, and the CGCM version 3.1 A1B scenario.

A sensitivity analysis conducted with the modified equilibrium temperature model confirms that water temperature in coldwater streams varies strongly with riparian shading, stream width, and both groundwater inflow rate and temperature. This sensitivity of stream temperature to groundwater parameters needs to be taken into account in climate change studies, since groundwater temperatures are expected to rise with air temperatures.

Overall, water temperatures in the streams were projected to increase between 4 and 5°C for the CGCM 2.0 CO_2 doubling climate change scenario, and between 3 and 4°C for the CGCM 3.1 A1B scenario. These stream temperature increases are larger than temperature increases projected by previous climate change studies based on air temperature – stream temperature regression analysis (2 to 3°C). Estimated increases in source water temperatures of groundwater due to climate change contributed about 60% of the total stream temperature increase, and the remaining 40% were provided by increases in atmospheric heat transfer. The ratio of the stream temperature increment to air temperature increment was found to vary from 0.8 to 1.08, larger than the slope of the observed stream temperature versus air temperature relationship.

Increases in source water temperatures were therefore found to contribute significantly to the response of stream temperatures to climate change. For the streams in Duluth, wetland temperatures were predicted to increase 2.7 to 3.5°C, based on a separate, calibrated heat transfer model. For the South Branch of the Vermillion River, groundwater temperatures were assumed to match long term increases in air temperature, ranging from 4 to 5°C. These results suggest that source water temperatures need to be considered in predicting the response of stream temperature to climate change. More work is needed to characterize groundwater and other water sources for coldwater streams.

A detailed report on stream temperature responses to climate in Minnesota can be found in Appendix G.

FISH COMMUNITY RESPONSES

Changes in Minnesota fish species abundance and distribution associated with local climate and lake characteristics (see Appendix I, Chapter 2).

Kristal Schneider[1], Raymond Newman[1], Donald Pereira[2]
[1]University of Minnesota, [2]Minnesota Department of Natural Resources

We analyzed historical Minnesota fisheries lake survey data (gillnet and trapnet) for 34 lakes, each with 15 to 43 years of data, to determine if fish distributions and abundances were changing over time. We then analyzed trends to determine effects of local climate on fish abundance and to determine if lake characteristics influenced trends in catch-per-unit-effort (CPUE) over time. Seven fish species from three families showed the strongest trends: centrarchids (*Micropterus salmoides*, *Micropterus dolomieu*, and *Lepomis macrochirus*); ictalurids (*Ameiurus melas* and *Ameiurus natalis*); whitefish (*Coregonus artedi* and *Coregonus clupaeformis*). We used simple linear regression to analyze CPUE over time, and we regressed mean latitudes of species occurrence against year to determine if ranges were advancing northward or contracting. Linear regressions were used to analyze the relationship between fish species' CPUE by lake and the following 5 temperature variables: maximum 7-day max temperature, average annual temperature, average summer temperature, average winter temperature, and degree-days above 5°C. We used stepwise regressions to determine if variability in slopes of CPUE vs. year could be explained by lake surface area, maximum depth, latitude, or longitude, and ANOVA to determine if variability in slopes could be explained by Schupp's lake classes. Linear regressions of CPUE vs. year indicated that centrarchid abundance was increasing, black bullhead (*Ameirus melas*) abundance was decreasing, and other species were increasing in some lakes and decreasing in others. The ranges of all species were significantly advancing northward except smallmouth bass and whitefish. Regressions of CPUE versus air temperature showed that bass and sunfish were increasing in lakes as summer air temperatures increased, and whitefish were decreasing in lakes as air temperatures increased. Location, lake surface area, and lake class may explain some variability in slopes of CPUE versus year. In summary, temporal trends in the abundance and distribution of some centrarchids, ictalurids, and whitefish may be responding to climate change, and trends may be affected by lake characteristics. Detailed results can be found in Appendix K.

Kristal Schneider completed her masters of science in June 2010 at the University of Minnesota with her thesis titled 'Biological Indicators of Climate Change: Trends in Fish Communities and the Timing of Walleye Spawning Runs in Minnesota". Chapter 3 of her thesis addressed fish community trends and is summarized above. Chapter 2 of her thesis was included in the final report for LCCMR2005 project: Impacts on Minnesota's aquatic resources from climate change Phase I - W-12 and has been accepted for publication.

Trend analyses for species of concern: Analysis of CPUE data for walleye, cisco, and smallmouth bass 1970-2008 (see Appendix J.)

David Staples[1], Lucinda Johnson[2], Jennifer Olker[2], Dan Brenneman[2]
[1]Minnesota Department of Natural Resources, [2]Natural Resources Research Institute, University of Minnesota Duluth

In addition to expected changes in the ranges of fish species, abundance also is expected to change. Prior models have projected changes in the availability of cold water fish habitat (REF) in Minnesota lakes. We hypothesized that cold water fish species such as cisco (also known as tulibee) and other salmonids would decline in abundance, while cool and warm water species (walleye, smallmouth bass) would increase in abundance.

Methods: Abundance measured as gill net catch per unit effort (CPUE) on walleye (2203 lakes), smallmouth bass (465), and cisco (701) from Minnesota lakes were examined for trends during the period 1970-2008. To account for repeated measures of lakes over time and correlated annual variation in catch per unit effort

(CPUE) among lakes, we used a linear mixed model (Venables and Ripley, 2002) to estimate the temporal trend in CPUE using the *lmer* function from the lme4 package in version 2.8.1 of the R statistical program (R Development Core Team, 2008).

A mixed model has two components, a fixed effects portion and a random effects portion. In this case, the fixed effect portion was an ordinary linear regression of $\log_e$ CPUE+1 versus time:

$$CPUE_j = \beta_0 + \beta_1 * j + \varepsilon_j,$$

for $j = (-19, \ldots, 19)$ representing the years 1970-2008, and for residual error $\varepsilon_j \sim N(0, \sigma)$. The β_1 parameter represents the intrinsic growth rate of the population (assuming CPUE is proportional to abundance); if the β_1 parameter is greater than zero, abundance is exponentially increasing, and conversely, if the β_1 parameter is less than zero, the abundance is declining over time.

The above regression would be a satisfactory model for a time series from a single population; however, our interest is not just in CPUE trends for a single lake, we also wanted to estimate the large scale, statewide trend in CPUE for each species. To analyze the data at that level, we use time series from many lakes (e.g., over 2200 lakes for walleye); however, the joint analysis of multiple time series introduces correlations among the observations that could potentially bias the trend estimate. We accounted for these correlations with random effects for year and lake-specific trends, giving the mixed effects model for the CPUE value in year *j* at lake *i*:

$$CPUE_{ij} = (\beta_0 + b_{0i}) + (\beta_1 + b_{1i}) * j + \psi_j + \varepsilon_{ij},$$

where b_{oi} and b_{1i} are random adjustments to the intercept and slope terms for lake *i*, and were assumed to be distributed as $N(0, \sigma_{L0})$ and $N(0, \sigma_{L1})$ respectively. The ψ_j term accounts for correlations in CPUE measurements within year *j*. Note that using the random effects adds 3 variance parameters to the model; an equivalent fixed effects-only model would use thousands of parameters for to account for individual lake and year effects. Though b_{0i}, b_{1i}, and ψ_j are not estimated parameters in the model, we can derive unique predictors of the individual lake regression coefficients and year effects. These predictors are denoted as BLUPs for 'best unbiased linear predictors,' and can be used to determine annual deviations from the linear trend and to estimate CPUE trends in the individual lakes. For example, the terms (β_0 + b_{0i}) give the mean CPUE value for lake *i* in 1989 (excluding the random year effect), and the (β_1 + b_{1i}) terms give the trend in CPUE for lake *i*. We also used the lake BLUPs to evaluate differences in mean CPUE or trend over latitudinal, longitudinal, maximum lake depth, and lake geomorphic (lake area, depth) gradients.

Walleye (*Sander vitreus)***:** The overall trend estimate for walleye was slightly positive (0.0007), but was not statistically different from zero ($t = 0.52$; $p = 0.61$ on 37 df). The variation in mean $\log_e$(CPUE+1) among lakes had a standard deviation σ_{L0} = 0.65, and the standard deviation of individual lake trends was σ_{L0} = 0.019; BLUPs of individual lake trends varied from a 5% per year decline to a 5% per year increase. Of the 2203 lakes with walleye gillnet captures 10.1% (223 lakes) had per year declines greater than 1%, while only 12.9% (283 lakes) had per year increased greater than 1%; the remainder of the lakes (77%) had changes less than 1%, which could not be distinguished from no or flat trend. The annual variation about the fixed trend (i.e., random year effects) had a standard deviation $\sigma_Y = 0.074$ (see figure below for plot of fixed trend along with random year effects).

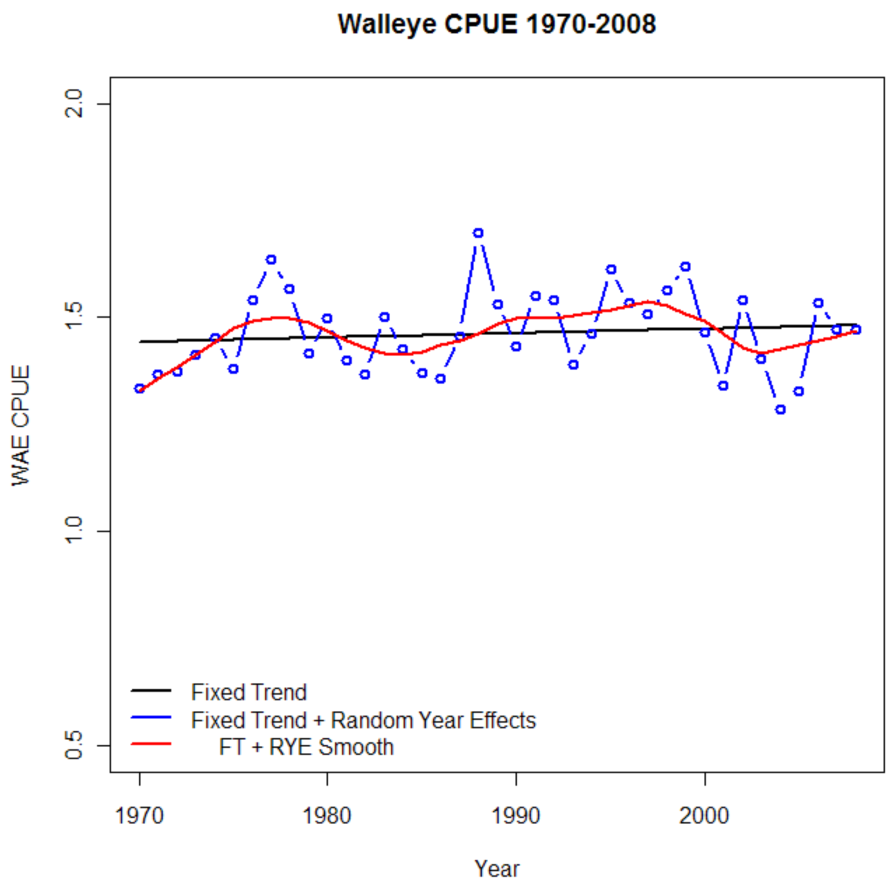

Figure 1. Average CPUE trend and annual deviations for walleye CPUE in 2203 MN lakes.

Cisco (*Corregonus species*): The overall trend estimate for cisco was significantly negative (-0.014, t = -5.28, p < .0001 on 37 df), indicating about a 1.5% per year decline since 1970. The variation in mean $\log_e$(CPUE+1) among lakes had a standard deviation σ_{L0} = 0.73, and the standard deviation of individual lake trends was σ_{L0} = 0.025; BLUPs of individual lake trends varied from a 5% per year decline to a 5% per year increase. Of the 701 lakes with cisco gillnet captures 63.9% (448 lakes) had per year declines greater than 1%, while only 4.4% (31 lakes) had per year increased greater than 1%. The annual variation about the fixed trend (i.e., random year effects) had a standard deviation σ_Y = 0.13 (see Figure 2 for plot of fixed trend along with random year effects).

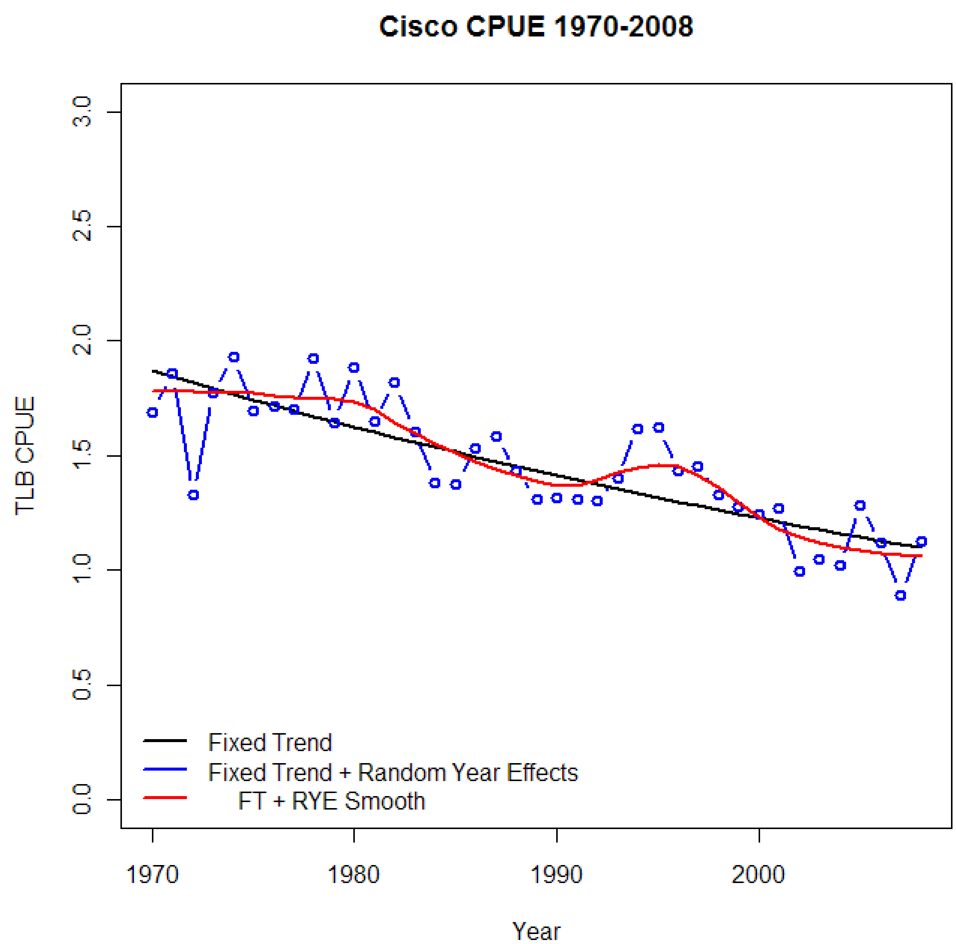

Figure 2. Average CPUE trend and annual deviations for cisco CPUE in 701 MN lakes.

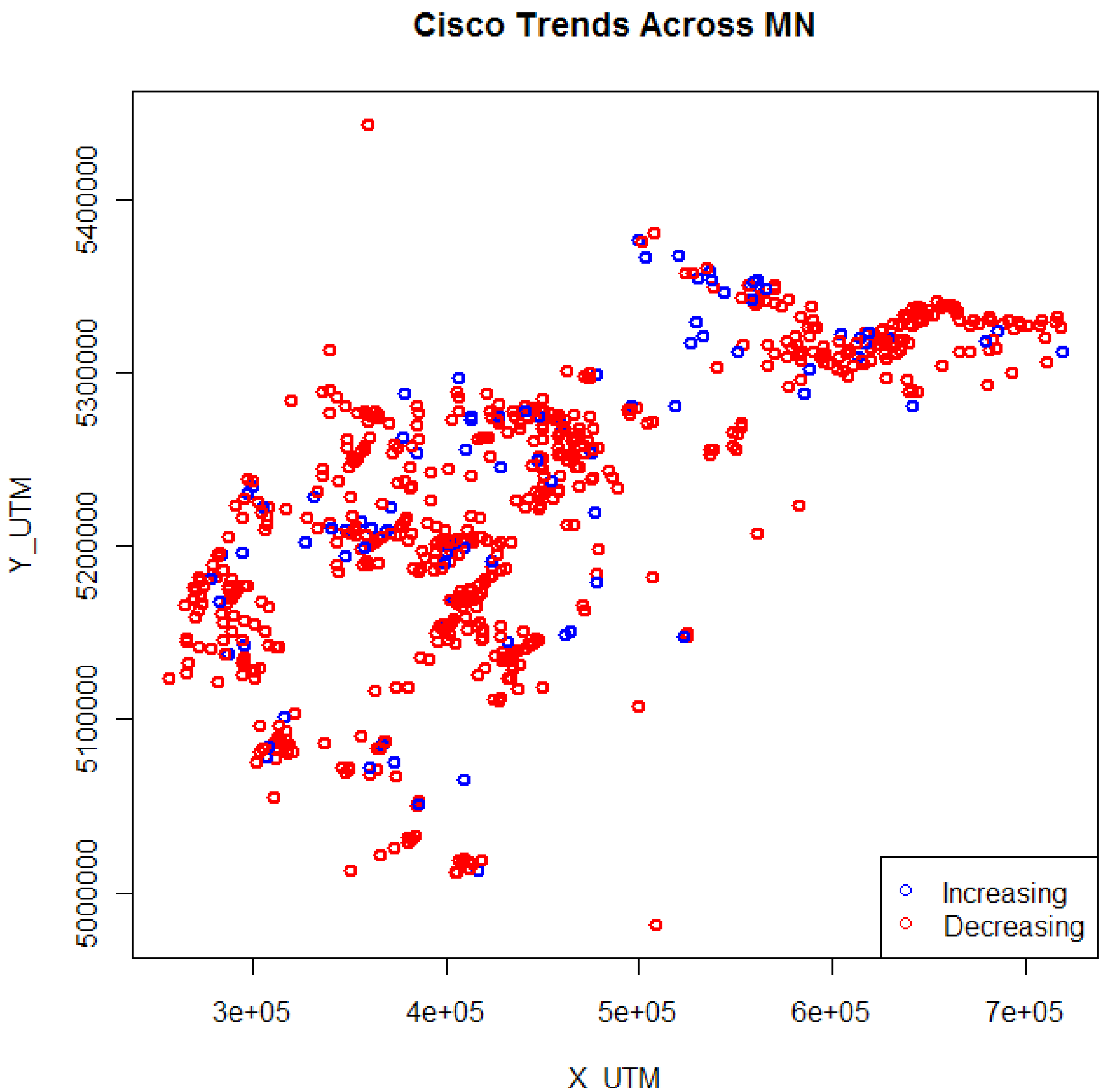

Figure 3. Spatial distribution of increasing and decreasing cisco lakes.

We did not detect a strong spatial pattern for increasing versus decreasing lakes (Figure 3). Nor did we detect any geomorphic relationship to increasing versus decreasing lakes or strength of decreasing trends. This is likely because the natural distribution of cisco includes deeper, coldwater lakes which mainly occur in the northern part of the state.

Smallmouth Bass (*Micropterus dolomieu*): The overall trend estimate for smallmouth bass was slightly positive (0.0006), but was not statistically different from zero (t = 0.35; p = 0.73 on 37 df). The variation in mean $\log_e$(CPUE+1) among lakes had a standard deviation σ_{L0} = 0.40, and the standard deviation of individual lake trends was σ_{L0} = 0.016; BLUPs of individual lake trends varied from a 4% per year decline to a 3.5% per year increase. Of the 465 lakes with smallmouth bass gillnet captures 6.7% (31 lakes) had per year declines greater than 1%, while 9.3% (43 lakes) had per year increased greater than 1%; the remainder of the lakes (84%) had changes less than 1%, which could not be distinguished from no or flat trend. The annual variation about the fixed trend (i.e., random year effects) had a standard deviation σ_Y = 0.067 (see Figure 4 for plot of fixed trend along with random year effects).

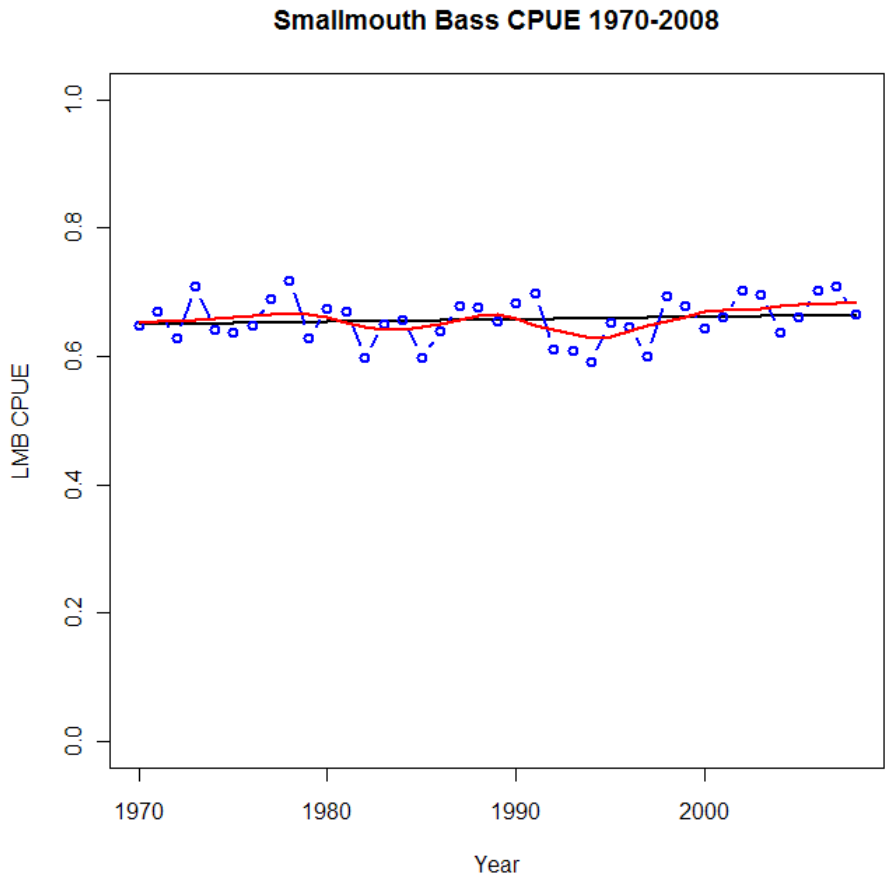

Figure 4. Average CPUE trend and annual deviations for smallmouth CPUE in 465 MN lakes.

We then plotted the average decadal abundance of four groups of fish adapted to different thermal regimes including cisco (coregonids), and trout (salmonids)), bullhead (ictalurids) and bluegill (centrarchids) for lakes which were shown to have surface water temperatures that were increasing at a greater than average rate (positive BLUPs; see below). These plots show a trend for large increases in centrarchid abundance, and a decline in coregonid abundance (Figure 5).

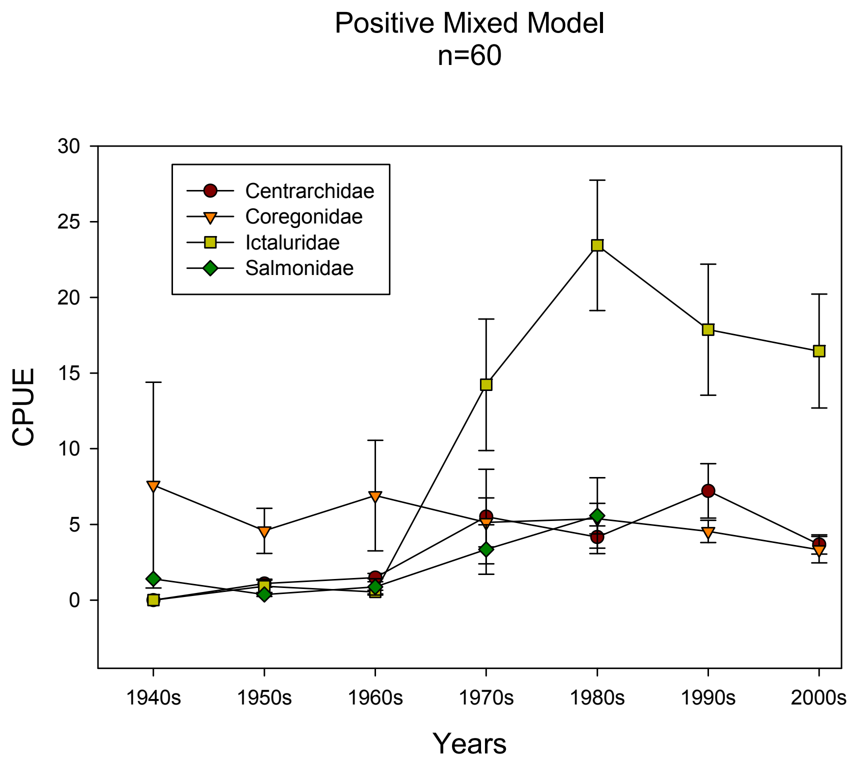

Figure 5. Fish assemblage changes in lakes showing a positive temperature trend based on results of the mixed model regression (60 lakes with long-term temperature records and fish abundance records).

Similar, but more exaggerated trends were observed for the 24 lakes with long term fish abundance data whose surface water temperatures showed significant positive trends based on the Mann Kendall analysis (see below).

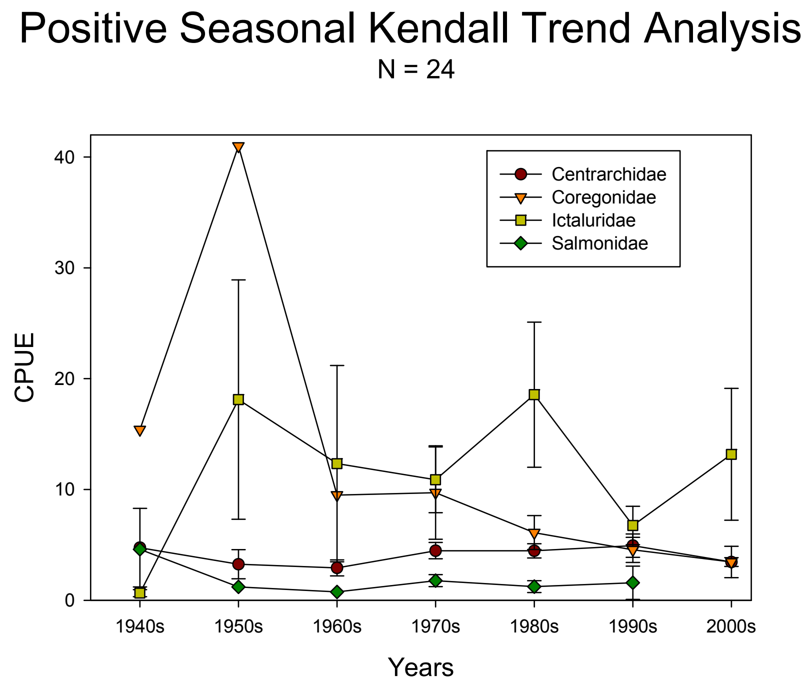

Figure 6. Fish assemblage changes in lakes showing a positive surface water temperature trend based on the Seasonal Kendall Trend analysis (24 lakes). See Appendix M for a discussion of these trend analysis data.

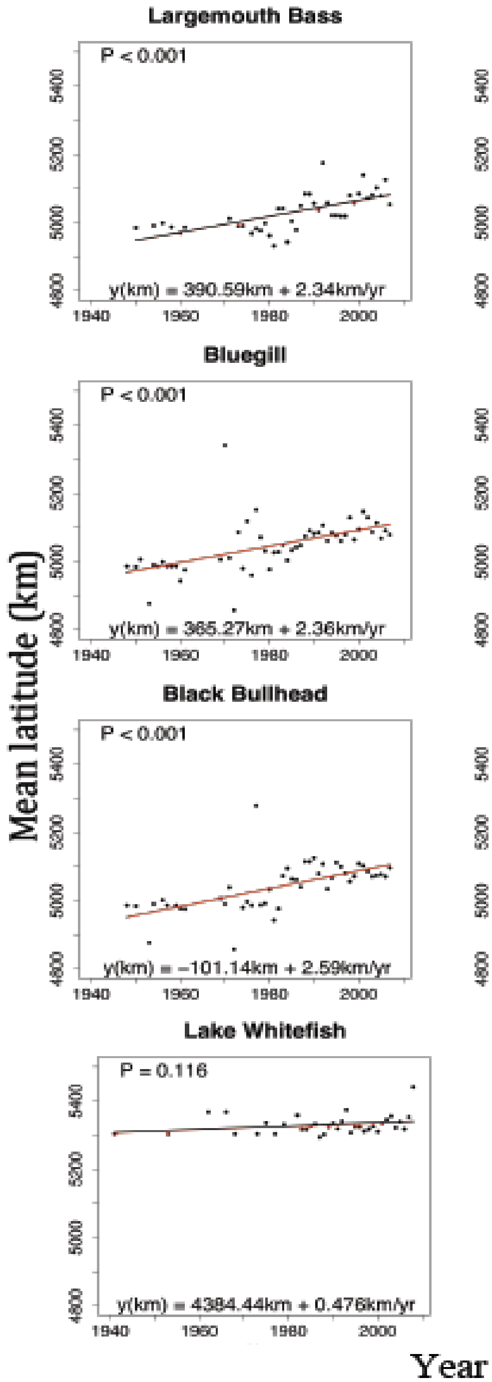

Figure 7. Changes in fish assemblages with latitude (from Schneider 2010). See Chapter 2 within Appendix I for a detailed discussion of these data.

WATER QUALITY RESPONSES

Water quality data was compiled, summarized and made available to project personnel as part of the LCCMR2005 project: Impacts on Minnesota's aquatic resources from climate change Phase I - W-12. The main accomplishments are summarized below but the full report is included in Appendix F of the 2005 project. Trends in water quality have been further analyzed with several methods, which are summarized below and detailed in Appendix K.

Lake water quality data

Richard Axler, Norm Will, Elaine Ruzycki, Jerry Henneck, Jennifer Olker, Joseph Swintek

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The focus of this effort was to:

1. Compile existing water quality data from lakes with long ice-out records to test for statistical associations;
2. Compile water quality data from lakes with >15 years of at least one water quality parameter and perform exploratory time trend analyses on all available parameters;
3. Develop an on-line Google-map based website for summarizing and presenting the results of the exploratory statistical analyses to allow other investigators to better visualize the data. The Water Quality Trend Tool would be a prototype for the Minnesota Pollution Control Agency and Minnesota Department of Natural Resources to consider for improving public access and understanding of lake water chemistry.

Mann-Kendall trend analysis

Trends and trend rates over time were determined using the Seasonal Kendall Trend Analysis software developed by the U.S. Geological survey that allow for trend analyses both seasonally and regionally. Sites were initially identified sites "Qualifying" if they had records from at least 5 different years and with a level of significance of $p < 0.1$ for either a positive or negative trend over time. Additional exploratory trend summaries with accompanying mapping tools were generated for $p < 0.05$ and < 0.01 and lakes having more years of data (5, 8, 12 and >18 years). Because of the large number of options for analyzing this broad data set, a comprehensive subproject website was constructed to make the trend results available to other project scientists and ultimately other interested individuals and groups (Minnesota Lake Trends Analyses website: (http://mnbeaches.org/gmap/trendswebsite). Google Maps TM-based tools were added for retrieving and displaying trend data including: a seaarch tool for lakes; ecoprovince, ecoregion and county boundary overlays; selection options for the long-term "Ice Out" lakes from this project and for the new DNR/MPCA SLICE (i.e., Sentinel) lakes. The website includes "processed raw" data, complete metadata, summary tables, links to Google Maps TM that identify sites with descriptive statistics, and graphs (box and whisker and regressions). The data are also incorporated into the larger project database that is now being used for more detailed examinations of climatic associations, geographic patterns, size and depth patterns, and associations with fish, and ice cover data.

Results: Thus far, the exploratory analyses have shown that for lakes with significant time trends during the period June–September, more than 90% showed surface water warming as compared to cooling. This result was found for over 26% of those lakes with at least 5 years of data (247 of the 551 lakes examined) and almost 2/3 of the 60 with 18 years or more data. Significant temperature trends were found in 37 of 60 lakes with 18 or more years of data. Of these, four flow-through lakes showed a negative trend in temperature, and 33 lakes showed positive trends. These lakes exhibited an increase of about 3°F over the period of record. Unfortunately, all of these lakes are clustered around the Twin Cities region, thus no trend is available for outstate lakes. Although only 16% of lakes with >5 years of data had significant trends in thermocline depth, 85% of those that did exhibited decreasing (i.e., shallower) thermocline depths. Thermocline gradient (stability) only showed statistically significant trends in 10-18% of lakes depending on the length of data record, but almost all trends were positive. Together these thermal effects over time suggest shallower, but more stable depth of stratification which is consistent with surface warming. The data also suggest that in those lakes, the hypolimnion (bottom most waters) could be more isolated from mixing of epilimnetic (surface waters) water although the population of lakes with such trends is relatively small. Trends in hypolimnetic water for two meter depth strata below a depth of 6 meters, showed the opposite effect with a preponderance of cooling trends. About 20% of the lakes having at least 5 years of temperature profile data had statistically significant trends and more than 75% of these exhibited cooling over time. This result is consistent with the surface warming and thermocline trends described above and the findings were similar whether there were 5, 8, 12 or 18 years of data.

Trend results were less clear for dissolved oxygen (DO). The number of positive versus negative trends in surface waters was similar although 60-75% showed increasing DO in the lakes with 12 to more than 18 years of data – an anomalous finding since one might have expected slightly decreasing DO due to warmer water. However, hypolimnetic strata for >20% of the lakes with available data showed significant trends with a clear (>75%) preponderance of increased DO.

The salt content of surface waters, as estimated by specific electrical conductivity (EC25), and chloride concentration has increased over time in more than a third of the lakes with >5 years of data, 50% of those with >8 years, and 90% with >18 years of data. This is consistent with increased summer surface warming but also with potential increased exposure to winter de-icing salts and/or increased stormwater runoff from either urban or agricultural areas. Increased loading to the whole lake such as would occur from runoff inputs are suggested by the fact that the trends with depth examined for the entire summer and for just the warmest month (July) all exhibited large (82-100%) predominance in increased relative to decreased salinity. Only ~15-19% of the lakes with >5 years of surface water pH data exhibited trends and there were roughly similar numbers of positives and negatives; only for the 37 lake data set having >18 years of data was there an excess in one direction - this being towards higher pH. This could potentially be a consequence of the Minnesota sulfate emission standards program but would need to be assessed on a lake by lake basis. Anomalously, alkalinity trends were overwhelming negative by > 80%: 20% for a substantial number of lakes and for all lengths of data records. We currently do not have an explanation for this rather striking result.

Perhaps the most surprising result found in this study was that there was internal consistency within the group of trophic status indictors (secchi depth clarity, chlorophyll-a, total phosphorus and total Kjeldahl nitrogen) that suggests an overall improvement in water quality. These trends were found for a large number of lakes- ~40% of the lakes in the secchi data set had statistically significant trends, and of these >80% were increasing (i.e., clearer water). This result was similar whether there were 5, 8, 12 or 18 years of data so the trend is nearly two decades old. We corroborated this result using an independent (software) Kendall statistical analysis for surface temperature, thermocline depth, secchi depth, surface chlorophyll-a, surface total phosphorus, and TSI-secchi data and also by cross-comparing our secchi trend rates with MPCA's estimates for CLMP lakes with more than 15 years of data. In both cases, the differences in results were negligible.

Overall, many lakes showed trends for many water quality parameters. However, it is extremely important to note that the current set of lakes is not distributed randomly across the state and is visually heavily biased towards the Minneapolis-St-Paul metropolitan area. More work is needed to examine individual lake records to see if these general trends are consistent for well monitored lakes. The analysis should also be extended to lakes with five or more years of data for parameters highlighted by this exploratory analysis since many of the trends found for longer data records were also significant when lakes were pooled with those with 5-8 years of data. There is also a need to calculate percent dissolved oxygen saturation as a "check" on some of the DO concentration results. Irrespective of temperatures in the upper mixed layer (epilimnion), most lakes would be expected to be saturated with oxygen in surface and near-surface water. This parameter was historically not calculated nor entered into STORET but could be calculated from DO concentration based upon corresponding temperature and EC25 values coupled with approximate lake surface elevation. As for other components of this overall Climate Change project, the exploratory analyses conducted to date point to the value and need for consistently collected environmental data over long periods of time for a large number of geographically distributed lakes in order to manage them most effectively.

Water quality responses during historical climate regimes (see Appendix K).

Richard Axler[1], Norm Will[1], Elaine Ruzycki[1], Jerry Henneck[1], Jennifer Olker[1], Lucinda Johnson[1], Kenneth Blumenfeld[2] Natural Resources Research Institute, University of Minnesota Duluth, [2]University of Minnesota

To detect the effects of extreme seasonal weather on water quality we used the water quality data and climate regimes (also called scenarios) summarized in Appendix E and reported in Appendix F of the LCCMR2005 project: Impacts on Minnesota's aquatic resources from climate change Phase I - W-12.

Methods: We used the following water quality indicators to test for responses in years with temperatures and precipitation outside of the ‘normal’ range: secchi depth, surface temperature, specific electrical conductivity (EC25), thermocline depth, trophic state index (TSI), surface levels of chlorophyll, and surface levels of phosphorus. Surface measurements included measurements from zero to two meters deep, with averages across these depths if both were recorded.

Each variable was tested independently over 3 different extreme weather cases: warm-wet, cold-wet and warm-dry. A region was considered ‘warm’ for a particular year if the temperature of that region for that year or portion of year was greater than 1.5 standard deviations above the mean temperature for that region over all years. Similarly a year was considered to be ‘cold’ for a region when the temperature for that year or portion of year was 1.5 standard deviations below the mean temperature. ‘Wet’ and ‘dry’ were identified with the same process using precipitation for the year or portion of year and 1.5 standard deviations above or below the mean precipitation levels, respectively. Only years that were extreme in both temperature and precipitation were included in these analyses: warm and dry, warm and wet, or cold and wet. Cold-dry was not used do to the lack of years that would be considered cold and dry. All three combinations of the comparisons for the contrasts of warm-wet, cold-wet and warm-dry are used. A lakes value for a variable for an extreme climate was the average of the lakes values for that variable over all years that were considered that combination of extreme climate for which there was data.

The effect extreme climate on water quality was tested using two methods with two sub-deviations of each way. Lakes that have values for both types of extreme climates were compared using a Mann-Wilcox paired test. This paired comparison analysis was completed for all lakes statewide as well as for lakes considered shallow across the state. Shallow lakes were further examined on a regional basis, using climate divisions, which allowed pooling of lakes by assuming that the sample set included lakes fairly homogeneous in water quality and morphometry. This analysis tested the effect extreme weather has on water quality within a region by performing a Mann-U test on all lakes within that region over all three possible extreme weather contrasts. Non-parametric tests were used because of the non-normality and heavy tailed nature of the data.

Table 1. Summary of significant water quality responses comparing years that were cold-wet, warm-wet, warm-dry (based on at least two standard deviations from the mean temperature and precipitation) across all lakes across Minnesota, and shallow lakes by climate division as well as statewide. Results are in **bold** if response in both all lakes and one of shallow lakes analyses; results in ***bold italics*** if response in both shallow lake analyses. n=sample size; Δ = difference between compared climate regimes

	Type of analysis		
Water quality indicator	**All lakes - statewide**[a] (pairwise comparisons)	**Shallow Lakes - Statewide**[b] (pairwise comparisons)	**Shallow Lakes - by Climate Division**[c]
Secchi depth (m)	Cold-wet<warm wet (n=235; p<0.0001; δ 0.18 m) Warm-wet> warm-dry (n=72; p<0.0001; δ 0.38 m)	***Cold-wet>warm-wet*** (n=42; p<0.05; δ 0.17 m)	South central: ***cold-wet>warm-wet*** (n=19,37; p<0.02; δ 0.17 m)
Mean trophic state index (TSI)	**Cold-wet<warm-dry** (n=90; p<0.05; δ 1.3) **Warm-wet<warm-dry** (n=72; p<0.01; δ 2.2)	**Cold-wet<warm-dry** (n=41; p<0.01; δ 3.6) ***Cold-wet<warm-wet*** (n=43; p<0.001; δ 3.4) Note: warm-dry to warm-wet comparison non-significant with n=252	South central: ***cold-wet<warm-wet*** (n=21,37; p<0.05; δ 3.4) West central: **warm-wet<warm-dry** (n=76,61; p= 0.08; δ 4.0)
Specific electrical conductivity (EC25)	Cold-wet<warm-wet (n=23; p<0.001; δ 140 μs /cm)	Warm-wet<warm-dry (n=42; p<0.001; δ 31 μs/cm)	None significant
Surface water temperature (°C)	**Cold-wet<warm-dry** (n=11; p<0.05; δ 2.6°c) **Cold-wet<warm-wet** (n=44; p<0.001; δ 4.0°c)	**Cold-wet<warm-dry** (n=6; p<0.05; δ 3.4°c) **Cold-wet<warm-wet** (n=7; p<0.05; δ 3.2°c) ***Warm-dry<warm-wet*** (n=80; p<0.01; δ 0.4°c)	South central: **cold-wet<warm-dry** (n=6,10; p<0.05, δ 2.0°c) **cold-wet<warm-wet** (n=6,10; p<0.05, δ 1.3°c) West central: **cold-wet<warm-dry** (n=8,16; p<0.05; δ 2.1°c) **cold-wet<warm-wet** (n=8,17; p<0.01; δ 2.5°c) East central: ***warm-dry<warm-wet*** (n=86,227; p<0.001; δ 0.9°c)
Thermocline depth (m)	None significant	None significant	None significant
Chlorophyll	None significant	None significant	None significant
Total phosphorous	None significant	None significant	None significant

[a] May-Oct Climate data, June-Sept WQ data
[b] May-Oct Climate data, June-Sept WQ data, (same results with water year Climate data)
[c] May-Oct Climate data, May-Oct WQ data

Summary: Across all lakes and analyses, warmer air temperatures resulted in warmer surface water temperatures. This pattern occurred in both warm-wet years and warm-dry years. Additionally, warm years had greater productivity than cold years, with the highest productivity in warm-dry years in shallow lakes as well as when all lakes were analyzed. We did not detect any effect of the potential for extra nutrients from runoff or wind in wet years. Specific electrical conductivity (EC25) was higher in warm and wet years in the statewide analysis with all lakes. This suggests a warm versus cold effect, which could be due to evaporation. Warm wet years also were associated with reduced algal growth and increased clarity, but we have been cautious about making conclusion due to the small sample size (n=23) which may be skewing the data.

In shallow lakes, secchi depth was shallower in warm years compared to cold years. This was an expected response, as cooler summers could have led to reduced algal growth (or vice versa); however the opposite response was detected when all lakes statewide were analyzed. We did not expect to find this response of deeper secchi depth in warm-wet years than in cold-wet years, suggesting that warm and wet periods from May-Oct led to clearer water (presumably from decreased algal growth). Although a warm summer could lead to a more stable stratification, a wet year might be expected to produce more wind leading to higher mixing (of some hypolimnetic nutrients) and certainly increased watershed runoff of nutrients.

Surface water temperature trends

Dave Staples[1], Lucinda Johnson[2], Jennifer Olker[2], Richard Axler[2], Dan Breneman[2]
[1]Minnesota Department of Natural Resources, [2]Natural Resources Research Institute, University of Minnesota Duluth

Water temperature data from 558 Minnesota lakes were examined for trends during the period 1970-2007. The data are temperature readings over time for the lakes, taken at a variety of water depths and at different times during the open-water season. For these analyses, we utilized only water temperature readings from depths of 0-2m taken from June to October. To account for repeated measures of lakes over time and correlated annual variation in temperature among lakes, we used a linear mixed model (Venables and Ripley,2002) to estimate the temporal trend in temperature using the *lmer* function from the lme4 package in version 2.8.1 of the R statistical program (R Development Core Team, 2008). The analysis goals were to describe patterns and trends in temperature data at state-wide, regional, and individual lake levels, in addition to examining for differences in temperature trends over spatial and geomorphology gradients. Specific results are presented in Appendix L.

Methods: A mixed model has two components, a fixed effects portion and a random effects portion. In this case, the fixed effect portion was an ordinary linear regression of water temperature versus time, adjusted for month of sample (Jun-Oct) and water depth category (0m and 0-2m):

$$Temp_j = \beta_0 + \beta_1 * j + M_k + D_h + \varepsilon_j,$$

for j = (-24,…, 13) representing the years 1970-2007 shifted by subtracting 1994, M_k representing the effect of month k = (Jun, Jul,…,Oct), D_h representing the effect of depth category h = (0 m and 0-2 m), and for residual error $\varepsilon_j \sim N(0, \sigma)$. The β_1 parameter represented the average annual change in temperature for this group of 558 lakes. Because the year data were shifted, the β_0 parameter represents the average temperature (excluding year effects we discuss below) over the group of lakes in 1994 for the reference month and depth category (August and 0 m respectively).

The joint analysis of multiple time series introduces correlations among the observations that could potentially bias the trend estimate. We accounted for these correlations with random effects for year and lake-specific trends, giving the mixed effects model for the temperature in year j at lake i:

$$Temp_{ijkh} = (\beta_0 + b_{0i}) + (\beta_1 + b_{1i}) * j + M_k + D_h + \psi_j + \varepsilon_{ijkh},$$

where b_{oi} and b_{1i} are random adjustments to the intercept and slope terms for lake i, and were assumed to be distributed as $N(0, \sigma_{L0})$ and $N(0, \sigma_{L1})$ respectively. The ψ_j term accounts for correlations in temperature measurements within year j, and was assumed to be distributed as $N(0, \sigma_Y)$. Though b_{0i}, b_{1i}, and ψ_j are not estimated parameters in the model, we can derive unique predictors of the individual lake regression coefficients and year effects. These predictors are denoted as BLUPs for 'best unbiased linear predictors', and can be used to determine annual deviations from the linear trend and to estimate temperature trends in the individual lakes. For example, the terms $(\beta_0 + b_{0i})$ give the mean temperature for lake i in 1994 (excluding the random year effect), and the $(\beta_1 + b_{1i})$ terms give the trend in temperature for lake i. We used the lake BLUPs to evaluate regional differences in mean temperature or trend over latitudinal, longitudinal, maximum lake depth, and lake geomorphic gradients.

The temperature data were not the result of a true random sample of MN lake water temperatures over time; e.g., over 57% of the 29,275 temperature readings in the data set were taken from the East Central region of the state. Thus, there was the potential that the fixed estimate of trend, β_1, would not represent temperature trends in areas of the state with fewer samples. To evaluate the robustness of the full model in describing trends across the state, we fit the above model for 9 regions of the state separately.

Results:

Statewide model

The trend estimate for the statewide model was slightly positive (0.014), but was not statistically significant (t = 1.28; p = 0.21 on 38 df). The variation in mean temperature among lakes had a standard deviation σ_{L0} = 1.18, and the standard deviation of lake trends was σ_{L1} = 0.05. The annual variation about the trend (i.e., the random year effects) had a standard deviation σ_Y = 0.69 degrees C; there was no temporal autocorrelation in the year effects, though they do suggest a slight nonlinearity in water temperatures between 1970 and 2007 (see figure below for temporal plot of fixed trend and random year effects).

Random effects:			
Groups Name	Variance	Std. Dev.	Corr
DOWLKNUM (Intercept)	1.3822266	1.175681	
Year	0.0021308	0.046161	0.151
Year (Intercept)	0.472351	0.687278	
Residual	4.6782457	2.162925	
Number of obs: 29275, groups: DOWLKNUM, 558; Year, 38			

Fixed effects:			
	Estimate	Std. Error	t value
(Intercept)	23.0138	0.14002	164.36
DepthRange00-02m	-0.17413	0.0258	-6.75
PeriodNameJul	1.13891	0.03997	28.49
PeriodNameJun	-1.99697	0.04077	-48.98
PeriodNameMay	-7.81504	0.04342	-179.98
PeriodNameOct	-11.75615	0.05555	-211.62
PeriodNameSep	-4.29226	0.04139	-103.71
Year	0.01403	0.01098	1.28

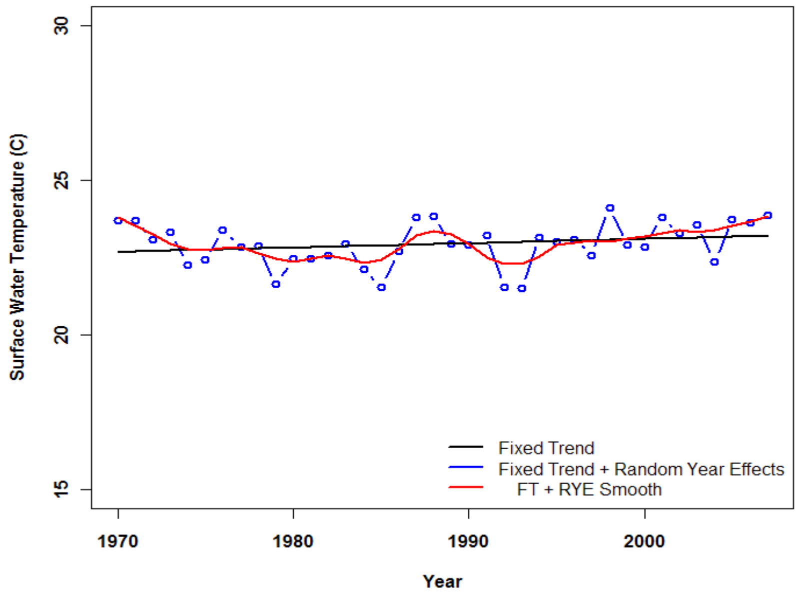

Figure 1. Fixed temperature trend and annual deviations for the statewide water temperature model.

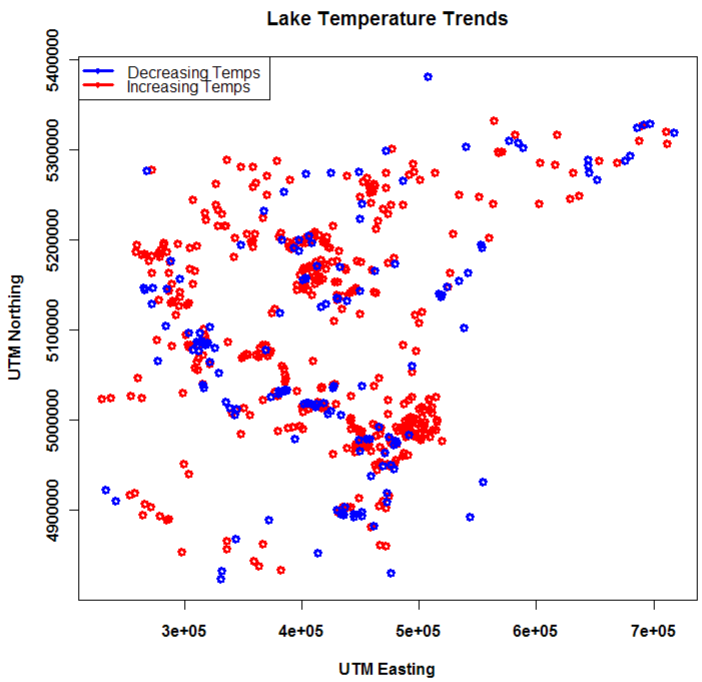

Figure 2. Spatial comparison of lakes with increasing and decreasing temperature trends.

Regional Model Comparisons

The estimated trend in all regions was similar to the statewide estimate in that they were all slightly positive but statistically not different from zero (see table and figure below for regional trends).

Region	Fixed trend
Northwest	0.029
North Central	0.047
Northeast	0.006
West Central	0.009
Central	0.015
East Central	0.018
Southwest	0.011
South Central	0.007
Southeast	0.009
Statewide	*0.014*

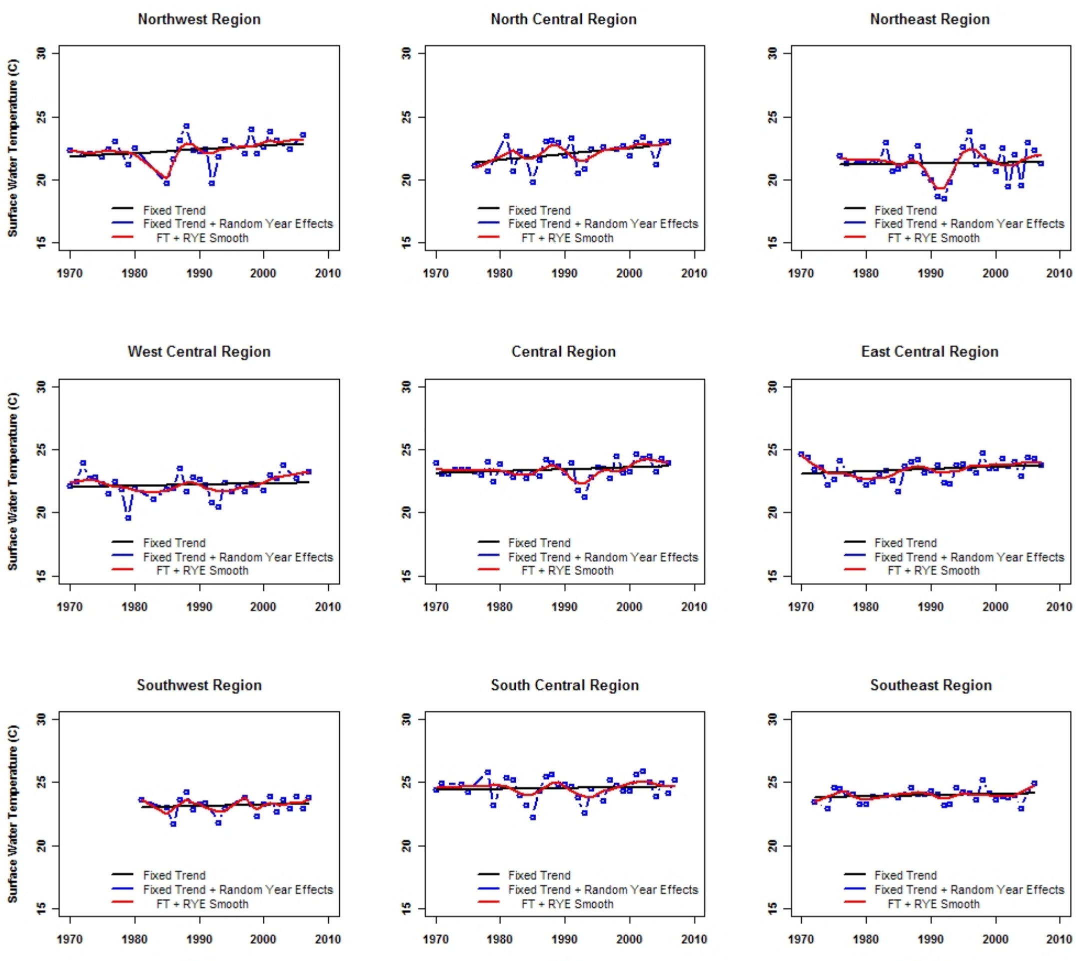

Figure 3. Trends in surface water temperatures for lakes within the 9 climate of Minnesota.

INVERTEBRATE RESPONSES

Aquatic invertebrates are important constituents of the food web in lakes, serving as prey for important fish species, and as biological indicators for environmental assessment. We planned to assess trends in lake and riverine invertebrate responses to changing climate, but found insufficient historic data upon which to base our analyses. Monitoring invertebrates within Minnesota lakes and rivers has been sporadic, with only 21 streams samples between 1976 – 1979, and 45 streams sampled in the Minnesota River Basin in 1990-1992l Thus, both the total number of systems monitored, and the number of lakes or rivers with repeated visits is low. As a result, trends could not be established for this indicator. Similarly, aquatic vegetation data, which was earlier compiled from MN DNR databases (Reschke et al. 2005, NRRI), was poorly distributed with respect to overlap with existing water quality and fishery data.

We used the resources dedicated to this result to enhance the web tools for extracting water quality data (see water quality trends, above), and to conduct additional analyses on fish community and ice out responses.

Result 4: Identify Optimal Indicators of Climate Change on Aquatic Systems.

Description: Planning an effective long-term monitoring and surveillance program requires identifying scientifically defensible, cost-efficient indicators, and testing methods for their deployment. However, reliable indicators of climate change and climate change impacts have not been identified. Based on the results from our Phase I LCCMR Climate Change project and this Phase II project, plus data compiled from a previous LCMR project on Environmental Indicators (led by Clarence Turner) and other related projects conducted by our team of scientists, we will propose indicators and recommend appropriate sampling protocols. An inventory of established monitoring programs will ensure existing programs are utilized where possible. Outcome: Recommendations of indicators and sampling protocols for assessing potential climate change impacts.

Summary Budget Information for Result 4:	**Trust Fund Budget:**	**$ 72,594**
	Amount Spent:	**$ 72,594**
	Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. Identify indicators	December 2009	$54,443	Completed
2. Compile sampling protocols	June, 2010	$18,151	Completed

Completion Date: *June 30, 2010*

Final Report Summary:

A cascade of interacting factors involving climate change-related shifts in temperature extremes and precipitation patterns, interacting with anthropogenic disturbances is certain to alter both water quality and biological assemblages in Minnesota's rivers and lakes. Climate change will affect chemical and biological water quality standards during development of the standard and during compliance monitoring (Barbour et al. 2010). It also can affect the underlying habitat in lakes and streams as a result of both temperature extremes, as well as disruption resulting from extreme weather events. The cumulative effects of changing climate will shift the baseline conditions at reference locations, and will thus require shifts in water quality and biological criteria. Furthermore, interactions with other anthropogenic factors (e.g., changing land use patterns) may cause unanticipated changes as thresholds and nonlinear responses occur within the ecosystem. Managers and policy makers must be prepared to adaptively manage regulations in response to these uncertainties.

Outside of the U.S. a number of countries have begun to implement regulatory frameworks and research agendas in response to the global challenge of a changing climate. The European Union (EU; (http://ec.europa.eu/environment/climat/studies/) and Australia (http://ec.europa.eu/environment/climat/studies/) are two countries with robust research agendas intended to provide support for science-based decision making. The United States Global Change Research Program (http://www.globalchange.gov/) also is intended to provide research support for climate-related studies. In addition, programs within the US government are being established to promote strategies to address effects of climate change at local and regional levels (e.g., Landscape Conservation Cooperatives (LCC's)).

A recent symposium published in the Journal of the North American Benthological Society (2010: volume 29(4), examined the impacts of climate change in relation to aquatic ecosystem management issues. Papers focused on describing impacts of climate change to aquatic ecosystems and communities, shifts in functional responses of the biotic communities, and responses to interacting stressors. Important take-home messages include:

1. Headwater streams may be important refugia and source of colonizers for aquatic assemblages in higher elevation regions (Herbst and Cooper 2010)
2. Changes in biodiversity as a result of differential responses to changing climate may have profound effects on baseline conditions that are used to define ecological status of a system (Durance and Omerod 2010).
3. Many metrics used in environmental assessment protocols respond differentially to temperature stress and other pollutants; new protocols are proposed to correctly identify metrics that are responsive to intended stressors rather than changing climate (Hamilton et al. 2010).
4. Shifts in species equitability (i.e., relative dominance of individuals within a community) may be an early warning indicator of climate change disturbance (Feio et al. 2010).
5. Species traits associated with thermal preferences are able to distinguish climate-related impacts from other stressors (Stamp et al. 2010); but other

traits including dominance of macroinvertebrates with large, long-lived species, and maximum body size of individuals (Lawrence et al. 2010) or flow-sensitive taxa (Poff et al. 2010) may be good indicators as well.
6. Restoration of streams impaired by land use appears to buffer the impacts of changing climate (Verdonschot and van den Hoorn 2010).

Recommended Indicators

Based on the data derived from our analyses, we recommend the following indicators be considered for monitoring potential impacts of climate change on Minnesota's lakes and streams. This list is biased towards data for which there are currently reasonably long-term records; additional indicators are listed below.

1. Ice-out date- Minnesota's historical ice-out dates for lakes is a useful tool for monitoring climatic conditions. Continued cooperation with state agencies and volunteers will provide even more standardized data collection and better indicators of change. Citizen monitoring is an essential component of this data gathering effort. See http://climate.umn.edu/doc/ice_out/ice_out_historical.htm for pertinent information about documenting ice out.

   Data should be sent to: ice.pca@state.mn.us. Reports should include name of the observer, CLMP number, lake name, ice-off date, and ice-on date (if available). If not already reported, historical dates from past years are especially valuable. Questions about ice cover can be submitted by e-mail, or from Ed Swain at 651-757- 2772 (Twin Cities) or 800-657-3864 (Greater MN).

2. Timing of walleye spawning runs- Walleye spawning runs and ice-out are occurring earlier in some lakes but not all (Schneider et al. Appendix K). However, there was a strong relationship between first egg-take and ice-out dates, and walleye egg-take appears to provide a good biological indicator of climate change. Because there is a strong relationship between dates of first egg-take and ice-out, and because ice-out has previously been related to climate change, the timing of walleye spawning runs may be a useful biological indicator of climate change.

3. Abundance of fish species:
   a. Largemouth bass and sunfish
   b. Whitefish and trout
   c. Cisco (Coregonus sp.)

   Sampling protocols are cited in MN DNR (1993).

4. Water Quality Parameters: The water quality parameters that have been found to respond to changing climate are listed below. These parameters are currently embedded in the state's water quality monitoring program (see *Minnesota's Monitoring Strategy 2004–2014; Anderson and Lindon 2006).*

a. Transparency (measured as water clarity observed from surface to Secchi plate disappearing and reappearing in the water column. Indicates light penetration, water staining, and amount of suspended particles in the water column. An average depth to nearest 0.1 m from repeated observations is recommended.)
b. Water Temperature (in degrees C from surface and 5 m increments where possible)
c. Conductivity (the ability of water to carry an electrical current. Measured as specific conductance (μmhos/cm) of water compensated to 25^0C)
d. Dissolved Oxygen (% saturation or mg/L. the oxygen concentration available for respiration by aquatic organisms)
e. Turbidity (light scattering property of water caused by suspended particles. Measured with a turbidimeter and expressed in nephelometric turbidity units (NTUs))
f. pH (negative log of hydrogen ion [H+] concentration)
g. Nutrients: (total phosphorus (P), total suspended solids (TSS), ammonia nitrogen (NH_3+NH_4), and nitrite-nitrate (NO_2+NO_3)).

The indicators identified herein are biased towards long-term data that are currently collected by the state's agencies. Additional indicators that could also provide important information include:

1. Macroinvertebrate assemblage traits related to thermal preferences, body size, life history, and flow preferences.
2. Trends in macroinvertebrate and fish assemblage composition that account for species shifts in dominance patterns.

Finally, we also recommend that: 1) management agencies increase efforts to collaborate on data collection to maximize the number of lakes for which both water quality and biological data are collected. Only 17 lakes have both 20 years of gillnet fish data and water quality data as well. When we tried to incorporate data dating back to the 1970's when climatic conditions began to change perceptibly, far fewer lakes has both data types, thus, long term trends are very difficult to track given this data record. 2) Agencies maximize efforts to use a common data framework to ensure that data can be assembled into a common database with minimal effort. 3) Further resources should be set aside to ensure the long-term viability of the climate data retrieval tool developed by the State Climatology Office. Currently this tool is accessible to a small number of researchers and staff because of limited computing (server) resources required to allow simultaneous access to the system. 4) Further resources also should be made available to allow all of the state's water quality data into the climate change database. Currently, the database contains data records for lakes with a minimum of 15 years of data for a single water quality parameter. We feel this database should be expanded to include data from lakes with a minimum of 5 years of data for a single parameter. This would maximize our ability to detect trends across both water quality and biological monitoring programs. 5) The state should consider establishment of a sentinel river (or watershed) program, in parallel with the sentinel lake program (http://www.dnr.state.mn.us/fisheries/slice/index.html).

References Cited:

Anderson, P, and M. Lindon. 2006. Standard operating procedures (sop): lake water quality sampling. Wq-sl-16. Minnesota Pollution Control Agency, Water Quality Programs and Monitoring Standard Operating Procedures. (http://www.pca.state.mn.us/index.php/view-document.html?gid=6492).

Barbour, M. T., B. G. Bierwagen, A. T. Hamilton, and N. G. Aumen. 2010. Climate change and biological indicators: detection, attribution, and management implications for aquatic ecosystems. Journal of the North American Benthological Society 29:1349-1353.

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Feio, M. J., C. N. Coimbra, M. A. S. Grac¸A, S. J. Nichols, and R. H. Norris. 2010. The influence of extreme climatic events and human disturbance on macroinvertebrate community patterns of a Mediterranean stream over 15 y. Journal of the North American Benthological Society 29:1397–1409.

Hamilton, A. T., J. D. Stamp, and B. G. Bierwagen. 2010. Vulnerability of biological metrics and multimetric indices to effects of climate change. Journal of the North American Benthological Society 29:1379–1396.

Herbst, D. B., and S. D. Cooper. 2010. Before and after the deluge: rain-on-snow flooding effects on aquatic invertebrate communities of small streams in the Sierra Nevada, California. Journal of the North American Benthological Society 29:1354–1366.

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Poff, N. L., M. I. Pyne, B. P. Bledsoe, and C. C. Cuhaciyan. 2010. Developing linkages between species traits and multi-scaled environmental variation to explore vulnerability of stream benthic communities to climate change. Journal of the North American Benthological Society 29: 1441–1458.

Verdonschot, P. F. M., and M. Van Den Hoorn. 2010. Using discharge dynamics characteristics to predict the effects of climate change on macroinvertebrates in lowland streams. Journal of the North American Benthological Society 29:1491–1509.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services:		
Personnel (not included in contracts):		$218,298
Contracts Total:		66,000
Metropolitan State University	$ 6,000	
Bemidji State University	$60,000	
Equipment:		2,500
Supplies:		8,387
Travel within Minnesota:		4,815
TOTAL TRUST FUND PROJECT BUDGET:		**$ 300,000**

VI. OTHER FUNDS and PARTNERS:

A. Project Partners: Dr. Richard Axler, University of Minnesota Duluth; Dr. Virginia Card, Metropolitan State University; Dr. Raymond Newman, University of Minnesota, Dr. Heinz Stefan, University of Minnesota; Dr. Patrick Welle, Bemidgi State University;

Peter Ciborowski, Dr. Edward Swain, Bruce Wilson, Minnesota Pollution Control Agency; Don Pereira, Kurt Rusterholz, David Wright, Jim Zandlo, Minnesota Department of Natural Resources.

VII. DISSEMINATION:

Project team members and their collaborators have made numerous presentations to general audiences, to agencies, and at professional conferences. Examples from the lead investigator are listed below.

Johnson, LB. et al. 2010. Impacts on Minnesota's Water Resources from climate change. Symposium. North American Benthological Society, June, 2010. Santa Fe.

Johnson, L.B. 2009. Are climate conditions changing? How can we tell? Invited presentation, Lake Superior Binational Forum. Duluth, MN, May 2009.

Johnson, L.B. Adapting to climate change in Minnesota. Invited presentation to Minnesota Pollution Control Agency- Committee to evaluate Adaption to climate change in Minnesota. September 1, 2009.

Johnson, L.B. Climate change and Minnesota's Aquatic Resources. Symposium. Minnesota Waters, Rochester, MN May 2009.

Johnson, L.B. Climate change and Minnesota's aquatic ecosystems. Science Museum of Minnesota, Thursday Evening Lecture Series. Exploring Water. April 9, 2009.

Johnson, L.B. Climate change and Minnesota's Natural Resources. Invited Presentation to Minnesota Coastal Zone Management Board. May, 2008.

Johnson, L.B., J. Pastor, G.R. Guntenspergen, J.H. Olker, W. C. Johnson, P. Schoff. Impacts of Climate Change on Northern Ecosystems. Special Symposium. Air Water Waste 2008. Bloomington, MN. February 27, 2008.

Johnson, L.B. Climate change impacts in Minnesota. Minnesota Water Conference Special event on Climate change sponsored by Will Steger. October 2007.

Johnson, L.B. Great Lakes in a Changing Climate. Minnesota DNR Parks and Recreation Annual Meeting, March 9, 2007.

Johnson, L.B. Great Lakes in a Changing Climate. Minnesota DNR Wildlife School. October 9-10, 2006.

Outreach and Communication products:

1. Data from Kristal Schneider's Master's thesis regarding the relationship between walleye spawning and ice out has been published in the Transactions of the American Fisheries Society 139(4):1198-1210.. http://afsjournals.org/doi/abs/10.1577/T09-129.1. Further publications are planned. In addition, the following products have been generated from this project.
2. A mapping tools was created to display trends for lakes having between 5 to >18 years of data. Because of the large number of options for analyzing this broad data set, a comprehensive subproject website was constructed to make the trend results available to other project scientists and ultimately others: (http://mnbeaches.org/gmap/trendswebsite). The website includes "processed raw" data, complete metadata, summary tables, links to Google Maps TM that identify sites with descriptive statistics, and graphs (box and whisker and regressions). The data are also incorporated into the larger project database that is now being used for more detailed examinations of climatic associations, geographic patterns, size and depth patterns, and associations with fish, and ice cover data.
3. The climate data retrieval tool, developed by the State Climatology Office, was essential to all climatic research undertaken in this project. The climate data retrieval tool enabled project participants to extract climate variables important to their own specific questions, at time and space scales they deem relevant. While the climate data retrieval tool is available to project investigators only at the present time, the Office of the State Climatologist plans to make it available widely to Minnesota resource managers and researchers at the conclusion of this project.
4. A third product is an annotated bibliography for the economics of climate change and environmental quality.

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than December 15, 2007; June 30, 2008 December 15, 2008; June 30, 2009; December 15, 2009; June 30, 2010. A final work program report and associated products will be submitted between June 30 and August 1, 2010 as requested by LCCMR.

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects -

Proposal Title: ***Minnesota's Water Resources: Impacts of Climate Change- Phase II _Serial Number 13***
Project Manager Name: *Lucinda B. Johnson*
LCMR Requested Dollars: $ *300,000*

2007 LCMR Proposal Budget	Result 1 Budget:	Amount Spent	Balance	Result 2 Budget:	Amount Spent	Balance	Result 3 Budget:	Amount Spent	Balance	Result 4 Budget:	Amount Spent	Balance	TOTAL FOR BUDGET ITEM
University of Minnesota Budget	*Economic Assessment*	*6/30/2010*	*6/30/2010*	*Climate Projections*	*6/30/2010*	*6/30/2010*	*Biological projections*	*6/30/2010*	*6/30/2010*	*Indicator Development*	*6/30/2010*	*6/30/2010*	
BUDGET ITEM													
PERSONNEL: Staff Expenses, wages, salaries	**19,198**	**19,198**	**0**	**26,066**	**29,428**	**-3,362**	**72,503**	**81,901**	**-9,398**	**51,626**	**51,626**	**0**	**169,393**
L. Johnson													
R. Axler													
J. Olker													
T. Hollenhorst													
E. Ruzycki													
GRA TBA - Department of Geography													
GRA TBA - St. Anthony Falls Laboratory													
GRA TBA - St. Anthony Falls Laboratory													
GRA TBA - Dept. Fisheries, Wildlife & Conserv.													
PERSONNEL: Staff benefits – *Be specific; list benefits for each person on a separate line*	**4,510**	**4,510**	**0**	**14,601**	**5,169**	**9,432**	**16,891**	**33,607**	**-16,716**	**12,903**	**12,903**	**0**	**48,905**
L. Johnson													
R. Axler													
J. Olker													
T. Hollenhorst													
E. Ruzycki													
GRA TBA - Department of Geography													
GRA TBA - St. Anthony Falls Laboratory													
GRA TBA - St. Anthony Falls Laboratory													
GRA TBA - Dept. Fisheries, Wildlife & Conserv.													
Contracts	**60,000**	**51,351**	**8,649**	**3,000**	**3,000**	**0**				**3,000**	**3,000**	**0**	**66,000**
Ice-Out Modeling: Metropolitan State University, St. Paul				**3,000**	**3,000**					**3,000**	**3,000**		
Economic Analysis: Bemidji State University	**60,000**	**51,351**											
Equipment / Tools: computer for database manager, devoted to project.				**1,250**	**0**	**1,250**	**1,250**	**0**	**1,250**				**2,500**
Other Supplies (field, computer / printing supplies)	**1,000**	**203**	**797**	**1,000**	**0**	**1,000**	**3,187**	**114**	**3,073**	**3,200**	**1,438**	**3,200**	**8,387**
Travel expenses in Minnesota	**750**	**0**	**750**	**1,100**	**1,076**	**24**	**1,100**	**800**	**300**	**1,865**	**703**	**1,162**	**4,815**
COLUMN TOTAL	**85,458**	**75,262**	**10,196**	**47,017**	**38,673**	**8,344**	**94,931**	**116,422**	**-21,491**	**72,594**	**69,670**	**2,924**	**300,000**

**Potential Impacts of Climate Change on Minnesota's Water Resources:
An Economic Analysis**

This study was conducted on behalf of the
Legislative-Citizens Commission on Minnesota Resources

by

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* Research assistance was provided by Brett Nelson. Two appendices were authored by Rabi Vandergon for his Masters of Science Thesis at Bemidji State University. His thesis is titled "Economic Impacts of Global Climate Change on Minnesota Fisheries through Decreases in Lake Ice." Portions of this report, such as the literature review and Section VIB, are based heavily on his work. Also as part of his survey of the literature he composed the annotated bibliography in Appendix D.

The authors are grateful to others who assisted this work, especially Lucinda Johnson who directed the overall project. Heinz Stefan, Virginia Card and other members of the project team shared findings on which this analysis is based. Officials from MN state agencies, most notably Denise Peterson, Frank Pafko, Shawn Chambers, and Luane Tasa provided data regarding weather-related damages. The analysis of recreational fishing benefited from information provided by Henry Drewes, Lyn Bergquist, Andrew Williquett and Donna Dustin. Keith Reeves was exceptionally helpful and accommodating in assisting with the creel survey database.

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EXECUTIVE SUMMARY

Introduction and Background

This report contains the economic component of a larger research project directed by the University of Minnesota, Natural Resources Research Institute. According to the 2007 LCCMR project Workplan, the overall purpose is “to quantify climate, hydrologic, and ecological variability and trends, along with economic impacts of environmental fluctuation on water resources, and to identify indicators of future climate change effects on aquatic systems. This report presents economic conceptualizations of climate change as a policy challenge and empirical findings on “economic impacts of environmental fluctuation on water resources.”

The Scientific Context for Climate Change Impacts on Minnesota Resources

According to USEPA Office of Water 2008“Climate change will have numerous and diverse impacts, including impacts on human health, natural systems, and the built environment. Many of the consequences of climate change relate to water resources, including:

- warming air and water;
- change in the location and amount of rain and snow;
- increased storm intensity;
- sea level rise; and
- changes in ocean characteristics.”

“Impacts should be expected to vary regionally, but in general, climate change could result in increased demands on our infrastructure systems, both in terms of O&M costs and the need for capital expenditures. The suite of expected impacts can be grouped according to the type of change a system may face and fall roughly into the following categories:

- more water (through increased precipitation and storm intensity) and sea level rise;
- less water, with increased frequency and duration of drought;
- temperature change; and
- damage from more intense storms.” USEPA Office of Water (2008), page 51.

The MPCA climate change website states: “Minnesota is already experiencing impacts from climate change, and will continue to experience impacts to our ecosystems, natural resources, and infrastructure.” The MPCA website quotes the US Global Change report which highlights Key Impacts in the Midwest:

- During the summer, public health and quality of life, especially in cities, will be negatively affected by increasing heat waves, reduced air quality, and increasing insect and waterborne diseases. In the winter, warming will have mixed impacts.
- The likely increase in precipitation in winter and spring, more heavy downpours, and greater evaporation in summer would lead to more periods of both floods and water deficits.

- While the longer growing season provides the potential for increased crop yields, increases in heat waves, floods, droughts, insects, and weeds will present increasing challenges to managing crops, livestock, and forests.
- Native species are very likely to face increasing threats from rapidly changing climate conditions, pests, diseases, and invasive species moving in from warmer regions.

Specific Findings on Climate Change Impacts on Minnesota's Water Resources

Climatologist Mark Seeley presented and discussed major trends in Minnesota's climate at the Climate Adaptation Summit, December 3, 2009. Those highlighted here are most relevant for this report given their potential socio-economic significance. Again the focus is on implications for water resources.

1. Changing character and quality of precipitation: there is an increasing proportion of annual precipitation coming in summer thunderstorms and these have more spatial variability than other precipitation events,
2. Warmer winter minimum temperatures,
3. Higher summer heat indices due to higher humidity and higher ambient air temperature,
4. Increase in the number of freeze/thaw days

Dedaser-Celik & Stefan (2009) analyzed trends in streamflow in Minnesota since 1946 using gauges from five different river basins across the state. The trends observed matched many predicted by other climate change literature such as increased high flow due to increased runoff. While extreme flood events have not increased, flows over a wide range of recurrence intervals have either increased over time or remained the same. These researchers did determine that rivers located in areas with higher rates of precipitation showed increases in streamflow.

Selected findings from the five basins are:

Flow Duration Curves. The Minnesota River Basin has experienced the largest stream flow changes in the last 20 years compared to the other four basins. High, medium, and low flows have increased significantly from the 1946-1965 to the 1986-2005 period (on average Q50 increased by about 200%). The increases in medium to low flows were larger than the increases in high flows. Considerable changes in flows were also observed in the Upper Mississippi River Basin and the Red River of the North Basin (on average Q50 increased by about 80%).

High and Low Flow Ranking. Both annual peak flows and 7-day average low flows were higher in the 1986-2005 period in the Minnesota River Basin, Red River of the North Basin, and Upper Mississippi River Basin. Increases in observed 7-day average low flows were more significant than increases in observed annual peak flows.

Flood Frequency Analyses. Separate flood frequency analyses were conducted on the stream flow data from the 36 stream gauging stations for the (1946-1965) and the (1986-2005) periods to identify changes in the 1-, 2-, 5-, 10- and 25-yr floods. The results were most consistent for the Red River of the North Basin. In this basin, magnitudes of the 2- to 25-yr floods increased at all six stream gauging stations (average increases were from about 30 to 60%) and the magnitude of the 1-yr flood decreased (average of 20%).

The river basins which showed the largest increases in stream flows (Minnesota River Basin and

Red River of the North Basins) drain regions (climate divisions) where significant increases in precipitation have been observed. Agricultural drainage and changes in crop patterns are other potential causes that need to be considered."

Ice Duration Analysis

Virginia Card (2010) provided findings from the dataset on dates of ice formation and ice thawing on 40 lakes from 1970 to 2008. The average number of days of ice duration lost or gained over this period was also calculated. It was found that lake ice duration in the Minnesota sample is significantly decreasing at a mean rate of 3.3 days per decade from the time period of 1970 to 2008.

Fish Habitat Changes and Fish Abundance Shifts

Two separate Minnesota studies have examined the impacts of climate change on freshwater fisheries. In the first study, Schneider, Newman, Card, Weisber, and Pereira (2005) examined the impacts on changing ice-out conditions in Minnesota on walleye spawning timing. The researchers found that for every one day decrease in the presence of lake ice there was a .5 to 1 day decrease to the day that a walleye lays its eggs. These authors postulated that this may have an impact on the well-being of the fishery if there is a mistiming in the availability of prey with a change in spawning timing.

In the second study, Schneider, Newman, Weisberg, and Pereira (2009) examined the current trends in fish communities in response to changing climate in Minnesota. Several temperature variables were compared with the abundance of species in 35 different lakes. These researchers discovered that the majority of fish species were expanding their range northward except smallmouth bass. In addition, these researchers discovered that increases in average summer temperature were correlated with increases in largemouth bass and sunfish abundance. Moreover, increasing air temperature was correlated with a decrease in the abundance of whitefish and trout.

Water Quality

The project team includes researchers focusing on trends in water quality in Minnesota lakes. Axler et al. (2009) provided online resources to access a voluminous database that they developed for water quality parameters from over 630 MN lakes. Lakes selected had more than 15 years of data for at least one water quality measure involving 1.9 million records. Major findings from their analysis of the data include: (pages 12-16)

"In the context of the climate change issue that spawned the present study, the most important result derived from the exploratory trend analyses has been that for lakes with significant time trends during the summer, more than 90% showed surface water warming as compared to cooling."

"*Warmer growing season air temperatures have generally been predicted to decrease the depth of the thermocline (i.e. creating a shallower epilimnion) in most lakes as a consequence of increased warming of the epilimnion and increased thermal stability. Although only 16% of lakes with >5 years of data had significant trends in thermocline depth, 85% of those that did,* *exhibited decreasing (i.e. shallower) thermocline depths."*

"The salt content of surface waters and chloride concentration has increased over time in more than a third of the lakes with >5 years of data, 50% of those with >8 years, and 90% with >18 years of data. This is consistent with increased summer surface warming but also with potential increased exposure to winter de-icing salts and/or increased stormwater runoff from either urban or agricultural areas."

"Perhaps the most surprising result found in this study was that there was internal consistency within the group of trophic status indicators (secchi depth clarity, chlorophyll-a, total phosphorus and total Kjeldahl nitrogen) that suggests a strong overall improvement in water quality."

There are countervailing trends at play here, such as reduced industrial discharges and nutrient reductions from some non-point sources, while increasing population and intensity of development in many lakesheds heightens impacts. A myriad of watershed impacts must be juxtaposed with effects of climate change. It is extremely difficult to isolate the impact of climate change separately.

Despite these mixed results on trends in Minnesota water quality, it is extremely important to consider potential impacts of climate change given the importance of the resources at stake. The current impaired waters list in Minnesota includes over 1,000 lakes and 400 rivers. Indeed preliminary efforts to improve these conditions, i.e. point and non-point pollution reduction efforts that have existed for decades, should be part of the positive changes evidenced by these project findings. A related, major concern for the future of Minnesota waters is the threat of invasive species. Climate change can be a contributing factor to a worse future for Minnesota's surface waters, such as impeding improvements from ongoing efforts.

Conceptual Framework for Inferring Economic Impacts

Potential economic impacts of climate change must be understood within the conceptual framework about what people value. Environmental economics identifies two major conceptual components of value: use values and passive-use value. The theory and practice has developed toward the conventional wisdom that only recognizing use values in evaluating environmental effects would lead to substantial underestimation of value to the public.

It is also worthwhile to relate conceptual components of value to the benefits estimation techniques available to measure them. Benefits estimation must be grounded in measurement of market and non-market Values. Market values ideally measure willingness-to-pay (WTP) based on derivation of the market demand curve. Actual expenditures are a lower-bound estimate of WTP in that consumer surplus would be missed. Non-market values are not directly revealed in market transactions. Purchases of items, such as bird-watching equipment, can indicate people's values for these activities. Existence values are most often measured through direct statements rather than being revealed through market choices.

In terms of water resources, some of the major **market values** that could be impacted are:

- recreational fishing,
- commercial fishing,

- commercial transportation on waterways,
- agricultural irrigation,
- infrastructure damages from flooding (drinking water, wastewater, and stormwater facilities, roads, bridges, culverts, and other structures),
- flood damages to crops, forests and other lands with commercial yields
- hydroelectric power generation,
- water-borne diseases
- insurance costs

In terms of water resources, some of the major **non-market values** that could be impacted are:

- water quality
- fish habitat
- preservation of "natural" distribution of cold-water species such as lake trout and cisco
- preservation of native aquatic plants
- preservation of "natural" levels of surface waters

Reducing the risk to water resources from climate change also generates a risk-aversion premium defined as option value. It is analogous to the motives for profit-generating insurance premiums being willingly paid to insurance companies. An important distinction is that option value accumulates to all individuals that are averse to these risks. So benefit accumulates simultaneously to all of these individuals due to policies that reduce these risks. This collective benefit fits the definition of a public good

Option value applies more widely to climate change impacts than just to water resources. In fact it addresses a fundamental aspect of the potential economic loss from climate change. Statisticians characterize distributions with measures of Central Tendency and Dispersion. Much of the concern about climate change impacts has focused on increases in measures of Central Tendency such as higher average temperatures of higher mean precipitation. But from a socio-economic perspective the potential damages linked to increasing dispersion, such as more extreme temperatures or precipitation patterns may be just as damaging to social and economic well-being. The concept of option value is fundamental to understanding the economic impacts of climate change.

Sustainability and the Precautionary Principle are crucial concepts to consider in understanding the economic aspects of climate change. The value of water resources and the ecological services provided are so large as to indicate that it would be economically efficient to incur substantial costs to avoid these losses. As the USEPA document "National Water Program Strategy: Response to Climate Change" suggests, large costs to reduce other bad actions that compromise drinking water or surface water quality may be warranted to offset the degradation that could be anticipated from climate change. For example, it may be economically efficient to invest in land-use changes and/or wastewater treatment that reduce nutrients so that climate change does not put us over the threshold toward lower water quality.

If an economic standard is met indicating that the benefits of protecting water quality against degradation from climate change are worth the costs, the next decision criterion would be to achieve these benefits at minimum cost. In order to protect these water resources, the costs of countervailing measures would need to be compared to the costs of reducing greenhouse gas emissions as root causes of these problems.

The evidence on climate change impacts suggests that irreversible damages could occur. Good policy formulation can provide flexibility to alter future pollution abatement investments. Human/social decisions should be more reversible than many environmental impacts; damages to ecosystems, loss of native species, etc. There are severe risks from disrupting energy flows in an ecosystem so that outcomes from the processes related to the First and Second Laws of Thermodynamics degrade ecological goods and services. Most importantly, climate change poses the risk of loss of human life. These risks are seen by this analyst as being much greater and more difficult to monetize than expenditures on pollution control devices.

Concepts of intergenerational equity are central to applying sustainability to the issue of climate change. One view of intergenerational equity relates closely to the Anishinaabe ethic of "The Seventh Generation." Similar environmental ethics can be found in various indigenous cultures around the world and generally imply that actions today must be in the interest of those seven generations into the future. Current generations of indigenous peoples face unusual threats from climate change. Traditional practices that depend on natural process and ecosystem services may disappear with disruption from climate change. The most vulnerable groups across many societies are likely to suffer the greatest losses from climate change. For indigenous people in regions around the planet attempting to live in traditional ways, climate change may put those ways of life in jeopardy.

Survey of the Literature on Economic Impacts of Climate Change

The Stern Review (2006) made extensive arguments as to why it would be economically efficient and equitable to take immediate action to reduce GHG emissions. One of his equity positions was that the long-term consequences of climate change make discounting unfair to future generations, being future impacts would be severely diminished in relative importance compared to current impacts. Stern estimates losses in terms of global gross domestic product (GDP). He also estimates the percentage of global GDP that would be needed to fend off the worst of future impacts. More detail on the Stern Review is provided in the annotated bibliography presented in Appendix D.

The methods and conclusions of the Stern Review have been subjects of substantial disagreement in the economics literature. Stern served a constructive purpose in stimulating enlightening discussion. Heal (2008) summarizes the economics literature on climate change as follows: "I suggest that the recent debate has clarified many important issues, and that we are now in a position to identify those conditions that are sufficient to make a case for strong action on climate change. However, more work is needed before we can have a fully satisfactory account of the relevant economics. In particular, we need to better understand how climate change affects natural capital - the natural environment and the ecosystems comprising it - and how this in turn affects human welfare."

Implications of climate change for the insurance industry were the subject of a great deal of analysis in the late 1990's. In an article on global change, Berz (1999) speculates that "changing probability distributions of many processes in the atmosphere" will result in "serious consequences for all types of property insurance." "In areas of high insurance density the loss potential of individual catastrophes can reach a level at which the national and international insurance industries will run into serious capacity problems." Three insurance industry experts, Mills, et al. (2001) estimate a 15-fold increase over the period 1970 -2000 in insured losses from catastrophic weather events (defined as exceeding $1 billion of damages.)

The focus of the workplan on water resources within the state leads to emphasis on the three categories of environmental impacts below. The major mechanisms for economic impacts to occur are included.

1. Lake and stream levels: flood damages, especially to infrastructure
2. Water temperatures: shorter ice duration, changes in fish populations, habitat, winter and summer kills
3. Water quality: multiple values of clean water

There is a great deal of evidence that water quality is extremely important to Minnesota, The value of water quality is manifested in recreational and tourism activities, property values for lakeshore, investments in policies to protect water, and other ways in which citizens demonstrate WTP and the role of water in the MN quality of life. The evidence of historical trends on water quality in MN lakes yields mixed results, with general trends toward improving water quality measures. It is difficult to isolate potentially negative impacts of climate change on lake water quality from the backdrop of other complex processes that are having a net positive effect.

If climate change has a negative impact on thousands of lakes within the state, the loss of economic value would be substantial. These assets (natural capital) would me much less valuable to MN than they otherwise could be. For a thousand lakes that might be degraded from climate change, the loss could be in the tens of billions of dollars. Time will tell what kinds of relative changes will result in light of other positive and negative processes impacting water quality, but the evidence in the literature indicates climate change is likely to have a negative net effect.

Potential Economic Effects of Changes in Minnesota's Water Resources

Research efforts on the implications of climate change for MN are in the early stages. Hence it is appropriate that economic analyses focus on advancing conceptual understanding. Economic analysis depends on underlying science describing the environmental effects to be valued. Evidence is emerging, and this overall project advances the science, but limited data make empirical evidence somewhat preliminary. The statistically meaningful trends in climate patterns on temperatures and precipitation do imply changes in water resources in MN: some resource changes are currently identifiable, others will take longer to reveal. Empirical economic analyses are reported here that match the strongest findings thus far.

Empirical economic analyses were performed on two impacts to MN water resources: 1) magnitudes and types of infrastructure damages due to weather-related events, particularly floods and 2) the trend toward shorter ice duration on MN lakes. This is likely to affect recreational fishing which is extremely important to MN.

The longest yearly record for weather-related damages in MN comes from figures reported in a NOAA study (2002) that re-examines damage figures from 1925-2000. Figures are provided state-by-state from 1955 to 2000. From 1955-2000 occasional weather events caused damages (in constant 1995 dollars) in the tens of millions of dollars. Damages in the hundreds of millions of dollars also occurred over this time period. By far the two years with the highest damages were 1997 and 1993. The floods of 1993 caused damages in excess of $1 billion in constant 1995 dollars.

The MN Department of Public Safety's Division of Homeland Security & Emergency Management provided summarized damage information over the past two decades. The damage figures for the 1990s are contained in a report "A Decade of Minnesota Disasters: A Historical Look at Minnesota Disasters in the 1990s." According to the report, these damages are increasing and during the 1990s there were 14 presidential declarations of major disasters. Most of the damages were the result of flooding, ice storms, snow removal, straight-line winds, tornadoes, and heavy rain. From the disasters of the 1990s, Minnesota taxpayers spent $827 million and the cost to insurance companies was more than $2 billion.

Analysis conducted by Virginia Card as part of the larger project found that ice duration is getting shorter in the state. The trend analysis indicated that ice-duration has on average been getting shorter by a third of a day in a typical year, or 3.3 days over the course of a decade. A direct socio-economic impact of shorter ice duration will be the switch of recreational days for ice-related activities to open-water activities. The change in environmental conditions will cause positive and negative effects on opportunities for recreation. Patterns of gains and losses will impact different groups and different communities differently. Certainly activities dependent on ice and snow are likely to suffer based on climate evidence. Indirect socio-economic effects are also likely to occur from shorter ice duration as one aspect of changing conditions in the aquatic ecosystem. There is an important linkage between ice-on/ice-off periods, limnological conditions/water quality, fish habitat and species distribution/abundance.

Creel survey data includes variables on the time respondents spent fishing, catch rates and other aspects of the fishing experience Shorter ice duration can reasonably be expected to diminish the benefits the public enjoys from ice fishing. Since some MN lakes, most notably Upper Red Lake, see higher use in winter months, the onset of climate change through decreasing lake ice will likely have a net negative impact on recreational benefits from use of these lakes.

Seasonal patterns of use were examined for other large walleye lakes in the state. These generate a very large portion of the overall fishing activity in the state. In contrast to Upper Red Lake, other large walleye lakes (and statewide data for smaller lakes) show that summer effort significantly exceeds effort in the winter. A higher amount of angler effort in the open-water season is likely to lead to a net positive impact from the onset of climate change.

An additional empirical question investigates whether changes already occurring in species distribution and abundance are leading to changing patterns of fishing effort. The results from the multiple regressions did not show significant results for a change in yield per unit of effort in response to change in species abundance over certain regions of the state over time. Nor did they indicate increasing effort thus far in areas where yields might be expected to increase in the future as certain species become more abundant. As mentioned in the literature, certain species, such as trout, have a higher WTP than walleye and panfish. Therefore, a change in these species abundances could have a significant impact on the WTP by anglers. For example, fewer trout (which are predicted to decline from climate change) would be detrimental to recreational benefits. The net impact from these changes in species abundance and the economic consequences cannot be estimated given current limitations of available data.

Further Conclusions

The relative emphases of the economic analyses and the empirical estimation are dependent upon the findings of the other environmental components of this research effort. To a certain extent, the findings on environmental impacts at this juncture are predicated on available data that are constrained in both temporal and spatial scale. So while evidence is mounting that Minnesota's water resources are vulnerable to the effects described in the workplan (higher surface water levels/streamflow, increased sedimentation, degraded water quality, infrastructure implications) some of the more extreme impacts anticipated at the global or regional scale are difficult to detect statistically at the smaller statewide scale. This is due in part to lack of small spatial scale data over the length of time needed to detect statistically meaningful trends.

MN should adopt a two-pronged approach to risk management to the degree that MN can inventory watersheds for the combination of two groups of characteristics. A convergence of two characteristics that cause greatest vulnerability to damages from flash floods should be inventoried. Watersheds most vulnerable to damages have: transportation infrastructure 1) geomorphology conducive to flash floods and 2) human and natural environments that put highly valued assets and human life in harm's way.

The economics literature on risk-aversion should inform decisions on climate change. The potential damages from climate change are the types of risks that people typically wish to guard against. Most citizens place a value on risk reduction and are willing to pay for the insurance value this yields. Public policy that provides this is a public good to all those who have risk-averse preferences. It is a collective value derived from the sort of individual value many people place on private insurance. Fundamental aspects of climate change involve risks and this conceptual economic approach is enlightening.

SECTION I.
INTRODUCTION AND BACKGROUND

A. Purpose of the Study and the Overall Research Project

This report contains the economic component of a larger research project directed by the University of Minnesota, Natural Resources Research Institute. According to the project 2007 LCCMR Workplan, the overall purpose is “to quantify climate, hydrologic, and ecological variability and trends, along with economic impacts of environmental fluctuation on water resources, and to identify indicators of future climate change effects on aquatic systems. This report presents economic conceptualizations of climate change as a policy challenge and empirical findings on “economic impacts of environmental fluctuation on water resources.”

Further background on the overall project is provided in the following excerpts from the “Project Summary and Results.” “Minnesota’s climate has become increasingly warmer, wetter, and variable, resulting in unquantified economic and ecological impacts. More recent changes in precipitation patterns combined with urban expansion and wetland losses have resulted in an increase in the frequency and intensity of flooding in parts of Minnesota with extensive and costly damage to the State’s infrastructure and ecosytems. We are examining historic climate records and developing a database of key climatic measures and their variability in a current LCCMR project “Impacts on Minnesota's aquatic resources from climate change”. To assess the consequences of past climate trends on aquatic resources we are analyzing hydrologic, water quality, and fish community responses. We propose to expand that study to develop prediction for future climate specific to Minnesota, and then quantify the potential economic impact of climate-induced changes in precipitation and hydrology on the water resource infrastructure, including storm sewers, bridges, water treatment facilities, and shoreline development.”

The economic asessment (Result 1 of the Workplan) is described as follows: “Economic assessment of potential impacts on water resource infrastructure. Description: Recent changes in precipitation patterns, combined with urbanization, wetland loss, and increased tile drainage have resulted in higher riverine base flows in Minnesota, compared to historic averages. These changes are associated with increased flood frequency and intensity. The economic impact of such floods has been substantial. We will use data from our current LCCMR project, along with the outcome of Result 2 to quantify the economic cost of flooding and degraded water quality and assess infrastructure changes needed to meet future climate projections (Result 2). Outcome: An economic analysis of floods and the cost of water quality protection and infrastructure needs under changing climatic conditions. The analysis will include estimates of flood damages to physical and natural assets, including costs due to increased sedimentation of surface waters using market valuation techniques. Damages to water quality will also be estimated using benefits transfer based on evidence from the literature on the public values of water quality. Costs to mitigate damages from flooding and reduced water quality will also be quantified using engineering costs and market values.”

The relative emphases of the economic analyses and the empirical estimation are dependent upon the findings of the other environmental components of this research effort. To a certain extent, the findings on environmental impacts at this juncture are predicated on available data that are constrained in both temporal and spatial scale. So while evidence is mounting that Minnesota's water resources are vulnerable to the effects described in the workplan (higher surface water levels/streamflow, increased sedimentation, degraded water quality, infrastructure implications) some of the more extreme impacts anticipated at the global or regional scale are difficult to detect statistically at the smaller statewide scale. This is due in part to lack of small spatial scale data over the length of time needed to detect statistically meaningful trends.

For example, one specific finding is that increased streamflows and flooding appear to be occurring but the data make this difficult to detect at the level of watersheds or tributaries and at the extremes of 100 or 500 year floods. Consequently, the economic analysis focuses on increased frequency of "moderate" floods consistent with the hydrological evidence, even though damage estimates seem to indicate that more severe floods are increasing in frequency.

The recent history on water quality trends presents "a mixed bag" of results that are environmental outcomes from a complex set of variables and processes that are impacting the quality of Minnesota's surface waters. Again the analytical frameworks and available data make it difficult to disaggregate current and future impacts of climate change from other positive and negative impacts on water quality. The historical record shows the net effect on water quality of these simultaneously occurring impacts. So it is extremely difficult to isolate the impact of climate change separately. Water quality changes and other potential impacts of climate change on Minnesota's water resources that may occur - according to national and international evidence - are discussed at a conceptual level in order to include these risks in the discussion without devoting scarce resources to empirical analysis prematurely.

The empirical analysis in this report does indicate worsening trends in infrastructure damage based on multiple data sets through time. On the other hand, the work of researchers on other components of the project found impacts that were more significant than anticipated in the initial workplan, such as shorter lake ice duration and changing range and abundance of certain species of fish. So the economic analyses reported here have been adjusted (less attention in some areas, more in others) to reflect the evidence of climate change impacts that has emerged from this project. Greater resources, time and effort within the economic analysis have been placed on those impacts on water resources that can be demonstrated from the available data rather than impacts that may or may not be occurring but cannot be discerned from available data.

B. Limits to the Scope of the Study Relative to Global Climate Change

Efforts to enhance understanding of climate change and its potential impacts within Minnesota benefit immensely from research that has been and is being undertaken at other levels within a variety of institutional settings – academia, research institutes, state, national and international entities, etc. Global climate change is seen by many as one of the most important and complex challenges humankind has ever confronted. Any economic analysis of climate change impacts needs to consider this broad context of potential global impacts as all could alter the economic setting within which we participate in the global economy as part of our daily lives. The foundation for understanding and addressing economic impacts as part of a sustainable future requires that no major climate change impacts be excluded from the discussion. Still, it is beyond the scope of this research with a Minnesota focus to thoroughly address the broader global economic issues. Section II alludes to the broad literature on global climate change and likely impacts in relation to Minnesota's place in regional, continental and global changes.

This overall project is bringing to bear evidence on the question of impacts Minnesota is experiencing or is likely to experience among the global impacts that are being documented in the international research literature. So it is important to cite some of the main sources on these global impacts such as the Intergovernmental Panel on Climate Change (IPCC), the United States Environmental Protection Agency (USEPA), the National Oceanic and Atmospheric Adminstration (NOAA), the National Science Foundation (NSF). Findings from these and other sources are highlighted in Section II.

The previous sub-section provides details on the scope of the broader study and the economic component within the workplan. While the literature covers myriad impacts of climate change, the workplan serves to establish the focus on water resources. The title of the project reflects this well: "Minnesota's Water Resources: Impacts of Climate Change." The economic discussion below refers to the broad array of impacts of global climate change that are discussed in the literature. Impacts that do not involve water resources are discussed on a conceptual level only within the economic context of sustainability. A major strategy that is offered applies to both water impacts and other potential consequences: wise investment should be pursued in "insurance policies" to manage societal risk from potential climate change impacts at an "acceptable" level.

The report is outlined as follows: II. The Scientific Context for Climate Change Impacts on Minnesota Resources, III. Specific Findings on Climate Change Impacts on Minnesota's Water Resources, IV. Conceptual Framework for Inferring Economic Impacts, V. Survey of the Literature on Economic Impacts of Climate Change, VI. Potential Economic Effects of Changes in Minnesota's Water Resources, and VII. Summary and Conclusions.

SECTION II.
THE SCIENTIFIC CONTEXT FOR CLIMATE CHANGE IMPACTS ON MINNESOTA RESOURCES

A. Categories of Impacts Globally

Conducting economic analysis of potential impacts of climate change requires familiarity with the scientific evidence on the types of environmental changes that could result from climate change. The team assembled for this project has multi-disciplinary expertise. The findings from other team members set the foundation for the effects on water resources that provide the core of this study. Before highlighting the specific findings from the project later in this section, an overview of the literature on impacts is needed to provide a broad context for the types of socio-economic influences that could occur.

One of the most widely cited sources is the Intergovernmental Panel on Climate Change (IPCC). The IPCC does not conduct research per se, but rather serves as a clearinghouse for documents and evidence from an international network of research efforts. For the purposes of this study, primary reliance on sources will be placed on various agencies of the United States government. The US Environmental Protection Agency (USEPA), National Oceanic and Atmospheric Administration (NOAA) and the US Department of Transportation (USDOT) provide a wealth of documentation on climate change and potential impacts on the environment and infrastructure. One excellent source of information on climate change is the Office of Global Change, which emphasizes climate change as a topic. Descriptions of impacts from this source as well as the USEPA Office of Water provide background with a focus on water resources. In the interest of the length and flow of the body of this report, descriptions from other key sources are detailed in Appendix A.

According to USEPA Office of Water 2008*"Climate change will have numerous and diverse impacts, including impacts on human health, natural systems, and the built environment. Many of the consequences of climate change relate to water resources, including:*
- *warming air and water;*
- *change in the location and amount of rain and snow;*
- *increased storm intensity;*
- *sea level rise; and*
- *changes in ocean characteristics."*

*"1. <u>Increases in Water Pollution Problems</u>**:** Warmer air temperatures will result in warmer water. Warmer waters will:*
- *hold less dissolved oxygen making instances of low oxygen levels and "hypoxia" (i.e., when dissolved oxygen declines to the point where aquatic species can no longer survive) more likely; and*
- *foster harmful algal blooms and change the toxicity of some pollutants.*

The number of waters recognized as "impaired" is likely to increase, even if pollution levels are stable.
*2. <u>More Extreme Water-Related Events</u>**:** Heavier precipitation in tropical and inland storms will increase the risks of flooding, expand floodplains, increase the variability*

of streamflows (i.e., higher high flows and lower low flows), increase the velocity of water during high flow periods and increase erosion. These changes will have adverse effects on water quality and aquatic system health. For example, increases in intense rainfall result in more nutrients, pathogens, and toxins being washed into waterbodies.
*3. <u>Changes to the Availability of Drinking Water Supplies</u>**:** In some parts of the country, droughts, changing patterns of precipitation and snowmelt, and increased water loss due to evaporation as a result of warmer air temperatures will result in changes to the availability of water for drinking. In other areas, sea level rise and salt water intrusion will have the same effect. Warmer air temperatures may also result in increased demands on drinking water supplies and the water needs for agriculture, industry, and energy production are likely to increase.*
*4. <u>Waterbody Boundary Movement and Displacement</u>**:** Rising sea levels will move ocean and estuarine shorelines by inundating lowlands, displacing wetlands, and altering the tidal range in rivers and bays. Changing water flow to lakes and streams, increased evaporation, and changed precipitation in some areas, will affect the size of wetlands and lakes, including the Great Lakes.*
*5. <u>Changing Aquatic Biology</u>**:** As waters become warmer, the aquatic life they now support will be replaced by other species better adapted to the warmer water (i.e., cold water fish will be replaced by warm water fish). This process, however, will occur at an uneven pace disrupting aquatic system health and allowing nonindigenous and/or invasive species to become established. In the long-term (i.e., 50 years), warmer water and changing flows may result in significant deterioration of aquatic ecosystem health in some areas.*
6. <u>Collective Impacts on Coastal Areas</u>: Most areas of the United States will see several of the water-related effects of climate change, but coastal areas are likely to see multiple impacts of climate change. These impacts include sea level rise, increased damage from floods and storms, changes in drinking water supplies, and increasing temperature and acidification of the oceans." USEPA Office of Water (2008), pages i-iii of Executive Summary.

"Impacts should be expected to vary regionally, but in general, climate change could result in increased demands on our infrastructure systems, both in terms of O&M costs and the need for capital expenditures. The suite of expected impacts can be grouped according to the type of change a system may face and fall roughly into the following categories:
• more water (through increased precipitation and storm intensity) and sea level rise;
• less water, with increased frequency and duration of drought;
• temperature change; and
• damage from more intense storms." USEPA Office of Water (2008), page 51.

"The impacts of climate change present ongoing challenges for the Agency's emergency response program. The possibility of more frequent and severe storms and flooding due to climate changes, along with the continued threat of terrorist attacks on our water and wastewater infrastructure, calls for a coordinated approach. To address this

challenge, EPA has developed an agency-wide approach that identifies roles and responsibilities for Regions and Headquarters. The EPA approach incorporates an Incident Command System (ICS) that provides a set of core concepts, terminologies, and technologies common to all federal agencies." USEPA Office of Water (2008), page 53.

The US Global Change Research Program reports impacts by sectors. Details are quoted in Appendix A. Sectors listed are: Water Resources, Energy Supply and Use, Transportation, Agriculture, Ecosystems, Human Health, and Society. Given the focus of this project, greater detail is paid to statements on the website about water resources.

Water Resources *"Climate change has already altered, and will continue to alter, the water cycle, affecting where, when, and how much water is available for all uses."* page 41

"Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change, and rainfall becomes more concentrated into heavy events (with longer, hotter dry periods in between)." Page 44

"Precipitation and runoff are likely to increase in the Northeast and Midwest in winter and spring, and decrease in the West, especially the Southwest, in spring and summer." . . .

"In areas where snowpack dominates, the timing of runoff will continue to shift to earlier in the spring and flows will be lower in late summer." Page 45

"Surface water quality and groundwater quantity will be affected by a changing climate." Page 46

"Climate change will place additional burdens on already stressed water systems." Page 47

"The past century is no longer a reasonable guide to the future for water management." Page 49

As a transition from the water sector to the other sectors, the US Global Change Program report discusses how water impacts will be interconnected to effects in other sectors. Highlights of the section Water-Related Impacts by Sector are:

"Human Health - Heavy downpours increase incidence of waterborne disease and floods, resulting in potential hazards to human life and health.

Energy Supply and Use - Hydropower production is reduced due to low flows in some regions. Power generation is reduced in fossil fuel and nuclear plants due to increased water temperatures and reduced cooling water availability.

Transportation - Floods and droughts disrupt transportation. Heavy downpours affect harbor infrastructure and inland waterways. Declining Great Lakes levels reduce freight capacity.

Agriculture and Forests - Intense precipitation can delay spring planting and damage crops. Earlier spring snowmelt leads to increased number of forest fires.

Ecosystems - Coldwater fish threatened by rising water temperatures.
Some warmwater fish will expand ranges."

Excerpts from other sections of the US Global Change Program report on potential climate change impacts on Energy Supply and Use, Transportation, Agriculture, Ecosystems, Human Health, and Society are provided in Appendix A.

Foreshadowing the economic discussion below is the following statement from the National Climatic Data Center (NCDC.) *"The National Climatic Data Center (NCDC) is the "Nation's Scorekeeper" in terms of addressing severe weather events in their historical perspective. As part of its responsibility of "monitoring and assessing the climate," NCDC* *tracks and evaluates climate events in the U.S. and globally that have great economic and societal impacts. NCDC is frequently called upon to provide summaries of global and US temperature and precipitation trends, extremes, and comparisons in their historical perspective."*

The report goes on to describe weather events that have had the greatest economic impact since 1980. *"The U.S. has sustained 96 weather-related disasters over the past 30 years in which overall damages/costs reached or exceeded $1 billion. The total normalized losses for the 96 events exceed $700 billion."*

Specific Sources on Climate Change and Freshwater Fisheries

Warming climate has the potential to impact the water temperature of freshwater lakes containing fish; Chu, Mandrak, and Minns (2005) showed how different species of freshwater fish were impacted from global climate change in Canada. A number of different variables were indicated to have a potential effect on freshwater fish populations. These researchers chose a select group of species (brook trout, walleye, and smallmouth bass) and attempted to model the effects on each population from the interaction of several variables. Variables of influence were selected by a correlation matrix. The model combined these variables to predict the occurrence of a species by region. For example, dew point, growing degree days, precipitation, and average hourly wind speed were included for determining the presence of walleye. This source indicated that cool water species will be threatened by warming water temperatures. These researchers further determined that previously existing warm-water species may expand their range northward, which may cause disruptions in previously existing population dynamics. For example, walleye and smallmouth bass may extend their range northward and prey upon previously undisturbed species.

These impacts that may occur are primarily due to changes in water temperature and changes in the levels of nutrients that may be present in the water bodies (Ficke, Myrick, & Hansen, 2007; Lettenmaier, Major, Poff, & Running, 2008). Changes in water temperature have been predicted to occur due to interactions between the changing air temperature and the surface water temperature (Lettenmaier et al., 2008). Changing the surface water temperature was predicted to cause a change in the amount of dissolved oxygen (DO) that is present in a water body (DeStasio, Hill, Kleinhans, Nibbelink, & Magnuson, 1996). Changing the amount of DO and its effects on fish populations was illustrated by Ficke, Myrick, and Hansen (2007) who illustrated that variables such as oxygen content and temperature have an effect on the well-being of fish populations. Stefan, Fang and Eaton (2001) reached similar findings for North American lakes.

B. Categories of Impacts in Minnesota

Discussions of potential impacts in Minnesota are provided by the MPCA, the MN DNR and the MN Sea Grant Office. Noteworthy assessments of climate change impacts in our region have also been provided for Wisconsin by the Wisconsin Initiative on Climate Change Impacts (WICCI.)

The MPCA climate change website states: *"Minnesota is already experiencing impacts from climate change, and will continue to experience impacts to our ecosystems, natural resources, and infrastructure."* The MPCA website quotes the US Global Change report which highlights Key Impacts in the Midwest:

- *During the summer, public health and quality of life, especially in cities, will be negatively affected by increasing heat waves, reduced air quality, and increasing insect and waterborne diseases. In the winter, warming will have mixed impacts.*
- *The likely increase in precipitation in winter and spring, more heavy downpours, and greater evaporation in summer would lead to more periods of both floods and water deficits.*
- *While the longer growing season provides the potential for increased crop yields, increases in heat waves, floods, droughts, insects, and weeds will present increasing challenges to managing crops, livestock, and forests.*
- *Native species are very likely to face increasing threats from rapidly changing climate conditions, pests, diseases, and invasive species moving in from warmer regions.*

The MN DNR has constructed an informative webpage on climate change strategies. In discussing the importance of climate change the DNR webpage states: *Climate change poses great challenges to natural resource management. It is impacting the health and productivity of lands and waters and the animals and plants that depend on them, and will exacerbate other threats from habitat loss and invasive species. It threatens the services natural lands provide—from clean water and forest products to outdoor recreation."*

"<u>*Increasing need to adapt to climate change*</u>***:*** *Minnesota ecosystems will be in transition over the next 50 to 100 years. Managers must find new ways to sustain the health, diversity, and productivity of ecosystems in the face of climate change.*

<u>*Warming waters*</u>***:*** *Climate change is expected to cause major changes in lakes and streams. Warming waters could shrink the number of trout streams and lake trout and cisco lakes, push walleye and northern pike populations northward, and expand the distribution of bass and panfish populations.*

<u>*Drying wetlands*</u>***:*** *Wetlands are projected to become drier, altering plant communities and degrading waterfowl and other wildlife habitat.*

<u>*Shifting forests*</u>***:*** *The range of major northern tree species such as black and white spruce and balsam fir is projected to shift northeastward out of the state if warming trends continue over the next 100 years. Forests may become savannas, and hardwood forests may persist mainly on north-facing slopes in some areas.*

<u>*Recreation and tourism*</u>***:*** *Recreation will be affected by changed winter weather, loss of habitat, and shifts in fisheries and wildlife populations."*

The Wisconsin Initiative on Climate Change Impacts (WICCI) is composed of a number of working groups on climate change. Their work is reported on a website. (For URL address, see Reference section at the end of this report.) The section on stormwater on the WICCI website is very relevant for economic analysis. The recommendation on adopting a risk/consequence approach to infrastructure planning in general and stormwater investment, in particular, is similar to the precautionary principle and the risk-aversion concepts discussed later in this report. The quote below is very relevant for this LCCMR project:

Stormwater *"Wisconsin's climate is changing. Wisconsin's cities and towns must also change how they manage their water resources if they are to adapt to the increases in rainfall and groundwater elevation we are already seeing. The Stormwater Working Group has brought together Wisconsin water resource managers to find ways to reduce risk to our communities and improve our stormwater management infrastructure."*

To highlight "Vulnerabilities" the website states:
Local and state government and private sector developers make significant investments in long-lived infrastructure that controls or is affected by stormwater runoff from large rainfalls. Likewise, municipal waste water treatment plant operators make substantial long-term investments in their system capacity that anticipates development, but not increased stormwater inflow and groundwater infiltration. This infrastructure is designed using standards based on rainfall data from the latter half of the 20th century. By having assumed "stationarity" of climate in the design of our infrastructure, we are now vulnerable to the following impacts from more intense rainfall events and elevated groundwater:

- *Conveyance systems filled beyond capacity cause flooded homes and urban streets;*
- *Roadways and bridges are washed-out or become impassable;*
- *Groundwater flooding of property and cropland increases;*
- *Rural residential wellheads are contaminated by flood waters and high groundwater;*
- *Impoundments and stormwater detention ponds fail more frequently;*
- *Raingardens and other biofiltration BMPs fail due to saturated soil conditions;*
- *Increased erosion of slopes by intense rainfall events leads to high sediment and phosphorus loading to surface waters;*
- *Runoff of manure from fields, and accompanying fish kills, are more frequent;*
- *Storm water inflow and groundwater infiltration to sanitary sewers, results in untreated municipal wastewater flowing into to lakes and streams.*

In summary, our previous investment in public safety and environmental protection risks being overwhelmed by precipitation impacts that are beyond those anticipated by past infrastructure designers and water resource managers."

This mindset is applied in the section on Adaptation Strategies.
"*There is a growing consensus that scientific knowledge about the potential increase in magnitude and frequency of large rainfalls is sufficient to warrant immediate changes in the methods used to design and manage storm water-related infrastructure." . . .*
"Use a risk/consequence approach to evaluating and modifying existing infrastructure to accommodate observed and predicted changes in climate."

The section on Adaptation Science is insightful, especially in applying the concepts of option value defined in Section IV of this report. "*Now imagine being a city planner or hydrologic engineer responsible for designing and implementing new storm water structures that are meant to last for the next fifty years. If you design these structures based on the weather from the last fifty years, they might lack sufficient capacity to handle rain storms of increasing intensity and frequency, perhaps leading to flooded streets and homes. On the other hand, if you plan for the worst-case scenario even though there is a small probability of it happening, you may over-design the system at a significant cost to the taxpayer if those extreme events do not materialize."*

It is noteworthy that this same challenge of weighing risks of being wrong can be applied to the trade-offs of risks in reducing greenhouse gas (GHG) emissions. Current investments in GHG reductions initiates an "insurance policy" for future decades to reduce the severity of future impacts, but there is a parallel risk in learning through time that these expenditures on emission reductions were less necessary than anticipated. The trade-offs in risks have been described as "Doing too little, too late, or doing too much, too soon." These concepts are covered in Section IV below.

The WICCI Stormwater Group offers Adaptation Science as a type of risk assessment and management. *"This conundrum represents the world of adaptation science. At a fundamental level, there are only two parts to adaptation science; calculating the probability of a future event, and creating contingency plans for those events most likely to materialize. Adaptation should focus on the greatest vulnerabilities. In short, where are the greatest risks if climate changes occur? Identifying these vulnerable locations or situations, and then creating a range of contingency plans, is the focus of many WICCI Working Groups."*

The WICCI report also provides helpful content on Milwaukee and the special risks and vulnerabilities of urban areas. Particularly relevant for this project is the section on coastal communities on Lake Superior and Lake Michigan. Numerous impacts that could result from coastal flooding and coastal erosion are highlighted. Further detail is provided in Appendix A.

The US Global Change Research Program predicts likely impacts on Lake Superior: *"Significant reductions in Great Lakes water levels, which are projected under higher emissions scenarios, lead to impacts on shipping, infrastructure, beaches, and ecosystems. . . .*
Higher temperatures will mean more evaporation and hence a likely reduction in Great Lakes water levels. Reduced lake ice increases evaporation in winter, contributing to the decline. This will affect shipping, ecosystems, recreation, infrastructure, and dredging requirements. Costs will include lost recreation and tourism dollars and increased repair and maintenance costs." pages 117 -122.

The MN Sea Grant Program also discusses likely impacts on Lake Superior. Categories of impacts are:

- *"Lake Superior's surface water temperature in summer has warmed twice as much as the air above it since 1980. Lake Superior's ice cover is diminishing.*
- *Wind speeds over Lake Superior are increasing.*

- *Lake Superior's summer stratification season is longer.*
- *Lake Superior's summer stratification season is longer."*

Another potential impact to water resources in MN is on fish and fisheries. The WICCI website emphasizes the vulnerabilities of coldwater fish and fisheries.
"*Coldwater fish, such as Wisconsin's native brook trout, are very sensitive to changes in water temperature and other environmental conditions and may be important ecological indicators for climate change. In addition, native coldwater fish are an integral part of Wisconsin's natural legacy, brook trout in net and coldwater fisheries are a core part of our culture and identity. Anglers make a significant contribution to the local and state economies in pursuit of their passion. In the face of changing climate conditions it is important to assess the potential impacts to coldwater fish and fisheries and implement adaptive management plans to ameliorate climate change impacts on Wisconsin's coldwater streams and inland lakes and their fisheries."*

The WIICI document advocates for maintaining the value of fisheries as a public good. It provides an example of an economic approach to maximizing net benefits given constrained resources. The Coldwater Fish Group considers a triage approach described as follows*:*
"A triage approach to the management of coldwater streams may involve classifying streams based on their potential to withstand climate change impacts. Our best, most resilient coldwater streams may be protected from habitat degradation. We may cease to allocate scarce resources to our marginal and least resilient coldwater streams. For those coldwater streams in between, we may allocate habitat restoration money or stocking quotas to those streams most likely to realize benefits in the face of changing climate." Other strategies noted are to establish *"refugia" from high water temperatures and to focus on best land-management practices in the watersheds of coldwater streams to enhance "biological integrity" and "resiliency to climate change impacts."* The underlying concepts for these precautionary approaches are discussed further in Section IV on non-market values and risk aversion premiums. Additional content from the WICCI Stormwater Working Group is provided in Appendix A.

Consistent with the approaches advocated by the WICCI Working Groups, MN should identify settings with the greatest vulnerability to catastrophic failure such as loss of life and property if structures fail. Most of the MN topography does not cause as great of danger of flash flooding as in more mountainous areas. The severe flood in southeastern MN in 2007 demonstrates that the topography of that part of the state makes it more vulnerable to severe flash floods. Elsewhere, overland flooding is more likely to occur rather than the deep rush of water with floods in hills and valleys. The tragedy of loss of life in the June 2010 disaster at the Albert Pike Recreation Area in Arkansas is an example of the type of worst-case scenario from flash flooding. MN should adopt a two-pronged approach to risk management to the degree that MN can inventory watersheds for combination of two groups of characteristics. A convergence of two characteristics that cause greatest vulnerability to damages from flash floods should be inventoried: 1) geomorphology conducive to flash floods and 2) human and natural environments that put highly valued assets and human life in harm's way.

Findings from the component of the project on streamflow reported in Section IIIC below indicate that the Minnesota River Basin and the Red River of the North have larger increases in sreamflow than the other three basins in the state. Even though extreme precipitation events are likely to be randomly located across the state, it would be a wise investment to protect against such disasters in the most vulnerable locations. This would be a sound application of the Precautionary Principle and risk aversion discussed further below in Section IV.

SECTION III.
SPECIFIC FINDINGS ON CLIMATE CHANGE IMPACTS ON MINNESOTA'S WATER RESOURCES

A. Evidence of Climate Change in Minnesota

Climatologist Mark Seeley presented at the Climate Adaptation Summit, December 3, 2009. Major trends in Minnesota's climate were discussed. Those highlighted here are most relevant for this report given their potential socio-economic significance. Again the focus is on implications for water resources.

1. Changing character and quality of precipitation: there is an increasing proportion of annual precipitation coming in summer thunderstorms and these have more spatial variability than other precipitation events,
2. Warmer winter minimum temperatures,
3. Higher summer heat indices due to higher humidity and higher ambient air temperature,
4. Increase in the number of freeze/thaw days

The overall research project included climatic analyses as a foundation for understanding potential impacts on Minnesota's water resources. This component of the research project was conducted by Richard Skaggs and Kenneth Blumenfeld. Findings are summarized in an earlier project report: LCCMR 2005 *Impacts on Minnesota's aquatic resources from climate change, Phase I - W-12*, Result 2: Historic Climate Data. The analysis of climatic regimes or episodes concludes: "Dry summers are likely to be normal or warm, and cool summers most frequently normal for precipitation. Also, warm, wet summers are quite rare. Warm summers tend to be dry or normal, and wet summers tend to have normal, or even cool temperatures. These patterns were consistent throughout the state, for summers, aquatic growing seasons, and for water years. During winter periods, no clear relationships emerged, but also, the differences in the total quantity of water between 'wet' and 'dry' winters was much smaller than for summers." Page 8

The MN Sea Grant findings on changes in climate in the region are as follows:
"*Although the details of regional climate predictions are still crude and model-dependent, it seems likely that around Lake Superior people should expect:*

- *More frequent and intense storms.*
- *Increased climate variability and extremes.*
- *Warmer annual temperatures.*
- *Drier summers (reduction in soil moisture).*
- *Warmer nights. (Minimum or 'overnight low' temperatures have been rising faster than the maximum temperature.)*
- *Warmer winters. (Winter temperatures have been rising about twice as fast as annual average temperatures.)*
- *Similar winter precipitation. (But more will fall as rain.)*
- *Lower water levels in Lake Superior. (Even for scenarios that forecast increases in precipitation, most climate models predict lower water levels for Lake Superior because of increased evaporation.)*

- *Changes in the species composition of both terrestrial and aquatic ecosystems.*
- *Longer growing seasons."*

B. Potential Environmental Changes in Minnesota

Some studies at the national or international level reduce the spatial scale down to the state level. Research for the National Weather Service has categorized weather-related damages by state. A study by Pielke, et al. (NOAA, 2002) estimates the monetized damage estimates from National Weather Service records for each state. This information is aggregated from separate datasets. Information from local regions was added to statewide data in some cases. Damage information spans from 1925 to 2000. Despite some data limitations that are explicitly noted, the document contains useful information. For example, flooding in Minnesota cost over $900 million in 1993 and $700 million in 1997. The annual damage figures for MN from 1955 to 2000 are reported in Section VI. Current and constant dollar estimates are provided.

Research by Lettenmaier, et al. (2008) examines the current relationship between climate change and water. This study projects the near term impacts of global climate change on water resources in the United States for the next 25 to 50 years. Major aspects included are streamflow, evaporation, drought, precipitation, runoff and water quality. Minor focus areas include land use and ground water impacts. In the analysis of streamflow, trends from 393 stations in the US were plotted on maps with statistically significant increases reported in the central portion of the United States, including source stations in Minnesota. Evaporation rates are examined and where net decreases occur plausible explanations are offered, such as being due to increased cloud cover.

Droughts are anticipated to occur more frequently in the West and Southwest. A wetter climate overall is found to occur based on data from 1915 to 2003. Droughts are not projected to affect the central portion of the United States. Regional analysis is conducted for the central portion of the US, which includes Minnesota. Two separate studies have indicated an overall increase in precipitation in this region.

In relation to increased precipitation, runoff rates are explored using USGS statistics on runoff trends from 1901 to 1970. Projection these trends into the future, suggests an overall increase in runoff in the central US. Within this region, there is likely to be an increase in runoff in the Upper Mississippi basin.

Water quality is also examined. Variables such as eutrophication from increased nutrient loads and increased temperature are explored. Nutrient loading may occur from increased runoff and more highly variable heavy precipitation events. Decreased consistent precipitation could cause eutrophication, especially in rivers, from the increased levels of nutrients without adequate consistent flows. Also, nutrients create the conditions for algal growth. The existence of algae will lower the amount of dissolved oxygen due to consumption when photosynthesis is not occurring. The reported past changes in water quality have not been attributed to climate change. Land use is also discussed as a major determinant of water quality. A MN study is cited referring to high rates of chloride and phosphorous in urban and agricultural area waters respectively. These differing land use practices can impact runoff rates.

Further detail on this study can be found in the Annotated Bibliography in Appendix D. Apppendix A and Section VI provide additional content from state agencies, including the MPCA, MNDNR, MN Department of Health (DOH), MN Department of Transportation (DOT) and the MN Department of Public Safety.

One of the themes that emerges in the literature applying economic analysis to climate change impacts is that infrastructure investment should establish a larger margin of safety for the future in roads, bridges, culverts, drinking water facilities, and wastewater and stormwater facilities as a precaution against more extreme weather patterns. It is informative to consult the manuals used by MNDOT for road, culvert and bridge design. The MNDOT Drainage Manual http://www.dot.state.mn.us/bridge/hydraulics/drainagemanual/ includes sections (see 3.2.1 and 4.2.3) with recommended design frequencies.

For bridges, typical design is for 50-year floods, with recommendations to check 100-year flow levels and to check scour for 100-year and 500-year flows or the minimum flow level that would cause overtopping. For roadside channels the recommended design is for a 100-year flood frequency. Culverts less than 48 inches have 50-year flood design and those greater than 48 inches require risk assessment and computation of the 500-year flood or floods that are more frequent that would be sufficient to cause overtopping. The required risk assessment utilizes hydrographs for anticipating rainfall and runoff for the particular watershed and location of the infrastructure. But climate change indicates that these hydrographs should be adjusted or a buffer built in for higher rainfall amounts and more frequent heavy rain events.

It is also useful to consult the State Aid Manual to Counties and Cities for projects using State or Federal funds. One topic is the design and construction of storm sewers for moving water off of roads. The manual includes tables which set the maximum fraction of a road surface (driving lane) that can have water over it during a severe rain event. This manual also has a section on “Sizing and Over-sizing.” This section has a “Maximum Allowable Spread Table” for state aid storm sewer design.

MNDOT officials regard the current design protocols as building in a margin of safety that should be sufficient to handle the increases in flows and more frequent flood events anticipated in the literature (personal correspondence, Frank Pafko, MNDOT Chief Environmental Officer and Director of Environmental Services.) It would be a mammoth undertaking requiring enormous investment to prepare most transportation infrastructure for 500-year floods. So a margin of safety is built in except perhaps for extreme events that are randomly distributed and impossible to anticipate.

C. Evidence of Environmental Changes in Minnesota: Project Findings

Water Levels in Lakes and Streams

Two reports have emerged on water resources as part of this LCCMR project. Dedaser-Celik and Stefan (2007, 2008) produces two main findings of particular importance for economic analysis. First, water levels were rising in some Minnesota lakes (Dedaser-Celik & Stefan, 2007). Second, precipitation in Minnesota had a trend that is increasing in intensity and amount (Dedaser-Celik & Stefan, 2008). These findings were similar to those predicted in the literature indicating that climate change may cause precipitation and runoff rates to increase in northern latitudes. However, these implications were contradicted by the study below.

Dedaser-Celik & Stefan (2009) analyzed trends in streamflow in Minnesota since 1946 using gauges from five different river basins across the state. The trends observed matched many predicted by other climate change literature such as increased high flow due to increased runoff. While extreme flood events have not increased, flows over a wide range of recurrence intervals have either increased over time or remained the same. These researchers did determine that rivers located in areas with higher rates of precipitation showed increases in streamflow.

Selected findings from the five basins are excerpted below from the project summary: "Stream Flow Studies: *Stream Flow Response to Climate in Minnesota."*
Data from 36 gauging stations located in five river basins of Minnesota (Minnesota River, Rainy River, Red River of the North, Lake Superior, and Upper Mississippi River Basins) were used for the 1946-2005 period.

Flow Duration Curves. To detect any changes that have occurred over time, data from the (1986-2005) and the (1946-1965) period of record were analyzed separately. Flow duration curves were prepared for all gauging stations, low flows (Q90, Q95), medium flows (Q50), and high flows (Q5, Q10) in the two time periods were examined.

The Minnesota River Basin has experienced the largest stream flow changes in the last 20 years compared to the other four basins. High, medium, and low flows have increased significantly from the 1946-1965 to the 1986-2005 period (on average Q50 increased by about 200%). The increases in medium to low flows were larger than the increases in high flows. Considerable changes in flows were also observed in the Upper Mississippi River Basin and the Red River of the North Basin (on average Q50 increased by about 80%). Streams in the Rainy River Basin and tributaries to Lake Superior showed little or no change in stream flow distribution (about 10 to 30% on average) between the 1946-1965 and 1986-2005 periods.

High and Low Flow Ranking. Both annual peak flows and 7-day average low flows were higher in the 1986-2005 period in the Minnesota River Basin, Red River of the North Basin, and Upper Mississippi River Basin. Increases in observed 7-day average low flows were more significant than increases in observed annual peak flows. For example, in the Minnesota River Basin and Red River of the North Basin, all stations showed more than the expected number of peak annual and 7-day average low flows in the last 20 years.

Flood Frequency Analyses. Separate flood frequency analyses were conducted on the stream flow data from the 36 stream gauging stations for the (1946-1965) and the (1986-2005) periods to identify changes in the 1-, 2-, 5-, 10- and 25-yr floods. The results were most consistent for the Red River of the North Basin. In this basin, magnitudes of the 2- to 25-yr floods increased at all six stream gauging stations (average increases were from about 30 to 60%) and the magnitude of the 1-yr flood decreased (average of 20%). Results obtained for the Minnesota River, Rainy River, Lake Superior, and Upper Mississippi River Basins were not conclusive because the changes observed at individual stations in each river basin were not consistent; both increases and decreases were observed. Average changes in the 1- to 25-yr floods were between 21 and 320% in the Minnesota River Basin, -7% and -20% in the Rainy River Basin, -11% and 26% in *the Lake Superior Basin, and -8 and 23% in the Upper Mississippi River Basin.*

There are many potential causes for changes in stream flows. Precipitation is one. The river basins which showed the largest increases in stream flows (Minnesota River Basin and Red River of the North Basins) drain regions (climate divisions) where significant increases in precipitation have been observed. River basins which showed little or no change in stream flow (Rainy River and Lake Superior Basin) drain climate divisions where changes in precipitation were not significant. Agricultural drainage and changes in crop patterns are other potential causes that need to be considered."

Ice Duration Analysis

Virginia Card (2010) provided findings from the dataset on dates of ice formation and ice thawing on 40 lakes from 1970 to 2008. These dates were used to calculate the days of ice duration each year. The average number of days of ice duration lost or gained over this period was also calculated. It was found that lake ice duration in the Minnesota sample is significantly decreasing at a mean rate of 3.3 days per decade from the time period of 1970 to 2008. As is explained further in Section VIB, these values were also uses in a one sample t-test to test the null hypothesis that there is no change in the amount of ice duration. The mean rate of 3.3 fewer days of ice duration per decade is significantly greater than zero at the 1% level of significance.

Fish Habitat Changes and Fish Abundance Shifts

Two separate Minnesota studies have examined the impacts of climate change on freshwater fisheries. In the first study, Schneider, Newman, Card, Weisber, and Pereira (2005) examined the impacts on changing ice-out conditions in Minnesota on walleye spawning timing. These researchers found that there is a significant relationship between the change in ice-out and the change in the time that walleye lay eggs. This piece of literature combined ice-out data from lakes around the state with data concerning egg-take from walleye populations. The researchers found that for every one day decrease in the presence of lake ice there was a .5 to 1 day decrease to the day that a walleye lays its eggs. These authors postulated that this may have an impact on the well-being of the fishery if there is a mistiming in the availability of prey with a change in spawning timing. It is not clear if this change in timing was also correlated with a change in spawning duration.

In the second study, Schneider, Newman, Weisberg, and Pereira (2009) examined the current trends in fish communities in response to changing climate in Minnesota. Several temperature variables were compared with the abundance of species in 35 different lakes. Some of these variables included summer temperature, average annual temperature and temperature extremes. The methods of this study utilized catch per unit effort (CPUE) from gillnet and trapnet surveys. These researchers discovered that the majority of fish species were expanding their range northward except smallmouth bass. In addition, these researchers discovered that increases in average summer temperature were correlated with increases in largemouth bass and sunfish abundance. Moreover, increasing air temperature was correlated with a decrease in the abundance of whitefish and trout. Fang, et al, (2004) projected fish habitat changes using a scenario of doubling C)2 emissions.

In summary, changes in water temperature and variables impacting the amount of DO in a water body are the main factors that may potentially impact fish populations from the onset of climate change. The evidence indicates that Minnesota is not currently seeing some of the predicted impacts found in the broader climate change literature. These potential impacts remain tangential to the research project at hand. However, the well-being of these populations influences the economic benefits from fishing. For example, studies discussed below indicate that catch rate had a significant impact on willingness to pay (Stevens, 1966). If fish populations are negatively impacted from climate change there may also be an economic impact.

Water Quality

The project team includes researchers focusing on trends in water quality in Minnesota lakes. Axler et al. (2009) provided online resources to access a voluminous database that they developed for water quality parameters from over 630 MN lakes. Lakes selected had more than 15 years of data for at least one water quality measure involving 1.9 million records. Major findings from their analysis of the data include: (pages 12-16)

- *"In the context of the climate change issue that spawned the present study, the most important result derived from the exploratory trend analyses has been that for lakes with significant time trends during the summer, more than 90% showed surface water warming as compared to cooling. This result was found for over 26% of those lakes with at least 5 years of data (247 of the 551 lakes examined) and almost 2/3 of the 60 lakes with 18 years or more data. For the 37 lakes that showed statistically significant warming over their period of record, the mean trend was 0.080 + oC/yr. This would project to an average increase of 0.8 oC (1.4 oF) in 10 years, and 3.3 oC (5.9 oF) by 2050."*

- *"Warmer growing season air temperatures have generally been predicted to decrease the depth of the thermocline (i.e. creating a shallower epilimnion) in most lakes as a consequence of increased warming of the epilimnion and increased thermal stability. Although only 16% of lakes with >5 years of data had significant trends in thermocline depth, 85% of those that did, exhibited decreasing (i.e. shallower) thermocline depths... Thermocline stability only showed statistically significant trends in 10-18% of lakes depending on the length of data record, but almost all trends were positive. Together, these data are consistent with surface warming. Trends in hypolimnetic water showed the opposite effect with about 20% of the lakes having at least 5 years of temperature profile data having statistically significant trends and more than 75% of those being negative (cooling)."*

- *"The salt content of surface waters and chloride concentration has increased over time in more than a third of the lakes with >5 years of data, 50% of those with >8 years, and 90% with >18 years of data. This is consistent with increased summer surface warming but also with potential increased exposure to winter de-icing salts and/or increased stormwater runoff from either urban or agricultural areas. Increased loading to the whole lake such as would occur from runoff inputs are suggested for the deeper lakes where trends were found, since the entire water column, not just the epilimnion exhibited increases."*

- *"Perhaps the most surprising result found in this study was that there was internal* *consistency within the group of trophic status indicators (secchi depth clarity, chlorophyll-a, total phosphorus and total Kjeldahl nitrogen) that suggests a strong overall improvement in water quality. These trends were found for a large number of lakes- ~40% of the lakes in the secchi data set had statistically significant trends, and of these >80% were increasing (i.e. clearer water)."*

Overall, these analyses suggested an overall "improvement" in the water quality of the great majority of lakes that showed trends over the past 20 years in the sense of increased clarity and decreased chlorophyll and nutrients. A much smaller fraction of the lakes in the data set exhibited trends in thermal and related characteristics, and of those, the great majority were consistent with the predictions of potential climate warming effects for lakes in the Upper Midwest. However, it is extremely important to note that the current set of lakes is not distributed randomly across the state because the preponderance of lakes with longer data sets are located in the central and Minneapolis-St-Paul metropolitan areas of the state.

There are countervailing trends at play here, such as reduced industrial discharges and nutrient reductions from some non-point sources, while increasing intensity of development in many lakesheds are likely to heighten non-point source impacts. These watershed impacts must be juxtaposed with the potential effects of climate change and so it is extremely difficult to isolate the impact of climate change separately.

Despite these "mixed" results on trends in Minnesota lake water quality, it is extremely important to consider potential impacts of climate change given the importance of the resources at stake. The current impaired waters list in Minnesota includes over 1,000 lakes and 400 rivers. Indeed, efforts to improve these conditions, i.e. the ongoing point and non-point pollution reduction efforts , should be part of the positive changes evidenced by these project findings. Equally important however, is the potential for increased sediment and nutrient loading from increased stormwater runoff due to projected increases in the frequency of intense storms, and for decreased cold water fish habitat due to warming, more stable thermal stratification, and decreased oxygen in stratified lakes. A related, major concern for the future of Minnesota waters is the threat of invasive species, which is also projected to increase in concert with projected changes in Minnesota's climate. Therefore, climate change can be a contributing factor to a worse future for Minnesota's surface waters, by impeding the improvements being made from ongoing mitigation and restoration efforts.

Given the tremendous importance of lakes and streams to Minnesotans, including economically, the discussion below conceptualizes water quality efforts as an insurance policy. Efforts to promote lake ecological integrity and resilience can establish a cushion for the negative impacts climate change could cause. Best practices can set a margin of safety against the worst-case scenario that climate change could bring to the state's lakes and streams. A more extensive discussion of potential economic impacts of changes in water quality is found below in Sections IV and VI.

SECTION IV.
CONCEPTUAL FRAMEWORK FOR INFERRING ECONOMIC IMPACTS

The foundation for economic analysis of potential impacts of climate change is in the conceptual framework for economic valuation. There is a rich literature that establishes the analytical basis for components of value that society places on environmental goods and services. The field of environmental economics expanded immensely in response to the needs for enhanced understanding of the economic implications of the environmental policies of the 1970s. The literature and tools of economic analysis of water resources grew in tandem with and in response to the policy processes that led to the Clean Water Act. Without repeating some of the excellent surveys of the literature available, it is worthwhile for the purposes of this study to recount some of the development of concepts regarding the economic value of water resources. The conceptual framework that emerged serves as a foundation for understanding the potential economic impacts of climate change on Minnesota's water resources. Excellent explanations of these concepts and summaries of the empirical evidence can be found in Tietenberg and Lewis (2009) and Boardman, et al. (2006).

Seminal work in the economics of water quality was conducted by Desvousges, Smith, and McGivney (1983) in a study for the EPA on the economics of cleaning up the Monongohela River in Pennsylvania. The empirical analysis emphasized use values for recreation but an insightful conceptual framework was constructed for understanding the various components of economic value of clean water. This study enhanced the understanding of non-use values of environmental quality, particularly water quality. Figure IV.1 below is adapted from the Desvousges, et al. (1983) report. Potential water quality benefits were broken into two main categories: Current user benefits and Intrinsic Benefits. The latter term was chosen to infer that water generates inherent value to society separate from the extractive, commercial, recreational or aesthetic values that we place on water. The potential use of water (an insurance premium against the risk of losing the option to use) that never materializes as actual use was included as an intrinsic benefit along with existence value. This second component of intrinsic benefits comes from motives towards stewardship or to bequeathe an environmental good or service totally unrelated to current "use" of water.

Through time the literature offered alternative sets of terminology such as "use" and "non-use" value and "use" and "passive use" value. Regardless of the pros and cons among these sets of terminology for grouping major components of value, the underlying components of value continued to be use value, option value, and existence value. Further development of these concepts was shown in a closely related figure from an important survey of the literature by Mitchell and Carson (1989). Slight variation from the Desvousges, et al. conceptual framework is shown in Figure IV.2.

Potential Water Quality Benefits	Current User Benefits	Direct Use	In Lake or Stream	Recreation - fishing, swimming, boating, rafting, etc.
				Commercial - fishing, navigation
			Withdrawal	Municipal - drinking water, waste disposal
				Agricultural - irrigation
				Industrial/Commercial - cooling, process treatment, waste disposal, steam generation
		Indirect Use	Near Lake or Stream	Recreational - hiking, picnicking, birdwatching, photography, etc.
				Relaxation - viewing
				Aesthetic - enhancement of adjoining site amenities
	Intrinsic Benefits	Potential Use	Option	Near-term potential use
				Long-term potential use
		No Use	Existence	Stewardship - maintaining a good environment for everyone to enjoy (including future family use-bequest)
				Vicarious consumption - enjoyment from the knowledge that others are using the resource.

Figure IV.1. A Spectrum of Water Quality Benefits
Source: Adapted from Desvousges, Smith and McGivney (1983)

Benefit Class	Benefit Category	Benefit Subcategory (examples)
Use	In-Stream	Recreational (water skiing, fishing, swimming, boating)
		Commercial (fishing, navigation)
	Withdrawal	Municipal (drinking water, waste disposal)
		Agriculture (irrigation)
		Industrial/Commercial (process treatment, waste disposal
	Aesthetic	Enhanced near-water recreation (hiking, picnicking, photography)
		Enhanced routine viewing (commuting, office/home views)
	Ecosystem	Enhanced recreation support (duck hunting)
		Enhanced general ecosystem support (food chain)
Existence	Vicarious Consumption	Significant others (relatives, close friends)
		Diffuse others (general public)
	Stewardship	Inherent (preserving remote wetlands)
		Bequest (family, future generations)

Figure IV.2. A Typology of Possible Benefits from an Improvement in Freshwater Quality

Source: Mitchell and Carson (1989), adapted from Figure 3-1.

Another categorization that has emerged in the literature is between market and non-market values. This analytical distinction has a practical reward in that it focuses attention among empirical analysts to operationalize these value components in techniques for measuring environmental benefits. From an empirical perspective, a key issue is whether observable market data directly reveal people's values or whether indirect measures of related behavior or statements of preferences are needed to comprehensively infer total economic value. A noteworthy advancement in the literature is the multitude of studies that recognized that empirical estimates of environmental benefits would be grossly understated for many environmental goods and services if only use values were included. The Desvousges et al. study was a catalyst in this process. So to was a study by Fisher and Raucher (1984) that surveyed the literature on water quality benefits and showed evidence that empirical estimates of intrinsic benefits of water are too substantial to ignore. Conventional methods of benefits estimation needed to go beyond use values and this was reflected in empirical practices supported by the EPA and within the field of environmental and natural resource economics.

The sub-sections below further develop the concepts of market and non-market values and apply them to the potential impacts of climate change.

A. Market Values

Complete estimation of total economic value is most straightforward when use value is the only component of value and market data exist to measure the market demand curve. Measuring the market demand curve captures entire willingness to pay (WTP) for a good or service. Net benefits to consumers can be found by subtracting consumers' expenditures from WTP to find consumers' surplus, which measures the net gain to consumers. Market estimates based solely on what consumers actually pay exclude consumers' surplus and are an underestimate of WTP.

Referring to the benefits taxonomies in Figures IV.1 and 2, use values such as commercial shipping on waterways can be measured via market transactions. This is also true for recreation where monetary transactions occur in the market, such as a guided fishing activity. Market data are often available for unguided activities as well, but some uses, such as boat access via a public access, may be more difficult to capture through market transactions. Still as recreational uses, economists would look to market transactions in purchasing gas, equipment, etc. as revealing the values of those activities. Similarly, in some settings there is a market for irrigation water so that market demand could be estimated but in others markets are absent or incomplete so market data would not capture the entire WTP.

Even though public drinking water and waste disposal is often provided through the public sector, again expenditures on these activities would be looked to as evidence of the value of these services. Public pricing schemes could make WTP for these services more difficult to discern, but use values should be possible to determine.

Climate change impacts found in the literature and highlighted above in Sections II and III indicate a multitude of market values that could be impacted by climate change. In terms of water resources, some of the major market values that could be impacted are:

- recreational fishing,
- commercial fishing,
- commercial transportation on waterways,
- agricultural irrigation,
- infrastructure damages from flooding (drinking water, wastewater, and stormwater facilities, roads, bridges, culverts, and other structures),
- flood damages to crops, forests and other lands with commercial yields
- hydroelectric power generation,
- water-borne diseases
- insurance costs

B. Non-Market Values

In addition to option values and existence values discussed earlier in this section, another value that tends not to be revealed through market transactions is quasi-option value. Quasi-option value represents the value of forthcoming information yielded by avoiding an irreversible outcome. If an irreversible choice is made that precludes learning about trade-offs through forthcoming information than the value of this information is destroyed. It is distinct from option value in that it is not a risk-aversion premium, per se. Preserving forthcoming information has a quasi-option value and is often referred to in settings where policies will enable endogenous learning. Avoiding potentially irreversible consequences of climate change should generate substantial quasi-option values.

The Basic Conceptual Framework for Option Value of Avoiding Damages From Climate Change

In the extensive literature on option value, the concept is consistently defined as the difference between option price and expected consumer surplus, where option price is the maximum willingness-to-pay to maintain the option of future consumption. The concept is used to explain why people willingly purchase insurance and pay a premium that exceeds the expected loss. Hence option value is referred to as a risk-aversion premium. The conceptual framework for the application of option value to protecting against climate change impacts is adapted from the model in Freeman (1985).

Equivalent surplus, ES, is defined as the willingness-to-pay to avoid certain damages to water resources from climate change. But given climate change poses a risk of impacts greater than 0 but less than 100% certain, efforts to reduce the impacts of climate change must be seen as lowering these probabilities. Similarly climate change can be conceptualized as increasing risks by increasing the dispersion of likely future states of the world. Even if the expected values for qualities and quantities of Minnesota water resources are assumed to remain unchanged, the widening of the extreme outcomes increases the riskiness of the world in the future. Given society is made up of individuals who typically are risk averse, increased risk due to climate change causes a loss in well-being.

The theoretical discussion of option value in the economics literature associates risk-averse preferences with characteristics of the typical individual's utility function. Specifically the utility function is assumed to be concave downward, i.e. exhibiting diminishing marginal utility of income. Departures from these and other theoretical assumptions lead to different conclusions about the sign and importance of option value. Boardman, et al. (2006) provides an informative overview of this debate.

Indeed the debate in the theoretical literature on option value has also played out in the economic analysis of climate change. The Stern Review (2006) provides seminal analysis of potential global economic impacts of climate change. It has been a catalyst for further scholarship on this topic. Stern relies heavily on option value as a component of the economic value of reducing the threat from climate change. Others have concurred with this conclusion while still others vehemently disagree. A key point of disagreement with the conclusion that option value should be counted as a positive benefit of reducing the threat of climate change is the view that individuals are also averse to the risk of losing income by spending on climate change mitigation that may turn out to be unnecessary. But this argument misses the point that the trade-off in risks uses income as the unit of account. Money is the common denominator for balancing the risks of "doing too much too soon, or too little too late." The income equivalent to reduce environmental risk is already in the form of this monetary expenditure. The count money again as a risk of unneeded expenditure would be double counting. The WTP of risk-averse individuals exceeds expected loss because they see the risk of environmental damage as warranting the risk of spending money, even if unnecessarily.

The reasoning some authors use to conclude that climate change mitigation will not generate economic benefits in the form of option value would also be flawed when applied to the insurance industry. This reasoning would wrongly imply that individuals would quit buying homeowners insurance. In reflecting back on a year where no insurance claims needed to be filed, would a risk-averse individual attach greater risk to spending on insurance unnecessarily because no damages occurred? The repeated expenditure for insurance demonstrates that individuals benefit from the sense of security from a loss (even if it has low-probability), and weigh avoidance of that loss more heavily than the chance that they could have gotten by without purchasing insurance. The insurance industry depends on individuals having preferences in weighing risks that are manifested in WTP being more than the actuarially expected loss. That risk-aversion premium is the source of profits to the insurance industry.

Reducing the risk to water resources from climate change also generates a risk-aversion premium defined as option value. But in addition to the insurance industry analogy, option value accumulates to all individuals that are averse to these risks. So benefit accumulates simultaneously to all of these individuals due to policies that reduce these risks. This collective benefit fits the definition of a public good, explained further below.

The literature applying the concept of option value to climate change is surveyed in Section V. But for the sake of flow within the body of the report, additional material on option value is contained in the appendices. Given the complexity and technical nature of this literature, some excerpts from the literature are provided in Appendix A. The basic analytical framework is presented in Appendix B. The annotated bibliography in Appendix D highlights selected sources that apply option value to climate change mitigation.

The discussion above applies to a simple case (Case 1) where option value serves to maximize expected utility when risk is introduced to a previously riskless situation. A more realistic characterization of the risks imposed by climate change is to add greater extremes to an already risky world. The simple case presented above portrays climate change as introducing risk to the future quality and quantity of water resources. In reality, the future of Minnesota's water resources is already risky, without the added threat of climate change. So the more complex scenario modeled in Case 2 shown in Appendix B portrays climate change as widening the dispersion of likely future states of the world.

The literature on impacts notes that some environmental changes could be negative and some positive. If the negative changes outweigh the positive, there will be a socio-economic loss due to climate change. But Case 2 in Appendix B emphasizes option value by assuming that the negative and positive impacts of climate change on water resources will be of equal magnitude and equally likely. So the loss is not due to a decline in expected values. Rather it is due to the preference to reduce the risk inherent in more dispersed outcomes.

To demonstrate the conceptual point, two future states of the world are considered in Case 2. One could be a gain in the quality and quantity water resources and the other could be an equal loss. So the expected value of the resource remains unchanged but the dispersion is more extreme. Again a risk-neutral individual would sense no loss from this greater dispersion so would have no option value. But being most people are risk averse, they would attach substantial option value to insure against the dispersion between the best-case and worst-case scenarios.

Option value applies more widely to climate change impacts than just to water resources. In fact it addresses a fundamental aspect of the potential economic loss from climate change. Statisticians characterize distributions with measures of Central Tendency and Dispersion. Much of the concern about climate change impacts has focused on increases in measures of Central Tendency such as higher average temperatures of higher mean precipitation. But from a socio-economic perspective the potential damages linked to increasing dispersion, such as more extreme temperatures or precipitation patterns may be just as damaging to social and economic well-being. The concept of option value is crucial to understanding the economic impacts of climate change.

Economists generally regard option value, existence value, and quasi-option value as not being captured in market transactions. Climate change impacts found in the literature and highlighted above in Sections II and III indicate a multitude of non-market values that could be impacted by climate change. In terms of water resources, some of the major non-market values that could be impacted are:

- water quality
- fish habitat
- preservation of "natural" distribution of cold-water species such as lake trout and cisco
- preservation of native aquatic plants
- preservation of "natural" levels of surface waters

C. Sustainability

The concept of sustainability covers a wide range of concepts that share an orientation toward future well-being. As a transition from the previous section it is noteworthy that one aspect of sustainability is risk-aversion toward degradation of the quality of life of future generations. As noted above, the Stern Review emphasized option value as an important component of the benefits of controlling greenhouse gas emissions. Along similar lines, sustainability provides a rationale to take preventive action. A related approach to risk-aversion for the sake of the current or future generations is the Precautionary Principle.

The Precautionary Principle and Risk Reduction as a Public Good

Water Resources are an important category demonstrating the potential economic consequences of extreme conditions, not just a matter of changing average water temperatures or streamflows, but the potentially dire consequences of greater extremes. Drinking water, stormwater and sanity sewer systems could require enormous investments to deal with extreme conditions. The Precautionary Principle indicates that in the face of potential damages, a margin of safety is in order. Risk-aversion suggests that actions are beneficial that "play it safe" or "hedge bets." The Precautionary Principle fortifies option value for the current generation and sustainability for the future.

The value of water resources and the ecological services provided are so large as to indicate that it would be economically efficient to incur substantial costs to avoid these losses. As the USEPA document "National Water Program Strategy: Response to Climate Change" suggests, large costs to reduce other bad actions that compromise drinking water or surface water quality may be warranted to offset the degradation that could be anticipated from climate change. For example, it may be economically efficient to invest in land-use changes and/or wastewater treatment that reduce nutrients so that climate change does not put us over the threshold toward lower water quality.

If an economic standard is met indicating that the benefits of protecting water quality against degradation from climate change are worth the costs, the next decision criterion would be to achieve these benefits at minimum cost. In order to protect these water resources, the costs of countervailing measures would need to be compared to the costs of reducing greenhouse gas emissions as root causes of these problems. The economic comparison needs to be mindful that measures that address root causes of problems often are more economically efficient than "band-aid" solutions that merely address the symptoms. A comparison of the costs of land-use changes versus greenhouse gas emissions reductions would need to consider that both choices have broader implications beyond water quality, especially the latter and on a global scale. All else equal, reducing the human causes of climate change are likely to yield larger net benefits than best practices to reduce nutrient loads to surface waters given the broader climate change impacts that could be avoided by reducing greenhouse gases.

The benefits of precautionary actions do not only accrue to one individual as with a private good. The value of precaution is a public good because it accumulates simultaneously to all individuals that are risk averse. While private goods are valued at individual WTP that is summed horizontally along the quantity axis for the good, public goods generate social benefits based on what economists call "vertical summation." This term comes from the convention of graphing WTP on the vertical axis in the market model. Benefits are aggregated for all individuals that benefit from the provision of a public good, such as reduced risks of damages from climate change.

A paper on the economic impacts of climate change by Heal and Kristrom (2002) is particularly thorough on the concept of option value and the Precautionary Principle. They extend the discussion of balancing risks in the previous section by including the aspect of irreversibility and endogenous learning. These concepts were discussed above in relation to quasi-option value. Heal and Kristrom state: "the preconditions necessary for the existence of an option value seem to be satisfied in the context of climate change. We expect to learn about the costs of climate change and about the costs of avoiding it over the next decades. And we expect that some of the decisions that we could take will have consequences that are irreversible. These are the hallmarks of decisions that give rise to option values associated with conservation . . . But although these conditions are necessary for the existence of option values they are not sufficient. . . . there is another possible real option value at work here. If substantial sunk costs must be incurred to begin the process of abating greenhouse gas emission and avoiding or minimizing climate change, if the return to this investment is the avoidance of climate change, and if we learn about the value of this over time, then there is also a real option value associated with postponing investment in greenhouse gas abatement." Page 25

Precaution against an irreversible outcome that destroys information is regarded in the literature as having quasi-option value. This argument assumes environmental damages are harder to reverse than the policies aimed to insure against them. This is referred to as asymmetric irreversibility. One view is that action should be taken to prevent potential impacts because by the time impacts are better known it may be too late. There is an opportunity for exogenous learning in waiting to see how bad damages become, but impacts may be irreversible by then. On the other hand, there could be endogenous learning enabled by taking action in that GHG abatement will teach us costs and these can be reversed later if we learn abatement is unnecessary. In fact, the EPA classifications of the kinds of pollution-control technologies, the best that might be achievable through time versus those already in place, invites an interpretation that endogenous learning can occur with these investments. Policies that generate endogenous learning are often comprised of what are commonly called "demonstration projects." Attempts to control pollution, or mitigate effects, are needed for endogenous learning to occur. But an opposing view in the literature contends that pollution control commitments may also be difficult to reverse. Heal and Kristrom advocate that policies be designed to be flexible enough to be adjusted as new information is forthcoming. They provide a conceptual framework with dollar ranges and probabilities of damages and costs of action. The Heal and Kristrom (2002) paper also contains an interesting discussion of humans' preferred temperatures and disutility from weather extremes.

Heal and Kristrom also discuss the role of the Precautionary Principle in the economics of climate change. A quote from the 1992 Rio Declaration (Article 15) is cited: "where there are threats of serious and irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." An opposing view is that precautions should be taken against premature expenditures on pollution control. Waiting to act until more is learned about the damages will also have an information value. This is described as the “learn then act” strategy. Heal and Kristrom note that “if we follow this strategy then the risk that society faces in the future will be greater. The principle result of the Gollier et al. paper is that the balance between these two effects depends on the shape of the utility function and in particular on whether or not society shows ‘prudence’.” Page 26

The evidence on climate change impacts suggests that irreversible damages could occur. Good policy formulation can provide flexibility to alter future pollution abatement investments. Human/social decisions should be more reversible than many environmental impacts; damages to ecosystems, loss of native species, etc. Being greenhouse gases have a long residency period in the atmosphere, emissions reduction today will have a long lag period. Investment today could prevent damages for the next generation. Damages from climate change are likely to have a longer lag and be relatively less reversible than pollution control actions.

Heal and Kristrom discuss uncertainties that are both ecological and economical. A major challenge to the Stern Review is the economic uncertainties that exist about future optimal discount rates, growth rates and technological advancement. However, it should also be noted that human behaviors and adjustments to information likely provide greater reversibility and are likely to be more flexible than ecosystem constraints. Unraveling ecosystem interconnections and irreversible threshold and cascade effects are potential consequences that need to be considered. In ecosystems, constraints such as the First and Second Laws of Thermodynamics and the Law of Conservation of Matter are immutable laws, in contrast to economic laws about behaviors and incentives.

The work of Heal and Kristrom is included in this section given its focus on option values and the Precautionary Principle. Conceptual issues are raised that get to the foundation of methodological limitations in conventional economics. Other sources on the economics of climate change, surveyed in Section V below, highlight the crucial debate about the substitutability between physical and natural capital. Theoretical and practical measurement issues involving key concepts (sustainability, option value, quasi-option value, irreversibility, exogenous and endogenous learning) push the envelope of conventional methodology in terms of attaching dollar values to effects, known as monetizing.

The debate about whether option value would be positive for reducing the threat of climate change boils down to whether there is an income equivalent that expresses WTP as a risk-aversion premium. The conclusion of this analyst is that purchases of physical capital in the form of pollution control equipment - whether it be to reduce greenhouse gases or reduce nutrient loads as a safety net for water quality – can be translated more readily into income equivalents that the consequences of losing natural capital. The same is true for the potential loss of human life. <u>There are severe risks from disrupting energy flows in an ecosystem so that outcomes from the processes related to the First and Second Laws of Thermodynamics degrade ecological goods and services. These risks are seen by this analyst as being much greater and more difficult to monetize than expenditures on pollution control devices.</u>

Public Good Values of Intergenerational Equity

In a meeting document assembled by the Minnesota Department of Health (2008) entitled "Public Health Impacts of Climate Change" a perspective on sustainability was represented in the following quote from Jonas Salk: "…the most important question we must ask ourselves is, "Are we being good ancestors?"

The sustainability literature in economics adapts the intra-generational social justice concepts developed by John Rawls (1971) to inter-generational ethical decisions. In particular, sustainability applies the Rawlsian "Maximin Principle" of providing maximum well-being to the least off individuals in society to maintaining non-declining opportunity for well-being to the least well-off generation through time. The operational criterion is whether our actions today provide the resources needed to allow for a "maximum" level of well-being for the "minimum" generation.

The literature includes two major points of disagreement as to how to apply this principle: 1) issue of contention is about whether the "minimum" generation going forward is the current one or some generation in the future. Given future states of the world are unknown, the Rawlsian "Veil of Ignorance" can also be applied to yield an action rule for inter-generational equity as follows: Economic sustainability requires that the current generation provide to future generations at least as much opportunity for well-being as is currently enjoyed.

Still the argument centers on whether technological advancement in the future will enhance social well-being and whether we will pass on to future generation a planet that provides for or compromises quality of life. This leads to the second point of dispute. 2) Is the substitutability between physical capital (technology) and natural capital (the planet's ecological services and natural resources) sufficient to allow some environmental degradation without bankrupting the well-being of future generations?

Various schools of thought emerged as to the level of substitutability between physical and natural capital in determining the resource stock needed to provide opportunity for well-being to future generations. Neumayer (1999) evaluated two paradigms based on contrasting assumptions that physical capital 1. poorly or 2. strongly substitutes for natural capital. If strong substitution is possible, sustainability is achieved if the total of physical and natural capital is adequately endowed to future generations: known as weak sustainability. If substitution is poor, a certain level of natural capital must be maintained: strong sustainability. A third version that is the strictest (environmental sustainability) requires that a constant level of physical service flows from natural capital be maintained, such as a sustainable yield from a fishery or a commercial forest.

In applying principles of inter-generational equity, climate change may be the greatest environmental justice challenge the world has ever faced. From a Rawlsian perspective, it not only poses immense ethical implications for the well-being of the least well off groups currently living around the globe but also for subsequent generations of these groups and all future inhabitants of the planet.

It is informative to note that these concepts of Intergenerational Equity relate closely to the Anishinaabe ethic of "The Seventh Generation." Similar environmental ethics can be found in various indigenous cultures around the world and generally imply that actions today must be in the interest of those seven generations into the future. Current generations of indigenous peoples face unusual threats from climate change. Traditional practices that depend on natural process and ecosystem services may disappear with disruption from climate change. The most vulnerable groups across many societies are likely to suffer the greatest losses from climate change. For indigenous people in regions around the planet attempting to live in traditional ways, climate change may put those ways of life in jeopardy.

In Minnesota, this is an extremely important concern, particularly focusing on water. Inequity and environmental injustice may result from the hardship climate change causes if traditional practices related to waters in Minnesota are destroyed. The book, Sacred Water, celebrates these cultural traditions and practices and highlights environmental threats such as acid rain and mercury. It is noteworthy that Minnesota pollution control policies on both of these issues led the way for national and international progress on these issues. Given the importance of water to the native people of this region, leadership in combating these pollutants is appropriate as part of our State legacy. Issues of equity and environmental justice deserve serious attention in formulation of climate change policy.

While these equity concerns are not quantifiable in an economic sense and so are beyond the empirical scope of this study, they belong in the discussion. Minnesota has a proud tradition in leading pollution control efforts, especially in being "good neighbors" in controlling pollutants that economists refer to as interjurisdictional externalities.

D. MN's Leadership Role in Controlling Interjurisdictional Externalities

Pollutants that drift downwind or flow downstream across borders are referred to as interjurisdictional externalities. This type of externality involves many parties so is perhaps the most difficult to resolve. The global impacts of climate change will likely have uneven geographic patterns. Economists refer to damages that aren't smooth as having non-convexities. Minnesota led the way among states in controlling acid deposition even though it is an interjurisdictional externality with non-convexities of impacts. MN's share of global greenhouse gas emissions also makes it difficult to connect pollution control efforts to any improvement in the local environment. Global GHG emission will not change discernibly on the margin even if MN emissions are substantially reduced. Yet Minnesota's history with interjurisdictional externalities has been to take action by reducing the state's contributions to problem even though that amount is only fraction of continental or global problem. Inaction could result from a mindset that one state's actions would have little influence on a global solution. But the state has resisted this mechanistic approach and instead has set an example by controlling emissions in the hope that it will prompt broader reductions by others who follow suit. State strategies in leading control efforts on acid deposition and mercury have succeeded in spurring cooperative agreements which brought broader jurisdictions into the solutions.

SECTION V.
SURVEY OF THE LITERATURE ON ECONOMIC IMPACTS OF CLIMATE CHANGE

A. Literature on Economic Impacts at the Global Level

The Stern Review (2006) made extensive arguments as to why it would be economically efficient and equitable to take immediate action to reduce GHG emissions. One of his equity positions was that the long-term consequences of climate change make discounting unfair to future generations, being future impacts would be severely diminished in relative importance compared to current impacts. Stern estimates losses in terms of global gross domestic product (GDP). He also estimates the percentage of global GDP that would be needed to fend off the worst of future impacts. More detail on the Stern Review is provided in the annotated bibliography presented in Appendix D.

The methods and conclusions of the Stern Review have been subjects of substantial disagreement in the economics literature. Stern served a constructive purpose in stimulating enlightening discussion. Heal (2008) summarizes the economics literature on climate change as follows: "I suggest that the recent debate has clarified many important issues, and that we are now in a position to identify those conditions that are sufficient to make a case for strong action on climate change. However, more work is needed before we can have a fully satisfactory account of the relevant economics. In particular, we need to better understand how climate change affects natural capital - the natural environment and the ecosystems comprising it - and how this in turn affects human welfare." Page 1

"The emission of greenhouse gases is a massive negative external effect - the Stern Review refers to it as possibly the greatest market failure in history." Heal (2008), page 2. Heal provides a conceptual discussion of the magnitude of the discount rate, importance of potential impacts on natural capital, risk & uncertainty, equity, and the costs of action vs. inaction as a percentage of global GDP. Heal notes that analysis based on GDP excludes non-market goods and he refers to mass extinction as an important non-market value. Heal focuses on the key issue of substitutability between physical and natural capital, and the degree to which consumption goods and services can replace ecological goods and services. "We have explored the model space and the parameter space much more thoroughly, though there are still unexplored regions. I think this should change the presumption that economists hold about the need for strong action on climate change from largely negative (prior to Stern) to positive. We can see many ways for making a case for strong action now, and few for denying it." page 15 "We have really not spent enough time on the impact of climate change on our natural capital and the ways in which this may compromise the flow of essential ecosystem services." page 16 As stated at the conclusion of Section IV.C.1 above, the reducing the risk of irreversible loss of natural capital is much more valuable than reducing the risk that investments in "damage control" might be made prematurely. Compelling scientific evidence in the literature surveyed in other sections of this report indicates that natural capital is in jeopardy.

Over a decade ago, Michael Tucker (1997) provided a perspective on climate change action based on the market for insurance. "A convincing economic argument for taking action to prevent or ameliorate climate change has not developed because of both uncertainty about the degree of change and its timing. Recent costly weather-related catastrophes with consequent negative impacts on the insurance industry has made the insurance industry a potential advocate for slowing what has been identified as a causal factor in climate change: emissions of greenhouse gases. However, rising costs of claims, without a longer-term trend of such catastrophic losses, will make it difficult to present a strong case for taking costly economic action." Tucker developed a technical, industry-specific argument regarding pricing of insurance to strengthen the case for action on climate change. He concluded that "economically justified higher insurance premiums" would result from "increasing levels of climate variability as embedded in the anticipated variability of damage to insured asset." While potential climate change impacts such as sea level rise are often conceptualized as not occurring until far into the future, Tucker's perspective of weather related damages brings the consequences into the present day, even in 1997. Ongoing discussion from the perspective of the insurance industry is highlighted below. In terms of empirical evidence provided in Section VI, summary statistics on weather-related damages over time are presented. Minnesota seems to be well above the medium in terms of magnitudes of weather-related damages.

Insurance Industry Perspectives

There is a wide array of literature relating climate change to the insurance industry. Following is a statement from the website of the Insurance Information Institute. "Catastrophes appear to be growing more destructive, but insured losses are also rising because of inflation and increasing development in areas subject to natural disasters. In 2005, the year of hurricanes Katrina, Wilma and Rita, catastrophe losses totaled $64.3 billion. Hurricane Katrina caused losses of $41.1 billion, the highest on record, about twice as much as Hurricane Andrew would have cost had it occurred in 2005. Seven of the 10 most expensive hurricanes in U.S. history occurred in the 14 months from August 2004 to October 2005. If, as suggested, hurricane-related losses grow by as much 40 percent over the next 20 years, a Katrina-like storm could cause $60 billion in losses, or significantly more if it struck a densely populated metropolitan area like Miami or New York City."

The evidence from the scientific literature does not lead to consensus about trends in hurricane frequency and severity. But these damage figures are of concern to many in the insurance industry and have broader implications for society as a whole.

In their paper on the economics of climate and insurance, Valerde and Andrews (2006) state: "As a key instrument and enabler of loss mitigation and risk transfer, the U.S. insurance industry lies at the nexus of several crucial dimensions of the climate change problem, especially as it relates to the potential implications of climate change for society and the global economy. Having sustained record-breaking natural catastrophe losses, insurers and reinsurers are openly—and, indeed, justifiably — questioning the potential linkage between anthropogenic climate change and extreme weather, looking at both the likely short-term implications for the industry, as well as potential long-term impacts on financial performance and corporate sustainability." page 1 "A fundamental question that we pose here, then, is whether the risks posed by global climate change are, in some way, structurally different than what has previously come to pass, thereby presenting insurers with new — and, some would argue, unprecedented— challenges, requiring a fundamental rethinking of the mindsets and methods that are used to manage these risks. Indeed, it may be the case that traditional underwriting and risk management methods are not adequate for this task." page 3 Despite the highly developed theory and practice of actuarial science these authors are suggesting that the risks posed by climate change may present unprecedented challenges.

Implications of climate change for the insurance industry were the subject of a great deal of analysis in the late 1990's. In an article on global change, Berz (1999) speculates that "changing probability distributions of many processes in the atmosphere" will result in "serious consequences for all types of property insurance." "In areas of high insurance density the loss potential of individual catastrophes can reach a level at which the national and international insurance industries will run into serious capacity problems." (A longer excerpt from the Berz paper is included in Appendix A.) Three insurance industry experts, Mills, et al. (2001) estimate a 15-fold increase over the period 1970 -2000 in insured losses from catastrophic weather events (defined as exceeding $1 billion of damages.)

In an analysis of trends in the Canadian insurance industry, White and Etkin (1997) "At the same time that a scientific consensus has arisen that the world will most likely experience a changing climate in the near future, with more frequent extreme events of some weather hazards, the insurance industry, worldwide, has been hit with rapidly escalating costs from weather-related disasters. This conjunction of scientific belief and economic impact has raised the questions as to (1) whether more frequent extreme events have contributed to the rising insurance costs and (2) how will future climate change affect the industry? Based upon historical data, it is difficult to support the hypothesis that the recent run of disasters both world-wide and in Canada are caused by climate change; more likely other factors such as increased wealth, urbanization, and population migration to vulnerable areas are of significance. It seems likely, though, that in the future some extreme events such as convective storms (causing heavy downpours, hail and tornadoes), drought and heat waves will result in increased costs to the industry, should the climate change as anticipated."

The evidence on worsening trends in weather-related damages has continued to grow over the last decade. The World Wildlife Fund for Nature and Allianz Insurance Company issued a report (2009) on tipping points from climate change and damage potential. The report notes that "The phrase 'tipping point' captures the intuitive notion that "a small change can make a big difference." As a concept for understanding risks, the tipping point invites comparisons to the argument by Valerde and Andrews that the insurance industry may need to develop a new paradigm. Tipping points in ecosystems, ecological goods and services and in the planet's life support systems could force tipping points in many human-social institutions. Further discussion of the tipping point and "tipping elements" is provided in Appendix A.

Studies on the Economic Effects of Impacts on Fisheries

Pendleton and Mendelsohn (1998) attempted to economically model the potential impact of climate change on sportfisheries using two different models. The first was the hedonic travel cost method. This used different characteristics and amounts resources expended to reach a specific recreation destination to estimate an economic value for the area. The second method used was a random utility model (RUM), which combined income, the travel cost function and a random variable for site location. These variables were combined to form a function explaining the utility gained from the activity. The results of the analyses indicated that a decline in the catch rates of certain types of fish could have a negative economic impact on the enjoyment of the people fishing. However, this study found that some Northeastern states may see a potential increase in welfare from the onset of warming. This was dependent on the preferences of anglers. For example, although rainbow trout were predicted to decline from climate change impacts, all other trout species and panfish were predicted to increase. This study revealed that climate change could positively impact the economics of the region, depending on which climate scenario emerges. These researchers indicated that climate change impacts may not be completely negative, which is consistent with the analysis in Section VI.

B. Literature on Potential Economic Impacts in Minnesota

Much of the literature on the economics of climate change addresses impacts at a global scale. Even analyses of industry impacts, such as the insurance industry, are done at the national level. It was noted at the conclusion of Section IV.D above that it is difficult to identify Minnesota's distinct share of global impacts. It would also be difficult to quantify a cause-and-effect relationship between emissions reductions within the state and environmental improvements. The same is true with economic analyses. The findings of the Stern Review on percentages of global GDP that could be lost due to climate change damages and lower proportions of GDP that should be invested in mitigation are difficult to apply at a smaller geographic scale. It is problematic to "downscale" these data and estimates to identify the Minnesota share of global loss of GDP. Added complications result from the fact that some of the most severe economic damages, from sea level rise, for example, would not impact the region or state directly. Rather these losses could reverberate through the global economy, so Minnesota would suffer as part of the global loss.

This provides another frame of reference on the difficulty of doing economic analysis, particularly benefit-cost analysis, on Minnesota actions given the state has a small share of global emissions & impacts. The focus of this workplan is to investigate environmental impacts on water resources and to draw economic implications from these changes. The economic component that fits the focus of the workplan is applied microeconomics rather than global macroeconomics. Global GDP is an untenable basis for economic analyses within this workplan. Benefit-Cost analysis offers the greatest insights on potential economic impacts of changes to Minnesota's water resources.

The focus of the workplan on water resources within the state leads to emphasis on the three categories of environmental impacts below. The major mechanisms for economic impacts to occur are included.

1. Lake and stream levels: flood damages, especially to infrastructure
2. Water temperatures: shorter ice duration, changes in fish populations, habitat, winter and summer kills
3. Water quality: multiple values of clean water identified in Section IV.

This list of categories of impacts and potential "receptors" that could lead to economic effects serves as a foundation for the empirical analyses reported in Section VI. Section VI.A relies on findings from the "lake and stream level" component of the larger study (led by Heinz

Stefan.) Changes in streamflow are considered as a basis for changes in damages from flooding. Historical data on damages to infrastructure from flooding and other weather-related damages is presented. Section VI.B uses evidence on shorter lake ice duration and creel survey data on patterns of recreational fishing to estimate potential changes in economic benefits from fishing.

As noted above in Section IIIC, the project findings on water quality were mixed, but generally historical trends, regardless of climate change, are toward improving measures of lake water quality. The historical trend results from a complex set of factors that influence water quality. Many factors are having a positive influence. Still the literature regards climate change as likely to have a negative impact on water quality. In this context, a brief overview of the importance of water quality in Minnesota is in order.

Overview of the Importance of Water Quality in Minnesota

The economics literature contains extensive conceptual treatment and empirical analyses of the value of water quality. Section IV covers major conceptual components and notes key contributions to the analytical framework and empirical evidence from works by Desvosges et al. (1983) and Fisher and Raucher (1984). Mitchell and Carson (1989) surveyed the literature thoroughly to that date. Various methods to measure economic benefits from water quality are found in the literature. Some employ techniques that include all aspects of WTP and others are lower-bound estimates based on market expenditures that capture only use values. Estimates in the literature also vary based on the narrowness or comprehensiveness of the water quality change evaluated. Water quality definitions in federal policy regarding suitability for boating, swimming and fishing have been the focus of benefits estimation studies. These aspects provide different foundations for defining the good to be valued. Under different circumstances, annual household values range from the double digits to low four digits.

There is a great deal of evidence that water quality is extremely important to Minnesota, “The Land of 10,000 Lakes.” These lakes contribute to the ecological, economic and cultural well being of the State. A report on water by the Minnesota Department of Natural Resources (MNDNR, 1998) stated: “High-quality water is essential for a healthy state economy.” The value of water quality is manifested in recreational and tourism activities, property values for lakeshore, investments in policies to protect water, and other ways in which citizens demonstrate WTP and the role of water in the MN quality of life.

A series of studies on the economic value of water have been conducted on surface waters in northern Minnesota. Henry, Ley and Welle assessed the willingness-to-pay for a particular lake, Lake Bemidji, among the general population in the surrounding trade region. Varying the geographical scope of water quality protection from national standards to aspects of a particular lake obviously affects the magnitude of value. Also the aggregate benefits to a population are directly related to population size. The average value for Minnesota households to protect lakes from acid rain was found by Welle (1986) to be around $75 per adult per year. Such average figures sum to large aggregate values when multiplied by millions of people who receive these benefits from protecting water quality.

Over the last twenty years a handful of studies have estimated the economic benefit of water quality as evidenced by tourism or recreational expenditures. Henry and Welle (1987) found tourists in northern Minnesota most often reported enjoying a clean environment as a motive for their trip, with spending of over $600 per party per vacation (thousands of dollars in today's terms.) Over three-fourths of respondents indicated an environmental attribute of the area as the thing they liked best about the area.

Throughout the 1990s a series of studies conducted by economists (Steinnes and Raab and others) at the University of Minnesota- Duluth and the Natural Resources Research Institute generated various estimates of benefits from water quality using recreational expenditure data, revealed preference techniques (travel-cost approach and hedonic-property values) as well as surveys. Total expenses for water-related recreation statewide were estimated at nearly $900 million with almost half of that designated as net gain to consumers (or consumer surplus.) Consumer surplus per acre of fishable water varied from over $100 to $900 across regions of Minnesota. In an extension of this approach, collaboration between the Minnesota Lakes Association and the Office of Tourism yielded estimates of the economic impact and employment effects of fishable lakes. The happy average that was plugged into the formula was that the typical acre of fishable lake generated $687 of direct consumer purchases. Economic values on a per acre basis were also estimated using Input-Output Analysis.

In a CVM study for the MN Pollution Control Agency, responses from Minnesota households yielded an average annual willingness-to-pay of about $200 to reduce mercury deposition in aquatic ecosystems in the state. Many respondents would explain that it was worth it to spend this amount on pollution prevention (which is equivalent to less than a dollar a day) to protect lakes that are such an essential part of our natural heritage. Again multiplying this average benefit per household times the millions of affected households yields an aggregate value in the hundreds of millions per year.

Krysel, et al. (2003) conducted a hedonic-pricing study on lakes in the Headwaters region of the state. Evidence from a series of studies in Maine indicated that water quality affects lakeshore property prices in a positive way because there is significant demand for it. Krysel et al. tested whether water quality similarly affects lakeshore property prices of Minnesota lakes. The major finding of this research is that water clarity positively influences lakeshore property prices.

The implicit prices of water clarity estimated in this study were based on a sample of lakeshore property transactions that took place on 37 lakes involving 1205 residential lakeshore property sales that occurred between 1996 and 2001. Property values were found to be higher on clearer lakes because buyers of lakeshore properties prefer and will pay more for properties on these lakes, all else equal. Therefore, sustaining and/or improving lake water quality will protect and/or improve lakeshore property values. On the other hand, if water quality is degraded, lower property values will result, which in turn will increase demand and development pressures on remaining lakes with the better water quality and could ultimately lower their water quality as well.

Based on prices in 1999, the median year of this study, a one meter decline in water clarity on the typical lake would result in loss of lakeshore property value of approximately $60 per frontage foot of lakeshore: known as the implicit price. This result was comparable to estimates in Maine that found the typical lakeshore lot would lose around $6,000-$8,000 in value due to the loss of clarity. The Headwaters Region of MN would be on the high end of this range considering the typical lot sold during the study period had about 150 feet of frontage. For many lakes in both Maine and MN with thousands of lakeshore lots, this translates to property value changes in the millions of dollars. Given inflation of lakeshore values since these data were collected of about 200% or a multiple of three, the implicit price today could be around $200 per front foot for a one meter loss in clarity. For a lot of 150 front feet, this converts to a $30,000 loss per lakeshore lot. This implies a loss of $1 million for lakeshore around a small lake with about 30-40 lots of typical size. An alternative calculation could b based on the total number of frontage feet on a typical lake, rather than the Maine calculation based on lots of typical size. If a loss of clarity of one meter resulted in a $200 loss in property value per front foot, this would amount to a $10 million loss for a MN lake of typical size of roughly 50,000 front feet of lakeshore. Most of the state's largest lakes and/or lakes with irregular shorelines have over 100,000 feet of shoreline. Leech Lake has over 880,000 feet of shoreline. These rough approximations suggest some lakes would see losses in the tens of millions or even hundreds of millions of dollars if climate change reduces water clarity by a meter.

If climate change has a negative impact on thousands of lakes within the state, the loss of economic value would be substantial. These assets (natural capital) would me much less valuable to MN than they otherwise could be. For a thousand lakes that might be degraded from climate change, the loss could be in the tens of billions of dollars. Time will tell what kinds of relative changes will result in light of other positive and negative processes impacting water quality, but the evidence in the literature indicates climate change is likely to have a negative net effect. Lakeshore property values provide just one measure of economic value of MN lakes to one group of citizens, riparian property owners. This excludes the benefits of water quality to all those resident and non-resident recreational users who don't own lakeshore. These people also have non-use values of water quality as do those who don't use the lakes at all.

Further evidence of high economic value of MN water quality is found in a study for the MPCA by Welle and Hodgson (2008). This study analyzed all components of public values for restoring water quality in impaired lakes within two watersheds in the Upper Mississippi River Basin of Minnesota. WTP for restoring impaired lakes is estimated among property owners (riparian and non-riparian) within the watersheds. The watersheds are the Sauk River (also known as the Horseshoe) Chain of Lakes and the Lake Margaret-Gull Lake Chain.

The causes of the impairments differ between the two watersheds, so different management options may generate different levels of net benefits. The analysis demonstrates that the watersheds are also different in terms of how property owners in the watershed relate to the impaired lakes. Many property owners are not residents of the watersheds (67% have ZIP codes outside the watershed for Margaret) and are wealthier and older than the average residents of the area. The pattern is less severe in the Sauk Watershed as about 11% of the property owners have mailing addresses outside of the watershed and Stearns County.

The Margaret-Gull Chain has a high degree of surface water as a percentage of watershed acreage compared to Sauk, and consequently a high proportion of lakeshore owners relative to the overall population of property owners in the watershed. The Margaret-Gull Chain also has many highly-valued lake properties owned by people with high incomes and a large amount of recreational use by lake owners and visitors.

The responses were utilized in various multiple regression functions to find specific equations that yield estimates of WTP. Estimates of mean WTP per household varied somewhat between alternative versions of the functions but the average was around $200 per year among respondents in the Margaret sample and around $20 for the Sauk respondents. These stark differences are explained in the model given the contrasts in the characteristics of the watersheds and the patterns of property ownership within the watershed. While the estimated equations for the two watersheds have slightly different coefficients, the extreme differences in WTP result from huge differences in the average values for the variables (percent of property that is riparian, percent who recreate on the impaired lakes, etc.) between the watersheds.

Even the lower end of this dollar range leads to substantial economic value for the population given water quality improvements are a public good enjoyed by all who hold preferences for water quality, regardless of whether they own riparian property or recreate on these lakes. These household WTP values can be used as the basis for crude estimates of the value of avoiding loss of water quality that could result from climate change. Evidence is lacking to determine whether only a few or very many MN lakes might be negatively impacted by climate change. But being it is a global phenomenon that pertains to all MN watersheds, as opposed to excess nutrient loads in a particular lake, the percentage of lakes impacted is more likely to be higher than lower. Given the introduction of aquatic invasive species is expanding through time, if climate change tilts the scale toward invasive plants crowding out native lake vegetation, this could damage thousands of MN lakes.

As an example that yields round numbers, the median of the dollar range for restoring lakes found by Welle and Hodgson (2008) could be used: $100 per household per year. The study found that the lower value for the average respondent in the Sauk watershed resulted from them living 20-40 miles from the impaired lakes and never recreating on them. Some of these respondents expressed much higher WTP to restore lakes in adjacent watersheds that were nearer to them and that they used for recreation. If one thousand MN lakes were to suffer negative impacts from climate change, this would encompass lakes that are “favorites” to many people around the state, not to mention visitors. In that case, the WTP for the average MN household would be much higher, perhaps even above the Margaret-Gull average WTP of $200 per household per year. Using $100 per year as the value of the public good and assuming the collective benefit goes to 2 million MN households, this would yield $200 million in economic benefit per year. When accumulated over decades, even with discounting of future values, this rough approximation indicates benefits in the billions of dollars. It should be noted that these billions of dollars in economic benefits would go to all citizens, most of whom don’t own lakeshore. So the portion of multi-billion dollar benefits accruing to Minnesotans who don’t own lakeshore would need to be added to the multi-billion dollar estimate of lakeshore property values that could be lost.

Use values and non-use values of non-residents for MN water quality would need to be considered to estimate the total value of these potential impacts. MN residents could reasonably be expected to also attach value to water quality in neighboring states and provinces. While the analysis of water quality trends conducted for this project do not allow isolation of climate change effects on MN water quality, this summary of economic evidence indicates that the stakes are high.

C. Other Potential Economic Impacts in MN

It is beyond the scope of this study to conduct thorough conceptual and/or empirical analyses of potential impacts of climate change on MN resources other than water. Still a cursory discussion of other major impacts provides context for the subject. Considering these other types of impacts also broadens and deepens the understanding of potential impacts on water resources. Major categories of impacts that could have significant economic consequences are listed below. This section concludes with elaboration on the economic channels through which these impacts could be manifested.

1. Health Impacts
2. Energy Impacts
3. Forestry Impacts
4. Agricultural Impacts
5. Cold-Weather Research
6. Transportation & infrastructure not related to Water
7. Ecological Impacts
8. Potential Recreational Impacts, non-water related

1. Potential Health Impacts

The MN Department of Health (MDH) has been studying the issue of climate change in the context of its mission as a state agency. MDH staff participated in the adaptation summit held in Decemeber of 2009 and shared helpful information for the purposes of this study. A document assembled for an agency meeting (MDH, 2010) was based in part on materials from the State Environmental Health Indicators Collaborative (SEHIC, see English, et al., 2009). Section V.C from the MDH report lists SEHIC's proposed categories of indicators for climate change. The categories below could have severe negative economic impacts leading to loss of state, national or global GDP. The GDP losses would be comprised of severe losses in specific markets. Substantial losses of non-market values could also occur. The health impacts stress - as much as any category of impacts - the potential loss of human life, which is difficult to value in dollar terms.

Environmental Indicators: Greenhouse Gas Emissions, Air Mass Stagnation Events, Ozone due to Climate Change, Maximum and Minimum Temperatures/ Heat Index, Increase in Heat Alerts/ Warnings, Pollen Counts, Wildfire Frequency, Severity, Distribution, and Duration, Droughts, and Harmful Algal Blooms;

Morbidity & Mortality Indicators: Excess Mortality due to Extreme Heat, Excess Morbidity due to Extreme Heat, Number of Injuries/ Mortality from Extreme Weather Events, Human Cases of Infectious Disease/ Positive Test Results in Sentinels and Reservoirs, Respiratory/ Allergic Disease and Mortality Related to Increased Air Pollution and Pollens;

Vulnerability Indicators: Population Vulnerability or General Social Vulnerability, Heat Vulnerability, Flood Vulnerability, and Sea Level Rise Vulnerability

2. Potential Energy Impacts

The interface between climate change and energy demand is often expressed as the change in heating and cooling degree days. Climate change evidence indicates increases in ambient temperatures so that MN is experiencing fewer heating degree days, especially in the cold months and more cooling degree days in the summer. In light of the research by Heal and Kristrom (2002) on humans' preferred temperatures mentioned above in-door climate control leads to changing energy demand. Given MN's image as a cold place, many might expect that fewer heating degree days would be a huge, positive result of climate change. But the dividing line between whether more energy is used for heating or cooling cuts through MN with the majority of the population in the metro area residing south of the line, so greater annual energy demand goes to cooling. Warmer ambient temperatures will increase energy demand. So even in MN this will be a positive feedback mechanism leading to a cycle of potentially greater GHG emissions.

Another energy feedback is associated with higher heat indices in the summer, which also project to greater demand for cooling. Higher ambient temperatures are being combined in summer with higher dew points, so that more cooling for comfort is needed to deal with higher humidity/heat indices. One energy impact that is related to water could be on hydroelectric generation. Given more extreme variations in streamflow, low flows could become insufficient for energy generation.

3. Potential Forestry Impacts

Projected changes to MN forests include changes away from the classic pine forests of northern MN to oak savanna and greater distribution of deciduous trees. A positive impact that is predicted is longer growing seasons so increased rates of growth in the commercial forests of the state. Yet there is concern about the changing composition of the forests that might shift toward less desirable tree species with less economic value. These are potentially large economic consequences. While economic impacts to forests are beyond the scope of this study, it is important to note that ecological goods and services extend beyond commercial forestry and cold have substantial market and non-market values.

4. Potential Agricultural Impacts

Potential impacts to agriculture that are water related include vulnerability of water supplies for irrigation. Drought-related low flows could lead to surface water and groundwater deficits. Just as trees could have longer growing seasons and higher rates of growth, so to could agricultural plants. Impacts to agricultural crops could become a positive impact.

5. Cold-Weather Research

Cold-weather research adds economic activity that is important to many MN communities. A major industry that utilizes the MN climate for product testing is the automotive industry. These and other products must hold up to the cold faced by millions of people within local and international markets. Evidence on climate change in MN cited above indicates that MN is experiencing warmer winters, especially higher minimum temperatures. Climate data indicates a shift toward more frequent freeze-thaw cycles. Some cold-weather research seeks out sub-freezing temperatures, while others come to MN in late winter to test product performance in freeze/thaw cycles. MN may become less suited for testing in sub-freezing conditions but more attractive for freeze/thaw testing. Given global climate change, global markets may shift away from sub-zero product performance concerns toward freeze/thaw performance as well as tolerance to extreme heat.

6. Transportation and Infrastructure Not Related to Water

Empirical analysis in Section VI.A below investigates damages to infrastructure from weather-related events. Historical trends in damages are presented, including from federally declared disasters. Many of the transportation damages come from flooding, such as washouts of roads, bridges and culverts. These damages are a focus of this study being they are water related. Transportation impacts not related to water include possible damages to road materials due to the increased freeze/thaw cycles noted above.

7. Ecological Impacts

Ecological changes that could result from climate change could have positive and negative effects on the flows of ecological goods and services. While some of the goods and services have values revealed in markets, many of these are non-market values. A major concern based on the literature should be loss of ecological integrity and resilience, with increased stress on many species that may confront conditions outside their tolerances. In particular, the literature points to circumstances which are conducive to native species being replaced by invasive species, both aquatic and terrestrial. Such changes could have severe socio-economic consequences, especially if conditions change beyond tolerances of native species.

8. Potential Recreational Impacts

Empirical analysis in Section VI.B below investigates potential climate change impacts on recreational fishing as a result of shorter ice duration. As important as water-based recreation is in MN, there could be climate impacts on recreation not related to water. Winter recreation is important to the way of life (and quality of life) of many in the state. Some choose to live in MN for the pronounced seasons or perhaps because winter is their preferred season. Winter conditions in MN will likely “soften” in the future. There will likely be a loss of recreation depending on cold and snow. But these losses may be completely or partially offset by more days for recreation that don’t depend on snow and ice.

SECTION VI
POTENTIAL ECONOMIC EFFECTS OF CHANGES IN MINNESOTA'S WATER RESOURCES

A. Potential Economic Impacts from Changes in Water Flows

Economic analysis of the potential impacts of climate change must be based on sound-reliable scientific evidence on the change that could result. This economic study is one component of a larger project designed to gather evidence of current changes that may be unfolding. Section IIIC above is critical to this report given its findings from other researchers on the project team regarding changes occurring to Minnesota's water resources. Section B below explores potential climate change impacts on recreational fishing due to shorter ice duration. The empirical evidence is summarized in that section. As a foundation for this section, the evidence on changing streamflows will be reviewed briefly.

While the literature on global changes, including US federal government research, indicates higher lake levels in the Midwest, except perhaps the Great Lakes, research on MN lake levels thus far yields mixed results. Lake levels appear to be less susceptible to immediate pulses of water from precipitation and snowmelt than are rivers and streams. In a sense it's like the vulnerabilities of rivers and streams to flash-flooding that is not an immediate concern for lakes. This is not to say that fluctuations in lake levels are not a concern in MN, but the evidence thus far points to water levels in rivers and streams warranting more attention.

Project team member Heinz Stefan and his colleagues have studied water levels in lakes, rivers and streams. The streamflow analysis was based on data from gauging stations in the five major river basins of the state. In general, this evidence is consistent with impacts predicted in the literature. Results vary between the five basins, but generally the data indicate higher median flows and higher 90th percentile flows. Methods of describing riverine flows utilize measurements of time spans, such as 1-year, 10-year, 20-year, 100-year and 500-year floods. Ten-year floods should occur every ten years so should have a one in ten chance of occurring in any given year. One-hundred year floods should have only a one-percent chance of occurring and 500-year floods should have a probability of only two tenths of one percent. The work by Stefan and associates indicates that these floods are happening more frequently than the odds predict, especially for the 10-20 yr. floods. The statistics are less meaningful for the most extreme events associated with the most severe damages: 100-year and 500-year floods. If the chances of these categories of floods are increasing beyond the corresponding frequencies, than the hydrographs to fit these definitions would need to be adjusted. While that is beyond the scope of this project, it may be pursued by relevant state agencies that rely on these hydrological measures, such as MDOT. The same is true for flow measures based on percentiles. Higher flow levels through time would mean the 90th percentile level would be exceeded more than 10 percent of the time. So the level defined as 90th percentile would have to be adjusted upward, i.e. a higher flow volume is defined as the 90th percentile and/or the old 90th percentile becomes a lower percentile, such as the new 85th percentile.

Even though the most extreme flow levels do not exhibit strong statistical changes, the increased baseline (median) flows and more frequent 10 to 20-year flood events could be evidenced by a trend toward increasing infrastructure damages. The evidence from the data must be couched in terms of limitations of data availability in terms of temporal and spatial scales: i.e. too few years of water levels are available to show long-term trends and too few flow measures have been taken within watersheds at the levels of tributaries or smaller in the five major basins. Downscaling of data may be necessary to enhance understanding of flooding patterns. Catastrophic events such as the southeastern MN flood of 2007 that severely damaged Rushford and the surrounding area must also be recognized even though data availability may make it hard to place these extreme events in context. The economic evidence below does include these extremely damaging events even though they may be difficult to define in terms of evidence of climate change.

Another nuance of the merging of evidence on streamflows and damages relates to the higher base flow levels, especially in late winter and spring as snow melt enters the major basins. This pattern worsens risks of spring flooding in ways that may be too difficult to discern from data available thus far. Higher base flows and greater snow melt create worse vulnerability to early spring rains putting rivers and streams even higher above flood stage. The extreme flood event in the Red River Valley in 1997 was unusual given the record snow depths of that winter, but increased likelihood of rain at this time would exacerbate the problem. The 1997 floods show up in the damage records below. Our retrieval efforts for data on damages to transportation infrastructure was most intensive for that year given its severity and for illustrative purposes.

It is essential to recognize that many variables are changing through time and some in consistent directions that would indicate historical trends for more or less flood damages. One factor suggesting that historical trends would be toward more damages is simply the inflation of the resources and materials that are lost. Increasing development also places more valuable assets in harm's way. MNDOT personnel (Frank Pafko and Luane Tasa, personal correspondence) note these and other changes that make dollar amounts difficult to compare over the years. Policy has been in place for some time to invest in prevention of future damages by making scheduled replacement of transportation infrastructure (roads, bridges, culverts, etc.) to withstand high flow events. Furthermore when damages occur and emergency repairs are needed thee too are being done to provide a buffer or guard against the failure of infrastructure repeating itself. This policy should lead to a decrease in damages over time. (State Aid and Design manuals for highways, culverts and stormwater cited in Section III reflect these policies.) Historical trends are difficult to interpret given outcomes on damages result from a combination of influences, some positive and some negative. As noted above, overall changes in the measures of water quality in MN lakes provide another important example of how complex processes make it difficult to isolate separate impacts of climate change. Multiple variables that influence infrastructure damages are in flux in MN so that the data on damages must be interpreted with caution.

While damages to transportation infrastructure as a result in changing streamflows were emphasized in the workplan, non-transportation infrastructure also merits attention. Some of the most expensive repairs are needed when drinking water facilities are overcome, especially if in conjunction with inundation of wastewater treatment plants. Precautions for human health make emergency water supply and long term repair have made this category of damages very costly when the occur. The evidence in MN would indicate that these catastrophic damages are not increasing as dramatically as more numerous washouts of less costly infrastructure such as secondary roads and culverts associated with 10 to 20-year flood events. The data on damages reported below warrants explicit mention of some basic arithmetic: total damages amass just as much through many incidents of low to moderate cost as with fewer incidents of high cost. The former, if not the latter, would appear to be occurring more frequently in MN as a result of climate change.

Before moving on to a discussion of damage figures, greater dispersion of flows, including more extreme low flows should also be mentioned. Project findings on generally higher flows should not mask the possibility of economic costs of extreme low flows during extended droughts. The basins that show the most significant changes in flow are the Red River of the North and the MN River. Concerns over dependable water supply in the Red River of the North (Fargo-Moorhead and Grand Forks-East Grand Forks) have led to research and policy discussions as to these vulnerabilities and possible remedies. Again climate change makes this situation more risky.

Damage figures below are presented in order of most general categories of infrastructure to data more specific to transportation at the end. Table VI.1 provides figures from a NOAA study (2002) that reports the history of U.S. flood damages from 1955 to the most recent year, 2000. The report re-examines date back to the 1920s but only details damages state-by-state from 1955- 2000. Damage figures for MN are included here.

Table VI.1. Flood Damage in Thousands of Current Dollars With Deflator to convert to 1995 $ (Note: constant dollars found by dividing by the implicit price deflator according to the U.S. Bureau of Economic Analysis, 2001. No estimates for 1980-1982.)

Year	Deflator	Current $	Constant 1995 $
1955	0.20163	0	0.000
1956	0.20846	11	52.768
1957	0.21539	9,128	42378.941
1958	0.22059	17	77.066
1959	0.22304	50	224.175
1960	0.2262	212	937.224
1961	0.22875	552	2413.115
1962	0.2318	1,290	5565.142
1963	0.23445	26	110.898
1964	0.23792	0	0.000
1965	0.24241	97,603	402636.030
1966	0.24934	4,300	17245.528
1967	0.25698	0	0.000
1968	0.26809	1,197	4464.918
1969	0.28124	67,168	238828.047
1970	0.29623	4,350	14684.536
1971	0.31111	15	48.214

1972	0.32436	64,318	198292.021
1973	0.34251	242	706.549
1974	0.37329	16,939	45377.588
1975	0.40805	139,726	342423.723
1976	0.43119	0	0.000
1977	0.45892	7,870	17148.958
1978	0.49164	65,000	132210.561
1979	0.53262	13,140	24670.497
1980	0.58145		
1981	0.63578		
1982	0.67533		
1983	0.70214	310	441.507
1984	0.72824	5,000	6865.868
1985	0.75117	500	665.628
1986	0.76769	1,501	1955.216
1987	0.79083	27,800	35152.941
1988	0.81764	555	678.783
1989	0.84883	17,600	20734.423
1990	0.88186	3,032	3438.187
1991	0.91397	1,280	1400.484
1992	0.93619	1,760	1879.960
1993	0.95872	964,050	1005559.496
1994	0.9787	1,867	1907.633
1995	1	3,750	3750.000
1996	1.01937	460	451.259
1997	1.03925	743,218	715148.424
1998	1.05199	2,529	2404.015
1999	1.06677	466	436.833
2000	1.09113	43,112	39511.332

The most informative column shows damages standardized in 1995 dollars, in thousands. This shows that from 1955 – 1970 there were three years with damages in the tens of millions of dollars and two in the hundreds of millions. From 1971 – 1984 (1980-82 missing) there were three years with damages in the tens of millions of dollars and three in the hundreds of millions. From 1985 – 2000 there were three years with damages in the tens of millions of dollars and the two years with the highest damages 1997 and 1993. The latter had damages in excess of $1 billion in constant 1995 dollars.

The MN Department of Public Safety's Division of Homeland Security & Emergency Management summarized damage information over the decade of the 1990s. The summary is more enlightening than the totals above being the damage figures are broken down into informative categories. The report "A Decade of Minnesota Disasters: A Historical Look at Minnesota Disasters in the 1990s" notes that the specter of climate change places increased importance on changing weather patterns and the increase in storm occurrence and intensity. The report focuses on weather related damages in Minnesota throughout the 1990s. According to the report, these damages are increasing and during the 1990s there was 14 presidential declarations of major disasters. Most of the damages were the result of flooding, ice storms, snow removal, straight-line winds, tornadoes, and heavy rain. From these disasters Minnesota taxpayers spent $827 million and the cost to insurance companies was more than $2 billion.

The types of aid used to finance these damages are listed below.
The Public Assistance Program totaled more than $370 million. This aid is used to rebuild schools, hospitals, fire stations, police stations, city offices, water and sewage treatment plants and other public buildings. Also included are non-profit electric cooperatives and transmission lines. Funds are given to state and local governments, school districts, Indian tribes, and certain private non-profit organizations, such as electric power co-operatives, and educational facilities. Money is used to repair, restore, or rebuild public infrastructure damaged during a presidentially declared disaster. Sub-categories and percentages paid include: building & equipment 25.9%, protective measures 20.9%, public utility systems 20.2%, roadways 12.6%, debris clearing 12.3%, park and recreational facilities 4.7%, and water control facilities 3.4%.

Another category is the Hazard Mitigation Grant Program: More than $51 million. This is intended to reduce or eliminate future damages. Funds are used for acquiring properties damaged by flooding, burying power lines, installing snow fences, and increasing weather radio coverage in the state. Sub-categories include: acquisition 64.7%, utility protective measures13.6% misc. projects 9.3%, stormwater management 9%, NOAA transmitters 1.10%, water and sewer protection .9%, management costs .3%, mitigation plans .2%, studies .1 %, and retrofitting .1%. This program provides 75% cost-share on the cost-effective mitigation measure of costs. Recipients include local communities, certain non-profits, and state agencies. Dollars are based on 15% of the Public Assistance and Individual Assistance Programs funds provided by FEMA.

The Individual and Family Grant Program helps cover expenses not covered by insurance, such as housing, personal property, medical and dental expenses caused by the disaster, funerals, and transportation. From 1990 – 1999 the USDA (Farm Service Agency) paid a total of $57,404,110. Eligibility within a county requires demonstration of 30% crop loss county-wide. The Small Business Administration (SBA) provides low-interest loans to homeowners and business affected by a disaster. More than $193 million was paid out of this program during the 1990s.

There are three types of SBA loans:
1. Home Disaster Loans: loans to repair or replace damages to real estate or personal property owned by victim. Renters are eligible for personal property losses.
2. Business Physical Disaster Loans: Businesses of any size are eligible to repair or replace losses such as real estate, machinery and equipment, inventory and supplies..
3. Economic Injury Disaster Loans: Loans for working capital to small businesses and small agricultural cooperatives.

The report also ranks MN hazards by category of loss that occurs. It is based on data from the Minnesota Hazard Mitigation Plan. The rankings are a composite of: likelihood of occurrence, frequency, and historical impacts as natural hazard affecting the state. Blizzards are the top cause of Deaths per year, first ranking for injuries per year (ice and sleet), and first ranking for economic impact per year (floods). Programs and policies to reduce future damages are: smart growth, efficient housing, uniform building codes, consumer education (flood insurance), comprehensive planning, policy formation, and hazard mitigation to reduce consequences before they happen.

Table VI.2 lists the 14 declared disasters for the 1990s, including totals by year. Some years had multiple declared disasters.

Table VI.2. FEMA Declared Disasters in MN During the 1990s

1. FEMA 1288 DR MN (1999) Total Cost $11.1 million
2. FEMA 1283 DR MN (1999) Total Cost $52.2 million
3. FEMA 1225 DR MN (1998) Total Cost $1.5 billion
4. FEMA 1212 DR MN (1998) Total Cost $246.1 million
5. FEMA 1187 DR MN (1997) Total Cost $85.4 million
6. FEMA 1175 DR MN (1997) Total Cost $545.0 million
7. FEMA 1158 DR MN (1997) Total Cost $82.4 million
8. FEMA 1151 DR MN (1997) Total Cost $20 million
9. FEMA 1116 DR MN (1996) Total Cost $48 million
10. FEMA 1078 DR MN (1996) Total Cost $6.7 million
11. FEMA 1064 DR MN (1995) Total Cost $18 million
12. FEMA 993 DR MN (1993) Total Cost $215.1 million
13. FEMA 946 DR MN (1992) Total Cost $32.5 million
14. FEMA 929 DR MN (1991) Total Cost $11.7 million

Totals by Year: Sum for Decade $2,874,200,000

Year	Totals
1999	63,300,000
1998	1,746,100,000
1997	732,800,000
1996	54,700,000
1995	18,000,000
1994	0
1993	215,100,000
1992	32,500,000
1991	11,700,000
Total	2,874,200,000

Denise Peterson of the Department of Public Safety was extremely helpful in sharing the most recent figures on damages over the past decade. While the decade 2000-2009 has not been summarized as yet into a report similar to the one for the 1990s, summary figures were provided for inclusion in this report. Damages are separated by categories A-G as follows.

FEMA Categories of Work

Emergency Work

Category A: Debris Removal	Clearance of trees and woody debris; certain building wreckage; damaged/ destroyed building contents; sand, mud, silt, and gravel; vehicles; and other disaster-related material deposited on public and, in very limited cases, private property.
Category B: Emergency Protective Measures	Measures taken before, during, and after a disaster to eliminate/reduce an immediate threat to life, public health, or safety, or to eliminate/reduce an immediate threat of significant damage to improved public and private property through cost-effective measures.

Permanent Work

Category C: Roads and Bridges	Repair of roads, bridges, and associated features, such as shoulders, ditches, culverts, lighting, and signs.
Category D: Water Control Facilities	Repair of drainage channels, pumping facilities, and some irrigation facilities. Repair of levees, dams, and flood control channels fall under Category D, but the eligibility of these facilities is restricted.
Category E: Buildings and Equipment	Repair or replacement of buildings, including their contents and systems; heavy equipment; and vehicles.
Category F: Utilities	Repair of water treatment and delivery systems; power generation facilities and distribution facilities; sewage collection and treatment facilities; and communications.
Category G: Parks, Recreational Facilities, and Other Facilities	Repair and restoration of parks, playgrounds, pools, cemeteries, mass transit facilities, and beaches. This category also is used for any work or facility that cannot be characterized adequately by Categories A-F.

Table VI.3.A. Damage Totals for FEMA Declared Disasters 2000-present

Eligible Damages by FEMA Category

* Disasters are "open" until all approved projects have been completed, reimbursed, and signed off by FEMA.
** Total includes only the federal and state share of funding paid under the Stafford Act. Other federal funds, special state appropriations, and local funds are not included.

	Public Assistance Program (PA)							
Declared	Category A Debris Removal	Category B Protective Measures	Category C Roads and Bridges	Category D Water Control Facilities	Category E Public Buildings	Category F Utilities	Category G Parks, Recreational/ Other Facilities	PA Total
04/19/2010	$ 2,364,969	$ 5,915,615	$ 7,412,674	$ 592,846	$ 23,917	$ 207,250	$ 1,389,798	$ 17,907,069
03/19/2010								$ -
04/09/2009	$ 2,273,264	$ 9,565,376	$ 20,490,489	$ 2,558,564	$ 287,597	$ 2,725,821	$ 320,740	$ 38,221,852
03/26/2009		$ 726,393						$ 726,393
06/25/2008	$ 358,976	$ 233,331	$ 6,485,242	$ 518,165	$ 39,599	$ 437,367	$ 165,383	$ 8,238,063
08/23/2007	$ 3,210,090	$ 3,344,675	$ 19,283,808	$ 964,055	$ 9,898,458	$ 3,232,683	$ 3,819,673	$ 43,753,443
06/05/2006	$ 360,922	$ 862,126	$ 4,914,017	$ 2,833,525	$ 1,877	$ 101,200	$ 50,243	$ 9,123,910
01/04/2006	$ 325,369	$ 866,692	$ -	$ -	$ -	$ 9,264,860	$ 8,450	$ 10,465,370
10/07/2004	$ 277,461	$ 368,535	$ 2,102,480	$ 833,865	$ 551,086	$ 545,368	$ 358,548	$ 5,037,343
06/14/2002	$ 2,168,277	$ 2,783,629	$ 18,052,322	$ 2,386,159	$ 2,301,735	$ 4,683,795	$ 1,567,348	$ 33,943,265
05/16/2001	$ 3,379,888	$ 8,059,208	$ 20,819,214	$ 2,329,718	$ 184,500	$ 9,661,881	$ 2,092,458	$ 46,526,867
06/27/2000	$ 2,636,168	$ 2,381,109	$ 5,380,831	$ 1,107,078	$ 883,210	$ 1,793,093	$ 659,441	$ 14,840,929

Table VI.3.B. Damage Totals for FEMA Declared Disasters 2000-present: Descriptions and Totals

* Disasters are "open" until all approved projects have been completed, reimbursed, and signed off by FEMA.
** Total includes only the federal and state share of funding paid under the Stafford Act. Other federal funds, special state appropriations, and local funds are not included.

	Description	Assistance Type	PA Total	Individual Assistance Program (IA)	Hazard Mitigation Grant Program (HMGP)	*Total
04/19/2010	Flooding (estimates)	PA, HMGP	$ 17,907,069		$ 2,686,060	$ 20,593,129
03/19/2010	Flooding	PA	$ -			$ -
04/09/2009	Severe Storms and Flooding	PA, IA, HMGP	$ 38,221,852	$ 3,100,059	$ 6,204,157	$ 47,526,068
03/26/2009	Severe Storms and Flooding	PA	$ 726,393			$ 726,393
06/25/2008	Severe Storms and Flooding	PA, HMGP	$ 8,238,063		$ 938,765	$ 9,176,828
08/23/2007	Severe Storms and Flooding	PA, IA, HMGP	$ 43,753,443	$ 31,506,210	$ 10,180,020	$ 85,439,673
06/05/2006	Flooding	PA, HMGP	$ 9,123,910		$ 510,479	$ 9,634,389
01/04/2006	Severe Winter Storm	PA, HMGP	$ 10,465,370		$ 624,188	$ 11,089,558
10/07/2004	Severe Storms and Flooding	PA, IA, HMGP	$ 5,037,343	$ 4,067,243	$ 607,510	$ 9,712,096
06/14/2002	Severe Storms, Flooding and Tornadoes	PA, IA, HMGP	$ 33,943,265	$ 10,573,453	$ 5,859,732	$ 50,376,450
05/16/2001	Flooding	PA, IA, HMGP	$ 46,526,867	$ 4,559,731	$ 5,625,419	$ 56,712,017
06/27/2000	Severe Storms, Flooding and Tornadoes	PA, IA, HMGP	$ 14,840,929	$ 5,012,976	$ 4,784,611	Declared

One of the infrastructure impacts anticipated in the literature is that extremely high streamflows will cause failure of dams. Consultation with MNDNR officials (Personal correspondence Jason Boyle, State Dam Safety Engineer) indicates that no dam failures have occurred in MN. We “don't have records on damage to dams or other infrastructure from floods or dam breaks. Several earthen dams experienced emergency spillway erosion caused by the flooding in SE MN in 2007 and 2008, though no dams we regulate actually failed.”

An extreme rain event occurred in SE MN in 2007. An excerpt from an email after the 2007 flooding sent out by the DNR Commissioner, is informative: “Now we are moving to the recovery phase, helping people and business to get back on their feet and to repair damages to public facilities. During the flood many DNR facilities were damaged. At the moment, based on preliminary damage assessments, those damages appear to total about $10.7 million. The damage occurred in state parks, wildlife management areas, in state forests, and at fish hatcheries.’

The southeastern MN flood event of 2007 caused considerable damage, but dam failure did not occur. Reviewing the damage amounts in the seven categories (A-G) for the FEMA declared disasters, reveals that Category C: Roads and Bridges typically suffer the largest damages. Further understanding can be gained by delving into transportation infrastructure as a category of damages.

Shawn Chambers, staff person of the Minnesota Department of Transportation, Office of Capital Programs and Performance Measures, assisted by sending available damage estimates for selected years in the last decade. She accessed summary information on the three most noteworthy flooding events in MN since 2000. Shawn Chambers (personal correspondence, 2010) described a statewide event in 2001 due to heavy rains and in 2002 and 2006 there were major springtime flooding events in the Red River Valley. She accessed information for the counties involved in the 2002 and 2006 flooding events and was able include damage estimates for counties in the 2001 flooding event as well.

She also noted the major flooding event in 1997 that included the counties of Big Stone, Blue Earth, Brown, Chippewa, Dakota, Grant, Lac Qui Parle, Le Sueur, Nicollet, Polk, Redwood, Renville, Sibley, Stevens, Swift, Traverse, Wilkin, and Yellow Medicine. The damage estimate reports were not collated electronically as were the more recent years so summary figures from MDOT was not available for 1997. Nor was it for the SE Minnesota flood in 2007. MNDOT staff noted these figures are for federal aid eligible routes only. Other road damage may have occurred but is not included if it was not eligible for Federal Highway Administration Emergency reimbursement. These damage figures are informative in indicating the level of transportation damages in recent years. But for the purposes of this study, the data span too short of a time to be more than illustrative of the magnitude of damages that have been occurring. Making projections about climate change impacts would not be sound with this limited data.

Table VI.4. Statewide Flood Events: 2001, 2002, and 2006
Damage Estimates by County and Road Authority

A. 2001 Red River Flood Event
MnDOT Highways

County	County Total
Kittson	184,931
Norman	16,253
Polk	57,562
Total MnDOT Highways	**258,746.00$**

2001: Local Roadways (CSAH & some city streets)

County	County Total
Kittson	27,757
Marshall	130,063
Norman	225,140
Polk	415,168
Total Local Roadways	**798,128.00$**

B. 2002 Red River Flood Event
Damage Estimates by County and Road Authority
MnDOT Highways

County	County Total
Becker	24,420
Clay	45,676
Clearwater	6,195
Hubbard	11,125
Koochiching	153,939
Lake of the Woods	301,956
Norman	703,747
Polk	66,325
Red Lake	43,476
Roseau	100,573
Total MnDOT Highways	**1,457,432.00$**

Local Roadways (CSAH)

County	County Total
Clearwater	183,380
Kittson	52,437
Lake of the Woods	294,308
Marshall	31,925
Norman	227,626
Polk	103,410
RoseauRoseau	931372,
Total Local Roadways	**1,824,458.00$**

C. 2006 Red River Flood Event
Damage Estimates by County and Road Authority
MnDOT Highways

County	**County Total**
Clay	1,064,667
Kittson	22,314
Marshall	479,461
Norman	86,655
Otter Tail	1,076,242
Polk	91,370
Total MnDOT Highways	**2,820,709.00$**

Local Roadways (CSAH)

County	**County Total**
Becker	60,339
Clay	8,757
Kittson	227,335
Marshall	105,791
Norman	337,644
Otter Tail	3,052,806
Polk	110,441
Roseau	42,257
Wilkin	24,256
Total Local Roadways	**3,969,626.00$**

To provide further illustration of the magnitude and types of damages to transportation infrastructure that have occurred, hard copies of damage reports for the 1997 Red River Valley flood were collated by hand. This information is summarized in Table VI.5 below.

Table VI.5. 1997 District 2 Flood Data

County	Location	Type of Damage	Total Damage
Marshall	CSAH # 4 (Big Woods Twp)	Shoulder washing, debris removal, bit. Paving	31,558
Marshall	CSAH # 9, (Oak Park Strip)	Shoulder washing & debris removal	10,877.07
Marshall	CSAH # 4, (Middle River Twp.)	Shoulder washing & replace 7 entrances	9,162.35
Marshall	CSAH # 10, Sec. 5, T-155-49	Shoulder Washing and Debris Removal	3982.66
Marshall	CSAH #2, N. Road ditch	road ditch eroded, washed out field approach	7000
Marshall	CSAH # 10, (Bloomer Twp.)	Bridge approach & wingwall	21,093
Marshall	CSAH #5, (Fork Twp.)	Should washout & removal (3miles)	26,560.00
Marshall	Bridge on CSAH # 6	Rip Rap & slopes under bridge washed out.	5,000
Norman	CSAH No. 30 Sec. 1 & 2 T146 N	Ditch erosion and sedimentation	4700
Norman	CSAH No. 14, TH 200 to CSAH 39	Roadway washout, surface and shoulders	37,469.30
Norman	CSAH 25 at Hendrum	Rd.washout and surface and shoulders	152621.66
Norman	CSAH 3 West of Shelly	Shoulder damage, ditch erosion, flood debris	35,210.19
Norman	Bridge #54532, on CSAH # 29	Erosion repair @ ne. cor. And repair rip-rap	18,450
Norman	Bridge #54528 on CSAH #14	rip-rap erosion at both piers	3,250
Norman	Bridge # 93302 on CSAH #38	Rip rap at bridge	5,550
Norman	Bridge #93473 on CSAH 29	Erosion Repair and riprap and clean debris	3,904
Pennington	Intersection of TH 59 and CSAH 3	Culvert replacement/washout	14,485.11
Roseau	CSAH 23 (south of TH # 11)	water overtopped rd.	31,657.00
Roseau	CSAH 8 (from CSAH # 3 to TH 89	spring flooding eroded ditches, backslopes	27,685.30
Roseau	CSAH 7 (4 miles east of west co. line)	water overtopped rd, eroded roadtop	128,885.41
Clearwater	CSAH 4 at 2.50 miles E. of TH92	Washout of road and centerline pipe	11,106.85
Beltrami	CSAH 5	Road and Culvert Washout	6,356.44
Beltrami	CSAH 5	Culvert washout	4,152.24

Beltrami	CSAH 22	Road and colvert washout	10,855.43
Beltrami	CSAH 23	Road and colvert washout	12,064.82
Beltrami	CSAH 36	Culvert washout	8,250
Kittson	CSAH 5 Marshall Co. line to TH 11	Road washout , loss of rdway and roadway surface	5,800
Kittson	CSAH 7	Loss of shoulder	29,535
Kittson	Co. Rd. 68	Aggregate surface loss and & debris	12,930
Kittson	CSAH 28 north of CSAH 10	Approx. 950' of Bit. Wearing course	8,190
Kittson	CSAH 22 Br.no.35502	Loss of slope and riprap material	7,568
Kittson	CSAH 6	Bit. Wearing course	20,910
Kittson	CSAH 4 b/w CSAH 16 & 4 Mi.East	Loss of aggregate surface and debris	38,605
Kittson	CSAH 16 from TH 175 to 6 miles North	Debris and aggregate shoulder loss	54,022.50
Polk	23rd st. River rd. to HWY 220N	Erosion, Buckling, culvert sep.	246,892
Polk	5th ave. NE	sothbound lane settled	1,326,809
Polk	East Grand Forks Bike Path	Washout, damaged shoulders, erosion, collaspe	157,608
Polk	1st st se	Damage from hauling	3,402
Polk	Bygland Rd SE (3rd st se)	Damage from hauling	14,256
Polk	Central Ave.	Damage from hauling	1,508
Polk	5th ave. NE, 17th st.ne,20th st ne	Pavement failure	42,320
Polk	Central Ave. and MNTH2	Pavement failure	33,047
Polk	CSAH 44	Runoff damage, washed out culverts	23,440
Polk	CSAH 1 MP DO 1.2	Overtopped rds, should+surface damage	38,445
Polk	CSAH 9 MP do MP0.4	Debris removal, road and shoulder washout	20,512
Polk	CSAH 72 MP 2.10	Shoulder and inslope washout, debris	11,297
Polk	CSAH 19 MP 2.8	Shoulder and inslope washout, debris	6,275
Polk	Intersection of CSAH 20 and CSAH 23	Shoulder and inslope washout, debris	5,855
Polk	CSAH 64, Demers ave. to N city limits	Damage from hauling	14,155

Polk	CSAH 72 TH 220 -EGF city limits	Damage from hauling	13,250
Polk	CSAH 47	washed out culvert (replaced)	16,510
Polk	CSAH 22 MP 6.7 to MP 10.5	Road and Shoulder wash. Debris	139,697
		Total=	2,924,725

B. Potential Economic Impacts from Recreational Changes due to Shorter Ice Duration

Rabi Vandergon's Masters of Science Thesis at Bemidji State University is the basis for this section. His entire thesis is provided in the Appendix. Empirical analysis of potential economic impacts of climate change in Minnesota must be founded on evidence of environmental effects. This section utilizes as a cornerstone the work on trends in ice duration conducted by Virginia Card as part of the larger LCCMR project. The results on ice duration are summarized above in Section III.

A direct socio-economic impact of shorter ice duration will be the switch of recreational days for ice-related activities to open-water activities. The change in environmental conditions will cause positive and negative effects on opportunities for recreation. Patterns of gains and losses will impact different groups and different communities differently. Certainly activities dependent on ice and snow are likely to suffer based on climate evidence. An empirical question that cannot be specifically addressed given available data is how gains may offset or exceed losses in the transition periods in both spring and fall as ice duration becomes shorter. But it is important to note that there will be both gains and losses from the resulting changes. A recurring theme of the economic perspective in this report is that it is both important to consider the change in the expected value - in this case the net change from gains and losses - but also to recognize the socio-economic consequences in increasing the variability of these impacts. In other words, analysis of expected values would yield be incomplete picture given the dispersion of outcomes will probably be wider.

Indirect socio-economic effects are also likely to occur from shorter ice duration as one aspect of changing conditions in the aquatic ecosystem. There is an important linkage between ice-on/ice-off periods, limnological conditions/water quality, fish habitat and species distribution/abundance. The effects described in Sections II and III imply that some species will thrive on changed conditions resulting from climate change and others will suffer. Increases in runoff from climate change (due to changes in precipitation patterns) and increases in temperature both have potential to decrease the amount of dissolved oxygen (DO) in water bodies, which could potentially impact fish populations. Within the project team, the work of Kristal Schneider on the potential fisheries changes provides another cornerstone of this analysis. Evidence already suggests that cold-water species will decline in Minnesota and other species will expand in range and abundance. Economic implications of these potential direct and indirect impacts are considered below.

The thesis research is summarized as follows: The main goal of this study is to determine what impact climate change may pose to recreational benefits provided by the activity of angling. Creel surveys from the Minnesota Department of Natural Resources Creel Database were utilized to determine statewide angler effort and preferences for certain species. Lake ice duration observations were gathered to determine current trends and future projections. These data were utilized and combined with fishing valuation literature to determine an economic impact from climate change. Statistical analysis shows that lake ice duration is significantly decreasing statewide. Since more anglers fish during the summer months, this could lead to a net economic gain. On the other hand, bodies of water such as East Upper Red Lake see more anglers during the ice-fishing season, so could potentially see an economic loss. The project also utilized creel surveys to test the hypothesis indicating a statewide decline of trout species and northeastern shift of largemouth bass and sunfish from the onset of climate change. A multiple regression was performed on historical creel data to determine if there was a change in effort over time across different climate regions by species group. These variables were tested to see their influence on the amount of fish caught. The regression indicates a positive relationship between the amount of effort and the amount of yield, but effort does not appear to be shifting regionally in response to climate change predictions.

Future changes in recreation patterns are difficult to predict based on past records of recreational activity. The analysis requires some caveats due to limitations of available data to support estimation of changing trends. Major disclaimers of the analysis are:

- The results contain information from DNR data that was aggregated into seasonal estimates. The conclusions drawn from the results would have been more accurate if they were drawn from stratified seasonal data. For example, the conclusions assume that every day experiences the same amount of pressure throughout a season. Since there are differences in use in different periods of a season, the results in this section must be considered only a representation of a potential method to model climate change impacts.
- The following results assume that an ice-fishing day is worth the same as an open-water fishing day. A travel cost analysis for ice anglers could reveal a different valuation for an ice-fishing day. In fact, statistical evidence shows that an ice-fishing day is slightly longer than an open-water day, which suggests a higher valuation by anglers.
- The following results also assume that a fishing day is worth the same regardless of the species being sought. Willingness-to-pay literature provides evidence to the contrary. For example, trout species are more highly valued than average and are amongst the most vulnerable in Minnesota to the effects of climate change.
- Benefits Transfer based on the average expenditure of $35 for a fishing day in Minnesota understates the full economic value as it excludes consumer surplus. Willingness to Pay for a fishing day would be greater than the average daily expenditure.
- The multiple regression testing the hypothesis of shifting species ranges and abundance was based on DNR data that contained many empty fields. The results were statistically significant, but were not based on a complete dataset.

These changes in fish populations and ice conditions are important concepts for the state to consider, due to the high popularity of the activity of angling statewide. The U.S. Fish and Wildlife Service estimated that Minnesota residents and nonresidents spent roughly 24 million days fishing in 2006 (U.S. Department of the Interior [USDI], Fish and Wildlife Service [FWS], and U.S. Department of Commerce, U.S. Census Bureau [USCB], 2008).

Fishing as an activity has an economic value. It has use values as conceptualized in Section IV. The U.S. Department of the Interior (2008) estimated in 2006 roughly $2.7 billion was spent in Minnesota on goods associated with angling. By conducting interviews on trip expenditures, the U.S. Fish and Wildlife Service estimated that individuals spent roughly $35 per day on the activity of fishing in Minnesota (USDI, FWS, USCB, 2008). The same study estimated that roughly $466 million was spent on angling activities in Minnesota by nonresidents alone (USDI, 2008). As noted above, these expenditures do not include the additional consumer surplus given that willingness to pay would generally exceed the expenditures actually paid in market transactions. Changing the abundance of available fish for the sport as well as the conditions in which an angler may pursue his or her prey could both potentially have an economic impact on the state.

This study utilized statewide statistics from creel surveys and from lake ice observations to determine a potential economic impact on the recreational benefits of angling. The economic estimate was performed utilizing benefit transfer, which is an economic tool for estimating value when the resources for conducting a primary study do not exist. Three different scenarios were tested to determine potential impacts to recreational benefits: these scenarios took into account the variation in the amount of use that some lakes see in each season, whether each day was worth the same amount of money per angler regardless of season, and if there might have been a change in the amount of species present in these lakes. This analysis provides an estimate of potential impacts under these three different scenarios.

Periodically, the Minnesota Department of Natural Resources (MN DNR) conducts summer and winter creel surveys to assess the amount of use certain lakes experience. These surveys analyze how many hours are spent recreating and how many fish are caught and kept or released by anglers. This survey database is used for the empirical analysis below of fishing activities. It contains information on fishing pressure gathered from 763 lakes. Out of these lakes, 400 contained information regarding winter pressure. These lakes are dispersed throughout Minnesota.

Main Hypotheses and Scenarios

The hypotheses tested in this thesis are represented by the function: $B = f(x_1, x_2, x_3, x_4)$. The components of this function include:
B = Recreational benefits from fishing
x_1 = Ice-on days
x_2 = Open-water days
x_3 = Angler hours per acre
x_4= Species

Recreational benefits are hypothesized to be a function of the above variables. When one of these variables is shifted, it is assumed that there will be an impact on the recreational benefits (B). In other words, it is assumed that a change in ice-on days, ice-off days and angler hours per acre will all have an impact on recreational benefits. These assumptions are represented below:
Assume: $\Delta B/\Delta x_1 > 0; \Delta B/\Delta x_2 > 0; \Delta B/\Delta x_3 > 0$

As mentioned above, three different scenarios are tested. The first tests the notion that the change in recreational benefits from a change in ice-on date is equal to the change in marginal benefits from a change in ice-off date. In other words, ice-fishing is not worth any more than open-water fishing.
Scenario 1: $\Delta B/\Delta x_1 = \Delta B/\Delta x_2$

The second scenario looks at the possibility of the change in recreational benefits being unequal from a change in ice-on and ice-off dates. Scenario 2a represents the case of locations such as East Upper Red Lake, MN, which have seen a higher proportion of anglers visiting in the winter than in the summer (MN DNR, 1997). This difference is mainly due to the ease of access in the winter. In the summer the geography of the lake results in large waves when wind is present, which makes open water fishing difficult.

Scenario 2a: $\Delta B/\Delta x_1 < \Delta B/\Delta x_2$

Scenario 2b applies to other areas around the state. The statistical analysis of fishing activity in Minnesota reveals a higher amount of angler hours on lakes during the summer months (see results). Therefore, an increase in the amount of ice-off days will have a greater positive impact on recreational benefits than the loss due to fewer ice-on days.

Scenario 2b: $\Delta B/\Delta x_1 > \Delta B/\Delta x_2$

The third scenario examines the impact of species on the marginal recreational benefits. The literature has indicated that certain species have had a higher willingness to pay (WTP) by anglers than others (Johnston, Ranson, & Helm, 2006). For example, trout species have had a higher WTP than species such as panfish and walleye (Johnston et al., 2006). Under this assumption, a change in abundance of one species, or decrease in abundance of another may have a significant impact on the recreational benefits.

Scenario 3: $\Delta B/\Delta x_4 > 0$

Using ice duration statistics (including ice-on and ice-off data), the estimated impact on the total number of days fished was determined. Lake ice records were tested to see if the ice duration was significantly increasing or decreasing.

Lake Ice Observation Methodology

Lake ice records were obtained from Dr. Virginia Card at Metropolitan State University, Saint Paul, MN. Her ice records were gathered from the Minnesota Pollution Control Agency (MPCA) and the Minnesota Ice Records Database. The Minnesota Ice Records Database consists of a combination of observations recorded in newspapers and from individual correspondence. She submitted to this project data from 40 lakes that contain both ice-on and ice-off observations dates, which made it possible to estimate ice duration. These 40 lakes are a set from another subset of her data consisting of 106 lakes. The set of 106 lakes were chosen from her dataset, because they contain information regarding gill net and water quality data. The ice trends are reported in days lost or gained and determine how many angler days would impacted.

Using the creel survey data, the average number of angler hours per season per acre was determined. The total amount of angler days was determined using the number of angler hours per fishing trip in the open-water and ice-fishing seasons (separately). The average number of angler days in each season per acre was then extrapolated with the total acreage of lakes in Minnesota.

In order to determine an impact on the number of open-water days and ice-on days, a baseline for the current total number of these days needed to be determined (seen below in the equation). To create this baseline, data from 1971-2000 was utilized from the 40 lakes in the ice coverage dataset.

Total Lake Acreage

The total lake acreage was determined using a GIS layer obtained from the GIS coordinator for the MN DNR, Lyn Bergquist. The layer contains all lakes that have division of waters (DOW) identification numbers, which totals to 16,141 lakes. This layer was specifically prepared to represent Minnesota lakes acreage. The portions of lakes that exist outside state boundaries were excluded from the acreage assessment. Out of these lakes, the DNR has sampled fish populations on 4,295 lakes. Using the sum feature in GIS, the acreage for the group of 16,141 lakes and the group of 4,295 lakes were each determined. The acreage for the 16,141 lakes is 4,555,898.54, and the acreage for the 4,295 lakes is 3,923,292.62. The different acreage estimates provide upper and lower bound numbers allowing a sensitivity analysis for the effect of the total amount of lake acreage in Minnesota.

Explanation of the Benefits Calculation

The result of combining angler days with the total lake acreage provides an estimate of the total number of trips (angler days) that occur in the open-water or ice-fishing seasons for the entire state. The total estimate can then be divided by the number of days in a season, which yielded the average number of trips per day. The number of trips per day was multiplied by the number of lost or gained days using the ice duration statistics. This provided an approximation of the number of angler days lost or gained from changing ice duration.

The estimated lost or gained fishing days was then transferred into an economic estimate to represent the economic gain or loss. Data from the U.S. Census Bureau valuing a fishing day was utilized as an estimate at $35 per day. Since a fishing day may be variable between seasons, the number of hours in a fishing day was found for each season using statistical analysis.

Mathematical Description of the Benefits Calculation

The procedure, mentioned above, for estimating the potential economic impact is as follows:
$X1_w$, $X1_s$ = Mean angler hours per acre per season
X2 = Total fishable acres (two estimates)
$X3_w$, $X3_s$ = Mean angler hours per trip in each season (trip length)
$X4_w$, $X4_s$ = Angler days per season in each climate region
$X5_w$, $X5_s$ = Days lost or gained in each season per decade
X6 = Value of a fishing day
$Y1_w$, $Y1_s$ = Total trips/season
Y2 = Average trips/day
$Y3_w$, $Y3_s$ = Trips lost/gained per season
$Y4_w$, $Y4_s$ = Economic estimate per season
Y5 = Total economic impact

$X5_w + X5_s = 0$

$Y3_w + Y3_s = 0$

$Y1_{w/s} = X1_{w/s} * X2/X3_{w/s}$
$Y2_{w/s} = Y1_{w/s} / X4_{w/s}$
$Y3_{w/s} = Y2 * X5_{w/s}$
$Y4_{w/s} = X6 * Y3_{w/s}$
$Y5 = Y4_w + Y4_s$

Multiple Regression on Shifts over Time of Harvest, Effort and Species

In addition to the above hypothesis, another hypothesis proposed by Schneider, Newman, Card, Weisberg, and Pereira (2009) was examined. This hypothesis indicated that largemouth bass and sunfish are predicted to shift their range north and east in response to climate change. In addition, the literature indicated trout species are predicted to decline in abundance. Angler surveys provided species-sought percentages and species yield (in pounds) that were examined across climate regions over time. Species included in the analysis were walleye (due to its high economic demand), largemouth bass, sunfish, and all trout species. These species elicited some of the highest rates of preference by anglers from the creel database (See Table 25 in the Appendix). Some of these values totaled to more than 100% due to multiple responses being coded for 100% in the same category. These inaccuracies were corrected for the benefits estimation calculation. Any remaining species were categorized as “other species.” The variables examined were species, percentage of “species-sought”, climate region and year. These variables were placed in a multiple regression (using dummy variables for climate regions and species) to determine their impact on total yield across the state. The multiple regression equation reads as follows:
$Y = f(x_1, x_2, x_3, x_4)$

$Y = \text{Weight}_{species}$
$x_1 = \text{Hours}_{species}$
x_2 = Climate region
x_3 = Survey year
x_4 = Percentage of anglers seeking each particular species

GIS was utilized to assign all of the survey lakes to one of the nine climate regions defined within the larger project. Besides running a multiple regression on all Minnesota lakes, separate regressions were run on Red Lake, as well as 9 out of 10 of the large walleye lakes in Minnesota that are important for economic reasons (MN DNR, 1997). The nine large walleye lakes are Lake Vermillion, Lake Mille Lacs, Cass Lake, Lake Winnibigoshish, Rainy Lake, Leech Lake, East Upper Red Lake, Lake of the Woods and Kabetogama.

The mean number of angler hours per acre in each season proved to be significantly different from one another at the 1% level based on an independent samples t-test. The mean angler hours per acre in the summer were 45.14 hours and in the winter were 8.88 hours.

The mean angler hours per trip were compared between seasons suing an independent samples t-test. Trip length is significantly different at the 1% level with mean summer trip length of 3.35 hours and winter at 3.77 hours.

As noted in Section III, based on the data and findings of Card (2010) it was found that lake ice duration in the Minnesota sample is significantly decreasing at a mean rate of 3.3 days per decade from the time period of 1970 to 2008. These values were used to calculate the potential losses from 3.3 fewer ice fishing days annually than a decade ago. These were compared to potential gains from 3.3 more open-water fishing days. Absent any available estimates for Minnesota on differences between the value of an ice-fishing day versus an open-water fishing day, the US Census figure for Minnesota of $35 per day was utilized. Given the two estimates of lake acreage, a lower and upper-bound estimate of changes in the dollar value of fishing is estimated for each of the nine climate regions. More detail on these computations is provided in the appendix containing the Vandergon Thesis.

Summary results statewide are provided here as an overview. The lower bound estimate of ice fishing trips per season is 9,241,071.2, and the upper bound is 10,731,135.0. By comparison, open-water trips per season had a lower-bound of 52,864,904.1 and upper bound of 61,389,032.9 trips per season. It is noteworthy that the lower-bound estimate based on the lower acreage calculation yields estimate from the creel surveys that are more consistent with the estimates of 24 million fishing days in 2006 according to the US Fish and Wildlife Service.

Total Impact Statewide (Across all Climate Regions)

The values below were calculated by summing the results above in each climate region. The typical number of anglers recreating on an ice-fishing day versus an open-water day are calculated for each climate region. The difference was determined between seasons individually for the upper and lower bounds. Because there are generally fewer anglers using Minnesota lakes on the typical ice-fishing day than the typical open-water day, the reduction of ice-fishing days due to climate change causes less of a loss in recreational value than the gain in open-water values. The net economic impact statewide is estimated as follows:

Lower Bound = $177,725,196.9 gain due to 3.3 fewer days ice duration

Upper Bound = $206,382,251.8 gain due to 3.3 fewer days ice duration

Multiple Regression Results

Regression Results for the State

The multiple regression model was created to show how angler effort has an impact on yield (in pounds) across climate regions over time. The aim was to see if yield per unit of effort of some species in some areas was improving in the climate regions with greater abundance as predicted by Schneider et al (2009). The model has a high F-statistic yielding the conclusion that the model is significant at the 1% level. The variable of effort (spphrs) was significant at the 1% level, indicating for every extra hour spent fishing .002 pounds of fish were caught. This finding was significant and the slope was identical in both of the regressions, with and without the constant.

The dummy variables for each species were significant at the 1% level. This indicated that the amount of effort that was devoted to angling for a specific species resulted in a significant relationship with the amount of yield. In other words, more time spent fishing for a certain species represents a relationship with the amount of catch for that species. The negative numbers for each species represents a significantly lower amount of influence from the four main species categories in comparison to the “other species” category (the “other species” category was the baseline, and assigned a zero in each of the four dummy categories). This result suggests that the influence of the “other species” category dominated the results for the weight category and that the “other species” category has a higher rate of pounds harvested per hour.

The dummy variable for climate region 2 was significant at the 10% level with a one-tailed test. These results indicate that the affect of angling effort on the amount of yield is significantly higher in this region (north central MN) compared to other climate regions. Interestingly, the amount of pounds caught in climate region 2 was the highest of all. Climate region 2 has over double the amount of fish caught in comparison to the mean elsewhere.

While greater effort results in higher harvest, greater reward for effort does not seem to be occurring in regions where populations of certain species are increasing. Another way to test whether anglers are changing behavior in response to species changes is to compare effort thru time for selected species in the regions where these species are increasing in abundance. The regression below tests this hypothesis.

Many of the same relationships described above hold in this model. Again climate region two has more hours of effort compared to the other regions. There is not a significant increase in angler hours in the regions where sunfish and bass are increasing in abundance.

Table VI.6. Multiple Regression Results: Fishing Effort (hours for species) by Climate Region

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.273[a]	.075	.070	1.19060E7

a. Predictors: (Constant), Dclmt8, Dwae, Dclmt1, Dclmt7, Dclmt5, SurveyYr, Dclmt2, Dlmb, Dclmt4, Dtrt, Dclmt3, Dsun, Dclmt6

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.876E16	13	2.212E15	15.604	.000[a]
	Residual	3.568E17	2517	1.418E14		
	Total	3.855E17	2530			

a. Predictors: (Constant), Dclmt8, Dwae, Dclmt1, Dclmt7, Dclmt5, SurveyYr, Dclmt2, Dlmb, Dclmt4, Dtrt, Dclmt3, Dsun, Dclmt6

b. Dependent Variable: spphrs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-9.082E7	5.459E7		-1.664	.096
	SurveyYr	45400.005	27293.197	.033	1.663	.096
	Dlmb	-2117239.393	802317.805	-.061	-2.639	.008
	Dsun	-1766307.781	725991.105	-.058	-2.433	.015
	Dtrt	-2312267.224	727063.507	-.076	-3.180	.001
	Dwae	5507432.503	720596.759	.184	7.643	.000
	Dclmt1	291984.395	4249273.296	.002	.069	.945
	Dclmt2	5706776.641	3502669.369	.153	1.629	.103
	Dclmt3	2803131.098	3481431.338	.090	.805	.421
	Dclmt4	1384243.877	3497827.193	.039	.396	.692
	Dclmt5	1636370.302	3536631.429	.037	.463	.644
	Dclmt6	3000398.053	3465298.380	.116	.866	.387
	Dclmt7	735854.799	3844732.800	.008	.191	.848
	Dclmt8	1148167.178	3562417.971	.024	.322	.747

a. Dependent Variable: spphrs

SECTION VII.
CONCLUSIONS AND IMPLICATIONS FOR FURTHER RESEARCH

A. Conclusions

The relative emphases of the economic analyses and the empirical estimation are dependent upon the findings of the other environmental components of this research effort. To a certain extent, the findings on environmental impacts at this juncture are predicated on available data that are constrained in both temporal and spatial scale. So while evidence is mounting that Minnesota's water resources are vulnerable to the effects described in the workplan (higher surface water levels/streamflow, increased sedimentation, degraded water quality, infrastructure implications) some of the more extreme impacts anticipated at the global or regional scale are difficult to detect statistically at the smaller statewide scale. This is due in part to lack of small spatial scale data over the length of time needed to detect statistically meaningful trends.

The economics literature on risk-aversion should inform decisions on climate change. The potential damages from climate change are the types of risks that people typically wish to guard against. Most citizens place a value on risk reduction and are willing to pay for the insurance value this yields. Public policy that provides this is a public good to all those who have risk-averse preferences. It is a collective value derived from the sort of individual value many people place on private insurance. Fundamental aspects of climate change involve risks and this conceptual economic approach is enlightening.

Policies to reduce risks from climate change can be to reduce GHG emissions and/or to mitigate impacts in other ways (enhance ecosystem integrity and resilience, adaptation through precautionary infrastructure design, etc.) Economic efficiency and equity goals are relevant to these decisions. If avoiding potential damages is deemed to generate net benefits and/or enhance equity, ways of achieving these goals at least cost should be pursued. Increasing the percentages of best land-use practices applied in many watersheds may be a cost-effective way to offset ecological stress on Minnesota's water resources.

Flood Damages

Consistent with the approaches advocated by the WICCI Working Groups, MN should identify settings with the greatest vulnerability to catastrophic failure such as loss of life and property if structures fail. Most of the MN topography does not cause as great of danger of flash flooding as in more mountainous areas. The severe flood in southeastern MN in 2007 demonstrates that the topography of that part of the state makes it more vulnerable to severe flash floods. Elsewhere, overland flooding is more likely to occur rather than the deep rush of water with floods in hills and valleys. The tragedy of loss of life in the June 2010 disaster at the Albert Pike Recreation Area in Arkansas is an example of the type of worst-case scenario from flash flooding. MN should adopt a two-pronged approach to risk management to the degree that MN can inventory watersheds for combinations of two groups of characteristics. Greatest vulnerability to damages from flash floods exists in watersheds that have: 1) geomorphology conducive to flash floods and 2) human and natural environments that put highly valued assets and human life in harm's way.

Findings from the component of the project on streamflow reported in Section IIIC below indicate that the Minnesota River Basin and the Red River of the North have larger increases in streamflow than the other three basins in the state. Even though extreme precipitation events are likely to be randomly located across the state, it would be a wise investment to protect against such disasters in the most vulnerable locations. This would be a sound application of the Precautionary Principle and risk aversion discussed further below in Section IV.

The longest yearly record for weather-related damages in MN comes from figures reported in a NOAA study (2002) that re-examines damage figures from 1925-2000. Figures are provided state-by-state from 1955 to 2000. It is most informative to compare damages that are standardized in constant dollars: this data series used 1995 dollars. From 1955-2000 occasional weather events caused damages in the tens of millions of dollars. Damages in the hundreds of millions of dollars also occurred over this time period. By far the two years with the highest damages were 1997 and 1993. The floods of 1993 caused damages in excess of $1 billion in constant 1995 dollars.

The MN Department of Public Safety's Division of Homeland Security & Emergency Management provided summarized damage information over the past two decades. The damage figures for the 1990s are contained in a report "A Decade of Minnesota Disasters: A Historical Look at Minnesota Disasters in the 1990s." According to the report, these damages are increasing and during the 1990s there were 14 presidential declarations of major disasters. Most of the damages were the result of flooding, ice storms, snow removal, straight-line winds, tornadoes, and heavy rain. From the disasters of the 1990s, Minnesota taxpayers spent $827 million and the cost to insurance companies was more than $2 billion.

Examination of transportation infrastructure as a major category of damages revealed that numerous weather-related events have occurred in the last two decades that caused damages to roads, bridges and culverts in the millions or tens of millions of dollars, per event.

Ice Duration and Recreational Fishing

Analysis conducted by Virginia Card as part of the larger project found that ice duration is getting shorter in the state. The trend analysis indicated that ice-duration has on average been getting shorter by a third of a day in a typical year, or 3.3 days over the course of a decade. A direct socio-economic impact of shorter ice duration will be the switch of recreational days for ice-related activities to open-water activities. The change in environmental conditions will cause positive and negative effects on opportunities for recreation. Patterns of gains and losses will impact different groups and different communities differently. Certainly activities dependent on ice and snow are likely to suffer based on climate evidence. Indirect socio-economic effects are also likely to occur from shorter ice duration as one aspect of changing conditions in the aquatic ecosystem. There is an important linkage between ice-on/ice-off periods, limnological conditions/water quality, fish habitat and species distribution/abundance.

An empirical question that cannot be specifically addressed given available data is how gains may offset or exceed losses in the transition periods in both spring and fall as ice duration becomes shorter. But it is important to note that there will be both gains and losses from the resulting changes. A recurring theme of the economic perspective in this report is that it is both important to consider the change in the expected value - in this case the net change from gains and losses - but also to recognize the socio-economic consequences in increasing the variability of these impacts. In other words, analysis of expected values would yield an incomplete picture given the dispersion of outcomes will probably be wider.

Creel survey data on recreational fishing in MN was utilized to discern patterns in activity and how it might relate to changes in ice duration and species distribution/abundance. Three scenarios were developed for modeling purposes.

Results from Three Fishing Scenarios

Scenario 1 assumes ice fishing days lost will lead to a loss equal to the open-water activity that will take its place on those days of transition: ice days that are now open-water.
The results from the benefits estimation calculations indicate that this scenario will not prove to be likely. All climate regions reveal that there may be net positive benefits from the onset of climate change and decreasing ice duration. However, this does not mean this may be a preferable result for those who enjoy the activity of ice fishing in the winter.

Scenario 2a recognizes that some lakes, most notably Upper Red Lake, are extremely popular for ice fishing. Results from East Upper Red Lake show that there are differences in the amount of pressure between the winter and the summer. Since Red Lake sees such a higher use in the winter months, the onset of climate change through decreasing lake ice will likely have a net negative impact on recreational benefits from use of this lake.

Scenario 2b looked at the large walleye lakes in the state. These generate a very large portion of the overall fishing activity in the state. In contrast to Upper Red Lake, other large walleye lakes (and statewide data for smaller lakes) show that summer effort significantly exceeds effort in the winter. A higher amount of angler effort in the open-water season is likely to lead to a net positive impact from the onset of climate change.

Scenario 3 investigates whether changes already occurring in species distribution and abundance are leading to changing patterns of fishing effort. The results from the multiple regressions did not show significant results for a change in yield per unit of effort in response to change in species abundance over certain regions of the state over time. As mentioned in the literature, certain species, such as trout, have a higher WTP than walleye and panfish. Therefore, a change in these species abundances could have a significant impact on the WTP by anglers. For example, fewer trout (which are predicted to decline from climate change) would be detrimental to recreational benefits. The net impact from these changes in species abundance and the economic consequences cannot be estimated given limitations of available data. However, further inquiries into these possibilities with better data on WTP by species and longer time periods would be warranted.

B. Implications for Further Research

Changes to lake ice duration impact the fishing that occurs at the beginning and the end of the ice season. Maintaining a strong dataset with these types of divisions would aid with understanding how much usage occurs in these transitional periods between ice and open-water fishing. For example, some anglers may fish more at the beginning of the ice fishing season when fish such as walleye may be biting and then wane off as the season progresses. In the spring, a renewed effort for species such as perch and crappie may ensue. In the fall, a large percentage of the angling population may be off of lakes after Labor Day. To explore these issues further, creel data would need to be determined for more specific seasonal strata such as early spring, late fall, early winter and late winter. Better understanding of how WTP varies across species of fish sought would strengthen the type of preliminary analysis performed here. Knowledge of these preferences and related behaviors would help with future studies.

The economic estimate of a fishing day provided by the U.S. Department of the Interior does not provide a distinct value for an ice fishing day. Angling on the ice has its own set of expenditures such as ice houses, augers and tackle that could amount to different travel cost estimation for individuals participating in this type of activity. Valuing ice fishing at a different rate would have the potential to alter the economic estimates.

The larger project identified future needs for data at scales appropriate to understanding climate change impacts in Minnesota. Much of the discussion in the research community at the national and state level is emphasizing the need to "downscale" data to allow meaningful analyses for smaller geographic areas, such as states. Needs to improve scale are:

1. Spatial Scale: consensus on need for "downscaling." Scaling Down Global and Regional Patterns to Minnesota
2. Temporal Scale
    a. Data to Determine variations over long enough time span
    b. Hydrologic Data to Determine variations in Stream Flows that occur within 7-day period, such as extreme flows within a 24-hour period

One major example of limitations due to too short of time span is described in an earlier project summary. It pertains to projecting biological responses to changing climate. Fish populations and other biological communities will be affected by warmer water temperatures, and altered thermal regimes, changes in flow regimes, total flows, water level, and water quality. These changes will affect the health of aquatic ecosystems, with impacts on productivity, species diversity, and species distributions. The paucity of historic data makes it difficult to assess past changes and predict biological responses to climate change.

The overall project, and the economic component, has generated useful information as an indication of where the state might be headed in terms of climate change. It also indicates how much remains to be done in order to generate more precise empirical evidence. A great deal is being learned about how climate change may impact the future and what options exist to address it. Climate change has implications in time scales longer than most institutions are equipped to handle. Research design and policy formulation needs to reckon with these long time horizons in determining actions today that will benefit the future.

SECTION VIII.
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APPENDIX A
KEY EXCERPTS FROM THE LITERATURE ON ENVIRONMENTAL AND ECONOMIC IMPACTS

US Global Change Research Program reports impacts by sectors (water resources covered above in Section II of this report):

Changes by Sector Water Resources pages 41-52, Energy Supply and Use 53-60, Transportation 61-70, Agriculture 71-78, Ecosystems 79-88, Human Health 89-98, Society 99-106

"Energy Supply and Use

- *Warming will be accompanied by decreases in demand for heating energy and increases in demand for cooling energy. The latter will result in significant increases in electricity use and peak demand in most regions.*
- *Energy production is likely to be constrained by rising temperatures and limited water supplies in many regions.*
- *Energy production and delivery systems are exposed to sea-level rise and extreme weather events in vulnerable regions.*
- *Climate change is likely to affect some renewable energy sources across the nation, such as hydropower production in regions subject to changing patterns of precipitation or snowmelt."*

"Transportation KEY MESSAGES:

- *Sea-level rise and storm surge will increase the risk of major coastal impacts, including both temporary and permanent flooding of airports, roads, rail lines, and tunnels.*
- *Flooding from increasingly intense downpours will increase the risk of disruptions and delays in air, rail, and road transportation, and damage from mudslides in some areas.*
- *The increase in extreme heat will limit some transportation operations and cause pavement and track damage. Decreased extreme cold will provide some benefits such as reduced snow and ice removal costs.*
- *Increased intensity of strong hurricanes would lead to more evacuations, infrastructure damage and failure, and transportation interruptions.*
- *Arctic warming will continue to reduce sea ice, lengthening the ocean transport season, but also resulting in greater coastal erosion due to waves.*
- *Permafrost thaw in Alaska will damage infrastructure. The ice road season will become shorter."*

"Agriculture KEY MESSAGES:

- *Many crops show positive responses to elevated carbon dioxide and lower levels of warming, but higher levels of warming often negatively affect growth and yields.*

- *Extreme events such as heavy downpours and droughts are likely to reduce crop yields because excesses or deficits of water have negative impacts on plant growth.*
- *Forage quality in pastures and rangelands generally declines with increasing carbon dioxide concentration because of the effects on plant nitrogen and protein content, reducing the land's ability to supply adequate livestock feed.*
- *Increased heat, disease, and weather extremes are likely to reduce livestock productivity."*

"Ecosystems KEY MESSAGES*:*

- *Ecosystem processes, such as those that control growth and decomposition, have been affected by climate change.*
- *Large-scale shifts have occurred in the ranges of species and the timing of the seasons and animal migration, and are very likely to continue.*
- *Fires, insect pests, disease pathogens, and invasive weed species have increased, and these trends are likely to continue.*
- *Deserts and drylands are likely to become hotter and drier, feeding a self-reinforcing cycle of invasive plants, fire, and erosion.*
- *Coastal and near-shore ecosystems are already under multiple stresses. Climate change and ocean acidification will exacerbate these stresses.*
- *Arctic sea ice ecosystems are already being adversely affected by the loss of summer sea ice and further changes are expected.*
- *The habitats of some mountain species and coldwater fish, such as salmon and trout, are very likely to contract in response to warming.*
- *Some of the benefits ecosystems provide to society will be threatened by climate change, while others will be enhanced."*

"Human Health KEY MESSAGES*:*

- *significant increases in the risk of illness and death related to extreme heat and heat waves are very likely. Some reduction in the risk of death related to extreme cold is expected.*
- *Warming is likely to make it more challenging to meet air quality standards necessary to protect human health.*
- *Extreme weather events cause physical and mental health problems. Some of these events are projected to increase.*
- *Some diseases transmitted by food, water, and insects are likely to increase.*
- *Rising temperature and carbon dioxide concentration increase pollen production and prolong the pollen season in a number of plants with highly allergenic pollen, presenting a health risk.*
- *Certain groups, including children, the elderly, and the poor, are most vulnerable to a range of climate-related health effects."*

"Society KEY MESSAGES*:*

- *Population shifts and development choices are making more Americans vulnerable to the expected impacts of climate change.*
- *Vulnerability is greater for those who have few resources and few choices.*
- *City residents and city infrastructure have unique vulnerabilities to climate change.*
- *Climate change affects communities through changes in climate-sensitive resources that occur both locally and at great distances.*
- *Insurance is one of the industries particularly vulnerable to increasing extreme weather events such as severe storms, but it can also help society manage the risks.*
- *The United States is connected to a world that is unevenly vulnerable to climate change and thus will be affected by impacts in other parts of the world."*

Additional content from the WICCI Stormwater Working Group:
"Adaptation Strategies
There is a growing consensus that scientific knowledge about the potential increase in magnitude and frequency of large rainfalls is sufficient to warrant immediate changes in the methods used to design and manage storm water-related infrastructure. For example, the following steps have been identified by the Stormwater working group:

- *Synthesize existing historical and model data for rainfall in the upper Midwestern U.S. to provide a more accurate account of current and future precipitation;*
- *Use a risk/consequence approach to evaluating and modifying existing infrastructure to accommodate observed and predicted changes in climate.*
- *Develop and evaluate alternative tools and strategies for the design of storm water-related infrastructure, using a collaborative process that includes climate scientists, water resource managers, design engineers, and regulators, and members of relevant business communities;*
- *Communicate findings and recommendations to water resource managers, design engineers, relevant government entities and other decision makers."*

"Adaptation Science
Now imagine being a city planner or hydrologic engineer responsible for designing and implementing new storm water structures that are meant to last for the next fifty years. If you design these structures based on the weather from the last fifty years, they might lack sufficient capacity to handle rain storms of increasing intensity and frequency, perhaps leading to flooded streets and homes. On the other hand, if you plan for the worst-case scenario even though there is a small probability of it happening, you may over-design the system at a significant cost to the taxpayer if those extreme events do not materialize."

"This conundrum represents the world of adaptation science. At a fundamental level, there are only two parts to adaptation science; calculating the probability of a future event, and creating contingency plans for those events most likely to materialize. Adaptation should focus on the greatest vulnerabilities. In short, where are the greatest risks if climate changes occur? Identifying these vulnerable locations or situations, and then creating a range of contingency plans, is the focus of many WICCI Working Groups."

"Coastal Communities: Potential Risks

- *Coastal Flooding: Climate change may cause the water levels on Lakes Superior and Michigan to extend beyond the range measured since 1860.*
- *Coastal Erosion: An increase in intense precipitation and storm events along with the impacts of warmer and wetter winters (more freeze/thaw cycles and less lake ice cover) could increase coastal erosion and may lead to more frequent episoidal deep-seated landslides.*

Vulnerabilities

- *Residential and commercial structures and property on the coast are vulnerable to erosion and flooding. The migration of the Ordinary High Water Mark (OHWM) towards the lake during extended periods of low lake levels may encourage development in hazardous areas.*
- *Harbors and marinas are susceptible to extreme water levels.*
- *Industrial facilities such as power plants and water/sewer treatment facilities are vulnerable to extreme water levels that exceed their design.*
- *Infrastructure such as roads and drainage are susceptible to coastal erosion and flooding.*
- *Shore protection structures need to be maintained over time and may not be effective if lake levels extend beyond their design parameters.*
- *Natural plant communities along the Great Lakes, including coastal wetlands, may be impacted by persistent extreme lake levels.*
- *Water intakes may be impacted by low water levels.*
- *Climate change may impact tourism in coastal communities. Issues include beach health and aesthetics for hotels.*
- *Changes in water temperatures and circulation patterns could affect mixing patterns in coastal waters.*
- *More intense coastal storms could impact dredging and re-suspend contaminated sediments. "*

The MN Sea Grant Program also discusses likely impacts on Lake Superior.
"Lake Superior's surface water temperature in summer has warmed twice as much as the air above it since 1980.

> *Per decade since 1980, surface water temperature in summer has increased about 2 °F (1 °C), while regional air temperature has increased 1 °F (0.5 °C).*

Lake Superior's ice cover is diminishing.

> *The area covered by ice each winter is decreasing by about 0.5% per year.1 Ice cover in Lake Superior has decreased from 23% to 12% over the last century.*

Wind speeds over Lake Superior are increasing.

> *Since 1985, wind speeds have increased by nearly 5% per decade, exceeding trends over land. Scientists believe the faster winds could accelerate the speed of Lake Superior's water currents, which in turn could affect the aquatic food web.*

Lake Superior's summer stratification season is longer.

> *Spring turnover has become earlier by about 1/2 day per year, leading to earlier summer stratification. The sun-warmed upper layer extends farther into the water column, making fall mixing later. The length of the positively stratified season has increased from 145 to 170 days over the last century.*

From Heal and Kristrom (2002) "Uncertainty and Climate Change"
"The reference to scientific uncertainty here implies, for the authors, the possible resolution of this uncertainty by research and learning. Most economists, if asked to think of a justification for this principle, would probably couch it in terms of learning, irreversibilities and option values, so intuitively we think the two are related. Gollier et al note that in fact the precautionary principle can be given a formal justification without invoking irreversibilities, just assuming a stock damage effect and possible learning over time. . . . there are two contradictory effects. One is that we invest less in prevention in the economy which may learn more because this investment may be inefficient: when we know more we
may be able to choose better investments. They describe this as the "learn then act" strategy. The opposing tendency is generated by the fact that if we follow this strategy then the risk that society faces in the future will be greater. The principle result of the Gollier et al paper is that the balance between these two effects depends on the shape of the utility function and in particular on whether or not society shows 'prudence'." Page 26

From Berz (1999) *"The present problems will be dramatically aggravated if the greenhouse predictions come true. The changing probability distributions of many processes in the atmosphere will force up the frequency and severity of heat waves, droughts, bush fires, tropical and extratropical cyclones, tornados, hailstorms, floods and storm surges in many parts of the world with serious consequences for all types of property insurance, apart from the consequences of the stratospheric ozone destruction for health and life insurance.*

Rates will have to be raised and in certain areas insurance cover will only be available after considerable restrictions have been imposed, as for example significant deductibles and low liability or loss limits. In areas of high insurance density the loss potential of individual catastrophes can reach a level at which the national and international insurance industries will run into serious capacity problems. Recent disasters showed the disproportionately high participation of reinsurers in extreme disaster losses and the need for more risk transparency if the insurance industry is to fulfill its obligations in an increasingly hostile environment."

From the World Wildlife Fund for Nature and Allianz Insurance Company report (2009)
"Climate change resulting from emissions of CO2 and other greenhouse gases (GHGs) is widely regarded to be the greatest environmental challenge facing the world today. It also represents one of the greatest social and economic threats facing the planet and the welfare of humankind." "The phrase 'tipping point' captures the intuitive notion that "a small change can make a big difference" for some systems (1). In addition, the term 'tipping element' has been introduced to describe those large-scale components of the Earth system that could be forced

past a 'tipping point' and would then undergo a transition to a quite different state. In its general form, the definition of tipping points may be applied to any time in Earth history (or future) and might apply to a number of candidate tipping elements. However, from the perspective of climate policy and this report we are most concerned with 'policy-relevant' tipping elements which might be triggered by human activities in the near future and would lead to significant societal impacts within this century."

APPENDIX B
ANALYTICAL FRAMEWORK FOR EXPECTED UTILITY AND OPTION VALUE

The conceptual framework for the application of option value to protecting against climate change impacts is adapted from the model in Freeman (1985). The literature distinguishes values yielded by reducing demand-side risks (based on probabilities 0 ≤ prob. < 100% of future income or preferences) and supply-side risks which threaten the availability of a resource. The former is known as demand-side option value and the latter is supply-side option value. While Freeman's model allows for both supply and demand uncertainty, it is his modeling of supply-side option value that is most illuminating for applying option value to the potential impacts of climate change.

The concepts can be demonstrated in the simplest case (Case 1) showing the income equivalent (loss) attached to the more risky world that exists due to the threat of climate change. The income equivalent is defined as the equivalent surplus, ES, for avoiding climate change damages:

$$U(Y,Wb) = U(Y\text{-}ES, Wa) = U \qquad (1)$$

where individual utility (U), is a function of income (Y), and the quality and quantity of water resources (W). If climate change does not impact water resources the preferred state of the world is shown at the right-most point, a, on the graph in Figure B.1. But the non-zero probability of damages from climate change introduces the threat that the future state of the world could be the left-most point, b. The expected loss (expected ES) from the possibility that climate change could damage water resources is shown by the horizontal movement on the Income axis to point c. The loss to risk neutral individuals from possible climate change damages would be the difference between income at a and c, or Ya – Yc. Expected utility theory suggests that a risk-averse individual would prefer to insure against the worst-case scenario at b so would be willing to pay more than the expected loss, expected ES. The loss of well-being to the risk-averse individual is seen by moving to point d, because the person would sacrifice more income to achieve a certain but lower level of water resources, $\underline{W}$, rather than face the worst-case scenario of water resources as low as b. The income equivalent measure of loss is Ya – Yd. This is a greater loss than that for the risk-neutral individual above. The widening of the dispersion of likely future states of the world due to climate change is the reason option value must be considered as an economic loss from potential climate change.

The more realistic characterization of the economic loss due to the threat of climate change is adding risk to an already risky situation. There are multiple levels of W, the quality and quantity of water resources, which could occur in the future. For the sake of modeling in Case 2, these multiple possibilities will be narrowed to four. See Figure B.2. For Case 2, the initial risk with climate change is shown as the chance (assume a 50-50 chance of the two outcomes) that W will be available at point a or at point b. Compared to Case 1 the premise is that background risks to water exist regardless of climate change. It is assumed further that equal magnitudes of positive or negative changes in water resources could occur in the future due to climate change and these are equally likely. With mitigation, however, these changes, both positive and negative, would be reduced. Under climate change mitigation, future levels of W could be at a2 or b2. As discussed in Section IV, being these are equal movements in a positive or negative direction, the expected level of W is identical between the more risky situation given the threat of climate change and the less risky situation due to mitigation. The more risky world due to climate change poses a 50-50 chance that W will be available at either point a or b. Again this assumes equally likely influences of climate change on water resources, W, that will be either positive or negative in equal magnitudes.

A risk-neutral individual would be indifferent between the risky scenarios modeled in Cases 1 and 2. Being expected surplus dependent on W is unchanged, the expected utility halfway between points a and c would be equal to the expected utility halfway between points a2 and c2. But being risk-averse preferences are held by the typical person, the income equivalent measure of loss due to climate change would be greater in Case 2 without mitigation. The loss in well-being from climate change in this more risky situation is shown by expected utility at point d being lower than at point d2. The loss to the risk-averse individual increases as the dispersion of the outcomes widens. Being climate change widens the dispersion, there would be a positive option value to reduce this risk representing a risk-aversion premium.

<u>For Case 2</u>

$$U(Y,Wb2) = U(Y-ES,Wa2) = U \qquad (2)$$

As in Case 1, Expected utility with no control of climate change is represented:

$$EU = q1\ U(Y,Wa) + q2\ U(Y,Wb) \qquad (3)$$

where q1 = 1 - q2. The probability of preserving environmental quality as a result of climate change mitigation is r2, (r1 = 1 - r2) such that r2 > q2 yields a probability increase denoted r2 - q2. Option price, OP, is a state independent payment which is the income equivalent for the improvement in expected utility as a result of the policy. Hence, OP is such that, with mitigation,

$$EUm = r1\ U(Y-OP,Wa2) + r2\ U(Y-OP,Wb2) \qquad (4)$$

and EU = EUm due to the payment of OP. Option price is related to equivalent surplus as follows:

$$q1\ U(Y-\underline{ES},Wa) + q2\ U(Y,Wb) = r1\ U(Y-OP,Wa2) + r2\ U(Y-OP,Wb2) \qquad (5)$$

While Case 2 is designed to yield expected incomes that are equal with and without mitigation, the higher expected utility under mitigation indicates a positive economic benefit from narrowing the dispersion of the risky situations. In addition to comparing the expected utility of the tow risky situations in Case 2 , the willingness to pay for a certainty equivalent to reduce the risk is also informative. The option price to reduce the eisk is much higher in the more risky (more dispersed) situation. The option value (OP – expected ES) is larger as a risk-aversion premium in the more risky situation shown in Case 2.

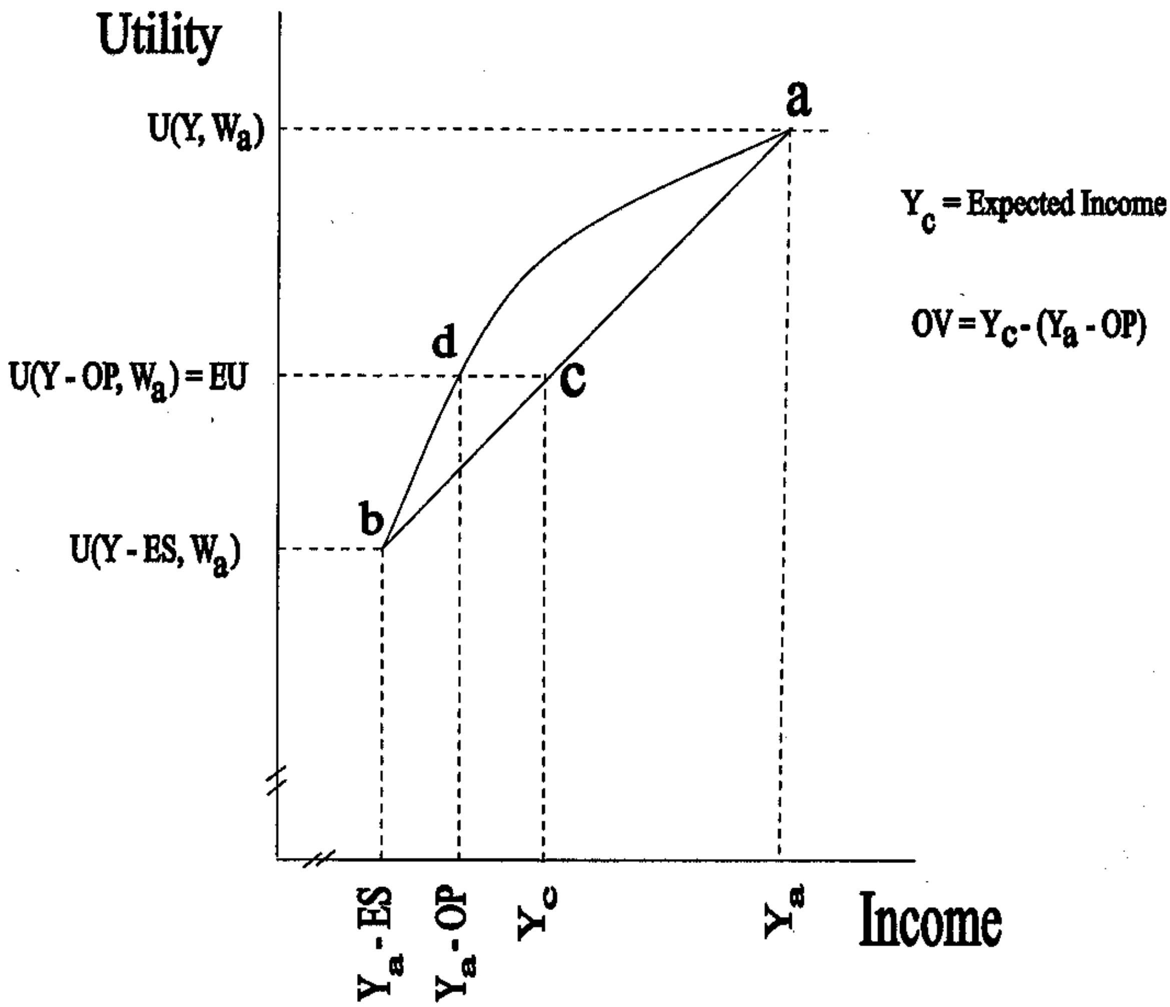
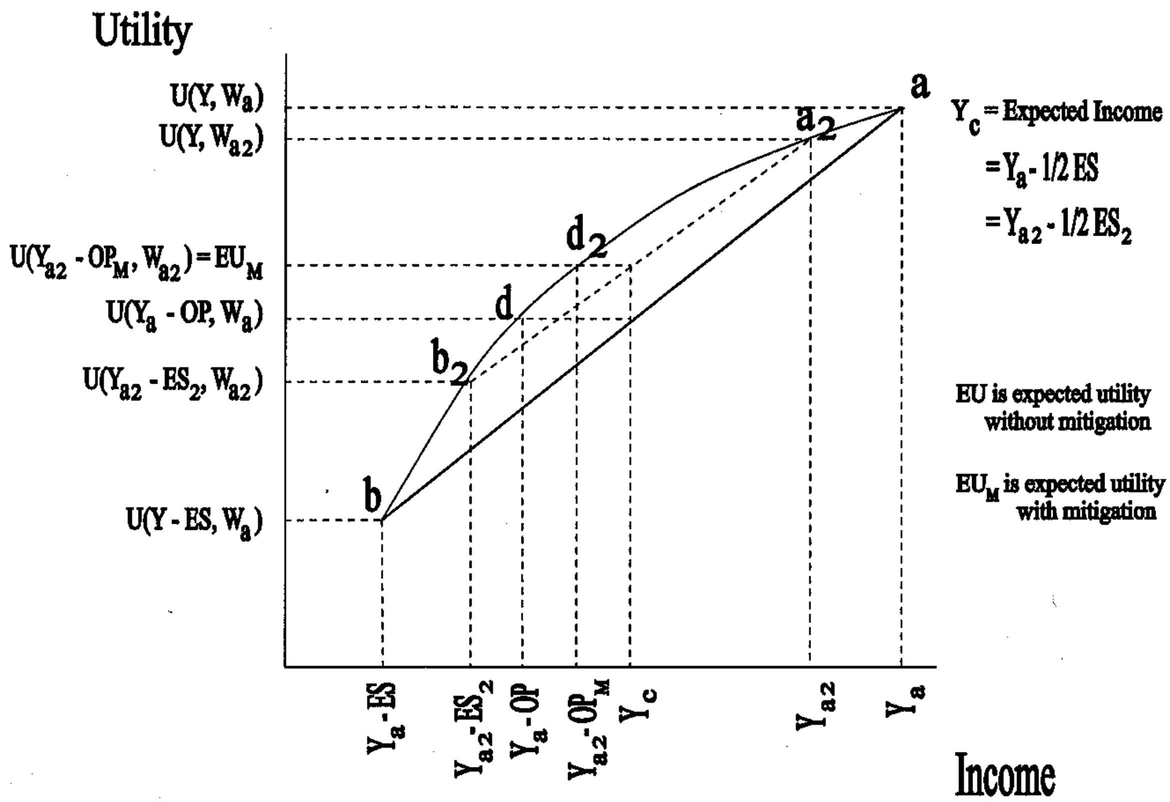


Figure B.1. Expected Utility and Option Value of Reduced Risks: Case 1



Figtre B.2. Expected Utility and Option Value of Reduced Risks: Case 2

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ECONOMIC IMPACTS OF GLOBAL CLIMATE CHANGE ON MINNESOTA FISHERIES THROUGH DECREASES IN LAKE ICE

by

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STATEMENT BY THE AUTHOR

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Signed: ___________________________

APPROVAL BY THESIS ADVISOR

THIS THESIS HAS BEEN APPROVED ON THE DATE SHOWN BELOW:

Dr. Patrick Welle, Committee Chair Professor of Environmental Studies	Date
Dean, School of Graduate Studies	Date

ECONOMIC IMPACTS OF GLOBAL CLIMATE CHANGE ON MINNESOTA FISHERIES THROUGH DECREASES IN LAKE ICE

Rabi J. Vandergon

Global climate change has recently come into popular light. It is becoming widely accepted as a problem that must be addressed for a wide variety of reasons. This study provides an in-depth analysis into the impacts that global climate change may pose to Minnesota fisheries and recreational anglers. The literature review covers a range of topics from biological impacts on recreational fisheries to economic impacts. The main goal of this study is to determine what impact climate change may pose to recreational benefits provided by the activity of angling. Creel surveys from the Minnesota Department of Natural Resources Creel Database were utilized to determine statewide angler effort and preferences for certain species. Lake ice duration observations were gathered to determine current trends and future projections. These data were utilized and combined with fishing valuation literature to determine an economic impact from climate change. Statistical analysis shows that lake ice duration is significantly decreasing statewide. Since more anglers fish during the summer months, this could lead to a net economic gain. On the other hand, bodies of water such as East Upper Red Lake seeing more anglers during the ice-fishing season could potentially see an economic loss. The project also utilized creel surveys to test the hypothesis indicating a statewide decline of trout species and northeastern shift of largemouth bass and sunfish from the onset of climate change. A multiple regression was performed on historical creel data to determine if there was a change in effort over time across different climate regions by species group. These variables were tested to see their influence on the amount of fish caught. The regression indicated a positive relationship between the amount of effort and the amount of yield, but effort does not appear to be shifting regionally in response to climate change predictions.

Approved by:

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Committee Chair Date

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Committee Member

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Committee Member

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Graduate Faculty Representative

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Chapter 1: INTRODUCTION

Overview of the Research

The Intergovernmental Panel on Climate Change (IPCC) has revealed a wide body of evidence that indicates human influences have caused a significant increase in the amount of carbon dioxide in Earth's atmosphere that has accelerated during recent years (International Panel on Climate Change [IPCC], 2007). The IPCC has also indicated that increasing the amount of carbon dioxide (among other green house gasses) in the atmosphere has caused an increase in radiative forcing, the act of trapping heat within the atmosphere (IPCC). Unchecked, the amount of contributing factors to increases in radiative forcing have continued to increase and this increase has caused an increase in the global average temperature (IPCC).

Besides increases in global temperature, there are other predicted impacts on natural systems from this atmospheric change. One particular change is the amount of lake ice that is present in the winter time. The literature review and the results sections show that this change is already taking place globally and in Minnesota.

Beneath the surface of lakes, fish populations may also potentially be impacted by a changing climate. This paper discusses current findings in Minnesota indicating changing abundance of largemouth bass, sunfish and trout populations. In addition, the literature review discusses how increases in runoff from climate change (due to changes in precipitation patterns) and increases in temperature both have potential to decrease the amount of dissolved oxygen (DO) in water bodies, which could potentially impact fish populations.

These changes in fish populations and ice conditions are important concepts for the state to consider, due to the high popularity of the activity of angling statewide. The U.S. Fish and Wildlife Service estimated that Minnesota residents and nonresidents spent roughly 24 million days fishing in 2006 (U.S. Department of the Interior [USDI], Fish and Wildlife Service [FWS], and U.S. Department of Commerce, U.S. Census Bureau [USCB], 2008). In addition, each season has different numbers of people enjoying angling, which can be seen below in the results section. Changing the amount of available fish or the conditions required to enjoy a certain type of this sport, such as ice fishing, could potentially change these numbers.

Fishing as an activity has an economic value. This value can be determined through a variety of different means, which are covered in the literature review below. For example, by conducting interviews on trip expenditures, the U.S. Fish and Wildlife Service estimated that individuals spent roughly $35 per day on the activity of fishing in Minnesota (USDI, FWS, USCB, 2008). The same study estimated that roughly $466 million was spent on angling activities in Minnesota by nonresidents alone (USDI, 2008). Changing the abundance of available fish for the sport as well as the conditions in which an angler may pursue his or her prey could both potentially have an economic impact on the state.

This study utilized statewide statistics from creel surveys and from lake ice observations to determine a potential economic impact on the recreational benefits of angling. The economic estimate was performed utilizing benefit transfer, which is an economic tool for estimating value when the resources for conducting a primary study do not exist. Three different scenarios were tested to determine potential impacts to recreational benefits: these scenarios took into account the variation in the amount of use that some lakes see in each season, whether each day was worth the same amount of money per angler regardless of season, and if there might have been a change in the amount of species present in these lakes. This analysis attempted to provide an estimate of potential impacts under these three different scenarios, which aimed to broaden the base of current climate change literature and provide direction for the focus of future state dollars.

CHAPTER 2: LITERATURE REVIEW

The following literature review covers a wide range of topics that were used in the construction of this thesis project. The review covers all of the necessary subjects that explain the state of affairs with the given scenario that have lead to a need for this type of work to be completed. In addition, the review covers the building blocks that were necessary for this project. Concepts are introduced such as benefits transfer, willingness to pay, the travel cost method, climate change and potential impacts to freshwater systems (including changes in ice, water chemistry and aquatic populations). This review explains and shows that exact work of this nature has not been completed previously. This project hopefully adds a new component to the body of climate change literature.

Climate Change

First, the overarching concept of climate change is discussed below, as it is the sole cause for the need for this type of study. The main organization leading the wave of information on this global concept is the Intergovernmental Panel on Climate Change (IPCC), which is a group of government officials and scientists from around the world organized through the United Nations (IPCC, 2007). The IPCC has released four different versions of their comprehensive study on climate change, which cites statistical evidence of noticeable alterations in Earth's climate (IPCC). The Fourth Assessment Report (FAR) contains a few main concepts in relation to current projections in Earth's climate.

The first topic discussed concerns chemical compounds causing radiative forcing. Radiative forcing may be associated with the commonplace term, the greenhouse effect

(IPCC, 2007). This process involves gasses that are causing heat to be retained that is normally radiated away from Earth's surface into the atmosphere (IPCC). This is occurring due to certain chemicals' properties that inhabit the stratosphere (IPCC). These chemical compounds, such as CO_2, SF_6 and CH_4, have been and are continuing to increase in concentration over time (IPCC).

The IPCC has concluded two robust findings in respect to compounds responsible for radiative forcing. The first finding stated that it is evident that the concentration of these chemicals is rising (IPCC, 2007). This was explained through analysis of ice cores that serve as a historical record of previous climate. These cores have properties that enable atmospheric composition to be examined from thousands of years in the past (IPCC). The second main robust finding is that these rising concentrations of chemicals causing radiative forcing are anthropogenic in nature, which indicates human behavior is the main driver of potential shifts in climate (IPCC). These chemicals have made a noticeable change on sea level and temperature and are predicted to continue their projected impacts as time passes (IPCC). Several climate scenarios were indicated in the Fourth Assessment Report, which is the most recent publication of the IPCC. Even with drastic global reductions in chemicals causing radiative forcing, it is predicted there will be noticeable continued effects seen through changing temperatures and precipitation (IPCC).

Research has also been conducted in regards to climate change in Minnesota. Skaggs & Blumenfeld (2005) divided Minnesota into nine climate divisions, as established by other researchers on this project. These researchers divided temperature and precipitation data into four different seasons that pertain to natural systems and conventional divisions. These researchers chose the climate regions from the four corners of the state and analyzed precipitation and temperature trends since 1891. These trends were translated into z-scores, which are the number of standard deviations from the mean. The trends were highly variable from the beginning of the analysis. However, there were consistently warmer summers since 1995 in all corners of the state.

These researchers, in their z-score analysis of temperature and precipitation, mainly focused on the difference between biological and meteorological summers. They found many differences between meteorological and biological summer, which is an extended time period beyond meteorological summer. Biological summer yielded differences in precipitation and temperature. These differences have not been consistent over time. For example, the evidence suggested that the extended summer definition yielded results that indicated that there was more precipitation during the early and late part of the summer season in the SE region of the state in the early part of the 20th century.

These researchers also analyzed the trends from climate regions in the northwest and southeast corners of the state. They discovered that warmer summers are usually correlated with dry or normal precipitation. They also found that wet summers were correlated with cool or normal temperatures. Both of the above trends were the same for both regions of the state, which indicated a consistent trend. Overall, this source did not provide evidence in regards to a clear upward or downward trend in precipitation or temperature. However, these researchers indicated useful climate regions, clear visualizations of year-to-year variability in temperature and precipitation, and relationships between temperature and precipitation.

Lake Ice and Climate Change

Lake ice is an excellent tool for explaining the current evidence of climate change. Lake ice is highly dependent on the surrounding temperature for its formation (De Stasio, Hill, Kleinhans, Nibbelink, & Magnuson, 1996). Furthermore, increasing temperatures have been linked to significant decreases in the presence of lake ice (Anderson, Robertson, & Magnusin, 1996; Hodgkins, James, & Huntington, 2002; Johnson and Stefan, 2006; Latifovic and Pouliot, 2007; Magnuson, Robertson, Benson et al., 2000; Moore, Hampton, Izmest'eva et al., 2009; Schindler, Beaty, Fee et al., 1990). These changes have been studied using two main techniques. The first type of analysis involves on the ground reports of yearly formation and break-up. Perhaps the most comprehensive study combining these reports is the work of Magnuson et al. (2000). This study published in *Science* is the collaboration of the work of a large number of scientists that analyzed trends in ice formation and break-up in northern latitudes (one of these researchers provided lake ice data for this project). These researchers were able to develop an assessment to compare current trends in ice formation to historical trends. A warming trend was evident prior to 1850, but the rate increased after the onset of the industrial revolution. Statistical analysis revealed a significant reduction in the total period of ice presence. Delayed freeze date and earlier breakup date were listed to be increasing by 5.8 and 5.6 days respectively per 100 years (Magnuson et al.).

The second type of lake ice analysis was exemplified by the work of Wynne and Lillesand (1993). These researchers illustrated how satellite observations could be used to analyze ice conditions. These researchers showed that certain wavelengths can be associated with different surfaces or materials such as clouds, ice and snow. These wavelengths were then transferred into a temperature value. The presence of lake ice was coupled with data from the National Oceanic and Atmospheric Administration (NOAA) weather stations around the state of Wisconsin. This provided a linkage between the presence of lake ice and the influence of surrounding weather conditions. Although these researchers could not determine the date of ice formation (because of cloud and fog interference), these scientists were able to provide a correlation between temperature and ice break-up. January through March provided the most influence in the event of break-up. This indication of the influence of temperature on the presence of lake ice clearly showed the need for this type of study given the current climate change problem.

Climate Change and Freshwater Fisheries

Warming climate has the potential to impact the water temperature of freshwater lakes containing fish; Chu, Mandrak, and Minns (2005) showed how different species of freshwater fish were impacted from global climate change in Canada. A number of different variables were indicated to have a potential effect on freshwater fish populations. These researchers chose a select group of species (brook trout, walleye, and smallmouth bass) and attempted to model the effects on each population from the interaction of several variables. Variables of influence were selected by a correlation matrix. The model combined these variables to predict the occurrence of a species by region. For example, dew point, growing degree days, precipitation, and average hourly wind speed were included for determining the presence of walleye. This source indicated that cool water species will be threatened by warming water temperatures. These researchers further determined that previously existing warm-water species may expand their range northward, which may cause disruptions in previously existing population dynamics. For example, walleye and smallmouth bass may extend their range northward and prey upon previously undisturbed species.

These impacts that may occur are primarily due to changes in water temperature and changes in the levels of nutrients that may be present in the water bodies (Ficke, Myrick, & Hansen, 2007; Lettenmaier, Major, Poff, & Running, 2008). Changes in water temperature have been predicted to occur due to interactions between the changing air temperature and the surface water temperature (Lettenmaier et al., 2008). Changing the surface water temperature was predicted to cause a change in the amount of dissolved oxygen (DO) that is present in a water body (DeStasio, Hill, Kleinhans, Nibbelink, & Magnuson, 1996).

Changing the amount of DO and its effects on fish populations was illustrated by Ficke, Myrick, and Hansen (2007) who illustrated that variables such as oxygen content and temperature have an effect on the well-being of fish populations. Specific ranges required for a population's health were indicated for these variables. Variations of effects were illustrated for both lentic (lakes and ponds) and lotic (rivers and streams) systems taking into account changes in precipitation, water availability and temperature. These researchers focused on the effects of eutrophication, which may occur from increased temperatures. Eutrophication was predicted to lower DO in systems. The effects of decreased DO depend on the fish's ability to adapt to these changes (Ficke et al., 2007). In addition, specific effects of the stratification of lentic systems were indicated to possibly place higher stress on fish species. This entails a decreased amount of habitable area in a water body during warmer months due to the expansion of an uninhabitable, warm upper layer (Ficke et al.). On the other hand, these researchers indicated warmer air temperature may also have the impacts of increasing water temperature, which may provide more food and optimal growth conditions for fish during the winter months (Ficke et al.). In addition, this may decrease the amount of stress placed on fish during the winter months (Ficke et al.).

Two separate Minnesota studies have examined the impacts of climate change on freshwater fisheries. In the first study, Schneider, Newman, Card, Weisber, and Pereira (2005) examined the impacts on changing ice-out conditions in Minnesota on walleye spawning timing. These researchers found that there is a significant relationship between the change in ice-out and the change in the time that walleye lay eggs. This piece of literature combined ice-out data from lakes around the state with data concerning egg-take from walleye populations. The researchers found that for every one day decrease in the presence of lake ice there was a .5 to 1 day decrease to the day that a walleye lays its eggs. These authors postulated that this may have an impact on the well-being of the fishery if there is a mistiming in the availability of prey with a change in spawning timing. It is not clear if this change in timing was also correlated with a change in spawning duration.

In the second study, Schneider, Newman, Weisberg, and Pereira (2009) examined the current trends in fish communities in response to changing climate in Minnesota. Several temperature variables were compared with the abundance of species in 35 different lakes. Some of these variables included summer temperature, average annual temperature and temperature extremes. The methods of this study utilized catch per unit effort (CPUE) from gillnet and trapnet surveys. These researchers discovered that the majority of fish species were expanding their range northward except smallmouth bass. In addition, these researchers discovered that increases in average summer temperature were correlated with increases in bass and sunfish abundance. Moreover, increasing air temperature was correlated with a decrease in the abundance of whitefish and trout.

Impacts to Water Resources

Lettenmaier, Major, Poff, and Running (2008) examined the near term impacts of global climate change on water resources in the United States (US) for the next 25 to 50 years. This piece of literature mainly examined variables including streamflow, evaporation, drought, precipitation, runoff and water quality. In the analysis of streamflow, trends from 393 stations were plotted on maps. These stations showed statistically significant flow increases reported in the central portion of the United States, which included source stations in Minnesota. Two separate studies in this report indicated an overall increase in precipitation in this region. However, studies examining Great Plains states to the near south of Minnesota showed a reversal of this upward trend.

Lettenmaier, Major, Poff, and Running (2008) explored runoff rates by reporting US Geological Survey (USGS) statistics on runoff for trends from 1901 to 1970. These were projected into the future, which suggested an overall increase in the central US. Runoff was further examined by region. The central portion of the US was shown to be likely to see an increase in runoff in the Upper Mississippi basin (Lettenmaier et al., 2008). Besides runoff rates, water quality was also examined. Changes such as eutrophication from increased nutrient loads and increased temperature were discussed. Nutrient loading was indicated to possibly occur from increased runoff and more highly variable heavy precipitation events. In addition, these authors found that decreased consistent precipitation could cause eutrophication from the increased levels of nutrients without adequate consistent flows.

The above claims were mirrored by Heino, Virkkala, and Toivonen (2009), which indicated that global climate change has the potential to impact biodiversity in freshwater regions. Four main variables were examined in respect to the differing impacts of climate change. These variables included the effects of climate change on acidification, eutrophication, land cover change, and an increase in exotic species. Acidification effects were indicated to have the potential to increase or decrease depending on the region, and changes in acidification were indicated to have the potential to impact fish populations. Sources cited within this article also indicated that climate change is predicted to cause increases in overall precipitation in northern latitudes. As mentioned above, these increases in precipitation can cause increases in runoff, which can lead to an increase in nutrient loading in water bodies (Heino et al., 2009). This increase in nutrients can have a potentially negative effect on the biodiversity of a freshwater body, depending on the starting point of the system (Heino et al.). For example, if a lake is initially oligotrophic, additional nutrients may cause an increase in diversity in the system. These researchers concluded that increasing nutrients can lead to a decline in biodiversity in southern boreal regions. Conversely, Heino et al. also indicated that land cover may be altered from climate change. In northern regions, deciduous trees may eventually replace existent coniferous varieties. Since deciduous leaves contain more bio-available nutrients, this change in vegetation structure can potentially provide more nutrients to the biological communities in these areas (Heino et al.).

Two separate Minnesota studies also pointed to some indications of effects on freshwater fisheries. In the first study, Stefan, Hondzo, and Fang (1993) used meteorological and lake quality information from sites around the state of Minnesota to examine the impact of changing air temperature on the dissolved oxygen content and stratification (or temperature) of a variety of lakes. Minnesota data was used due to its high level of data quality. Among many findings, these researchers discovered that increasing temperature decreased the amount of dissolved oxygen in the upper layer of lakes (which agrees with the above studies). In addition, increasing temperature also prolonged the period of stratification, with the turnover occurring earlier in the spring and later in the fall (Stefan et al., 1993). A prolonged stratification was predicted to lead to a lower amount of DO in the hypolimnion (Stefan et al.).

The second study by Stefan, Fang, and Eaton (2001) examined the impacts of climate warming on several different lake types across the contiguous United States. Conclusions were derived concerning the well-being of cold, cool and warm-water fish types and their responses to climate change. The lake type (such as mesotrophic or eutrophic) and the lake depth both determined the well-being of cold and cool-water fish habitats. Only deep lakes along the northern border are expected to retain their cool and cold-water fish habitats. These researchers also indicated there may be a predicted increase in summer kill due to increased temperatures. On the other hand, snow and ice prevent the interchange of atmospheric oxygen to a water body, and so climate warming was also expected to yield an expected decline of winterkill that results from decreased DO (Stefan et al., 2001).

Two reports by Dedaser-Celik and Stefan (2007, 2008) indicated two main findings. First, water levels were rising in some Minnesota lakes (Dedaser-Celik & Stefan, 2007). Second, precipitation in Minnesota had a trend that is increasing in intensity and amount (Dedaser-Celik & Stefan, 2008). These findings were similar to those predicted that indicate climate change may cause precipitation and runoff rates to increase in northern latitudes. However, these implications were contradicted by the study below.

Dedaser-Celik & Stefan (2009) analyzed trends in streamflow in Minnesota since 1946 using gauges from five different rivers across the state. The trends observed did not match those predicted by other climate change literature such as increased high flow due to increased runoff. However, these researchers did determine that rivers located in areas with higher rates of precipitation showed increases in streamflow.

In summary, changes in water temperature and variables impacting the amount of DO in a water body are the main factors that may potentially impact fish populations from the onset of climate change. The studies near the end of this section indicated that Minnesota is not currently seeing some of the predicted impacts found in the broader climate change literature. These potential impacts remain tangential to the research project at hand. However, the well-being of these populations influences the economic benefits from fishing. For example, studies discussed below indicate that catch rate had a significant impact on willingness to pay (Stevens, 1966). If fish populations are negatively impacted from climate change there may also be an economic impact.

Economic Impacts of Climate Change on Freshwater Fishing

The work of Pendleton and Mendelsohn (1998) established ground work for studying how global climate change can create an economic impact through changes in fisheries. These researchers indicated that global climate change has the potential to impact sportfisheries in freshwater regions in the northeastern U.S. These potential impacts were predicted to have economic influences depending on the magnitude of climate effects as well as other variables. Three different groups were examined: rainbow trout, all other trout species, and panfish.

Pendleton and Mendelsohn (1998) attempted to economically model the potential impact of climate change on sportfisheries using two different models. The first was the hedonic travel cost method. This used different characteristics involved with the resources expended to reach a certain recreation location to estimate a value for a certain area. The second method used was a random utility model (RUM), which combined income, the travel cost function and a random variable for site location. These variables were combined to form a function explaining utility. This study was unique from others in that it was origin specific for its calculated RUM. The results of the analyses indicated that a decline in the catch rates of the types of fish could have a negative economic impact on the people fishing. However, this study found that some Northeastern states may see a potential increase in welfare from the onset of warming. This was dependent on the preferences of anglers (Pendleton & Mendelsohn, 1998). For example, although rainbow trout were predicted to decline from climate change impacts, all other trout species and panfish were predicted to increase. This study revealed that climate change could positively impact the economics of the region, depending on which climate scenario was selected. These researchers indicated that climate change impacts may not be completely negative, which is determined in the analysis below.

Creel Surveys

In general, creel surveys are a method to predict and represent an entire population fishing in a particular body of water, which is based on interviews conducted from a sample (Cook and Younk, 1998). These surveys have all come from different sources and have been collected from different researchers with different methodologies (See Tables 26 & 27). For example, the sampling methodology from a large lake is different from the sampling methodology of a smaller lake. Any method utilized to represent a population from a smaller sample may be prone to bias, as illustrated below. Therefore the process of creel survey interviews and the associated biases are further discussed below.

Creel Survey History

Creel surveys have been conducted to create generalizations of a population of anglers on a certain body of water through the use of statistical analysis (Cook and Younk, 1998). Creel surveys are generally utilized for management implications and may reflect details such as fishing pressure, catch rate, species composition and demographic information on anglers (Cook and Younk).

Creel surveys in Minnesota have transitioned from initial reporting of personal accounts of fishing trips into more comprehensive surveys (Cook and Younk, 1998). These surveys have been initiated partly due to concerns over the well-being of fisheries and the increased access that was given to many lakes upon the completion of roadways with the onset of logging in the 1930s (Cook and Younk). These rudimentary surveys have transitioned over time. In the beginning there were no established techniques for surveying anglers (Cook and Younk). In the 1950s a technique was formulated involving statistical selection and gathering data both by interviewing anglers and also by conducting visual counts (Cook and Younk).

Over time, these methods of surveying transitioned to be applied over a wider range of lakes and were compared across a known population (Cook and Younk, 1998). These initial surveys, over the chronological history of creel survey data, have transitioned between agencies that were responsible for conducting and analyzing the research (Cook and Younk).

In 1964, a team of researchers published a report that covered the technique for conducting a roving creel survey using incomplete trip information and instantaneous counts. Cook and Younk (1998) indicated that the above report served as a baseline for conducting methodology in many creel surveys around the state and that it was one of the most commonly cited sources in the methods sections of these reports.

Most of the surveys initially took place on small lakes (Cook and Younk, 1998). In the 30’s there were many individuals available through the Civilian Conservation Corps. The availability allowed for an almost complete record of all fishing trips to Lake Winnibigoshish (Cook and Younk). When the availability of personnel waned, airplanes were combined with interviews to provide counts of the anglers (Cook and Younk). However, airplane usage became costly, which led to the creation of access based pressure estimates (Cook and Younk). This probability-based design has been indicated to still be utilized today except on lakes that have shoreline that may encumber the validity of using this design type (Cook and Younk). In the 1970s a method was developed to sample a number of lakes and streams all at a specific period of time, specifically when usage was predicted to be at its highest (Cook and Younk). For example, the time period just after fishing opener and for a time thereafter was assumed to be the time period that would obtain information from the majority of anglers (Cook and Younk).

Also in the 1970s, individual lake management grew with increasing popularity, which sparked an increase in the number of creels conducted on individual lakes (Cook and Younk, 1998). This increase in the number of lakes continued into the 1990s along with the ongoing change in the structure of how the creels were conducted (Cook and Younk). In the mid-1990 a general report format was established along with a computer program utilized by the state to statistically analyze the creel reports (Cook and Younk).

Creel survey validity

The validity of creel surveys as an estimation technique could be challenged as a whole. However, the DNR has utilized survey designs written by accomplished individuals in the field and these researchers have utilized sampling techniques from reputable sources such as Pollock, Jones, and Brown (1994). For example, Pollock et al. (1994) illustrated the roving creel survey design that was utilized for larger lakes such as East Upper Red Lake and Lake of the Woods (Standera, 2009; Heinrich, 2007).

The large variety of different dates from the database in which the surveys were conducted could be questioned as to their statistical validity. The MN DNR utilized two main types of survey techniques (See Tables 26 & 27). The first type was the roving creel and the second type was the access point survey design. Newer surveys also employed an aerial-access design where an airplane was utilized to conduct counts and in-person interviews were utilized to determine all other variables (K. Reeves, personal communication; See Tables 26 & 27). For some lakes in the dataset, if there were many different access points to a certain lake such as by shoreline, then a roving creel survey design proved to be more favorable (Pollock, Jones, & Brown, 1994).

The three above methods all had their own respective methodologies for conducting and gathering survey data. These three methods also were subject to error that can apply generally to all types when conducting a survey. The following discussion of the shortcomings of creel survey design were reported in Pollock, Jones, and Brown, (1994), which was utilized by DNR creel survey reports for methodological construction (Standera, 2009).

Survey error

Pollock, Jones, and Brown (1994) illustrated three main types of errors that could have occurred in the interview process: sampling, response and nonresponse errors. Sampling error consists of errors that are made in the selection process in which anglers are selected to be interviewed (Pollock et al., 1994). This includes problems such as incorrect sampling techniques such as choosing a convenience sample that is easiest to reach (Pollock et al.). This also includes avidity bias and length-of-stay bias (Pollock et al.). Avidity bias refers to individuals that may fish more often than other anglers (Pollock et al.). If more anglers were selected who fished more frequently than other anglers, this could have potentially biased the pressure estimate. Similarly, length-of-stay bias is another type of sampling error that could have occurred (Pollock et al.). Anglers who were located on the ice for longer periods of time had a greater probability of being selected than anglers who fished for shorter periods of time (Pollock et al.). Therefore, anglers who fished for longer periods of time were also more likely to have biased the pressure estimate in an upward direction.

Another type of survey error that could have occurred is in the category labeled response errors (Pollock, Jones, & Brown, 1994). Response errors for the creel surveys could have taken place in a multitude of forms and could have impacted pressure estimates (Pollock et al., 1994). Pressure estimates could have been impacted by recall bias, prestige bias, rounding or digit bias, lies or intentional deception and question misinterpretation (Pollock et al.).

The following paragraph discusses five main types of response errors. The first type is recall bias, which consists of anglers being unable to recall past events accurately. This may not have severely impacted pressure estimates due to the fact that it may have been easier to remember the events that occurred during the same day the interview was conducted as opposed to events that took place over a longer period of time (Pollock, Jones, & Brown, 1994). The next type of bias is prestige bias, which would have impacted harvest estimates through the means of exaggerated catch rates (Pollock et al., 1994). However, some individuals could also have claimed longer periods of time fishing (impacting pressure estimates) in the winter during cold days to have appeared macho or tough. The third type of bias is rounding or digit bias, which could have occurred when changing a smaller number to a larger number. For example, this could have taken place when rounding a smaller number to a multiple of five, which could have occurred with pressure estimates. The next type of response error involves lies or intentional deception. This could have occurred due to the hope that a false response would have potentially benefited the angler, the angler had conducted some sort of violation, or the angler harbored hard feelings toward the interviewing agency (Pollock et al.). The last type of response error impacting pressure estimates is question misinterpretation (Pollock et al.). If the clerk did not phrase the question in understandable terms or the respondent did not understand the question, the angler may not have elicited a viable or accurate response (Pollock et al.).

The last type of error outlined by Pollock, Jones, and Brown (1994) that could have occurred is a nonresponse error. However, these types of errors are less likely to occur with in-person interviews and have occurred more often with mail surveys (Pollock et al., 1994). These specifically may have taken place when a respondent did not understand the question or if he or she simply chose not to answer (Pollock et al.). Some of the estimations of pressure were conducted using indirect counting methods, which are further discussed below.

Creel survey methodology

The following discussion shifts from pointing out potential biases of surveys to explaining the methodology of the creel surveys, specifically focusing on access point surveys and roving creel surveys. An access point survey consists of interviewers gathering information based on a trip that has occurred in the immediate past (Pollock, Jones, & Brown, 1994). This information is considered complete (Pollock et al., 1994). Information being complete refers to the fact that an angler has already gone through the fishing experience (Pollock et al.). On the other hand, a roving creel survey consists of interviewing anglers while the trip is still in progress (Pollock et al.). Therefore the data from a roving creel survey is based on incomplete information. However, instantaneous counts made by a creel clerk could have eliminated this potential bias in the results

(Vaughan and Russell, 1982). Instantaneous counts and roving creel surveys are discussed below.

The methods for access point surveys may have varied depending on the type of site (Pollock, Jones, & Brown, 1994). For example, some lakes may have had a multitude of different access points that allowed anglers to go on and off of a body of water (Pollock et al., 1994). The amount of time spent at these access points depends on the individual study’s methods (Pollock et al.). There are many different types of ways that an access point survey may have been constructed that can account for the type of lake being examined. For example, a large lake with many access points could have utilized a “bus stop” method for access point surveys (Pollock et al.). This method entails a schedule that is laid out for a creel clerk to spend specific amounts of time at each sampling location and then move on to the next. This allowed the clerk to be more engaged with the project and also a greater sample area may have been included with the results. Access points could also have been randomly selected for time and location, thereby giving statistical accuracy to a project (Pollock et al.).

The sampling days and times may also have been chosen to better reflect the actual population of anglers when an access point survey was conducted. Days of a month, days of the week and day periods (such as AM or PM) may have been chosen randomly (Pollock, Jones, & Brown, 1994). The careful construction of temporal and spatial location could also have helped to lead toward a better representation of a creel survey. However, access point surveys may still have been subjected to bias. Access point surveys are prone mainly to avidity bias with their questioning (Pollock et al.). However, this does not appear to be a major factor in respect to estimating pressure

(Pollock et al.). The methods of this type of study are discussed for their strengths and weaknesses below.

Roving creel surveys, unlike access point surveys, are mainly prone to length-of-stay bias. This is due to the fact that anglers who spend more time on the ice have a greater probability of being sampled than anglers who spend less time on the ice (Pollock, Jones, & Brown, 1994). These surveys are also subject to lacking a complete amount of trip information, since the interviews are conducted during the trip (Pollock et al., 1994). Therefore, other methods have been utilized that estimate the amount of trip length. These include techniques such as estimating the expected trip length and instantaneous counts (Pollock et al.). Trip estimation is subject to large amounts of bias because there may be other extraneous variables that impact the amount of time spent fishing such as changes in weather and enthusiasm (Pollock et al.). Therefore, effort estimations are generally not conducted in the interview process. Instead these are calculated as counts, either progressively or instantaneously. These counts are then multiplied by the number of fishing hours in a day to estimate effort (Pollock et al.).

Instantaneous, aerial and progressive counts:

This project relied heavily on the estimation of total fishing pressure (time spent fishing) that was statistically analyzed from the creel survey database. The following is a discussion of the methods that were used to conduct pressure estimates in the absence of an access creel survey.

Instantaneous and progressive counts could have occurred while conducting a roving creel survey (Pollock, Jones, & Brown, 1994). These counts are used to estimate the total amount of effort or fishing pressure on a given body of water (Pollock et al., 1994). An instantaneous count consists of a creel clerk counting the number of anglers that are fishing at a particular moment in time. These types of counts generally take less than 15 minutes to complete (Pollock et al.). If the count takes longer than an hour to complete, it is referred to as a progressive count. A progressive count consists of selecting interval time periods to take scheduled counts of anglers (Pollock et al.).

Both of these types of counts are subject to bias. Each of the counts assumes that all anglers are fishing when they were counted on the water. Some may have been along with a party and not fishing at all. In addition, some estimates of effort may not have been able to adequately account for the total number of anglers in a party (in a boat or in an ice-house). Therefore, the total number of hours being fished could have been misrepresented. In addition, Pollock, Jones, and Brown (1994) stated that the amount of anglers is multiplied by the number of hours in a fishing day. This assumption of how long an angler would stay could have been incorrect. However, the discussion surrounding Pierce and Bindman (1994) indicated that instantaneous counts could have been highly accurate in regards to estimating the total amount of fishing pressure.

Pierce and Bindman (1994) provided defensible material in regards to the validity of instantaneous counts as a method to estimate effort. These researchers conducted a creel survey in which creel clerks used a stratified-random creel sampling design. This involved the creel clerk counting the number of anglers on the lake at a randomly specified time from different areas of the lake. This estimate was then compared against an absolute estimate that was derived by the clerk keeping a complete record of all anglers on the lake and noting their arrival and departure times. It was found that the instantaneous method was a reliable estimator of pressure in comparison to the absolute method. The conclusion was derived off of the statistical results that supported a one-to-one ratio with a high level of confidence. These results meant the same amount of time spent angling was found through each method.

Aerial counts comprise another method that was utilized to estimate the total amount of pressure on some Minnesota lakes. This method is beginning to replace the utilization of snowmobiles in the winter (roving creel surveys) due to issues with safety (K. Reeves, personal communication). Aerial counts utilize a progressive roving design and are able to cover a large amount of area in a sampling period (Pollock, Jones, & Brown, 1994). However, there are a number of biases and complications to the aerial design. For example, observer error can occur and individuals can be missed (Pollock et al., 1994). In addition, these counts are extrapolated much like the instantaneous and progressive designs: it is assumed these counted anglers are present for the entire fishing day. The observer also may not be able to discern multiple anglers in a party (Pollock, et al.). For example, a fishing boat could have more than two people, which would give the count of one fishing boat an underestimation of effort if it was assumed that only one angler was present.

Sampling techniques

Many types of sampling techniques have been implemented with the access, roving and aerial survey designs. In the database, all the creel surveys were coded according to the method utilized (See Table 26). These techniques are discussed in the following paragraphs. The first technique is stratified random sampling, which is implemented along with a roving creel. This type of sampling is best conducted with prior knowledge of the fishery in order to properly proportion the amount of sampling that took place during specified periods (Pollock, Jones, & Brown, 1994). Different strata that could have been chosen include the months, days in the week, weekends versus weekdays and time periods in a day such as AM and PM. If prior knowledge of effort was known, these different strata could have been sampled in relative proportion to previous effort (Pollock et al., 1994).

The second type of sampling that was utilized for roving surveys was nonuniform probability, which is also referred to as unequal probability sampling (Pollock, Jones, & Brown, 1994). This type of survey takes place when some areas of a sample are expected to see a higher volume of activity than others. This statistically complex type of sampling method allows a greater focus to be paid toward certain areas over others (Pollock et al., 1994).

The third type of survey design utilized was systematic sampling, which is also referred to as systematic random sampling (Pollock, Jones, & Brown, 1994). Instead of randomly selecting from a sample, a selected interval is chosen that is utilized to draw from a sample. Pollock et al. (1994) gave the example of selecting fishing licenses at a random interval versus randomly selecting the sheets of paper, which could be more costly in respect to time.

The two types of access surveys utilized were nonuniform probability (discussed above) and no probability. No probability access surveys may have been utilized if there was only one access point to a certain body of water (Pollock, Jones, & Brown, 1994). These types of surveys are useful when the body of water is very small (Pollock et al., 1994).

Some of the surveys conducted may also have been through the process of angler diaries or through volunteers reporting information. As mentioned above, volunteer data may have been subject to bias if the individual had motivation to influence policy in his or her own favor (Pollock, Jones, & Brown, 1994). In addition, this survey method is prone to several other shortcomings that involve nonresponse bias and the likelihood that avid anglers may be more prone to complete these surveys than others (Pollock et al., 1994). Despite its ease of use, this survey technique was listed as being rare by Pollock et al. and did not take a high priority in the MN DNR creel database.

Validity of pressure estimates

As mentioned above in the dialogue surrounding the Pollock, Jones, and Brown (1994) discussion of bias, there are many factors that could have influenced the validity of a creel survey. Validity of creel surveys was also touched upon and is defensible from works such as Pierce and Bindman (1994). These biases that were presented by each of these survey types are addressed above. While there was no perfect sampling technique in respect to estimating effort, these estimates of fishing pressure have undergone scrutiny in design and have been developed by accomplished researchers. These estimates helped to provide a baseline of estimated fishing pressure for different climate regions throughout Minnesota, with the hope to have modeled the potential effect of decreased lake ice on the activity of ice fishing.

Fisheries Valuation

Besides the intrinsic enjoyment of the activity, recreational fishing has been valued economically. The U.S. Department of the Interior (2008) estimated in 2006 roughly $2.7 billion was spent in Minnesota on goods associated with angling. Besides this widely cited study, other researchers have aimed toward estimating the valuation of fisheries. However, none of these studies appeared to solely focus on the activity of ice fishing. These studies utilized random utility models and the hedonic travel cost method. While these external studies were useful for discussion concerning valuation literature, the USDI value for a fishing day was utilized in the model due to its prevalent application in DNR literature, its simplicity of use, and the sound statistical methods, which are discussed below.

As seen below, the process of attempting to provide a value to a fishery has been conducted numerous times. This process utilizes information from anglers that has been ascertained through direct or indirect measures (Chen, Hunt, & Ditton, 2003). The reliability of the data depended upon the methods used to collect the information from the anglers. A brief description of studies that have attempted to model the economic benefits of angling is described below.

Chen, Hunt, and Ditton (2003) sought to provide an estimate for the total economic value for a largemouth bass fishery for a reservoir in Texas. Information from creel survey data was obtained in order to perform follow up surveys asking for willingness to pay (WTP) estimates. These estimates were derived by asking anglers questions such as how much was spent during their trip on certain activities and resources such as food, gas, lodging, and boat rental. In addition, anglers were asked to indicate where they were traveling from and how many miles were traveled to reach their destination. These methods created a WTP estimate for the anglers as well as an estimated total expense that was incurred by the anglers while recreating. The estimates of WTP were separated by direct and indirect expenditures. Indirect expenditures encompassed activities that were not directly related to the fishing experience such as lodging and dining. In addition, estimates from out of state, local and non-local residents were individually reported. Out-of-state and non-local residents spent the most on their trips. The majority of the anglers were non-local residents from in-state. The breakdowns of expenditures were reported by percentage of total costs. In addition, an estimate was provided of total dollars generated by supporting businesses. The subsequent creation of jobs was also estimated. This study illustrated the clear economic value and generation of revenue that has been created from a fishery.

A large number of studies have been associated with the estimation of WTP for recreational fishing. Johnston, Ranson, and Helm (2006) compiled and reviewed a large number of these dissertations, journal articles and one book and determined what variables had an influence on the final WTP estimate. The authors concluded that research methodology played an important role in determining the final value. The main variations in research methodology involved the means by which the estimate was calculated: these were the hedonic travel cost method, the random utility method (RUM), and stated preference. The authors discovered that the year the study was conducted also played an important role in the final estimate; the more recent studies had a higher WTP. In addition, it was found that the variables of year and the type of study had an effect on the final value of the estimate. The estimated WTP varied considerably between fish species. Trout species exceeded WTP over species such as panfish and walleye. This study provided a quality assemblage of information that showed consistent positive economic valuation for fisheries.

Stevens (1966) examined the effect of quality on the economic valuation of sport fishing in the Willamette Valley of Oregon. The author theorized that a change in quality could have negatively impacted the economic valuation of the sport fishery. This was predicted to occur, because decreases in quality could have negatively affected the catch rate (Stevens). In turn, catch rate was proportional to effort made by anglers. Effort made by anglers was calculated into an economic valuation through analysis of opportunity cost of time and expenditures made to reach and enjoy a recreation destination. Stevens found a decrease in quality would impact these expenditures through reduced catch rates. This author used calculations of willingness to pay to estimate reduction from decreased quality. Although this project did not examine catch rates, this study validated the potential economic impact from potential changes in fish populations caused by climate change.

Vaughan and Russell (1982) covered an overview of the methodology involved with calculating the value of a fishing day using the travel cost method. The authors focused on the economic methods used to derive the travel cost estimate. They pointed out that travel to a site is based on several characteristics. One of these is the type of fish being sought. The type of fish was predicted to impact the WTP value. Other characteristics that affected travel cost included the socioeconomic status of the anglers and the site characteristics. The authors concluded there was a potentially significant difference between the WTP dependent upon species sought.

The USDI (2008) provided a large database of information on economic valuations for fishing, hunting and wildlife associated recreation. These valuations were divided by each state, with a large amount of information available for Minnesota.

Individual estimations were provided for each recreation sector, and these were combined together to create an aggregate estimate. Interesting numbers included total estimated statewide anglers, dollars spent on angling, and days spent fishing. These numbers provided a justification for the relevancy of the research question depicted above. Numbers were broken down into expenses on specific equipment, days spent on each recreation activity and miles spent traveling. However, winter-specific information was not discernable from the information provided.

The methods behind the estimates made by the U.S. Census Bureau took place through a multistep process. Procedures were utilized to prevent bias in the estimates. These included using statistically sound sampling techniques. The selection process involved the utilization of sampling units for the entire United States. Each of these units were then divided into different stratum. Each selected unit within a stratum was used to estimate the entire stratum. The sample size for the Minnesota sample consisted of 778 households. Sportspersons were chosen through a screening process that selected these respondents apart from non-sportspersons. The individuals selected were then chosen to be interviewed, predominantly in-person. The response rate of these interviews was 90 percent. The average trip expenditure per day for residents and nonresidents of Minnesota was estimated to be $35. This estimate served as a baseline in the economic analysis that was performed below.

Travel Cost Method

The estimation provided by the U.S. Census Bureau utilized the travel cost method (TCM) to derive the total valuation for a fishing day in Minnesota. The travel cost technique is the utilization of expenditures incurred upon traveling to a recreation destination to indirectly determine the economic value of the recreation activity (Brown and Mendelsohn, 1984). The travel cost value was the backbone of this project. The sources discussed below cover the intricacies surrounding this valuation method.

Agnello and Han (1993) explored the methodology related to conducting an analysis of recreational fishing values in Long Island when the opportunity for substitutes existed. The researchers discovered that the availability of substitutes lowered the potential value of consumer surplus. The majority of this paper focused on the methodology utilized to perform an analysis of this recreational fishery. However, these researchers indicated the effect of substitutes, which had an impact on a travel cost value.

Randall (1994) also analyzed the technique of valuing non-market goods, specifically through the TCM. A variety of weaknesses were indicated, which were clearly illustrated. These included problems with joint costs and the effects of substitutes on the final valuation. In addition, different inclusions of variables lead to different estimates for the same non-market good. Also, there could have been variability in certain costs such as the price of equipment over time. The weaknesses lead Randall to conclude that the travel cost method could only most appropriately have been used in an ordinal scale, and anything more would have been biased. However, the travel cost technique may have held to be viable since the availability of substitutes may not have existed when a fishing day was valued for the entire state.

Benefit Transfer

The baseline value for ice fishing that was used to determine the potential economic impact from climate change was calculated by using a technique referred to as benefit transfer. This is the process of using values from a previously existing study and “transferring” the values to another realm of policy. This technique is especially useful when a project is limited for time and resources (Kirchhoff, Colby, & LaFrance, 1997).

Desvousges, Naughton, & Parsons (1992) provided a critical discussion related to the benefit transfer technique. These authors primarily focused on analyzing the method through an experimental design focused on water quality. However, the concepts discussed throughout the essay were relevant across disciplines. The discussion revolved first around the basic premises involved in performing a benefits transfer. The premises related to the differences between the study site and the policy site. The study site was where the initial empirical work took place and the policy site was where the valuation was applied. The variables included sound methodologies, similar socioeconomic characteristics, similar site characteristics and the inclusion of the effects of substitutes. The authors drew on information from an earlier version of the Department of the Interior’s census, which was cited above. However, it was noted that users typically travel to the sites nearest to their location, and a national (or statewide) average may have skewed these characteristics. In addition, these authors evaluated transfers based both on contingent valuation (CV) and the TCM. They indicated that there was no specific criterion for evaluating the reliability of existing studies that a benefit transfer would have been based upon.

The benefit transfer technique was further embellished upon by Bergstrom and Civita (1999). These authors provided an overview of the reliability of benefit transfer in North America. The authors used their background from Environment Canada and economics to effectively draw on a wide variety of literature. Benefit transfer methodology was covered along with its flaws. In addition, the authors provided a literary analysis of studies that have evaluated the reliability of benefit transfer. These evaluations used two different types of techniques. One method evaluated the values by comparing the results from individual studies across study sites to see if they were comparable. The authors concluded that benefit transfer equations were more reliable than unit transfers. The authors also indicated the shortcomings of many benefit transfer values when applied to a policy site from a study site. Last, the paper provided informative discussion on the necessity for accuracy. For example, a high level of accuracy was not required when broad policy statements were being made from the transfers. This latter concept especially applied to this research project, as the estimate derived simply aimed to provide an estimate of potential impacts.

CHAPTER 3: METHODS

Creel Surveys

Periodically, the Minnesota Department of Natural Resources (MN DNR) has conducted summer and winter creel surveys to assess the amount of use certain lakes were experiencing (Cook & Younk, 1998). These surveys analyzed how many hours were spent recreating and how many fish were caught and released by anglers (Cook & Younk). A large sample of these surveys were gathered from the statewide creel survey database.

As mentioned in the literature review, creel surveys provided a means to represent the characteristics of a population of anglers on a particular body of water (Cook & Younk, 1998). These surveys could have been prone to several types of biases including response, nonresponse and sampling errors (Pollock, Jones, & Brown, 1994). However, with proper survey design, these biases may have been addressed and avoided.

As can be seen from the analysis of the history of creel surveys, the methods have been constantly changing and improving. The modern creation of a statistical program and general reporting format provides evidence of this improvement. The state has utilized a wide variety of different sampling designs for conducting their creel surveys (see Appendix 1). Each of these surveys has been associated with potential respective biases (Pollock, Jones, & Brown, 1994). Therefore, no estimate derived from this data may have been taken to be completely accurate.

As analysis of the surveys continued, it became evident that the creel surveys were not without their imperfections. For example, some of the lakes may not have been selected evenly or randomly statewide. In addition, some lakes may have had more extensive creel information than other lakes. Furthermore, some lakes may not have been accounted for due to sampling or selection techniques. Lastly, some lakes and lake classes have had sparsely collected data. If a minimal amount of data existed for some lakes, it was considered a potential bias in the benefit transfer process. In other words, a biased amount of pressure may have impacted the final dollar value estimate.

Despite these biases, analyses of the validity of some creel survey designs such as instantaneous counting methods have yielded defensible results (Pierce & Bindman 1994). Therefore, while these surveys may have had some potential weaknesses, they still may have proved to be useful in calculating an estimate of the potential impact of climate change on recreational benefits.

In the survey database, information was provided on fishing pressure gathered from 763 lakes. Out of these lakes, 400 contained information regarding winter pressure. These lakes are found dispersed throughout Minnesota (Cook & Younk, 1998). Many of the surveys in the database were based on methods from Pollock, Jones, and Brown (1994), which was discussed above and in the literature review.

Main Hypothesis and Scenarios

The hypotheses tested in this thesis are represented by the function: $B = f(x_1, x_2, x_3, x_4)$. The components of this function include:

B = Recreational benefits from fishing
x_1 = Ice-on days
x_2 = Open-water days
x_3 = Angler hours per acre
x_4= Species

Recreational benefits are hypothesized to be a function of the above variables. When one of these variables is shifted, it is assumed that there will be an impact on the recreational benefits (B). In other words, it is assumed that a change in ice-on days, ice-off days and angler hours per acre will all have an impact on recreational benefits. These assumptions are represented below:

Assume: $\Delta B/\Delta x_1 > 0; \Delta B/\Delta x_2 > 0; \Delta B/\Delta x_3 > 0$

As mentioned above, three different scenarios are tested. The first tests the notion that the change in recreational benefits from a change in ice-on date is equal to the change in marginal benefits from a change in ice-off date. In other words, ice-fishing is not worth any more than open-water fishing.

Scenario 1: $\Delta B/\Delta x_1 = \Delta B/\Delta x_2$

The second scenario looks at the possibility of the change in recreational benefits being unequal from a change in ice-on and ice-off dates. Scenario 2a represents the case of locations such as East Upper Red Lake, MN, which have seen a higher proportion of anglers visiting in the winter than in the summer (MN DNR, 1997). This difference is mainly due to the ease of access in the winter. In the summer the geography of the lake results in large waves when wind is present, which makes open water fishing difficult.

Scenario 2a: $\Delta B/\Delta x_1 < \Delta B/\Delta x_2$

Scenario 2b applies to other areas around the state. The statistical analysis of fishing activity in Minnesota reveals a higher amount of angler hours on lakes during the summer months (see results). Therefore, an increase in the amount of ice-off days will have a greater positive impact on recreational benefits than the loss due to fewer ice-on days.

Scenario 2b: $\Delta B/\Delta x_1 > \Delta B/\Delta x_2$

The third scenario examines the impact of species on the marginal recreational benefits. The literature has indicated that certain species have had a higher willingness to pay (WTP) by anglers than others (Johnston, Ranson, & Helm, 2006). For example, trout species have had a higher WTP than species such as panfish and walleye (Johnston et al., 2006). Under this assumption, a change in abundance of one species, or decrease in abundance of another may have a significant impact on the recreational benefits.

Scenario 3: $\Delta B/\Delta x_4 > 0$

The following are the methods for the hypotheses being tested in this thesis. Using ice duration statistics (including ice-on and ice-off data), the estimated impact on the total number of days fished was determined. There are three different scenarios that were examined (mentioned above). Lake ice records were tested to see if the ice duration was significantly increasing or decreasing.

Lake Ice Observation Methodology

Lake ice records were obtained from Dr. Virginia Card at Metropolitan State University, Saint Paul, MN. Her ice records were gathered from the Minnesota Pollution Control Agency (MPCA) and the Minnesota Ice Records Database. The Minnesota Ice Records Database consists of a combination of observations recorded in newspapers and from individual correspondence. She submitted to this project data from 40 lakes that contain both ice-on and ice-off observations dates, which made it possible to estimate ice duration. These 40 lakes are a set from another subset of her data consisting of 106 lakes. The set of 106 lakes were chosen from her dataset, because they contain information regarding gill net and water quality data. Any missing observations in this dataset were estimated by a comparison modeling procedure against nearby lakes (within 50 km).

This included using a set of 6-10 lakes to estimate the ice-on or ice-out date of the modeled lake. The modeling procedure yielded an error rate less than 2-3 days when the procedure was compared against actual observations (Card, 2009).

Observation error and typographical errors are perhaps the largest weaknesses in regards to ice duration data. Her data was checked in three separate ways to account for these potential weaknesses. Dr. Card checked errors “by comparison of ice-out records from one lake by two or more independent observers; by comparison of multiple redactions of the same record; and by comparison of each year of a very long ice-out record to contemporary reports of ice-out dates from archival record at the Minnesota Historical Society” (Card, 2009). Through her analysis, she discovered untrained observers would make errors on average of 1-2 days per year. When recording proved to be in error, this occurred every 1 in 20 dates with an average of 2-3 days being off of the actual date (Card).

The ice trends, which were reported in days lost or gained, determined how many angler days were impacted. Using the creel survey data, the average number of angler hours per season per acre was determined. The total amount of angler days was determined using the number of angler hours per fishing trip in the open-water and ice-fishing seasons (separately). The average number of angler days in each season per acre was then extrapolated with the total acreage of lakes in Minnesota.

In order to determine an impact on the number of open-water days and ice-on days, a baseline for the current total number of these days needed to be determined (seen below in the equation). To create this baseline, data from 1971-2000 was utilized from the 40 lakes in the ice coverage dataset. Using the previous 30 years of data ending on the most recent zero year represents a climate normal in meteorology (Hulme, Dessai, Lorenzoni, & Nolson, 2009). Normals were created for each climate region by averaging the length of ice-on and open water days for lakes in the ice duration dataset. Some climate regions had several lakes to be averaged, while others had only a couple. Climate region 7 and 9 had no ice duration observations. These climate regions were estimated by using the number of days in the horizontally adjacent climate region containing data (climate region 8).

Total Lake Acreage

The total lake acreage was determined using a GIS layer obtained from the GIS coordinator for the MN DNR, Lyn Bergquist. The layer contains all lakes that have division of waters (DOW) identification numbers, which totals to 16,141 lakes. This layer was specifically prepared to represent Minnesota lakes acreage. The portions of lakes that exist outside state boundaries were excluded from the acreage assessment. Out of these lakes, the DNR has surveyed (not creel surveys) the fish populations on 4,295 lakes. Using the sum feature in GIS, the acreage for the group of 16,141 lakes and the group of 4,295 lakes were each determined. The acreage for the 16,141 lakes is 4,555,898.54, and the acreage for the 4,295 lakes is 3,923,292.62. The different acreage estimates provided by the upper and lower bound numbers provide a sensitivity analysis for the total amount of lake acreage in Minnesota.

Explanation of Benefits Calculation

The result of combining angler days with the total lake acreage provided an estimate of the total number of trips (angler days) that occurred in the open-water or ice-fishing seasons for the entire state. The total estimate was then divided by the number of days in a season, which yielded the average number of trips per day. The number of trips per day was multiplied by the number of lost or gained days using the ice duration statistics. This provided an approximation of the number of angler days lost or gained from changing ice duration.

The estimated lost or gained fishing days was then transferred into an economic estimate to represent the economic gain or loss. Data from the U.S. Census Bureau valuing a fishing day was utilized as an estimate at $35 per day. Since a fishing day may be variable between seasons, the number of hours in a fishing day was found for each season using statistical analysis.

As mentioned above, the U.S. Fish and Wildlife Service has conducted a national survey in collaboration with the U.S. Census Bureau every five years (USDI, 2008). In this survey, individuals were contacted and interviewed with a variety of questions regarding their participation in activities such as fishing, hunting, wildlife viewing or any combination of these activities. In questioning, the respondents were asked a variety of questions regarding their expenditures related to these activities. Through these inquiries an estimation of a value for each activity was created (USDI). This USDI estimate for the value of a fishing day was utilized to form a baseline in the equation mentioned below, which determines the projected impact from climate change. The estimate is $35 per day by Minnesota residents and nonresidents in 2006 dollars (USDI).

Mathematical Description of Benefits Calculation

The procedure, mentioned above, for estimating the potential economic impact is as follows:

$X1_w$, $X1_s$ = Mean angler hours per acre per season
X2 = Total fishable acres (two estimates)

$X3_{w}$, $X3_{s}$ = Mean angler hours per trip in each season (trip length)
$X4_{w}$, $X4_{s}$ = Angler days per season in each climate region
$X5_{w}$, $X5_{s}$ = Days lost or gained in each season per decade
X6 = Value of a fishing day
$Y1_{w}$, $Y1_{s}$ = Total trips/season
Y2 = Average trips/day
$Y3_{w}$, $Y3_{s}$ = Trips lost/gained per season
$Y4_{w}$, $Y4_{s}$ = Economic estimate per season
Y5 = Total economic impact

$X5_{w} + X5_{s} = 0$
$Y3_{w} + Y3_{s} = 0$

$Y1_{w/s} = X1_{w/s} * X2/X3_{w/s}$
$Y2_{w/s} = Y1_{w/s} / X4_{w/s}$
$Y3_{w/s} = Y2 * X5_{w/s}$
$Y4_{w/s} = X6 * Y3_{w/s}$
$Y5 = Y4_{w} + Y4_{s}$

Multiple Regression of Species Shift over Time

In addition to the above hypothesis, another hypothesis proposed by Schneider, Newman, Card, Weisberg, and Pereira (2009) was examined. This hypothesis indicated that largemouth bass and sunfish are predicted to shift their range north and east in response to climate change. In addition, the literature indicated trout species are predicted to decline in abundance. Angler surveys provided species-sought percentages and species yield (in pounds) that were examined across climate regions over time. Species included in the analysis were walleye (due to its high economic demand), largemouth bass, sunfish, and all trout species. These species elicited some of the highest rates of preference by anglers from the creel database (See Table 25). Some of these values totaled to more than 100% due to multiple responses being coded for 100% in the same category. These inaccuracies were corrected for the benefits estimation calculation. Any remaining species were categorized as “other species.” The variables examined were species, percentage of “species-sought”, climate region and year. These variables were placed in a multiple regression (using dummy variables for climate regions and species) to determine their impact on total yield across the state. The multiple regression equation reads as follows:

$Y = f(x_1, x_2, x_3, x_4)$

$Y = Weight_{species}$
$x_1 = Hours_{species}$
x_2 = Climate region
x_3 = Survey year
x_4 = Percentage of anglers seeking each particular species

The hours each angler spent fishing for each species was determined by multiplying two variables together: the percentage of anglers in each creel that fished for the above mentioned species and the total amount of angler effort (pressure). This calculation was extended vertically in one column labeled “spphrs”. In addition, the total catch for each of the above mentioned species was also extended vertically in one column labeled “spplbs”. Each of these cases were identified with a dummy variable indicating their respective climate region and species. This process was performed individually for the entire compilation of creel data for the state, for the big 9 walleye lakes and for East Upper Red Lake (due to its uniquely high winter pressure compared to summer). Two cases were removed from the Red Lake dataset. One case was from 1995 when the reported yield of walleye harvest was 0. The other case was from 1980 when the reported yield for all other species was reported as 0. The big 9 walleye lakes include Lake Vermillion, Lake Mille Lacs, Cass Lake, Lake Winnibigoshish, Rainy Lake, Leech Lake, East Upper Red Lake, Lake of the Woods and Kabetogama.

Geographic Information System (GIS) Procedure

To perform both of the above analyses, the data of fishing pressure on Minnesota lakes were input into geographic information systems (GIS) software, ArcGIS 9.3 to visually represent lakes in the study. In addition, ArcGIS was used to join datasets together using Strata ID and each lake's division of waters (DOW) number as a unique identifier between different datasets.

GIS was utilized to assign all of the survey lakes to a climate region. This was a multistep process. First, the Minnesota counties layer was dissolved by climate region (designated by the LCCMR – see report). These climate regions were then used to perform a spatial join with the Minnesota lakes layer provided by the MN DNR. Lakes on the edges of these regions, or those contained within multiple regions were assigned a climate region depending on which county they resided within.

For the first equation estimating recreation benefits from changing lake ice, the Minnesota lakes with assigned climate regions were paired with the most recent creel surveys in each season. For example, in each season, although there were multiple years of data for some lakes, only the most recent was chosen using GIS. The lakes data were joined with the most recent summer and winter creels. This was accomplished by matching the DOW number on the lakes table and the creel tables.

The second hypothesis, the multiple regression tracking changes in species over time and location, utilized a separate dataset that was queried from the creel survey database. This dataset included all possible years of data, and included "species-sought" percentages, catch (lbs) by species and total effort (pressure). This dataset was joined by the attribute of DOW number to the lakes layer with assigned climate regions. Besides running a multiple regression on all Minnesota lakes, a separate regression was run on Red Lake, as well as 9 out of 10 of the large walleye lakes in Minnesota that are important for economic reasons (MN DNR, 1997).

After preparing the data and assigning climate regions in ArcGIS, these data were input into Statistical Package for the Social Sciences (SPSS) 16.0. SPSS was used to calculate the variables and multiple regression results for the equations referred to above.

CHAPTER 4: RESULTS

The following is a disclaimer to the results that are listed below in the following section.

- The results contain information from DNR data that was aggregated into seasonal estimates. The conclusions drawn from the results would have been more accurate if they were drawn from stratified seasonal data. For example, the conclusions assume that every day experiences the same amount of pressure throughout a season. Since there are differences in use in different periods of a season, the results in this section must be considered only a representation of a potential method to model climate change impacts.
- The following results assume that an ice-fishing day is worth the same as an open-water fishing day. A travel cost analysis for ice anglers could reveal a different valuation for an ice-fishing day. In fact, statistical evidence shows that an ice-fishing day is slightly longer than an open-water day, which suggests a higher valuation by anglers.
- The following results also assume that a fishing day is worth the same regardless of the species being sought. Willingness-to-pay literature provides evidence to the contrary. For example, trout species are more highly valued than average and are amongst the most vulnerable in Minnesota to the effects of climate change.
- The multiple regression testing the hypothesis of shifting species ranges and abundance was based on DNR data that contained many empty fields. The results were statistically significant, but were not based on a complete dataset.

Results from Benefits Calculation from Changing Ice Duration

The components with values determined for the equation mentioned in the methods are the following:

$X1_w$, $X1_s$ = Mean angler hours per acre per season
X2 = Total fishable acres
$X3_w$, $X3_s$ = Mean angler hours per trip in each season (trip length)
$X4_w$, $X4_s$ = Angler days per season in each climate region
$X5_w$, $X5_s$ = Days lost or gained in each season per decade
X6 = Value of a fishing day

The mean number of angler hours per acre in each season proved to be significantly different from one another at the 1% level when equal variance was assumed and when it was not assumed (See Table 1). This was discovered by using an independent samples t-test for the variable in each season. The mean angler hours per acre in the summer were 45.14 hours and in the winter were 8.88 hours.

As mentioned above in the methods section, there are two estimates for total fishable acres. The first estimate is 4,555,898.54 acres, which includes all lakes in Minnesota with a DNR DOW assigned number. The second estimate for the total includes all lakes that have been surveyed for their fish populations, which is 3,923,292.62 acres.

The third value calculated is X3, the mean angler hours per trip in each season. An independent samples t-test was also performed for this variable. It was determined that the trip length is significantly different at the 1% level when equal variances are assumed and when they are not assumed. Summer trip length was a mean of 3.35 hours and winter trip length was slightly longer with a mean of 3.77 hours (See Table 2).

A one sample t-test was performed on the average number of days of changing lake ice duration for the 40 lakes in the dataset. Each lake in the dataset represented a different case. Dr. Card provided the average number of days lost or gained of ice duration from the period of 1970 to 2008 for each of the 40 lakes in her dataset. These averages were input into a one sample t-test. The null hypothesis was that there is no change in the amount of ice duration. It was found that lake ice duration in the Minnesota sample is significantly decreasing at a mean rate of 3.3 days per decade from the time period of 1970 to 2008. This mean rate of change is significantly different from zero at the 1% level of significance (See Table 3). A stem and leaf diagram further solidifies these results by showing that all of the cases elicited negative values for the direction of changing ice duration (See Table 4).

As mentioned above, the average trip expenditure for Minnesota residents and nonresidents for the activity of angling in the state is $35 per day in 2006 dollars. This value represents the variable X6 in the model.

The methods section laid out the meaning of each individual variable. The results for these variables are discussed above, and are indicated next to their variable names below. In addition, an upper and lower bound estimate are shown for each season in accordance with the variation in acreage presented from the MN DNR. The estimates represent the potential impacts per decade, as these were units of the predicted shifts in ice duration.

$X1_w$, $X1_s$ = 8.88, 45.14 hours per acre
X2 = 3,923,292.62, 4,555,898.54 acres
$X3_w$, $X3_s$ = 3.77, 3.35 hours
$X4_w$, $X4_s$ = Climate Region (CR) 1: 148.85 days(d), 216.40 d; CR 2: 146.26 d, 219.00 d; CR 3: 152.50 d, 212.76 d; CR 4: 149.43 d, 215.83 d; CR 5: 134.22 d, 231.03 d; CR 6: 133.17 d, 232.08 d; CR 7: 136.23 d, 229.02 d; CR 8: 136.23 d, 229.02 d; CR 9: 136.23 d, 229.02 d
$X5_w$, $X5_s$ = -3.3, 3.3 days per decade
X6 = $35 per day

$Y1_{w}$, $Y1_{s}$ = lower bound: 9241071.2, 52864904.1 trips per season; upper bound: 10731135.0, 61389032.9 trips per season

Climate Region 1

Ice Fishing Season

Lower bound acreage estimate

$Y2_{w}$ = 62,083.1 average trips/day
$Y3_{w}$ = 204,874.2 trips lost
$Y4_{w}$ = -\$7,170,599.4 per decade

Upper bound acreage estimate

$Y2_{w}$ = 72,093.6 average trips/day
$Y3_{w}$ = 237,908.9 trips lost
$Y4_{w}$ = -\$8,326,812.8 per decade

Open Water Season

Lower bound acreage estimate

$Y2_{s}$ = 244,292.5 average trips/day
$Y3_{s}$ = 806,165.3 trips gained
$Y4_{s}$ = \$28,215,787.5 per decade

Upper bound acreage estimate

$Y2_{s}$ = 283,683.1 average trips/day
$Y3_{s}$ = 936,154.3 trips gained
$Y4_{s}$ = \$32,765,403.4 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = \$21,045,188.1 per decade

Upper bound acreage estimate

Y5 = \$24,438,590.5 per decade

Climate Region 2

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 63,182.4 average trips/day
$Y3_w$ = 208,502.2 trips lost
$Y4_w$ = -$7,297,577.7 per decade

Upper bound acreage estimate

$Y2_w$ = 73,370.2 average trips/day
$Y3_w$ = 242,121.8 trips lost
$Y4_w$ = -$8,474,265.6 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 241,392.2 average trips/day
$Y3_s$ = 796,594.4 trips gained
$Y4_s$ = $27,880,805.6 per decade

Upper bound acreage estimate

$Y2_s$ = 280,315.2 average trips/day
$Y3_s$ = 925,040.2 trips gained
$Y4_s$ = $32,376,407.7 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $20,583,227.8 per decade

Upper bound acreage estimate

Y5 = $23,902,142.0 per decade

Climate Region 3

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 60,597.1 average trips/day
$Y3_w$ = 199,970.7 trips lost
$Y4_w$ = -$6,998,975.2 per decade

Upper bound acreage estimate

$Y2_w$ = 70,368.0 average trips/day
$Y3_w$ = 232,214.7 trips lost
$Y4_w$ = -$8,127,515.3 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 248,472.0 average trips/day
$Y3_s$ = 819,957.6 trips gained
$Y4_s$ = $28,698,516.7 per decade

Upper bound acreage estimate

$Y2_s$ = 288,536.5 average trips/day
$Y3_s$ = 952,170.5 trips gained
$Y4_s$ = $33,325,969.6 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $21,699,541.5 per decade

Upper bound acreage estimate

Y5 = $25,198,454.2 per decade

Climate Region 4

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 61,842.1 average trips/day
$Y3_w$ = 204,079.0 trips lost
$Y4_w$ = -$7,142,767.3 per decade

Upper bound acreage estimate

$Y2_w$ = 71,813.7 average trips/day
$Y3_w$ = 236,985.5 trips lost
$Y4_w$ = -$8,294,493.0 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 244,937.7 average trips/day
$Y3_s$ = 808,294.4 trips gained
$Y4_s$ = $28,290,304.5 per decade

Upper bound acreage estimate

$Y2_s$ = 284,432.3 average trips/day
$Y3_s$ = 938,626.7 trips gained
$Y4_s$ = $32,851,935.7 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $21,147,537.1 per decade

Upper bound acreage estimate

Y5 = $24,557,442.7 per decade

Climate Region 5

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 68,850.1 average trips/day
$Y3_w$ = 227,205.5 trips lost
$Y4_w$ = -$7,952,195.8 per decade

Upper bound acreage estimate

$Y2_w$ = 79,951.8 average trips/day
$Y3_w$ = 263,841.0 trips lost
$Y4_w$ = -$9,234,436.7 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 228,822.6 average trips/day
$Y3_s$ = 755,114.8 trips gained

$Y4_s$ = $26,429,019.7 per decade

Upper bound acreage estimate

$Y2_s$ = 265,718.8 average trips/day
$Y3_s$ = 876,872.3 trips gained
$Y4_s$ = $30,690,530.6 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $18,476,823.9 per decade

Upper bound acreage estimate

Y5 = $21,456,093.9 per decade

Climate Region 6

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 69,393.0 average trips/day
$Y3_w$ = 228,997.0 trips lost
$Y4_w$ = -$8,014,896.1 per decade

Upper bound acreage estimate

$Y2_w$ = 80,582.2 average trips/day
$Y3_w$ = 265,921.3 trips lost
$Y4_w$ = -$9,307,247.0 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 227,787.4 average trips/day
$Y3_s$ = 751,698.4 trips gained
$Y4_s$ = $26,309,446.8 per decade

Upper bound acreage estimate

$Y2_s$ = 264,516.6 average trips/day
$Y3_s$ = 872,905.0 trips gained

$Y4_s$ = \$30,551,677.4 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = \$18,294,550.6 per decade

Upper bound acreage estimate

Y5 = \$21,244,430.3 per decade

Climate Region 7

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 67,834.3 average trips/day
$Y3_w$ = 223,853.2 trips lost
$Y4_w$ = -\$7,834,865.4 per decade

Upper bound acreage estimate

$Y2_w$ = 78,772.1 average trips/day
$Y3_w$ = 259,948.2 trips lost
$Y4_w$ = -\$9,098,187.5 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 230,830.9 average trips/day
$Y3_s$ = 761,742.1 trips gained
$Y4_s$ = \$26,660,974.7 per decade

Upper bound acreage estimate

$Y2_s$ = 268,050.9 average trips/day
$Y3_s$ = 884,568.1 trips gained
$Y4_s$ = \$30,959,886.8 per decade

Total Economic Impact

Lower bound acreage estimate

$Y5$ = $18,826,109.2 per decade

Upper bound acreage estimate

$Y5$ = $21,861,699.3 per decade

Climate Region 8

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 67,834.3 average trips/day
$Y3_w$ = 223,853.2 trips lost
$Y4_w$ = -$7,834,865.4 per decade

Upper bound acreage estimate

$Y2_w$ = 78,772.1 average trips/day
$Y3_w$ = 259,948.2 trips lost
$Y4_w$ = -$9,098,187.5 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 230,830.9 average trips/day
$Y3_s$ = 761,742.1 trips gained
$Y4_s$ = $26,660,974.7 per decade

Upper bound acreage estimate

$Y2_s$ = 268,050.9 average trips/day
$Y3_s$ = 884,568.1 trips gained
$Y4_s$ = $30,959,886.8 per decade

Total Economic Impact

Lower bound acreage estimate

$Y5$ = $18,826,109.2 per decade

Upper bound acreage estimate

$Y5$ = $21,861,699.3 per decade

Climate Region 9

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 67,834.3 average trips/day
$Y3_w$ = 223,853.2 trips lost
$Y4_w$ = -$7,834,865.4 per decade

Upper bound acreage estimate

$Y2_w$ = 78,772.1 average trips/day
$Y3_w$ = 259,948.2 trips lost
$Y4_w$ = -$9,098,187.5 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 230,830.9 average trips/day
$Y3_s$ = 761,742.1 trips gained
$Y4_s$ = $26,660,974.7 per decade

Upper bound acreage estimate

$Y2_s$ = 268,050.9 average trips/day
$Y3_s$ = 884,568.1 trips gained
$Y4_s$ = $30,959,886.8 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $18,826,109.2 per decade

Upper bound acreage estimate

Y5 = $21,861,699.3 per decade

Statewide Mean Total Impact across all Regions and Bounds = $21,339,302.71 per decade

Total Impact Statewide (Across all Climate Regions)

The values below were calculated by summing the results above in each climate region. The difference was determined between seasons individually for the upper and lower bounds.

Lower Bound = $177,725,196.9 per decade

Upper Bound = $206,382,251.8 per decade

Multiple Regression Results

Regression Results for the State

The multiple regression shows several main points (See Table 5). The model was created to show how angler effort has an impact on yield (in pounds) across climate regions over time. The aim was to see if yield per unit of effort of some species in some areas was improving in the climate regions with greater abundance as predicted by Schneider et al (2009). First of all, the model has a relatively high R-squared value of .505, indicating a relatively good fit. The F-statistic is very high, yielding a result that indicates that the model is significant at the 1% level. Although not significant, the constant was very high, which represents the background rate of pounds harvested. A sensitivity analysis was run on the model by eliminating the constant from the regression, which is discussed below. The variable of effort (spphrs) was significant at the 1% level, indicating for every extra hour spent fishing .002 pounds of fish were caught. This finding was significant and the slope was identical in both of the regressions, with and without the constant.

The dummy variables for each species were significant at the 1% level. This indicated that the amount of effort that was devoted to angling for a specific species resulted in a significant relationship with the amount of yield. In other words, more time spent fishing for a certain species represents a relationship with the amount of catch for that species. The negative numbers for each species represents a significantly lower amount of influence from the four main species categories in comparison to the "other species" category (the "other species" category was the baseline, and assigned a zero in each of the four dummy categories). This result suggests that the influence of the "other species" category dominated the results for the weight category. Table 7 indicates that the mean species pounds per hour is .0021. The four species categories are all lower than this value, except for sunfish (See Table 8-11). This implies that the "other species" category has a higher rate of pounds per hour (to balance out the mean). Therefore, the high rate of categorized "other species" is responsible for the negative "slope coefficients" on the dummy variables for the four species categories.

The dummy variables for each climate region were not significant in the model. The closest variable was climate region 2, which would be significant at the 10% level with a one-tailed test. These results indicate that the affect of angling effort on the amount of yield is not significantly different across climate regions statewide. Interestingly, the amount of pounds caught in climate region 2 was the highest out of all of the other 7 climate regions (excluding climate region 9), which can be seen in Tables 12-19. Climate region 2 has over double the amount of fish caught in comparison to the mean (See Table 7 and 13). This high rate of activity is the cause for the significant result in climate region 2.

Regression Results without the Constant

Eliminating the constant from the equation above resulted in a few changes in the statistical output (See Table 6). First, the R-squared value increased from .505 to .524 in the adjusted model. Second, the F-statistic increased from 181.952 to 196.411, still resulting in a significant model at the 1% level. Third, the amount of effort anglers performed resulted in an identical slope from the first model, .002 pounds for every extra hour of effort. Fourth, all of the significance levels from the previous model decreased (meaning more significant results), which yielded climate region 2 to be significant at the 5% level with a one tailed test. Again, this significance is most likely due to the high amount of activity that took place in this climate region (See Table 13). All of the previously significant variables proved to be robust upon the adjustment that took place.

Regression Results for the Big Nine Walleye Lakes

This model excluded some of the climate regions from the analysis, due to the lack of large walleye lakes in these regions (See Table 20). The model was significant at the 1% level and also had a relatively high R-squared value of .515, indicating a relatively good fit. The F-statistic was 41.61, indicating the model was significant at the 1% level. All of the species dummy variables were significant in this model at the 1% level. Climate region 2 was significant at the 1% level, again most likely for similar reasons indicated above. The amount of effort (spphrs) yielded similar results to the first regression. For every extra hour spent angling, .002 pounds were caught.

Regression Results for East Upper Red Lake

All other climate regions were excluded from this model, since East Upper Red Lake is located in one climate region. The R-squared value was very high at .924 (See

Table 21). The F-statistic was slightly smaller than the previous two models, but still proved that the model is significant at the 1% level. The species dummy variables were all insignificant, as well as the year (which was insignificant in all of the previous models). This indicates that effort over time for a specific species did not have any statistical influence on the amount of a certain species that was caught. However, the amount of time spent fishing in general had a significant amount of impact (at the 1% level) on the yield.

Results from Each Scenario

Scenario 1

The results from the benefits estimation calculations above indicate that this scenario will not prove to be likely. All climate regions reveal that there may be net positive benefits from the onset of climate change and decreasing ice duration. However, this does not mean this may be a preferable result for those who enjoy the activity of ice fishing in the winter.

Scenario 2a

Results from East Upper Red Lake, seen in Table 22, show that there are differences in the amount of pressure between the winter and the summer. The statistical analysis of this data did not yield significant results (due to holes in the creel survey database). However, a larger sample size would most likely indicate robust findings concerning this estimate. Since Red Lake sees such a higher use in the winter months, the onset of climate change through decreasing lake ice will likely have a net negative impact on recreational benefits from use of this lake.

Scenario 2b

Other large walleye lakes as well as statewide data show that summer effort significantly exceeds effort in the winter (See Table 23). In addition, statewide results mimic this finding (See Table 24). The benefits calculation estimated above yields results that align well with this scenario. A higher amount of angler effort in the open-water season is likely to lead to a net positive impact from the onset of climate change.

Scenario 3

The results from the multiple regressions did not show significant results for a change in yield per unit of effort in response to change in species abundance over certain regions of the state over time. Despite these results, more accurate testing of fisheries abundance by research conducted outside this project has yielded results suggesting that there is indeed a change in abundance (Schneider, 2009). Further examination of whether effort is increasing in these regions would be a topic for further research. As mentioned in the literature review, certain species, such as trout, have a higher WTP than walleye and panfish (Johnston et al., 2006). Therefore, a change in these species abundances could have a significant impact on the WTP by anglers. For example, fewer trout (which are predicted to decline from climate change) would be detrimental to recreational benefits. The net impact from these changes in species abundance and the economic consequences that result are beyond the scope of this project. However, further inquiries into these suggestions would provide interesting additional research opportunities.

CHAPTER 5: DISCUSSION OF RESULTS AND CONCLUSION

Statement of the Problem

This project attempted to discover the potential impact of climate change on the recreational benefits provided by open-water and ice fishing. Three main scenarios were tested regarding these different scenarios. Lake ice, species abundance, and regional and seasonal usage all played a role in determining the impacts from climate change on recreational benefits. Below is a discussion of the results from the analysis conducted above.

Discussion of the Findings

This project has covered a wide range of topics and multiple hypotheses have been tested determining the potential impact of global climate change on Minnesota fisheries and anglers. Some conclusions have been reached from relatively strong statistical output, while others need improvement. The datasets upon which these conclusions are based are by no means perfect, yielding potential areas for enhancement for future studies.

The creel survey data is not without its areas for needed improvement. Due to different methodology of different fisheries offices and creel clerks, there is a lack of continuity in the type of information that is collected. For example, thousands of cases were missing species-sought data that was used in the multiple regression analysis above. Making uniform methodology and reporting systems could have the potential to benefit the state by providing more accurate information on characteristics of anglers. In addition, changes to lake ice duration impact the fishing that occurs at the beginning and the end of the ice season. Maintaining a strong dataset with these types of divisions would aid with understanding how much usage occurs at these periods of the ice fishing season. For example, some anglers may fish more at the beginning of the ice fishing season when fish such as walleye may be biting and then wane off as the season progresses. In the spring, a renewed effort for species such as perch and crappie may ensue. Knowledge of these behaviors would help with further studies of the valuation process.

The economic estimate of a fishing day provided by the U.S. Department of the Interior is not without its areas for needed improvement. No distinct value for an ice fishing day was provided. Angling on the ice has its own set of expenditures such as ice houses, augers and tackle that could amount to different travel cost estimation for individuals participating in this type of activity. Valuing ice fishing at a different rate would have the potential to alter some of the estimates reached above.

Another point to touch on is the significant difference in trip length between winter and summer. The strongest statistical conclusion (1% level) was found on the comparison of trip length. Winter trip length is longer than summer, which points to a possible higher valuation of ice fishing in comparison to open-water fishing. These findings and the lack of unique valuation studies published in economic journals point to the need for further inquiry into this subject.

The lake ice calculations were generalized in regards to estimating the number of days in a season. Lakes with a greater depth and a larger surface area may have different ice-on an ice-off dates than those used in this estimation, which would change the mean number of days in each season. Changing the starting point of the number of mean days in a season would have impacted the final dollar estimate for each season. To refine this idea further in future work, a researcher could determine the ice duration for particular lakes (such as the big 9 walleye lakes) and individually determine the potential impacts. Despite these generalizations, the lake ice statistics did show that lake ice has been decreasing in duration over the last 30 years, which matches climate change predictions mentioned in the literature review.

The seasonal impacts were also generalized. An increase or a decrease in the number of days of ice is assumed to have a proportional impact on the amount of fishing that takes place during this period and a proportional economic impact. However, a decrease or increase in the amount of days of ice in the spring or fall does not necessarily mean an increase in the amount of open-water or ice fishing. For example, a large percentage of the angling population may be off of lakes after Labor Day (Drewes, H., personal communication). To further accurately explore these impacts, creel data would need to be determined for more specific strata such as early spring, late fall, early winter and late winter.

The multiple regression yielded results that were mostly intuitive. A higher amount of effort results in a significant positive relationship with the amount of yield. More time spent trying to catch fish results in a greater number of fish caught. However, the slope coefficient indicates that a relatively low number of pounds of fish were caught for every additional hour that was spent fishing (.002 pounds per extra hour). This slope coefficient could be due to inaccurate survey methods, lack of quality sampling methods, or missing data in the database. Specific effort for a particular species proved to have less impact on yield than the baseline, “other species.” This was most likely due to the influence of the “other species” category. In further analysis, this category could be explored to determine the particular species that has a stronger weight of influence on the amount of yield.

Climate region 2 was the sole area of the state that showed a significant difference from other regions in respect to the amount of yield that was produced. The tables of activity by climate region indicate the reasons for this relationship. Climate region 2 had the highest amount of species yield in comparison with all of the other climate regions in the state. Lake of the Woods, Red Lake, Cass Lake and Winnibigoshish all lie in climate region 2, which could be the reason why these yield rates are high in this region.

The multiple regression results were highly dependent upon the quality of the creel data. The historical data contain many holes for reasons mentioned above. An improvement of this system could be beneficial for reaching more defensible results from studies concerning angling in Minnesota. For example, a large percentage of the cases were missing data in the “species-sought” category. A greater amount of information could have been provided this area, which would have yielded more defensible results.

Conclusion

Although a net positive gain was found for anglers with the onset of climate change, potential issues remain with the biology of fish populations and the behavior of anglers. Increasing temperatures of water bodies, decreasing levels of dissolved oxygen and increases in runoff have the potential to alter the aquatic ecosystems statewide. As mentioned above, the magnitude of the impacts depends on the starting point of the water body (if it is oligotrophic, mesotrophic, or eutrophic). However, it will be a gamble to play with the outcome of these impacts.

Angler behavior may also have an uncertain future. Many anglers may value the first days of ice-on to be the best ice fishing days due to fish behavior. In the springtime when crappie are active, anglers may have uncertain responses to changes in fish behavior due to ice-changes. Some anglers may be uneasy about fishing on unstable ice. On the other hand, more anglers may be able to fish on open water (and their success could depend on fish species behavior). In addition, earlier ice-off may cause changes to spawning behavior of walleye, as mentioned above. Leaving a walleye opener to be in May could cause a mistiming in the peak activity (post spawning) for these trophy fish, which would leave an underutilization of this natural resource. The Minnesota DNR may have to take these issues into account in the upcoming decades when dealing with the after-effects of global climate change.

In relation to valuing a fishing day, certain days of the year may be worth more money to some anglers than others. This project values all days to be equal. For example, a day lost to ice-fishing is worth the same as a day gained for open water fishing. It is unclear if these days are of equal proportional worth. This empirical question is beyond the scope of this project. However, asking if certain days are worth more than others would be a worthwhile question for future studies estimating the value of angling in responses to climate change.

These potential forecasted impacts, both biological and economic, give ideas as to what could be expected for future scenarios from the onset of global climate change. However, these attempts at forecasting the economic future cannot be altogether certain. As mentioned above, certain times of the year may be worth more to an angler than others. Policy makers must be cognizant that certain decisions can be made to avoid increasing contributing factors for climate change. Choosing not to act to prevent these impacts could potentially be an expensive wager in regards to fish biology as well as angler behavior.

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Appendix A: Tables of Results

Table 1

Independent samples t-test of variables $X1_w$ and $X1_s$

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
AngHrsAc	WI	400	8.8768	13.82285	.69114
	SU	763	45.1388	84.29788	3.05179

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
AngHrsAc	Equal variances assumed	75.318	.000	-8.542	1161	.000	-36.26205	4.24533	-44.59143	-27.93267
	Equal variances not assumed			-11.589	837.960	.000	-36.26205	3.12907	-42.40379	-30.12031

Table 2

Independent samples t-test of variables $X3_w$ and $X3_s$

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
TripLength	SU	98	3.3535	.84311	.08517
	WI	74	3.7723	1.04980	.12204

s

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TripLength	Equal variances assumed	5.353	.022	-2.901	170	.004	-.41883	.14437	-.70383	-.13383
	Equal variances not assumed			-2.814	136.972	.006	-.41883	.14882	-.71310	-.12455

Table 3

One sample t-test of variable $X5_w$

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
1970-2008 Ice Duration (d/d)	40	-3.30676788122881E0	1.111868838372952E0	1.758018994312076E-1

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
1970-2008 Ice Duration (d/d)	-18.810	39	.000	-3.306767881228813E0	-3.66236078693348E0	-2.95117497552414E0

Table 4

Stem and leaf diagram of variable $X5_w$

```
1970-2008 Ice Duration (d/d) Stem-and-Leaf Plot

 Frequency    Stem &  Leaf

     1.00       -5 .  5
     2.00       -5 .  02
     5.00       -4 .  67889
     3.00       -4 .  013
     7.00       -3 .  5556677
     5.00       -3 .  00223
     6.00       -2 .  555789
     6.00       -2 .  112234
     4.00       -1 .  6899
     1.00       -1 .  3

 Stem width:  1.000000
 Each leaf:       1 case(s)
```

Table 5

Multiple Regression Results for Minnesota

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.710[a]	.505	.502	26256.37969

Note. a. Predictors: (Constant), Dclmt8, Dwae, Dclmt1, Dclmt7, Dclmt5, SurveyYr, Dclmt2, Dlmb, spphrs, Dclmt4, Dsun, Dclmt3, Dtrt, Dclmt6

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.710[a]	.505	.502	26256.37969

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.756E12	14	1.254E11	181.952	.000[a]
	Residual	1.724E12	2501	6.894E8		
	Total	3.480E12	2515			

Note. a. Predictors: (Constant), Dclmt8, Dwae, Dclmt1, Dclmt7, Dclmt5, SurveyYr, Dclmt2, Dlmb, spphrs, Dclmt4, Dsun, Dclmt3, Dtrt, Dclmt6. b. Dependent Variable: spplbs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	99621.440	121037.324		.823	.411
	SurveyYr	-45.858	60.516	-.011	-.758	.449
	spphrs	.002	.000	.689	47.110	.000
	Dlmb	-9592.286	1792.790	-.090	-5.350	.000
	Dsun	-9513.854	1602.922	-.105	-5.935	.000

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.710[a]	.505	.502	26256.37969

Dtrt	-11014.143	1606.623	-.121	-6.855	.000
Dwae	-12610.019	1607.478	-.140	-7.845	.000
Dclmt1	-66.374	9371.390	.000	-.007	.994
Dclmt2	12371.982	7728.626	.110	1.601	.110
Dclmt3	1810.100	7678.988	.019	.236	.814
Dclmt4	1840.808	7714.342	.017	.239	.811
Dclmt5	2061.490	7800.169	.016	.264	.792
Dclmt6	735.620	7643.355	.009	.096	.923
Dclmt7	1835.628	8479.097	.007	.216	.829
Dclmt8	1292.708	7856.836	.009	.165	.869

a. Dependent Variable: spplbs

Table 6

Multiple Regression Results for Minnesota without constant

Model Summary

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate

1	.724[a]	.524	.521	26254.68711

Note. a. Predictors: SurveyYr, Dclmt1, Dclmt7, spphrs, Dclmt8, Dclmt5, Dlmb, Dclmt2, Dclmt4, Dsun, Dtrt, Dclmt3, Dwae, Dclmt6. b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

ANOVAc,d

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.895E12	14	1.354E11	196.411	.000[a]
	Residual	1.725E12	2502	6.893E8		
	Total	3.620E12	2516			

Note. a. Predictors: SurveyYr, Dclmt1, Dclmt7, spphrs, Dclmt8, Dclmt5, Dlmb, Dclmt2, Dclmt4, Dsun, Dtrt, Dclmt3, Dwae, Dclmt6. b. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin. c. Dependent Variable: spplbs d. Linear Regression through the Origin

Coefficients[a,b]

Model	Unstandardized Coefficients	Standardized Coefficients	t	Sig.

Model Summary

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.724[a]	.524	.521	26254.68711

Note. a. Predictors: SurveyYr, Dclmt1, Dclmt7, spphrs, Dclmt8, Dclmt5, Dlmb, Dclmt2, Dclmt4, Dsun, Dtrt, Dclmt3, Dwae, Dclmt6. b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

		B	Std. Error	Beta		
1	Dlmb	-9622.061	1792.309	-.096	-5.369	.000
	Dsun	-9499.157	1602.719	-.115	-5.927	.000
	Dtrt	-11002.064	1606.453	-.133	-6.849	.000
	Dwae	-12591.675	1607.220	-.155	-7.834	.000
	Dclmt1	791.186	9312.689	.002	.085	.932
	Dclmt2	12902.994	7701.154	.121	1.675	.094
	Dclmt3	2360.212	7649.352	.027	.309	.758
	Dclmt4	2510.283	7670.846	.025	.327	.744
	Dclmt5	2808.998	7746.616	.022	.363	.717
	Dclmt6	1392.505	7601.083	.022	.183	.855
	Dclmt7	2341.107	8456.281	.009	.277	.782
	Dclmt8	2118.763	7791.968	.015	.272	.786
	spphrs	.002	.000	.687	47.112	.000

Model Summary

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.724[a]	.524	.521	26254.68711

Note. a. Predictors: SurveyYr, Dclmt1, Dclmt7, spphrs, Dclmt8, Dclmt5, Dlmb, Dclmt2, Dclmt4, Dsun, Dtrt, Dclmt3, Dwae, Dclmt6. b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

	SurveyYr	3.851	3.821	.202	1.008	.314

Note. a. Dependent Variable: spplbs. b. Linear Regression through the Origin

Table 7

Mean Species Pounds and Species Pounds per Hour

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	6716	.00	977228.00	6864.6532	36598.84119
spplbsperspphr	3777	.00	.15	.0021	.00801
Valid N (listwise)	3777				

Table 8

Mean Pounds per Hour for Largemouth Bass

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbsperspphr	693	.00	.01	.0001	.00081
Valid N (listwise)	693				

Table 9

Mean Pounds per Hour for Sunfish

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbsperspphr	878	.00	.07	.0021	.00522
Valid N (listwise)	878				

Table 10

Mean Pounds per Hour for all Trout Species

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbsperspphr	603	.00	.00	.0000	.00017
Valid N (listwise)	603				

Table 11

Mean Pounds per Hour for Walleye

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbsperspphr	845	.00	.01	.0008	.00116
Valid N (listwise)	845				

Table 12

Mean Pounds Caught in Climate Region 1

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	190	.00	24733.00	1871.3453	3461.62685
Valid N (listwise)	190				

Table 13

Mean Pounds Caught in Climate Region 2

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	1115	.00	599760.00	14945.7165	54539.28063
Valid N (listwise)	1115				

Table 14

Mean Pounds Caught in Climate Region 3

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	1770	.00	172392.00	3475.2702	13759.72086
Valid N (listwise)	1770				

Table 15

Mean Pounds Caught in Climate Region 4

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	755	.00	55453.00	3450.9691	6905.07233
Valid N (listwise)	755				

Table 16

Mean Pounds Caught in Climate Region 5

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	475	.00	78995.80	2854.3945	7333.68505
Valid N (listwise)	475				

Table 17

Mean Pounds Caught in Climate Region 6

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	1966	.00	977228.00	9118.9576	51112.48791
Valid N (listwise)	1966				

Table 18

Mean Pounds Caught in Climate Region 7

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	60	.00	50903.00	1846.5000	7165.63713
Valid N (listwise)	60				

Table 19

Mean Pounds Caught in Climate Region 8

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation

spplbs	360	.00	43953.10	2583.6844	5822.30248
Valid N (listwise)	360				

Table 20

Multiple Regression Results for the Big Nine Walleye Lakes

Warnings

For models with dependent variable spplbs, the following variables are constants or have missing correlations: Dclmt1, Dclmt4, Dclmt5, Dclmt7, Dclmt8. They will be deleted from the analysis.

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	SurveyYr, Dwae, Dclmt6, Dsun, Dclmt2, Dlmb, Dtrt, spphrs[a]	.	Enter

Note. a. Tolerance = .000 limits reached. b. Dependent Variable: spplbs

Model Summary

Warnings

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.717[a]	.515	.502	67214.62708

Note. a. Predictors: (Constant), SurveyYr, Dwae, Dclmt6, Dsun, Dclmt2, Dlmb, Dtrt, spphrs

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.504E12	8	1.880E11	41.612	.000[a]
	Residual	1.419E12	314	4.518E9		
	Total	2.923E12	322			

Note. a. Predictors: (Constant), SurveyYr, Dwae, Dclmt6, Dsun, Dclmt2, Dlmb, Dtrt, spphrs
b. Dependent Variable: spplbs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	686999.307	1030333.251		.667	.505
	spphrs	.002	.000	.698	12.532	.000
	Dlmb	-59926.223	12016.593	-.247	-4.987	.000
	Dsun	-59151.036	12010.124	-.243	-4.925	.000

Warnings

Dtrt	-60128.090	12018.495	-.247	-5.003	.000
Dwae	-68975.559	13106.728	-.302	-5.263	.000
Dclmt2	23744.502	8148.802	.122	2.914	.004
Dclmt6	-9905.060	12785.822	-.035	-.775	.439
SurveyYr	-317.771	516.721	-.024	-.615	.539

Note. a. Dependent Variable: spplbs

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dclmt3	.[a]	.	.	.	.000

Note. a. Predictors in the Model: (Constant), SurveyYr, Dwae, Dclmt6, Dsun, Dclmt2, Dlmb, Dtrt, spphrs b. Dependent Variable: spplbs

Table 21

Multiple Regression Results for Red Lake

Warnings

For models with dependent variable spplbs, the following variables are constants or have missing correlations: Dclmt1, Dclmt2, Dclmt3, Dclmt4, Dclmt5, Dclmt6, Dclmt7, Dclmt8. They will be deleted from the analysis.

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	SurveyYr, Dwae, Dtrt, Dlmb, Dsun, spphrs[a]	.	Enter

Note. a. All requested variables entered.
b. Dependent Variable: spplbs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.961[a]	.924	.868	4244.85461

Note. a. Predictors: (Constant), SurveyYr, Dwae, Dtrt, Dlmb, Dsun, spphrs

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.761E9	6	2.935E8	16.290	.000[a]
	Residual	1.442E8	8	1.802E7		
	Total	1.905E9	14			

Note. a. Predictors: (Constant), SurveyYr, Dwae, Dtrt, Dlmb, Dsun, spphrs
b. Dependent Variable: spplbs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-188479.135	486204.386		-.388	.708
	Dlmb	-1671.553	3783.434	-.059	-.442	.670
	Dsun	-1671.553	3783.434	-.059	-.442	.670
	Dtrt	-1671.553	3783.434	-.059	-.442	.670
	Dwae	-3633.945	9565.123	-.129	-.380	.714
	spphrs	.003	.001	1.021	2.692	.027
	SurveyYr	94.901	243.076	.046	.390	.706

Note. a. Dependent Variable: spplbs

Table 22

Independent samples t-test for total angler hours between seasons on East Upper Red Lake

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
AngHrs	SU	7	118107.14	62610.324	23664.478
	WI	4	86893.50	89299.646	44649.823

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
AngHrs	Equal variances assumed	.732	.414	.686	9	.510	31213.643	45507.699	-71731.924	134159.209
	Equal variances not assumed			.618	4.735	.565	31213.643	50533.298	-100901.004	163328.290

Table 23

Independent samples t-test for total angler hours between seasons on the big 9 walleye lakes

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
AngHrs	SU	124	572679.73	486284.997	43669.682
	WI	50	912197.88	849624.529	120155.053

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
AngHrs	Equal variances assumed	41.571	.000	-3.311	172	.001	-339518.154	102553.626	-541943.851	-137092.458
	Equal variances not assumed			-2.656	62.366	.010	-339518.154	127844.741	-595046.284	-83990.025

Table 24

Independent samples t-test for total angler hours between seasons statewide

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
AngHrs	SU	867	1.110503E5	2.6666392E5	9.0563817E3
	WI	482	1.039292E5	3.8689016E5	1.7622364E4

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
AngHrs	Equal variances assumed	4.437	.035	.398	1347	.691	7.1211660E3	1.7891969E4	-2.7977987E4	4.2220319E4
	Equal variances not assumed			.359	739.955	.719	7.1211660E3	1.9813272E4	-3.1775757E4	4.6018089E4

Table 25

Mean rates of "species-sought" statewide

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Percent * Species	2899	100.0%	0	.0%	2899	100.0%

Report

Percent

Species	Mean	N	Std. Deviation
BAS	14.1000	2	2.96985
BLC	11.5327	237	13.41761
BLG	11.4778	209	12.19294
BLH	.5400	4	.78043
BNT	3.2000	1	.
CAP	2.4000	5	2.97069
CAT	1.1000	1	.
CCF	1.3667	3	1.19304
CRP	19.3122	271	21.29177
FRD	.4000	1	.
HSF	10.2600	5	11.95232

LAT	43.6750	4	46.64814
LKW	14.7000	3	.36056
LMB	13.5361	64	12.34311
MUE	8.0143	14	9.32225
NOP	14.5478	653	13.48272
NPS	4.6000	8	5.91439
OTS	1.0000	1	.
PAN	17.1221	208	17.37646
PMK	4.9455	11	9.11618
RBS	10.8000	1	.
RBT	20.6000	1	.
RKB	2.9509	35	3.10750
SMB	5.3653	30	5.73570
SUN	18.5226	292	17.10178
TLC	3.7000	2	1.83848
TRT	16.0543	7	28.48856
WAE	43.7395	613	28.66025
WHB	.5000	3	.26458
WHC	3.6000	1	.
WNP	2.3222	9	3.36518
WTS	.3000	1	.
YEP	7.5276	199	13.83888
Total	20.3447	2899	22.73019

Table 26

Creel Types

Crl_Type	CreelType	Desc_Crl_Type
1	STRATOM	Roving - Stratified Random
2	SYSMTIC	Systematic Sampling
3	AERIAL	Aerial Fishing Pressure
4	NONPROB	Access - Nonuniform Probability
5	UNKNOWN	Unknown Methodology
6	ACCESS	Access - No Probability
7	NETTING	Coregonid Netting Survey
8	VOLUN	Volunteer or Angler Diaries
9	TOURN	Fishing Tournament
10	MIXED	Mixed Methodology
11	HABEVAL	Habitat Evaluations
12	NONROV	Roving - Nonuniform Probability

Table 27

Frequency table of creel types

Crl_Type

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	2	.1	.1	.1
	1	2119	62.1	62.1	62.1
	2	364	10.7	10.7	72.8
	3	231	6.8	6.8	79.6
	4	205	6.0	6.0	85.6
	5	153	4.5	4.5	90.0

	6	136	4.0	4.0	94.0
	7	68	2.0	2.0	96.0
	8	49	1.4	1.4	97.5
	9	42	1.2	1.2	98.7
	10	41	1.2	1.2	99.9
	11	1	.0	.0	99.9
	12	3	.1	.1	100.0
	Total	3414	100.0	100.0	

Appendix B: Figures

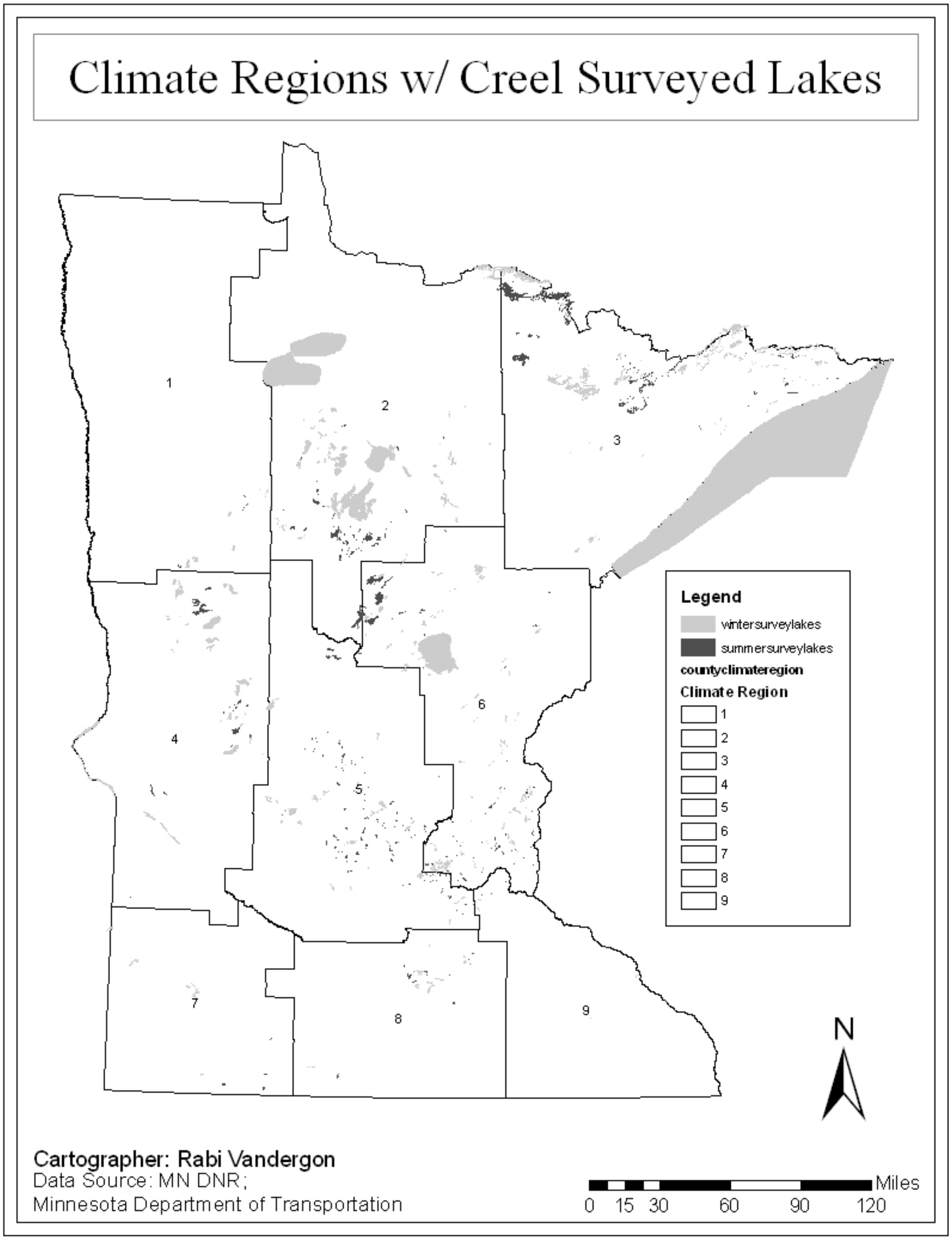


Figure 1. Climate Regions with Creel Surveyed Lakes

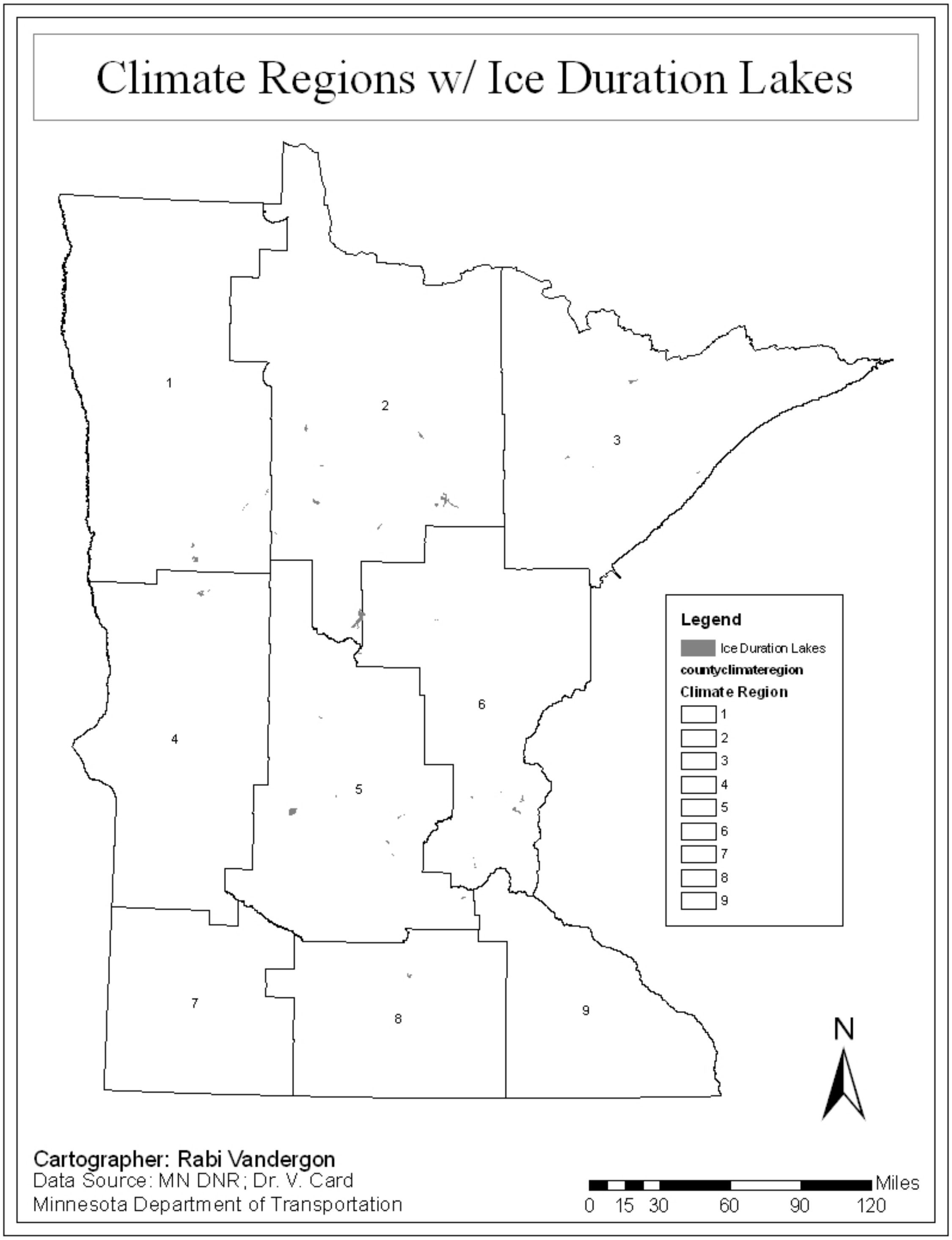


Figure 2. Climate Regions with Observed Ice Duration Lakes

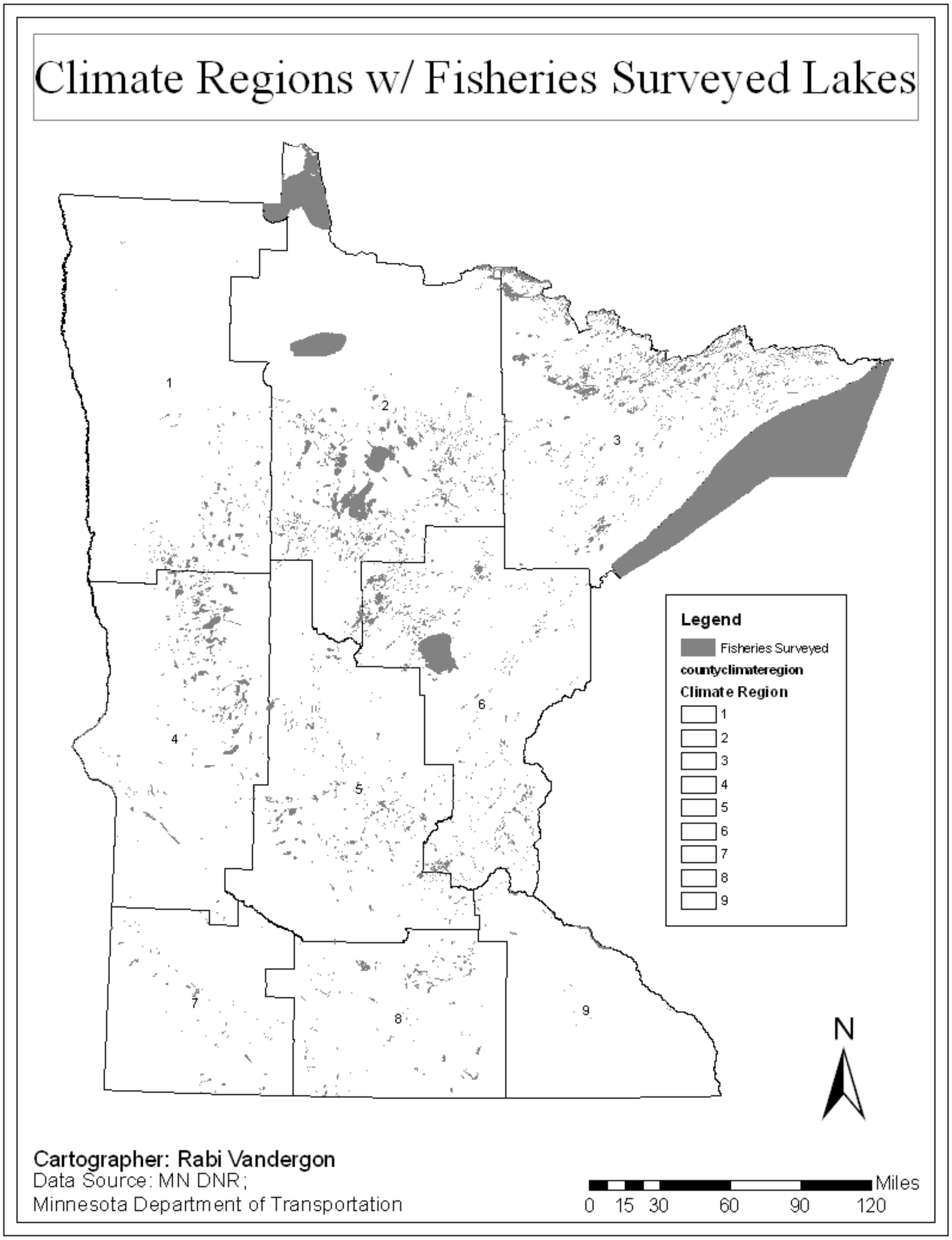


Figure 3. Climate Regions with Fisheries Surveyed Lakes

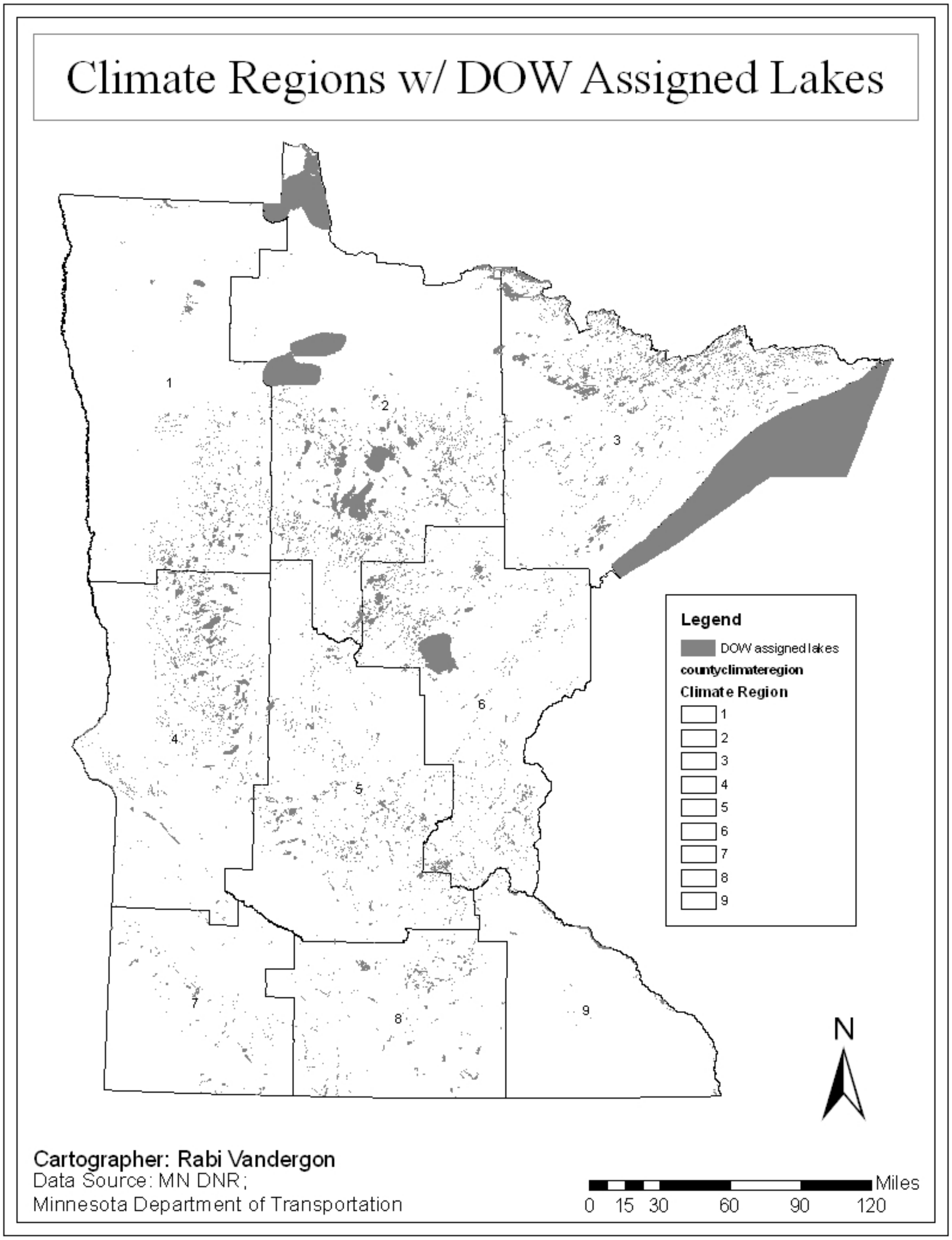


Figure 4. Climate Regions with Division of Waters (DOW) Identified Lakes

Annotated Literature Review of Economic Analysis of Water Impacts from Climate Change

Compiled by Rabi Vandergon
December 15th, 2008
For Dr. Patrick Welle and the LCCMR

Introduction: The following reference list is divided into two sections. The first covers literature related to economic modeling of climate change. The second section covers information about effects to water systems. The sources in each section are organized alphabetically. The annotations have a half-inch indent. The sources are not indented.

Economic Modeling Resources

Hope, C. (2003). “The Marginal Impacts of CO2, CH4 and SF6 Emissions.” Judge Institute of Management Research Paper No.2003/10, Cambridge, UK, University of Cambridge, Judge Institute of Management.

This source provides the primary economic model for the popular Stern Review published recently by the English treasury. Hope illustrates the PAGE2002 model, which uses a discount rate of 3% per year discounted back to the year 2000. The time span is over the next two centuries, from 2000 to 2200. First, this source shows how marginal impact is calculated. Next, CO2, CH4 and SF6 are analyzed for their marginal impacts in 2000 US dollars. The marginal impacts are said to justify the mitigation costs if they are below the damages.

The IPCC scenario A2 and B2 are mentioned, but A2 is specifically utilized. These scenarios show different emission levels with different rates of population growth and GDP changes.

The PAGE2002 model is an updated form from the 1995 model that analyzes several variables. First, it adds a third GHG, SF6. It also takes into special account the cooling effect from the properties of sulphate aerosols including backscattering and solar radiation and inhibiting cloud production. Third, the source examines thresholds and what the impact is when these are breached. Next, regional growth in GDP is measured. Fifth, adaptation levels are taken into account. The source also considers the amount of CO_2 that makes it into the atmosphere. Radiative forcing is another scientific variable considered by this source.

The PAGE2002 model lists that there are 6 different scenarios in the IPCC's TAR. As mentioned previously, only one scenario, A2 is utilized. This scenario assumes no intervention or control.

The discount rate criticism of the Stern Review cited in sources such as Nordhaus (2008) does not consistently match up with the data that is present. The Stern Review cites Hope as the main economic model used for its statements for mitigation. The Hope model uses a discount rate of 3%. Perhaps the difference in discount rate estimates is between Nicholas Stern's discount rate and Hope's discount rate.

The marginal damage calculated was based on findings from a 10% reduction of carbon dioxide. This was repeated at 20% to check for errors. It was found that NH_4 and SF_6 have factors of 21 and 40,000 times the impact of carbon dioxide. The source further lists drawbacks of projects versus the method of creating marginal impacts, which have economic and real world validity.

It was found that little change existed between the marginal impacts from the 1995 model and the 2000 model. For example, the cost per ton of carbon decreased from $21 to $19. This was found by updating the dollar values from 1995 to 2000. Also, the differences between these prices are discussed. For example, updated scientific information has concluded the decreased ability for oceans to remove carbon dioxide when the temperature is high.

Lastly, the source emphasizes that for future studies, more than one scenario should be utilized from the IPCC's TAR. This would improve the validity for marginal damage estimates and provide a more accurate picture of potential results (the proper marginal damage estimates will lead to proper policy related to mitigation).

Mendelsohn, Robert O. (2006). "Is there a case for aggressive, near-term mitigation of greenhouse gasses? A Critique of the Stern Report." Regulation, Winter 2006-2007.

This article critically examines the Stern Report's methodologies on several main points and proves to be an informative tool for understanding the reasoning behind the suggestion toward high level mitigation procedures in the near-term. The source identifies and questions the fact that the Stern Report concludes an initial rapid mitigation at a high cost will be lowered in the future due to increases in technology. The reasoning behind this conclusion and the underlying methodologies are highly scrutinized by this economist.

The report lists several factors explaining why the Stern Report estimates climate change will be more costly. First, the demographic assumptions are reviewed. This includes information on the population growth rate and the per capita income. Second, the discount rate is examined. The low discount rate in the report is scrutinized, because it is based on an ethical responsibility to future generations saying that they are equally important to those alive currently. For example, the rate is extended until 2200, saying this time period is equal, giving a 1.4% discount rate. Third, the report is criticized for assuming no adaptation to the problems incurred from climate change such as building dams. It is suggested that the costs of climate change could be overestimated with no adaptation. Fourth, the paper points out that extreme weather is cited to incur damages even though the IPCC points to uncertainty in this conclusion. Fifth, the non-market damages of climate change in the report are criticized to be too high of a proportion of GDP and quotes the 5% statistic in 2200 to be very high, projecting to be $23 trillion per year. Sixth, the report's inclusion of knock-on damages or cascade costs of climate change such as decreased investments could potentially go in an opposite direction according to the report. For example, Mendelsohn points out if warming turns out to be less severe, mitigation costs could cause knock-on costs similar to those implied to occur from climate change. Seventh, the risk premium used by the Stern Report is criticized as being possibly unnecessary. Eight, the review's use of equal weight to damages to poor people, through the use of equity, is questioned for its logic.

The paper criticizes that if these above assumptions were not followed, there would be a possible overestimation of the costs of each ton of CO2, expressed as a percentage of income. The overestimation is compared to the author's own estimation, which lowers the 5% cost of income in the Stern Review to .1% of GDP. This assumes only small changes in extreme events and markets through 2100.

Furthermore, the paper scrutinizes mitigation strategies for their feasibility. The Stern Report makes assumptions of the assumed static nature of systems such as no increases in land use crops.

Lastly, the marginal damage theory is discussed for its strength. The paper indicates that this method implies that each extra ton of CO2 would essentially cost nothing, since it would not impact the goal of 550 ppm concentration of CO2. The method of marginal logic is questioned along with the basis for the selection of 550 ppm as a concentration level.

Nordhaus, W.D and J.G. Boyer (2000). "Warming the World: the Economics of the Greenhouse Effect." Cambridge, MA: MIT Press.

This source is specifically cited in the Stern Review as a key source for illustrating the economic estimates for global impacts from increased carbon dioxide. The information in this source was specifically examined for its analysis on non-market impacts from rising carbon dioxide. It first illustrates the gap of empirical evidence in this sector. Time use is emphasized as a key impact area in non-market sectors. In addition, the impacts on human health, settlements and ecosystems are also evaluated.

These authors outline three studies of non-market activities. They touch on a study by Nordhaus that covers University of Michigan surveys of non-market time in 1975 and 1981. These analyzed climate sensitive activities involving people's use of time and found that less than 5% were climate sensitive. The other study considered is Robinson and Godbey (1997) that explores outdoor leisure as a major nonmarket sector. They indicate that surveyed Americans in 1985 spent nearly 39 free hours a week, of which 2.2 hours were climate sensitive activities. At least 2% of .77 hours were spent specifically doing outdoor recreation. They conclude that out of 235 million participants, only 2.5 million participate in activities negatively affected by a warming climate such as skiing and hockey. Other activities are said to benefit due to the increased temperatures.

A study by Nordhaus (1998c) is also analyzed. An intensive study of time use for 100 people in different regions of the country (US) was analyzed. It was found that time gained by warm weather activities such as camping would outweigh time lost by cold weather activities such as skiing. There appears to be a lack of similar studies. Technological changes are ignored since the determinants of time are physiological. Different regional effects were calculated by multiplying time by average wage, which should be equal to share in GDP. Assuming there are 1500 hours per worker and no income elasticity, they conclude that a warmer climate may see negative effects, where cold and temperate climates may see positive effects (however, this source discounts the value of wintertime activities as being equal to summer. Summer and winter activities may both be considered essential in an outdoors person's point of view).

Nordhaus, William (2008). "A Question of Balance: Weighing the Options on Global Warming Policies." New Haven, Yale University Press.

This source explains a detailed model of methods and an estimate of the costs related to global climate change. A focus was paid specifically on the book's critical review of the Stern Review. It outlines that the Stern Review was written as a policy tool that was not peer reviewed, and has a low reproducibility. It explains in detail the problem with the Stern Review's use of a low discount rate (about .1). It gives the argument that indicates intergenerational equity is like carrying a baton in a race. To give future generations an improper discount rate would be to drop the baton in a race. This is the ethical argument spelled out by the Stern Review. However, Nordhaus points out that modern practices in the economy do not practically reflect this line of reasoning. He further illustrates that reducing spending now would increase savings to the benefit of future generations, making them richer. This previous argument points out the logic behind the conventional model (argued against in the Stern Review, which says immediate mitigation is necessary) that indicates a ramp up on policy. A policy ramp would include slow, then fast mitigation when it is cost effective. Nordhaus further relates consumption to discount rates and discusses their significance. In addition, he analyzes consumption elasticity versus the time discount rate.

Nordhaus is critical of the Stern Review and the main study it cites for an economic model (seen in this annotated collection):

> "It is virtually impossible for those outside the modeling group to understand the detailed results of the Stern Review. It would involve studying the economics and geophysics in several chapters, taking apart a complex analysis (the PAGE

> [Policy Analysis of the Greenhouse Effect] model), and examining the derivation and implications of each of the economic and scientific judgments. Understanding the analysis is made even more difficult because the detailed calculations behind the Stern Review have not been made available."

Nordhaus further criticizes the Stern Review by comparing it against his personal model, DICE, with three different runs: zero discount, zero discount and different consumption elasticity, and optimal policy from DICE 2007. This impacts savings and returns rates, which are claimed to be unrealistically modeled previously.

He touts a similar analysis by Hope (PAGE), that changing discount to .1 raises a carbon cost from $43 to $364 per ton of carbon. He reports that similar findings were found in the DICE model. Therefore, the discount rate appears to be the major weakness of the Stern Review.

Stern, Nicholas (2006). "Chapter 5: Costs of Climate Change in Developed Countries." *Stern Review on the Economics of Climate Change*. London, UK: Her Majesty's Treasury. Available online < http://www.hm-treasury.gov.uk/sternreview_index.htm>.

This source leads up to the next chapter's description of modeling by laying out variables to be considered. It covers a range of agricultural impacts. The source discusses heating costs and overheating deaths. It touches on extreme weather patterns and past impacts on GDP such as hurricane Katrina. Insurance premiums are covered, and the domino effect into other financial sectors and non-market sectors are discussed. Overall, this source examines different ideas of impacts to social welfare by analyzing individual variables.

Stern, Nicholas (2006). "Chapter 6: Economic modeling of climate change impacts." *Stern Review on the Economics of Climate Change*. London, UK: Her Majesty's Treasury. Available online < http://www.hm-treasury.gov.uk/sternreview_index.htm>.

This document provides a detailed description of a few main aspects regarding the estimates of the global cost of global climate change. First of all, assumptions are made regarding climate change. It is assumed that a business as usual approach will exist in respect to the discharges of greenhouse gasses such as carbon dioxide. Second, the model lists detailed factors that may be included in an impact assessment model (IAM) and provides examples of different models. Third, the sources of current climate projection information are revealed as predictors of temperature increases. Fourth, a final assessment is made regarding how global GDP affects global consumption, which in turn, impacts social welfare.

The model lists factors that are predictors in previously published IAMs. These IAMs report a spectrum of varying economic impacts from very little significant change to drops in GDP that are quite large in respect to changes in global climate. Three of these models are explained below.

First, the Mendelsohn model uses strictly market values of agriculture, forestry, energy, water and coastal zones to conclude that there would be no significant impact from climate change. Second, the Tol model extends the determinant factors to include market and non-market values. This model curiously shows an initial increase of GDP from the first initial sign of warming and then an overall decrease of GDP from an increased amount of warming. Third, the Nordhaus model also uses market and non-market impacts, but also takes into account “large-scale changes” such as El Nino and changes in monsoon patterns. Changing determinant factors such as market and non-market values and including catastrophic changes drastically changes the IAMs.

The Stern Review model is based on the predictions published in the IPCC *Third Assessment Report*. This report provides the baseline, conservative estimate of a 3.0-5.3 degree Celsius change in temperature by the year 2100. The baseline information is then extended to a high climate scenario (of which sources are cited in Chapter 1 of the Stern Review). This scenario includes the instance of the decreased ability for natural sources to act as carbon sinks and increased feedback loops such as methane releases from the thawing of permafrost. Using a range of conservative and extended methods, a spectrum of effects is created.

Next, a mathematical equation ensues. An estimated baseline GDP growth is run against global climate change factors, which results in percentage losses of GDP. These percentage losses are based off the PAGE2002 IAM published by Hope (2003). 1000 runs of global GDP from 2001 to 2200 are calculated. Each of these runs is then divided into GDP per capita and by a constant population growth rate. Each run is then divided by global consumption per capita (population scenario), which is estimated to be the savings rate of 20%. Consumption is then transferred into utility, which is further transformed into social welfare. In summary, two main factors impact the variation of the IAMs in respect to global climate change. The first is the utilization of market and non-market forces. Second is the decision to use baseline climate change data or to use extended scenarios such as those including feedback loops.

Tol, Richard S.J. (2001). Estimates of the Damage Costs of Climate Change. *Environmental and Resource Economics* 21: 135-160.

This article cited in the *Stern Review* aims to use economic modeling to monetize the impacts of global climate change worldwide. The author divides the world into separate regions, North America being separate, each with their own qualities and variations in responses to the impacts of climate change. Next, different categories are indicated that may be economically affected by the alteration of climate. First, agriculture is examined for changes in crop yield combined with the influence of trade. Second, forestry is analyzed. It is cited that forestry has a linear relationship with climate change and that forestry will grow at the same rate as agriculture. Third, water resources are examined. The equation developed is used for the purpose of solving the water resources impact alone and cannot be extrapolated, because it relies on a single source for its variables. The variables include the region, income, temperature and time. Fourth, energy consumption is reviewed. The article looks at several variables including the income elasticity for heating and cooling energy, to understand the demand for these sectors in response to factors such as improved energy efficiency. Fifth, sea level rise is examined, but since it does not pertain to a study on Minnesota economics, it will not be analyzed further. Sixth, ecosystems are examined with a willingness to pay approach valuing these systems with a "warm glow" attitude toward their existence. Seventh, vector borne diseases are discussed. These produced no economic impact in North America. Lastly, heat and cold stress were examined with their effects on the health of human beings. The mortality from these stresses, as in all previous estimates, is displayed in terms of losses in GDP.

Tol, Richard S.J. (2005). "The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties." *Energy Policy* 33: 2064-2074.

This is an incredible source that can serve as a jumping point in many tangents for the subjects relating to the economics of mitigating climate change. The issue of weighing abatement costs versus the damage is laid out as one of the major determinants for the necessity of analysis. The source examines 27 independent studies with 94 estimates and creates a new model based on these assumptions. The reference list is very extensive and thorough.

In its analysis, the study points out major argument points of the literature. First, it covers the weaknesses of incomplete market information and climate variability. Next, it examines adaptation estimates, which depends on mitigation goals such as the business as usual (BAU) approach (which the Stern Review assumes). Third, it takes into account that adaptation may reduce costs of climate change. For example, a malaria vaccine would lower damage costs in the vector-born disease category.

This study analyzes the impacts from a doubling of carbon dioxide in the published literature. Each source is scrutinized for its validity and credibility of methods. For example, it was found that high estimates have a high vulnerability and a low discount rate. This has been argued from an ethical standpoint to be just (and is utilized in the Stern Review). It says that there is a moral obligation to protect future generations as much as those in the present. The counter argument is that in practice, current discount rates do not reflect this line of reasoning. The discount rate accounted for a large portion of variability between sources.

Each of the 27 studies was analyzed for its estimates of the marginal damage costs in terms of the price per ton of carbon dioxide. Each study was given equal weight, except those using independent models. Five criteria were used in the analysis asking if the study was peer-reviewed, based on an independent impact assessment, based on a dynamic climate change scenario, based on economic scenarios, and if it estimates the marginal costs.

Analysis of Damages to Water Resources

Alexander et al (2005). Global observed changes in daily climate extremes of temperature and precipitation. Retrieved July 3, 2008 from Global Extreme Indices. Web site: http://secamlocal.ex.ac.uk/people/staff/dbs202/publications/2005/Alexander.pdf.

This study shows an upward overall trend in global precipitation. It illustrates that the greater capacity for warm air to hold higher amounts of precipitation causes more numerous extreme precipitation events.

Bernstein et al (2007). Climate Change 2007: Synthesis Report. Retrieved July 3, 2008 from Intergovernmental Panel on Climate Change. Web site: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

This illustrates the science behind warming in areas and cooling in others.

Dadaser-Celik, Filiz and Heinz G. Stefan (December 2007). "Lake Level Response to Climate in Minnesota." University of Minnesota St. Anthony Falls Laboratory. Project Report Number 502. Prepared for Legislative Citizens Committee on Minnesota Resources: St. Paul, MN.

This source concerns the historical analyses of 25 Minnesota lakes. It involves a study to determine a correlation between climate variables and lake levels. Some of the lake level data reaches back to 1906. It was found that a majority of the lakes have seen increases in lake levels. Some of the greatest increases have occurred since 1990. A moderate correlation was found between precipitation and annual water levels. A weak correlation was found between air temperatures, dew point and lake water levels. A strong correlation was found between mean water levels in lakes in the same climate region, which suggests climatic influences on water levels. Conversely, a low correlation was found between mean water levels between all of the lakes studied (in different climate regions). This study shows that overall, there is an increase in water levels in the state of Minnesota, and that it could increase in the future.

Dadaser-Celik, Filiz and Heinz G. Stefan (March 2008). "Lake Evaporation Response to Climate in Minnesota." University of Minnesota St. Anthony Falls Laboratory. Project Report Number 506 Prepared for Legislative Citizens Committee on Minnesota Resources: St. Paul, MN.

This source analyzes the precipitation and evaporation rates for 6 Minnesota stations during the open water seasons. It finds that 3 stations report an upward trend in evaporation and

3 report a downward trend. Overall, a positive trend in evaporation was found for the last 12 months. The evaporation rates had a decreasing trend at 5 stations in the last 20 years. Besides evaporation, precipitation rates were found to be increasing at four out of six stations. Precipitation minus evaporation equals water availability. It was found that there was an increasing level of water availability, with a significant increase in the past 40 years. There was no reported correlation found between the three separate variables mentioned above. This study explains the findings of the work done in these author's analyses of 25 Minnesota lakes mentioned above.

D.P. Lettenmaier, D. Major, L. Poff, and S. Running. "Chapter 4; Water Resources." The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity. The U.S. Climate Change Science Program, pp. 121-150. Available online <http://www.usgcrp.gov/usgcrp/default.php>.

The parent material and website of this source has further resources dealing with the current relationship between water and climate change.

This source examines the near term impacts of global climate change on water resources in the United States for the next 25 to 50 years. This piece of literature mainly examines variables including streamflow, evaporation, drought, precipitation, runoff and water quality. Minor focus areas include land use and ground water impacts. The sources of these studies are well cited, creating a positive waypoint for further research.

In the analysis of streamflow, trends from 393 stations in the US were plotted on maps and discussed with statistically significant increases reported in the central portion of the United States, which includes source stations in Minnesota (figure 4.7).

Evaporation rates are examined through several sources and the net decrease in these rates are discussed using varying hypotheses. For example, pan evaporation techniques are examined against theories such as the decreased amount of evaporation due to increased cloud cover.

Droughts are also discussed to occur more frequently in the West and Southwest and an overall wetter climate is discussed as occurring from studying data from 1915 to 2003. Droughts are not projected to affect the central portion of the United States.

An in-depth regional analysis is conducted for the central portion of the US, which includes Minnesota. Two separate studies have indicated an overall increase in precipitation in this region. However, studies examining Great Plains states to the near south of Minnesota show a reversal of this upward trend.

Runoff rates are explored by reporting USGS statistics on runoff for trends from 1901 to 1970. These are projected into the future, suggesting an overall increase in the central US. Runoff is further examined by region. The central portion of the US is likely to see an increase in runoff in the Upper Mississippi basin. However, there is conflicting information regarding the increase or decrease of water levels in the great lakes.

Water quality is also examined. Variables such as eutrophication from increased nutrient loads and increased temperature are discussed. Nutrient loading may occur from increased runoff and more highly variable heavy precipitation events. Decreased consistent precipitation could cause eutrophication from the increased levels of nutrients without adequate consistent flows. Also, nutrients create the conditions for algal growth. The existence of algae will lower the amount of dissolved oxygen due to consumption when photosynthesis is not occurring. The reported past changes in water quality have not been attributed to climate change. Land use is also discussed as a major determinant of water quality. A MN study is cited referring to high rates of chloride and phosphorous in urban and agricultural area waters respectively. These differing land use practices can impact runoff rates.

Additional variables are discussed besides surface water such as groundwater impacts, growing season impacts (which would positively impact tree growth), the increased amount of wildfires from increases in droughts in the South and Southwest, and increases in insects and disease from less harsh winters.

Lastly, this source examines observational methods from streamflow gauges, snow weight measurement techniques, evapotransporation methods and soil moisture characteristics. The source questions the outcomes of many of these models as climate change induced or from decadal or longer-term variability.

Groisman et al. (2001). Heavy precipitation and high stream flow in the contiguous United States: Trends in the twentieth century. Bulletin of the American Meteorological Society, 82, 219-246.

This study indicates that the Midwest is a region that is experiencing some of the highest increases of 1-day extreme precipitation events.

Karl et al. (1998). Secular trends of precipitation amount, frequency, and intensity in the United States. Bulletin of the American Meteorological Society, 79, 231-241.

Since 1990, a 10% overall increase in precipitation has occurred.

Klatter, H.E.; Vrouwenvelder, A.C.W.M.; van Noortwijk, J.M. (2006). Societal aspects of bridge management and safety in the Netherlands. In Proceedings of the Third International Conference on Bridge Maintenance, Safety and Management (IABMAS), Porto, Portugal, 16-19 July 2006. London: Taylor & Francis Group.

Bridge analyses by these Dutch researchers indicate that bridges and other infrastructure generally have a 50 to 100 year lifetime on average. If original functionality is preserved, bridges and structures may have extended lifetimes and would only retire when original use is no longer viable. These structures do degrade over time, as shown by in-depth maintenance analyses. Variables of degradation can include intensified use and the age of structures.

Maintenance is usually cost effective if it is only a small fraction of construction cost (0.66% in the case of the Dutch). Maintenance types can include “inspections, replacements, perfect repairs and lifetime extensions (also called partial repairs).” A bridge must be repaired when the probability of failure increases to an unacceptable level.

Although damages will occur worldwide, with the most damage in developing countries, the economic impacts of climate change will be specifically examined in the state of Minnesota. The direct lifecycle costs of a bridge include “construction, maintenance, and demolition.” Society and the environment also incur indirect costs. These may occur through time delays and environmental pollution (externalities). Maintenance costs can include costs such as coating steel with a protective layer. This application can have additional expenditures such as the necessity of using environmental barriers to prevent the spread of coating chemicals into the environment.

Maintenance costs include corrective and preventative costs. These may create direct costs such as the paying for the time of the workers. These may also create external costs such as the increased amount of time spent driving during detours.

Although intensified use and age are listed as important degrading mechanisms, Klatter et al. tout weather and environmental damage to be the most important variables for a bridge needing replacement. For example, chloride existing in the water can cause the corrosion of concrete bridges. In addition, steel can also be corroded by other environmental factors.

Construction, maintenance, deconstruction and external costs have been discussed above. Other costs associated with bridge damage include the price of paying inspectors to monitor bridges and structures to assess their integrity.

Kunkel, K, et al. (2003). Temporal variations of extreme precipitation events in the United States: 1895-2000. Geophysical Research Letters, 30, 1900.

Some of the data in this study show that the current increases in precipitation may be attributed to natural variations. Utilized National Weather Service Cooperative Observer Network (COOP) and NOAA performed analysis on precipitation events over the last 107 years. Data was compiled from the 1800s and digitized. Separate events were all analyzed in the study including 1,5, 10, and 30 day events at periods of 1.5, and 20 years. It was found that “extreme precipitation” events occurred in high frequency in the late 19th and early 20th century. Since greenhouse gases were not as prevalent at the turn of the century, the existence of a possible natural variability in extreme precipitation events is likely. However, data from 1895-1910 appeared odd and was subjected to manual interpretation and the information with the most irregular data was removed. This anomaly could have affected the final results regarding the frequency of the extreme precipitation events of this time period. Therefore, the irregularity of data could have created a discrepancy in the reliability of the conclusion that natural variation can explain the peaks in extreme precipitation events. The study is still being analyzed by researchers even after the information was published.

Panagoulia, D, & Dimou, G. (1997). Sensitivity of flood events to global climate change. Journal of Hydrology, 191, 208-222.

High volumes of water can destroy structures such as roads, bridges and levees.

Pielke, Jr., R.A., M.W. Downton, and J.Z. Bernard Miller (2002). Flood Damage in the United States, 1926-2000: A Reanalysis of National Weather Service Estimates. Retrieved July 3, 2008 from Environmental and Societal Impacts Group National Center for Atmospheric Research. Web site: http://www.flooddamagedata.org/flooddamagedata.pdf.

This source estimates the monetized damage estimates from National Weather Service records. This information is aggregated from separate datasets. Information from local regions was added to statewide data in some cases. Damage information spans from 1925 to 2000. However, the source indicates it is not to be used as a policy tool, due to inaccuracies. The inaccuracies are clearly spelled out in the abstract. Despite the flaws, the document contains useful estimate information to generate ideas. For example, flooding in Minnesota cost over $900 million in 1993 and $700 million in 1997.

Shuya, Abe, Watanabe Yasuharu, and Suzuki Yuichi (2005). Analysis of Flood Damage to Bridges on Saru River from Typhoon Etau. Monthly Report of Civil Engineering Research Institute, 631, 2-9.

Accumulation of debris may cause bridge pilings to wash out, and can lead to significant damages of these structures.

U.S. Army Corp of Engineers. (2003). U.S. Army Corp of Engineers Annual Flood Damage Reduction Report to Congress for Fiscal Year 2003. Retrieved July 3, 2008 from U.S. Army Corp of Engineers. Web site: http://www.usace.army.mil/cw/cecwe/flood2003/2003_Flood_Damage_Report.pdf.

This source provides information regarding flood reduction projects and spending by the USACE. Information presented includes average totals of money spent nation-wide for the last ten years, money spent by each state over the last ten years, flood damages incurred by each state over the last 10 years and lives lost. For example, Minnesota spent a relatively low amount on flood reduction (compared to the national rising average) of $54 million between 1994 and 2003. In addition, in Minnesota over $131 million in damages were also indicated for the fiscal years of 1994 to 2003. The document compares the potential damages (avoided by mitigation) to the actual damages in a well-laid out graph. Oceanic storm damage and lives lost on average from flooding are also included in the summary. The source has very useful graphs and the damages are clearly laid out in a table format, both of which can be found in the appendix.

Full Report of Climatic Analyses for
LCCMR 2005 *Impacts on Minnesota's aquatic resources from climate change Phase I - W-12*, Result 2: Historic Climate Data

Prepared by Richard Skaggs and Kenneth Blumenfeld

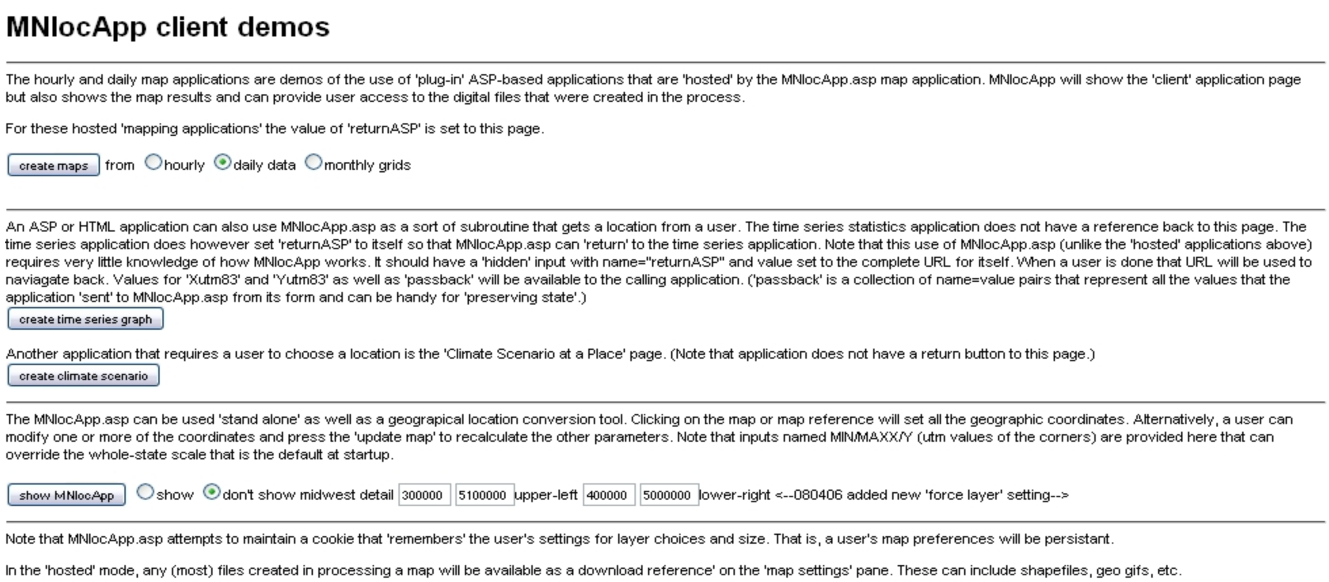
Introduction

This report summarizes three major accomplishments and undertakings during our investigation of Minnesota's historical climate record: 1) the development of a comprehensive, online, climate data retrieval tool; 2) the creation of data sets that summarize the temperature and precipitation characteristics over nine divisions within the state and over a wide variety of pre-defined "seasons"; and 3) the identification of persistent climatic episodes or regimes believed to be of particular relevance to Minnesota's aquatic resources. This report expands upon the abstract and project summary provided in the Result 2 Final Report.

Online Climatic Data Retrieval Tool

The climate data retrieval tool, developed by the State Climatology Office, was essential to all climatic research undertaken in this project, because relating climate data to aquatic ecosystems and hydrology is a complex undertaking: different species have different critical and optimal climate conditions that vary geographically and through time, and the hydrologic implications of climate vary with the local topography. Thus, climate summaries must be tailored to the specific questions and locations of interest. The climate data retrieval tool has enabled project participants to extract climate variables important to their own specific questions, at time and space scales they deem relevant.

The climate data retrieval tool has three major components—a mapping tool, a climate scenario visualizer, and a climate time-series generator. Each of these can be accessed from a common page, shown as the first three buttons in Figure 1, below.



MNlocApp client demos

The hourly and daily map applications are demos of the use of 'plug-in' ASP-based applications that are 'hosted' by the MNlocApp.asp map application. MNlocApp will show the 'client' application page but also shows the map results and can provide user access to the digital files that were created in the process.

For these hosted 'mapping applications' the value of 'returnASP' is set to this page.

create maps from hourly daily data monthly grids

An ASP or HTML application can also use MNlocApp.asp as a sort of subroutine that gets a location from a user. The time series statistics application does not have a reference back to this page. The time series application does however set 'returnASP' to itself so that MNlocApp.asp can 'return' to the time series application. Note that this use of MNlocApp.asp (unlike the 'hosted' applications above) requires very little knowledge of how MNlocApp works. It should have a 'hidden' input with name="returnASP" and value set to the complete URL for itself. When a user is done that URL will be used to naviagate back. Values for 'Xutm83' and 'Yutm83' as well as 'passback' will be available to the calling application. ('passback' is a collection of name=value pairs that represent all the values that the application 'sent' to MNlocApp.asp from its form and can be handy for 'preserving state'.)

create time series graph

Another application that requires a user to choose a location is the 'Climate Scenario at a Place' page. (Note that application does not have a return button to this page.)

create climate scenario

The MNlocApp.asp can be used 'stand alone' as well as a geograpical location conversion tool. Clicking on the map or map reference will set all the geographic coordinates. Alternatively, a user can modify one or more of the coordinates and press the 'update map' to recalculate the other parameters. Note that inputs named MIN/MAXX/Y (utm values of the corners) are provided here that can override the whole-state scale that is the default at startup.

show MNlocApp show don't show midwest detail 300000 5100000 upper-left 400000 5000000 lower-right <--080406 added new 'force layer' setting-->

Note that MNlocApp.asp attempts to maintain a cookie that 'remembers' the user's settings for layer choices and size. That is, a user's map preferences will be persistant.

In the 'hosted' mode, any (most) files created in processing a map will be available as a download reference' on the 'map settings' pane. These can include shapefiles, geo gifs, etc.

Figure 1. The "launch" or home page of the climate data retrieval tool.

The mapping component allows the user to select a time period of interest, and then map a climate variable of interest in a number of ways. Variables available are:

- maximum temperature
- minimum temperature
- average temperature
- precipitation amount (rain, melted snow etc.)
- snowfall amount
- snow cover (snow depth)

These variables can be mapped as the total or average, as the percentile rank, or as the departure from the "normal." Data can be viewed in the native monthly form, or aggregated into user-defined "seasons," such as November through March, or the "water year" of October through September. For example, Figure 2 below shows the percentile rank of total precipitation during the May-October period of 1993, when conditions were abnormally wet, especially in the southern half of Minnesota.

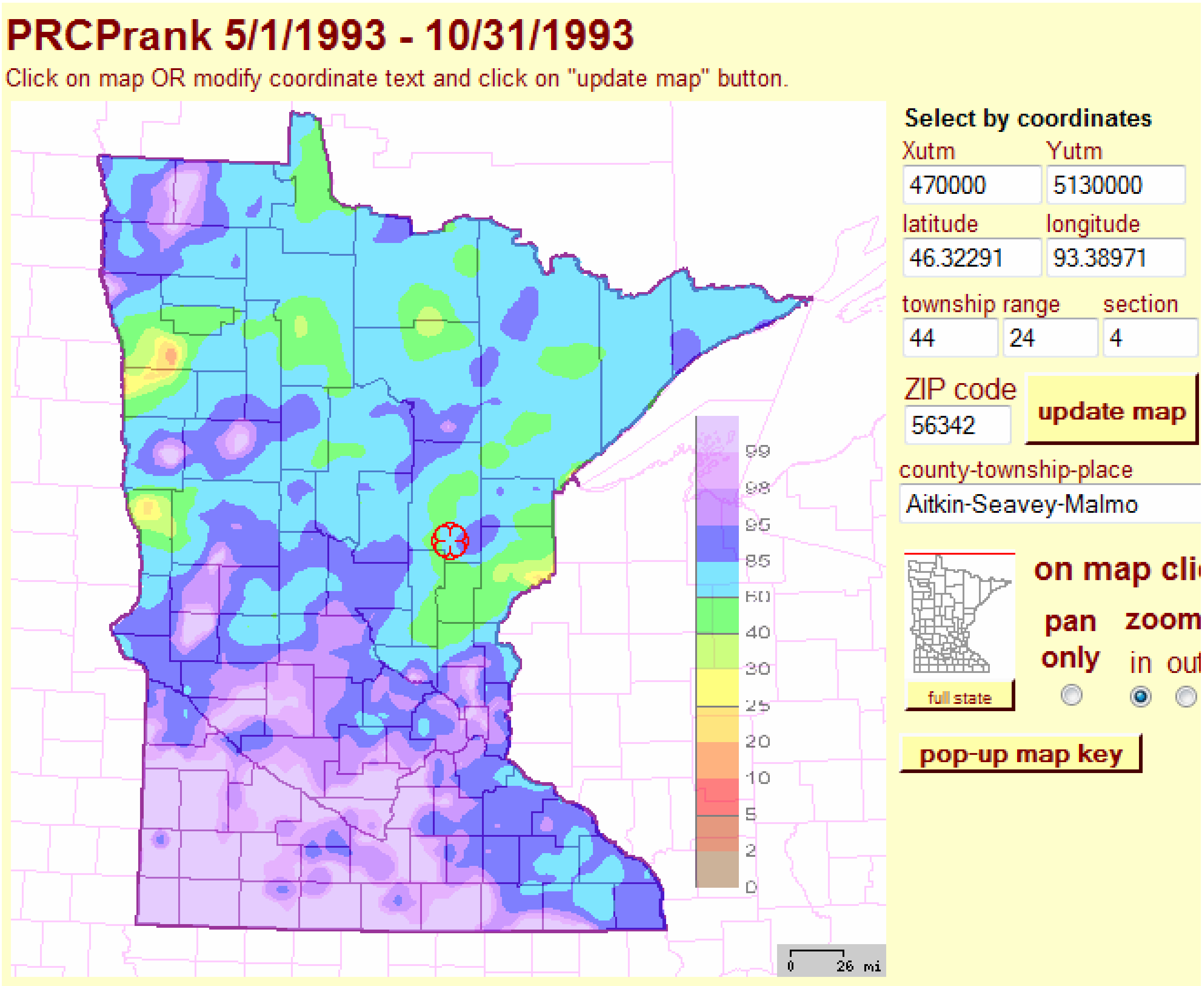


Figure 2. Percentile rank of total precipitation, May-October 1993; high values correspond to abnormally wet conditions.

The time-series generator extracts climate time series data for point locations in the state. The location is specified by the user, and the data can be summarized in many different ways. Once again, a user-defined season can be specified, along with the starting and ending years if the entire record is not wanted. For example, the number of days with an average temperature at or above freezing, per November-March "winter" for Grand Rapids, during the period 1900-2008 is shown in Figure 3, below.

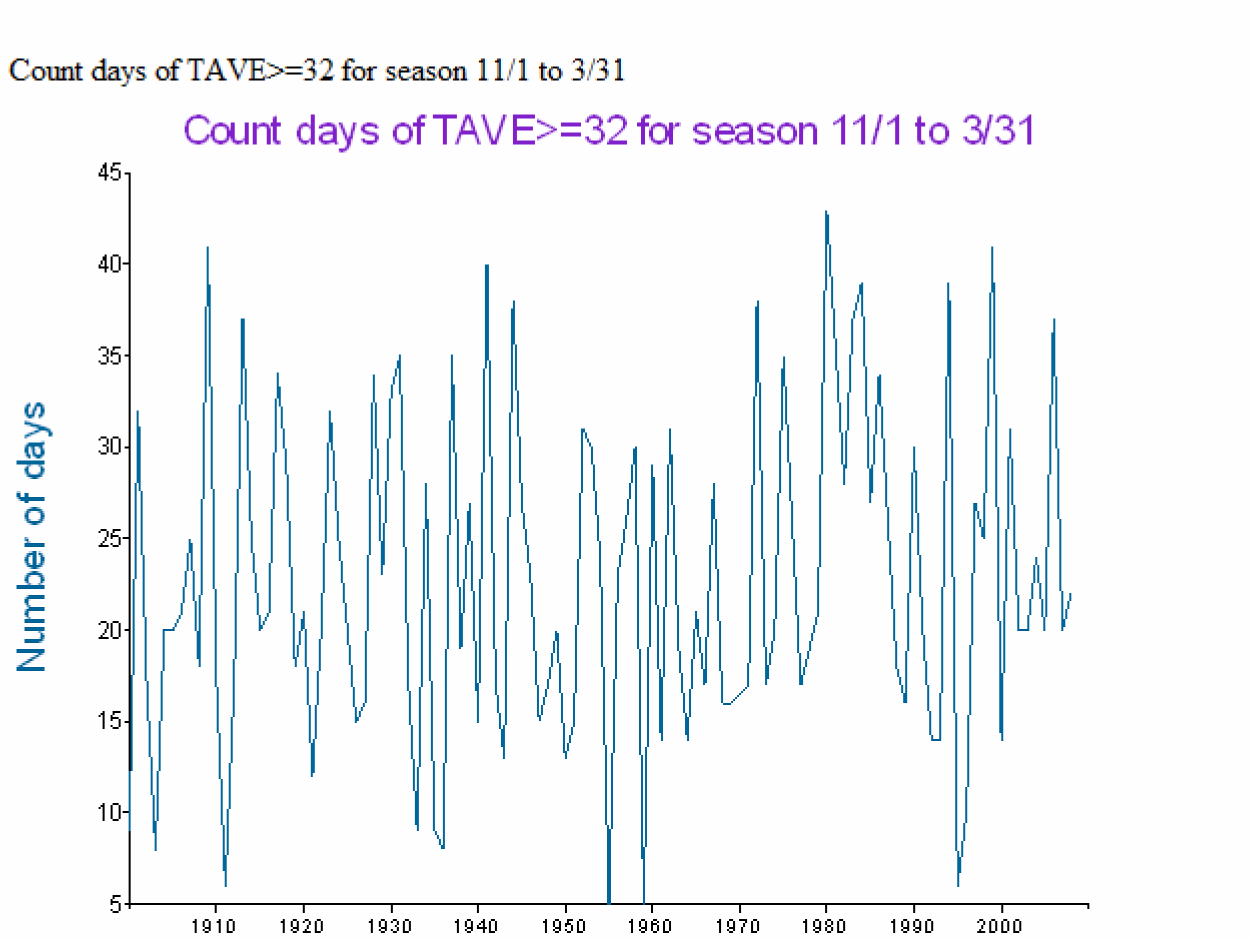


Figure 3. Time series of days per November-March "winter" season in which the average temperature equaled or exceeded 32 degrees F at Grand Rapids, for the period 1900-2008.

The climate scenario visualizer uses monthly climate data and allows researchers to examine two climate variables of interest simultaneously, over an area or spatial unit of the investigator's choosing. Potential spatial units include:

- The entire state
- Nine climatological divisions
- Any of the 85 counties
- Any of 83 river basins
- Any of 37 major and minor ecoregions
- Any lakeshed with Division of Waters lake number
- Any point in the state

For any of these spatial units, the user may then select pairs of climate data variables (the same climate variables mentioned above). For the spatial unit and month or season selected, the visualizer ranks the climate variables from lowest to highest and plots them on a graph. This allows to the investigator to determine which years match some important combination of the two climate variables for a particular location or area. For example, the investigator can isolate the fifteen jointly warmest and driest May through September periods over the Cottonwood River basin, as is shown in Figure 4.

Edit one or more of the numerical rank values - on your next click or keypress *outside the text box* the selection rectangle will be updated.

var	low rank	val	dep	high rank	val	dep
PRCP inches May-Sep ave 16.935	0.000	8.490	-8.445	0.297	14.330	-2.605
TAVE °F May-Sep ave 65.479	0.677	66.236	0.757	1.000	69.830	4.351

All years:

```
Year,var1,V1rank,var2,V2rank
1891,  12.840,0.1217,  64.238,0.2000
1892,  23.700,0.9478,  61.634,0.0174
1893,  10.830,0.0435,  64.700,0.3304
```

Floating your cursor over any of the plotted values will give the [year,var1,var2] for that point (precision needed for the small 'not selected' points.)

Selected years:

```
1894    8.560   68.314
1922    8.980   67.282
1931    9.980   69.194
1932   13.830   67.018
```

The above list gives contains [year,var1,var2] values coresponding to the light selection rectangle.

OR - (then) while pressing the *shift key* drag anywhere on the select bo
lower right corner.

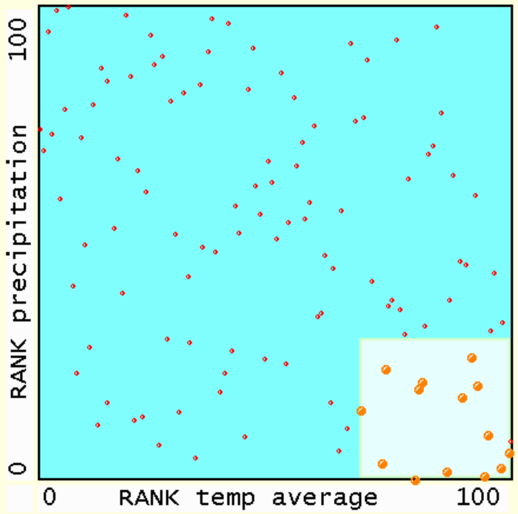


Figure 4. The climate visualizing tool shown in the lower right, with the fifteen warmest and driest May through September periods in the Cottonwood River Basin highlighted. The scrollable box in the lower left shows the corresponding year, total precipitation in inches, and average temperature (F). The highlighted area in the visualizing tool can be moved and/or resized, resulting in different values displayed in the scrollable box.

Climate Data Sets

For each of the nine climatic divisions (see Figure 5), we have 116 years of monthly temperature and precipitation data (1891-2006). For each climatic division we have created data sets summarizing the temperature and precipitation characteristics of the following seasons or periods, as recommended by our LCCMR project partners working in other scientific fields:

- Meteorological Summer (June through August)
- Aquatic Growing Season (May through October)
- “Winter” (November through March)
- Water Year (October through September)

For each season (or period) and division, we have calculated the long-term averages of temperature and precipitation, and have calculated z-scores (or standard scores) for individual years in each division’s time series of temperatures and precipitation. The z-score for a given value x is simply $\frac{x-\mu}{\sigma}$, where μ is the mean and σ is the standard deviation. Thus, the z-score gives the number of standard deviations a given observation is from the mean. Using z-scores on un-transformed data assumes the data are normally distributed, which they are in this case.

Figure 5. Minnesota’s nine climatic divisions. These divisions will be referred to by their location within the state--e.g., “northwest” or “NW”—rather than by number.

This project was particularly concerned with "climatologically significant" periods, i.e., those believed by participants in this LCCMR project to exert an impact on freshwater resources. In general, that means periods of abnormal warmth, coolness, dryness, or wetness; obviously the impacts of these different climatic states on water resources will vary with the time of year, among other factors. In any case, we have identified periods nominally described as *warmer*, *cooler*, *wetter*, or *drier*, by finding seasons that are greater than one standard deviation from the mean for either temperature or precipitation. In normal distributions, approximately 17% of the values will have $z \geq 1$, and 17% will have $z \leq -1$. Thus, for each division, we are interested in seasons that are either the warmest 17%, the coolest 17%, the wettest 17% or the driest 17% (with some combinations of wet/cool, warm/dry etc.).

After consulting with our partners on this project, we agreed to further stratify data to identify periods that were *very* warm, wet, cool, or dry, and *extremely* warm, wet, cool, or dry. For the very and extreme categories, we selected thresholds of +/- 1.5 and +/- 2 standard deviations, respectively. In other words, these categories were defined by z-scores of 1.5, -1.5, 2, and -2. Any given season, therefore, can be described in terms of its temperature, and its precipitation characteristics. For instance, the summer of 2002 in northwest Minnesota had normal temperatures (z-score of 0.34) and was extremely wet (z-score of 2.8). Statistical analyses can be performed using either the raw z-scores, or the categorical variables.

For every division and the four seasons and periods described above, we have provided data sets containing the raw temperature and precipitation values, the respective z-scores, and the descriptive categorizations of those z-scores. We provided these data sets to the LCCMR project members via an online wiki page, and have included the data sets in Appendix 1 of this document. All of the data were extracted using the online data retrieval tool described earlier. That tool will also enable users to select different periods (for example, just June and July, or December through February), and different spatial units, such as watersheds. We provided the data at the climatic division level for simplicity, with the understanding that other project participants were using the online tool to generate their own data sets to be used in conjunction with, or independently of, those that we provided.

Climatic Regimes (Episodes)

We have explored each of the data sets we created, looking for patterns in how temperature and precipitation characteristics combine to define “episodes” or “regimes” of climate. For instance, how frequently has a given division during a given season been simultaneously warm and wet? How common are warm and wet summers in northeastern Minnesota? To explore these questions, we created scatterplots of the temperature z-scores versus the precipitation z-scores, and plotted them in a way that ignores “normal-normal” years and that emphasizes years that are non-normal for temperature and/or precipitation. These scatterplots can be interpreted in accordance with the table given below.

Temp ≥1 z, Prec. ≤ -1 z **WARM, DRY**	Temp ≥1 z, -1z < Prec < 1z **WARM, NORMAL**	Temp ≥1 z, Prec ≥ 1 z **WARM, WET**
-1z < Temp < 1z, Prec. ≤ 1z **NORMAL, DRY**	-1z < Temp < 1z, -1z < Prec < 1z **NORMAL, NORMAL**	1z < Temp< 1z, Prec ≥ 1 z **NORMAL, WET**
Temp ≤ 1 z, Prec. ≤ -1 z **COOL, DRY**	Temp ≤ 1 z,-1z < Prec < 1z **COOL, NORMAL**	Temp ≤ 1 z, Prec ≥ 1 z **COOL, WET**

Here, as an example, we will look at meteorological summer, June through August (JJA), for climate divisions 1 and 9: the northwest and southeast, respectively. These are shown in Figures 6 and 7, below. Though the graphs are not identical, they both contain similar patterns (again, the years that are “normal-normal” have been omitted). In both cases, cool, dry summers are extremely rare. Dry summers are likely to be normal or warm, and cool summers most frequently normal for precipitation. Also, warm, wet summers are quite rare. Warm summers tend to be dry or normal, and wet summers tend to have normal, or even cool temperatures. These patterns were consistent throughout the state, for summers, aquatic growing seasons, and for water years. During winter periods, no clear relationships emerged, but also, the differences in the total quantity of water between “wet” and “dry” winters was much smaller than for summers.

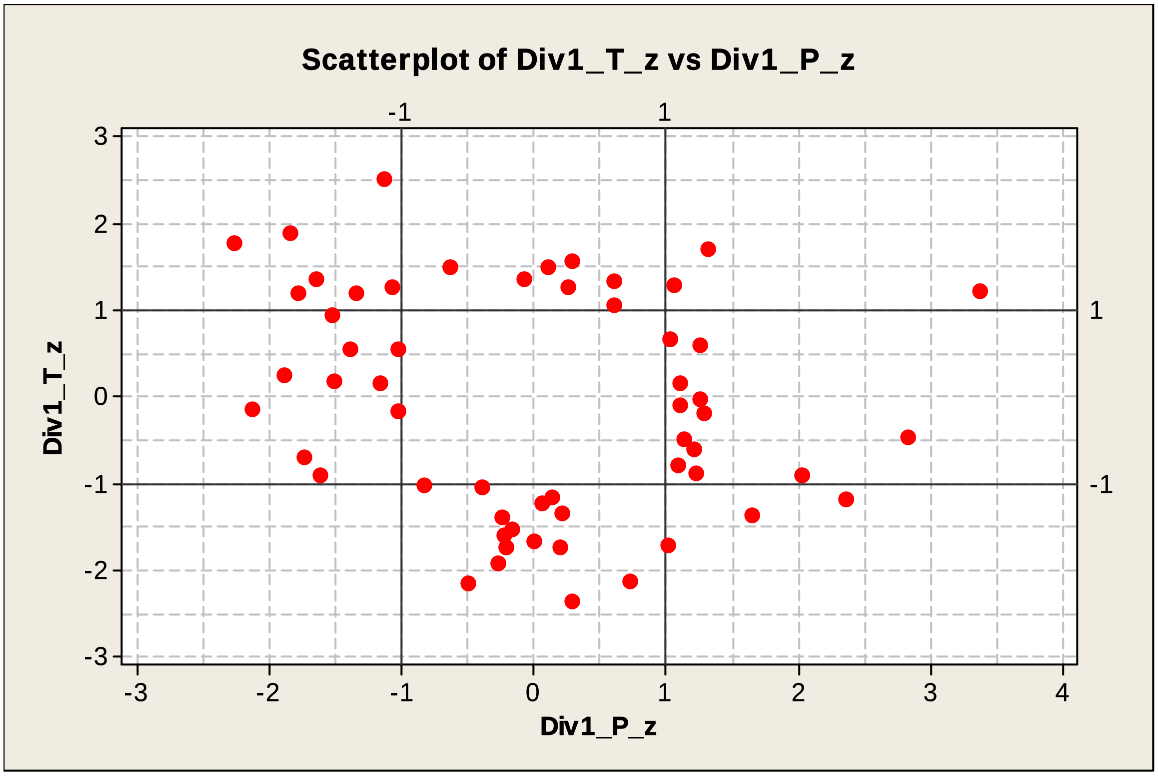


Figure 6. Scatterplot of temperature z-scores versus precipitation z-scores, for summer in northwestern Minnesota, with all seasons that were "normal" in both categories removed. Temperature increases with height on the graph, and precipitation increases from left to right.

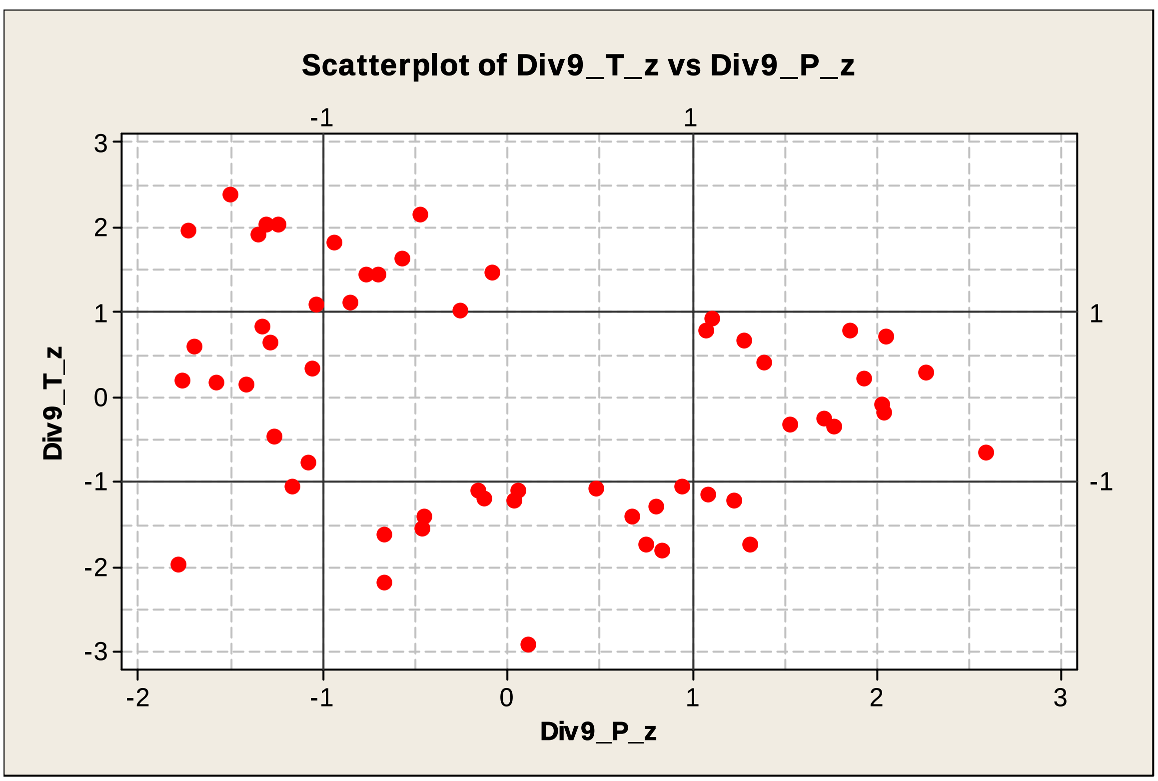


Figure 7. Same as Figure 6, except for southeast Minnesota

A problem with using the scatterplot approach is that it becomes difficult to see how patterns of "cool and wet," for example, persist through time. One way to reveal any extended periods of generalized departures from the average is to decompose the data into "signal" and "noise". There are a variety of methods to attempt the decomposition. Here we choose to use Exploratory Data Analysis (EDA) smoothing. This approach relies on repeated application of moving or running medians of differing lengths. The median is used because it eliminates exceptionally large or small observed data without being substantially affected. In contrast, moving or running averages, another very popular smoothing method, are greatly affected by large "outliers", both positive and negative. A common and effective EDA smoother is the 4253H smoother. The data are successively smoothed by moving medians of lengths of 4 then 2 then 5 and then 3. This filter eliminates outliers while maintaining data centered on the observation times. The process is then finished (polished) by applying a three term moving average with weights of .25, .5, and .25 (Hanning).

Climatological divisions at the four corners of the state (NW, NE, SW, SE) were selected for this analysis. Two seasons are analyzed: June through August (traditional summer) and May through October (recommended by the biologists cooperating on the project). For each division and season the average temperature and total precipitation observed data were standardized, i.e., converted to z-scores by subtracting the mean and dividing by the standard deviation. The time series of z-scores were then smoothed with the 4253H smoother. The resulting smoothed time series are shown in Figures 8 through 15, two diagrams for each of the four divisions. In the graphs, the time series of the smoothed temperature z-scores and smoothed precipitation z-scores are plotted as a function of year from 1891 through 2006. Positive z-scores indicated positive departures from the long term mean and negative z-scores mean the converse.

The first thing to note is all divisions have differences between the smoothed z-scores of the summer season and the May through October season. This implies at least some intraseasonal variability. In other words, a pattern of temperature and/or precipitation departures in a season tend to persist but there are month to month fluctuations that occasionally are substantial. In the SE division, there are differences between the summer and the May through October season. The differences are strongest in the precipitation departures. In the early part of the record (1899 through 1910 approximately) the positive precipitation departures are much more pronounced in the May through October season. This implies that the early and late parts of the growing season were wetter. Conversely, the negative precipitation departures during the May through October season during the late 1940s and 1950s are not matched during the summer season. In the SW division, the early century positive precipitation departures are quite similar between the summer and the May through October period. But the negative temperature departures are stronger and extend for a long period in the May through October season. The NW division has notable reversals of the sign of precipitation departures between the summer and the May through October seasons. Between about 1940 and 1970 there are small positive precipitation departures in the summer but sometimes substantial negative precipitation departures in the May through October season. The NW division has, in common with the SE and NE divisions, stronger positive precipitation departures in the early part of the 20th century.

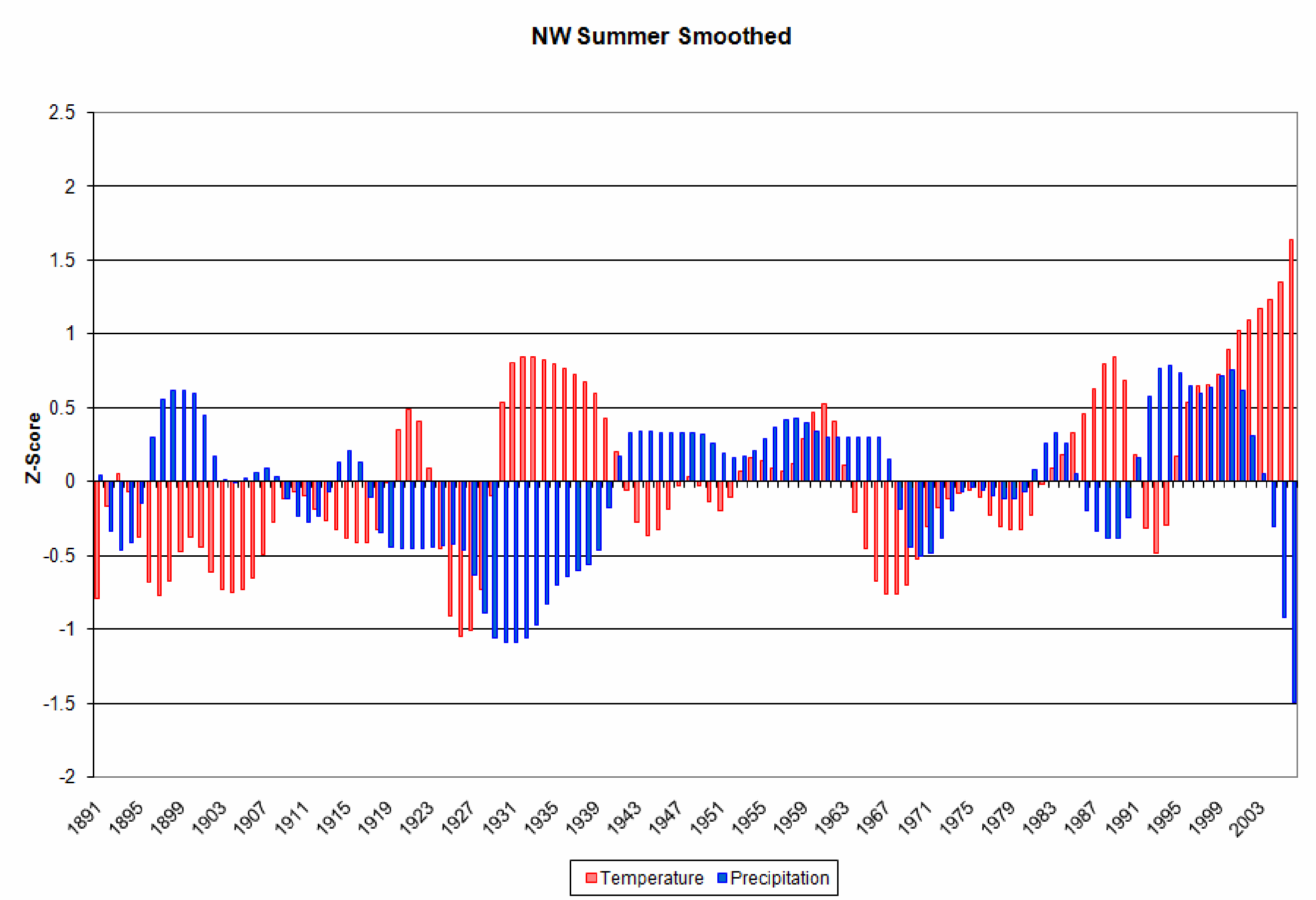


Figure 8. Smoothed z-scores for temperature (red) and precipitation (blue) during summer in northwest Minnesota.

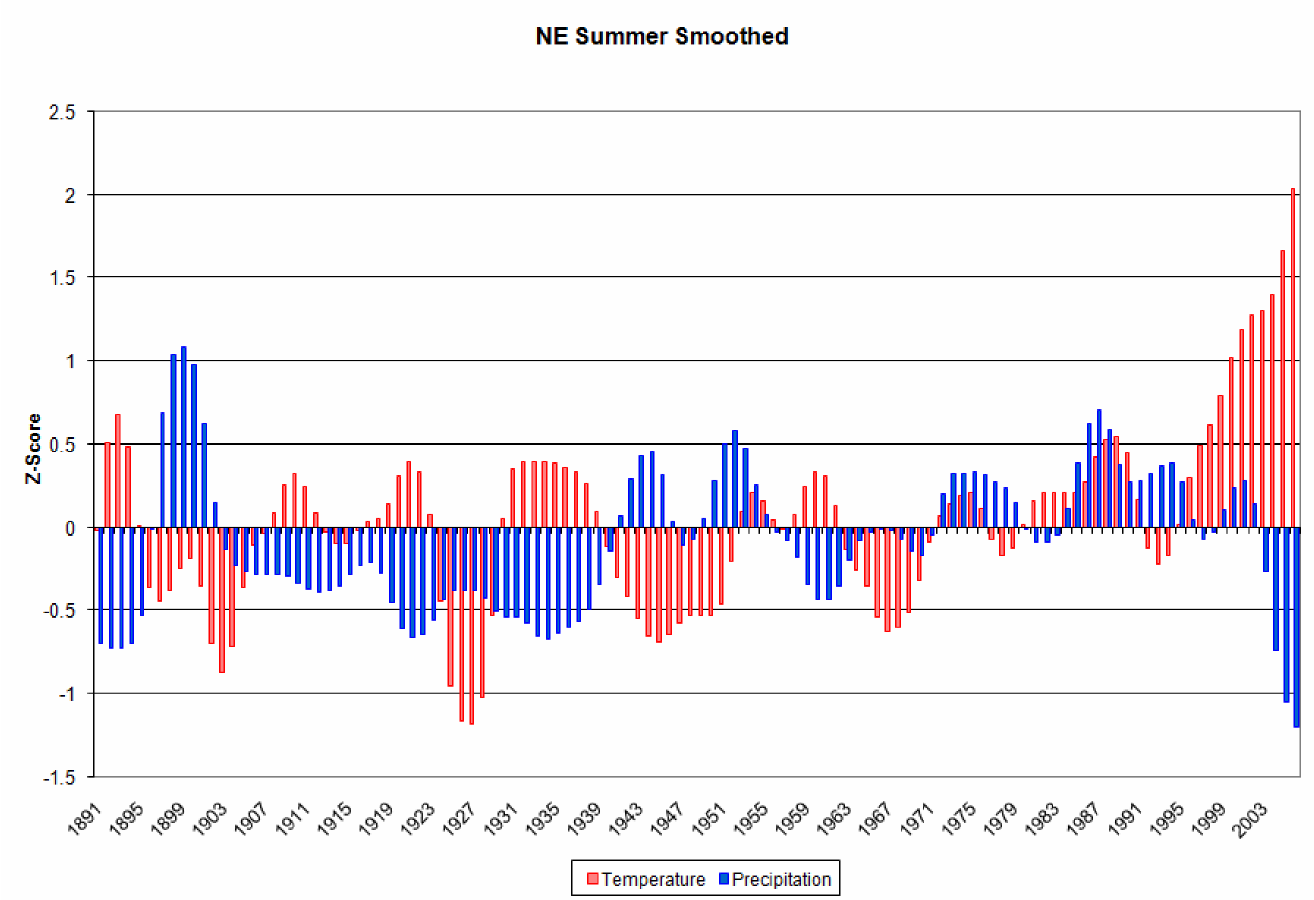


Figure 9. Same as above, except for the northeast.

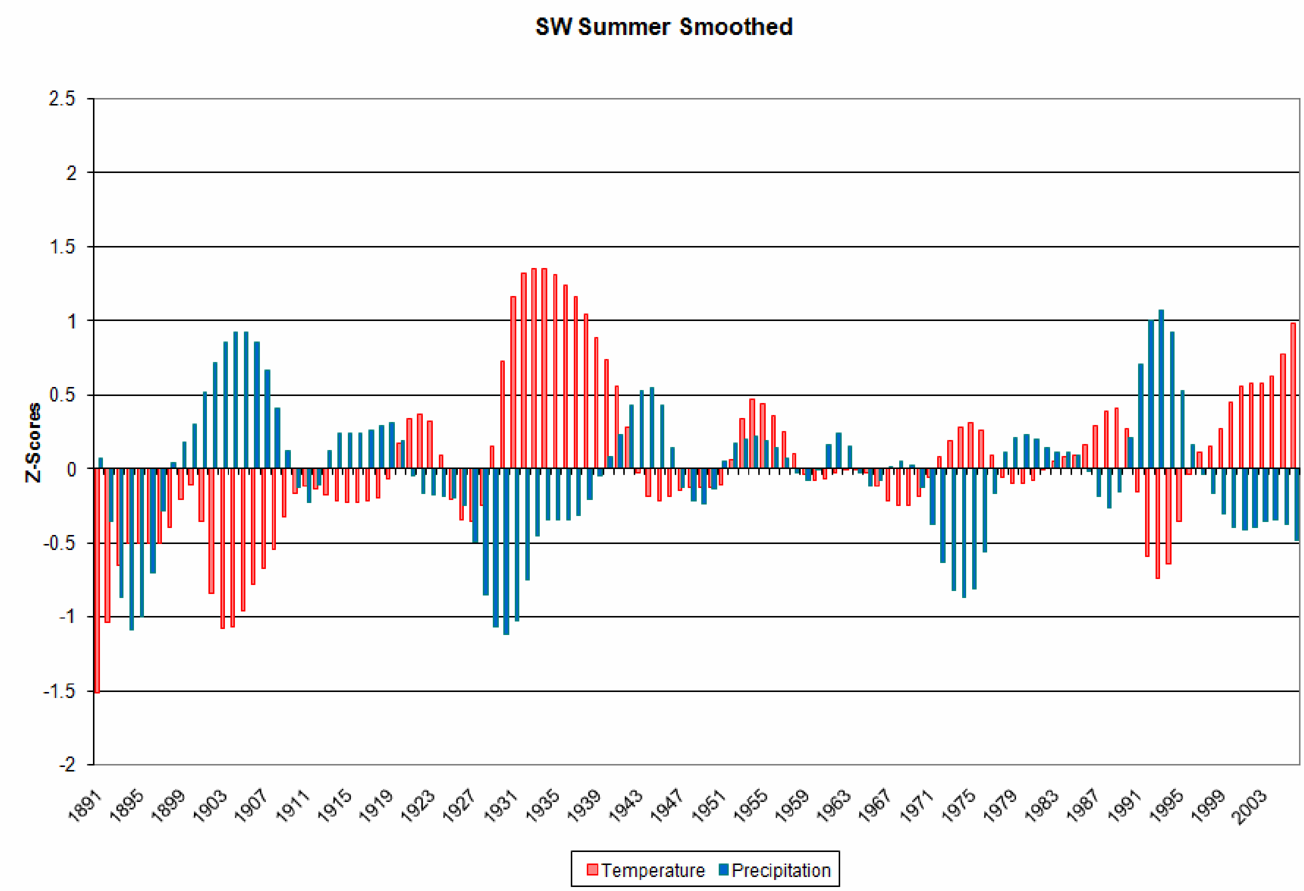


Figure 10. Same as above, except for the southwest.

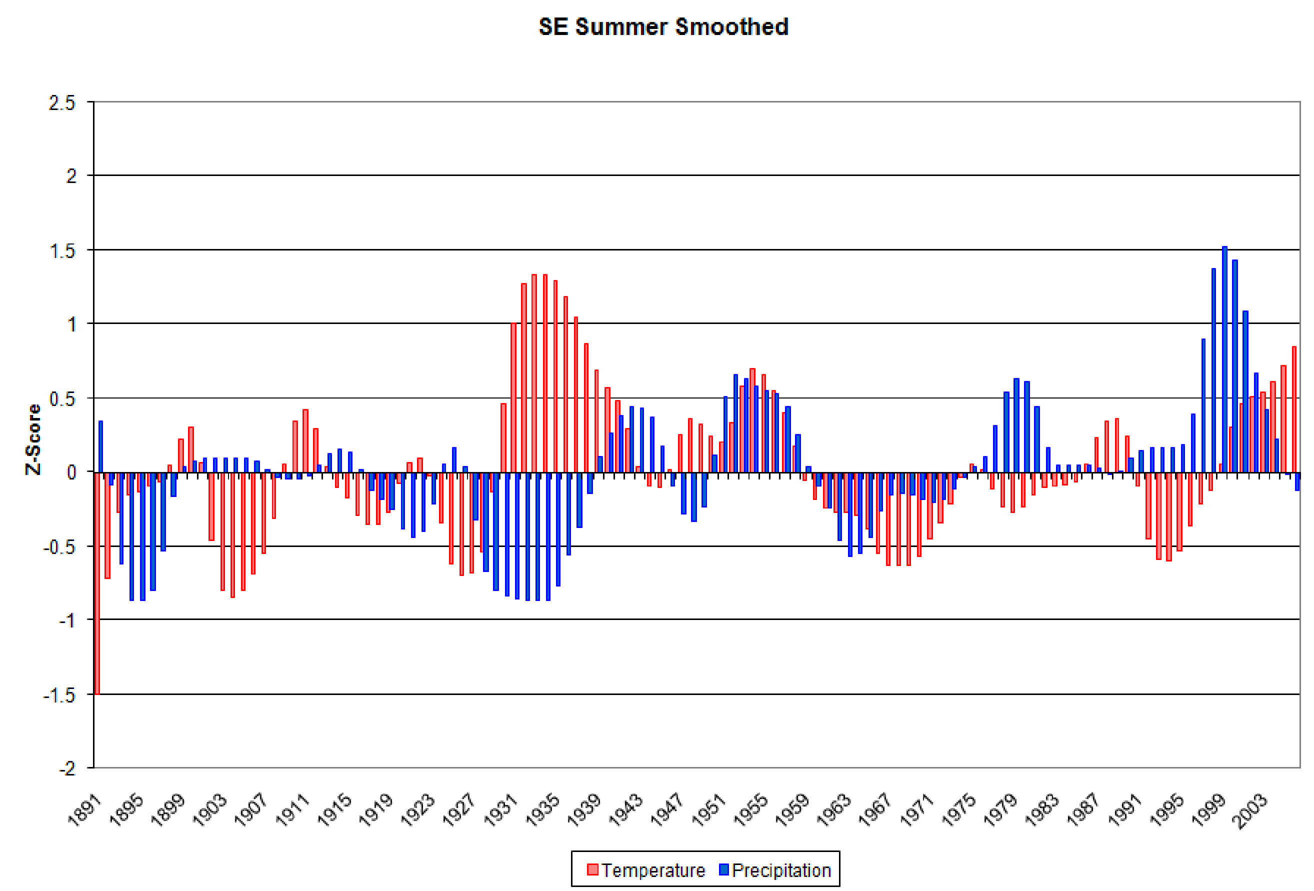


Figure 11. Same as above, except for the southeast.

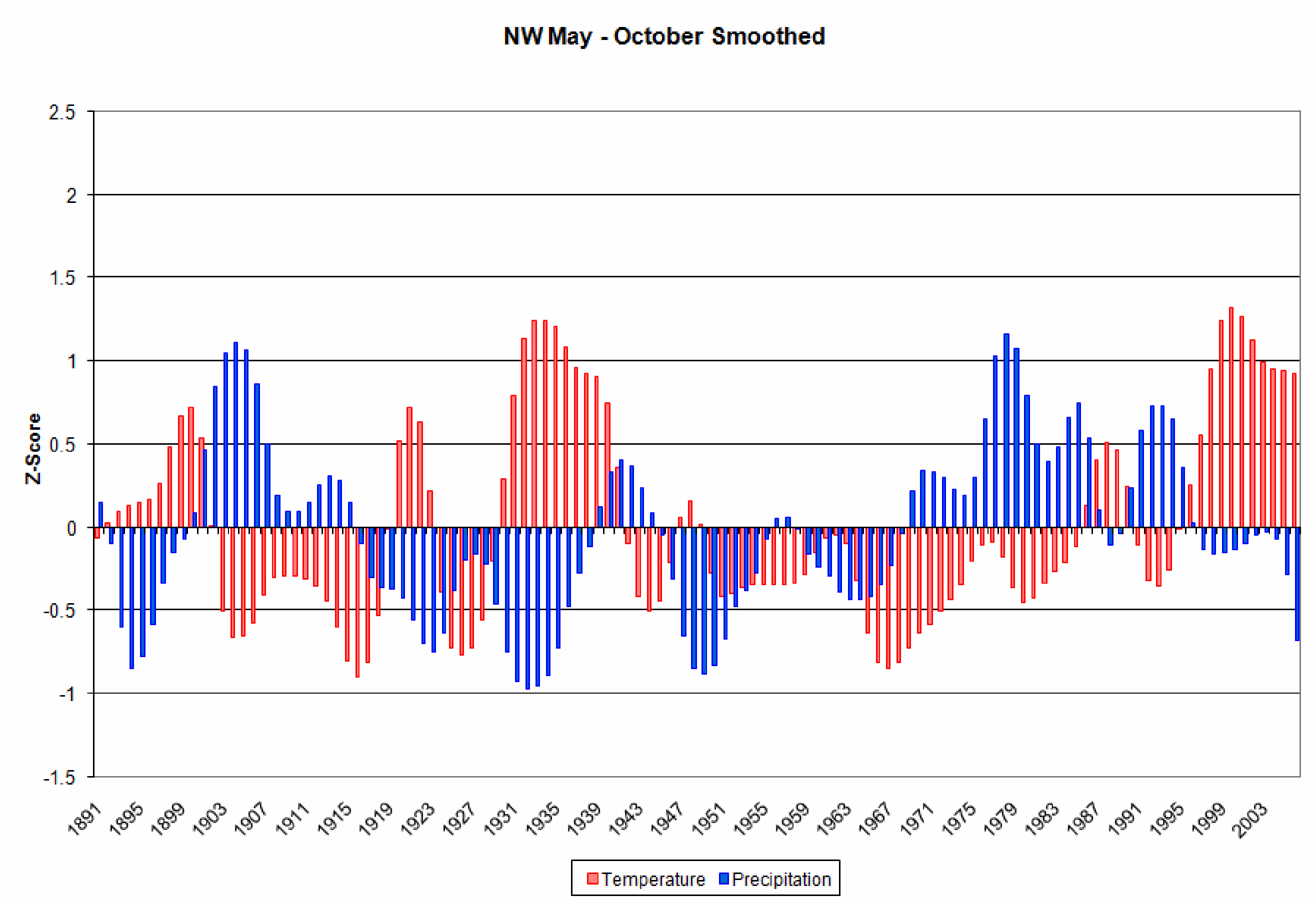


Figure 12. Same as above, except for the May-October aquatic growing season, and for the northwest.

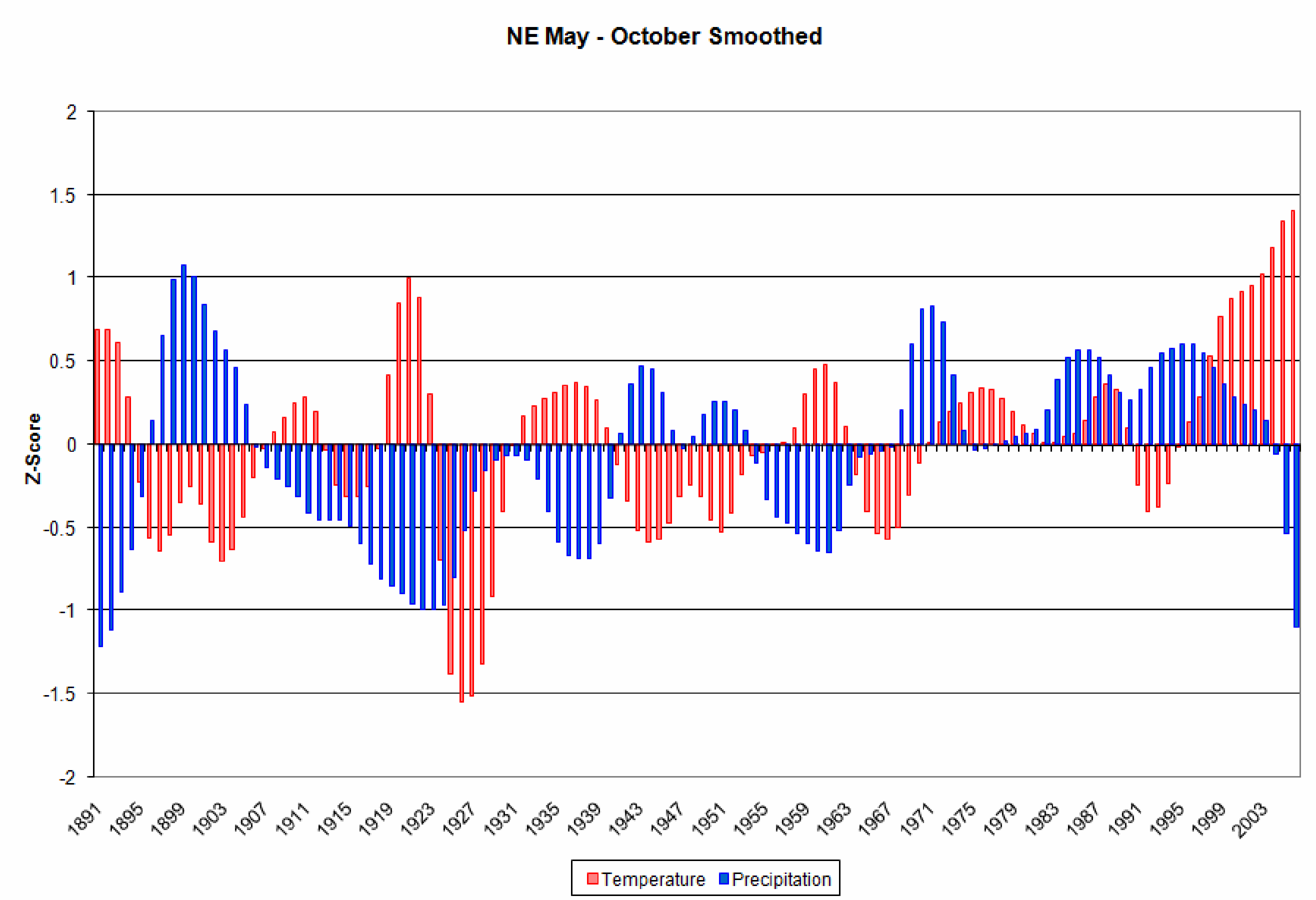


Figure 13. Same as above, except for the northeast.

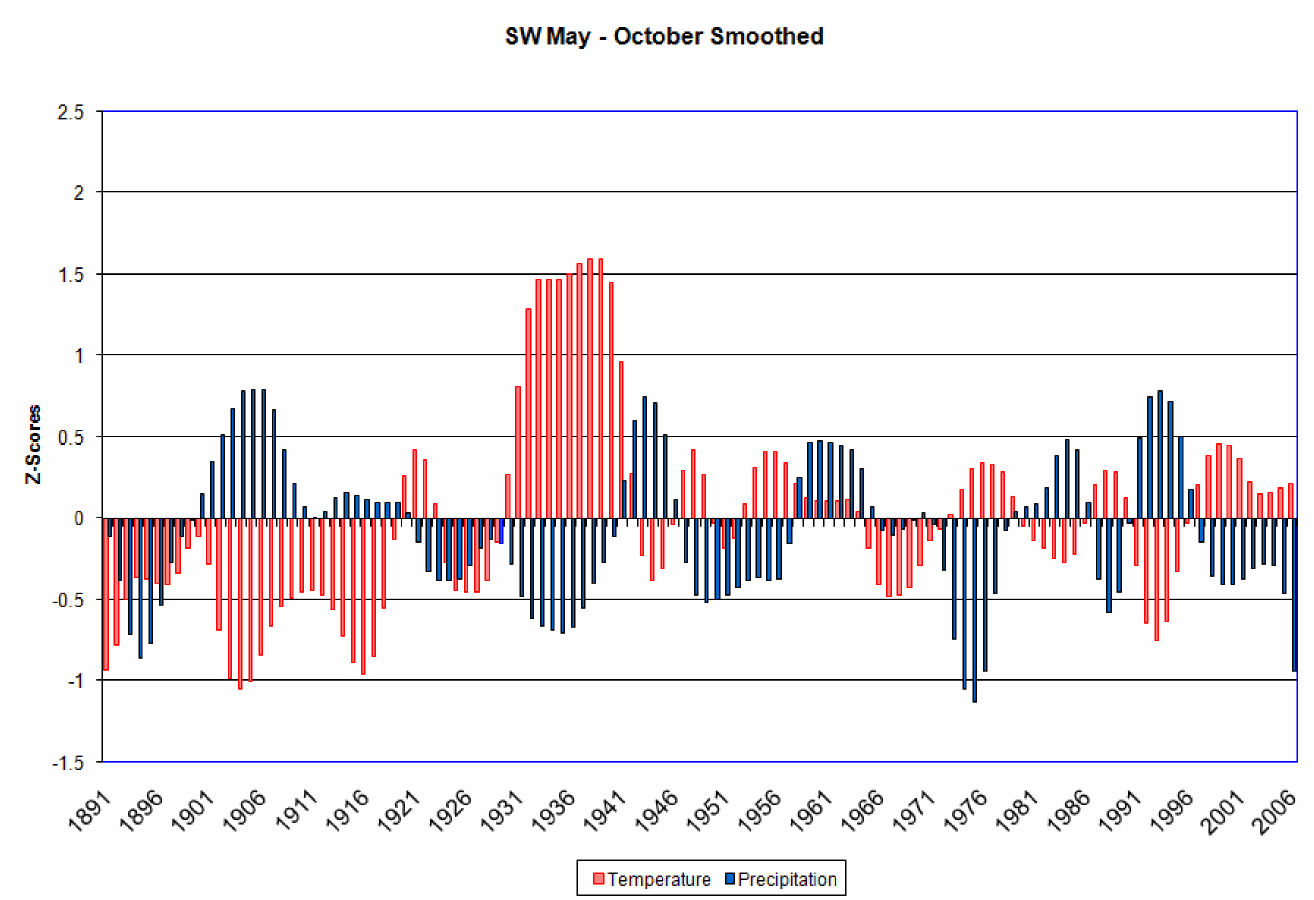


Figure 14. Same as above, except for the southwest.

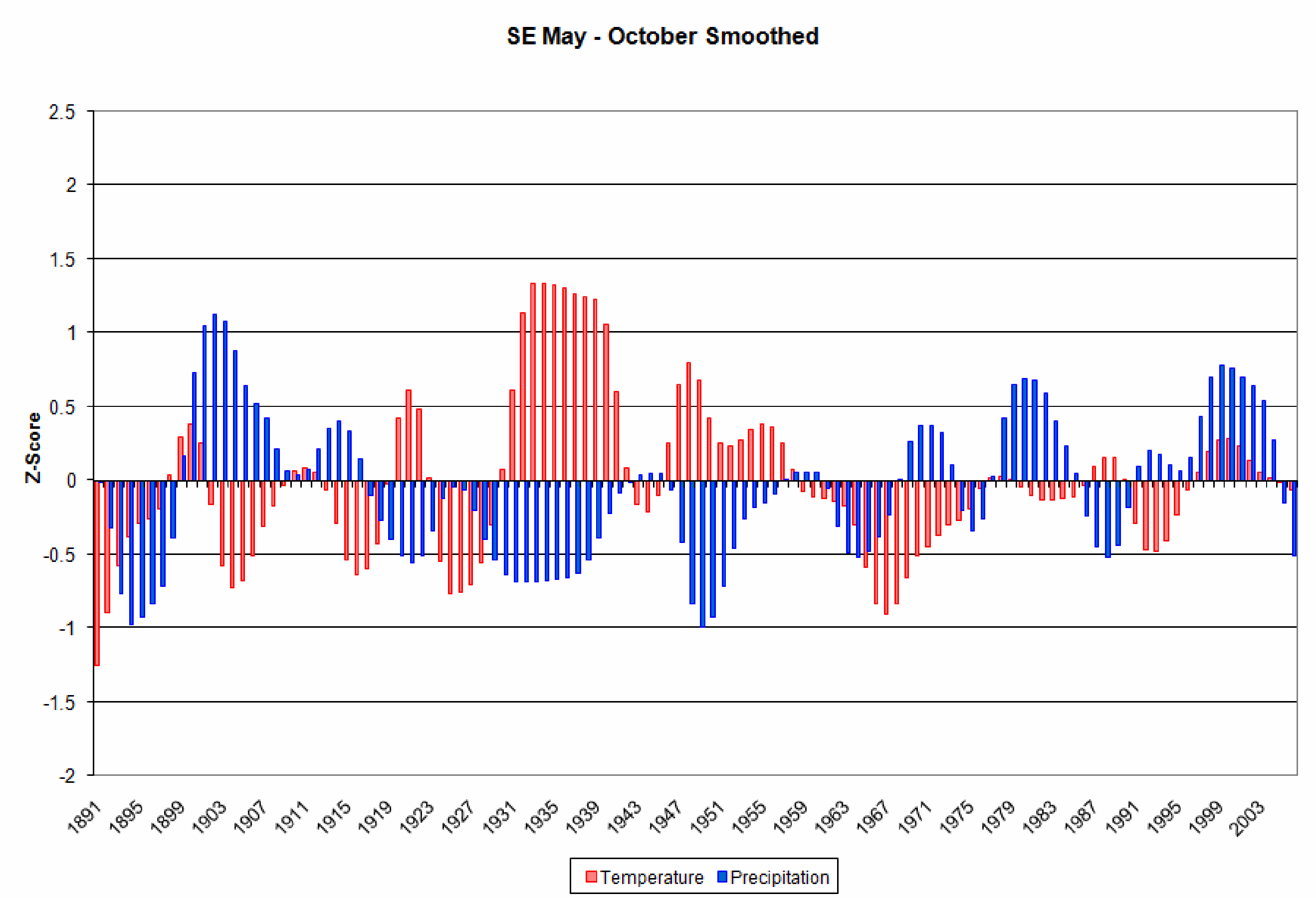


Figure 15. Same as above, except for the southeast.

Appendix 1: Data Tables

Key

Variable Name	**Meaning**
[division]_T	Average temperature, November-March for representative grid cell within division
[division]_P	Total precipitation, November-March for representative grid cell within division
[division]_Tz	Z-score (number of standard devions from mean) for corresponding value of [division]_T
[division]_Pz	Z-score (number of standard devions from mean) for corresponding value of [division]_P
T_class	Classification of temps based on Z-score: <u><</u>-2 extremely cool, <u><</u>-1.5 very cool, <u><</u>-1 cool, > -1 to < 1 normal, <u>></u>1 warm, <u>></u>1.5 very warm, <u>></u>2 extremely warm
P_class	Classification of precip based on Z-score: <u><</u>-2 extremely dry, <u><</u>-1.5 very dry, <u><</u>-1 dry, > -1 to < 1 normal, <u>></u>1 wet, <u>></u>1.5 very wet, <u>></u>2 extremely wet

May-October: Northwest MN

YEAR	NW_T	NW_P	NW_Tz	NW_Pz	T_class	P_class
1891	62.053	14.66	-0.03128	-1.28143	normal	dry
1892	61.95	28.85	-0.09253	1.581874	normal	very wet
1893	62.72	15.23	0.36536	-1.16641	normal	dry
1894	64.593	14.02	1.47916	-1.41057	warm	dry
1895	61.79	17	-0.18768	-0.80926	normal	normal
1896	61.653	18.11	-0.26914	-0.58528	normal	normal
1897	63.383	22.18	0.75962	0.235981	normal	normal
1898	62.382	19.51	0.164364	-0.30278	normal	normal
1899	63.035	20.34	0.552678	-0.1353	normal	normal
1900	65.927	27.66	2.272437	1.341752	ext. warm	wet
1901	64.333	17.71	1.324548	-0.66599	warm	normal
1902	61.617	23.22	-0.29055	0.445835	normal	normal
1903	60.727	30.36	-0.8198	1.886566	normal	very wet
1904	60.282	27.22	-1.08442	1.252967	cool	wet
1905	60.932	28.48	-0.69789	1.507214	normal	very wet
1906	61.953	25.57	-0.09075	0.920025	normal	normal
1907	58.935	20.75	-1.88543	-0.05257	very cool	normal
1908	62.098	23.86	-0.00452	0.574976	normal	normal
1909	61.227	20.16	-0.52247	-0.17162	normal	normal
1910	62.285	9.64	0.106682	-2.29438	normal	ext. dry

1911	61.783	29.68	-0.19184	1.749353	normal	very wet
1912	60.855	21.78	-0.74368	0.155268	normal	normal
1913	61.405	22.41	-0.41662	0.282391	normal	normal
1914	63.282	24.6	0.699559	0.724296	normal	normal
1915	58.6	22.71	-2.08464	0.342926	ext. cool	normal
1916	61.205	20.19	-0.53555	-0.16557	normal	normal
1917	58.13	18.06	-2.36413	-0.59537	ext. cool	normal
1918	60.753	18.63	-0.80434	-0.48035	normal	normal
1919	61.882	19.43	-0.13297	-0.31892	normal	normal
1920	63.423	20.99	0.783406	-0.00414	normal	normal
1921	65.142	19.36	1.805629	-0.33305	very warm	normal
1922	64.562	15.28	1.460725	-1.15632	warm	dry
1923	63.022	15.26	0.544947	-1.16036	normal	dry
1924	59.92	20.87	-1.29969	-0.02835	cool	normal
1925	60.27	16.05	-1.09156	-1.00095	cool	dry
1926	60.965	20.65	-0.67827	-0.07275	normal	normal
1927	60.285	20.66	-1.08264	-0.07073	cool	normal
1928	61.207	22.3	-0.53436	0.260195	normal	normal
1929	61.08	16.82	-0.60988	-0.84558	normal	normal
1930	63.29	19.04	0.704316	-0.39762	normal	normal
1931	64.897	15.42	1.659937	-1.12807	very warm	dry
1932	62.668	13.82	0.334437	-1.45093	normal	dry
1933	64.648	16.35	1.511866	-0.94041	very warm	normal
1934	64.858	16.74	1.636745	-0.86172	very warm	normal
1935	61.833	20.36	-0.1621	-0.13126	normal	normal
1936	64.89	9.13	1.655774	-2.39729	very warm	ext. dry
1937	63.595	19.05	0.885688	-0.3956	normal	normal
1938	63.62	27.3	0.900555	1.26911	normal	wet
1939	63.807	21.1	1.011756	0.018055	warm	normal
1940	62.952	16.51	0.503321	-0.90813	normal	normal
1941	64.088	25.74	1.178856	0.954328	warm	normal
1942	60.073	25.87	-1.20871	0.98056	cool	normal
1943	61.16	19.49	-0.56231	-0.30682	normal	normal
1944	62.33	21.28	0.133442	0.054376	normal	normal
1945	58.27	21.02	-2.28088	0.001913	ext. cool	normal
1946	60.772	22.74	-0.79304	0.348979	normal	normal
1947	62.888	15.41	0.465263	-1.13009	normal	dry
1948	62.985	13.2	0.522945	-1.57603	normal	very dry
1949	63.308	17.72	0.71502	-0.66397	normal	normal
1950	60.955	13.87	-0.68422	-1.44084	normal	dry
1951	59.817	28.09	-1.36094	1.428518	cool	wet
1952	60.752	17.33	-0.80493	-0.74267	normal	normal
1953	63.753	18.37	0.979644	-0.53281	normal	normal
1954	60.798	21.37	-0.77758	0.072537	normal	normal
1955	64.733	18.66	1.562412	-0.4743	very warm	normal

1956	62.313	22.68	0.123333	0.336872	normal	normal
1957	60.537	26.78	-0.93279	1.164183	normal	wet
1958	60.72	16.52	-0.82396	-0.90611	normal	normal
1959	61.685	22.22	-0.25011	0.244052	normal	normal
1960	62.128	20.32	0.01332	-0.13934	normal	normal
1961	62.212	16.22	0.063272	-0.96665	normal	normal
1962	61.578	24.81	-0.31374	0.76667	normal	normal
1963	64.28	16.26	1.293031	-0.95857	warm	normal
1964	62.255	17.26	0.088842	-0.75679	normal	normal
1965	59.998	27.85	-1.25331	1.380091	cool	wet
1966	60.655	16.22	-0.86262	-0.96665	normal	normal
1967	59.113	18.05	-1.77958	-0.59738	very cool	normal
1968	60.753	27.99	-0.80434	1.40834	normal	wet
1969	60.675	11.42	-0.85072	-1.9352	normal	very dry
1970	62.1	24.19	-0.00333	0.641565	normal	normal
1971	61.46	24.38	-0.38391	0.679903	normal	normal
1972	60.147	21.36	-1.1647	0.070519	cool	normal
1973	62.028	22.58	-0.04615	0.316694	normal	normal
1974	59.905	16.7	-1.30861	-0.86979	cool	normal
1975	62.27	25.81	0.097762	0.968453	normal	normal
1976	61.542	9.51	-0.33515	-2.32061	normal	ext. dry
1977	62.588	28.49	0.286864	1.509232	normal	very wet
1978	62.487	28.24	0.226804	1.458786	normal	wet
1979	59.987	26	-1.25985	1.006792	cool	wet
1980	61.325	26.47	-0.46419	1.10163	normal	wet
1981	60.258	21.66	-1.0987	0.131054	cool	normal
1982	61.585	20.21	-0.30958	-0.16153	normal	normal
1983	62.453	21.88	0.206585	0.175446	normal	normal
1984	61.777	26.58	-0.19541	1.123826	normal	wet
1985	60.515	26.59	-0.94587	1.125844	normal	wet
1986	61.88	28.05	-0.13416	1.420447	normal	wet
1987	63.54	19.19	0.852982	-0.36735	normal	normal
1988	65.202	17.05	1.841308	-0.79917	very warm	normal
1989	62.903	16.46	0.474183	-0.91822	normal	normal
1990	62.248	27.01	0.08468	1.210593	normal	wet
1991	62.77	27.61	0.395093	1.331663	normal	wet
1992	59.878	16.51	-1.32467	-0.90813	cool	normal
1993	59.58	27.91	-1.50188	1.392197	very cool	wet
1994	62.805	21.57	0.415906	0.112893	normal	normal
1995	62.5	29.42	0.234534	1.69689	normal	very wet
1996	61.165	18.68	-0.55934	-0.47026	normal	normal
1997	62.582	20.8	0.283296	-0.04248	normal	normal
1998	65.548	19.7	2.047061	-0.26444	ext. warm	normal
1999	63.927	23.74	1.083115	0.550762	warm	normal
2000	64.787	17.47	1.594524	-0.71442	very warm	normal
2001	64.777	19.04	1.588577	-0.39762	very warm	normal
2002	62.683	35.03	0.343357	2.828893	normal	ext. wet
2003	63.848	20.04	1.036137	-0.19583	warm	normal

2004	63.508	24.52	0.833953	0.708153	normal	normal
2005	65.298	25.92	1.898396	0.990649	very warm	normal
2006	63.663	17.68	0.926125	-0.67204	normal	normal

May-October: North-central MN

YEAR	NC_T	NC_P	NC_Tz	NC_Pz	T_class	P_class
1891	55.633	18.64	-0.91505	-0.01597	normal	normal
1892	56.765	13.36	-0.14455	-1.45495	normal	dry
1893	56.403	16.67	-0.39095	-0.55286	normal	normal
1894	58.187	14.49	0.823329	-1.14698	normal	dry
1895	53.825	20.15	-2.14566	0.395551	ext. cool	normal
1896	55.547	20.2	-0.97358	0.409178	normal	normal
1897	56.973	18.37	-0.00298	-0.08956	normal	normal
1898	54.865	21.62	-1.43778	0.796174	cool	normal
1899	55.945	25.11	-0.70268	1.747313	normal	very wet
1900	59.92	26.49	2.002892	2.123408	ext. warm	ext. wet
1901	58.552	21.86	1.071766	0.861582	warm	normal
1902	56.153	19.27	-0.56111	0.155723	normal	normal
1903	56.097	20.55	-0.59922	0.504565	normal	normal
1904	55.495	16.38	-1.00897	-0.6319	cool	normal
1905	56.337	27.97	-0.43587	2.526757	normal	ext. wet
1906	57.455	18.35	0.325095	-0.09501	normal	normal
1907	53.777	17.1	-2.17833	-0.43567	ext. cool	normal
1908	56.568	17.81	-0.27864	-0.24217	normal	normal
1909	57.31	20.62	0.226401	0.523642	normal	normal
1910	57.892	10.78	0.622538	-2.15808	normal	ext. dry
1911	57.182	17.49	0.139278	-0.32939	normal	normal
1912	56.397	16.64	-0.39503	-0.56104	normal	normal
1913	55.942	20.55	-0.70472	0.504565	normal	normal
1914	59.187	21.75	1.503977	0.831604	very warm	normal
1915	54.983	20.28	-1.35747	0.430981	cool	normal
1916	56.337	20.07	-0.43587	0.373749	normal	normal
1917	54.258	10.6	-1.85094	-2.20714	very cool	ext. dry
1918	55.753	14.62	-0.83337	-1.11155	normal	dry
1919	57.067	23.07	0.061004	1.191347	normal	wet
1920	58.857	15.92	1.279363	-0.75726	warm	normal
1921	59.498	15.79	1.715659	-0.79269	very warm	normal
1922	59.523	13.93	1.732675	-1.2996	very warm	dry
1923	58.437	12.85	0.993491	-1.59394	normal	very dry
1924	54.772	16.19	-1.50108	-0.68368	very cool	normal
1925	54.442	18.66	-1.7257	-0.01052	very cool	normal
1926	54.698	18.92	-1.55145	0.060336	very cool	normal
1927	55.423	16.94	-1.05798	-0.47928	cool	normal
1928	55.59	20.96	-0.94431	0.616303	normal	normal
1929	56.08	11.63	-0.6108	-1.92643	normal	very dry
1930	57.705	13.59	0.495257	-1.39226	normal	dry
1931	59.675	16.45	1.836133	-0.61282	very warm	normal

1932	57.395	15.95	0.284256	-0.74909	normal	normal
1933	58.607	12.5	1.109201	-1.68932	warm	very dry
1934	57.603	15.2	0.425831	-0.95349	normal	normal
1935	56.182	18.57	-0.54137	-0.03505	normal	normal
1936	58.127	10.16	0.78249	-2.32705	normal	ext. dry
1937	57.948	21.57	0.660654	0.782548	normal	normal
1938	58.535	14.78	1.060195	-1.06795	warm	dry
1939	57.802	17.68	0.56128	-0.2776	normal	normal
1940	57.643	13.06	0.453057	-1.5367	normal	very dry
1941	58.94	22.45	1.335857	1.022377	warm	wet
1942	55.363	19.96	-1.09882	0.34377	cool	normal
1943	57.2	18.98	0.15153	0.076688	normal	normal
1944	57.765	26.05	0.536096	2.003494	normal	ext. wet
1945	54.153	15.67	-1.9224	-0.82539	very cool	normal
1946	55.977	19.21	-0.6809	0.139371	normal	normal
1947	58.082	19.1	0.751861	0.109392	normal	normal
1948	58.57	12.6	1.084017	-1.66207	warm	very dry
1949	58.037	24.91	0.721232	1.692807	normal	very wet
1950	55.745	20.77	-0.83881	0.564522	normal	normal
1951	55.523	18.88	-0.98992	0.049435	normal	normal
1952	56.788	15.78	-0.1289	-0.79542	normal	normal
1953	58.593	22.76	1.099672	1.106862	warm	wet
1954	55.545	14.44	-0.97494	-1.16061	normal	dry
1955	59.662	17.76	1.827285	-0.2558	very warm	normal
1956	56.808	14.22	-0.11528	-1.22057	normal	dry
1957	56.782	19.81	-0.13298	0.30289	normal	normal
1958	56.022	15.66	-0.65027	-0.82812	normal	normal
1959	57.433	21.74	0.310121	0.828878	normal	normal
1960	57.09	16.09	0.076659	-0.71093	normal	normal
1961	57.465	16.68	0.331902	-0.55014	normal	normal
1962	56.597	24.15	-0.2589	1.485682	normal	wet
1963	59.555	16.92	1.754455	-0.48473	very warm	normal
1964	56.372	20.8	-0.41205	0.572698	normal	normal
1965	54.695	22.33	-1.55349	0.989673	very cool	normal
1966	56.177	17.89	-0.54477	-0.22037	normal	normal
1967	54.872	11.97	-1.43302	-1.83377	cool	very dry
1968	55.848	23.05	-0.76871	1.185896	normal	wet
1969	55.372	20.78	-1.09269	0.567247	cool	normal
1970	57.582	16.22	0.411537	-0.6755	normal	normal
1971	56.76	21.59	-0.14796	0.787998	normal	normal
1972	56.09	19.09	-0.60399	0.106667	normal	normal
1973	57.898	23.14	0.626622	1.210424	normal	wet
1974	55.553	17.86	-0.9695	-0.22855	normal	normal
1975	57.632	18.7	0.44557	0.000379	normal	normal
1976	57.073	12.26	0.065088	-1.75473	normal	very dry
1977	58.18	23.18	0.818565	1.221325	normal	wet
1978	58.097	20.83	0.762071	0.580874	normal	normal
1979	54.598	17.11	-1.61952	-0.43295	very cool	normal
1980	56.783	15.9	-0.1323	-0.76271	normal	normal

1981	56.662	21.82	-0.21466	0.850681	normal	normal
1982	56.9	21.05	-0.05266	0.640831	normal	normal
1983	58.262	20.91	0.874378	0.602676	normal	normal
1984	57.467	19.91	0.333263	0.330144	normal	normal
1985	55.48	23.56	-1.01918	1.324888	cool	wet
1986	57.202	17.86	0.152891	-0.22855	normal	normal
1987	58.098	18.92	0.762752	0.060336	normal	normal
1988	59.462	18.3	1.691155	-0.10863	very warm	normal
1989	58.347	18.76	0.932233	0.016731	normal	normal
1990	57.532	14.44	0.377505	-1.16061	normal	dry
1991	58.352	21	0.935636	0.627204	normal	normal
1992	55.027	17.19	-1.32752	-0.41115	cool	normal
1993	54.523	20.88	-1.67056	0.5945	very cool	normal
1994	58.245	21.76	0.862807	0.834329	normal	normal
1995	57.938	21.99	0.653848	0.897012	normal	normal
1996	57.042	19.71	0.043988	0.275637	normal	normal
1997	57.405	18.95	0.291063	0.068512	normal	normal
1998	59.8	20.64	1.921214	0.529092	very warm	normal
1999	57.46	27.07	0.328498	2.281477	normal	ext. wet
2000	57.298	20.3	0.218233	0.436431	normal	normal
2001	58.728	21.32	1.19156	0.714415	warm	normal
2002	56.947	22.35	-0.02067	0.995123	normal	normal
2003	58.902	17.17	1.309992	-0.4166	warm	normal
2004	55.758	23.71	-0.82996	1.365768	normal	wet
2005	58.937	21.32	1.333815	0.714415	warm	normal
2006	58.697	13.34	1.17046	-1.4604	warm	dry

May-October: Northeast MN

YEAR	NE_T	NE_P	NE_Tz	NE_Pz	T_class	P_class
1891	55.067	16.31	-0.0265	-0.95999	normal	normal
1892	57.102	14.56	1.395454	-1.47926	warm	dry
1893	56.148	16.71	0.728849	-0.8413	normal	normal
1894	56.428	16.87	0.924498	-0.79383	normal	normal
1895	53.86	18.74	-0.86989	-0.23895	normal	normal
1896	53.862	19.29	-0.86849	-0.07576	normal	normal
1897	54.653	22.03	-0.31578	0.737271	normal	normal
1898	53.513	24.53	-1.11235	1.479082	cool	wet
1899	54.122	27.19	-0.68681	2.26837	normal	ext. wet
1900	57.155	23.59	1.432488	1.200161	warm	wet
1901	56.082	18.96	0.682731	-0.17367	normal	normal
1902	53.288	20.94	-1.26957	0.413841	cool	normal
1903	53.518	23.41	-1.10886	1.146751	cool	wet
1904	53.282	19.91	-1.27376	0.108214	cool	normal
1905	55.562	27.29	0.319382	2.298042	normal	ext. wet
1906	55.79	18.49	0.478697	-0.31313	normal	normal
1907	52.348	16.06	-1.92639	-1.03418	very cool	dry
1908	54.963	19.86	-0.09917	0.093378	normal	normal
1909	55.253	24.28	0.103469	1.404901	normal	wet
1910	56.368	13.52	0.882573	-1.78786	normal	very dry
1911	55.817	19.02	0.497563	-0.15587	normal	normal
1912	55.203	17.01	0.068532	-0.75229	normal	normal
1913	53.875	20.24	-0.85941	0.206133	normal	normal
1914	57.493	16.39	1.668664	-0.93626	very warm	normal
1915	53.488	18.87	-1.12982	-0.20038	cool	normal
1916	55.645	22.99	0.377378	1.022126	normal	wet
1917	52.832	16.12	-1.5882	-1.01637	very cool	dry
1918	54.298	13.35	-0.56383	-1.8383	normal	very dry
1919	55.732	17.05	0.43817	-0.74042	normal	normal
1920	56.802	17.11	1.18583	-0.72261	warm	normal
1921	58.7	16.46	2.512053	-0.91549	ext. warm	normal
1922	56.805	14.1	1.187926	-1.61576	warm	very dry
1923	56.757	14.97	1.154386	-1.35761	warm	dry
1924	52.403	16.53	-1.88796	-0.89472	very cool	normal
1925	53.125	16.68	-1.38347	-0.85021	cool	normal
1926	52.293	21.98	-1.96482	0.722434	very cool	normal
1927	52.638	16.31	-1.72376	-0.95999	very cool	normal
1928	53.128	24.41	-1.38137	1.443475	cool	wet
1929	53.56	13.11	-1.07951	-1.90951	cool	very dry
1930	54.802	20.17	-0.21167	0.185363	normal	normal
1931	57.405	19.62	1.607175	0.022164	very warm	normal
1932	55.057	19.83	-0.03349	0.084476	normal	normal
1933	56.07	18.19	0.674346	-0.40215	normal	normal

1934	55.322	16.39	0.151683	-0.93626	normal	normal
1935	54.01	20.34	-0.76507	0.235806	normal	normal
1936	55.698	12.21	0.414412	-2.17657	normal	ext. dry
1937	57.203	18.79	1.466027	-0.22412	warm	normal
1938	55.863	14.95	0.529705	-1.36354	normal	dry
1939	55.12	19.88	0.010536	0.099312	normal	normal
1940	55.087	15.21	-0.01252	-1.28639	normal	dry
1941	56.163	23.99	0.73933	1.318851	normal	wet
1942	53.505	18.52	-1.11794	-0.30423	cool	normal
1943	54.258	22.16	-0.59178	0.775845	normal	normal
1944	55.023	28.01	-0.05724	2.511684	normal	ext. wet
1945	52.1	18.93	-2.09968	-0.18258	ext. cool	normal
1946	53.91	21.18	-0.83495	0.485055	normal	normal
1947	54.792	17.71	-0.21865	-0.54458	normal	normal
1948	56.593	12.93	1.039791	-1.96292	warm	very dry
1949	55.513	22.64	0.285144	0.918273	normal	normal
1950	52.89	21.27	-1.54767	0.51176	very cool	normal
1951	53.543	21.21	-1.09139	0.493956	cool	normal
1952	54.79	17.93	-0.22005	-0.4793	normal	normal
1953	56.413	23.09	0.914017	1.051799	normal	wet
1954	54.023	16.02	-0.75599	-1.04604	normal	dry
1955	57.97	21.77	2.001967	0.660122	ext. warm	normal
1956	54.95	14.75	-0.10825	-1.42289	normal	dry
1957	54.862	18.7	-0.16974	-0.25082	normal	normal
1958	54.348	17.34	-0.5289	-0.65437	normal	normal
1959	56.048	21.05	0.658974	0.44648	normal	normal
1960	55.797	15.66	0.483588	-1.15287	normal	dry
1961	56.22	16.67	0.779158	-0.85317	normal	normal
1962	54.738	18.68	-0.25639	-0.25676	normal	normal
1963	57.595	16.78	1.739937	-0.82053	very warm	normal
1964	54.908	22.31	-0.1376	0.820353	normal	normal
1965	53.342	22.45	-1.23184	0.861895	cool	normal
1966	54.797	16.27	-0.21516	-0.97186	normal	normal
1967	53.472	15.83	-1.141	-1.10242	cool	dry
1968	54.645	25.04	-0.32137	1.630412	normal	very wet
1969	53.927	19.83	-0.82307	0.084476	normal	normal
1970	56.15	22.9	0.730246	0.995421	normal	normal
1971	55.537	22.89	0.301914	0.992454	normal	normal
1972	54.327	20.69	-0.54357	0.339659	normal	normal
1973	56.093	23.67	0.690417	1.223899	normal	wet
1974	53.557	19.82	-1.08161	0.081509	cool	normal
1975	56.02	17.32	0.639409	-0.6603	normal	normal
1976	55.36	12.88	0.178235	-1.97776	normal	very dry
1977	55.608	26.06	0.351525	1.933071	normal	very wet
1978	56.007	20.93	0.630325	0.410873	normal	normal
1979	53.382	19.12	-1.20389	-0.1262	cool	normal
1980	55.483	18.56	0.264181	-0.29236	normal	normal
1981	54.965	19.72	-0.09777	0.051837	normal	normal
1982	54.737	23.37	-0.25708	1.134882	normal	wet

1983	56.183	20.47	0.753305	0.27438	normal	normal
1984	55.562	18.54	0.319382	-0.2983	normal	normal
1985	53.553	23.78	-1.0844	1.256539	cool	wet
1986	54.512	21.65	-0.4143	0.624515	normal	normal
1987	56.195	21.61	0.76169	0.612646	normal	normal
1988	57.025	24.01	1.34165	1.324785	warm	wet
1989	55.565	17.89	0.321479	-0.49117	normal	normal
1990	54.775	19.06	-0.23053	-0.144	normal	normal
1991	55.785	22.06	0.475203	0.746172	normal	normal
1992	52.972	20.17	-1.49037	0.185363	cool	normal
1993	52.607	22.21	-1.74542	0.790681	very cool	normal
1994	55.928	20.7	0.575124	0.342627	normal	normal
1995	55.608	22.23	0.351525	0.796615	normal	normal
1996	54.522	22.92	-0.40732	1.001356	normal	wet
1997	54.958	16	-0.10266	-1.05198	normal	dry
1998	58.585	20.62	2.431697	0.318889	ext. warm	normal
1999	56.313	26.06	0.844142	1.933071	normal	very wet
2000	55.753	18.89	0.452843	-0.19444	normal	normal
2001	57.065	21.66	1.3696	0.627482	warm	normal
2002	55.923	20.28	0.57163	0.218002	normal	normal
2003	57.06	18.6	1.366107	-0.2805	warm	normal
2004	54.373	20.52	-0.51143	0.289216	normal	normal
2005	57.288	20.31	1.525421	0.226904	very warm	normal
2006	57.107	15.83	1.398948	-1.10242	warm	dry

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YEAR	WC_T	WC_P	WC_Tz	WC_Pz	T_class	P_class
1891	60.495	13.88	-0.29563	-1.02326	normal	dry
1892	59.193	19.33	-1.11645	0.455577	cool	normal
1893	60.035	14.02	-0.58563	-0.98527	normal	normal
1894	62.102	10.51	0.717467	-1.93769	normal	very dry
1895	58.972	14.91	-1.25578	-0.74377	cool	normal
1896	59.17	19.47	-1.13095	0.493566	cool	normal
1897	60.995	17.51	0.019582	-0.03827	normal	normal
1898	59.492	17.61	-0.92795	-0.01114	normal	normal
1899	59.762	22.84	-0.75774	1.408	normal	wet
1900	63.112	18.69	1.354201	0.281916	warm	normal
1901	61.823	15.85	0.541577	-0.48871	normal	normal
1902	58.473	15.76	-1.57036	-0.51313	very cool	normal
1903	58.443	22.15	-1.58927	1.220772	very cool	wet
1904	58.545	18.62	-1.52497	0.262922	very cool	normal
1905	58.957	23.66	-1.26523	1.630504	cool	very wet
1906	60.27	25.11	-0.43748	2.023955	normal	ext. wet
1907	57.347	15.3	-2.28022	-0.63795	ext. cool	normal
1908	60.322	20.97	-0.4047	0.900584	normal	normal
1909	60.378	17.01	-0.36939	-0.17394	normal	normal
1910	60.77	10.54	-0.12226	-1.92955	normal	very dry
1911	60.487	20.32	-0.30068	0.72421	normal	normal
1912	59.467	19.31	-0.94371	0.45015	normal	normal
1913	59.74	20.92	-0.77161	0.887017	normal	normal
1914	61.977	22.63	0.638663	1.351018	normal	wet
1915	57.46	22.78	-2.20899	1.39172	ext. cool	wet
1916	59.667	21.63	-0.81763	1.079672	normal	wet
1917	57.762	11.06	-2.0186	-1.78845	ext. cool	very dry
1918	60.203	13.88	-0.47972	-1.02326	normal	dry
1919	59.75	18.01	-0.7653	0.097401	normal	normal
1920	61.802	20.73	0.528338	0.835461	normal	normal
1921	63.252	17.22	1.442461	-0.11696	warm	normal
1922	63.512	9.65	1.606372	-2.17105	very warm	ext. dry
1923	62.03	13.74	0.672076	-1.06124	normal	dry
1924	58.642	18.62	-1.46382	0.262922	cool	normal
1925	58.847	16.44	-1.33458	-0.32861	cool	normal
1926	59.75	17.57	-0.7653	-0.02199	normal	normal
1927	59.395	14.44	-0.98911	-0.8713	normal	normal
1928	59.983	18.06	-0.61841	0.110969	normal	normal
1929	59.743	14.47	-0.76972	-0.86316	normal	normal
1930	61.363	14.83	0.25158	-0.76548	normal	normal
1931	63.697	14.37	1.723002	-0.8903	very warm	normal
1932	61.503	13.5	0.33984	-1.12637	normal	dry
1933	63.465	12.31	1.576742	-1.44927	very	dry

					warm	
1934	63.703	13.15	1.726784	-1.22134	very warm	dry
1935	60.74	15.49	-0.14118	-0.58639	normal	normal
1936	63.98	8.7	1.901413	-2.42883	very warm	ext. dry
1937	62.305	15.52	0.845444	-0.57825	normal	normal
1938	62.962	17.48	1.259636	-0.04641	warm	normal
1939	62.753	15.48	1.127876	-0.5891	warm	normal
1940	62.802	15.48	1.158768	-0.5891	warm	normal
1941	62.912	19.97	1.228115	0.629239	warm	normal
1942	58.945	23.1	-1.2728	1.47855	cool	wet
1943	60.775	20.18	-0.11911	0.686221	normal	normal
1944	61.853	20.27	0.56049	0.710642	normal	normal
1945	58.752	15.48	-1.39447	-0.5891	cool	normal
1946	59.937	22.18	-0.64741	1.228912	normal	wet
1947	62.357	14.57	0.878226	-0.83603	normal	normal
1948	62.573	15.81	1.014399	-0.49956	warm	normal
1949	62.533	18.26	0.989182	0.165238	normal	normal
1950	60.19	15.47	-0.48791	-0.59182	normal	normal
1951	58.963	19.93	-1.26145	0.618385	cool	normal
1952	61.167	15.59	0.128016	-0.55926	normal	normal
1953	62.613	19.23	1.039616	0.428443	warm	normal
1954	59.685	16.42	-0.80628	-0.33404	normal	normal
1955	63.652	18.22	1.694632	0.154384	very warm	normal
1956	61.673	17.13	0.447013	-0.14138	normal	normal
1957	60.425	25.53	-0.33976	2.13792	normal	ext. wet
1958	60.737	13.01	-0.14307	-1.25933	normal	dry
1959	61.635	19.4	0.423056	0.474572	normal	normal
1960	61.54	17.57	0.363166	-0.02199	normal	normal
1961	61.3	15.61	0.211863	-0.55383	normal	normal
1962	60.705	24.45	-0.16324	1.844867	normal	very wet
1963	63.578	18.96	1.647981	0.35518	very warm	normal
1964	61.652	14.96	0.433774	-0.7302	normal	normal
1965	59.503	24.15	-0.92102	1.763463	normal	very wet
1966	60.473	16.26	-0.3095	-0.37745	normal	normal
1967	58.7	12.4	-1.42725	-1.42485	cool	dry
1968	60.06	18.36	-0.56987	0.192372	normal	normal
1969	59.852	15.1	-0.701	-0.69221	normal	normal
1970	61.863	15.52	0.566794	-0.57825	normal	normal
1971	60.55	22.73	-0.26096	1.378152	normal	wet
1972	59.988	18.8	-0.61526	0.311764	normal	normal
1973	61.982	16.92	0.641815	-0.19837	normal	normal
1974	60.008	14.48	-0.60265	-0.86045	normal	normal
1975	61.897	16.39	0.588229	-0.34218	normal	normal
1976	61.953	6.7	0.623533	-2.97152	normal	ext. dry
1977	62.078	21.43	0.702337	1.025403	normal	wet
1978	62.24	16.27	0.804466	-0.37474	normal	normal
1979	59.425	18.6	-0.97019	0.257495	normal	normal
1980	61.1	15.79	0.085777	-0.50499	normal	normal
1981	60.285	18.8	-0.42802	0.311764	normal	normal

1982	60.468	19.86	-0.31265	0.599391	normal	normal
1983	61.99	17.64	0.646859	-0.003	normal	normal
1984	60.942	22.79	-0.01383	1.394433	normal	wet
1985	59.713	21.02	-0.78863	0.914151	normal	normal
1986	60.878	22.66	-0.05418	1.359158	normal	wet
1987	62.247	13.82	0.808879	-1.03954	normal	dry
1988	64.345	14.15	2.13152	-0.94999	ext. warm	normal
1989	61.985	16.4	0.643707	-0.33947	normal	normal
1990	61.2	18.41	0.14882	0.205939	normal	normal
1991	62.06	22.12	0.690989	1.212632	normal	wet
1992	58.797	15.47	-1.3661	-0.59182	cool	normal
1993	58.497	23.49	-1.55523	1.584375	very cool	very wet
1994	62.025	17.07	0.668924	-0.15766	normal	normal
1995	61.445	22.28	0.303275	1.256047	normal	wet
1996	60.838	17.75	-0.0794	0.026851	normal	normal
1997	62.363	16.53	0.882009	-0.30419	normal	normal
1998	64.245	20.55	2.068477	0.786619	ext. warm	normal
1999	62.28	20.45	0.829683	0.759484	normal	normal
2000	62.183	16.24	0.768532	-0.38288	normal	normal
2001	62.807	17.27	1.16192	-0.10339	warm	normal
2002	61.358	19.31	0.248428	0.45015	normal	normal
2003	62.355	15.24	0.876966	-0.65423	normal	normal
2004	59.712	24.24	-0.78926	1.787884	normal	very wet
2005	62.613	23.58	1.039616	1.608796	warm	very wet
2006	61.727	15.86	0.481056	-0.48599	normal	normal

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YEAR	C_T	C_P	C_Tz	C_Pz	T_class	P_class
1891	60.448	14.7	-0.36194	-1.17741	normal	dry
1892	59.178	23.69	-1.18233	1.019742	cool	wet
1893	60.477	13.12	-0.34321	-1.56356	normal	very dry
1894	62.345	12.46	0.863483	-1.72487	normal	very dry
1895	59.592	16.59	-0.9149	-0.7155	normal	normal
1896	59.527	18.15	-0.95689	-0.33423	normal	normal
1897	60.48	21.42	-0.34127	0.464954	normal	normal
1898	59.85	19.41	-0.74824	-0.02629	normal	normal
1899	60.042	21.91	-0.62421	0.58471	normal	normal
1900	63.707	22.26	1.743307	0.67025	very warm	normal
1901	62.03	15.68	0.66	-0.9379	normal	normal
1902	58.58	18.98	-1.56863	-0.13138	very cool	normal
1903	58.593	25.92	-1.56023	1.564753	very cool	very wet
1904	58.307	21.29	-1.74498	0.433182	very cool	normal
1905	58.645	26.33	-1.52664	1.664957	very cool	very wet
1906	60.54	26.39	-0.30251	1.679621	normal	very wet
1907	57.843	17.84	-2.04472	-0.41	ext. cool	normal
1908	60.782	21.84	-0.14618	0.567602	normal	normal
1909	60.453	17.33	-0.35871	-0.53464	normal	normal
1910	61.695	9.43	0.443597	-2.4654	normal	ext. dry
1911	60.947	23.74	-0.0396	1.031962	normal	wet
1912	60.315	19.96	-0.44785	0.108131	normal	normal
1913	60.67	23.69	-0.21853	1.019742	normal	wet
1914	62.78	23.43	1.144484	0.956198	warm	normal
1915	57.955	21.97	-1.97237	0.599374	very cool	normal
1916	60.23	22.81	-0.50276	0.80467	normal	normal
1917	57.712	14.22	-2.12934	-1.29472	ext. cool	dry
1918	60.355	16.49	-0.42202	-0.73994	normal	normal
1919	60.688	17.64	-0.2069	-0.45888	normal	normal
1920	62.467	19.99	0.942293	0.115463	normal	normal
1921	63.59	16.55	1.667728	-0.72527	very warm	normal
1922	63.567	10.89	1.65287	-2.10857	very warm	ext. dry
1923	62.018	13.64	0.652248	-1.43647	normal	dry
1924	58.875	19.83	-1.37806	0.076359	cool	normal
1925	59.09	16.58	-1.23918	-0.71794	cool	normal
1926	60.1	21.79	-0.58674	0.555382	normal	normal
1927	59.367	15.8	-1.06024	-0.90857	cool	normal
1928	60.28	20.09	-0.47046	0.139903	normal	normal
1929	60.095	16.02	-0.58997	-0.8548	normal	normal
1930	61.878	16.68	0.561811	-0.6935	normal	normal
1931	64.11	14.66	2.003637	-1.18719	ext. warm	dry

1932	61.723	14.79	0.461684	-1.15542	normal	dry
1933	63.66	14.45	1.712946	-1.23851	very warm	dry
1934	63.618	15.84	1.685815	-0.8988	very warm	normal
1935	60.83	19.07	-0.11518	-0.10938	normal	normal
1936	63.568	10.74	1.653516	-2.14523	very warm	ext. dry
1937	62.165	18.28	0.747207	-0.30246	normal	normal
1938	62.537	20.84	0.987511	0.323203	normal	normal
1939	62.518	18.35	0.975238	-0.28535	normal	normal
1940	62.202	17.44	0.771108	-0.50776	normal	normal
1941	62.71	23.4	1.099266	0.948866	warm	normal
1942	58.723	23.19	-1.47625	0.897542	cool	normal
1943	60.31	20.6	-0.45108	0.264547	normal	normal
1944	61.233	22.69	0.145154	0.775342	normal	normal
1945	57.995	19.51	-1.94653	-0.00185	very cool	normal
1946	59.672	22.27	-0.86322	0.672694	normal	normal
1947	62.375	15.67	0.882863	-0.94034	normal	normal
1948	62.193	14.9	0.765295	-1.12853	normal	dry
1949	62.92	18.31	1.234921	-0.29513	warm	normal
1950	60.222	14.65	-0.50793	-1.18963	normal	dry
1951	59.1	24.57	-1.23272	1.234813	cool	wet
1952	60.733	19.5	-0.17784	-0.00429	normal	normal
1953	62.7	22.16	1.092806	0.64581	warm	normal
1954	59.787	19.98	-0.78893	0.113019	normal	normal
1955	63.628	19.7	1.692275	0.044587	very warm	normal
1956	61.677	20.8	0.431969	0.313427	normal	normal
1957	60.182	27.58	-0.53377	1.970456	normal	very wet
1958	60.47	15.13	-0.34773	-1.07232	normal	dry
1959	61.565	21.71	0.359619	0.53583	normal	normal
1960	61.117	17.18	0.070221	-0.5713	normal	normal
1961	61.045	18.06	0.02371	-0.35623	normal	normal
1962	60.667	23.46	-0.22047	0.96353	normal	normal
1963	63.393	20.39	1.54047	0.213223	very warm	normal
1964	61.768	17.49	0.490753	-0.49554	normal	normal
1965	59.612	25.2	-0.90198	1.388785	normal	wet
1966	60.358	17.02	-0.42008	-0.6104	normal	normal
1967	58.66	14.87	-1.51695	-1.13586	very cool	dry
1968	60.352	24.56	-0.42395	1.232369	normal	wet
1969	60.057	13.89	-0.61452	-1.37537	normal	dry
1970	61.785	18.78	0.501735	-0.18026	normal	normal
1971	60.78	23.88	-0.14747	1.066177	normal	wet
1972	59.833	23.38	-0.75922	0.943978	normal	normal
1973	61.753	20.77	0.481064	0.306095	normal	normal
1974	59.858	15.3	-0.74307	-1.03077	normal	dry
1975	61.88	16.43	0.563103	-0.7546	normal	normal
1976	61.09	9.49	0.052779	-2.45073	normal	ext. dry
1977	62.062	23.48	0.680671	0.968418	normal	normal
1978	62.15	20.82	0.737517	0.318315	normal	normal

1979	59.533	21.78	-0.95301	0.552938	normal	normal
1980	60.88	19.38	-0.08288	-0.03362	normal	normal
1981	60.068	21.54	-0.60741	0.494282	normal	normal
1982	60.835	22.02	-0.11195	0.611594	normal	normal
1983	62.048	22.46	0.671628	0.71913	normal	normal
1984	61.03	24.72	0.014021	1.271473	normal	wet
1985	59.765	24.89	-0.80314	1.313021	normal	wet
1986	60.965	26.35	-0.02797	1.669845	normal	very wet
1987	62.435	16.48	0.921621	-0.74238	normal	normal
1988	64.173	13.32	2.044334	-1.51468	ext. warm	very dry
1989	61.598	16.58	0.380937	-0.71794	normal	normal
1990	60.953	23.24	-0.03572	0.909762	normal	normal
1991	61.993	24.97	0.636099	1.332573	normal	wet
1992	58.508	17.06	-1.61514	-0.60063	very cool	normal
1993	58.335	26.42	-1.72689	1.686953	very cool	very wet
1994	61.678	20.3	0.432615	0.191227	normal	normal
1995	61.233	23.18	0.145154	0.895098	normal	normal
1996	60.247	17.23	-0.49178	-0.55908	normal	normal
1997	61.78	20.07	0.498505	0.135015	normal	normal
1998	64.167	21	2.040458	0.362307	ext. warm	normal
1999	62.328	21.58	0.852502	0.504058	normal	normal
2000	62.283	16	0.823433	-0.85969	normal	normal
2001	62.588	15.82	1.020456	-0.90368	warm	normal
2002	61.243	28.34	0.151614	2.1562	normal	ext. wet
2003	62.272	17.69	0.816327	-0.44666	normal	normal
2004	60.35	24.7	-0.42525	1.266585	normal	wet
2005	63.227	25.62	1.433237	1.491433	warm	wet
2006	62.238	15.48	0.794364	-0.98678	normal	normal

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YEAR	EC_T	EC_P	EC_Tz	EC_Pz	T_class	P_class
1891	59.01	14.95	-0.08242	-1.37975	normal	dry
1892	59.133	21.96	0.000646	0.355864	normal	normal
1893	59.555	13.8	0.285654	-1.66448	normal	very dry
1894	61.365	14.15	1.50808	-1.57782	very warm	very dry
1895	58.392	17.81	-0.49981	-0.67164	normal	normal
1896	58.57	18.72	-0.37959	-0.44633	normal	normal
1897	60.097	23.06	0.651706	0.628215	normal	normal
1898	59.105	21.05	-0.01826	0.130556	normal	normal
1899	59.49	26.38	0.241754	1.450218	normal	wet
1900	63.022	22.51	2.627175	0.492039	ext. warm	normal
1901	60.98	18.4	1.248062	-0.52556	warm	normal
1902	58.482	22.79	-0.43902	0.561365	normal	normal
1903	57.845	28.76	-0.86924	2.039486	normal	ext. wet
1904	58.047	22.76	-0.73281	0.553937	normal	normal
1905	58.623	27.42	-0.34379	1.707713	normal	very wet
1906	59.447	24.03	0.212713	0.868378	normal	normal
1907	56.502	19.14	-1.77626	-0.34234	very cool	normal
1908	59.372	23.34	0.16206	0.69754	normal	normal
1909	58.515	18.95	-0.41674	-0.38939	normal	normal
1910	59.558	11.09	0.28768	-2.33545	normal	ext. dry
1911	58.165	22.92	-0.65312	0.593552	normal	normal
1912	57.705	18.57	-0.96379	-0.48347	normal	normal
1913	57.922	23.23	-0.81723	0.670305	normal	normal
1914	60.383	22.77	0.844863	0.556413	normal	normal
1915	55.85	21.22	-2.21661	0.172647	ext. cool	normal
1916	58.025	21.15	-0.74767	0.155315	normal	normal
1917	54.605	14.83	-3.05745	-1.40946	ext. cool	dry
1918	57.448	16.48	-1.13736	-1.00094	cool	dry
1919	58.313	18.65	-0.55316	-0.46366	normal	normal
1920	59.968	21.66	0.564583	0.281587	normal	normal
1921	61.663	16.99	1.709342	-0.87467	very warm	normal
1922	61.192	13.89	1.391241	-1.6422	warm	very dry
1923	59.753	15.5	0.419378	-1.24358	normal	dry
1924	56.625	21.35	-1.69319	0.204833	very cool	normal
1925	56.607	16.72	-1.70535	-0.94151	very cool	normal
1926	57.492	20.58	-1.10764	0.014188	cool	normal
1927	57.003	17.3	-1.4379	-0.79791	cool	normal
1928	58.035	23.21	-0.74091	0.665353	normal	normal
1929	58.21	14.92	-0.62272	-1.38718	normal	dry
1930	60.13	16.59	0.673994	-0.9737	normal	normal
1931	61.977	19	1.921409	-0.37701	very warm	normal
1932	59.905	14.06	0.522035	-1.60011	normal	very dry

1933	61.468	17.06	1.577644	-0.85733	very warm	normal
1934	60.62	17.61	1.004927	-0.72116	warm	normal
1935	58.268	21.64	-0.58355	0.276635	normal	normal
1936	60.643	10.95	1.020461	-2.37012	warm	ext. dry
1937	59.877	18.57	0.503124	-0.48347	normal	normal
1938	60.348	23.26	0.821225	0.677733	normal	normal
1939	60.502	17.34	0.925233	-0.78801	normal	normal
1940	59.915	16.53	0.528788	-0.98856	normal	normal
1941	61.068	26.13	1.307494	1.38832	warm	wet
1942	57.262	22.65	-1.26298	0.526702	cool	normal
1943	58.85	22.43	-0.19048	0.472232	normal	normal
1944	59.558	27.58	0.28768	1.747328	normal	very wet
1945	56.22	20.26	-1.96672	-0.06504	very cool	normal
1946	58.042	23.65	-0.73619	0.774294	normal	normal
1947	60.635	15.59	1.015058	-1.22129	warm	dry
1948	60.477	13.08	0.908348	-1.84275	normal	very dry
1949	60.727	21.84	1.077192	0.326153	warm	normal
1950	58.14	16.04	-0.67	-1.10988	normal	dry
1951	57.412	26.82	-1.16167	1.559158	cool	very wet
1952	58.708	22.18	-0.28639	0.410334	normal	normal
1953	60.802	24.88	1.127845	1.078831	warm	wet
1954	57.75	22.05	-0.9334	0.378147	normal	normal
1955	61.665	23.16	1.710693	0.652974	very warm	normal
1956	59.242	18.61	0.074262	-0.47357	normal	normal
1957	58.442	23.61	-0.46604	0.76439	normal	normal
1958	58.133	18.46	-0.67473	-0.51071	normal	normal
1959	59.672	22.17	0.364673	0.407858	normal	normal
1960	59.467	16.32	0.226221	-1.04055	normal	dry
1961	59.557	16.31	0.287005	-1.04303	normal	dry
1962	58.685	22.39	-0.30192	0.462328	normal	normal
1963	61.318	18.68	1.476338	-0.45624	warm	normal
1964	59.523	20.95	0.264042	0.105797	normal	normal
1965	57.405	25.42	-1.1664	1.21253	cool	wet
1966	58.325	18.12	-0.54506	-0.59489	normal	normal
1967	56.858	15.7	-1.53583	-1.19406	very cool	dry
1968	58.54	27.71	-0.39985	1.779515	normal	very wet
1969	58.138	14.88	-0.67135	-1.39708	normal	dry
1970	59.735	19.87	0.407221	-0.1616	normal	normal
1971	58.88	23.5	-0.17022	0.737155	normal	normal
1972	57.72	25.9	-0.95366	1.331374	normal	wet
1973	59.663	23.96	0.358594	0.851047	normal	normal
1974	57.43	18.22	-1.14952	-0.57013	cool	normal
1975	59.758	20.54	0.422755	0.004284	normal	normal
1976	58.88	11.03	-0.17022	-2.35031	normal	ext. dry
1977	59.727	25.43	0.401818	1.215006	normal	wet
1978	59.818	24.33	0.463277	0.942656	normal	normal
1979	57.292	20.99	-1.24272	0.115701	cool	normal
1980	58.617	19.98	-0.34785	-0.13437	normal	normal
1981	57.722	21.87	-0.95231	0.333581	normal	normal

1982	58.722	21.82	-0.27693	0.321201	normal	normal
1983	59.927	21.93	0.536893	0.348436	normal	normal
1984	59.083	24.5	-0.03312	0.984746	normal	normal
1985	57.605	24.94	-1.03133	1.093687	cool	wet
1986	59.012	28	-0.08107	1.851316	normal	very wet
1987	60.462	16.95	0.898218	-0.88457	normal	normal
1988	61.495	17.04	1.595879	-0.86229	very warm	normal
1989	59.822	18.59	0.465979	-0.47852	normal	normal
1990	59.152	23.49	0.013478	0.734679	normal	normal
1991	60.168	25.78	0.699658	1.301663	normal	wet
1992	57.128	17.57	-1.35348	-0.73106	cool	normal
1993	56.977	23.64	-1.45546	0.771818	cool	normal
1994	60.218	21.29	0.733427	0.189978	normal	normal
1995	60.015	26.28	0.596326	1.425459	normal	wet
1996	58.835	19.3	-0.20062	-0.30273	normal	normal
1997	59.187	19.66	0.037116	-0.2136	normal	normal
1998	61.987	20.02	1.928163	-0.12446	very warm	normal
1999	60.522	25.76	0.93874	1.296711	normal	wet
2000	59.993	17.61	0.581468	-0.72116	normal	normal
2001	60.83	19.51	1.146755	-0.25073	warm	normal
2002	59.138	28.99	0.004023	2.096432	normal	ext. wet
2003	60.563	20.29	0.966431	-0.05761	normal	normal
2004	58.457	22.94	-0.45591	0.598504	normal	normal
2005	61.297	25.3	1.462155	1.182819	warm	wet
2006	**60.55**	**15.73**	**0.957651**	**-1.18663**	**normal**	**dry**

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YEAR	SW_T	SW_P	SW_Tz	SW_Pz	T_class	P_class
1891	61.687	14.55	-0.4586	-1.04412	normal	dry
1892	60.187	22.44	-1.39443	0.828434	cool	normal
1893	61.845	11.69	-0.36003	-1.72289	normal	very dry
1894	64.947	11.08	1.575269	-1.86766	very warm	very dry
1895	61.993	16.45	-0.26769	-0.59319	normal	normal
1896	60.042	20.34	-1.48489	0.330036	cool	normal
1897	62.268	16.77	-0.09612	-0.51724	normal	normal
1898	60.808	17.36	-1.007	-0.37721	cool	normal
1899	61.663	20.05	-0.47357	0.26121	normal	normal
1900	64.613	21.79	1.366891	0.674168	warm	normal
1901	63.48	17.35	0.660028	-0.37959	normal	normal
1902	60.382	20.46	-1.27277	0.358516	cool	normal
1903	59.41	31.1	-1.87919	2.883733	very cool	ext. wet
1904	60.397	20.74	-1.26341	0.424969	cool	normal
1905	61.11	26.2	-0.81858	1.720804	normal	very wet
1906	61.785	21.84	-0.39746	0.686035	normal	normal
1907	59.54	20.35	-1.79808	0.33241	very cool	normal
1908	61.562	24.8	-0.53659	1.388539	normal	wet
1909	61.557	18.82	-0.5397	-0.03071	normal	normal
1910	61.882	13.08	-0.33694	-1.393	normal	dry
1911	62.188	22.12	-0.14603	0.752488	normal	normal
1912	60.557	14.43	-1.16359	-1.0726	cool	dry
1913	61.653	19.7	-0.47981	0.178144	normal	normal
1914	63.862	26.42	0.898353	1.773017	normal	very wet
1915	59.003	21.34	-2.13311	0.567369	ext. cool	normal
1916	61.467	15.91	-0.59585	-0.72135	normal	normal
1917	58.51	16.17	-2.44069	-0.65964	ext. cool	normal
1918	62.05	20.36	-0.23213	0.334783	normal	normal
1919	61.422	20.57	-0.62393	0.384623	normal	normal
1920	62.8	22.52	0.235786	0.847421	normal	normal
1921	64.822	17.9	1.497283	-0.24905	warm	normal
1922	64.753	11.45	1.454235	-1.77985	warm	very dry
1923	62.513	16.81	0.05673	-0.50775	normal	normal
1924	60.342	17.97	-1.29773	-0.23244	cool	normal
1925	61.033	16.67	-0.86662	-0.54097	normal	normal
1926	62.802	19.12	0.237033	0.040491	normal	normal
1927	61.383	16.17	-0.64826	-0.65964	normal	normal
1928	61.952	18.93	-0.29327	-0.0046	normal	normal
1929	61.495	19.82	-0.57839	0.206624	normal	normal
1930	63.028	18.28	0.378032	-0.15887	normal	normal
1931	66.088	12.97	2.287123	-1.4191	ext. warm	dry
1932	63.265	16.22	0.525893	-0.64777	normal	normal
1933	65.058	16.29	1.644521	-0.63116	very warm	normal
1934	65.715	18.03	2.054414	-0.2182	ext.	normal

					warm	
1935	62.603	15.15	0.11288	-0.90172	normal	normal
1936	65.883	12.77	2.159227	-1.46657	ext. warm	dry
1937	63.913	16.61	0.930171	-0.55521	normal	normal
1938	65.09	21.94	1.664485	0.709768	very warm	normal
1939	65.082	18.11	1.659494	-0.19921	very warm	normal
1940	64.748	16.51	1.451116	-0.57895	warm	normal
1941	65.038	18.4	1.632043	-0.13039	very warm	normal
1942	60.77	23.77	-1.0307	1.144086	cool	wet
1943	61.733	26.29	-0.4299	1.742164	normal	very wet
1944	62.923	22.44	0.312524	0.828434	normal	normal
1945	59.912	19.41	-1.566	0.109317	very cool	normal
1946	61.313	21.94	-0.69193	0.709768	normal	normal
1947	63.948	16.94	0.952007	-0.47689	normal	normal
1948	63.563	16.87	0.711811	-0.49351	normal	normal
1949	64.118	16.51	1.058068	-0.57895	warm	normal
1950	61.327	15.63	-0.6832	-0.7878	normal	normal
1951	60.013	21.74	-1.50299	0.662302	very cool	normal
1952	62.305	14.07	-0.07304	-1.15804	normal	dry
1953	63.97	20.46	0.965732	0.358516	normal	normal
1954	61.632	17.62	-0.49291	-0.31551	normal	normal
1955	65.407	12.44	1.862257	-1.54489	very warm	very dry
1956	63.862	17.5	0.898353	-0.34399	normal	normal
1957	61.287	25.23	-0.70815	1.490592	normal	wet
1958	62.765	11.85	0.21395	-1.68492	normal	very dry
1959	63.027	21.9	0.377408	0.700275	normal	normal
1960	62.412	21.82	-0.00628	0.681288	normal	normal
1961	61.977	19.05	-0.27767	0.023878	normal	normal
1962	62.518	21.22	0.05985	0.538889	normal	normal
1963	65.03	22.53	1.627052	0.849794	very warm	normal
1964	62.977	18.61	0.346213	-0.08055	normal	normal
1965	61.52	21.43	-0.56279	0.588729	normal	normal
1966	62.02	17.04	-0.25085	-0.45316	normal	normal
1967	60.343	13.51	-1.2971	-1.29094	cool	dry
1968	61.557	27.51	-0.5397	2.03171	normal	ext. wet
1969	61.217	18.15	-0.75183	-0.18972	normal	normal
1970	63.02	20.29	0.373041	0.31817	normal	normal
1971	62.472	17.95	0.031151	-0.23719	normal	normal
1972	61.148	20.15	-0.79487	0.284943	normal	normal
1973	63.727	15.43	0.814128	-0.83527	normal	normal
1974	61.638	13.66	-0.48917	-1.25534	normal	dry
1975	63.413	13.5	0.618228	-1.29332	normal	dry
1976	62.523	9.54	0.062969	-2.23315	normal	ext. dry
1977	63.543	23.8	0.699333	1.151206	normal	wet
1978	63.112	16.12	0.430438	-0.67151	normal	normal
1979	61.208	27.9	-0.75744	2.124269	normal	ext. wet

1980	62.932	16.78	0.318139	-0.51487	normal	normal
1981	61.883	18.74	-0.33632	-0.0497	normal	normal
1982	62.017	22.07	-0.25272	0.740621	normal	normal
1983	63.618	17.9	0.746124	-0.24905	normal	normal
1984	61.963	21.95	-0.28641	0.712142	normal	normal
1985	60.832	21.31	-0.99202	0.560249	normal	normal
1986	61.988	24.4	-0.27081	1.293606	normal	wet
1987	63.307	15.41	0.552096	-0.84001	normal	normal
1988	65.142	11.72	1.696927	-1.71577	very warm	very dry
1989	62.973	13.99	0.343718	-1.17702	normal	dry
1990	62.435	19.18	0.008067	0.054731	normal	normal
1991	63.003	22.96	0.362434	0.951847	normal	normal
1992	59.707	22.12	-1.69389	0.752488	very cool	normal
1993	59.73	32.9	-1.67955	3.310931	very cool	ext. wet
1994	63.025	20.76	0.37616	0.429716	normal	normal
1995	62.072	23.1	-0.2184	0.985074	normal	normal
1996	61.028	19.96	-0.86974	0.23985	normal	normal
1997	62.76	16.12	0.21083	-0.67151	normal	normal
1998	64.97	18.33	1.589619	-0.147	very warm	normal
1999	63.285	14.42	0.53837	-1.07497	normal	dry
2000	63.278	18.79	0.534003	-0.03783	normal	normal
2001	63.53	15.25	0.691223	-0.87799	normal	normal
2002	62.128	19.74	-0.18347	0.187637	normal	normal
2003	62.63	16.26	0.129725	-0.63828	normal	normal
2004	61.553	24.31	-0.5422	1.272246	normal	wet
2005	64.223	25.97	1.123576	1.666218	warm	very wet
2006	62.767	15	0.215197	-0.93732	normal	normal

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YEAR	SC_T	SC_P	SC_Tz	SC_Pz	T_class	P_class
1891	60.833	15.31	-1.21477	-1.3467	cool	dry
1892	59.755	25.47	-1.91415	1.033836	very cool	wet
1893	61.823	13.97	-0.57247	-1.66067	normal	very dry
1894	64.26	12.77	1.008607	-1.94184	warm	very dry
1895	62.11	18.26	-0.38627	-0.6555	normal	normal
1896	61.535	18.23	-0.75932	-0.66253	normal	normal
1897	62.822	17.5	0.075659	-0.83358	normal	normal
1898	61.572	17.66	-0.73532	-0.79609	normal	normal
1899	62.975	23.5	0.174923	0.572255	normal	normal
1900	65.758	24.05	1.980481	0.701122	very warm	normal
1901	64.785	20.33	1.349217	-0.17049	warm	normal
1902	61.097	27.14	-1.04349	1.425125	cool	wet
1903	60.785	29.83	-1.24591	2.055406	cool	ext. wet
1904	60.873	19.13	-1.18882	-0.45166	cool	normal
1905	61.822	26.27	-0.57312	1.22128	normal	wet
1906	62.33	25.66	-0.24354	1.078354	normal	wet
1907	59.217	21.97	-2.2632	0.213768	ext. cool	normal
1908	62.49	28.22	-0.13974	1.678175	normal	very wet
1909	61.988	21.39	-0.46542	0.077871	normal	normal
1910	62.753	11.86	0.030893	-2.15506	normal	ext. dry
1911	63.095	25.09	0.252776	0.9448	normal	normal
1912	61.458	17.87	-0.80928	-0.74688	normal	normal
1913	62.68	21.78	-0.01647	0.16925	normal	normal
1914	64.6	24.59	1.229192	0.827647	warm	normal
1915	59.61	24.12	-2.00823	0.717524	ext. cool	normal
1916	62.145	20.58	-0.36357	-0.11192	normal	normal
1917	59.275	19.98	-2.22557	-0.2525	ext. cool	normal
1918	62.258	26.92	-0.29025	1.373578	normal	wet
1919	62.405	20.49	-0.19488	-0.133	normal	normal
1920	63.472	16.96	0.497367	-0.9601	normal	normal
1921	65.278	20.15	1.669066	-0.21267	very warm	normal
1922	65.155	13.23	1.589266	-1.83406	very warm	very dry
1923	62.812	18.77	0.069171	-0.53601	normal	normal
1924	60.102	21.55	-1.68903	0.11536	very cool	normal
1925	60.518	21.36	-1.41913	0.070842	cool	normal
1926	62.22	21.23	-0.31491	0.040382	normal	normal
1927	61.15	17.73	-1.0091	-0.77969	cool	normal
1928	61.907	21.05	-0.51798	-0.00179	normal	normal
1929	61.427	18.87	-0.82939	-0.51258	normal	normal
1930	62.762	21.17	0.036732	0.026324	normal	normal
1931	65.765	17.06	1.985023	-0.93667	very warm	normal
1932	63.032	16.74	0.211903	-1.01165	normal	dry

1933	65.108	15.47	1.558773	-1.30922	very warm	dry
1934	65.883	15.79	2.061579	-1.23424	ext. warm	dry
1935	62.055	20.61	-0.42196	-0.10489	normal	normal
1936	65.388	14.61	1.740432	-1.51072	very warm	very dry
1937	63.98	18	0.826948	-0.71642	normal	normal
1938	64.853	23.81	1.393334	0.644889	warm	normal
1939	65.205	16.08	1.621705	-1.16629	very warm	dry
1940	64.013	21.42	0.848358	0.0849	normal	normal
1941	64.87	23.86	1.404363	0.656604	warm	normal
1942	61.243	23.04	-0.94877	0.464474	normal	normal
1943	61.948	27.22	-0.49138	1.44387	normal	wet
1944	63.348	24.57	0.416918	0.822961	normal	normal
1945	60.135	22.59	-1.66762	0.359037	very cool	normal
1946	61.882	23.03	-0.5342	0.462131	normal	normal
1947	64.628	20.97	1.247358	-0.02054	warm	normal
1948	63.93	17.62	0.794509	-0.80546	normal	normal
1949	65.178	16.11	1.604188	-1.15926	very warm	dry
1950	62.063	16.03	-0.41677	-1.178	normal	dry
1951	61.103	25.36	-1.0396	1.008062	cool	wet
1952	62.505	17.58	-0.13	-0.81483	normal	normal
1953	64.787	19.97	1.350515	-0.25484	warm	normal
1954	62.267	22.3	-0.28441	0.291088	normal	normal
1955	65.54	15.75	1.839047	-1.24361	very warm	dry
1956	63.803	20.92	0.712114	-0.03225	normal	normal
1957	62.162	23.99	-0.35254	0.687064	normal	normal
1958	62.983	13.08	0.180113	-1.8692	normal	very dry
1959	63.422	26.88	0.464928	1.364206	normal	wet
1960	62.818	22.08	0.073064	0.239541	normal	normal
1961	62.455	21.73	-0.16244	0.157535	normal	normal
1962	62.563	23.08	-0.09238	0.473846	normal	normal
1963	64.987	20.76	1.480271	-0.06974	warm	normal
1964	63.445	22.82	0.47985	0.412927	normal	normal
1965	61.74	23.86	-0.62632	0.656604	normal	normal
1966	61.918	18.51	-0.51084	-0.59693	normal	normal
1967	60.238	18.59	-1.60079	-0.57818	very cool	normal
1968	61.825	32.23	-0.57118	2.617738	normal	ext. wet
1969	61.755	17.92	-0.61659	-0.73517	normal	normal
1970	63.212	23.18	0.328684	0.497277	normal	normal
1971	62.778	20.28	0.047113	-0.18221	normal	normal
1972	61.385	20.45	-0.85664	-0.14238	normal	normal
1973	63.473	20.95	0.498016	-0.02522	normal	normal
1974	61.498	17.38	-0.78333	-0.86169	normal	normal
1975	63.717	16.08	0.656318	-1.16629	normal	dry
1976	62.233	12.28	-0.30647	-2.05665	normal	ext. dry
1977	63.718	24.69	0.656967	0.851078	normal	normal
1978	63.488	19.5	0.507748	-0.36497	normal	normal

1979	61.41	25.76	-0.84042	1.101784	normal	wet
1980	62.8	20.02	0.061386	-0.24313	normal	normal
1981	61.61	24.92	-0.71066	0.904968	normal	normal
1982	62.197	24.02	-0.32983	0.694093	normal	normal
1983	63.87	21.4	0.755582	0.080214	normal	normal
1984	62.517	21.72	-0.12222	0.155191	normal	normal
1985	61.367	20.49	-0.86832	-0.133	normal	normal
1986	62.63	27.18	-0.04891	1.434497	normal	wet
1987	63.938	18.71	0.799699	-0.55007	normal	normal
1988	65.673	12.09	1.925335	-2.10117	very warm	ext. dry
1989	63.195	14.3	0.317655	-1.58335	normal	very dry
1990	62.792	25.04	0.056196	0.933085	normal	normal
1991	63.418	26.69	0.462333	1.319688	normal	wet
1992	59.945	22.18	-1.79088	0.262972	very cool	normal
1993	60.078	32.91	-1.7046	2.777066	very cool	ext. wet
1994	63.118	23.91	0.267698	0.66832	normal	normal
1995	62.732	23.83	0.017269	0.649575	normal	normal
1996	61.148	20.8	-1.0104	-0.06037	cool	normal
1997	62.393	22.14	-0.20267	0.2536	normal	normal
1998	64.977	23.48	1.473783	0.567569	warm	normal
1999	63.083	21.76	0.244991	0.164564	normal	normal
2000	63.347	22.86	0.416269	0.422299	normal	normal
2001	63.205	19.44	0.324142	-0.37902	normal	normal
2002	62.37	24.33	-0.21759	0.766728	normal	normal
2003	62.842	16.01	0.088635	-1.18269	normal	dry
2004	61.69	30.27	-0.65876	2.1585	normal	ext. wet
2005	64.537	26.53	1.188319	1.282199	warm	wet
2006	63.15	17.61	0.288459	-0.8078	normal	normal

May-Oct southeast MN

YEAR	SE_T	SE_P	SE_Tz	SE_Pz	T_class	P_class
1891	60.04	17.44	-1.3667	-0.96678	cool	normal
1892	60.372	26.17	-1.1461	0.944002	cool	normal
1893	61.777	14.75	-0.21252	-1.55556	normal	very dry
1894	63.577	14.8	0.983513	-1.54462	normal	very dry
1895	61.348	18.47	-0.49758	-0.74134	normal	normal
1896	61.158	18.56	-0.62383	-0.72164	normal	normal
1897	62.38	17.95	0.188148	-0.85516	normal	normal
1898	61.622	16.88	-0.31552	-1.08936	normal	dry
1899	62.23	24.32	0.088478	0.539082	normal	normal
1900	64.948	29.7	1.894495	1.716635	very warm	very wet
1901	63.863	23.97	1.17355	0.462475	warm	normal
1902	61.508	29.67	-0.39127	1.710068	normal	very wet
1903	60.537	30.04	-1.03646	1.791052	cool	very wet
1904	60.612	23.16	-0.98663	0.285186	normal	normal
1905	61.285	24.78	-0.53944	0.639765	normal	normal
1906	62.42	24.9	0.214726	0.66603	normal	normal
1907	59.175	22.79	-1.94146	0.204202	very cool	normal
1908	62.03	24.41	-0.04442	0.558781	normal	normal
1909	61.552	20.47	-0.36203	-0.30359	normal	normal
1910	62.677	11.32	0.385494	-2.30631	normal	ext. dry
1911	62.723	30.25	0.416059	1.837016	normal	very wet
1912	60.567	20.15	-1.01653	-0.37363	cool	normal
1913	62.413	22.99	0.210075	0.247977	normal	normal
1914	63.743	25.01	1.093814	0.690106	warm	normal
1915	58.95	26.07	-2.09097	0.922115	ext. cool	normal
1916	61.595	20.07	-0.33346	-0.39114	normal	normal
1917	57.85	21.77	-2.82188	-0.01905	ext. cool	normal
1918	61.062	21.61	-0.68762	-0.05407	normal	normal
1919	61.765	19	-0.2205	-0.62534	normal	normal
1920	63.098	18.3	0.665234	-0.77855	normal	normal
1921	64.76	21	1.769576	-0.18759	very warm	normal
1922	64.082	16.43	1.319068	-1.18785	warm	dry
1923	62.552	17.66	0.302436	-0.91863	normal	normal
1924	59.568	24.08	-1.68033	0.486552	very cool	normal
1925	59.925	25.57	-1.44312	0.812677	cool	normal
1926	61.355	20.87	-0.49293	-0.21604	normal	normal
1927	60.417	18.53	-1.1162	-0.72821	cool	normal
1928	61.617	24.78	-0.31884	0.639765	normal	normal
1929	60.903	17.53	-0.79327	-0.94709	normal	normal
1930	62.298	20.56	0.133662	-0.28389	normal	normal
1931	65.425	18.54	2.211446	-0.72602	ext. warm	normal

1932	62.418	15.42	0.213397	-1.40891	normal	dry
1933	64.46	18.64	1.570236	-0.70413	very warm	normal
1934	65.087	19.06	1.986856	-0.61221	very warm	normal
1935	61.553	23.41	-0.36137	0.339905	normal	normal
1936	65.203	16.58	2.063934	-1.15502	ext. warm	dry
1937	63.667	17.68	1.043315	-0.91425	warm	normal
1938	63.87	29.96	1.178202	1.773542	warm	very wet
1939	64.533	15.73	1.618742	-1.34106	very warm	dry
1940	63.185	19.97	0.723043	-0.41303	normal	normal
1941	64.308	22.06	1.469237	0.044422	warm	normal
1942	60.43	30.28	-1.10756	1.843583	cool	very wet
1943	61.313	21.83	-0.52084	-0.00592	normal	normal
1944	62.478	20.86	0.253265	-0.21823	normal	normal
1945	59.81	23.28	-1.51953	0.311451	very cool	normal
1946	61.667	22.13	-0.28562	0.059744	normal	normal
1947	63.875	22.01	1.181524	0.033479	warm	normal
1948	63.832	14.65	1.152952	-1.57745	warm	very dry
1949	65.202	14.3	2.06327	-1.65406	ext. warm	very dry
1950	62.423	18.03	0.21672	-0.83765	normal	normal
1951	61.147	25.8	-0.63114	0.863018	normal	normal
1952	61.628	18.13	-0.31153	-0.81576	normal	normal
1953	64.222	19.93	1.412093	-0.42178	warm	normal
1954	61.98	26.47	-0.07764	1.009665	normal	wet
1955	64.963	15.9	1.904462	-1.30385	very warm	dry
1956	63.382	21.23	0.853942	-0.13724	normal	normal
1957	61.733	26.49	-0.24176	1.014043	normal	wet
1958	61.967	15.3	-0.08628	-1.43518	normal	dry
1959	62.865	29.47	0.510414	1.666293	normal	very wet
1960	61.892	22.31	-0.13611	0.099141	normal	normal
1961	61.798	20.4	-0.19857	-0.31891	normal	normal
1962	61.342	23.44	-0.50157	0.346471	normal	normal
1963	63.387	16.39	0.857265	-1.1966	normal	dry
1964	62.515	17.07	0.277851	-1.04777	normal	dry
1965	60.745	25.5	-0.89825	0.797356	normal	normal
1966	60.725	18.25	-0.91154	-0.7895	normal	normal
1967	59.295	18.34	-1.86173	-0.7698	very cool	normal
1968	61.005	28.89	-0.72549	1.539345	normal	very wet
1969	60.588	20.89	-1.00257	-0.21166	cool	normal
1970	62.583	26.27	0.323034	0.96589	normal	normal
1971	61.985	20.64	-0.07432	-0.26638	normal	normal
1972	60.342	25.98	-1.16603	0.902416	cool	normal
1973	62.38	25.81	0.188148	0.865207	normal	normal
1974	60.14	18.77	-1.30026	-0.67568	cool	normal

1975	62.45	17.88	0.23466	-0.87048	normal	normal
1976	61.047	11.86	-0.69758	-2.18811	normal	ext. dry
1977	62.913	22.16	0.542308	0.06631	normal	normal
1978	62.44	27.41	0.228016	1.215409	normal	wet
1979	61.298	24.48	-0.5308	0.574102	normal	normal
1980	62.392	25.91	0.196121	0.887095	normal	normal
1981	60.832	25.01	-0.84044	0.690106	normal	normal
1982	61.935	23.96	-0.10754	0.460287	normal	normal
1983	62.773	25.58	0.449283	0.814866	normal	normal
1984	61.903	21.1	-0.1288	-0.1657	normal	normal
1985	61.265	18.22	-0.55273	-0.79606	normal	normal
1986	61.617	31.48	-0.31884	2.106234	normal	ext. wet
1987	62.732	21.6	0.42204	-0.05626	normal	normal
1988	64.492	14.9	1.591499	-1.52273	very warm	very dry
1989	62.23	16.09	0.088478	-1.26227	normal	dry
1990	61.94	28.35	-0.10422	1.421152	normal	wet
1991	62.867	24.23	0.511743	0.519383	normal	normal
1992	59.543	18.93	-1.69694	-0.64066	very cool	normal
1993	59.79	29.14	-1.53282	1.594064	very cool	very wet
1994	62.6	23.5	0.33433	0.359604	normal	normal
1995	62.775	19.95	0.450612	-0.41741	normal	normal
1996	60.502	17.96	-1.05972	-0.85297	cool	normal
1997	61.425	25.26	-0.44642	0.744825	normal	normal
1998	64.39	27.61	1.523724	1.259184	very warm	wet
1999	62.798	24.96	0.465894	0.679163	normal	normal
2000	62.86	26.25	0.507091	0.961513	normal	normal
2001	62.493	22.29	0.263232	0.094764	normal	normal
2002	61.993	26.67	-0.069	1.05344	normal	wet
2003	62.295	15.73	0.131668	-1.34106	normal	dry
2004	61.125	31.96	-0.64576	2.211294	normal	ext. wet
2005	63.72	24.26	1.078532	0.525949	warm	normal
2006	61.998	19.55	-0.06568	-0.50496	normal	normal

Jun-Aug northwest MN

YEAR	NW_T	NW_P	NW_Tz	NW_Pz	T_class	P_class
1891	62.373	12.2	-1.53046	0.822185	very cool	normal
1892	65.283	8.02	-0.05445	-0.79951	normal	normal
1893	66.107	9.58	0.363496	-0.19428	normal	normal
1894	68.38	5.23	1.516402	-1.88193	very warm	very dry
1895	61.593	13.16	-1.92609	1.194631	very cool	wet
1896	64.617	7.14	-0.39226	-1.14092	normal	dry
1897	63.117	13.85	-1.15309	1.462327	cool	wet
1898	63.017	11.08	-1.20381	0.387664	cool	normal
1899	64.647	11.12	-0.37704	0.403183	normal	normal
1900	67.243	12.62	0.939696	0.98513	normal	normal
1901	66.177	13.66	0.399001	1.388614	normal	wet
1902	63.407	9.65	-1.00599	-0.16713	cool	normal
1903	63.393	7.96	-1.01309	-0.82279	cool	normal
1904	62.82	8.54	-1.30373	-0.59777	cool	normal
1905	64.153	14.49	-0.62761	1.710625	normal	very wet
1906	65.147	10.35	-0.12343	0.10445	normal	normal
1907	63.957	10.72	-0.72702	0.247997	normal	normal
1908	64.04	9.08	-0.68492	-0.38827	normal	normal
1909	66.387	13.19	0.505517	1.20627	normal	wet
1910	66.35	3.94	0.48675	-2.38241	normal	ext. dry
1911	64.687	9.6	-0.35675	-0.18652	normal	normal
1912	63.153	8.87	-1.13483	-0.46974	cool	normal
1913	65.333	8.27	-0.02909	-0.70252	normal	normal
1914	65.303	12.39	-0.04431	0.895898	normal	normal
1915	60.027	11.54	-2.72039	0.566128	ext. cool	normal
1916	65.28	11.12	-0.05597	0.403183	normal	normal
1917	63.613	5.87	-0.90151	-1.63363	normal	very dry
1918	63.99	8.33	-0.71028	-0.67924	normal	normal
1919	67.083	14.7	0.858541	1.792097	normal	very wet
1920	65.037	7.91	-0.17923	-0.84218	normal	normal
1921	68.053	9.56	1.350542	-0.20204	warm	normal
1922	66.197	7.38	0.409146	-1.04781	normal	dry
1923	66.52	9.56	0.572977	-0.20204	normal	normal
1924	62.157	8.22	-1.64001	-0.72192	very cool	normal
1925	64.087	12.44	-0.66108	0.915296	normal	normal
1926	63.413	8	-1.00295	-0.80727	cool	normal
1927	62.41	8.06	-1.51169	-0.78399	very cool	normal
1928	62.907	13.76	-1.2596	1.42741	cool	wet
1929	65.433	4.75	0.021631	-2.06815	normal	ext. dry
1930	67.93	6.01	1.288154	-1.57932	warm	very dry
1931	66.967	8.62	0.799703	-0.56673	normal	normal
1932	67.763	7.23	1.203449	-1.106	warm	dry
1933	68.983	5.61	1.822255	-1.7345	very warm	very dry

1934	65.143	8.44	-0.12546	-0.63656	normal	normal
1935	65.73	11.1	0.172275	0.395423	normal	normal
1936	68.87	4.58	1.764939	-2.13411	very warm	ext. dry
1937	67.29	10.7	0.963535	0.240237	normal	normal
1938	66.52	7.02	0.572977	-1.18747	normal	dry
1939	66.77	8.95	0.699781	-0.4387	normal	normal
1940	65.107	8.24	-0.14372	-0.71416	normal	normal
1941	66.89	11.44	0.760648	0.527331	normal	normal
1942	63.647	12.04	-0.88426	0.76011	normal	normal
1943	65.91	11.11	0.263574	0.399303	normal	normal
1944	64.58	17.01	-0.41103	2.688296	normal	ext. wet
1945	63.33	9.24	-1.04505	-0.32619	cool	normal
1946	64.653	8.95	-0.374	-0.4387	normal	normal
1947	65.97	11.54	0.294007	0.566128	normal	normal
1948	66.173	11.3	0.396972	0.473016	normal	normal
1949	67.633	12.13	1.137511	0.795027	warm	normal
1950	63.53	8.3	-0.9436	-0.69088	normal	normal
1951	63.097	9.86	-1.16323	-0.08565	cool	normal
1952	65.53	11.78	0.070831	0.659239	normal	normal
1953	66.343	10.08	0.483199	-0.0003	normal	normal
1954	65.433	7.8	0.021631	-0.88486	normal	normal
1955	68.577	10.92	1.616324	0.32559	very warm	normal
1956	65.583	11.05	0.097714	0.376025	normal	normal
1957	65.477	12.51	0.043949	0.942454	normal	normal
1958	62.357	9.99	-1.53857	-0.03522	very cool	normal
1959	67.303	12.29	0.970129	0.857102	normal	normal
1960	65.547	11.04	0.079454	0.372145	normal	normal
1961	67.513	5.87	1.076644	-1.63363	warm	very dry
1962	65.167	11.08	-0.11329	0.387664	normal	normal
1963	67.56	9.91	1.100484	-0.06626	warm	normal
1964	64.283	12.59	-0.56167	0.973491	normal	normal
1965	63.773	9.67	-0.82035	-0.15937	normal	normal
1966	65.983	12.19	0.300601	0.818305	normal	normal
1967	63.733	6.01	-0.84064	-1.57932	normal	very dry
1968	63.433	14.39	-0.9928	1.671828	normal	very wet
1969	63.767	8.8	-0.82339	-0.4969	normal	normal
1970	67.387	7.53	1.012735	-0.98961	warm	normal
1971	64.49	8.9	-0.45668	-0.4581	normal	normal
1972	64.507	8.27	-0.44805	-0.70252	normal	normal
1973	66.087	9.37	0.353352	-0.27576	normal	normal
1974	65.29	10.73	-0.0509	0.251876	normal	normal
1975	65.43	11.57	0.020109	0.577767	normal	normal
1976	67.457	8.46	1.04824	-0.6288	warm	normal
1977	64.057	9.16	-0.6763	-0.35723	normal	normal
1978	64.997	10.56	-0.19952	0.185922	normal	normal
1979	63.943	9.42	-0.73412	-0.25636	normal	normal
1980	64.997	9.4	-0.19952	-0.26412	normal	normal
1981	65.063	12.28	-0.16604	0.853222	normal	normal
1982	62.837	9.36	-1.29511	-0.27964	cool	normal

1983	68.55	12.47	1.602629	0.926935	very warm	normal
1984	67.133	8.82	0.883902	-0.48914	normal	normal
1985	61.863	12.84	-1.78914	1.070482	very cool	wet
1986	65.383	9.23	-0.00373	-0.33007	normal	normal
1987	66.95	9.54	0.791081	-0.2098	normal	normal
1988	70.38	7.5	2.530838	-1.00125	ext. warm	dry
1989	67.183	8.21	0.909262	-0.7258	normal	normal
1990	66.4	8.48	0.512111	-0.62104	normal	normal
1991	68.237	10.81	1.44387	0.282913	warm	normal
1992	61.04	11.62	-2.20658	0.597165	ext. cool	normal
1993	63.02	16.4	-1.20229	2.451638	cool	ext. wet
1994	64.187	12.96	-0.61036	1.117038	normal	wet
1995	67.943	11.99	1.294748	0.740712	warm	normal
1996	66.357	7.62	0.4903	-0.95469	normal	normal
1997	66.77	11.16	0.699781	0.418701	normal	normal
1998	66.58	10.99	0.60341	0.352747	normal	normal
1999	66.943	12.81	0.78753	1.058843	normal	wet
2000	65.967	13.35	0.292485	1.268344	normal	wet
2001	68.397	10.12	1.525025	0.015218	very warm	normal
2002	68.287	17.86	1.469231	3.018066	warm	ext. wet
2003	67.39	8.44	1.014257	-0.63656	warm	normal
2004	61.55	8.61	-1.9479	-0.57061	very cool	normal
2005	66.877	13.1	0.754054	1.171353	normal	wet
2006	68.613	6.13	1.634584	-1.53276	very warm	very dry

Jun-Aug north-central MN

YEAR	NC_T	NC_P	NC_Tz	NC_Pz	T_class	P_class
1891	60.807	11.87	-1.79624	0.303142	very cool	normal
1892	64.053	7.12	-0.05466	-1.45065	normal	dry
1893	64.867	11.21	0.382081	0.059457	normal	normal
1894	66.947	5.7	1.498071	-1.97494	warm	very dry
1895	60.827	13.44	-1.78551	0.882817	very cool	normal
1896	63.663	8.83	-0.26391	-0.81929	normal	normal
1897	61.77	15.05	-1.27956	1.47726	cool	wet
1898	62.36	13.75	-0.96301	0.997275	normal	normal
1899	63.83	15.38	-0.1743	1.599102	normal	very wet
1900	65.64	15.11	0.796821	1.499413	normal	wet
1901	65.28	13.83	0.603669	1.026812	normal	wet
1902	62.503	10.81	-0.88628	-0.08823	normal	normal
1903	61.637	8.62	-1.35092	-0.89682	cool	normal
1904	61.827	8.64	-1.24898	-0.88944	cool	normal
1905	63.413	17.15	-0.39804	2.252621	normal	ext. wet
1906	64.41	10.2	0.136885	-0.31345	normal	normal
1907	63.1	11.13	-0.56597	0.02992	normal	normal
1908	62.16	9.82	-1.07031	-0.45376	cool	normal
1909	65.797	12.83	0.881057	0.657593	normal	normal
1910	65.49	5.06	0.716341	-2.21124	normal	ext. dry
1911	64.393	11.08	0.127764	0.011459	normal	normal
1912	62.133	8.88	-1.0848	-0.80082	cool	normal
1913	64.577	11.58	0.226486	0.196068	normal	normal
1914	64.603	13.46	0.240436	0.890201	normal	normal
1915	60.103	12.82	-2.17396	0.6539	ext. cool	normal
1916	65.393	11.77	0.664298	0.26622	normal	normal
1917	63.097	6.35	-0.56758	-1.73495	normal	very dry
1918	63.707	8.52	-0.2403	-0.93374	normal	normal
1919	65.95	16.6	0.963147	2.04955	normal	ext. wet
1920	63.85	9.03	-0.16357	-0.74544	normal	normal
1921	67.097	8.78	1.578551	-0.83775	very warm	normal
1922	64.903	7.37	0.401396	-1.35835	normal	dry
1923	65.84	8.99	0.904128	-0.76021	normal	normal
1924	60.98	9.97	-1.70342	-0.39838	very cool	normal
1925	63.127	11.1	-0.55149	0.018843	normal	normal
1926	61.92	9.62	-1.19908	-0.5276	cool	normal
1927	61.233	9.8	-1.56768	-0.46114	very cool	normal
1928	61.777	14.58	-1.27581	1.303727	cool	wet
1929	64.04	5.67	-0.06163	-1.98602	normal	very dry
1930	66.137	6.38	1.063479	-1.72387	warm	very dry
1931	65.74	9.98	0.850475	-0.39468	normal	normal
1932	65.947	9.65	0.961537	-0.51653	normal	normal
1933	67.253	5.2	1.66225	-2.15955	very warm	ext. dry
1934	63.21	8.88	-0.50695	-0.80082	normal	normal

1935	64.5	13.85	0.185173	1.034197	normal	wet
1936	66.153	5.34	1.072063	-2.10786	warm	ext. dry
1937	66.427	14.18	1.219073	1.156039	warm	wet
1938	65.593	7.47	0.771604	-1.32142	normal	dry
1939	65.277	11.33	0.60206	0.103763	normal	normal
1940	63.623	7.65	-0.28537	-1.25496	normal	dry
1941	65.533	11.64	0.739412	0.218221	normal	normal
1942	62.553	13.56	-0.85946	0.927123	normal	normal
1943	65.41	11.91	0.673419	0.317911	normal	normal
1944	64.067	18.71	-0.04715	2.828603	normal	ext. wet
1945	61.87	9.28	-1.22591	-0.65314	cool	normal
1946	63.4	9.57	-0.40501	-0.54606	normal	normal
1947	65.367	11.26	0.650348	0.077918	normal	normal
1948	64.537	10.02	0.205025	-0.37991	normal	normal
1949	66.21	15.5	1.102646	1.643409	warm	very wet
1950	61.74	11.28	-1.29566	0.085302	cool	normal
1951	61.553	10.88	-1.39599	-0.06239	cool	normal
1952	64.247	14.05	0.04943	1.10804	normal	wet
1953	65.17	14.83	0.544651	1.396032	normal	wet
1954	64.077	8.13	-0.04178	-1.07774	normal	dry
1955	67.593	10.03	1.844671	-0.37622	very warm	normal
1956	64.073	8.93	-0.04393	-0.78236	normal	normal
1957	64.157	12.74	0.001142	0.624363	normal	normal
1958	61.11	10.82	-1.63367	-0.08454	very cool	normal
1959	66.107	12.81	1.047383	0.650208	warm	normal
1960	63.867	10.61	-0.15445	-0.16207	normal	normal
1961	65.6	7.64	0.77536	-1.25866	normal	dry
1962	62.797	13.12	-0.72854	0.764666	normal	normal
1963	65.363	11.64	0.648202	0.218221	normal	normal
1964	62.64	13.53	-0.81278	0.916046	normal	normal
1965	61.86	10.19	-1.23127	-0.31715	cool	normal
1966	64.487	13.22	0.178198	0.801588	normal	normal
1967	62.173	7.97	-1.06334	-1.13681	cool	dry
1968	62.107	13.64	-1.09875	0.95666	cool	normal
1969	62.38	10.74	-0.95228	-0.11408	normal	normal
1970	66.097	6.94	1.042017	-1.51711	warm	very dry
1971	63.223	8.67	-0.49998	-0.87836	normal	normal
1972	62.903	12.12	-0.67167	0.395447	normal	normal
1973	64.927	11.69	0.414273	0.236682	normal	normal
1974	64.173	11.51	0.009727	0.170223	normal	normal
1975	64.723	12.02	0.30482	0.358525	normal	normal
1976	66.04	10.75	1.011435	-0.11038	warm	normal
1977	63.063	10.99	-0.58583	-0.02177	normal	normal
1978	63.623	14.15	-0.28537	1.144962	normal	wet
1979	62.323	10.03	-0.98286	-0.37622	normal	normal
1980	63.997	10.83	-0.0847	-0.08085	normal	normal
1981	64.193	13.42	0.020458	0.875432	normal	normal
1982	62.233	9.69	-1.03115	-0.50176	cool	normal
1983	67.367	13.31	1.723415	0.834818	very warm	normal

1984	66.04	10.56	1.011435	-0.18054	warm	normal
1985	60.747	13.12	-1.82844	0.764666	very cool	normal
1986	63.903	11.34	-0.13514	0.107456	normal	normal
1987	65.713	10.32	0.835988	-0.26915	normal	normal
1988	67.98	11.63	2.05231	0.214529	ext. warm	normal
1989	65.567	11.71	0.757655	0.244067	normal	normal
1990	65.343	9	0.637471	-0.75652	normal	normal
1991	66.783	10.34	1.410079	-0.26176	warm	normal
1992	59.873	12.32	-2.29737	0.469291	ext. cool	normal
1993	62.437	14.91	-0.9217	1.425569	normal	wet
1994	63.487	13.92	-0.35833	1.060042	normal	wet
1995	66.633	12.34	1.329599	0.476675	warm	normal
1996	64.707	10.22	0.296236	-0.30607	normal	normal
1997	65.17	11.27	0.544651	0.08161	normal	normal
1998	64.997	10.03	0.451831	-0.37622	normal	normal
1999	65.047	15.01	0.478657	1.462491	normal	wet
2000	63.777	12.82	-0.20274	0.6539	normal	normal
2001	66.66	11.6	1.344086	0.203453	warm	normal
2002	67.007	16.53	1.530263	2.023705	very warm	ext. wet
2003	66.277	10.73	1.138593	-0.11777	warm	normal
2004	60.543	8.8	-1.93789	-0.83036	very cool	normal
2005	66.187	11.24	1.090305	0.070534	warm	normal
2006	67.19	6.12	1.628448	-1.81987	very warm	very dry

Jun-Aug northeast MN

YEAR	NE_T	NE_P	NE_Tz	NE_Pz	T_class	P_class
1891	59.507	10.18	-1.15579	-0.31839	cool	normal
1892	63.823	8.38	1.074023	-1.05185	warm	dry
1893	63.64	10.18	0.979478	-0.31839	normal	normal
1894	63.99	5.44	1.160302	-2.24982	warm	ext. dry
1895	60.327	9.51	-0.73215	-0.5914	normal	normal
1896	60.973	9.47	-0.3984	-0.6077	normal	normal
1897	59.477	15.87	-1.17129	2.000139	cool	ext. wet
1898	60.607	13.8	-0.58749	1.156666	normal	wet
1899	61.18	16.54	-0.29146	2.273147	normal	ext. wet
1900	63.01	13.75	0.653995	1.136292	normal	wet
1901	62.487	13.26	0.383792	0.93663	normal	normal
1902	59.2	10.31	-1.3144	-0.26542	cool	normal
1903	58.743	10	-1.55051	-0.39174	very cool	normal
1904	59.153	10.74	-1.33869	-0.09021	cool	normal
1905	62.453	15.04	0.366227	1.661935	normal	very wet
1906	62.403	9.78	0.340395	-0.48138	normal	normal
1907	60.777	9.25	-0.49966	-0.69734	normal	normal
1908	59.817	10.84	-0.99564	-0.04946	normal	normal
1909	63.083	14.64	0.69171	1.498945	normal	wet
1910	63.75	6.4	1.036309	-1.85865	warm	very dry
1911	62.737	11.71	0.512952	0.305044	normal	normal
1912	60.553	7.22	-0.61539	-1.52452	normal	very dry
1913	60.777	10.05	-0.49966	-0.37136	normal	normal
1914	62.547	10.05	0.414791	-0.37136	normal	normal
1915	58.423	10.2	-1.71583	-0.31024	very cool	normal
1916	64.003	11.8	1.167019	0.341717	warm	normal
1917	60.953	10.77	-0.40873	-0.07798	normal	normal
1918	61.287	6.07	-0.23618	-1.99311	normal	very dry
1919	63.533	11.49	0.924198	0.2154	normal	normal
1920	61.12	9.97	-0.32245	-0.40396	normal	normal
1921	65.927	8.78	2.161034	-0.88886	ext. warm	normal
1922	61.513	8.62	-0.11942	-0.95405	normal	normal
1923	63.55	10.83	0.932981	-0.05353	normal	normal
1924	57.523	9.78	-2.18081	-0.48138	ext. cool	normal
1925	61.38	9.84	-0.18813	-0.45693	normal	normal
1926	59.5	11.06	-1.15941	0.040185	cool	normal
1927	57.677	9.77	-2.10125	-0.48546	ext. cool	normal
1928	58.807	16.78	-1.51744	2.370941	very cool	ext. wet
1929	60.52	6.03	-0.63244	-2.00941	normal	ext. dry
1930	62.523	9.6	0.402391	-0.55473	normal	normal
1931	62.847	9.76	0.569783	-0.48953	normal	normal
1932	62.753	13.34	0.521219	0.969228	normal	normal
1933	63.52	7.74	0.917481	-1.31263	normal	dry
1934	60.507	8.1	-0.63915	-1.16594	normal	dry
1935	61.537	12.89	-0.10702	0.785864	normal	normal

1936	63.223	5.92	0.764039	-2.05423	normal	ext. dry
1937	65.69	10.49	2.03859	-0.19208	ext. warm	normal
1938	62.03	8.81	0.147688	-0.87663	normal	normal
1939	61.767	12.36	0.011811	0.569903	normal	normal
1940	60.453	9.01	-0.66705	-0.79514	normal	normal
1941	62.203	11.86	0.237067	0.366165	normal	normal
1942	59.843	10.22	-0.9822	-0.30209	normal	normal
1943	61.37	13.33	-0.19329	0.965153	normal	normal
1944	60.637	19.79	-0.57199	3.59744	normal	ext. wet
1945	58.887	12.54	-1.47611	0.643248	cool	normal
1946	60.203	8.84	-0.79621	-0.86441	normal	normal
1947	60.43	10.08	-0.67894	-0.35914	normal	normal
1948	61.64	10.22	-0.0538	-0.30209	normal	normal
1949	62.847	12.57	0.569783	0.655472	normal	normal
1950	57.483	11.47	-2.20147	0.20725	ext. cool	normal
1951	58.957	11.09	-1.43995	0.05241	cool	normal
1952	61.94	15.43	0.10119	1.82085	normal	very wet
1953	62.647	14.16	0.466455	1.303357	normal	wet
1954	62.037	7.49	0.151304	-1.4145	normal	dry
1955	65.617	11.6	2.000876	0.260222	ext. warm	normal
1956	61.283	8.31	-0.23824	-1.08037	normal	dry
1957	61.683	11.73	-0.03159	0.313193	normal	normal
1958	59.317	11.56	-1.25396	0.243923	cool	normal
1959	63.9	10.2	1.113805	-0.31024	warm	normal
1960	62.087	7.86	0.177136	-1.26373	normal	dry
1961	63.52	6.07	0.917481	-1.99311	normal	very dry
1962	60.187	10.55	-0.80448	-0.16763	normal	normal
1963	62.747	10.81	0.518119	-0.06168	normal	normal
1964	60.9	12.75	-0.43612	0.728818	normal	normal
1965	59.543	9.94	-1.1372	-0.41619	cool	normal
1966	63.017	11.01	0.657611	0.019812	normal	normal
1967	60.427	11.02	-0.68049	0.023886	normal	normal
1968	60.187	14.22	-0.80448	1.327806	normal	wet
1969	60.437	10.47	-0.67532	-0.20022	normal	normal
1970	64.333	8.44	1.33751	-1.0274	warm	dry
1971	61.35	9.43	-0.20363	-0.624	normal	normal
1972	60.957	13.45	-0.40667	1.01405	normal	wet
1973	62.817	12.97	0.554283	0.818462	normal	normal
1974	61.923	11.77	0.092407	0.329492	normal	normal
1975	62.67	10.91	0.478337	-0.02094	normal	normal
1976	64.203	10.58	1.270347	-0.1554	warm	normal
1977	60.38	12.89	-0.70477	0.785864	normal	normal
1978	61.16	13.66	-0.30179	1.09962	normal	wet
1979	60.517	10.16	-0.63399	-0.32654	normal	normal
1980	62.69	11.1	0.48867	0.056484	normal	normal
1981	62.603	10.88	0.443723	-0.03316	normal	normal
1982	59.49	10.13	-1.16458	-0.33877	cool	normal
1983	64.77	11.15	1.563281	0.076858	very warm	normal
1984	63.493	10.41	0.903532	-0.22467	normal	normal

1985	58.553	11.84	-1.64867	0.358016	very cool	normal
1986	60.593	13.1	-0.59472	0.871434	normal	normal
1987	63.723	13.25	1.022359	0.932555	warm	normal
1988	65.203	16.12	1.786987	2.102007	very warm	ext. wet
1989	62.453	10.29	0.366227	-0.27357	normal	normal
1990	62.5	11.26	0.390509	0.12168	normal	normal
1991	63.537	10.87	0.926264	-0.03723	normal	normal
1992	57.627	11.97	-2.12708	0.410987	ext. cool	normal
1993	60.617	14.68	-0.58232	1.515244	normal	very wet
1994	61.347	11.92	-0.20518	0.390614	normal	normal
1995	63.96	10.79	1.144803	-0.06983	warm	normal
1996	61.587	13.24	-0.08118	0.92848	normal	normal
1997	62.037	8.88	0.151304	-0.84811	normal	normal
1998	63.887	9.21	1.107088	-0.71364	warm	normal
1999	63.37	14.49	0.839985	1.437824	normal	wet
2000	61.56	11.62	-0.09513	0.268371	normal	normal
2001	64.337	12.52	1.339576	0.635099	warm	normal
2002	65.357	12.86	1.866549	0.77364	very warm	normal
2003	64.14	10.05	1.237798	-0.37136	warm	normal
2004	59.103	8.33	-1.36452	-1.07222	cool	dry
2005	64.27	8.84	1.304961	-0.86441	warm	normal
2006	65.647	8.05	2.016375	-1.18631	ext. warm	dry

Jun-Aug west-central MN

YEAR	WC_T	WC_P	WC_Tz	WC_Pz	T_class	P_class
1891	65.137	8.61	-1.48176	-0.76982	cool	normal
1892	66.02	11.62	-1.04751	0.463673	cool	normal
1893	68.513	9.52	0.178515	-0.3969	normal	normal
1894	70.403	5.25	1.107994	-2.14675	warm	ext. dry
1895	65.323	10.53	-1.39029	0.016993	cool	normal
1896	66.333	8.88	-0.89358	-0.65918	normal	normal
1897	65.193	13.15	-1.45422	1.090666	cool	wet
1898	66.903	10.19	-0.61326	-0.12234	normal	normal
1899	67.353	14.07	-0.39196	1.467681	normal	wet
1900	69.153	12.66	0.493259	0.889864	normal	normal
1901	69.25	9.3	0.540963	-0.48706	normal	normal
1902	64.757	8.67	-1.66864	-0.74523	very cool	normal
1903	64.07	11.61	-2.0065	0.459575	ext. cool	normal
1904	64.04	10.62	-2.02125	0.053874	ext. cool	normal
1905	65.947	13.48	-1.08341	1.225899	cool	wet
1906	66.467	14.1	-0.82768	1.479975	normal	wet
1907	66.037	9.77	-1.03915	-0.29445	cool	normal
1908	65.97	10.85	-1.0721	0.148128	cool	normal
1909	68.34	9.44	0.093436	-0.42969	normal	normal
1910	67.94	6.5	-0.10328	-1.6345	normal	very dry
1911	67.61	11.47	-0.26557	0.402204	normal	normal
1912	65.45	10.94	-1.32783	0.18501	cool	normal
1913	68.38	11.84	0.113107	0.553829	normal	normal
1914	67.87	14.59	-0.1377	1.680776	normal	very wet
1915	62.663	13.32	-2.69845	1.160332	ext. cool	wet
1916	68.383	13.46	0.114582	1.217703	normal	wet
1917	66.413	6.53	-0.85424	-1.6222	normal	very dry
1918	68	7.8	-0.07377	-1.10176	normal	dry
1919	68.73	12.13	0.285233	0.672671	normal	normal
1920	67.01	12.85	-0.56064	0.967726	normal	normal
1921	71.34	8.01	1.5688	-1.0157	very warm	dry
1922	69.3	5.14	0.565552	-2.19182	normal	ext. dry
1923	69.55	9.21	0.688499	-0.52394	normal	normal
1924	65.13	11.61	-1.4852	0.459575	cool	normal
1925	67.36	12.1	-0.38852	0.660377	normal	normal
1926	66.533	9.91	-0.79523	-0.23708	normal	normal
1927	65.04	8.15	-1.52947	-0.95833	very cool	normal
1928	66.367	13.41	-0.87686	1.197213	normal	wet
1929	68.23	5.79	0.039339	-1.92545	normal	very dry
1930	69.947	6.93	0.883739	-1.45828	normal	dry
1931	70.743	9.01	1.275202	-0.6059	warm	normal
1932	70.103	8.37	0.960458	-0.86817	normal	normal
1933	72.19	6.5	1.98682	-1.6345	very warm	very dry
1934	70.097	7.19	0.957507	-1.35174	normal	dry

1935	69.39	12.32	0.609813	0.750533	normal	normal
1936	72.123	4.71	1.95387	-2.36804	very warm	ext. dry
1937	70.593	10.48	1.201434	-0.0035	warm	normal
1938	69.893	7.73	0.857183	-1.13044	normal	dry
1939	69.273	11.31	0.552274	0.336636	normal	normal
1940	68.413	9.66	0.129336	-0.33953	normal	normal
1941	69.663	11.14	0.744071	0.26697	normal	normal
1942	66.617	9.63	-0.75392	-0.35183	normal	normal
1943	69.497	13.56	0.662434	1.258683	normal	wet
1944	68.213	13.26	0.030978	1.135744	normal	wet
1945	66.117	10.13	-0.99981	-0.14693	normal	normal
1946	67.827	11.7	-0.15885	0.496457	normal	normal
1947	69.38	8.66	0.604895	-0.74933	normal	normal
1948	68.683	11.34	0.262119	0.34893	normal	normal
1949	70.557	12.19	1.18373	0.697259	warm	normal
1950	66.353	6.97	-0.88375	-1.44189	normal	dry
1951	65.137	12.85	-1.48176	0.967726	cool	normal
1952	68.617	12.96	0.229661	1.012804	normal	wet
1953	69.22	14.44	0.526209	1.619306	normal	very wet
1954	68.443	8.46	0.14409	-0.83129	normal	normal
1955	70.843	14.72	1.324381	1.73405	warm	very wet
1956	68.533	11.78	0.188351	0.529241	normal	normal
1957	68.58	15.3	0.211465	1.971733	normal	very wet
1958	65.403	9.06	-1.35095	-0.58541	cool	normal
1959	70.807	9.88	1.306677	-0.24938	warm	normal
1960	68.213	12.34	0.030978	0.758729	normal	normal
1961	69.647	7.36	0.736203	-1.28207	normal	dry
1962	66.873	13.49	-0.62802	1.229997	normal	wet
1963	69.47	11.64	0.649156	0.471869	normal	normal
1964	68.61	10.79	0.226218	0.12354	normal	normal
1965	67.21	11.32	-0.46229	0.340734	normal	normal
1966	68.71	11.62	0.275397	0.463673	normal	normal
1967	66.027	9.21	-1.04407	-0.52394	cool	normal
1968	67.687	8.96	-0.2277	-0.62639	normal	normal
1969	66.673	7.3	-0.72638	-1.30666	normal	dry
1970	70.117	7.62	0.967343	-1.17552	normal	dry
1971	67.383	12.61	-0.37721	0.869374	normal	normal
1972	67.363	10.54	-0.38704	0.021091	normal	normal
1973	69.327	8.32	0.57883	-0.88866	normal	normal
1974	68.247	8.86	0.047699	-0.66737	normal	normal
1975	69.477	11.53	0.652599	0.426791	normal	normal
1976	71.513	5.11	1.653879	-2.20412	very warm	ext. dry
1977	67.457	10.71	-0.34081	0.090756	normal	normal
1978	68.137	10.05	-0.0064	-0.17971	normal	normal
1979	66.773	11.86	-0.6772	0.562025	normal	normal
1980	68.187	10.97	0.018192	0.197304	normal	normal
1981	67.67	12.9	-0.23606	0.988216	normal	normal
1982	66.88	9.95	-0.62458	-0.22069	normal	normal
1983	71.247	11.61	1.523064	0.459575	very	normal

					warm	
1984	69.543	11.99	0.685057	0.615299	normal	normal
1985	65.337	11.05	-1.3834	0.230088	cool	normal
1986	68.157	14.29	0.003438	1.557837	normal	very wet
1987	69.85	7.56	0.836036	-1.20011	normal	dry
1988	73.43	7.63	2.596637	-1.17142	ext. warm	dry
1989	69.553	9.6	0.689975	-0.36412	normal	normal
1990	68.31	11.75	0.078682	0.516947	normal	normal
1991	70.03	13.75	0.924558	1.336545	normal	wet
1992	63.44	11.47	-2.31633	0.402204	ext. cool	normal
1993	65.76	15.89	-1.17538	2.213515	cool	ext. wet
1994	67.05	10.15	-0.54097	-0.13873	normal	normal
1995	70.36	12.39	1.086848	0.779219	warm	normal
1996	68.553	7.14	0.198186	-1.37223	normal	dry
1997	69.427	10.53	0.628009	0.016993	normal	normal
1998	69.017	10.74	0.426376	0.10305	normal	normal
1999	69.967	12.66	0.893575	0.889864	normal	normal
2000	68.403	9.87	0.124418	-0.25347	normal	normal
2001	70.7	10.01	1.254056	-0.1961	warm	normal
2002	71.187	12.76	1.493556	0.930844	warm	normal
2003	69.84	8.59	0.831118	-0.77802	normal	normal
2004	64.533	9.75	-1.7788	-0.30265	very cool	normal
2005	69.813	13.75	0.817839	1.336545	normal	wet
2006	70.48	7.36	1.145862	-1.28207	warm	dry

Jun-Aug central MN

YEAR	C_T	C_P	C_Tz	C_Pz	T_class	P_class
1891	65.067	9.52	-1.49994	-0.63894	cool	normal
1892	65.707	15.59	-1.17931	1.475009	cool	wet
1893	68.653	8.02	0.296623	-1.16133	normal	dry
1894	70.32	4.47	1.13178	-2.39766	warm	ext. dry
1895	66.307	9.09	-0.87871	-0.78869	normal	normal
1896	66.81	8.31	-0.62671	-1.06034	normal	dry
1897	64.88	15.67	-1.59363	1.502869	very cool	very wet
1898	66.903	9.7	-0.58012	-0.57625	normal	normal
1899	67.44	12.52	-0.31108	0.405845	normal	normal
1900	69.497	13.19	0.719462	0.63918	normal	normal
1901	69.517	9.81	0.729482	-0.53794	normal	normal
1902	64.53	10.96	-1.76898	-0.13744	very cool	normal
1903	64.06	12.49	-2.00444	0.395397	ext. cool	normal
1904	64.153	11.81	-1.95785	0.158579	very cool	normal
1905	65.517	15.43	-1.27449	1.419287	cool	wet
1906	66.867	14.39	-0.59815	1.057094	normal	wet
1907	66.5	10.73	-0.78202	-0.21754	normal	normal
1908	66.407	10.7	-0.82861	-0.22799	normal	normal
1909	68.74	9.83	0.34021	-0.53098	normal	normal
1910	68.603	5.34	0.271573	-2.09467	normal	ext. dry
1911	68.127	12.2	0.0331	0.294401	normal	normal
1912	65.85	11.83	-1.10766	0.165544	cool	normal
1913	69.037	14.41	0.489005	1.06406	normal	wet
1914	68.36	14.94	0.149832	1.248638	normal	wet
1915	62.763	12.37	-2.65423	0.353606	ext. cool	normal
1916	68.53	13.2	0.235001	0.642663	normal	normal
1917	65.913	9.36	-1.0761	-0.69466	cool	normal
1918	67.81	8.41	-0.12571	-1.02551	normal	dry
1919	68.993	12.37	0.466961	0.353606	normal	normal
1920	67.473	11.25	-0.29455	-0.03645	normal	normal
1921	71.48	8.52	1.712933	-0.9872	very warm	normal
1922	68.903	5.93	0.421872	-1.8892	normal	very dry
1923	69.427	9.38	0.684393	-0.6877	normal	normal
1924	65.323	13.27	-1.37169	0.667041	cool	normal
1925	67.57	11.84	-0.24595	0.169027	normal	normal
1926	66.607	11.53	-0.72841	0.061066	normal	normal
1927	64.747	7.95	-1.66026	-1.18571	very cool	dry
1928	66.373	13	-0.84564	0.573011	normal	normal
1929	68.083	6.5	0.011056	-1.69069	normal	very dry
1930	70.213	7.24	1.078174	-1.43298	warm	dry
1931	71.01	8.61	1.477466	-0.95586	warm	normal
1932	70.333	9.24	1.138293	-0.73645	warm	normal
1933	72.247	6.27	2.097196	-1.77079	ext. warm	very dry
1934	69.9	7.9	0.921363	-1.20312	normal	dry

1935	69.327	13.67	0.634293	0.806346	normal	normal
1936	71.247	5.84	1.596202	-1.92054	very warm	very dry
1937	70.533	11.05	1.238492	-0.1061	warm	normal
1938	69.537	9.25	0.739502	-0.73297	normal	normal
1939	68.933	12.64	0.436901	0.447636	normal	normal
1940	67.907	11.67	-0.07712	0.109823	normal	normal
1941	69.057	11.2	0.499025	-0.05386	normal	normal
1942	66.227	10.63	-0.91879	-0.25237	normal	normal
1943	69.387	11.69	0.664353	0.116788	normal	normal
1944	67.577	14.86	-0.24245	1.220777	normal	wet
1945	65.237	13.2	-1.41477	0.642663	cool	normal
1946	67.12	9.62	-0.4714	-0.60411	normal	normal
1947	69.277	10.1	0.609243	-0.43695	normal	normal
1948	68.443	11.6	0.191414	0.085444	normal	normal
1949	70.92	10.85	1.432377	-0.17575	warm	normal
1950	66.25	5.05	-0.90727	-2.19567	normal	ext. dry
1951	65.087	14.83	-1.48992	1.21033	cool	wet
1952	68.09	16.91	0.014563	1.934714	normal	very wet
1953	69.123	17.06	0.53209	1.986953	normal	very wet
1954	68.583	11.13	0.261553	-0.07824	normal	normal
1955	70.987	15.45	1.465943	1.426252	warm	wet
1956	68.213	15.25	0.076186	1.3566	normal	wet
1957	68.193	18.38	0.066166	2.446659	normal	ext. wet
1958	64.957	9.56	-1.55505	-0.62501	very cool	normal
1959	70.163	10.53	1.053124	-0.2872	warm	normal
1960	67.71	10.28	-0.17581	-0.37426	normal	normal
1961	68.773	8.78	0.356742	-0.89665	normal	normal
1962	66.357	12.74	-0.85366	0.482463	normal	normal
1963	69.25	11.52	0.595717	0.057583	normal	normal
1964	68.573	11.11	0.256544	-0.0852	normal	normal
1965	66.947	11.97	-0.55807	0.214301	normal	normal
1966	68.55	11.36	0.245021	0.001861	normal	normal
1967	66.053	11.69	-1.00596	0.116788	cool	normal
1968	67.613	11.72	-0.22441	0.127236	normal	normal
1969	66.657	7.71	-0.70336	-1.26929	normal	dry
1970	69.9	8.69	0.921363	-0.928	normal	normal
1971	67.263	11.74	-0.39976	0.134201	normal	normal
1972	66.93	14.81	-0.56659	1.203364	normal	wet
1973	69.023	11.11	0.481991	-0.0852	normal	normal
1974	67.87	9.7	-0.09566	-0.57625	normal	normal
1975	69.103	11.15	0.52207	-0.07127	normal	normal
1976	70.263	6.94	1.103224	-1.53746	warm	very dry
1977	67.57	12.6	-0.24595	0.433706	normal	normal
1978	67.76	13.09	-0.15076	0.604354	normal	normal
1979	66.707	12.41	-0.67831	0.367536	normal	normal
1980	68.233	12.44	0.086206	0.377984	normal	normal
1981	67.55	14.3	-0.25597	1.025751	normal	wet
1982	66.857	9.23	-0.60316	-0.73994	normal	normal
1983	71.11	13.45	1.527566	0.729728	very warm	normal

1984	69.44	13.34	0.690905	0.69142	normal	normal
1985	65.347	13.49	-1.35966	0.743659	cool	normal
1986	67.95	15.87	-0.05558	1.572522	normal	very wet
1987	70.157	10.35	1.050118	-0.34988	warm	normal
1988	73.11	7.3	2.529554	-1.41208	ext. warm	dry
1989	69.217	9.71	0.579184	-0.57277	normal	normal
1990	68.257	14.96	0.098229	1.255604	normal	wet
1991	70.057	13	1.000019	0.573011	warm	normal
1992	63.3	11.71	-2.3852	0.123753	ext. cool	normal
1993	66.03	17.37	-1.01748	2.094914	cool	ext. wet
1994	66.853	11.99	-0.60517	0.221266	normal	normal
1995	70.163	13.65	1.053124	0.799381	warm	normal
1996	67.617	7.96	-0.22241	-1.18223	normal	dry
1997	69.057	14.68	0.499025	1.15809	normal	wet
1998	68.793	12.19	0.366762	0.290919	normal	normal
1999	69.67	12.93	0.806134	0.548632	normal	normal
2000	68.313	10.16	0.126285	-0.41605	normal	normal
2001	70.443	8.86	1.193403	-0.86879	warm	normal
2002	70.82	19.28	1.382277	2.760094	warm	ext. wet
2003	69.55	9.92	0.746015	-0.49964	normal	normal
2004	64.837	10.13	-1.61517	-0.4265	very cool	normal
2005	70.587	11.97	1.265546	0.214301	warm	normal
2006	70.953	8.67	1.44891	-0.93496	warm	normal

Jun-Aug east-central MN

YEAR	EC_T	EC_P	EC_Tz	EC_Pz	T_class	P_class
1891	63.453	9.57	-1.39384	-0.71699	cool	normal
1892	66.12	14.86	0.034417	1.008668	normal	wet
1893	68.093	8.48	1.09102	-1.07256	warm	dry
1894	69.127	3	1.644759	-2.8602	very warm	ext. dry
1895	64.79	9.04	-0.67784	-0.88988	normal	normal
1896	66.127	7.92	0.038166	-1.25524	normal	dry
1897	64.73	16.82	-0.70997	1.648043	normal	very wet
1898	65.74	11.17	-0.16908	-0.19505	normal	normal
1899	66.667	14.29	0.327353	0.822728	normal	normal
1900	68.393	15.02	1.25168	1.060862	warm	wet
1901	67.683	12.87	0.871452	0.359507	normal	normal
1902	64.52	13.14	-0.82243	0.447585	normal	normal
1903	63.14	13.74	-1.56147	0.643311	very cool	normal
1904	63.637	11.81	-1.29531	0.013723	cool	normal
1905	65.373	16.01	-0.36562	1.383811	normal	wet
1906	65.727	11.5	-0.17605	-0.0874	normal	normal
1907	65.197	9.74	-0.45988	-0.66153	normal	normal
1908	64.72	12.09	-0.71533	0.105063	normal	normal
1909	66.7	11.81	0.345025	0.013723	normal	normal
1910	66.673	6.17	0.330566	-1.82611	normal	very dry
1911	65.167	11.81	-0.47594	0.013723	normal	normal
1912	63.057	9.89	-1.60591	-0.6126	very cool	normal
1913	66.097	12.81	0.0221	0.339935	normal	normal
1914	65.597	15.54	-0.24567	1.230492	normal	wet
1915	61.01	11.39	-2.70215	-0.12329	ext. cool	normal
1916	66.457	11.4	0.214891	-0.12002	normal	normal
1917	62.79	9.34	-1.7489	-0.79202	very cool	normal
1918	65.207	7.85	-0.45452	-1.27807	normal	dry
1919	66.663	12.19	0.325211	0.137684	normal	normal
1920	64.853	10.76	-0.6441	-0.3288	normal	normal
1921	69.54	9.5	1.865934	-0.73982	very warm	normal
1922	66.377	7.78	0.172049	-1.30091	normal	dry
1923	66.85	9.99	0.425355	-0.57998	normal	normal
1924	62.92	13.8	-1.67928	0.662884	very cool	normal
1925	65.413	11.75	-0.3442	-0.00585	normal	normal
1926	64.187	10.95	-1.00076	-0.26682	cool	normal
1927	62.46	9.43	-1.92563	-0.76266	very cool	normal
1928	63.973	14.63	-1.11537	0.93364	cool	normal
1929	66.023	6.25	-0.01753	-1.80001	normal	very dry
1930	68.23	7.2	1.164388	-1.49011	warm	dry
1931	68.453	11.58	1.283811	-0.06131	warm	normal
1932	68.68	8.32	1.405377	-1.12475	warm	dry
1933	70.073	5.89	2.151372	-1.91745	ext.	very dry

					warm	
1934	66.59	8.58	0.286117	-1.03994	normal	dry
1935	66.703	14.98	0.346632	1.047814	normal	wet
1936	68.16	4.61	1.126901	-2.335	warm	ext. dry
1937	68.13	10.6	1.110835	-0.38099	warm	normal
1938	67.373	10.38	0.705438	-0.45276	normal	normal
1939	67.207	11.2	0.61654	-0.18527	normal	normal
1940	65.67	10.21	-0.20657	-0.50821	normal	normal
1941	67.327	13.01	0.680803	0.405177	normal	normal
1942	64.633	11.83	-0.76192	0.020248	normal	normal
1943	67.54	12.48	0.794871	0.232285	normal	normal
1944	65.99	19.54	-0.0352	2.535338	normal	ext. wet
1945	63.347	14.81	-1.45061	0.992358	cool	normal
1946	65.15	12	-0.48505	0.075704	normal	normal
1947	67.493	9.4	0.769701	-0.77245	normal	normal
1948	66.537	10.86	0.257734	-0.29618	normal	normal
1949	68.67	12.14	1.400022	0.121373	warm	normal
1950	63.953	6.03	-1.12608	-1.87178	cool	very dry
1951	63.28	15.96	-1.48649	1.367501	cool	wet
1952	66.23	19.98	0.093326	2.678871	normal	ext. wet
1953	67.233	17.77	0.630463	1.957943	normal	very wet
1954	66.327	12.37	0.145272	0.196402	normal	normal
1955	69.263	16.95	1.717592	1.69045	very warm	very wet
1956	65.473	11.62	-0.31207	-0.04826	normal	normal
1957	66.233	15.3	0.094932	1.152201	normal	wet
1958	62.85	12.51	-1.71677	0.242071	very cool	normal
1959	67.883	10.23	0.978559	-0.50169	normal	normal
1960	66.02	9.39	-0.01914	-0.77571	normal	normal
1961	67.1	6.61	0.559238	-1.68258	normal	very dry
1962	64.287	11.45	-0.94721	-0.10371	normal	normal
1963	66.963	10.67	0.48587	-0.35816	normal	normal
1964	65.853	12.05	-0.10857	0.092014	normal	normal
1965	64.04	12.81	-1.07949	0.339935	cool	normal
1966	66.51	12.71	0.243274	0.307314	normal	normal
1967	64.067	12.18	-1.06503	0.134422	cool	normal
1968	65.087	13.08	-0.51879	0.428012	normal	normal
1969	64.623	8.3	-0.76727	-1.13128	normal	dry
1970	67.873	8	0.973203	-1.22914	normal	dry
1971	64.87	10.77	-0.635	-0.32554	normal	normal
1972	64.527	17.36	-0.81868	1.824197	normal	very wet
1973	66.753	12.72	0.373408	0.310576	normal	normal
1974	65.557	12.45	-0.26709	0.222499	normal	normal
1975	66.67	14.22	0.328959	0.799893	normal	normal
1976	67.843	8.61	0.957137	-1.03015	normal	dry
1977	64.89	14.07	-0.62429	0.750961	normal	normal
1978	65.153	17.01	-0.48344	1.710023	normal	very wet
1979	64.293	11.8	-0.944	0.010461	normal	normal
1980	65.997	12.22	-0.03145	0.14747	normal	normal
1981	65.183	14.06	-0.46738	0.747699	normal	normal

1982	64.233	8.93	-0.97613	-0.92577	normal	normal
1983	68.577	12.67	1.350217	0.294265	warm	normal
1984	67.203	12.58	0.614397	0.264906	normal	normal
1985	62.987	12.83	-1.6434	0.346459	very cool	normal
1986	65.6	15.75	-0.24406	1.298996	normal	wet
1987	68.343	10.55	1.224903	-0.3973	warm	normal
1988	69.923	9.15	2.071042	-0.854	ext. warm	normal
1989	66.95	10.09	0.478908	-0.54736	normal	normal
1990	66.52	14.88	0.24863	1.015192	normal	wet
1991	67.873	12.75	0.973203	0.320362	normal	normal
1992	61.893	11.74	-2.22927	-0.00911	ext. cool	normal
1993	64.67	15.97	-0.7421	1.370763	normal	wet
1994	65.33	11.87	-0.38865	0.033296	normal	normal
1995	68.393	16.02	1.25168	1.387073	warm	wet
1996	65.807	10.16	-0.1332	-0.52453	normal	normal
1997	66.143	13.18	0.046734	0.460633	normal	normal
1998	66.55	11.73	0.264696	-0.01237	normal	normal
1999	67.79	15.88	0.928754	1.341404	normal	wet
2000	65.83	11.52	-0.12089	-0.08088	normal	normal
2001	68.553	11.04	1.337365	-0.23746	warm	normal
2002	68.5	18.46	1.308981	2.183029	warm	ext. wet
2003	67.723	11.07	0.892874	-0.22767	normal	normal
2004	63.087	9.36	-1.58985	-0.78549	very cool	normal
2005	68.603	11.15	1.364141	-0.20158	warm	normal
2006	69.293	8.76	1.733658	-0.98122	very warm	normal

Jun-Aug southwest MN

YEAR	SW_T	SW_P	SW_Tz	SW_Pz	T_class	P_class
1891	66.297	9.54	-1.58577	-0.46493	very cool	normal
1892	66.573	12.47	-1.44903	0.60335	cool	normal
1893	69.58	6.49	0.040745	-1.57696	normal	very dry
1894	72.653	3.94	1.563221	-2.50669	very warm	ext. dry
1895	68.23	7.79	-0.62809	-1.10298	normal	dry
1896	67.853	9.14	-0.81487	-0.61077	normal	normal
1897	66.51	12.2	-1.48024	0.504908	cool	normal
1898	68.513	9.36	-0.48789	-0.53056	normal	normal
1899	69.183	13	-0.15594	0.796588	normal	normal
1900	70.663	11.56	0.577303	0.271564	normal	normal
1901	71.933	8.77	1.206507	-0.74567	warm	normal
1902	66.59	13.5	-1.44061	0.978888	cool	normal
1903	65.273	15.43	-2.0931	1.682565	ext. cool	very wet
1904	65.417	12.19	-2.02176	0.501262	ext. cool	normal
1905	68.48	14.44	-0.50423	1.321612	normal	wet
1906	68.127	10.99	-0.67912	0.063742	normal	normal
1907	68.037	14.24	-0.72371	1.248692	normal	wet
1908	66.75	12.77	-1.36134	0.71273	cool	normal
1909	69.577	10.91	0.039259	0.034574	normal	normal
1910	69.033	7.94	-0.23026	-1.04829	normal	dry
1911	69.473	10.33	-0.01227	-0.17689	normal	normal
1912	66.593	8.48	-1.43912	-0.8514	cool	normal
1913	70.16	11.56	0.328098	0.271564	normal	normal
1914	70.107	14.94	0.30184	1.503912	normal	very wet
1915	63.987	12.69	-2.73023	0.683562	ext. cool	normal
1916	69.593	8.88	0.047186	-0.70556	normal	normal
1917	66.84	8.85	-1.31675	-0.7165	cool	normal
1918	69.48	12.1	-0.0088	0.468448	normal	normal
1919	69.977	14.31	0.237434	1.274214	normal	wet
1920	67.863	13.47	-0.80992	0.96795	normal	normal
1921	72.54	8.52	1.507237	-0.83682	very warm	normal
1922	70.48	7.04	0.486638	-1.37643	normal	dry
1923	70.39	10.8	0.442049	-0.00553	normal	normal
1924	67.103	12.65	-1.18645	0.668978	cool	normal
1925	69.727	10.89	0.113574	0.027282	normal	normal
1926	69.353	9.65	-0.07172	-0.42482	normal	normal
1927	66.537	6.37	-1.46687	-1.62071	cool	very dry
1928	68.087	11.99	-0.69894	0.428342	normal	normal
1929	69.557	8.37	0.02935	-0.89151	normal	normal
1930	71.59	6.61	1.036572	-1.53321	warm	very dry
1931	73.44	7.01	1.953129	-1.38737	very warm	dry
1932	71.55	10.49	1.016755	-0.11856	warm	normal
1933	73.457	8.58	1.961552	-0.81494	very warm	normal

1934	71.937	10.81	1.208489	-0.00189	warm	normal
1935	71.283	10.75	0.884473	-0.02376	normal	normal
1936	73.96	6.75	2.210756	-1.48216	ext. warm	dry
1937	72.08	9.36	1.279336	-0.53056	warm	normal
1938	71.687	9.91	1.08463	-0.33003	warm	normal
1939	71.07	13.37	0.778945	0.93149	normal	normal
1940	70.553	11.54	0.522805	0.264272	normal	normal
1941	71.253	9.89	0.86961	-0.33732	normal	normal
1942	68.69	11.05	-0.40019	0.085618	normal	normal
1943	70.563	17.4	0.527759	2.400827	normal	ext. wet
1944	68.947	14.88	-0.27287	1.482036	normal	wet
1945	66.693	11.64	-1.38958	0.300732	cool	normal
1946	68.747	8.41	-0.37195	-0.87693	normal	normal
1947	70.333	11.02	0.413809	0.07468	normal	normal
1948	69.833	10.46	0.166091	-0.1295	normal	normal
1949	72.063	9.37	1.270914	-0.52691	warm	normal
1950	66.99	6.31	-1.24243	-1.64259	cool	very dry
1951	66.21	12.7	-1.62887	0.687208	very cool	normal
1952	70.01	11.39	0.253783	0.209582	normal	normal
1953	70.617	14.16	0.554513	1.219524	normal	wet
1954	70.56	10.07	0.526273	-0.27169	normal	normal
1955	72.607	9.42	1.540431	-0.50868	very warm	normal
1956	70.27	13.06	0.382596	0.818464	normal	normal
1957	69.803	16.43	0.151228	2.047165	normal	ext. wet
1958	67.39	8.43	-1.04426	-0.86963	cool	normal
1959	72.147	8.84	1.31253	-0.72015	warm	normal
1960	69.007	11.57	-0.24314	0.27521	normal	normal
1961	69.52	9.83	0.011019	-0.35919	normal	normal
1962	68.14	13.11	-0.67268	0.836694	normal	normal
1963	70.74	14.91	0.615451	1.492974	normal	wet
1964	69.81	9.8	0.154696	-0.37013	normal	normal
1965	68.903	7.66	-0.29466	-1.15038	normal	dry
1966	70.317	9.2	0.405882	-0.58889	normal	normal
1967	67.56	11.33	-0.96004	0.187706	normal	normal
1968	69.4	12.71	-0.04843	0.690854	normal	normal
1969	67.87	11.91	-0.80645	0.399174	normal	normal
1970	70.657	9.56	0.57433	-0.45764	normal	normal
1971	69.317	10.38	-0.08955	-0.15866	normal	normal
1972	68.16	9.53	-0.66277	-0.46857	normal	normal
1973	71.173	6.04	0.829975	-1.74103	normal	very dry
1974	69.613	7.47	0.057095	-1.21965	normal	dry
1975	70.753	9.14	0.621892	-0.61077	normal	normal
1976	71.81	5.99	1.145568	-1.75926	warm	very dry
1977	69.1	11.95	-0.19706	0.413758	normal	normal
1978	69.4	10.49	-0.04843	-0.11856	normal	normal
1979	68.25	16.31	-0.61818	2.003413	normal	ext. wet
1980	70.36	10.59	0.427186	-0.0821	normal	normal
1981	69.283	13.84	-0.1064	1.102852	normal	wet
1982	68.21	9.74	-0.638	-0.39201	normal	normal
1983	72.797	10.7	1.634564	-0.04199	very	normal

					warm	
1984	70.487	12.14	0.490106	0.483032	normal	normal
1985	66.46	10.81	-1.50502	-0.00189	very cool	normal
1986	68.84	12.72	-0.32588	0.6945	normal	normal
1987	70.673	10.01	0.582257	-0.29357	normal	normal
1988	73.723	6.02	2.093338	-1.74832	ext. warm	very dry
1989	70.47	9.41	0.481684	-0.51233	normal	normal
1990	69.46	11.42	-0.01871	0.22052	normal	normal
1991	70.853	12.73	0.671436	0.698146	normal	normal
1992	64.357	15.04	-2.54692	1.540372	ext. cool	very wet
1993	67.363	22.78	-1.05764	4.362374	cool	ext. wet
1994	67.82	14.04	-0.83122	1.175772	normal	wet
1995	71.15	11.87	0.81858	0.38459	normal	normal
1996	68.543	10.6	-0.47302	-0.07845	normal	normal
1997	70.197	10.45	0.34643	-0.13314	normal	normal
1998	69.323	11.15	-0.08658	0.122078	normal	normal
1999	70.76	9.37	0.62536	-0.52691	normal	normal
2000	69.373	9.9	-0.06181	-0.33367	normal	normal
2001	71.243	8.86	0.864656	-0.71286	normal	normal
2002	72.053	12.73	1.265959	0.698146	warm	normal
2003	70.077	7.79	0.286977	-1.10298	normal	dry
2004	66.233	11.04	-1.61748	0.081972	very cool	normal
2005	71.203	11.78	0.844838	0.351776	normal	normal
2006	71.477	9.47	0.980588	-0.49045	normal	Normal

Jun-Aug south-central MN

YEAR	SC_T	SC_P	SC_Tz	SC_Pz	T_class	P_class
1891	65.76	10	-1.96017	-0.67779	very cool	normal
1892	66.377	14.85	-1.64705	0.917238	very cool	normal
1893	69.287	8.21	-0.17023	-1.26647	normal	dry
1894	72.39	4.75	1.404526	-2.40436	warm	ext. dry
1895	68.483	8.35	-0.57826	-1.22042	normal	dry
1896	68.847	7.16	-0.39353	-1.61178	normal	very dry
1897	66.933	12.97	-1.36488	0.298961	cool	normal
1898	68.373	10.09	-0.63409	-0.64819	normal	normal
1899	69.907	15.66	0.144413	1.183624	normal	wet
1900	71.643	11.65	1.025426	-0.13515	warm	normal
1901	73.133	9.67	1.781595	-0.78631	very warm	normal
1902	66.763	17.35	-1.45115	1.739416	cool	very wet
1903	66.177	13.36	-1.74855	0.42722	very cool	normal
1904	66.093	11.15	-1.79118	-0.29958	very cool	normal
1905	68.91	12.97	-0.36156	0.298961	normal	normal
1906	68.473	14.33	-0.58334	0.746225	normal	normal
1907	67.587	15.41	-1.03298	1.101406	cool	wet
1908	67.81	15.05	-0.91981	0.983012	normal	normal
1909	70.083	12.06	0.233733	-0.00031	normal	normal
1910	69.683	6.98	0.030734	-1.67098	normal	very dry
1911	70.25	11.41	0.318484	-0.21408	normal	normal
1912	67.337	11.63	-1.15985	-0.14173	cool	normal
1913	71.223	11.88	0.812278	-0.05951	normal	normal
1914	70.683	15.27	0.53823	1.055364	normal	wet
1915	64.453	12.77	-2.62347	0.233187	ext. cool	normal
1916	70.373	11.64	0.380906	-0.13844	normal	normal
1917	67.71	10.35	-0.97056	-0.56268	normal	normal
1918	69.54	14.57	-0.04184	0.825154	normal	normal
1919	70.597	14.37	0.494586	0.75938	normal	normal
1920	68.31	9.84	-0.66606	-0.73041	normal	normal
1921	73.303	9	1.86787	-1.00666	very warm	dry
1922	70.39	7.27	0.389534	-1.5756	normal	very dry
1923	70.633	11.39	0.512855	-0.22066	normal	normal
1924	66.533	14.84	-1.56788	0.91395	very cool	normal
1925	68.987	13.33	-0.32248	0.417354	normal	normal
1926	68.663	8.43	-0.48691	-1.19411	normal	dry
1927	66.23	6.32	-1.72165	-1.88803	very cool	very dry
1928	67.937	13.61	-0.85535	0.509438	normal	normal
1929	69.07	9.1	-0.28036	-0.97377	normal	normal
1930	71.043	10	0.720929	-0.67779	normal	normal
1931	73.033	8.23	1.730846	-1.25989	very warm	dry
1932	71.517	10.62	0.961482	-0.47389	normal	normal

1933	73.183	7.1	1.80697	-1.63151	very warm	very dry
1934	72.19	9.41	1.303027	-0.87182	warm	normal
1935	70.353	13.26	0.370756	0.394333	normal	normal
1936	73.157	7.11	1.793775	-1.62822	very warm	very dry
1937	72.157	9.67	1.286279	-0.78631	warm	normal
1938	71.267	10.02	0.834608	-0.67121	normal	normal
1939	71.127	10.6	0.763558	-0.48046	normal	normal
1940	70.083	15.69	0.233733	1.19349	normal	wet
1941	70.797	9.67	0.596085	-0.78631	normal	normal
1942	68.877	11.11	-0.37831	-0.31274	normal	normal
1943	70.993	17.93	0.695554	1.930161	normal	very wet
1944	69.343	16.27	-0.14181	1.384235	normal	wet
1945	66.957	13.85	-1.3527	0.588367	cool	normal
1946	69.05	8.91	-0.29051	-1.03626	normal	dry
1947	70.78	13.17	0.587457	0.364735	normal	normal
1948	70.277	11.84	0.332187	-0.07266	normal	normal
1949	73.147	9.5	1.7887	-0.84222	very warm	normal
1950	67.493	9.09	-1.08068	-0.97706	cool	normal
1951	66.947	14.97	-1.35777	0.956703	cool	normal
1952	70.35	14.42	0.369234	0.775824	normal	normal
1953	71.233	14.72	0.817353	0.874485	normal	normal
1954	70.903	12.46	0.649879	0.131237	normal	normal
1955	72.673	11.75	1.548147	-0.10226	very warm	normal
1956	70.077	16.03	0.230688	1.305306	normal	wet
1957	70.553	15.32	0.472256	1.071808	normal	wet
1958	67.507	8.69	-1.07358	-1.10861	cool	dry
1959	71.82	12.95	1.115253	0.292383	warm	normal
1960	69.237	10.51	-0.19561	-0.51006	normal	normal
1961	69.677	11.58	0.027689	-0.15817	normal	normal
1962	68.03	14.8	-0.80816	0.900795	normal	normal
1963	70.393	13.69	0.391056	0.535748	normal	normal
1964	70.16	10.77	0.27281	-0.42456	normal	normal
1965	68.737	11.29	-0.44936	-0.25354	normal	normal
1966	69.867	11.25	0.124113	-0.2667	normal	normal
1967	67.34	14.32	-1.15833	0.742937	cool	normal
1968	69.103	17.6	-0.26361	1.821634	normal	very wet
1969	68.093	10.69	-0.77618	-0.45087	normal	normal
1970	70.577	8.48	0.484436	-1.17767	normal	dry
1971	69.223	9.76	-0.20271	-0.75672	normal	normal
1972	68.16	10.41	-0.74218	-0.54295	normal	normal
1973	70.737	9.47	0.565635	-0.85209	normal	normal
1974	69.183	10.37	-0.22301	-0.5561	normal	normal
1975	70.77	10.72	0.582382	-0.441	normal	normal
1976	71.027	7.94	0.712809	-1.35526	normal	dry
1977	69.26	12.38	-0.18394	0.104927	normal	normal
1978	69.057	12.7	-0.28696	0.210166	normal	normal
1979	68.427	18.07	-0.60668	1.976203	normal	very wet

1980	70.317	11.45	0.352487	-0.20092	normal	normal
1981	69.237	18.01	-0.19561	1.956471	normal	very wet
1982	68.093	10.47	-0.77618	-0.52322	normal	normal
1983	72.917	11.41	1.671976	-0.21408	very warm	normal
1984	70.49	11.91	0.440283	-0.04964	normal	normal
1985	66.673	10.6	-1.49683	-0.48046	cool	normal
1986	69.15	15.28	-0.23976	1.058653	normal	wet
1987	71.343	13.35	0.873178	0.423932	normal	normal
1988	74.21	6.55	2.328169	-1.81239	ext. warm	very dry
1989	70.523	9.9	0.457031	-0.71067	normal	normal
1990	69.887	17.45	0.134263	1.772303	normal	very wet
1991	71.39	14.6	0.89703	0.83502	normal	normal
1992	64.807	13.9	-2.44382	0.604811	ext. cool	normal
1993	67.653	23.4	-0.99948	3.729085	normal	ext. wet
1994	67.81	14.85	-0.91981	0.917238	normal	normal
1995	71.677	13.17	1.042681	0.364735	warm	normal
1996	68.357	12.52	-0.64221	0.150969	normal	normal
1997	69.73	14.91	0.054586	0.936971	normal	normal
1998	69.347	13.43	-0.13978	0.450241	normal	normal
1999	70.343	13.74	0.365682	0.552191	normal	normal
2000	69.067	14.2	-0.28188	0.703472	normal	normal
2001	71.083	10.37	0.741229	-0.5561	normal	normal
2002	71.49	16.1	0.947779	1.328327	normal	wet
2003	70.213	9	0.299707	-1.00666	normal	dry
2004	66.1	14.62	-1.78762	0.841598	very cool	normal
2005	71.69	12.03	1.049279	-0.01018	warm	normal
2006	71.727	11.65	1.068056	-0.13515	warm	normal

Jun-Aug southeast MN

YEAR	SW_T	SW_P	SW_Tz	SW_Pz	T_class	P_class
1891	64.893	11.45	-2.04492	-0.23486	ext. cool	Normal
1892	67.04	15.23	-0.94713	0.912681	normal	Normal
1893	69.63	8.1	0.377173	-1.25185	normal	Dry
1894	71.597	4.6	1.382926	-2.31439	warm	ext. dry
1895	68.13	9.89	-0.3898	-0.70844	normal	Normal
1896	68.61	8.83	-0.14437	-1.03024	normal	Dry
1897	66.813	13.39	-1.0632	0.354091	cool	Normal
1898	68.833	8.06	-0.03034	-1.264	normal	Dry
1899	69.173	16.93	0.143503	1.428769	normal	Wet
1900	70.977	12.58	1.065912	0.10819	warm	Normal
1901	72.11	10.99	1.64523	-0.3745	very warm	Normal
1902	66.88	15.51	-1.02894	0.997683	cool	Normal
1903	65.717	12.8	-1.6236	0.174978	very cool	Normal
1904	65.803	11.58	-1.57962	-0.19539	very cool	Normal
1905	68.03	12.92	-0.44093	0.211408	normal	Normal
1906	68.567	10.43	-0.16635	-0.54451	normal	Normal
1907	67.11	15.94	-0.91134	1.128223	normal	Wet
1908	67.22	12.99	-0.85509	0.232658	normal	normal
1909	69.617	11.11	0.370526	-0.33807	normal	normal
1910	70.433	5.16	0.787758	-2.14438	normal	ext. dry
1911	69.847	13.92	0.488128	0.514989	normal	normal
1912	65.877	12.01	-1.54179	-0.06485	very cool	normal
1913	70.69	11.45	0.919165	-0.23486	normal	normal
1914	69.64	16.1	0.382286	1.176796	normal	wet
1915	63.703	13.71	-2.65338	0.451237	ext. cool	normal
1916	69.547	9.89	0.334734	-0.70844	normal	normal
1917	65.997	12.31	-1.48043	0.026223	cool	normal
1918	67.933	11.14	-0.49053	-0.32897	normal	normal
1919	69.29	11.82	0.203326	-0.12253	normal	normal
1920	67.67	11.68	-0.625	-0.16503	normal	normal
1921	72.367	7.66	1.776638	-1.38543	very warm	dry
1922	68.957	8.5	0.033059	-1.13042	normal	dry
1923	70.317	10.38	0.728445	-0.55969	normal	normal
1924	65.723	15.95	-1.62053	1.131259	very cool	wet
1925	68.103	15.87	-0.4036	1.106973	normal	wet
1926	67.54	9.65	-0.69147	-0.7813	normal	normal
1927	64.893	6.61	-2.04492	-1.70419	ext. cool	very dry
1928	67.52	16.51	-0.7017	1.301265	normal	wet
1929	68.183	8.98	-0.3627	-0.9847	normal	normal
1930	70.137	10.52	0.636409	-0.51719	normal	normal
1931	72.56	8.28	1.875321	-1.19721	very warm	dry
1932	70.857	9.51	1.004554	-0.8238	warm	normal

1933	72.627	7.19	1.909579	-1.52811	very warm	very dry
1934	71.287	10.07	1.224419	-0.6538	warm	normal
1935	69.527	13.72	0.324508	0.454273	normal	normal
1936	72.737	7.87	1.965823	-1.32168	very warm	dry
1937	71.773	9.25	1.472917	-0.90274	warm	normal
1938	70.07	15.05	0.602151	0.858036	normal	normal
1939	70.313	11.36	0.7264	-0.26218	normal	normal
1940	69.507	14.4	0.314281	0.660708	normal	normal
1941	70.25	7.73	0.694187	-1.36418	normal	dry
1942	67.89	15.32	-0.51251	0.940003	normal	normal
1943	70.3	14.47	0.719753	0.681959	normal	normal
1944	68.477	12.62	-0.21237	0.120333	normal	normal
1945	66.453	13.62	-1.24727	0.423915	cool	normal
1946	68.163	9.23	-0.37292	-0.90881	normal	normal
1947	70.02	12.65	0.576585	0.129441	normal	normal
1948	70.523	9.14	0.833776	-0.93613	normal	normal
1949	73.13	9.37	2.16677	-0.86631	ext. warm	normal
1950	67.407	13.04	-0.75948	0.247837	normal	normal
1951	66.833	16.67	-1.05297	1.349838	cool	wet
1952	69.667	14.2	0.396092	0.599992	normal	normal
1953	70.483	16.03	0.813323	1.155546	normal	wet
1954	70.49	13.91	0.816902	0.511953	normal	normal
1955	72.14	10.11	1.660569	-0.64166	very warm	normal
1956	69.7	14.12	0.412965	0.575705	normal	normal
1957	69.81	18.16	0.469209	1.802174	normal	very wet
1958	66.417	9.71	-1.26568	-0.76309	cool	normal
1959	70.537	16.88	0.840934	1.41359	normal	wet
1960	67.947	11.19	-0.48337	-0.31379	normal	normal
1961	68.803	9.76	-0.04568	-0.74791	normal	normal
1962	66.653	14.91	-1.14501	0.815535	cool	normal
1963	68.827	9.61	-0.03341	-0.79345	normal	normal
1964	69.42	6.99	0.269797	-1.58883	normal	very dry
1965	67	11.62	-0.96758	-0.18325	normal	normal
1966	68.713	10.52	-0.0917	-0.51719	normal	normal
1967	66.48	12.39	-1.23346	0.05051	cool	normal
1968	67.977	15.01	-0.46803	0.845893	normal	normal
1969	66.793	12.5	-1.07342	0.083904	cool	normal
1970	69.62	9.42	0.37206	-0.85113	normal	normal
1971	67.957	9.58	-0.47825	-0.80255	normal	normal
1972	66.873	13.4	-1.03252	0.357127	cool	normal
1973	69.467	12.66	0.293829	0.132477	normal	normal
1974	67.853	11.29	-0.53143	-0.28343	normal	normal
1975	69.553	12.92	0.337802	0.211408	normal	normal
1976	69.893	7.19	0.511648	-1.52811	normal	very dry
1977	68.483	12.07	-0.2093	-0.04664	normal	normal
1978	68.24	16.98	-0.33355	1.443948	normal	wet
1979	68.167	15.39	-0.37088	0.961254	normal	normal
1980	69.923	14.27	0.526988	0.621243	normal	normal
1981	68.477	18.18	-0.21237	1.808245	normal	very

						wet
1982	67.41	8.99	-0.75794	-0.98167	normal	normal
1983	71.71	11.98	1.440705	-0.07396	warm	normal
1984	69.417	11.16	0.268263	-0.3229	normal	normal
1985	66.8	8.2	-1.06984	-1.2215	cool	dry
1986	68.047	15.13	-0.43224	0.882322	normal	normal
1987	70.213	15.07	0.675269	0.864108	normal	normal
1988	73.35	7.57	2.279259	-1.41275	ext. warm	dry
1989	69.397	10.12	0.258037	-0.63862	normal	normal
1990	68.967	20.69	0.038172	2.570234	normal	ext. wet
1991	70.673	12.25	0.910473	0.008008	normal	normal
1992	64.42	9.34	-2.28677	-0.87541	ext. cool	normal
1993	67.447	20.78	-0.73902	2.597557	normal	ext. wet
1994	67.51	14.25	-0.70681	0.615171	normal	normal
1995	71.757	10.17	1.464736	-0.62344	warm	normal
1996	67.293	10.46	-0.81777	-0.5354	normal	normal
1997	68.42	16.78	-0.24152	1.383232	normal	wet
1998	68.697	18.32	-0.09988	1.850747	normal	very wet
1999	69.833	16.95	0.48097	1.43484	normal	wet
2000	68.48	18.16	-0.21084	1.802174	normal	very wet
2001	70.147	11.29	0.641522	-0.28343	normal	normal
2002	70.637	17.85	0.892065	1.708064	normal	very wet
2003	69.51	8	0.315815	-1.28221	normal	dry
2004	65.717	15.42	-1.6236	0.970361	very cool	Normal
2005	70.903	12.54	1.028075	0.096047	warm	Normal
2006	70.573	11.79	0.859341	-0.13164	normal	Normal

Nov-Mar northwest MN

YEAR	NW_T	NW_P	NW_Tz	NW_Pz	T_class	P_class
1892	13.75	4.16	-0.04305	0.444066	normal	normal
1893	5.946	5.24	-2.15896	1.474385	ext. cool	wet
1894	11.554	3.84	-0.63845	0.138786	normal	normal
1895	11.994	1.78	-0.51915	-1.82645	normal	very dry
1896	12.392	4.23	-0.41124	0.510846	normal	normal
1897	8.614	6.55	-1.43558	2.724123	cool	ext. wet
1898	13.794	2.49	-0.03112	-1.14911	normal	dry
1899	7.808	2.68	-1.65411	-0.96785	very cool	normal
1900	15.024	2.65	0.302376	-0.99647	normal	normal
1901	13.184	2.99	-0.19651	-0.67211	normal	normal
1902	17.536	3.36	0.983458	-0.31913	normal	normal
1903	14.352	3.18	0.120175	-0.49085	normal	normal
1904	8.378	5.09	-1.49957	1.331285	cool	wet
1905	15.78	2.98	0.507351	-0.68165	normal	normal
1906	15.162	3.69	0.339792	-0.00431	normal	normal
1907	10.866	5.75	-0.82499	1.960924	normal	very wet
1908	17.16	3.29	0.881513	-0.38591	normal	normal
1909	14.336	2.84	0.115837	-0.81521	normal	normal
1910	15.854	3.87	0.527415	0.167406	normal	normal
1911	11.73	3.1	-0.59073	-0.56717	normal	normal
1912	7.76	2.58	-1.66713	-1.06325	very cool	dry
1913	11.76	2.5	-0.5826	-1.13957	normal	dry
1914	16.158	2.25	0.609839	-1.37807	normal	dry
1915	14.526	2.41	0.167352	-1.22543	normal	dry
1916	9.844	5.61	-1.10209	1.827364	cool	very wet
1917	7.532	3.07	-1.72894	-0.59579	very cool	normal
1918	13.194	1.88	-0.1938	-1.73105	normal	very dry
1919	16.674	3.69	0.749743	-0.00431	normal	normal
1920	8.314	4.43	-1.51692	0.701645	very cool	normal
1921	17.282	3.87	0.914591	0.167406	normal	normal
1922	13.242	3.9	-0.18078	0.196026	normal	normal
1923	11.312	5.61	-0.70407	1.827364	normal	very wet
1924	17.946	1.9	1.094622	-1.71197	warm	very dry
1925	12.202	2.74	-0.46276	-0.91061	normal	normal
1926	16.524	2.65	0.709073	-0.99647	normal	normal
1927	13.432	3.95	-0.12927	0.243726	normal	normal
1928	12.612	3.53	-0.35159	-0.15695	normal	normal
1929	13.516	3.27	-0.10649	-0.40499	normal	normal
1930	12.884	3.91	-0.27785	0.205566	normal	normal
1931	20.81	4.41	1.871144	0.682565	very warm	normal
1932	16.35	3.62	0.661896	-0.07109	normal	normal
1933	12.374	4.27	-0.41612	0.549006	normal	normal
1934	12.24	3.63	-0.45246	-0.06155	normal	normal

1935	16.136	3.37	0.603874	-0.30959	normal	normal
1936	4.588	4.42	-2.52716	0.692105	ext. cool	normal
1937	9.474	3.43	-1.20241	-0.25235	cool	normal
1938	14.9	3.16	0.268755	-0.50993	normal	normal
1939	10.944	3.83	-0.80384	0.129246	normal	normal
1940	17.3	2.52	0.919471	-1.12049	normal	dry
1941	14.382	4.13	0.128309	0.415446	normal	normal
1942	20.04	3.18	1.662372	-0.49085	very warm	normal
1943	9.662	3.95	-1.15143	0.243726	cool	normal
1944	17.064	2.54	0.855484	-1.10141	normal	dry
1945	18.578	4.91	1.265978	1.159565	warm	wet
1946	14.732	3.55	0.223205	-0.13787	normal	normal
1947	13.514	2.85	-0.10703	-0.80567	normal	normal
1948	10.282	4.71	-0.98333	0.968765	normal	normal
1949	12.118	4.45	-0.48553	0.720725	normal	normal
1950	10.616	5.36	-0.89277	1.588864	normal	very wet
1951	10.734	4.24	-0.86078	0.520386	normal	normal
1952	12.524	3.79	-0.37545	0.091086	normal	normal
1953	18.8	3.86	1.326169	0.157866	warm	normal
1954	17.014	3.57	0.841928	-0.11879	normal	normal
1955	14.216	3.1	0.083301	-0.56717	normal	normal
1956	8.76	4.28	-1.39599	0.558546	cool	normal
1957	14.314	3.56	0.109872	-0.12833	normal	normal
1958	19.658	1.5	1.5588	-2.09357	very warm	ext. dry
1959	11.818	3.77	-0.56687	0.072006	normal	normal
1960	13.81	2.38	-0.02678	-1.25405	normal	dry
1961	17.27	2.56	0.911337	-1.08233	normal	dry
1962	11.996	4.17	-0.51861	0.453606	normal	normal
1963	15.612	1.99	0.461801	-1.62611	normal	very dry
1964	15.046	2.73	0.30834	-0.92015	normal	normal
1965	8.776	3.35	-1.39166	-0.32867	cool	normal
1966	12.4	5.86	-0.40907	2.065864	normal	ext. wet
1967	11.392	3.91	-0.68237	0.205566	normal	normal
1968	15.248	3.72	0.363109	0.024306	normal	normal
1969	12.14	4.04	-0.47957	0.329586	normal	normal
1970	12.15	3.4	-0.47686	-0.28097	normal	normal
1971	11.336	3.61	-0.69756	-0.08063	normal	normal
1972	10.746	3.33	-0.85753	-0.34775	normal	normal
1973	16.764	2.68	0.774145	-0.96785	normal	normal
1974	11.314	3.68	-0.70352	-0.01385	normal	normal
1975	15.434	4.68	0.41354	0.940145	normal	normal
1976	16.346	3.7	0.660812	0.005226	normal	normal
1977	12.582	3.27	-0.35973	-0.40499	normal	normal
1978	9.346	4.82	-1.23711	1.073705	cool	wet
1979	6.53	5.07	-2.00062	1.312205	ext. cool	wet
1980	14.324	3.21	0.112583	-0.46223	normal	normal
1981	19.686	2.67	1.566392	-0.97739	very warm	normal
1982	12.938	3.83	-0.26321	0.129246	normal	normal

1983	20.078	4	1.672675	0.291426	very warm	normal
1984	15.218	3.61	0.354975	-0.08063	normal	normal
1985	14.43	2.66	0.141323	-0.98693	normal	normal
1986	12.348	3.08	-0.42317	-0.58625	normal	normal
1987	20.474	4.55	1.780044	0.816125	very warm	normal
1988	16.352	3.55	0.662438	-0.13787	normal	normal
1989	12.04	5.52	-0.50668	1.741504	normal	very wet
1990	15.914	3.61	0.543683	-0.08063	normal	normal
1991	16.536	2.75	0.712327	-0.90107	normal	normal
1992	19.124	3.68	1.414016	-0.01385	warm	normal
1993	13.32	3.56	-0.15963	-0.12833	normal	normal
1994	11.518	3.52	-0.64821	-0.16649	normal	normal
1995	18.194	5.03	1.161863	1.274045	warm	wet
1996	8.296	5.52	-1.5218	1.741504	very cool	very wet
1997	9.37	6.57	-1.2306	2.743203	cool	ext. wet
1998	21.69	3.88	2.10974	0.176946	ext. warm	normal
1999	19.164	5.11	1.424861	1.350365	warm	wet
2000	23.848	2.75	2.694842	-0.90107	ext. warm	normal
2001	13.036	5.58	-0.23663	1.798744	normal	very wet
2002	21.494	2.2	2.056598	-1.42577	ext. warm	dry
2003	15.25	2.14	0.363651	-1.48301	normal	dry
2004	15.658	4.52	0.474273	0.787505	normal	normal
2005	16.852	3.2	0.798004	-0.47177	normal	normal
2006	20.248	6.15	1.718768	2.342524	very warm	ext. wet

Nov-Mar north-central MN

YEAR	NC_T	NC_P	NC_Tz	NC_Pz	T_class	P_class
1892	14.254	5.11	-0.00206	0.528525	normal	normal
1893	7.842	5.69	-1.91155	0.969237	very cool	normal
1894	11.712	5.18	-0.75906	0.581714	normal	normal
1895	11.756	2.78	-0.74596	-1.24192	normal	dry
1896	12.62	4.79	-0.48866	0.285373	normal	normal
1897	9.932	9.14	-1.28915	3.590716	cool	ext. wet
1898	12.728	3.02	-0.4565	-1.05956	normal	dry
1899	7.232	3.3	-2.09321	-0.8468	ext. cool	normal
1900	14.958	2.63	0.207595	-1.3559	normal	dry
1901	13.074	4.73	-0.35346	0.239782	normal	normal
1902	17.078	3.17	0.838932	-0.94558	normal	normal
1903	14.452	4.96	0.056908	0.414547	normal	normal
1904	7.584	5.8	-1.98838	1.05282	very cool	wet
1905	15.062	3.55	0.238566	-0.65684	normal	normal
1906	15.754	4.43	0.444644	0.011827	normal	normal
1907	12.022	7.43	-0.66675	2.291374	normal	ext. wet
1908	17.408	3.73	0.937206	-0.52007	normal	normal
1909	14.446	3.75	0.055122	-0.50487	normal	normal
1910	17.012	4.36	0.819277	-0.04136	normal	normal
1911	13.264	4.24	-0.29688	-0.13254	normal	normal
1912	8.028	2.73	-1.85616	-1.27992	very cool	dry
1913	12.554	3.29	-0.50832	-0.8544	normal	normal
1914	16.812	3.02	0.759717	-1.05956	normal	dry
1915	15.818	2.54	0.463703	-1.42429	normal	dry
1916	11.862	6.13	-0.71439	1.303571	normal	wet
1917	9.156	2.75	-1.52024	-1.26472	very cool	dry
1918	13.372	1.84	-0.26472	-1.95618	normal	very dry
1919	18.188	4.66	1.16949	0.186593	warm	normal
1920	9.586	4.77	-1.39219	0.270176	cool	normal
1921	17.794	3.99	1.052156	-0.32251	warm	normal
1922	12.6	4.19	-0.49462	-0.17054	normal	normal
1923	11.068	6.09	-0.95085	1.273177	normal	wet
1924	17.114	2.2	0.849652	-1.68264	normal	very dry
1925	12.246	2.61	-0.60004	-1.3711	normal	dry
1926	15.23	3.56	0.288597	-0.64924	normal	normal
1927	13.128	4.7	-0.33738	0.216986	normal	normal
1928	11.714	3.58	-0.75847	-0.63404	normal	normal
1929	13.64	2.95	-0.18491	-1.11275	normal	dry
1930	12.552	4.03	-0.50891	-0.29211	normal	normal
1931	20.882	3.98	1.971763	-0.3301	very warm	normal
1932	17.798	5.57	1.053348	0.878055	warm	normal
1933	12.246	6.33	-0.60004	1.45554	normal	wet
1934	11.904	4.62	-0.70189	0.156199	normal	normal
1935	15.602	4.99	0.399378	0.437343	normal	normal
1936	7.212	4.49	-2.09916	0.057418	ext. cool	normal

1937	10.066	5.58	-1.24924	0.885654	cool	normal
1938	16.08	3.53	0.541727	-0.67204	normal	normal
1939	11.612	6.48	-0.78884	1.569518	normal	very wet
1940	17.508	3.1	0.966986	-0.99877	normal	normal
1941	14.912	4.67	0.193896	0.194191	normal	normal
1942	19.672	3	1.611425	-1.07476	very warm	dry
1943	9.94	4.02	-1.28677	-0.29971	cool	normal
1944	16.878	2.55	0.779372	-1.41669	normal	dry
1945	18.542	5.63	1.274911	0.923646	warm	normal
1946	15.182	4.64	0.274302	0.171396	normal	normal
1947	13.78	3.64	-0.14321	-0.58845	normal	normal
1948	11.24	4.67	-0.89963	0.194191	normal	normal
1949	13.11	5.01	-0.34274	0.45254	normal	normal
1950	11.318	5.54	-0.8764	0.85526	normal	normal
1951	11.016	5.64	-0.96633	0.931245	normal	normal
1952	13.508	4.69	-0.22422	0.209388	normal	normal
1953	18.226	3.88	1.180806	-0.40609	warm	normal
1954	16.984	5.59	0.810938	0.893252	normal	normal
1955	14.586	4.12	0.096814	-0.22373	normal	normal
1956	10.582	4.66	-1.09558	0.186593	cool	normal
1957	13.44	4.53	-0.24447	0.087812	normal	normal
1958	18.718	2.48	1.327324	-1.46988	warm	dry
1959	11.744	3.96	-0.74953	-0.3453	normal	normal
1960	13.594	2.44	-0.1986	-1.50027	normal	very dry
1961	17.49	3.13	0.961625	-0.97598	normal	normal
1962	12.904	4.11	-0.40409	-0.23132	normal	normal
1963	14.614	2.62	0.105152	-1.3635	normal	dry
1964	15.228	3.5	0.288001	-0.69483	normal	normal
1965	9.254	4.29	-1.49106	-0.09455	cool	normal
1966	13.524	8	-0.21945	2.724488	normal	ext. wet
1967	12.06	4.45	-0.65543	0.027024	normal	normal
1968	15.6	4.06	0.398783	-0.26932	normal	normal
1969	13.704	5.3	-0.16585	0.672896	normal	normal
1970	13.3	4.15	-0.28616	-0.20093	normal	normal
1971	11.554	5.06	-0.80612	0.490532	normal	normal
1972	10.924	4.41	-0.99373	-0.00337	normal	normal
1973	17.192	3.08	0.872881	-1.01397	normal	dry
1974	13.126	3.91	-0.33797	-0.38329	normal	normal
1975	16.27	6.98	0.598309	1.949442	normal	very wet
1976	16.116	4.73	0.552448	0.239782	normal	normal
1977	12.954	3.99	-0.3892	-0.32251	normal	normal
1978	11.064	5.75	-0.95204	1.014828	normal	wet
1979	8.584	6.03	-1.69058	1.227586	very cool	wet
1980	14.474	4.06	0.06346	-0.26932	normal	normal
1981	18.444	3.57	1.245727	-0.64164	warm	normal
1982	13.346	4.37	-0.27246	-0.03376	normal	normal
1983	20.162	4.45	1.757347	0.027024	very warm	normal
1984	14.756	4.97	0.14744	0.422146	normal	normal
1985	14.906	3.55	0.19211	-0.65684	normal	normal

1986	13.316	3.9	-0.28139	-0.39089	normal	normal
1987	21.254	4	2.082545	-0.31491	ext. warm	normal
1988	15.928	4.29	0.496461	-0.09455	normal	normal
1989	13.106	6.56	-0.34393	1.630306	normal	very wet
1990	15.776	4.11	0.451196	-0.23132	normal	normal
1991	16.514	3.67	0.670972	-0.56566	normal	normal
1992	18.504	5.02	1.263595	0.460138	warm	normal
1993	14.944	4.18	0.203426	-0.17814	normal	normal
1994	12.108	4.28	-0.64114	-0.10215	normal	normal
1995	18.596	5.03	1.290992	0.467737	warm	normal
1996	8.404	6.38	-1.74419	1.493533	very cool	wet
1997	11.526	7.32	-0.81445	2.207791	normal	ext. wet
1998	22.212	3.91	2.367838	-0.38329	ext. warm	normal
1999	18.872	5.63	1.373185	0.923646	warm	normal
2000	22.7	2.77	2.513164	-1.24952	ext. warm	dry
2001	13.816	6.2	-0.13249	1.35676	normal	wet
2002	21.366	3.66	2.115899	-0.57326	ext. warm	normal
2003	15.258	1.99	0.296935	-1.8422	normal	very dry
2004	16.418	4.97	0.642383	0.422146	normal	normal
2005	16.892	4.48	0.783541	0.04982	normal	normal
2006	20.41	7.34	1.831202	2.222988	very warm	ext. wet

Nov-Mar northeast MN

YEAR	NE_T	NW_P	NE_Tz	NE_Pz	T_class	P_class
1892	17.744	6.65	0.655186	0.485151	normal	normal
1893	11.838	7.04	-1.40658	0.72051	cool	normal
1894	14.604	6.9	-0.44098	0.636022	normal	normal
1895	14.742	4.83	-0.3928	-0.61319	normal	normal
1896	15.778	6.32	-0.03114	0.286	normal	normal
1897	13.93	10.83	-0.67627	3.007724	normal	ext. wet
1898	15.318	4.06	-0.19172	-1.07788	normal	dry
1899	9.966	5.01	-2.06009	-0.50457	ext. cool	normal
1900	16.514	3.59	0.225796	-1.36152	normal	dry
1901	13.496	4.52	-0.82778	-0.80028	normal	normal
1902	17.55	3.77	0.587461	-1.25289	normal	dry
1903	15.978	7.55	0.03868	1.028288	normal	wet
1904	8.73	5.73	-2.49158	-0.07006	ext. cool	normal
1905	15.822	5.07	-0.01578	-0.46836	normal	normal
1906	17.554	4.76	0.588857	-0.65544	normal	normal
1907	14.924	8.89	-0.32927	1.83696	normal	very wet
1908	18.704	4.09	0.990319	-1.05977	normal	dry
1909	16.234	5.6	0.128049	-0.14851	normal	normal
1910	19.658	6.97	1.323358	0.678266	warm	normal
1911	16.318	6.36	0.157373	0.31014	normal	normal
1912	11.022	5.24	-1.69145	-0.36577	very cool	normal
1913	14.794	4.6	-0.37465	-0.752	normal	normal
1914	19.192	4.09	1.160678	-1.05977	warm	dry
1915	17.936	3.4	0.722212	-1.47618	normal	dry
1916	14.814	10.32	-0.36767	2.699946	normal	ext. wet
1917	12.542	5.08	-1.16082	-0.46232	cool	normal
1918	15.334	2.93	-0.18614	-1.75982	normal	very dry
1919	21.606	6.09	2.003399	0.147198	ext. warm	normal
1920	12.91	5.77	-1.03235	-0.04592	cool	normal
1921	20.688	5.21	1.682928	-0.38387	very warm	normal
1922	15.394	5.33	-0.16519	-0.31145	normal	normal
1923	13.136	7.27	-0.95345	0.859312	normal	normal
1924	18.16	3.93	0.80041	-1.15633	normal	dry
1925	13.598	3.92	-0.79217	-1.16237	normal	dry
1926	15.934	4.91	0.02332	-0.56492	normal	normal
1927	14.938	9.71	-0.32438	2.331819	normal	ext. wet
1928	15.05	4.69	-0.28528	-0.69768	normal	normal
1929	15.166	4.71	-0.24479	-0.68561	normal	normal
1930	14.014	4.39	-0.64695	-0.87873	normal	normal
1931	22.244	4.38	2.226123	-0.88476	ext. warm	normal
1932	20.104	6.42	1.479055	0.346349	warm	normal
1933	14.884	5.87	-0.34323	0.014431	normal	normal
1934	13.092	5.41	-0.96881	-0.26317	normal	normal
1935	17.04	7.8	0.409421	1.17916	normal	wet
1936	11.248	5.89	-1.61255	0.026501	very	normal

					cool	
1937	13.338	7.65	-0.88294	1.088637	normal	wet
1938	17.978	6.44	0.736874	0.358418	normal	normal
1939	14.468	9.22	-0.48846	2.036111	normal	ext. wet
1940	19.726	3.03	1.347096	-1.69947	warm	very dry
1941	17.136	6.39	0.442935	0.328244	normal	normal
1942	20.68	4.55	1.680135	-0.78217	very warm	normal
1943	12.64	4.84	-1.12661	-0.60716	cool	normal
1944	18.076	3.6	0.771086	-1.35548	normal	dry
1945	19.358	7.55	1.218629	1.028288	warm	wet
1946	16.448	6.1	0.202756	0.153233	normal	normal
1947	15.636	4.69	-0.08071	-0.69768	normal	normal
1948	14.4	6.92	-0.5122	0.648092	normal	normal
1949	17.018	7.56	0.401741	1.034323	normal	wet
1950	14.374	6.73	-0.52127	0.53343	normal	normal
1951	13.446	6.92	-0.84523	0.648092	normal	normal
1952	15.736	4.96	-0.0458	-0.53474	normal	normal
1953	19.924	5.07	1.416218	-0.46836	warm	normal
1954	19.044	6.59	1.109012	0.448941	warm	normal
1955	16.984	5.22	0.389872	-0.37784	normal	normal
1956	15	5.71	-0.30274	-0.08213	normal	normal
1957	15.218	5.32	-0.22663	-0.31749	normal	normal
1958	18.598	4.18	0.953315	-1.00546	normal	dry
1959	12.56	4.55	-1.15453	-0.78217	cool	normal
1960	15.278	3.36	-0.20569	-1.50032	normal	very dry
1961	18.14	4.73	0.793428	-0.67354	normal	normal
1962	14.456	4.84	-0.49265	-0.60716	normal	normal
1963	14.278	3.69	-0.55479	-1.30117	normal	dry
1964	16.786	4.73	0.320751	-0.67354	normal	normal
1965	10.848	6.88	-1.75219	0.623953	very cool	normal
1966	15.704	9.56	-0.05697	2.241296	normal	ext. wet
1967	12.926	5.58	-1.02676	-0.16058	cool	normal
1968	16.616	4.92	0.261404	-0.55888	normal	normal
1969	15.758	7.06	-0.03812	0.73258	normal	normal
1970	14.522	5.55	-0.46961	-0.17868	normal	normal
1971	13.66	7.5	-0.77053	0.998114	normal	normal
1972	11.748	7.18	-1.438	0.804998	cool	normal
1973	17.486	4.47	0.565119	-0.83045	normal	normal
1974	14.2	4.88	-0.58201	-0.58302	normal	normal
1975	17.312	7.97	0.504376	1.281753	normal	wet
1976	16.874	7.93	0.351471	1.257613	normal	wet
1977	13.028	4.46	-0.99116	-0.83648	normal	normal
1978	13.45	6.12	-0.84384	0.165303	normal	normal
1979	10.452	8.27	-1.89043	1.462799	very cool	wet
1980	16.38	4.15	0.179017	-1.02357	normal	dry
1981	18.662	4.75	0.975657	-0.66147	normal	normal
1982	14.348	5.95	-0.53035	0.06271	normal	normal
1983	19.93	6.76	1.418312	0.551534	warm	normal
1984	14.716	6.01	-0.40188	0.098919	normal	normal
1985	15.742	5.13	-0.04371	-0.43215	normal	normal

1986	13.718	5.25	-0.75028	-0.35973	normal	normal
1987	21.166	4.1	1.849796	-1.05374	very warm	dry
1988	15.84	5.27	-0.0095	-0.34766	normal	normal
1989	13.764	7.44	-0.73422	0.961905	normal	normal
1990	15.03	4.18	-0.29226	-1.00546	normal	dry
1991	16.376	5.88	0.177621	0.020466	normal	normal
1992	18.052	7.69	0.762708	1.112777	normal	wet
1993	16.058	5.16	0.066608	-0.41404	normal	normal
1994	12.482	5.72	-1.18176	-0.07609	cool	normal
1995	19.108	5.93	1.131354	0.05064	warm	normal
1996	9.466	9.17	-2.23464	2.005937	ext. cool	ext. wet
1997	13.042	10.03	-0.98627	2.524935	normal	ext. wet
1998	22.862	6.14	2.441865	0.177373	ext. warm	normal
1999	19.28	7.69	1.191399	1.112777	warm	wet
2000	21.998	4.38	2.140245	-0.88476	ext. warm	normal
2001	14.574	7.34	-0.45145	0.901556	normal	normal
2002	21.432	5.51	1.942656	-0.20282	very warm	normal
2003	14.968	2.82	-0.31391	-1.8262	normal	very dry
2004	17.1	6.44	0.430367	0.358418	normal	normal
2005	16.636	6.17	0.268386	0.195477	normal	normal
2006	20.448	7.87	1.599145	1.221404	very warm	wet

Nov-Mar west-central MN

YEAR	WC_T	WC_P	WC_Tz	WC_Pz	T_class	P_class
1892	18.158	4.4	-0.19171	0.119223	normal	normal
1893	11.064	4.95	-2.23417	0.541681	ext. cool	normal
1894	15.27	3.73	-1.02321	-0.39541	cool	normal
1895	15.468	1.52	-0.9662	-2.09292	normal	ext. dry
1896	17.422	4.88	-0.40362	0.487914	normal	normal
1897	13.4	7.33	-1.5616	2.36977	very cool	ext. wet
1898	20.188	2.57	0.392748	-1.28641	normal	dry
1899	12.948	2.63	-1.69174	-1.24032	very cool	dry
1900	19.89	3.78	0.30695	-0.357	normal	normal
1901	18.074	3.33	-0.2159	-0.70265	normal	normal
1902	20.854	3.36	0.584498	-0.67961	normal	normal
1903	17.562	4.98	-0.36331	0.564724	normal	normal
1904	13.536	3	-1.52245	-0.95612	very cool	normal
1905	19.602	2.33	0.224031	-1.47075	normal	dry
1906	20.272	4.55	0.416933	0.234439	normal	normal
1907	17.216	4.63	-0.46293	0.295887	normal	normal
1908	22.304	3.87	1.001971	-0.28787	warm	normal
1909	19.56	4.87	0.211939	0.480232	normal	normal
1910	20.226	4.51	0.403689	0.203715	normal	normal
1911	18.088	2.48	-0.21187	-1.35554	normal	dry
1912	12.946	3.04	-1.69232	-0.9254	very cool	normal
1913	18.754	2.28	-0.02012	-1.50916	normal	very dry
1914	21.852	3.05	0.871835	-0.91772	normal	normal
1915	19.104	3.59	0.080651	-0.50294	normal	normal
1916	16.054	6.14	-0.79748	1.455726	normal	wet
1917	13.328	5.18	-1.58233	0.718345	very cool	normal
1918	18.202	2.65	-0.17905	-1.22496	normal	dry
1919	22.58	5.87	1.081435	1.248337	warm	wet
1920	15.194	5.67	-1.04509	1.094716	cool	wet
1921	23.24	4.1	1.271458	-0.11121	warm	normal
1922	16.654	5.39	-0.62474	0.879647	normal	normal
1923	17.26	6.96	-0.45026	2.085571	normal	ext. wet
1924	22.37	2.65	1.020973	-1.22496	warm	dry
1925	18.168	1.91	-0.18884	-1.79336	normal	very dry
1926	20.198	3.57	0.395627	-0.5183	normal	normal
1927	19.156	4.41	0.095622	0.126904	normal	normal
1928	17.688	4.32	-0.32703	0.057775	normal	normal
1929	17.982	3.73	-0.24239	-0.39541	normal	normal
1930	18.694	2.82	-0.03739	-1.09438	normal	dry
1931	26.328	4.68	2.160532	0.334293	ext. warm	normal
1932	21.148	4.09	0.669144	-0.11889	normal	normal
1933	18.982	3.5	0.045525	-0.57207	normal	normal
1934	19.622	2.11	0.229789	-1.63974	normal	very dry
1935	21.952	3.58	0.900626	-0.51062	normal	normal
1936	10.236	4.07	-2.47256	-0.13425	ext.	normal

					cool	
1937	14.644	5.77	-1.20344	1.171527	cool	wet
1938	19.576	3.22	0.216545	-0.78714	normal	normal
1939	18.522	4.46	-0.08691	0.16531	normal	normal
1940	20.842	3.9	0.581043	-0.26483	normal	normal
1941	19.124	4.08	0.086409	-0.12657	normal	normal
1942	24.884	3.04	1.744786	-0.9254	very warm	normal
1943	15.048	4.56	-1.08712	0.24212	cool	normal
1944	22.058	3.78	0.931145	-0.357	normal	normal
1945	22.664	4.68	1.10562	0.334293	warm	normal
1946	19.214	5.54	0.112321	0.994863	normal	normal
1947	19.924	3.17	0.316739	-0.82555	normal	normal
1948	14.67	5.49	-1.19595	0.956457	cool	normal
1949	17.514	4.12	-0.37713	-0.09585	normal	normal
1950	16.826	5.13	-0.57521	0.67994	normal	normal
1951	13.858	5.6	-1.42974	1.040949	cool	wet
1952	15.632	6.9	-0.91898	2.039485	normal	ext. wet
1953	21.96	4.68	0.902929	0.334293	normal	normal
1954	21.214	5.39	0.688146	0.879647	normal	normal
1955	19.836	2.23	0.291403	-1.54756	normal	very dry
1956	13.402	3.83	-1.56103	-0.3186	very cool	normal
1957	19.786	4.35	0.277007	0.080818	normal	normal
1958	22.582	2.68	1.082011	-1.20192	warm	dry
1959	18.674	3.16	-0.04315	-0.83323	normal	normal
1960	17.746	3.24	-0.31033	-0.77178	normal	normal
1961	22.712	2.59	1.11944	-1.27105	warm	dry
1962	16.338	4.59	-0.71572	0.265163	normal	normal
1963	20.436	2.8	0.46415	-1.10974	normal	dry
1964	20.448	3.13	0.467605	-0.85627	normal	normal
1965	13.476	4.32	-1.53972	0.057775	very cool	normal
1966	18.842	5.16	0.005217	0.702983	normal	normal
1967	17.234	4.23	-0.45775	-0.01135	normal	normal
1968	21.054	2.64	0.64208	-1.23264	normal	dry
1969	15.524	6.7	-0.95008	1.885864	normal	very wet
1970	16.612	3.74	-0.63683	-0.38773	normal	normal
1971	16.764	5.86	-0.59307	1.240656	normal	wet
1972	15.488	5.3	-0.96044	0.810518	normal	normal
1973	20.882	4.76	0.592559	0.395741	normal	normal
1974	17.528	3.6	-0.3731	-0.49526	normal	normal
1975	19.146	6.6	0.092743	1.809054	normal	very wet
1976	21.576	4.77	0.792371	0.403422	normal	normal
1977	16.622	6.29	-0.63395	1.570941	normal	very wet
1978	14.08	6.16	-1.36582	1.471088	cool	wet
1979	11.994	6.6	-1.96641	1.809054	very cool	very wet
1980	19.586	3.43	0.219425	-0.62584	normal	normal
1981	24.316	2.56	1.581252	-1.29409	very warm	dry

1982	16.226	5.07	-0.74796	0.633853	normal	normal
1983	23.566	4.69	1.365317	0.341974	warm	normal
1984	17.884	5.87	-0.2706	1.248337	normal	wet
1985	19.472	3.67	0.186602	-0.44149	normal	normal
1986	16.304	4.83	-0.7255	0.449508	normal	normal
1987	26.096	3.67	2.093736	-0.44149	ext. warm	normal
1988	20.692	3.7	0.537856	-0.41845	normal	normal
1989	17.578	5.62	-0.3587	1.056311	normal	wet
1990	21.708	3.6	0.830375	-0.49526	normal	normal
1991	22.058	3.45	0.931145	-0.61048	normal	normal
1992	23.946	3.77	1.474724	-0.36468	warm	normal
1993	17.092	4.94	-0.49863	0.534	normal	normal
1994	15.508	5.43	-0.95468	0.910371	normal	normal
1995	22.606	5.5	1.088921	0.964138	warm	normal
1996	15.208	4.13	-1.04106	-0.08817	cool	normal
1997	14.796	7.38	-1.15968	2.408175	cool	ext. wet
1998	24.266	4.19	1.566856	-0.04208	very warm	normal
1999	24.76	4.42	1.709085	0.134585	very warm	normal
2000	27.48	3.23	2.492207	-0.77946	ext. warm	normal
2001	15.148	7.07	-1.05833	2.170063	cool	ext. wet
2002	25.636	4.11	1.961296	-0.10353	very warm	normal
2003	20.44	1.76	0.465302	-1.90857	normal	very dry
2004	21.098	3.62	0.654749	-0.4799	normal	normal
2005	22.41	2.84	1.03249	-1.07902	warm	Dry
2006	23.116	5.7	1.235756	1.117759	warm	Wet

Nov-Mar central MN

YEAR	C_T	C_P	C_Tz	C_Pz	T_class	P_class
1892	19.66	5.58	0.008831	0.457248	normal	normal
1893	13.54	4.56	-1.88367	-0.19604	very cool	normal
1894	17.628	4.56	-0.61953	-0.19604	normal	normal
1895	17.026	2.31	-0.80569	-1.63712	normal	very dry
1896	19.666	4.36	0.010686	-0.32414	normal	normal
1897	15.676	8.03	-1.22315	2.026426	cool	ext. wet
1898	20.68	2.83	0.324247	-1.30407	normal	dry
1899	13.752	3.66	-1.81811	-0.77248	very cool	normal
1900	20.776	3.68	0.353933	-0.75967	normal	normal
1901	18.596	3.17	-0.32019	-1.08631	normal	dry
1902	21.394	2.56	0.545038	-1.477	normal	dry
1903	19.178	6.31	-0.14022	0.924799	normal	normal
1904	13.624	3.38	-1.85769	-0.95181	very cool	normal
1905	19.946	2.26	0.097271	-1.66915	normal	very dry
1906	20.57	4.66	0.290231	-0.13199	normal	normal
1907	18.54	5.01	-0.33751	0.092174	normal	normal
1908	23.026	4.56	1.049704	-0.19604	warm	normal
1909	20.5	5.12	0.268585	0.162626	normal	normal
1910	21.26	5.38	0.503601	0.329151	normal	normal
1911	19.926	2.15	0.091086	-1.7396	normal	very dry
1912	13.494	3.2	-1.89789	-1.0671	very cool	dry
1913	19.808	2.11	0.054597	-1.76522	normal	very dry
1914	23.366	3.07	1.154843	-1.15036	warm	dry
1915	20.316	3.07	0.211686	-1.15036	normal	dry
1916	17.188	6.82	-0.75559	1.251444	normal	wet
1917	14.56	5.44	-1.56825	0.36758	very cool	normal
1918	19.14	2.3	-0.15197	-1.64353	normal	very dry
1919	23.826	8.09	1.297089	2.064855	warm	ext. wet
1920	15.904	6.13	-1.15264	0.809512	cool	normal
1921	24.17	4.26	1.403465	-0.38819	warm	normal
1922	17.18	6.07	-0.75806	0.771083	normal	normal
1923	18.358	6.1	-0.39379	0.790298	normal	normal
1924	23.14	2.96	1.084956	-1.22081	warm	dry
1925	19.282	2.69	-0.10806	-1.39374	normal	dry
1926	20.594	3.58	0.297653	-0.82371	normal	normal
1927	19.84	4.65	0.064492	-0.1384	normal	normal
1928	18.664	5.55	-0.29916	0.438033	normal	normal
1929	18.95	3.81	-0.21072	-0.6764	normal	normal
1930	19.754	3.5	0.037898	-0.87495	normal	normal
1931	26.588	4.97	2.151187	0.066554	ext. warm	normal
1932	22.642	6.23	0.930959	0.87356	normal	normal
1933	19.712	4.5	0.024911	-0.23447	normal	normal
1934	19.922	2.56	0.089849	-1.477	normal	dry
1935	21.946	4.81	0.715734	-0.03592	normal	normal
1936	11.934	5.2	-2.38029	0.213865	ext. cool	normal

1937	15.644	5.69	-1.23304	0.527701	cool	normal
1938	20.562	4.17	0.287757	-0.44583	normal	normal
1939	19.358	5.75	-0.08456	0.566129	normal	normal
1940	21.254	3.83	0.501746	-0.66359	normal	normal
1941	19.078	6.21	-0.17114	0.860751	normal	normal
1942	24.916	3.8	1.634152	-0.68281	very warm	normal
1943	15.718	5.11	-1.21016	0.156222	cool	normal
1944	21.752	4.6	0.655743	-0.17042	normal	normal
1945	22.262	5.26	0.813451	0.252294	normal	normal
1946	20.214	6.26	0.180145	0.892775	normal	normal
1947	20.292	3.7	0.204265	-0.74686	normal	normal
1948	15.48	6.16	-1.28376	0.828727	cool	normal
1949	18.288	6.15	-0.41544	0.822322	normal	normal
1950	17.6	5.75	-0.62819	0.566129	normal	normal
1951	14.526	7.3	-1.57876	1.558875	very cool	very wet
1952	16.922	7.58	-0.83785	1.738209	normal	very wet
1953	22.152	4.6	0.779436	-0.17042	normal	normal
1954	22.334	5.7	0.835716	0.534105	normal	normal
1955	20.108	3.03	0.147366	-1.17598	normal	dry
1956	14.53	4.34	-1.57753	-0.33695	very cool	normal
1957	20.324	5	0.21416	0.085769	normal	normal
1958	22.636	2.61	0.929104	-1.44498	normal	dry
1959	19.4	2.47	-0.07157	-1.53465	normal	very dry
1960	18.064	3.51	-0.4847	-0.86855	normal	normal
1961	23.176	3.08	1.096089	-1.14395	warm	dry
1962	17.284	5.2	-0.7259	0.213865	normal	normal
1963	20.504	2.65	0.269822	-1.41936	normal	dry
1964	21.206	3.16	0.486903	-1.09272	normal	dry
1965	14.436	7.33	-1.6066	1.578089	very cool	very wet
1966	19.848	6.84	0.066966	1.264254	normal	wet
1967	17.618	5.04	-0.62262	0.111388	normal	normal
1968	21.828	3.14	0.679245	-1.10553	normal	dry
1969	17.228	6.86	-0.74322	1.277063	normal	wet
1970	17.05	4.48	-0.79826	-0.24728	normal	normal
1971	17.158	7.51	-0.76487	1.693376	normal	very wet
1972	16.186	6.22	-1.06544	0.867155	cool	normal
1973	21.93	5.05	0.710786	0.117793	normal	normal
1974	18.918	4.66	-0.22062	-0.13199	normal	normal
1975	19.482	7.57	-0.04621	1.731805	normal	very wet
1976	21.752	7.17	0.655743	1.475612	normal	wet
1977	17.016	5.91	-0.80878	0.668606	normal	normal
1978	15.728	5.67	-1.20707	0.514891	cool	normal
1979	13.444	7.75	-1.91335	1.847091	very cool	very wet
1980	20.076	3.81	0.137471	-0.6764	normal	normal
1981	24.776	3.11	1.590859	-1.12474	very warm	dry

1982	17.208	5.34	-0.74941	0.303532	normal	normal
1983	23.938	7.33	1.331723	1.578089	warm	very wet
1984	18.086	6.74	-0.4779	1.200205	normal	wet
1985	20.256	4.95	0.193133	0.053745	normal	normal
1986	17.112	4.97	-0.77909	0.066554	normal	normal
1987	26.476	2.78	2.116553	-1.3361	ext. warm	Dry
1988	20.832	4.73	0.37125	-0.08716	normal	Normal
1989	18.516	6.02	-0.34493	0.739059	normal	Normal
1990	21.958	5.07	0.719445	0.130602	normal	Normal
1991	22.332	4.31	0.835097	-0.35616	normal	Normal
1992	23.17	5.67	1.094233	0.514891	warm	Normal
1993	18.666	5.07	-0.29855	0.130602	normal	Normal
1994	16.552	5.64	-0.95226	0.495677	normal	Normal
1995	22.938	5.09	1.022492	0.143412	warm	Normal
1996	15.578	4.77	-1.25345	-0.06154	cool	Normal
1997	16.228	8.59	-1.05245	2.385095	cool	ext. wet
1998	25.064	5.46	1.679918	0.38039	very warm	Normal
1999	24.718	5.22	1.572924	0.226675	very warm	Normal
2000	27.602	3.94	2.464748	-0.59314	ext. warm	Normal
2001	16.572	8.02	-0.94608	2.020021	normal	ext. wet
2002	26.648	6.49	2.169741	1.040085	ext. warm	Wet
2003	21.524	2.2	0.585238	-1.70758	normal	very dry
2004	22.36	4.53	0.843756	-0.21526	normal	Normal
2005	23.598	4.02	1.226585	-0.5419	warm	Normal
2006	24.384	6.06	1.469641	0.764678	warm	Normal

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YEAR	EC_T	EC_P	EC_Tz	EC_Pz	T_class	P_class
1892	19.25	6.1	0.245577	0.471415	normal	normal
1893	13.676	6.02	-1.56307	0.423518	very cool	normal
1894	17.74	7.1	-0.24439	1.070119	normal	wet
1895	17.28	3.33	-0.39365	-1.187	normal	dry
1896	18.744	5	0.08139	-0.18716	normal	normal
1897	16.704	10.28	-0.58055	2.973999	normal	ext. wet
1898	20.302	3.33	0.586928	-1.187	normal	dry
1899	12.53	4.65	-1.93492	-0.39671	very cool	normal
1900	20.698	3.78	0.715421	-0.91758	normal	normal
1901	17.596	4.1	-0.29111	-0.72599	normal	normal
1902	21.076	3.25	0.838074	-1.23489	normal	dry
1903	18.83	8.02	0.109296	1.620927	normal	very wet
1904	12.448	4.56	-1.96153	-0.45059	very cool	normal
1905	19.798	2.35	0.423391	-1.77373	normal	very dry
1906	19.542	6.26	0.340324	0.567207	normal	normal
1907	17.796	6.27	-0.22622	0.573194	normal	normal
1908	22.17	4.08	1.193053	-0.73797	warm	normal
1909	19.614	4.97	0.363687	-0.20512	normal	normal
1910	20.14	5.84	0.534362	0.315752	normal	normal
1911	18.258	3.11	-0.07631	-1.31871	normal	dry
1912	11.126	3.4	-2.39049	-1.14509	ext. cool	dry
1913	16.884	3.4	-0.52214	-1.14509	normal	dry
1914	21.01	3.21	0.816658	-1.25884	normal	dry
1915	18.96	3.46	0.151478	-1.10917	normal	dry
1916	15.396	7.47	-1.00496	1.29164	cool	wet
1917	12.562	4.8	-1.92453	-0.3069	very cool	normal
1918	17.15	1.78	-0.43583	-2.11499	normal	ext. dry
1919	21.944	6.74	1.119721	0.854586	warm	normal
1920	13.596	6.65	-1.58902	0.800702	very cool	normal
1921	21.932	4.32	1.115827	-0.59428	warm	normal
1922	16.004	7.33	-0.80768	1.207821	normal	wet
1923	16.188	6.73	-0.74798	0.848599	normal	normal
1924	21.166	2.63	0.867277	-1.60609	normal	very dry
1925	17.398	3.27	-0.35536	-1.22292	normal	dry
1926	18.05	3.9	-0.1438	-0.84574	normal	normal
1927	17.716	5.53	-0.25217	0.130153	normal	normal
1928	16.01	5.02	-0.80573	-0.17519	normal	normal
1929	17.412	3.97	-0.35081	-0.80383	normal	normal
1930	17.916	3.59	-0.18728	-1.03133	normal	dry
1931	25.056	5.05	2.129498	-0.15722	ext. warm	normal
1932	22.152	6.33	1.187213	0.609117	warm	normal
1933	17.682	5.45	-0.26321	0.082257	normal	normal
1934	17.51	3.81	-0.31902	-0.89962	normal	normal
1935	19.43	6.1	0.303983	0.471415	normal	normal

1936	11.642	5.94	-2.22305	0.375622	ext. cool	normal
1937	14.596	5.92	-1.26455	0.363648	cool	normal
1938	19.774	4.72	0.415603	-0.3548	normal	normal
1939	17.2	6.98	-0.4196	0.998275	normal	normal
1940	19.964	3.9	0.477254	-0.84574	normal	normal
1941	18.152	6.57	-0.1107	0.752806	normal	normal
1942	23.706	3.67	1.691452	-0.98344	very warm	normal
1943	14.792	4.51	-1.20095	-0.48053	cool	normal
1944	20.286	3.96	0.581736	-0.80981	normal	normal
1945	21.192	6.74	0.875713	0.854586	normal	normal
1946	19.452	5.19	0.311121	-0.07341	normal	normal
1947	18.792	3.91	0.096965	-0.83975	normal	normal
1948	14.982	6.84	-1.1393	0.914456	cool	normal
1949	17.494	7.03	-0.32421	1.02821	normal	wet
1950	16.284	6.62	-0.71683	0.782741	normal	normal
1951	14.066	7	-1.43652	1.010249	cool	wet
1952	16.616	6.8	-0.6091	0.890508	normal	normal
1953	20.872	4.86	0.77188	-0.27098	normal	normal
1954	21.108	6.47	0.848457	0.692935	normal	normal
1955	18.578	3.86	0.027527	-0.86968	normal	normal
1956	14.09	4.67	-1.42873	-0.38473	cool	normal
1957	18.066	4.53	-0.13861	-0.46855	normal	normal
1958	21.33	3.04	0.920492	-1.36062	normal	dry
1959	17.232	2.86	-0.40922	-1.46839	normal	dry
1960	17.386	3.51	-0.35925	-1.07923	normal	dry
1961	22.088	3.8	1.166446	-0.90561	warm	normal
1962	17.042	5.84	-0.47087	0.315752	normal	normal
1963	18.482	2.92	-0.00362	-1.43247	normal	dry
1964	20.022	3.72	0.496074	-0.9535	normal	normal
1965	13.77	7.51	-1.53256	1.315588	very cool	wet
1966	18.816	8.79	0.104753	2.08193	normal	ext. wet
1967	16.766	5.28	-0.56043	-0.01952	normal	normal
1968	20.152	3.83	0.538256	-0.88764	normal	normal
1969	17.388	6.72	-0.3586	0.842611	normal	normal
1970	16.758	5.19	-0.56302	-0.07341	normal	normal
1971	16.08	8.28	-0.78302	1.77659	normal	very wet
1972	15.06	6.57	-1.11399	0.752806	cool	normal
1973	20.526	5.04	0.659611	-0.16321	normal	normal
1974	17.994	4.65	-0.16197	-0.39671	normal	normal
1975	19.184	8.34	0.224161	1.812513	normal	very wet
1976	20.142	7.96	0.535011	1.585005	normal	very wet
1977	15.562	5.79	-0.9511	0.285816	normal	normal
1978	15.94	5.13	-0.82845	-0.10933	normal	normal
1979	13.118	7.68	-1.74412	1.417368	very cool	wet
1980	18.704	3.87	0.068411	-0.8637	normal	normal
1981	22.616	3.61	1.337771	-1.01936	warm	dry
1982	16.392	5.38	-0.68178	0.040347	normal	normal

1983	22.802	7.48	1.398124	1.297627	warm	wet
1984	17.574	6.64	-0.29825	0.794715	normal	normal
1985	18.91	5.31	0.135254	-0.00156	normal	normal
1986	16.256	5.5	-0.72591	0.112192	normal	normal
1987	24.716	2.78	2.019175	-1.51628	ext. warm	very dry
1988	19.34	5.71	0.27478	0.23792	normal	normal
1989	17.426	6.62	-0.34627	0.782741	normal	normal
1990	20.348	5.1	0.601854	-0.12729	normal	normal
1991	21.154	4.75	0.863383	-0.33684	normal	normal
1992	21.984	7.15	1.1327	1.100054	warm	wet
1993	19.18	5	0.222863	-0.18716	normal	normal
1994	16.226	5.96	-0.73565	0.387596	normal	normal
1995	22.2	5.83	1.202788	0.309764	warm	normal
1996	14.206	5.88	-1.39109	0.3397	cool	normal
1997	16.244	9.91	-0.72981	2.752479	normal	ext. wet
1998	24.784	5.87	2.04124	0.333713	ext. warm	normal
1999	23.638	5.85	1.669388	0.321739	very warm	normal
2000	26.198	4.36	2.500052	-0.57033	ext. warm	normal
2001	16.936	8.56	-0.50527	1.944228	normal	very wet
2002	25.514	6.31	2.278109	0.597143	ext. warm	normal
2003	19.928	2.17	0.465573	-1.88149	normal	very dry
2004	21.042	5.08	0.827042	-0.13926	normal	normal
2005	21.396	5.11	0.941907	-0.1213	normal	normal
2006	24.016	5.68	1.79204	0.219959	very warm	normal

Nov-Mar southwest MN

YEAR	SW_T	SW_P	SW_Tz	SW_Pz	T_class	P_class
1892	21.032	6.84	-0.35203	1.318766	normal	wet
1893	15.754	4.16	-1.98808	-0.30513	very cool	normal
1894	20.114	3.9	-0.63659	-0.46267	normal	normal
1895	19.732	2.17	-0.755	-1.51092	normal	very dry
1896	22.078	4.51	-0.0278	-0.09305	normal	normal
1897	17.768	7.33	-1.36379	1.615672	cool	very wet
1898	22.68	2.63	0.158804	-1.2322	normal	dry
1899	14.006	4.6	-2.52992	-0.03852	ext. cool	normal
1900	22.264	4.28	0.029855	-0.23241	normal	normal
1901	21.56	2.82	-0.18837	-1.11707	normal	dry
1902	22.638	2.63	0.145785	-1.2322	normal	dry
1903	21.442	6.66	-0.22495	1.209699	normal	wet
1904	17.22	2.67	-1.53366	-1.20796	very cool	dry
1905	22.632	3.67	0.143926	-0.60203	normal	normal
1906	24.008	4.93	0.570452	0.161441	normal	normal
1907	22.708	3.09	0.167484	-0.95347	normal	normal
1908	25.526	3.49	1.040994	-0.7111	warm	normal
1909	23.328	6.43	0.359668	1.070335	normal	wet
1910	23.036	5.51	0.269156	0.51288	normal	normal
1911	22.422	2.28	0.078831	-1.44427	normal	dry
1912	15.728	3.09	-1.99614	-0.95347	very cool	normal
1913	22.598	1.58	0.133386	-1.86842	normal	very dry
1914	25.688	2.88	1.09121	-1.08071	warm	dry
1915	21.852	5.38	-0.09786	0.434109	normal	normal
1916	20.046	5.98	-0.65767	0.797667	normal	normal
1917	17.03	6.23	-1.59256	0.949149	very cool	normal
1918	20.936	2.91	-0.38179	-1.06254	normal	dry
1919	26.382	9.3	1.306333	2.809353	warm	ext. wet
1920	19.564	6.16	-0.80708	0.906734	normal	normal
1921	27.146	4.73	1.543154	0.040255	very warm	normal
1922	20.84	4.08	-0.41155	-0.3536	normal	normal
1923	22.066	5.67	-0.03152	0.609829	normal	normal
1924	25.19	3.56	0.936842	-0.66868	normal	normal
1925	21.332	2.79	-0.25904	-1.13525	normal	dry
1926	23.49	2.63	0.409884	-1.2322	normal	dry
1927	23.314	5.8	0.355329	0.688599	normal	normal
1928	21.998	5.46	-0.0526	0.482583	normal	normal
1929	20.686	3.8	-0.45929	-0.52326	normal	normal
1930	22.672	1.79	0.156325	-1.74118	normal	very dry
1931	29.966	4	2.417285	-0.40207	ext. warm	normal
1932	24.736	7.51	0.796114	1.724739	normal	very wet
1933	22.91	3.99	0.230099	-0.40813	normal	normal
1934	24.168	2.15	0.620048	-1.52304	normal	very dry

1935	25.572	3.96	1.055253	-0.42631	warm	normal
1936	14.284	5.99	-2.44375	0.803726	ext. cool	normal
1937	18.94	5.18	-1.0005	0.312923	cool	normal
1938	22.224	4.5	0.017456	-0.09911	normal	normal
1939	22.894	4.05	0.225139	-0.37178	normal	normal
1940	23.558	3.18	0.430963	-0.89894	normal	normal
1941	22.536	4.89	0.114168	0.137204	normal	normal
1942	27.034	5.21	1.508437	0.331101	very warm	normal
1943	19.898	3.14	-0.70355	-0.92317	normal	normal
1944	24.604	4.68	0.755197	0.009958	normal	normal
1945	26.108	4.01	1.2214	-0.39601	warm	normal
1946	23.518	6.08	0.418564	0.85826	normal	normal
1947	23.016	3.31	0.262956	-0.82017	normal	normal
1948	19.662	4.85	-0.7767	0.112966	normal	normal
1949	20.912	6.53	-0.38923	1.130928	normal	wet
1950	21.082	3.35	-0.33654	-0.79593	normal	normal
1951	17.948	5.97	-1.308	0.791607	cool	normal
1952	19.666	5.42	-0.77546	0.458346	normal	normal
1953	24.658	4.76	0.771936	0.058433	normal	normal
1954	24.876	6.18	0.83951	0.918853	normal	normal
1955	23.212	2.21	0.323711	-1.48669	normal	dry
1956	16.632	3.35	-1.71593	-0.79593	very cool	normal
1957	22.938	4.54	0.238778	-0.07487	normal	normal
1958	24.732	3.01	0.794874	-1.00194	normal	dry
1959	21.346	2.69	-0.2547	-1.19584	normal	dry
1960	19.388	4.43	-0.86163	-0.14152	normal	normal
1961	24.732	3.99	0.794874	-0.40813	normal	normal
1962	19.142	5.74	-0.93789	0.652244	normal	normal
1963	23.05	2.5	0.273495	-1.31097	normal	dry
1964	24.058	2.25	0.58595	-1.46245	normal	dry
1965	17.386	4.59	-1.4822	-0.04458	cool	normal
1966	22.966	4.39	0.247457	-0.16576	normal	normal
1967	21.706	3.2	-0.14311	-0.88682	normal	normal
1968	24.556	2.24	0.740318	-1.46851	normal	dry
1969	18.406	7.65	-1.16603	1.809569	cool	very wet
1970	19.42	4.11	-0.85172	-0.33542	normal	normal
1971	20.048	6.01	-0.65705	0.815845	normal	normal
1972	19.372	4.97	-0.86659	0.185678	normal	normal
1973	24.502	5.67	0.723579	0.609829	normal	normal
1974	22.358	4.73	0.058992	0.040255	normal	normal
1975	21.75	5.13	-0.12947	0.282627	normal	normal
1976	24.948	6.84	0.861828	1.318766	normal	wet
1977	20.47	6.39	-0.52624	1.046098	normal	wet
1978	17.442	5.22	-1.46485	0.33716	cool	normal
1979	14.732	7.2	-2.30488	1.536901	ext. cool	very wet
1980	23.484	3.36	0.408025	-0.78987	normal	normal
1981	27.628	2.88	1.692562	-1.08071	very warm	dry
1982	20.204	4.81	-0.60869	0.088729	normal	normal

1983	25.332	9.23	0.980859	2.766938	normal	ext. wet
1984	19.586	9	-0.80026	2.627574	normal	ext. wet
1985	22.998	5.29	0.257377	0.379575	normal	normal
1986	19.034	5.33	-0.97137	0.403813	normal	normal
1987	28.252	4.8	1.885987	0.08267	very warm	normal
1988	22.52	5.37	0.109208	0.42805	normal	normal
1989	22.336	5.14	0.052173	0.288686	normal	normal
1990	24.67	4.4	0.775655	-0.1597	normal	normal
1991	24.508	3.66	0.725439	-0.60809	normal	normal
1992	26.402	6.16	1.312533	0.906734	warm	normal
1993	19.888	5.33	-0.70665	0.403813	normal	normal
1994	19.136	5.33	-0.93975	0.403813	normal	normal
1995	25.692	5.49	1.09245	0.500761	warm	normal
1996	19.552	4.33	-0.8108	-0.20212	normal	normal
1997	17.44	8.04	-1.46547	2.045882	cool	ext. wet
1998	25.44	6.04	1.014336	0.834023	warm	normal
1999	26.592	4.58	1.371428	-0.05063	warm	normal
2000	29.99	2.73	2.424724	-1.1716	ext. warm	dry
2001	17.062	7.1	-1.58264	1.476308	very cool	wet
2002	27.832	6.65	1.755797	1.20364	very warm	wet
2003	23.186	2.1	0.315652	-1.55334	normal	very dry
2004	23.958	4.43	0.554953	-0.14152	normal	normal
2005	26.256	3.51	1.267276	-0.69898	warm	normal
2006	25.738	6.86	1.106709	1.330885	warm	wet

Nov-Mar south-central MN

YEAR	SC_T	SC_P	SC_Tz	SC_Pz	T_class	P_class
1892	21.412	6.16	-0.34926	0.326405	normal	normal
1893	14.908	6.06	-2.4269	0.269385	ext. cool	normal
1894	20.98	5.73	-0.48726	0.081217	normal	normal
1895	19.692	3.37	-0.8987	-1.26447	normal	dry
1896	23.506	3.92	0.319653	-0.95085	normal	normal
1897	19.502	8.82	-0.95939	1.84315	normal	very wet
1898	23.802	3.59	0.414207	-1.13902	normal	dry
1899	16.152	6.15	-2.02952	0.320703	ext. cool	normal
1900	23.534	4.4	0.328597	-0.67716	normal	normal
1901	21.594	3.14	-0.29112	-1.39561	normal	dry
1902	23.22	3.15	0.228292	-1.38991	normal	dry
1903	23.058	6.76	0.176543	0.668528	normal	normal
1904	17.064	3.3	-1.73819	-1.30438	very cool	dry
1905	21.87	4.75	-0.20295	-0.47758	normal	normal
1906	25.17	6.54	0.851203	0.543083	normal	normal
1907	22.938	4.85	0.13821	-0.42056	normal	normal
1908	26.62	3.71	1.314393	-1.0706	warm	dry
1909	23.764	6.82	0.402068	0.70274	normal	normal
1910	23.506	7.68	0.319653	1.193116	normal	wet
1911	23.622	3.1	0.356708	-1.41842	normal	dry
1912	16.572	4.62	-1.89535	-0.55171	very cool	normal
1913	23	3.99	0.158015	-0.91094	normal	normal
1914	26.47	3.16	1.266477	-1.38421	warm	dry
1915	22.51	5.64	0.001489	0.029899	normal	normal
1916	21.102	6.45	-0.44828	0.491765	normal	normal
1917	17.502	6.73	-1.59827	0.651422	very cool	normal
1918	21.414	3.75	-0.34862	-1.04779	normal	dry
1919	26.916	8.27	1.408948	1.529537	warm	very wet
1920	19.466	6.94	-0.97089	0.771165	normal	normal
1921	27.06	4.74	1.454947	-0.48329	warm	normal
1922	21.206	4.73	-0.41506	-0.48899	normal	normal
1923	22.04	6.43	-0.14865	0.48036	normal	normal
1924	25.1	4.29	0.828842	-0.73988	normal	normal
1925	21.638	4.02	-0.27706	-0.89383	normal	normal
1926	23.368	3.65	0.27557	-1.10481	normal	dry
1927	23.002	6.64	0.158654	0.600103	normal	normal
1928	22.528	5.43	0.007239	-0.08984	normal	normal
1929	20.51	5.23	-0.63739	-0.20389	normal	normal
1930	22.258	3.35	-0.07901	-1.27587	normal	dry
1931	28.854	4.02	2.028025	-0.89383	ext. warm	normal
1932	25.074	9.61	0.820537	2.293612	normal	ext. wet
1933	22.852	7.14	0.110738	0.885206	normal	normal
1934	24.388	3.25	0.6014	-1.33289	normal	dry
1935	24.77	7.39	0.723427	1.027757	normal	wet

1936	14.782	7.57	-2.46715	1.130394	ext. cool	wet
1937	19.13	6.05	-1.07822	0.263683	cool	normal
1938	23.358	4.3	0.272375	-0.73418	normal	normal
1939	23.36	5.8	0.273014	0.121131	normal	normal
1940	23.554	3.48	0.334986	-1.20174	normal	dry
1941	22.34	7.49	-0.05282	1.084778	normal	wet
1942	27.226	5.14	1.507975	-0.2552	very warm	normal
1943	19.338	4.66	-1.01178	-0.5289	cool	normal
1944	24.412	4.92	0.609066	-0.38065	normal	normal
1945	25.542	5.8	0.970035	0.121131	normal	normal
1946	24.46	8.32	0.6244	1.558048	normal	very wet
1947	23.406	5.05	0.287708	-0.30652	normal	normal
1948	19.782	6.29	-0.86995	0.400532	normal	normal
1949	22.21	9.35	-0.09434	2.145359	normal	ext. wet
1950	21.602	5.49	-0.28856	-0.05563	normal	normal
1951	17.188	8.8	-1.69858	1.831746	very cool	very wet
1952	20.798	6.69	-0.54539	0.628614	normal	normal
1953	24.956	5.68	0.782843	0.052707	normal	normal
1954	26.396	6.12	1.242838	0.303597	warm	normal
1955	23.376	3.37	0.278125	-1.26447	normal	dry
1956	17.602	4.56	-1.56633	-0.58592	very cool	normal
1957	23.734	4.25	0.392485	-0.76269	normal	normal
1958	24.986	3.43	0.792426	-1.23025	normal	dry
1959	21.252	3.39	-0.40037	-1.25306	normal	dry
1960	21.308	4.18	-0.38248	-0.8026	normal	normal
1961	25.104	5.8	0.83012	0.121131	normal	normal
1962	19.512	5.31	-0.9562	-0.15827	normal	normal
1963	22.782	3.12	0.088377	-1.40702	normal	dry
1964	24.482	2.37	0.631427	-1.83467	normal	very dry
1965	18.034	7.43	-1.42833	1.050565	cool	wet
1966	23.198	6.19	0.221265	0.343511	normal	normal
1967	21.984	5.03	-0.16654	-0.31793	normal	normal
1968	24.906	1.83	0.766871	-2.14258	normal	ext. dry
1969	19.738	6.94	-0.884	0.771165	normal	normal
1970	19.196	4.83	-1.05714	-0.43197	cool	normal
1971	19.946	8.29	-0.81756	1.540941	normal	very wet
1972	19.77	5.4	-0.87378	-0.10695	normal	normal
1973	24.37	7.29	0.59565	0.970737	normal	normal
1974	22.256	6.85	-0.07965	0.719846	normal	normal
1975	21.816	6.7	-0.2202	0.634316	normal	normal
1976	26.538	8.87	1.288199	1.87166	warm	very wet
1977	20.282	5.88	-0.71023	0.166748	normal	normal
1978	17.468	4.3	-1.60913	-0.73418	very cool	normal
1979	15.138	8.66	-2.35343	1.751917	ext. cool	very wet
1980	22.892	5.23	0.123516	-0.20389	normal	normal

1981	27.078	3.3	1.460697	-1.30438	warm	dry
1982	19.956	5.3	-0.81436	-0.16397	normal	normal
1983	26.158	10.21	1.166811	2.635735	warm	ext. wet
1984	19.718	7.96	-0.89039	1.352774	normal	wet
1985	23.338	7.39	0.265986	1.027757	normal	wet
1986	19.456	5.62	-0.97409	0.018494	normal	normal
1987	28.458	2.98	1.901527	-1.48685	very warm	dry
1988	23.28	6.27	0.247459	0.389128	normal	normal
1989	22.58	6.07	0.02385	0.275087	normal	normal
1990	24.914	5.4	0.769426	-0.10695	normal	normal
1991	24.28	5.2	0.5669	-0.22099	normal	normal
1992	25.536	8.95	0.968119	1.917277	normal	very wet
1993	20.48	7.03	-0.64698	0.822483	normal	normal
1994	19.63	4.7	-0.9185	-0.50609	normal	normal
1995	25.952	5.18	1.101006	-0.2324	warm	normal
1996	19.464	5.75	-0.97153	0.092621	normal	normal
1997	18.884	7.79	-1.15681	1.255839	cool	wet
1998	25.994	6.25	1.114423	0.377724	warm	normal
1999	26.78	4.69	1.365504	-0.5118	warm	normal
2000	29.42	4.08	2.208829	-0.85962	ext. warm	normal
2001	17.176	8.14	-1.70241	1.455411	very cool	wet
2002	28.78	5.99	2.004387	0.22947	ext. warm	normal
2003	23.584	3.25	0.344569	-1.33289	normal	dry
2004	24.496	5.69	0.6359	0.058409	normal	normal
2005	25.974	5.17	1.108034	-0.2381	warm	normal
2006	25.724	6.24	1.028174	0.372021	warm	normal

Nov-Mar southeast MN

YEAR	SE_T	SE_P	SE_Tz	SE_Pz	T_class	P_class
1892	22.434	7.34	-0.07298	0.610246	normal	normal
1893	15.674	7.67	-2.2742	0.793785	ext. cool	normal
1894	20.942	6.51	-0.55881	0.14862	normal	normal
1895	18.896	3.88	-1.22504	-1.31412	cool	dry
1896	22.23	4.86	-0.13941	-0.76907	normal	normal
1897	20.258	8.98	-0.78154	1.522376	normal	very wet
1898	22.678	5.42	0.006473	-0.45761	normal	normal
1899	15.104	6.72	-2.45981	0.265417	ext. cool	normal
1900	21.946	6.01	-0.23188	-0.12947	normal	normal
1901	20.858	4.85	-0.58616	-0.77463	normal	normal
1902	22.502	4.09	-0.05084	-1.19733	normal	dry
1903	23.762	8.7	0.35945	1.366646	normal	wet
1904	17.068	4.05	-1.82028	-1.21957	very cool	dry
1905	21.842	5.25	-0.26575	-0.55216	normal	normal
1906	23.458	8	0.26046	0.977323	normal	normal
1907	23.376	6.82	0.233759	0.321035	normal	normal
1908	26.354	4.77	1.203468	-0.81913	warm	normal
1909	23.642	6.37	0.320375	0.070755	normal	normal
1910	23.72	8.27	0.345773	1.12749	normal	wet
1911	23.404	3.58	0.242876	-1.48098	normal	dry
1912	16.4	5.22	-2.0378	-0.56885	ext. cool	normal
1913	22.972	5.91	0.102206	-0.18509	normal	normal
1914	26.526	4.01	1.259475	-1.24182	warm	dry
1915	22.182	5.29	-0.15504	-0.52992	normal	normal
1916	21.858	6.35	-0.26054	0.059632	normal	normal
1917	17.2	6.28	-1.7773	0.020699	very cool	normal
1918	20.772	4.12	-0.61417	-1.18064	normal	dry
1919	27.514	7.09	1.581192	0.471202	very warm	normal
1920	18.532	7.07	-1.34357	0.460079	cool	normal
1921	27.184	6.19	1.473736	-0.02936	warm	normal
1922	21.546	6.33	-0.36213	0.048508	normal	normal
1923	21.472	6.5	-0.38623	0.143058	normal	normal
1924	24.49	5.37	0.596504	-0.48542	normal	normal
1925	22.556	4.29	-0.03325	-1.08609	normal	dry
1926	22.49	4.99	-0.05474	-0.69677	normal	normal
1927	23.002	6.68	0.111975	0.24317	normal	normal
1928	23.212	5.78	0.180356	-0.25739	normal	normal
1929	20.946	6.75	-0.55751	0.282102	normal	normal
1930	22.41	4.08	-0.08079	-1.20289	normal	dry
1931	28.66	4.44	1.954357	-1.00267	very warm	dry
1932	25.852	10.7	1.040004	2.478999	warm	ext. wet
1933	23.416	8.02	0.246784	0.988446	normal	normal
1934	23.862	3.41	0.392012	-1.57553	normal	very dry
1935	23.906	8.87	0.406339	1.461196	normal	wet

1936	16.652	7.36	-1.95574	0.62137	very cool	normal
1937	19.826	5.8	-0.92221	-0.24627	normal	normal
1938	25.082	5.52	0.789274	-0.40199	normal	normal
1939	23.59	6.62	0.303442	0.209799	normal	normal
1940	23.054	3.59	0.128908	-1.47541	normal	dry
1941	22.408	8.41	-0.08145	1.205355	normal	wet
1942	27.058	5.93	1.432707	-0.17396	warm	normal
1943	19.218	5.4	-1.12019	-0.46874	cool	normal
1944	24.862	4.73	0.717636	-0.84137	normal	normal
1945	25.218	6.7	0.833559	0.254294	normal	normal
1946	25.068	8.14	0.784715	1.055187	normal	wet
1947	24.304	5	0.535938	-0.69121	normal	normal
1948	20.056	5.94	-0.84731	-0.1684	normal	normal
1949	23.43	9.71	0.251342	1.928384	normal	very wet
1950	22.178	6.34	-0.15634	0.05407	normal	normal
1951	17.914	8.51	-1.5448	1.260973	very cool	wet
1952	21.688	7.27	-0.3159	0.571314	normal	normal
1953	25.476	5.76	0.91757	-0.26851	normal	normal
1954	27.238	5.61	1.49132	-0.35194	warm	normal
1955	23.314	3.42	0.21357	-1.56996	normal	very dry
1956	18.616	5.31	-1.31621	-0.51879	cool	normal
1957	24.308	3.62	0.53724	-1.45873	normal	dry
1958	25.022	4.04	0.769736	-1.22514	normal	dry
1959	20.504	5.12	-0.70143	-0.62447	normal	normal
1960	22.366	4.36	-0.09512	-1.04716	normal	dry
1961	25.432	6.49	0.903242	0.137496	normal	normal
1962	19.836	5.93	-0.91895	-0.17396	normal	normal
1963	21.622	3.48	-0.33739	-1.53659	normal	very dry
1964	24.492	3.68	0.597155	-1.42536	normal	dry
1965	18.452	7.15	-1.36962	0.504573	cool	normal
1966	23.292	8.5	0.206406	1.255411	normal	wet
1967	21.828	6.9	-0.27031	0.365529	normal	normal
1968	24.486	2.08	0.595202	-2.31524	normal	ext. dry
1969	20.676	6.81	-0.64543	0.315473	normal	normal
1970	19.738	5.11	-0.95086	-0.63003	normal	normal
1971	19.584	8.99	-1.00101	1.527937	cool	very wet
1972	19.88	6.11	-0.90462	-0.07385	normal	normal
1973	24.038	8.06	0.449322	1.010693	normal	wet
1974	22.15	7.16	-0.16546	0.510135	normal	normal
1975	22.04	6.48	-0.20128	0.131935	normal	normal
1976	25.986	10.6	1.083638	2.423381	warm	ext. wet
1977	19.284	5.12	-1.0987	-0.62447	cool	normal
1978	17.486	4.59	-1.68417	-0.91924	very cool	normal
1979	16.002	8.18	-2.16739	1.077435	ext. cool	wet
1980	23.126	5.66	0.152353	-0.32413	normal	normal
1981	26.892	4.05	1.378654	-1.21957	warm	dry
1982	20.342	5.46	-0.75419	-0.43537	normal	normal
1983	27.094	10.61	1.44443	2.428943	warm	ext. wet

1984	20.738	8.84	-0.62524	1.444511	normal	wet
1985	23.066	7.88	0.132815	0.910582	normal	normal
1986	19.332	6.61	-1.08307	0.204238	cool	normal
1987	27.374	3.77	1.535604	-1.3753	very warm	dry
1988	24.242	7.08	0.515749	0.465641	normal	normal
1989	23.136	7.11	0.155609	0.482326	normal	normal
1990	24.866	6.35	0.718939	0.059632	normal	normal
1991	24.772	5.77	0.68833	-0.26295	normal	normal
1992	25.586	11.36	0.953388	2.846075	normal	ext. wet
1993	21.758	8.63	-0.2931	1.327714	normal	wet
1994	20.598	4.96	-0.67083	-0.71345	normal	normal
1995	26.542	5.56	1.264685	-0.37975	warm	normal
1996	19.46	6.69	-1.04139	0.248732	cool	normal
1997	20.072	9.5	-0.8421	1.811587	normal	very wet
1998	27.51	7.39	1.579889	0.638055	very warm	normal
1999	27.336	5.01	1.523231	-0.68564	very warm	normal
2000	29.218	5	2.136056	-0.69121	ext. warm	normal
2001	18.696	8.28	-1.29016	1.133052	cool	wet
2002	30.012	6.59	2.394601	0.193114	ext. warm	normal
2003	23.302	3.65	0.209662	-1.44204	normal	dry
2004	24.912	6.95	0.733917	0.393338	normal	normal
2005	25.638	6.92	0.970321	0.376652	normal	normal
2006	26.202	6.73	1.153973	0.270979	warm	normal

Water year (Oct-Sep) northwest MN

Year	NW_T	NW_P	NW_Tz	NW_Pz	T_class	P_class
1892	37.363	21.16	-0.41786	-0.22634	normal	normal
1893	34.338	21.74	-1.91646	-0.06789	very cool	normal
1894	38.083	17.21	-0.06117	-1.30541	normal	dry
1895	36.935	23.37	-0.6299	0.377396	normal	normal
1896	36.732	24.62	-0.73046	0.718875	normal	normal
1897	35.978	24.24	-1.104	0.615065	cool	normal
1898	37.612	20.45	-0.29451	-0.4203	normal	normal
1899	34.593	23.18	-1.79013	0.325491	very cool	normal
1900	40.276	25.15	1.025249	0.863662	warm	normal
1901	39.242	25.03	0.513001	0.83088	normal	normal
1902	39.429	23.09	0.605642	0.300905	normal	normal
1903	37.871	22.9	-0.1662	0.249	normal	normal
1904	35.032	23.22	-1.57265	0.336419	very cool	normal
1905	38.843	28.08	0.315335	1.664087	normal	very wet
1906	39.152	23.41	0.468415	0.388323	normal	normal
1907	34.423	22.47	-1.87435	0.131532	very cool	normal
1908	39.442	20.52	0.612082	-0.40117	normal	normal
1909	38.022	23.4	-0.09139	0.385592	normal	normal
1910	39.079	14.31	0.432251	-2.09764	normal	ext. dry
1911	37.586	21.41	-0.30739	-0.15804	normal	normal
1912	35.118	23.26	-1.53004	0.347346	very cool	normal
1913	37.447	17.45	-0.37625	-1.23985	normal	dry
1914	38.75	23.18	0.269263	0.325491	normal	normal
1915	37.953	22.65	-0.12557	0.180704	normal	normal
1916	35.64	24.4	-1.27144	0.658774	cool	normal
1917	34.053	13.14	-2.05765	-2.41726	ext. cool	ext. dry
1918	35.852	17.32	-1.16642	-1.27536	cool	dry
1919	40.262	26.1	1.018313	1.123185	warm	wet
1920	34.547	19.68	-1.81292	-0.63065	very cool	normal
1921	41.214	21.85	1.489937	-0.03784	warm	normal
1922	38.863	20.68	0.325243	-0.35747	normal	normal
1923	37.634	20.31	-0.28361	-0.45854	normal	normal
1924	37.969	19.3	-0.11765	-0.73446	normal	normal
1925	38.108	26.86	-0.04879	1.330804	normal	wet
1926	37.745	16.45	-0.22862	-1.51303	normal	very dry
1927	36.596	22.22	-0.79784	0.063236	normal	normal
1928	36.714	22.82	-0.73938	0.227146	normal	normal
1929	37.318	13.59	-0.44016	-2.29433	normal	ext. dry
1930	38.676	19.4	0.232603	-0.70714	normal	normal
1931	41.771	19.96	1.765877	-0.55416	very warm	normal
1932	40.377	19.18	1.075285	-0.76724	warm	normal
1933	38.396	17.88	0.09389	-1.12238	normal	dry
1934	37.338	15.93	-0.43025	-1.65508	normal	very dry

1935	38.898	21.9	0.342582	-0.02418	normal	normal
1936	35.188	13.58	-1.49537	-2.29706	cool	ext. dry
1937	36.423	23.74	-0.88354	0.478474	normal	normal
1938	38.678	18.38	0.233594	-0.98579	normal	normal
1939	38.176	17.6	-0.0151	-1.19887	normal	dry
1940	39.26	18.02	0.521919	-1.08413	normal	dry
1941	40.073	29.76	0.924682	2.123034	normal	ext. wet
1942	40.233	23.11	1.003946	0.306369	warm	normal
1943	36.142	21.24	-1.02275	-0.20448	cool	normal
1944	39.497	26.42	0.639329	1.210604	normal	wet
1945	38.614	22.38	0.201888	0.106945	normal	normal
1946	38.323	19.95	0.057725	-0.55689	normal	normal
1947	37.156	23.76	-0.52041	0.483937	normal	normal
1948	38.179	20.32	-0.01361	-0.45581	normal	normal
1949	38.678	23.32	0.233594	0.363737	normal	normal
1950	35.392	27.23	-1.3943	1.431882	cool	wet
1951	36.362	20.11	-0.91376	-0.51318	normal	normal
1952	38.353	18.7	0.072587	-0.89837	normal	normal
1953	39.837	22.41	0.807767	0.115141	normal	normal
1954	39.383	18.61	0.582853	-0.92295	normal	normal
1955	40.112	21.83	0.944003	-0.04331	normal	normal
1956	35.12	20.84	-1.52905	-0.31376	very cool	normal
1957	38.659	26.72	0.224181	1.292559	normal	wet
1958	40.319	16.47	1.046551	-1.50757	warm	very dry
1959	37.946	22.98	-0.12904	0.270855	normal	normal
1960	37.748	21.61	-0.22713	-0.10341	normal	normal
1961	39.542	17.9	0.661622	-1.11691	normal	dry
1962	36.954	27.15	-0.62048	1.410027	normal	wet
1963	40.087	18.71	0.931617	-0.89564	normal	normal
1964	39.475	25.07	0.62843	0.841807	normal	normal
1965	34.789	24.77	-1.69303	0.759852	very cool	normal
1966	37.164	23.91	-0.51645	0.524915	normal	normal
1967	36.103	16.59	-1.04207	-1.47478	cool	dry
1968	37.983	26.5	-0.11071	1.232458	normal	wet
1969	37.436	21.31	-0.3817	-0.18536	normal	normal
1970	36.952	22.28	-0.62147	0.079627	normal	normal
1971	36.827	21.49	-0.6834	-0.13619	normal	normal
1972	36.697	23.41	-0.7478	0.388323	normal	normal
1973	39.063	22.93	0.424324	0.257196	normal	normal
1974	36.651	23.43	-0.77059	0.393787	normal	normal
1975	38.196	23.44	-0.00519	0.396519	normal	normal
1976	40.53	15.93	1.151081	-1.65508	warm	very dry
1977	38.295	22.85	0.043854	0.235341	normal	normal
1978	36.987	22.89	-0.60413	0.246268	normal	normal
1979	33.858	20.88	-2.15425	-0.30283	ext. cool	normal
1980	38.934	17.49	0.360417	-1.22892	normal	dry
1981	40.45	23.13	1.111449	0.311832	warm	normal
1982	36.975	22.24	-0.61008	0.0687	normal	normal
1983	41.214	26.13	1.489937	1.131381	warm	wet
1984	38.942	17.74	0.36438	-1.16062	normal	dry

1985	38.112	30.39	-0.0468	2.295139	normal	ext. wet
1986	37.733	23	-0.23456	0.276318	normal	normal
1987	42.709	20.17	2.230566	-0.49679	ext. warm	normal
1988	40.938	16.8	1.353206	-1.41741	warm	dry
1989	37.639	20.14	-0.28113	-0.50498	normal	normal
1990	39.557	16.35	0.669054	-1.54035	normal	very dry
1991	40.717	25.57	1.243722	0.978398	warm	normal
1992	38.852	22.77	0.319794	0.213486	normal	normal
1993	36.916	24.5	-0.63931	0.686093	normal	normal
1994	37.117	23.43	-0.53973	0.393787	normal	normal
1995	40.493	25.37	1.132751	0.923762	warm	normal
1996	35.352	23.06	-1.41412	0.292709	cool	normal
1997	36.297	27.36	-0.94596	1.467396	normal	wet
1998	43.424	25.14	2.58478	0.86093	ext. warm	normal
1999	41.545	33.4	1.653916	3.11742	very warm	ext. wet
2000	42.61	22.07	2.181521	0.022258	ext. warm	normal
2001	39.546	26.66	0.663604	1.276168	normal	wet
2002	41.818	28.02	1.789161	1.647696	very warm	very wet
2003	39.038	18.97	0.411939	-0.82461	normal	normal
2004	38.368	26.21	0.080018	1.153235	normal	wet
2005	40.751	26.39	1.260566	1.202408	warm	wet
2006	42.988	21.18	2.368784	-0.22087	ext. warm	normal

Water year (Oct-Sep) north-central MN

Year	NC_T	NC_P	NC_Tz	NC_Pz	T_class	P_class
1892	36.895	22.14	-0.42423	-0.67876	normal	normal
1893	34.463	24.72	-1.71044	-0.03071	very cool	normal
1894	37.374	21.24	-0.17091	-0.90483	normal	normal
1895	36.109	28.34	-0.83992	0.878572	normal	normal
1896	36.076	27.65	-0.85738	0.705256	normal	normal
1897	35.44	28.93	-1.19373	1.02677	cool	wet
1898	36.374	24.73	-0.69977	-0.0282	normal	normal
1899	33.804	30.36	-2.05896	1.385962	ext. cool	wet
1900	39.428	28.71	0.915385	0.97151	normal	normal
1901	38.653	27.33	0.505514	0.624878	normal	normal
1902	38.624	26	0.490176	0.290804	normal	normal
1903	37.158	26.75	-0.28514	0.479192	normal	normal
1904	33.977	24.3	-1.96747	-0.13621	very cool	normal
1905	37.835	33.55	0.072901	2.187236	normal	ext. wet
1906	38.809	25.16	0.588017	0.079811	normal	normal
1907	34.422	26.17	-1.73212	0.333505	very cool	normal
1908	38.694	23.24	0.527197	-0.40246	normal	normal
1909	37.346	23.95	-0.18571	-0.22412	normal	normal
1910	39.343	18.57	0.870431	-1.57549	normal	very dry
1911	37.889	23.45	0.10146	-0.34971	normal	normal
1912	34.681	20.85	-1.59514	-1.00279	very cool	dry
1913	37.394	23.04	-0.16033	-0.4527	normal	normal
1914	38.627	27.2	0.491763	0.592224	normal	normal
1915	38.523	24.72	0.436761	-0.03071	normal	normal
1916	36.673	28.76	-0.54164	0.984069	normal	normal
1917	34.463	13.88	-1.71044	-2.75353	very cool	ext. dry
1918	35.843	18.53	-0.9806	-1.58553	normal	very dry
1919	40.188	29.23	1.317324	1.102125	warm	wet
1920	34.697	22.28	-1.58668	-0.6436	very cool	normal
1921	41.057	22.19	1.776908	-0.6662	very warm	normal
1922	38.168	19.31	0.249013	-1.38961	normal	dry
1923	37.028	20.49	-0.35389	-1.09321	normal	dry
1924	36.942	19.67	-0.39938	-1.29918	normal	dry
1925	37.477	24.61	-0.11643	-0.05834	normal	normal
1926	36.22	20.5	-0.78122	-1.0907	normal	dry
1927	35.813	24.6	-0.99647	-0.06085	normal	normal
1928	35.577	26.26	-1.12128	0.356112	cool	normal
1929	36.89	15.23	-0.42688	-2.41444	normal	ext. dry
1930	37.749	19.03	0.027418	-1.45994	normal	dry
1931	41.367	20.24	1.940857	-1.15601	very warm	dry
1932	40.277	23.15	1.364393	-0.42507	warm	normal
1933	37.616	21.18	-0.04292	-0.9199	normal	normal
1934	36.203	20.01	-0.79021	-1.21378	normal	dry

1935	37.918	26.72	0.116797	0.471656	normal	normal
1936	35.054	16.84	-1.39788	-2.01003	cool	ext. dry
1937	35.952	30.86	-0.92295	1.511554	normal	very wet
1938	38.435	21.31	0.390221	-0.88724	normal	normal
1939	37.396	23.53	-0.15927	-0.32962	normal	normal
1940	38.552	19.39	0.452098	-1.36952	normal	dry
1941	39.714	30.74	1.066641	1.481412	warm	wet
1942	39.731	24.91	1.075632	0.017015	warm	normal
1943	35.831	24.11	-0.98695	-0.18393	normal	normal
1944	38.996	30.7	0.686915	1.471364	normal	wet
1945	38.076	23.6	0.200358	-0.31203	normal	normal
1946	37.85	22.63	0.080834	-0.55568	normal	normal
1947	36.919	27.1	-0.41154	0.567106	normal	normal
1948	37.833	20.31	0.071843	-1.13843	normal	dry
1949	38.149	27.45	0.238965	0.65502	normal	normal
1950	34.894	30.22	-1.4825	1.350796	cool	wet
1951	35.654	26.11	-1.08056	0.318434	cool	normal
1952	37.951	22.91	0.134249	-0.48535	normal	normal
1953	38.929	28.26	0.651481	0.858478	normal	normal
1954	38.576	21.56	0.464791	-0.82445	normal	normal
1955	39.571	23.15	0.991013	-0.42507	normal	normal
1956	35.248	20.53	-1.29528	-1.08317	cool	dry
1957	37.592	27.4	-0.05561	0.64246	normal	normal
1958	39.241	19.06	0.816487	-1.45241	normal	dry
1959	37.381	25.47	-0.1672	0.157677	normal	normal
1960	36.925	21.84	-0.40837	-0.75412	normal	normal
1961	38.821	22.54	0.594363	-0.57829	normal	normal
1962	36.473	30.72	-0.64742	1.476388	normal	wet
1963	38.636	22.62	0.496523	-0.55819	normal	normal
1964	38.769	27.71	0.566862	0.720327	normal	normal
1965	34.273	27.04	-1.81092	0.552035	very cool	normal
1966	36.759	28.18	-0.49616	0.838383	normal	normal
1967	35.622	20.29	-1.09748	-1.14345	cool	dry
1968	37.454	28.37	-0.1286	0.886108	normal	normal
1969	37.488	27.19	-0.11062	0.589712	normal	normal
1970	36.909	22.47	-0.41683	-0.59587	normal	normal
1971	36.277	25.73	-0.75107	0.222985	normal	normal
1972	36.111	29.9	-0.83886	1.270418	normal	wet
1973	38.598	25.73	0.476426	0.222985	normal	normal
1974	36.847	26.2	-0.44962	0.341041	normal	normal
1975	38.235	27.79	0.284447	0.740422	normal	normal
1976	39.61	19.39	1.011639	-1.36952	warm	dry
1977	37.653	26.93	-0.02335	0.524404	normal	normal
1978	36.869	29.49	-0.43798	1.167433	normal	wet
1979	34.099	22.21	-1.90294	-0.66118	very cool	normal
1980	38.123	22.07	0.225214	-0.69634	normal	normal
1981	39.289	25.42	0.841873	0.145118	normal	normal
1982	36.785	26.26	-0.48241	0.356112	normal	normal
1983	40.903	27.57	1.695463	0.685162	very warm	normal

1984	38.258	23.17	0.296611	-0.42004	normal	normal
1985	37.821	33.93	0.065497	2.282685	normal	ext. wet
1986	37.715	26.69	0.009437	0.464121	normal	normal
1987	42.308	22.76	2.43852	-0.52303	ext. warm	normal
1988	39.786	22.89	1.104719	-0.49037	warm	normal
1989	37.267	26.05	-0.2275	0.303363	normal	normal
1990	38.915	18.79	0.644077	-1.52022	normal	very dry
1991	39.945	28.46	1.188809	0.908714	warm	normal
1992	38.074	25	0.1993	0.039621	normal	normal
1993	36.938	26.54	-0.40149	0.426443	normal	normal
1994	36.757	26.31	-0.49722	0.368671	normal	normal
1995	40.002	26.76	1.218954	0.481703	warm	normal
1996	34.709	27.67	-1.58034	0.71028	very cool	normal
1997	36.44	28.82	-0.66487	0.99914	normal	normal
1998	42.743	24.12	2.668577	-0.18142	ext. warm	normal
1999	40.477	37.93	1.470166	3.287417	warm	ext. wet
2000	41.077	23.08	1.787486	-0.44265	very warm	normal
2001	38.835	30.97	0.601767	1.539184	normal	very wet
2002	41.066	28.74	1.781668	0.979046	very warm	normal
2003	38.352	20.71	0.346325	-1.03795	normal	dry
2004	38.037	27.32	0.179732	0.622366	normal	normal
2005	40.256	27.34	1.353286	0.62739	warm	normal
2006	42.238	24.03	2.4015	-0.20403	ext. warm	normal

Water year (Oct-Sep) northeast MN

Year	NE_T	NE_P	NE_Tz	NE_Pz	T_class	P_class
1892	38.574	25.27	0.74501	-0.54346	normal	normal
1893	35.989	25.24	-0.77326	-0.55129	normal	normal
1894	37.768	26.11	0.271616	-0.32447	normal	normal
1895	37.129	31.57	-0.10369	1.098966	normal	wet
1896	36.613	28.18	-0.40676	0.215182	normal	normal
1897	35.778	33.59	-0.89719	1.625586	normal	very wet
1898	36.446	27.54	-0.50484	0.048332	normal	normal
1899	33.996	34.61	-1.94382	1.891503	very cool	very wet
1900	38.497	29.32	0.699785	0.512384	normal	normal
1901	37.435	24.96	0.076032	-0.62428	normal	normal
1902	37.254	25.73	-0.03028	-0.42354	normal	normal
1903	36.336	32.4	-0.56945	1.315349	normal	wet
1904	33.213	27.01	-2.40371	-0.08984	ext. cool	normal
1905	37.651	36.33	0.202897	2.339912	normal	ext. wet
1906	38.636	25.02	0.781425	-0.60864	normal	normal
1907	34.891	27.45	-1.41815	0.024869	cool	normal
1908	38.294	26.03	0.580555	-0.34533	normal	normal
1909	37.112	29.52	-0.11368	0.564524	normal	normal
1910	39.637	23.94	1.36935	-0.8902	warm	normal
1911	38.257	27.38	0.558824	0.00662	normal	normal
1912	35.178	24.03	-1.24959	-0.86674	cool	normal
1913	37.063	24.13	-0.14246	-0.84067	normal	normal
1914	38.854	25.18	0.909464	-0.56693	normal	normal
1915	38.55	22.1	0.730914	-1.36989	normal	dry
1916	37.412	37.3	0.062523	2.592794	normal	ext. wet
1917	35.07	21.66	-1.31302	-1.4846	cool	dry
1918	35.903	18.31	-0.82377	-2.35796	normal	ext. dry
1919	40.648	24.79	1.963148	-0.6686	very warm	normal
1920	35.463	23.37	-1.0822	-1.0388	cool	dry
1921	41.879	25.3	2.68616	-0.53564	ext. warm	normal
1922	37.983	20.81	0.397893	-1.7062	normal	very dry
1923	36.968	23.24	-0.19825	-1.07269	normal	dry
1924	36.278	21.83	-0.60352	-1.44028	normal	dry
1925	36.875	22.96	-0.25288	-1.14569	normal	dry
1926	35.326	25.11	-1.16266	-0.58518	cool	normal
1927	35.186	29.98	-1.24489	0.684448	cool	normal
1928	35.424	30.42	-1.1051	0.799157	cool	normal
1929	36.117	19.42	-0.69808	-2.06858	normal	ext. dry
1930	36.748	25.33	-0.32747	-0.52782	normal	normal
1931	40.597	24.06	1.933194	-0.85891	very warm	normal
1932	39.817	28.45	1.47507	0.285572	warm	normal
1933	37.303	25.39	-0.0015	-0.51218	normal	normal
1934	35.489	22.71	-1.06693	-1.21086	cool	dry
1935	37.348	30.5	0.024934	0.820013	normal	normal
1936	35.529	21.46	-1.04343	-1.53674	cool	very dry
1937	36.903	29.39	-0.23643	0.530633	normal	normal

1938	37.788	26.18	0.283362	-0.30622	normal	normal
1939	36.987	28.37	-0.1871	0.264716	normal	normal
1940	38.318	21.53	0.594651	-1.51849	normal	very dry
1941	38.985	33.13	0.986405	1.505662	normal	very wet
1942	38.987	24.81	0.98758	-0.66339	normal	normal
1943	35.369	28.49	-1.13741	0.296	cool	normal
1944	38.068	33.91	0.447817	1.709011	normal	very wet
1945	37.211	28.82	-0.05553	0.382032	normal	normal
1946	36.963	25.38	-0.20119	-0.51479	normal	normal
1947	36.058	28.15	-0.73273	0.207361	normal	normal
1948	37.991	24.27	0.402592	-0.80417	normal	normal
1949	38.411	26.74	0.649274	-0.16023	normal	normal
1950	34.774	32.59	-1.48687	1.364883	cool	wet
1951	35.71	29.89	-0.93713	0.660984	normal	normal
1952	37.788	26.62	0.283362	-0.19151	normal	normal
1953	38.599	29.43	0.759693	0.541061	normal	normal
1954	38.559	24.6	0.7362	-0.71814	normal	normal
1955	39.555	27.23	1.321188	-0.03249	warm	normal
1956	36.231	22.95	-0.63112	-1.1483	normal	dry
1957	37.425	27.02	0.070159	-0.08723	normal	normal
1958	38.172	22.83	0.5089	-1.17958	normal	dry
1959	36.778	25.05	-0.30985	-0.60082	normal	normal
1960	37.042	22.11	-0.15479	-1.36729	normal	dry
1961	38.538	25.29	0.723866	-0.53825	normal	normal
1962	36.197	26.84	-0.65109	-0.13416	normal	normal
1963	37.271	22.66	-0.02029	-1.2239	normal	dry
1964	38.546	30.07	0.728564	0.707911	normal	normal
1965	34.054	29.98	-1.90976	0.684448	very cool	normal
1966	36.925	27.99	-0.22351	0.165648	normal	normal
1967	35.111	25.74	-1.28894	-0.42093	cool	normal
1968	37.1	30.69	-0.12073	0.869547	normal	normal
1969	37.432	31.15	0.07427	0.98947	normal	normal
1970	36.742	27.01	-0.33099	-0.08984	normal	normal
1971	36.375	31.4	-0.54655	1.054646	normal	wet
1972	35.508	34.63	-1.05577	1.896717	cool	very wet
1973	37.762	27.3	0.268092	-0.01424	normal	normal
1974	36.191	28.73	-0.65462	0.358569	normal	normal
1975	37.674	26.91	0.216406	-0.11591	normal	normal
1976	38.89	22.64	0.930608	-1.22911	normal	dry
1977	36.193	30.31	-0.65344	0.77048	normal	normal
1978	36.602	30.08	-0.41322	0.710518	normal	normal
1979	34.243	26.82	-1.79875	-0.13937	very cool	normal
1980	38.117	24.77	0.476596	-0.67382	normal	normal
1981	38.441	25.1	0.666894	-0.58778	normal	normal
1982	35.821	30.41	-0.87193	0.79655	normal	normal
1983	39.552	30.49	1.319426	0.817406	warm	normal
1984	37.123	25.77	-0.10722	-0.41311	normal	normal
1985	37.057	33.01	-0.14598	1.474378	normal	wet
1986	36.461	31.11	-0.49603	0.979042	normal	normal

1987	40.956	26.22	2.144048	-0.2958	ext. warm	normal
1988	38.326	29.15	0.59935	0.468064	normal	normal
1989	36.035	26.3	-0.74624	-0.27494	normal	normal
1990	37.028	24.61	-0.16301	-0.71553	normal	normal
1991	38.317	31.57	0.594064	1.098966	normal	wet
1992	36.786	31.05	-0.30515	0.9634	normal	normal
1993	36.147	29.51	-0.68046	0.561917	normal	normal
1994	35.653	28.68	-0.9706	0.345534	normal	normal
1995	38.783	27.22	0.867763	-0.03509	normal	normal
1996	33.804	35.03	-2.05659	2.000998	ext. cool	ext. wet
1997	35.789	28.47	-0.89073	0.290786	normal	normal
1998	42.097	25.04	2.8142	-0.60343	ext. warm	normal
1999	39.959	39.36	1.558472	3.129843	very warm	ext. wet
2000	39.75	24.82	1.435719	-0.66078	warm	normal
2001	38.125	34.14	0.481295	1.768973	normal	very wet
2002	40.441	27.7	1.841569	0.090045	very warm	normal
2003	37.303	24.57	-0.0015	-0.72596	normal	normal
2004	37.302	26.45	-0.00208	-0.23583	normal	normal
2005	39.116	26.97	1.063347	-0.10027	warm	normal
2006	41.309	27.49	2.351378	0.035297	ext. warm	normal

Water year (Oct-Sep) west-central MN

Year	WC_T	WC_P	WC_Tz	WC_Pz	T_class	P_class
1892	40.278	27.78	-0.861	0.864759	normal	normal
1893	37.902	22.8	-2.08539	-0.3184	ext. cool	normal
1894	41.037	16.92	-0.46987	-1.71539	normal	very dry
1895	40.405	20.69	-0.79555	-0.8197	normal	normal
1896	40.356	28.91	-0.8208	1.133228	normal	wet
1897	39.088	27.72	-1.47423	0.850504	cool	normal
1898	42.427	19.96	0.246421	-0.99314	normal	normal
1899	38.412	27.57	-1.82258	0.814867	very cool	normal
1900	43.316	24.53	0.704539	0.092616	normal	normal
1901	42.765	21.45	0.420598	-0.63914	normal	normal
1902	41.691	20.32	-0.13285	-0.90761	normal	normal
1903	40.007	28.84	-1.00065	1.116597	cool	wet
1904	38.1	23.67	-1.98336	-0.11171	very cool	normal
1905	41.541	28.17	-0.21015	0.957417	normal	normal
1906	42.402	31.31	0.233538	1.703426	normal	very wet
1907	38.672	21.62	-1.6886	-0.59875	very cool	normal
1908	43.172	26.58	0.630333	0.57966	normal	normal
1909	41.474	23.26	-0.24468	-0.20911	normal	normal
1910	42.179	17.6	0.118622	-1.55383	normal	very dry
1911	42.037	23	0.045447	-0.27089	normal	normal
1912	38.608	27.57	-1.72158	0.814867	very cool	normal
1913	42.049	23.13	0.05163	-0.24	normal	normal
1914	42.81	28.02	0.443788	0.921779	normal	normal
1915	41.328	28.11	-0.31991	0.943162	normal	normal
1916	40.293	31.98	-0.85327	1.862606	normal	very wet
1917	38.361	18.85	-1.84886	-1.25685	very cool	dry
1918	40.197	18.21	-0.90274	-1.40891	normal	dry
1919	43.953	26.72	1.032797	0.612922	warm	normal
1920	38.988	28.74	-1.52576	1.092839	very cool	wet
1921	45.53	23.53	1.845454	-0.14497	very warm	normal
1922	42.251	17.01	0.155725	-1.69401	normal	very dry
1923	42.001	22.91	0.026895	-0.29227	normal	normal
1924	41.547	22.97	-0.20706	-0.27801	normal	normal
1925	42.607	21.68	0.339178	-0.58449	normal	normal
1926	41.076	20.45	-0.44977	-0.87672	normal	normal
1927	40.953	21.79	-0.51316	-0.55836	normal	normal
1928	40.715	22.87	-0.6358	-0.30177	normal	normal
1929	41.029	19.91	-0.47399	-1.00502	normal	dry
1930	42.474	20.26	0.270641	-0.92186	normal	normal
1931	46.192	18.85	2.186594	-1.25685	ext. warm	dry
1932	43.815	20.33	0.961683	-0.90523	normal	normal
1933	43.074	18.08	0.579832	-1.43979	normal	dry

1934	43.109	14.54	0.597868	-2.28083	normal	ext. dry
1935	43.371	23.66	0.732881	-0.11408	normal	normal
1936	39.538	14.39	-1.24233	-2.31647	cool	ext. dry
1937	40.627	26.02	-0.68115	0.446614	normal	normal
1938	42.555	23.47	0.312382	-0.15922	normal	normal
1939	43.286	19.98	0.689079	-0.98838	normal	normal
1940	42.87	20.25	0.474707	-0.92424	normal	normal
1941	43.904	28.14	1.007546	0.950289	warm	normal
1942	44.006	30.44	1.060108	1.496729	warm	wet
1943	40.282	24.78	-0.85894	0.152012	normal	normal
1944	43.368	28.18	0.731335	0.959792	normal	normal
1945	42.427	22.08	0.246421	-0.48946	normal	normal
1946	42.121	25.12	0.088733	0.23279	normal	normal
1947	42.053	24.31	0.053692	0.040348	normal	normal
1948	41.839	24.75	-0.05659	0.144884	normal	normal
1949	42.376	21.37	0.22014	-0.65815	normal	normal
1950	39.798	23.4	-1.10835	-0.17585	cool	normal
1951	38.9	26.41	-1.57111	0.539271	very cool	normal
1952	41.119	25.77	-0.42762	0.387218	normal	normal
1953	42.798	26.81	0.437604	0.634304	normal	normal
1954	43.003	24.22	0.543244	0.018965	normal	normal
1955	44.042	23.27	1.07866	-0.20674	warm	normal
1956	39.195	22.5	-1.41909	-0.38968	cool	normal
1957	42.632	31.7	0.352061	1.796083	normal	very wet
1958	43.238	19.51	0.664344	-1.10005	normal	dry
1959	42.95	21.74	0.515932	-0.57024	normal	normal
1960	41.066	25.35	-0.45493	0.287434	normal	normal
1961	43.211	20.58	0.65043	-0.84584	normal	normal
1962	40.343	31.16	-0.8275	1.667788	normal	very wet
1963	43.557	24.07	0.828731	-0.01667	normal	normal
1964	43.863	22.8	0.986418	-0.3184	normal	normal
1965	38.661	31.27	-1.69427	1.693923	very cool	very wet
1966	41.502	22.7	-0.23025	-0.34216	normal	normal
1967	40.137	20.28	-0.93366	-0.91711	normal	normal
1968	42.358	22.79	0.210864	-0.32078	normal	normal
1969	40.553	25.53	-0.71929	0.330198	normal	normal
1970	40.917	21.94	-0.53171	-0.52272	normal	normal
1971	40.766	27.33	-0.60952	0.757847	normal	normal
1972	40.257	30.64	-0.87182	1.544245	normal	very wet
1973	42.49	22.27	0.278886	-0.44432	normal	normal
1974	41.265	21.22	-0.35238	-0.69378	normal	normal
1975	41.821	25.56	-0.06586	0.337326	normal	normal
1976	44.683	13.51	1.408979	-2.52554	warm	ext. dry
1977	41.774	27.57	-0.09008	0.814867	normal	normal
1978	40.458	27.91	-0.76824	0.895645	normal	normal
1979	37.993	23.5	-2.0385	-0.15209	ext. cool	normal
1980	42.781	22.17	0.428843	-0.46808	normal	normal
1981	44.188	21.08	1.153896	-0.72704	warm	normal

1982	40.254	25.43	-0.87337	0.30644	normal	normal
1983	44.259	25.19	1.190484	0.24942	warm	normal
1984	41.489	26.37	-0.23695	0.529768	normal	normal
1985	42.247	32.39	0.153663	1.960015	normal	very wet
1986	40.894	33.89	-0.54356	2.316389	normal	ext. wet
1987	46.707	17.57	2.451983	-1.56096	ext. warm	very dry
1988	44.558	18.62	1.344564	-1.3115	warm	dry
1989	41.472	23.58	-0.24571	-0.13309	normal	normal
1990	43.488	22.66	0.793174	-0.35166	normal	normal
1991	44.269	31.36	1.195637	1.715305	warm	very wet
1992	42.68	20.96	0.376796	-0.75555	normal	normal
1993	39.978	30.56	-1.01559	1.525239	cool	very wet
1994	40.709	23.32	-0.6389	-0.19486	normal	normal
1995	43.745	29.88	0.92561	1.363683	normal	wet
1996	39.793	21.98	-1.11093	-0.51322	cool	normal
1997	40.506	27.36	-0.74351	0.764975	normal	normal
1998	46.282	23.77	2.232973	-0.08795	ext. warm	normal
1999	45.599	31.03	1.881011	1.636903	very warm	very wet
2000	45.952	19.93	2.062918	-1.00026	ext. warm	dry
2001	41.638	29.95	-0.16017	1.380314	normal	wet
2002	45.468	24.43	1.813504	0.068858	very warm	normal
2003	42.682	21.14	0.377827	-0.71279	normal	normal
2004	42.596	27.07	0.33351	0.696076	normal	normal
2005	44.624	29.18	1.378575	1.197375	warm	wet
2006	45.061	25.79	1.603769	0.39197	very warm	normal

Water year (Oct-Sep) central MN

Year	C_T	C_P	C_Tz	C_Pz	T_class	P_class
1892	40.838	32.46	-0.80355	1.218375	normal	wet
1893	39.122	22.07	-1.72866	-0.96974	very cool	normal
1894	42.27	20.86	-0.03154	-1.22456	normal	dry
1895	41.446	22.94	-0.47577	-0.78652	normal	normal
1896	41.518	25.67	-0.43695	-0.21159	normal	normal
1897	39.684	32.87	-1.42568	1.30472	cool	wet
1898	42.681	20.3	0.190028	-1.3425	normal	dry
1899	38.963	27.12	-1.81437	0.09378	very cool	normal
1900	43.949	28.99	0.873617	0.487599	normal	normal
1901	43.143	21.99	0.439096	-0.98659	normal	normal
1902	41.971	22.67	-0.19274	-0.84338	normal	normal
1903	40.752	33.68	-0.84991	1.475305	normal	wet
1904	38.139	25.39	-2.2586	-0.27055	ext. cool	normal
1905	41.419	31.79	-0.49033	1.077274	normal	wet
1906	42.651	32.94	0.173855	1.319462	normal	wet
1907	39.495	24.79	-1.52757	-0.39691	very cool	normal
1908	43.697	28.37	0.737762	0.357028	normal	normal
1909	41.988	24.66	-0.18357	-0.42429	normal	normal
1910	43.114	16.59	0.423462	-2.12382	normal	ext. dry
1911	43.164	24.07	0.450417	-0.54854	normal	normal
1912	39.169	29.14	-1.70332	0.519189	very cool	normal
1913	42.889	26.61	0.302163	-0.01362	normal	normal
1914	43.886	28.66	0.839653	0.418102	normal	normal
1915	42.252	26.48	-0.04125	-0.041	normal	normal
1916	41.056	32.73	-0.68602	1.275237	normal	wet
1917	38.882	22.45	-1.85804	-0.88971	very cool	normal
1918	40.773	19.23	-0.83859	-1.56784	normal	very dry
1919	44.559	28.94	1.202473	0.477069	warm	normal
1920	39.863	27.67	-1.32918	0.209609	cool	normal
1921	46.172	24.33	2.072053	-0.49379	ext. warm	normal
1922	42.375	17.5	0.025061	-1.93217	normal	very dry
1923	42.582	22.6	0.136657	-0.85812	normal	normal
1924	41.943	25.47	-0.20783	-0.25371	normal	normal
1925	43.244	21.71	0.493546	-1.04556	normal	dry
1926	41.418	24.95	-0.49086	-0.36322	normal	normal
1927	41.241	23.02	-0.58629	-0.76967	normal	normal
1928	41.193	26.8	-0.61216	0.026389	normal	normal
1929	41.668	21.45	-0.35609	-1.10031	normal	dry
1930	43.291	21.97	0.518884	-0.9908	normal	normal
1931	46.506	19.25	2.252115	-1.56363	ext. warm	very dry
1932	44.574	24.07	1.210559	-0.54854	warm	normal
1933	43.518	20.43	0.641261	-1.31512	normal	dry
1934	43.182	17.61	0.460121	-1.90901	normal	very dry
1935	43.471	27.42	0.615923	0.15696	normal	normal

1936	40.032	19.29	-1.23807	-1.5552	cool	very dry
1937	41.042	27.32	-0.69357	0.1359	normal	normal
1938	42.75	28.97	0.227227	0.483387	normal	normal
1939	43.397	24.89	0.576029	-0.37585	normal	normal
1940	42.864	22.18	0.288685	-0.94658	normal	normal
1941	43.736	32.43	0.758787	1.212057	normal	wet
1942	43.948	32.26	0.873078	1.176255	normal	wet
1943	40.3	25.19	-1.09359	-0.31267	cool	normal
1944	42.843	32.04	0.277364	1.129924	normal	wet
1945	41.844	26.8	-0.2612	0.026389	normal	normal
1946	42.176	25.74	-0.08222	-0.19685	normal	normal
1947	42.237	26.18	-0.04934	-0.10418	normal	normal
1948	42.096	23.92	-0.12535	-0.58013	normal	normal
1949	42.75	23.25	0.227227	-0.72123	normal	normal
1950	40.209	23.74	-1.14265	-0.61804	cool	normal
1951	39.245	33.79	-1.66235	1.498471	very cool	wet
1952	41.57	30.3	-0.40892	0.763483	normal	normal
1953	42.898	30	0.307015	0.700303	normal	normal
1954	43.569	27.8	0.668756	0.236987	normal	normal
1955	44.148	24.88	0.980899	-0.37796	normal	normal
1956	39.72	26.57	-1.40627	-0.02205	cool	normal
1957	42.866	34.5	0.289763	1.647995	normal	very wet
1958	43.072	20.45	0.400819	-1.31091	normal	dry
1959	43.23	23.6	0.485998	-0.64753	normal	normal
1960	41.097	25.16	-0.66392	-0.31899	normal	normal
1961	43.247	21.91	0.495163	-1.00344	normal	dry
1962	40.756	31.07	-0.84775	0.925643	normal	normal
1963	43.537	25.86	0.651505	-0.17157	normal	normal
1964	44.255	24.77	1.038584	-0.40113	warm	normal
1965	39.071	35.18	-1.75615	1.791202	very cool	very wet
1966	41.952	25.06	-0.20298	-0.34005	normal	normal
1967	40.315	22.89	-1.0855	-0.79705	cool	normal
1968	42.852	28.12	0.282216	0.304379	normal	normal
1969	41.475	26.97	-0.46014	0.062191	normal	normal
1970	41.202	23.8	-0.60731	-0.60541	normal	normal
1971	40.979	31.34	-0.72753	0.982505	normal	normal
1972	40.597	36.01	-0.93347	1.965999	normal	very wet
1973	42.796	26.46	0.252026	-0.04521	normal	normal
1974	41.824	23.88	-0.27199	-0.58856	normal	normal
1975	41.94	27.64	-0.20945	0.203291	normal	normal
1976	44.401	18.13	1.117294	-1.7995	warm	very dry
1977	41.935	29.29	-0.21215	0.550779	normal	normal
1978	41.046	33	-0.69141	1.332098	normal	wet
1979	38.799	26.92	-1.90279	0.051661	very cool	normal
1980	42.929	26.45	0.323727	-0.04732	normal	normal
1981	44.188	24.36	1.002464	-0.48747	warm	normal
1982	40.757	29.47	-0.84721	0.588686	normal	normal
1983	44.477	32.59	1.158266	1.245753	warm	wet
1984	41.602	31.66	-0.39167	1.049896	normal	wet

1985	42.776	36.96	0.241244	2.166067	normal	ext. wet
1986	41.355	38.55	-0.52483	2.500918	normal	ext. wet
1987	46.96	19.44	2.49687	-1.52361	ext. warm	very dry
1988	44.602	19.13	1.225654	-1.5889	warm	very dry
1989	41.611	24.51	-0.38682	-0.45588	normal	normal
1990	43.563	29.36	0.665521	0.56552	normal	normal
1991	44.28	35.32	1.052062	1.820686	warm	very wet
1992	42.276	24.33	-0.02831	-0.49379	normal	normal
1993	40.505	33.95	-0.98307	1.532166	normal	very wet
1994	40.903	27.79	-0.7685	0.234881	normal	normal
1995	43.749	30.38	0.765795	0.780331	normal	normal
1996	39.694	22.95	-1.42029	-0.78441	cool	normal
1997	40.905	31.27	-0.76743	0.967763	normal	normal
1998	46.527	26.56	2.263436	-0.02415	ext. warm	normal
1999	45.563	31.71	1.743737	1.060426	very warm	wet
2000	46.053	20.28	2.007899	-1.34671	ext. warm	dry
2001	42.281	31.08	-0.02561	0.927749	normal	normal
2002	45.838	35.4	1.891991	1.837534	very warm	very wet
2003	43.153	25.38	0.444487	-0.27266	normal	normal
2004	43.472	29.11	0.616463	0.512871	normal	normal
2005	45.492	31.56	1.70546	1.028837	very warm	wet
2006	45.939	27.78	1.946441	0.232775	very warm	normal

Water year (Oct-Sep) east-central MN

Year	EC_T	EC_P	EC_Tz	EC_Pz	T_class	P_class
1892	40.522	31.1	-0.13878	0.64991	normal	normal
1893	38.74	23.28	-1.14031	-1.01088	cool	dry
1894	41.587	22.98	0.459782	-1.07459	normal	dry
1895	40.836	26.53	0.0377	-0.32065	normal	normal
1896	40.579	25.47	-0.10674	-0.54577	normal	normal
1897	39.938	36.72	-0.467	1.843467	normal	very wet
1898	42.079	22.27	0.736299	-1.22538	normal	dry
1899	38.168	32.31	-1.46179	0.906886	cool	normal
1900	43.617	28.99	1.600696	0.201795	very warm	normal
1901	42.183	25.03	0.79475	-0.63922	normal	normal
1902	41.685	26.65	0.51486	-0.29517	normal	normal
1903	40.241	39.45	-0.29671	2.423255	normal	ext. wet
1904	37.423	27.1	-1.8805	-0.1996	very cool	normal
1905	41.303	33.87	0.300166	1.238193	normal	wet
1906	41.641	32.21	0.490131	0.885648	normal	normal
1907	38.572	27.71	-1.23473	-0.07005	cool	normal
1908	42.442	29.48	0.940315	0.305859	normal	normal
1909	40.501	26.66	-0.15058	-0.29304	normal	normal
1910	41.563	18.56	0.446293	-2.01329	normal	ext. dry
1911	40.774	25.89	0.002854	-0.45657	normal	normal
1912	36.732	26.42	-2.26886	-0.34401	ext. cool	normal
1913	40.087	26.75	-0.38326	-0.27393	normal	normal
1914	41.477	29.94	0.397959	0.403553	normal	normal
1915	40.467	24.37	-0.16969	-0.77939	normal	normal
1916	39.099	33.46	-0.93854	1.151119	normal	wet
1917	36.255	20.46	-2.53694	-1.60978	ext. cool	very dry
1918	38.308	19.24	-1.3831	-1.86888	cool	very dry
1919	42.196	28.58	0.802056	0.11472	normal	normal
1920	37.501	29.6	-1.83666	0.331345	very cool	normal
1921	44.046	25.34	1.841806	-0.57338	very warm	normal
1922	40.49	22.52	-0.15676	-1.17228	normal	dry
1923	40.248	24.27	-0.29277	-0.80062	normal	normal
1924	39.862	26.94	-0.50971	-0.23358	normal	normal
1925	40.968	21.9	0.111887	-1.30396	normal	dry
1926	38.837	23.2	-1.08579	-1.02787	cool	dry
1927	39.028	25.99	-0.97844	-0.43534	normal	normal
1928	38.7	28.51	-1.16279	0.099854	cool	normal
1929	39.98	21.22	-0.4434	-1.44837	normal	dry
1930	41.401	21.6	0.355245	-1.36767	normal	dry
1931	44.623	24	2.166095	-0.85797	ext. warm	normal
1932	43.357	23.13	1.454569	-1.04273	warm	dry
1933	41.449	23.23	0.382222	-1.0215	normal	dry
1934	40.463	21.52	-0.17194	-1.38466	normal	dry
1935	40.887	30.19	0.066363	0.456647	normal	normal

1936	38.311	20.46	-1.38142	-1.60978	cool	very dry
1937	39.226	27.07	-0.86716	-0.20597	normal	normal
1938	41.213	32.39	0.249584	0.923876	normal	normal
1939	41.149	24.79	0.213614	-0.69019	normal	normal
1940	41.109	22.16	0.191133	-1.24874	normal	dry
1941	42.317	34.98	0.870061	1.473931	normal	wet
1942	42.603	31.09	1.030801	0.647786	warm	normal
1943	38.962	27.33	-1.01554	-0.15075	cool	normal
1944	41.323	35.3	0.311407	1.541892	normal	very wet
1945	40.419	29.85	-0.19667	0.384439	normal	normal
1946	40.75	25.88	-0.01063	-0.4587	normal	normal
1947	40.602	26.13	-0.09381	-0.4056	normal	normal
1948	40.904	23.07	0.075918	-1.05548	normal	dry
1949	41.185	26.42	0.233847	-0.34401	normal	normal
1950	38.494	27.57	-1.27857	-0.09978	cool	normal
1951	38.159	35.33	-1.46685	1.548263	cool	very wet
1952	40.393	33.28	-0.21128	1.112891	normal	wet
1953	41.27	32.83	0.281619	1.017321	normal	wet
1954	41.832	31.47	0.597478	0.728489	normal	normal
1955	42.358	28.37	0.893104	0.070121	normal	normal
1956	38.192	24.01	-1.4483	-0.85584	cool	normal
1957	40.868	31.19	0.055685	0.669024	normal	normal
1958	41.361	23.24	0.332764	-1.01937	normal	dry
1959	41.056	24.68	0.161346	-0.71355	normal	normal
1960	39.959	24.51	-0.4552	-0.74965	normal	normal
1961	41.983	21.84	0.682344	-1.3167	normal	dry
1962	39.623	30.88	-0.64404	0.603187	normal	normal
1963	41.434	24.5	0.373792	-0.75178	normal	normal
1964	42.502	28.46	0.974036	0.089235	normal	normal
1965	37.58	33.91	-1.79226	1.246688	very cool	wet
1966	40.438	28.58	-0.18599	0.11472	normal	normal
1967	38.842	24.1	-1.08298	-0.83673	cool	normal
1968	40.996	31.68	0.127624	0.773088	normal	normal
1969	40.489	26.97	-0.15732	-0.22721	normal	normal
1970	39.898	24.51	-0.48948	-0.74965	normal	normal
1971	39.336	32.18	-0.80534	0.879277	normal	normal
1972	38.995	38.84	-0.99699	2.293706	normal	ext. wet
1973	41.054	28.4	0.160222	0.076493	normal	normal
1974	40.143	28.36	-0.35178	0.067997	normal	normal
1975	40.617	32.12	-0.08538	0.866534	normal	normal
1976	42.456	20.78	0.948183	-1.54182	normal	very dry
1977	39.892	30.95	-0.49285	0.618053	normal	normal
1978	39.865	34.76	-0.50803	1.427209	normal	wet
1979	37.523	27.06	-1.82429	-0.20809	very cool	normal
1980	41.011	26.21	0.136054	-0.38861	normal	normal
1981	41.877	26.08	0.62277	-0.41622	normal	normal
1982	39.077	28.4	-0.95091	0.076493	normal	normal
1983	42.792	33.28	1.137024	1.112891	warm	wet
1984	40.358	30.94	-0.23095	0.615929	normal	normal

1985	40.849	36.59	0.045006	1.815858	normal	very wet
1986	39.976	40.02	-0.44564	2.54431	normal	ext. wet
1987	45.048	19.86	2.404956	-1.7372	ext. warm	very dry
1988	42.417	23.42	0.926264	-0.98114	normal	normal
1989	40.107	26.81	-0.37202	-0.26119	normal	normal
1990	41.88	29.73	0.624456	0.358954	normal	normal
1991	42.77	35.45	1.124659	1.573748	warm	very wet
1992	40.948	27.17	0.100647	-0.18473	normal	normal
1993	39.965	31.28	-0.45183	0.688138	normal	normal
1994	39.892	29.22	-0.49285	0.250641	normal	normal
1995	42.677	32.88	1.072391	1.02794	warm	wet
1996	38.418	27.56	-1.32128	-0.1019	cool	normal
1997	39.557	31.69	-0.68113	0.775212	normal	normal
1998	45.078	26.81	2.421817	-0.26119	ext. warm	normal
1999	44.145	35.77	1.897446	1.641709	very warm	very wet
2000	44.12	22.93	1.883396	-1.08521	very warm	dry
2001	41.44	34.98	0.377164	1.473931	normal	wet
2002	44.144	37.12	1.896884	1.928418	very warm	very wet
2003	41.46	27.26	0.388404	-0.16562	normal	normal
2004	41.643	28.31	0.491255	0.057379	normal	normal
2005	43.437	30.21	1.499531	0.460894	warm	normal
2006	44.804	27.68	2.267822	-0.07642	ext. warm	normal

Water year (Oct-Sep) southwest MN

Year	SW_T	SW_P	SW_Tz	SW_Pz	T_class	P_class
1892	41.885	34.78	-1.25513	1.825312	cool	very wet
1893	40.984	20.45	-1.74248	-1.19649	very cool	dry
1894	44.615	16.51	0.22154	-2.02733	normal	ext. dry
1895	44.058	23.73	-0.07974	-0.50483	normal	normal
1896	43.308	29.25	-0.48542	0.659187	normal	normal
1897	41.498	28.9	-1.46446	0.585382	cool	normal
1898	44.325	21.71	0.064678	-0.93079	normal	normal
1899	39.753	25.29	-2.40834	-0.17587	ext. cool	normal
1900	45.225	29.16	0.551492	0.640209	normal	normal
1901	45.14	23.16	0.505515	-0.62503	normal	normal
1902	43.208	24.63	-0.53951	-0.31504	normal	normal
1903	42.477	38.49	-0.93491	2.607649	normal	ext. wet
1904	40.508	24	-1.99995	-0.44789	very cool	normal
1905	44.116	32.74	-0.04837	1.395132	normal	wet
1906	44.785	27.61	0.313494	0.313357	normal	normal
1907	42.33	25.78	-1.01443	-0.07254	cool	normal
1908	45.218	30.12	0.547706	0.842646	normal	normal
1909	43.757	28.2	-0.24256	0.437771	normal	normal
1910	44.197	19.83	-0.00456	-1.32723	normal	dry
1911	44.87	21.2	0.359471	-1.03834	normal	dry
1912	40.273	25.46	-2.12707	-0.14002	ext. cool	normal
1913	44.453	25.27	0.133914	-0.18009	normal	normal
1914	45.599	30.01	0.75379	0.81945	normal	normal
1915	43.333	29.3	-0.4719	0.669731	normal	normal
1916	43.089	25.1	-0.60388	-0.21593	normal	normal
1917	40.36	27.1	-2.08001	0.205812	ext. cool	normal
1918	42.392	23.32	-0.98089	-0.59129	normal	normal
1919	45.991	34.36	0.965825	1.736746	normal	very wet
1920	41.672	30.88	-1.37034	1.00291	cool	wet
1921	48.067	26.21	2.088742	0.018135	ext. warm	normal
1922	44.787	15.09	0.314576	-2.32677	normal	ext. dry
1923	44.644	26.05	0.237227	-0.0156	normal	normal
1924	43.746	22.6	-0.24851	-0.74311	normal	normal
1925	45.277	21.38	0.579619	-1.00038	normal	dry
1926	43.937	21.72	-0.14519	-0.92868	normal	normal
1927	43.813	26.59	-0.21226	0.098267	normal	normal
1928	43.688	24.79	-0.27988	-0.2813	normal	normal
1929	43.209	27.68	-0.53897	0.328118	normal	normal
1930	45.166	22.61	0.519579	-0.74101	normal	normal
1931	49.108	17.85	2.651824	-1.74476	ext. warm	very dry
1932	46.327	26.13	1.147569	0.001265	warm	normal
1933	45.741	21.97	0.830599	-0.87596	normal	normal
1934	46.201	19.91	1.079415	-1.31036	warm	dry

1935	46.07	23.18	1.008556	-0.62081	warm	normal
1936	42.334	20.52	-1.01226	-1.18173	cool	dry
1937	43.352	24.55	-0.46162	-0.33191	normal	normal
1938	44.796	30.31	0.319444	0.882712	normal	normal
1939	46.461	22.96	1.22005	-0.6672	warm	normal
1940	45.127	20.55	0.498483	-1.1754	normal	dry
1941	46.433	26.43	1.204904	0.064527	warm	normal
1942	46.027	32.94	0.985297	1.437307	normal	wet
1943	42.962	28.69	-0.67257	0.541099	normal	normal
1944	44.989	30.94	0.423839	1.015562	normal	wet
1945	44.473	25.39	0.144732	-0.15478	normal	normal
1946	44.765	25.54	0.302676	-0.12315	normal	normal
1947	44.301	25.12	0.051696	-0.21172	normal	normal
1948	44.824	25.85	0.334589	-0.05778	normal	normal
1949	44.486	23.55	0.151764	-0.54279	normal	normal
1950	42.305	20.41	-1.02795	-1.20493	cool	dry
1951	41.238	30.51	-1.60509	0.924887	very cool	normal
1952	43.468	22	-0.39888	-0.86964	normal	normal
1953	44.704	29.05	0.269681	0.617013	normal	normal
1954	45.813	24.44	0.869544	-0.35511	normal	normal
1955	46.427	18.8	1.201659	-1.54443	warm	very dry
1956	41.8	22.21	-1.30111	-0.82535	cool	normal
1957	44.668	29.87	0.250208	0.789928	normal	normal
1958	45.029	19.39	0.445475	-1.42002	normal	dry
1959	44.943	22.26	0.398957	-0.81481	normal	normal
1960	42.433	32.39	-0.95871	1.321327	normal	wet
1961	44.543	22.78	0.182595	-0.70516	normal	normal
1962	42.558	30.16	-0.8911	0.851081	normal	normal
1963	45.639	26.7	0.775426	0.121463	normal	normal
1964	46.167	25.43	1.061024	-0.14635	warm	normal
1965	41.326	29.71	-1.55749	0.756189	very cool	normal
1966	44.209	22.02	0.001933	-0.86542	normal	normal
1967	43.023	21.66	-0.63958	-0.94133	normal	normal
1968	44.817	28.84	0.330803	0.57273	normal	normal
1969	42.577	30.96	-0.88082	1.019779	normal	wet
1970	43.032	25.11	-0.63471	-0.21382	normal	normal
1971	43.118	25.2	-0.58819	-0.19485	normal	normal
1972	42.697	29.34	-0.81591	0.678166	normal	normal
1973	44.959	23.42	0.407611	-0.5702	normal	normal
1974	44.389	21.33	0.099296	-1.01092	normal	dry
1975	43.857	22.89	-0.18847	-0.68196	normal	normal
1976	46.493	17.59	1.237359	-1.79959	warm	very dry
1977	44.29	29.56	0.045746	0.724558	normal	normal
1978	42.58	28.4	-0.8792	0.479946	normal	normal
1979	40.033	33.19	-2.25688	1.490025	ext. cool	wet
1980	45.411	24.55	0.6521	-0.33191	normal	normal
1981	46.637	21.21	1.315249	-1.03623	warm	dry
1982	42.725	28	-0.80077	0.395597	normal	normal
1983	45.742	31.79	0.83114	1.194803	normal	wet
1984	42.755	32.3	-0.78454	1.302348	normal	wet

1985	44.51	34.04	0.164745	1.669267	normal	very wet
1986	42.646	35.81	-0.8435	2.042511	normal	ext. wet
1987	48.202	21.56	2.161764	-0.96242	ext. warm	normal
1988	45.698	20.36	0.80734	-1.21547	normal	dry
1989	44.097	21.33	-0.05865	-1.01092	normal	dry
1990	45.535	23.8	0.719172	-0.49007	normal	normal
1991	45.881	31.83	0.906325	1.203238	normal	wet
1992	44.14	28.16	-0.03539	0.429336	normal	normal
1993	41.747	43.12	-1.32977	3.583989	cool	ext. wet
1994	42.806	28.87	-0.75696	0.579056	normal	normal
1995	45.404	31.83	0.648314	1.203238	normal	wet
1996	41.928	25	-1.23187	-0.23702	cool	normal
1997	41.928	27.78	-1.23187	0.349205	cool	normal
1998	46.989	23.2	1.505647	-0.61659	very warm	normal
1999	46.852	27.36	1.431543	0.260638	warm	normal
2000	47.656	22.11	1.86643	-0.84644	very warm	normal
2001	42.983	31.08	-0.66122	1.045084	normal	wet
2002	47.019	26.14	1.521874	0.003374	very warm	normal
2003	44.032	23.9	-0.09381	-0.46898	normal	normal
2004	44.738	30.09	0.288072	0.83632	normal	normal
2005	47.183	32.04	1.610583	1.247522	very warm	wet
2006	46.715	27.94	1.357439	0.382944	warm	normal

Water year (Oct-Sep) south-central MN

Year	SC_T	SW-P	SC_Tz	SC_Pz	T_class	P_class
1892	41.943	36.45	-1.45187	1.597939	cool	very wet
1893	40.338	24.89	-2.35048	-0.97046	ext. cool	normal
1894	44.906	21.92	0.207059	-1.63034	normal	very dry
1895	43.972	26.16	-0.31587	-0.68829	normal	normal
1896	44.487	24.79	-0.02753	-0.99268	normal	normal
1897	42.613	29.8	-1.07675	0.120441	cool	normal
1898	45.153	21.4	0.345349	-1.74587	normal	very dry
1899	41.436	31.01	-1.73573	0.389279	very cool	normal
1900	46.442	29.55	1.067036	0.064896	warm	normal
1901	45.947	27.35	0.789895	-0.4239	normal	normal
1902	44.092	31.98	-0.24868	0.604794	normal	normal
1903	43.772	38.06	-0.42785	1.95565	normal	very wet
1904	40.984	24.26	-1.9888	-1.11044	very cool	dry
1905	44.053	32.39	-0.27052	0.695888	normal	normal
1906	45.718	34.47	0.661682	1.158023	normal	wet
1907	42.28	28.65	-1.26319	-0.13507	cool	normal
1908	46.123	33.83	0.888434	1.015827	normal	wet
1909	44.265	32.08	-0.15183	0.627012	normal	normal
1910	44.867	21.08	0.185223	-1.81697	normal	very dry
1911	45.831	24.31	0.724949	-1.09933	normal	dry
1912	41.105	30.27	-1.92105	0.224866	very cool	normal
1913	45.211	28	0.377823	-0.27948	normal	normal
1914	46.411	30.35	1.04968	0.24264	warm	normal
1915	44.045	31.64	-0.275	0.529253	normal	normal
1916	43.872	31.49	-0.37186	0.495926	normal	normal
1917	41.052	29.88	-1.95072	0.138215	very cool	normal
1918	42.751	30.05	-0.99949	0.175986	normal	normal
1919	46.629	34.88	1.171734	1.249116	warm	wet
1920	42.147	26.25	-1.33765	-0.6683	cool	normal
1921	48.401	27.33	2.163844	-0.42834	ext. warm	normal
1922	44.905	19.79	0.206499	-2.10358	normal	ext. dry
1923	44.852	27.49	0.176825	-0.3928	normal	normal
1924	43.572	27.82	-0.53982	-0.31948	normal	normal
1925	45.172	26.67	0.355987	-0.57498	normal	normal
1926	43.56	25.42	-0.54654	-0.85271	normal	normal
1927	43.585	28.23	-0.53254	-0.22838	normal	normal
1928	43.722	29.08	-0.45584	-0.03953	normal	normal
1929	43.188	27.56	-0.75482	-0.37724	normal	normal
1930	44.828	26.98	0.163388	-0.50611	normal	normal
1931	48.386	20.76	2.155446	-1.88807	ext. warm	very dry
1932	46.368	30.96	1.025605	0.37817	warm	normal
1933	45.689	24.02	0.645446	-1.16376	normal	dry
1934	46.387	19.64	1.036243	-2.13691	warm	ext. dry

1935	45.42	29.61	0.494838	0.078227	normal	normal
1936	42.308	24.75	-1.24751	-1.00157	cool	dry
1937	43.565	26.7	-0.54374	-0.56832	normal	normal
1938	45.214	32.94	0.379502	0.818087	normal	normal
1939	46.632	22.79	1.173414	-1.43704	warm	dry
1940	44.936	25.19	0.223855	-0.90381	normal	normal
1941	46.287	32.17	0.980255	0.647008	normal	normal
1942	46.426	34.5	1.058078	1.164688	warm	wet
1943	42.876	32.13	-0.9295	0.638121	normal	normal
1944	45.112	32.99	0.322394	0.829196	normal	normal
1945	44.476	32.4	-0.03369	0.69811	normal	normal
1946	45.239	28.98	0.393499	-0.06175	normal	normal
1947	44.943	30.82	0.227774	0.347065	normal	normal
1948	45.144	27.73	0.34031	-0.33947	normal	normal
1949	45.505	25.99	0.542428	-0.72607	normal	normal
1950	43.101	24.66	-0.80353	-1.02157	normal	dry
1951	41.485	36.69	-1.7083	1.651263	very cool	very wet
1952	44.255	27.24	-0.15742	-0.44834	normal	normal
1953	45.221	29.23	0.383421	-0.0062	normal	normal
1954	46.829	28.63	1.283711	-0.13951	warm	normal
1955	46.687	22.43	1.204207	-1.51703	warm	very dry
1956	42.23	27.46	-1.29118	-0.39946	cool	normal
1957	45.568	28.16	0.5777	-0.24393	normal	normal
1958	45.272	20.95	0.411975	-1.84585	normal	very dry
1959	45.22	29.22	0.382861	-0.00842	normal	normal
1960	43.608	32.19	-0.51967	0.651452	normal	normal
1961	44.896	27.15	0.20146	-0.46834	normal	normal
1962	42.921	31.63	-0.90431	0.527031	normal	normal
1963	45.385	25.64	0.475242	-0.80383	normal	normal
1964	46.683	30.38	1.201968	0.249306	warm	normal
1965	41.725	35.26	-1.57392	1.333545	very cool	wet
1966	44.297	23.82	-0.13391	-1.2082	normal	dry
1967	43.189	28.96	-0.75426	-0.06619	normal	normal
1968	45.042	34.85	0.283203	1.242451	normal	wet
1969	43.48	28.95	-0.59133	-0.06841	normal	normal
1970	43.132	28.43	-0.78617	-0.18395	normal	normal
1971	43.204	29.76	-0.74586	0.111554	normal	normal
1972	43.113	30.81	-0.79681	0.344843	normal	normal
1973	44.787	32.33	0.140433	0.682557	normal	normal
1974	44.28	26.41	-0.14343	-0.63275	normal	normal
1975	43.992	28.05	-0.30467	-0.26837	normal	normal
1976	47.112	22.26	1.442157	-1.5548	warm	very dry
1977	44.472	30.25	-0.03593	0.220422	normal	normal
1978	42.572	30.7	-1.0997	0.320403	cool	normal
1979	40.55	33.66	-2.23178	0.978057	ext. cool	normal
1980	45.097	28.45	0.313996	-0.1795	normal	normal
1981	46.171	29.88	0.915309	0.138215	normal	normal
1982	42.581	30.34	-1.09467	0.240418	cool	normal
1983	46.293	35.71	0.983614	1.433526	normal	wet
1984	43.078	31.13	-0.8164	0.415941	normal	normal

1985	45.002	33.58	0.260807	0.960282	normal	normal
1986	43.303	37.67	-0.69043	1.868999	normal	very wet
1987	48.618	24.19	2.285338	-1.12599	ext. warm	dry
1988	46.386	21.72	1.035683	-1.67478	warm	very dry
1989	44.264	23.73	-0.15239	-1.22819	normal	dry
1990	45.859	32.58	0.740626	0.738102	normal	normal
1991	46.006	37.05	0.822928	1.731248	normal	very wet
1992	44.068	31.34	-0.26212	0.462599	normal	normal
1993	42.174	46.61	-1.32254	3.85529	cool	ext. wet
1994	43.095	30.33	-0.80689	0.238197	normal	normal
1995	45.941	31.31	0.786536	0.455933	normal	normal
1996	41.975	28.47	-1.43395	-0.17506	cool	normal
1997	42.457	32.56	-1.16409	0.733658	cool	normal
1998	47.348	28.66	1.574289	-0.13284	very warm	normal
1999	46.895	36.04	1.320663	1.506846	warm	very wet
2000	47.407	28.06	1.607322	-0.26615	very warm	normal
2001	43.007	33.58	-0.85616	0.960282	normal	normal
2002	47.409	30.79	1.608442	0.340399	very warm	normal
2003	44.516	24.03	-0.01129	-1.16154	normal	dry
2004	45.103	36.81	0.317355	1.677924	normal	very wet
2005	47.109	35.04	1.440477	1.284665	warm	wet
2006	47.047	30.16	1.405765	0.200426	warm	normal

Water year (Oct-Sep) southeast MN

Year	SE_T	SE_P	SE_Tz	SE_Pz	T_class	P_class
1892	42.681	38.18	-0.91989	1.503065	normal	very wet
1893	40.764	26.85	-2.02532	-0.81497	ext. cool	normal
1894	44.566	23.89	0.167092	-1.42057	normal	dry
1895	43.262	27.37	-0.58485	-0.70859	normal	normal
1896	43.648	27.63	-0.36227	-0.65539	normal	normal
1897	42.637	29.68	-0.94526	-0.23598	normal	normal
1898	44.617	21.21	0.196501	-1.96888	normal	very dry
1899	40.616	35.61	-2.11066	0.977261	ext. cool	normal
1900	45.371	31.8	0.631292	0.197761	normal	normal
1901	45.102	35.88	0.476174	1.032501	normal	wet
1902	43.929	36.31	-0.20023	1.120476	normal	wet
1903	44.093	42.5	-0.10566	2.386907	normal	ext. wet
1904	40.846	27.14	-1.97803	-0.75564	very cool	normal
1905	43.719	31.4	-0.32133	0.115924	normal	normal
1906	44.965	34.76	0.397174	0.803357	normal	normal
1907	42.559	32.48	-0.99024	0.336885	normal	normal
1908	45.7	30.7	0.821009	-0.02729	normal	normal
1909	43.962	31.84	-0.1812	0.205945	normal	normal
1910	44.944	21.11	0.385064	-1.98934	normal	very dry
1911	45.36	28.15	0.624949	-0.549	normal	normal
1912	40.664	34.37	-2.08298	0.723566	ext. cool	normal
1913	44.984	29.37	0.40813	-0.2994	normal	normal
1914	46.002	33.14	0.995156	0.471916	normal	normal
1915	43.544	33.1	-0.42224	0.463732	normal	normal
1916	43.861	30.58	-0.23944	-0.05184	normal	normal
1917	40.336	30.78	-2.27212	-0.01092	ext. cool	normal
1918	41.715	26.89	-1.47693	-0.80679	cool	normal
1919	46.323	29.63	1.180259	-0.24621	warm	normal
1920	41.74	29.18	-1.46251	-0.33827	cool	normal
1921	48.34	30.69	2.343354	-0.02934	ext. warm	normal
1922	44.525	25.77	0.143449	-1.03593	normal	dry
1923	44.337	26.05	0.03504	-0.97865	normal	normal
1924	42.994	31.25	-0.7394	0.085235	normal	normal
1925	45.152	30.69	0.505007	-0.02934	normal	normal
1926	42.794	27.43	-0.85472	-0.69631	normal	normal
1927	43.161	27.78	-0.6431	-0.6247	normal	normal
1928	43.93	32.64	-0.19965	0.36962	normal	normal
1929	43.239	29.97	-0.59812	-0.17664	normal	normal
1930	44.594	26.49	0.183238	-0.88863	normal	normal
1931	48.113	23.53	2.212455	-1.49422	ext. warm	dry
1932	46.364	30.04	1.203902	-0.16232	warm	normal
1933	45.613	27.36	0.77084	-0.71063	normal	normal
1934	45.692	23.61	0.816395	-1.47786	normal	dry
1935	44.657	33.88	0.219567	0.623315	normal	normal

1936	43.02	26.13	-0.7244	-0.96228	normal	normal
1937	43.774	25.73	-0.28961	-1.04412	normal	dry
1938	45.526	40.28	0.720672	1.932711	normal	very wet
1939	46.237	23.9	1.130667	-1.41852	warm	dry
1940	44.43	24.12	0.088668	-1.37351	normal	dry
1941	46.03	31.29	1.011302	0.093419	warm	normal
1942	45.917	40.55	0.946141	1.987951	normal	very wet
1943	42.476	28.25	-1.0381	-0.52854	cool	normal
1944	44.772	29.55	0.285881	-0.26257	normal	normal
1945	44.25	34.37	-0.01513	0.723566	normal	normal
1946	45.147	28.18	0.502123	-0.54287	normal	normal
1947	45.037	31.16	0.438692	0.066822	normal	normal
1948	45.243	24.05	0.557481	-1.38783	normal	dry
1949	45.873	25.17	0.920768	-1.15869	normal	dry
1950	43.549	27.51	-0.41936	-0.67994	normal	normal
1951	41.924	36.24	-1.35641	1.106155	cool	wet
1952	44.307	29.8	0.017741	-0.21142	normal	normal
1953	45.05	29.46	0.446189	-0.28099	normal	normal
1954	47.042	32.65	1.594868	0.371666	very warm	normal
1955	46.298	24.24	1.165843	-1.34896	warm	dry
1956	42.46	28.06	-1.04732	-0.56742	cool	normal
1957	45.6	31.4	0.763344	0.115924	normal	normal
1958	44.785	22.25	0.293377	-1.7561	normal	very dry
1959	44.532	34.95	0.147486	0.84223	normal	normal
1960	43.708	30.76	-0.32767	-0.01502	normal	normal
1961	44.616	26.34	0.195924	-0.91932	normal	normal
1962	42.458	32.76	-1.04848	0.394171	cool	normal
1963	43.984	23.02	-0.16852	-1.59857	normal	very dry
1964	46.202	24.93	1.110485	-1.20779	warm	dry
1965	41.307	36.41	-1.7122	1.140936	very cool	wet
1966	43.724	24.99	-0.31844	-1.19552	normal	dry
1967	42.588	29.82	-0.97351	-0.20733	normal	normal
1968	44.399	34.43	0.070792	0.735841	normal	normal
1969	43.279	29.33	-0.57505	-0.30758	normal	normal
1970	42.966	31.38	-0.75554	0.111832	normal	normal
1971	42.575	33.46	-0.98101	0.537386	normal	normal
1972	42.689	34.18	-0.91527	0.684693	normal	normal
1973	43.948	39.67	-0.18928	1.807909	normal	very wet
1974	43.573	29.04	-0.40552	-0.36692	normal	normal
1975	43.401	30.72	-0.5047	-0.0232	normal	normal
1976	46.151	25.21	1.081076	-1.15051	warm	dry
1977	43.56	28.5	-0.41301	-0.4774	normal	normal
1978	42.158	37.41	-1.22147	1.345529	cool	wet
1979	40.773	31.41	-2.02013	0.11797	ext. cool	normal
1980	44.948	35.27	0.387371	0.907699	normal	normal
1981	45.632	32.36	0.781797	0.312334	normal	normal
1982	42.567	30.32	-0.98562	-0.10504	normal	normal
1983	46.148	40.27	1.079346	1.930665	warm	very

						wet
1984	43.115	32.68	-0.66962	0.377803	normal	normal
1985	44.873	30.88	0.344122	0.009536	normal	normal
1986	42.875	40.62	-0.80802	2.002272	normal	ext. wet
1987	47.399	29.08	1.80073	-0.35873	very warm	normal
1988	46.218	24.92	1.119711	-1.20984	warm	dry
1989	43.971	25.21	-0.17601	-1.15051	normal	dry
1990	45.412	39.66	0.654935	1.805863	normal	very wet
1991	45.912	34.88	0.943258	0.827908	normal	normal
1992	43.923	33.89	-0.20369	0.625361	normal	normal
1993	42.529	43.43	-1.00754	2.577179	cool	ext. wet
1994	43.273	31.64	-0.57851	0.165027	normal	normal
1995	46.143	27.25	1.076463	-0.73314	warm	normal
1996	41.79	26.63	-1.43368	-0.85998	cool	normal
1997	42.514	37.07	-1.01619	1.275967	cool	wet
1998	47.697	35.93	1.972571	1.042731	very warm	wet
1999	47.007	39.26	1.574685	1.724026	very warm	very wet
2000	47.118	32.43	1.638693	0.326655	very warm	normal
2001	43.412	35.46	-0.49836	0.946572	normal	normal
2002	47.639	35.08	1.939125	0.868827	very warm	normal
2003	44.223	24.64	-0.0307	-1.26712	normal	dry
2004	44.882	39.03	0.349312	1.676969	normal	very wet
2005	46.517	34.73	1.292128	0.797219	warm	normal
2006	46.677	31.45	1.384392	0.126154	warm	normal

Minnesota Climate in Century 21

Richard H. Skaggs

Introduction

Projections the climate of Minnesota for the remainder of this century must be rather general and include rather large uncertainties. In the absence of known quasi-periodic or predictable variations of the external and internal climate forcing functions, GCMs provide the best means of attempting such projections. But using GCM output poses several problems. GCM output is generated for grid points that are located 200 to 300 kilometers apart requiring downscaling to a spatial scale consistent with the size of Minnesota or the use of one or more grid points in or close to the area of interest. GCM output is usually biased, i.e., the values of climate variables such as temperature and precipitation are systematically overestimated or underestimated when compared with observed values. This requires attempting to remove the bias, a difficult task that goes beyond the resources available for this project. Finally, some 22 GCMs participated in the IPCC 4th assessment. Each of the models provided somewhat different projections for the 21st century depending on such things as the spatial scale of the GCM grid, the initial conditions, the land process model used, the coupling scheme to the oceans used, and the parameterizations of sub-grid-scale processes used. The choices available are to either use a composite of the many models or select an individual model to use. Again the resources available precluded the former approach.

In light of the resources available and the issues identified above, this report presents two projections. The first is of temperature, precipitation, and soil moisture on a monthly time scale for four points representing the northwest (NW), northeast (NE), southwest (SW), and southeast (SE) climatological division of Minnesota. The data are part of the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset and are bias-corrected and spatially downscaled climate projections, which were obtained from the CMIP3 data served at: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/, as described by Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy (2007), 'Fine-resolution climate projections enhance regional climate change impact studies', *Eos Trans. AGU*, *88*(47), 504. The specific GCM used is the GFDL CM2.1 as run under the A2 (business as usual) scenario for CO2 change over the century.

The second projection uses the GFDL CM2.1 A2 and B1 (rapid control of CO2) scenarios but for daily data for a grid point that is located close to the Twin Cities metropolitan area. These data are used to estimate projected changes in maximum daily precipitation, annual maximum daily temperature, and annual minimum daily temperature for 10 year and 100 year return periods. The results are based on the Generalized Extreme Value (GEV) distribution. The daily data are not bias-corrected. And it is likely that there is residual bias in the monthly data. Therefore, projected changes and not absolute values are presented for both the monthly and daily data analyses.

Monthly Data Analyses

The monthly temperature and precipitation data are time averaged over three periods: 1950-99, 2000-49, and 2050-99. The average monthly temperature and precipitation data are input to a Thornthwaite water balance model. The Thornthwaite water balance model output includes calculated monthly evapotranspiration and calculated soil moisture values. Calculation of the soil moisture requires knowledge of the field capacity of the soil that is assumed for purposes of easier comparison to be 200 mm for all four locations within Minnesota. Mean monthly temperature change in degrees Celsius between the 2000-49 averaging period and the 1950-99 averaging period and between the 2050-99 averaging period and the 1950-99 averaging period are shown in the first four graphs at the end of this report. It is clear that the temperature change will be greatest in the second half of the 21st century. Monthly temperature increases in the 2000-49 period are generally less than 2 degrees Celsius and generally well above 2 degrees Celsius in the second half of the century. There is an annual cycle of the monthly temperature increases with the largest increases occurring in the late summer and in the winter. The late summer temperature increases are larger than the winter increases in the southern part of the state but in the northern part of the state the two increases are comparable in magnitude. The late summer peak in temperature increase is very important when combined with the projected changes in precipitation.

Changes in precipitation are shown as per cent change in the next four graphs at the end of this report. Precipitation is projected to increase in most months with peaks of increase occurring in the late fall and early winter and in the spring. However, the months of July, August, and September are projected to have precipitation decreases or little change, which is crucial when combined with the temperature increase peak in the same months. In general, the projected precipitation changes are larger in the second half of the 21st century. Also the projected precipitation changes appear to be more erratic than the projected temperature changes. It is likely that using per cent change is partially responsible, but it also the case that GMCs have a much harder time projecting precipitation.

The combination of the projected late summer increases in temperature and decreases in precipitation is crucial for soil moisture. The higher temperatures imply larger amounts of water loss (evapotranspiration) at the same time water supply is reduced. The last four graphs at the end of this report present the projected per changes in soil moisture. With rare exceptions, soil moisture is projected to decrease throughout the year. And the soil moisture decreases in the late summer are projected to be very large. In general, the soil moisture results demonstrate that the projected increases in precipitation are well short of what are required to offset the projected temperature increases and the associated projected increases in evapotranspiration. The soil moisture changes are shown as constant for four to six months depending on the location, scenario, and time averaging period, as the result of frozen soil.

While these monthly analyses are instructive, they do not provide insight into combinations of months into important seasons. For a look at seasons, we analyzed mean seasonal temperature and total seasonal precipitation for each year, for the two seasons of summer (June, July, and August) and winter (November through March), for the four climatological divisions, and for two carbon dioxide scenarios A2 (business as usual) and B1 (rapid emissions reductions). 20th century means and standard deviations were then calculated. Five categories of temperature and precipitation were constructed for each climatological division and season based on standard deviations from the mean as indicated in this table.

Limits	Temperature	Precipitation
-2 sds or greater below the mean	Very Cold	Very Dry
-1 to -2 sds below the mean	Cold	Dry
-1 to +1 sds around the mean	Normal	Normal
1 to 2 sds above mean	Warm	Wet
2 sds or more above the mean	Very Warm	Very Wet

For each division and season the value of the boundaries of these categories were determined and the output of the A2 and B1 scenarios results were compared with the critical values to produce a frequency count of seasons in each category, season, and division in 50 year increments from 1950 through 2100. These frequency counts are contained in the following tables.

Northwest Division, Summer

Temperature	Very Cool	Cool	Normal	Warm	Very Warm
1951-2000	0	3	28	12	7
A2: 2000-2049	0	0	7	11	32
B1: 2000-2049	0	0	6	18	26
A2: 2050-2099	0	0	0	2	48
B1: 2050-2099	0	0	1	4	45
Precipitation	Very Dry	Dry	Normal	Wet	Very Wet
1951-2000	3	8	23	10	6
A2: 2000-2049	4	6	26	8	6
B1: 2000-2049	4	4	30	5	7
A2: 2050-2099	3	9	26	4	8
B1: 2050-2099	3	7	21	12	7

Northeast Division, Summer

Temperature	Very Cool	Cool	Normal	Warm	Very Warm
1951-2000	2	7	33	8	0
A2: 2000-2049	0	0	16	17	17
B1: 2000-2049	0	0	16	16	18
A2: 2050-2099	0	0	1	3	46
B1: 2050-2099	0	0	3	8	39
Precipitation	Very Dry	Dry	Normal	Wet	Very Wet
1951-2000	1	6	26	10	7
A2: 2000-2049	0	8	18	18	6
B1: 2000-2049	1	9	19	14	7
A2: 2050-2099	2	9	22	10	7
B1: 2050-2099	0	9	19	16	6

Southwest Division, Summer

Temperature	Very Cool	Cool	Normal	Warm	Very Warm
1951-2000	1	5	36	6	2
A2: 2000-2049	0	0	14	17	19
B1: 2000-2049	0	0	19	11	20
A2: 2050-2099	0	0	0	3	47
B1: 2050-2099	0	0	3	12	35
Precipitation	Very Dry	Dry	Normal	Wet	Very Wet
1951-2000	0	10	34	5	1
A2: 2000-2049	1	10	26	10	3
B1: 2000-2049	2	9	29	6	4
A2: 2050-2099	6	10	29	4	1
B1: 2050-2099	3	4	31	8	4

Southeast Division, Summer

Temperature	Very Cool	Cool	Normal	Warm	Very Warm
1951-2000	1	3	32	11	3
A2: 2000-2049	0	0	7	13	30
B1: 2000-2049	0	0	6	20	24
A2: 2050-2099	0	0	0	0	50
B1: 2050-2099	0	0	0	4	46
Precipitation	Very Dry	Dry	Normal	Wet	Very Wet
1951-2000	0	7	35	8	0
A2: 2000-2049	2	8	26	13	1
B1: 2000-2049	1	9	31	6	3
A2: 2050-2099	7	9	27	6	1
B1: 2050-2099	3	6	29	10	2

Northwest Division, Winter

Temperature	Very Cool	Cool	Normal	Warm	Very Warm
1951-2000	0	0	41	7	1
A2: 2000-2049	0	0	33	13	4
B1: 2000-2049	0	0	26	16	8
A2: 2050-2099	0	0	6	18	26
B1: 2050-2099	0	0	14	20	16

Precipitation	Very Dry	Dry	Normal	Wet	Very Wet
1951-2000	0	7	36	5	1
A2: 2000-2049	0	6	38	5	1
B1: 2000-2049	0	3	33	9	5
A2: 2050-2099	0	2	27	13	8
B1: 2050-2099	0	1	38	8	3

Northeast Division, Winter

Temperature	Very Cool	Cool	Normal	Warm	Very Warm
1951-2000	1	7	33	7	1
A2: 2000-2049	0	1	23	19	7
B1: 2000-2049	0	3	17	17	13
A2: 2050-2099	0	0	1	9	40
B1: 2050-2099	0	0	6	17	27

Precipitation	Very Dry	Dry	Normal	Wet	Very Wet
1951-2000	1	7	34	5	2
A2: 2000-2049	0	7	38	5	0
B1: 2000-2049	0	5	32	9	4
A2: 2050-2099	0	2	28	11	9
B1: 2050-2099	0	7	28	13	2

Southwest Division, Winter

Temperature	Very Cool	Cool	Normal	Warm	Very Warm
1951-2000	0	9	30	10	1
A2: 2000-2049	0	1	28	17	4
B1: 2000-2049	0	3	24	18	5
A2: 2050-2099	0	0	7	19	24
B1: 2050-2099	0	0	12	27	11

Precipitation	Very Dry	Dry	Normal	Wet	Very Wet
1951-2000	0	9	32	6	3
A2: 2000-2049	0	2	32	9	7
B1: 2000-2049	0	2	32	12	4
A2: 2050-2099	0	2	23	15	10
B1: 2050-2099	0	3	35	9	3

Southeast Division, Winter

Temperature	Very Cool	Cool	Normal	Warm	Very Warm
1951-2000	0	9	31	8	1
A2: 2000-2049	0	1	26	18	5
B1: 2000-2049	0	3	21	18	8
A2: 2050-2099	0	0	4	16	30
B1: 2050-2099	0	0	11	22	17

Precipitation	Very Dry	Dry	Normal	Wet	Very Wet
1951-2000	0	9	31	7	2
A2: 2000-2049	0	5	32	9	4
B1: 2000-2049	0	1	36	10	3
A2: 2050-2099	0	1	28	9	12
B1: 2050-2099	0	2	37	9	2

Conclusions drawn from these tables include:

- The models, after removing the bias, reproduce the 20th century temperature and precipitation regimes as the second half of the century is well known to have been slightly warmer and wetter.
- The summer temperatures in the 21st century, especially in the last half, are projected to be much warmer for all divisions with most of the summer seasons being in the 20th century category of very warm.
- The winter temperature also are projected to be warmer but not to the degree of summer temperatures.
- Precipitation will not change to the degree that temperature changes; the changes are toward slightly wetter conditions but not significantly so.
- The largest changes in both temperature and precipitation occur in the second half of the current century.
- The combination of much high temperatures and little change in precipitation imply that summers will be much drier than was experienced in the 20th century leading to a reduction in lake volume and stream flow and an increase in moisture stress for plants.

Daily Data Analyses

The GFDL CM2.1 daily data are for the period 1961 through 2099. Daily time series of maximum temperature, minimum temperature, and precipitation were acquired for the A2 and the B1 scenarios. The total time period was divided into segments: 1961-2000, 2000-49, and 2050-99. Within each time segment and each scenario, time series of the maximum temperature each year, the minimum temperature each year, and maximum daily precipitation each year were extracted. The GEV distribution was fit to each of the 18 time series. It is necessary to express the results as changes rather than absolute values because the input data from the models are biased. In Tables 1 and 2, the 24 hour, 10 year and 100 year return period maximum daily precipitation for the A2 and B1 scenarios are presented. But it is clear that the absolute values for the 1961-2000 base period are underestimates by nearly 50 per cent. Thus it is necessary to focus attention on the per cent increases, which range from about 1 per cent for the B1 10 year return period to about 24 per cent for the B1 100 year return period.

Table 1
24 Hour, 10 Year Return Period

Period	A2 GEV	Per Cent Increase	B1 GEV	Per Cent Increase
1961-2000	49.5		49.5	
2001-2050	55.7	11.1	49.8	0.6
2051-2100	59.8	17.2	54.4	9.0

Table 2
24 Hour, 100 Year Return Period

Period	A2 GEV	Per Cent Increase	B1 GEV	Per Cent Increase
1961-2000	64.9		64.9	
2001-2050	70.3	7.7	66.8	2.9
2051-2100	80.3	19.2	85.4	24.0

Tables 3 and 4 and Tables 5 and 6 present similar information for annual maximum temperature and annual minimum temperature respectively. Once again the absolute values are biased estimates and focus should be on the differences.

Table 3
Annual Maximum Temperature, 10 Year Return Period

Period	A2 GEV	Increase	B1 GEV	Increase
1961-2000	42.4		42.4	
2001-2050	45.5	3.1	46.0	3.6
2051-2100	51.7	9.3	48.1	5.7

Table 4
Annual Maximum Temperature, 100 Year Return Period

Period	A2 GEV	Increase	B1 GEV	Increase
1961-2000	45.6		45.6	
2001-2050	51.2	5.7	47.8	2.2
2051-2100	53.6	8.1	51.5	5.9

Table 5
Annual Minimum Temperature, 10 Year Return Period

Period	A2 GEV	Increase	B1 GEV	Increase
1961-2000	-38.9		-38.9	
2001-2050	-36.9	2.0	-39.6	-0.7
2051-2100	-32.4	6.5	-34.7	4.2

Table 6
Annual Minimum Temperature, 100 Year Return Period

Period	A2 GEV	Increase	B1 GEV	Increase
1961-2000	-43.3		-43.3	
2001-2050	-40.5	2.8	-45.3	-2.0
2051-2100	-36.7	6.6	-37.1	6.2

An approximation of the absolute values can be obtained by applying the changes in the tables above to observed data for the Twin Cities. The full 20th century records for annual maximum temperature, annual minimum temperature, and annual daily precipitation were analyzed by fitting the GEV to the appropriate annual time series. The differences were then applied to the results for the observed 20th century climate (Tables 7, 8, and 9).

Table 7
Annual Maximum Temperature

	10 Year Return Period		100 Year Return Period	
	A2	B1	A2	B1
20th Cent.	38.9	38.9	41.1	41.1
2001-2050	42.0	42.5	46.8	43.3
2051-2100	48.2	44.6	49.2	47.0

Table 8
Annual Minimum Temperature

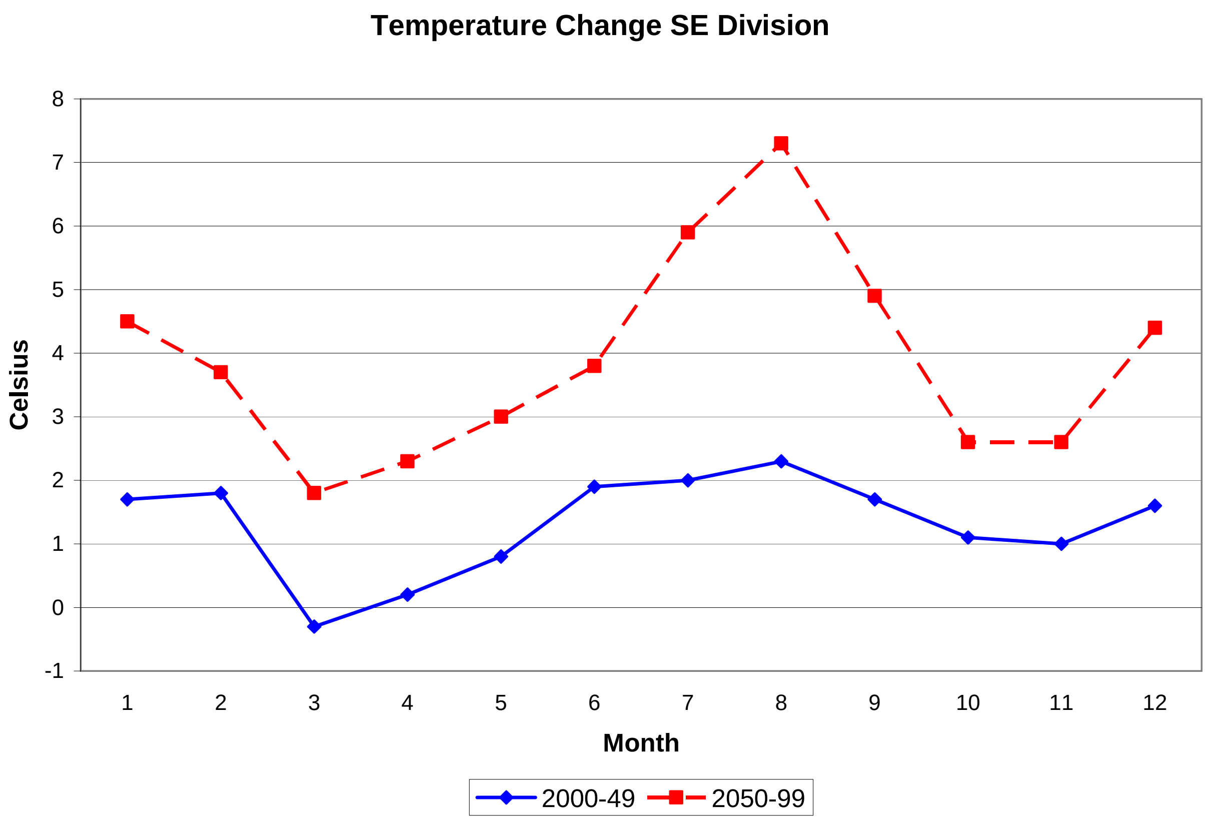
	10 Year Return Period		100 Year Return Period	
	A2	B1	A2	B1
20th Cent.	-34.2	-34.2	-36.8	-36.8
2001-2050	-32.2	-34.9	-34.0	-38.8
2051-2100	-27.2	-30.0	-30.2	-30.6

Table 9
Annual Maximum Precipitation

	10 Year Return Period		100 Year Return Period	
	A2	B1	A2	B1
20th Cent.	87.9	87.9	155.5	155.5
2001-2050	97.7	88.4	167.5	160.0
2051-2100	103.0	95.8	185.4	192.8

Summary

The broad outlines of the likely climate of Minnesota over the remainder the 21st century as projected by a particular GCM (GFDL CM2.1) seem relatively clear. The temperature will be warmer especially in the second half of the century and the late summer and winter. Precipitation will increase marginally except in the late summer. The combined temperature and precipitation changes likely will lead to decreases in available soil moisture and a general drying of the climate. The magnitude of maximum temperature extremes will increase while the coldest days are likely to be warmer. Precipitation in extreme events such as the 100 year storm will be larger.


Temperature Change SE Division
Celsius
Month
-1
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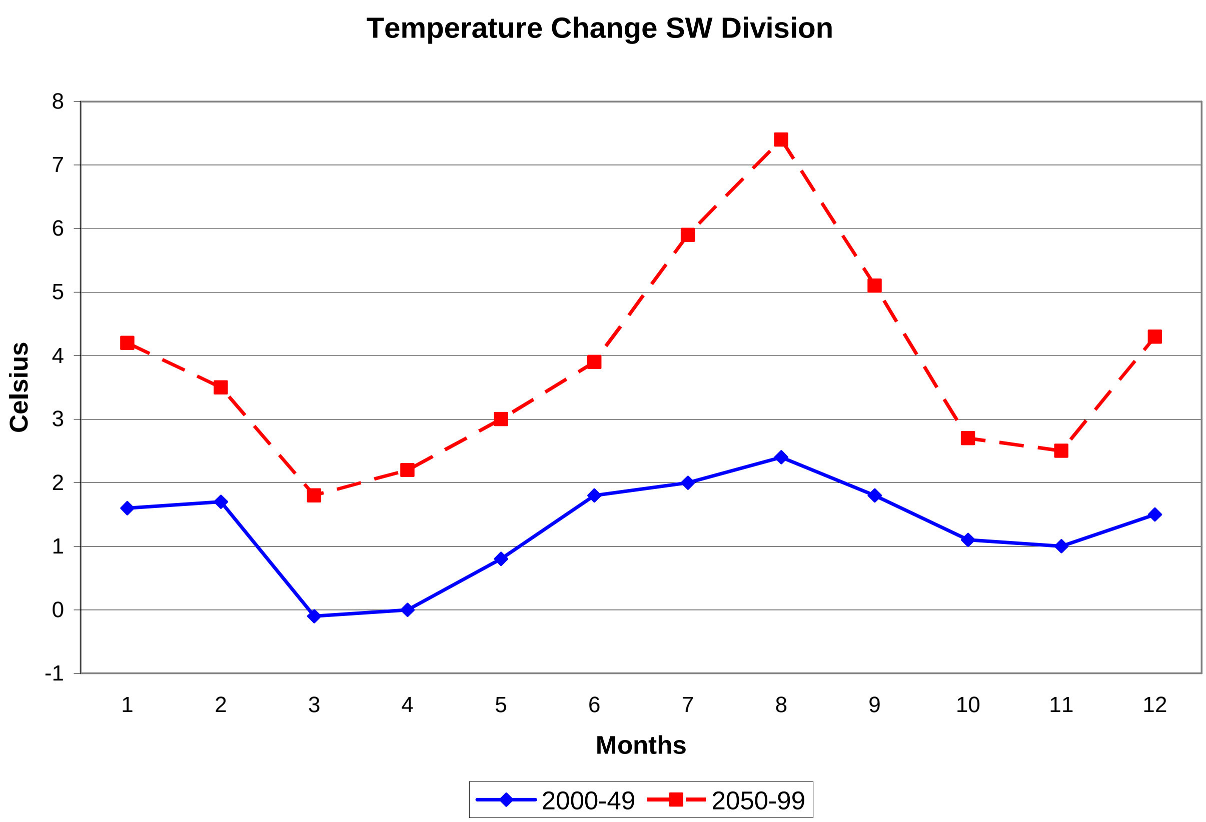
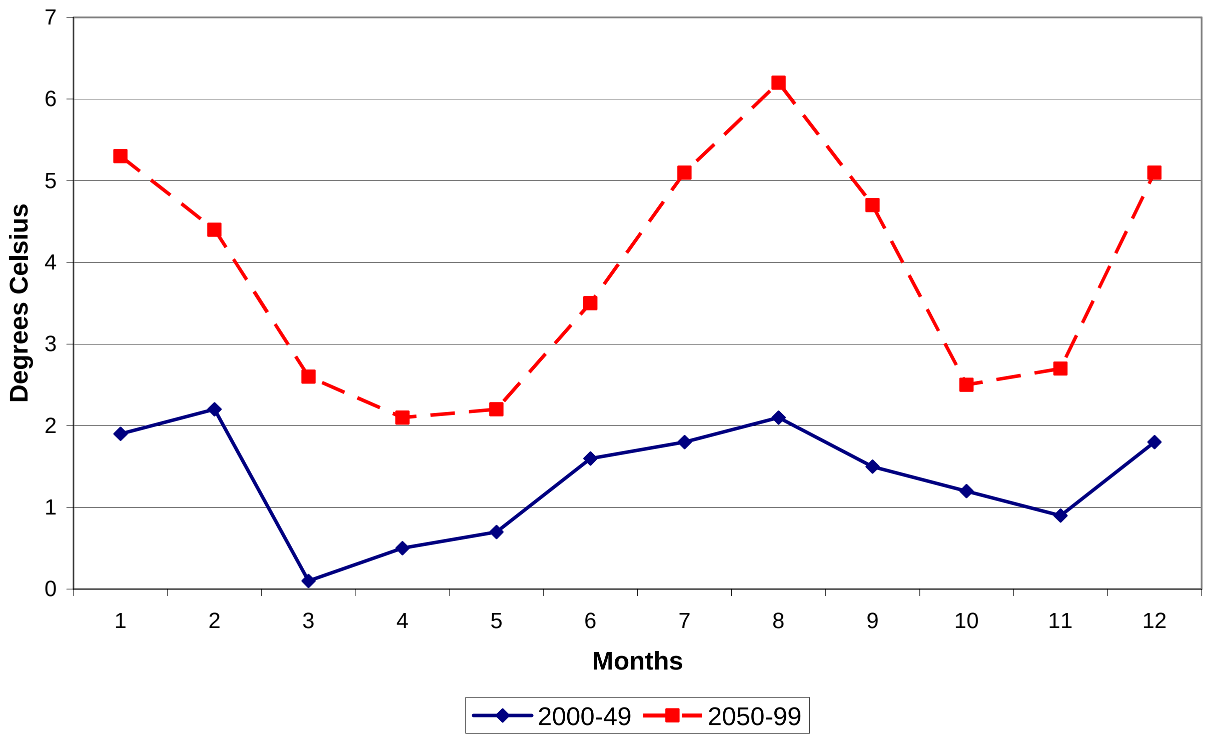
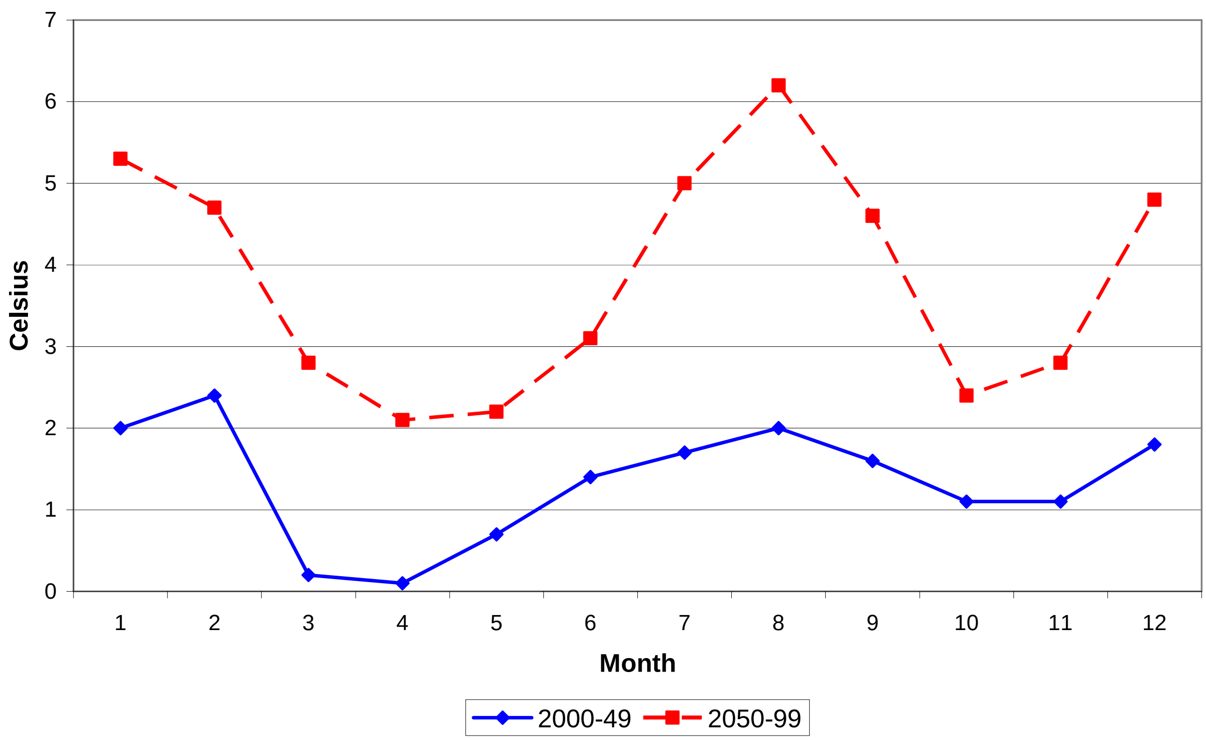
12
2000-49
2050-99


Temperature Change SW Division
Celsius
Months
-1
0
1
2
3
4
5
6
7
8
1
2
3
4
5
6
7
8
9
10
11
12
2000-49
2050-99

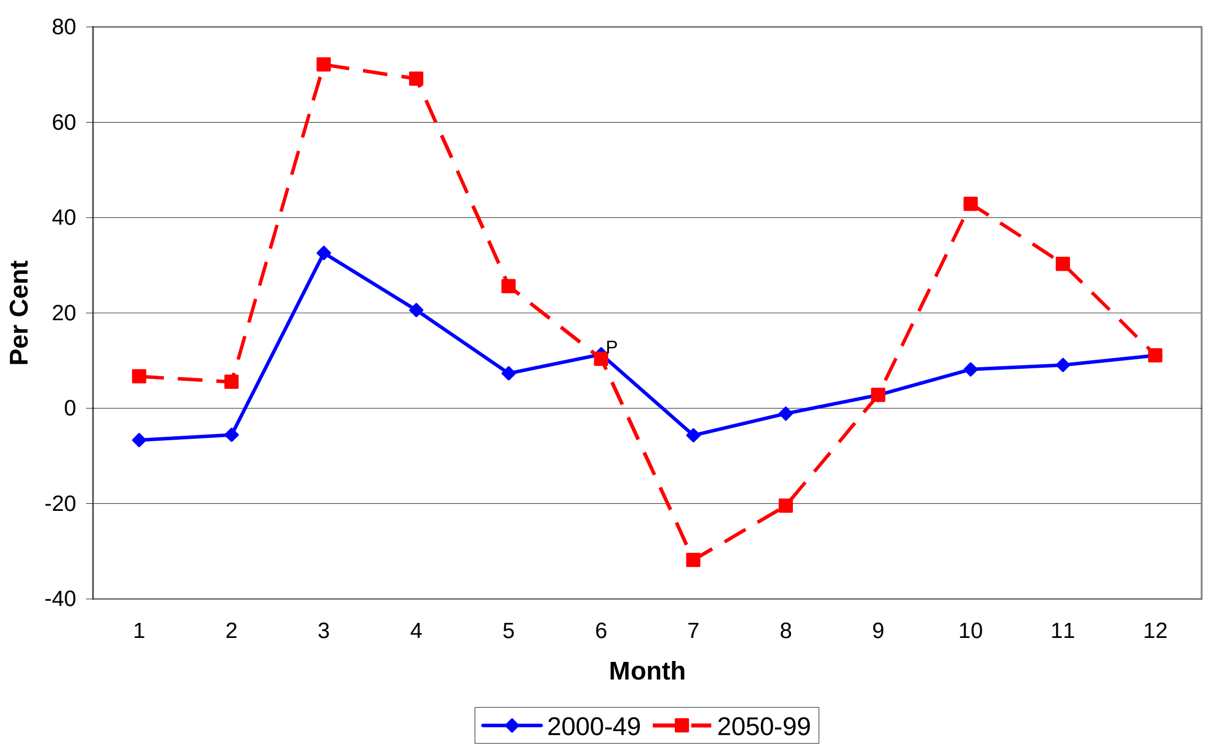
Temperature Change NW Division



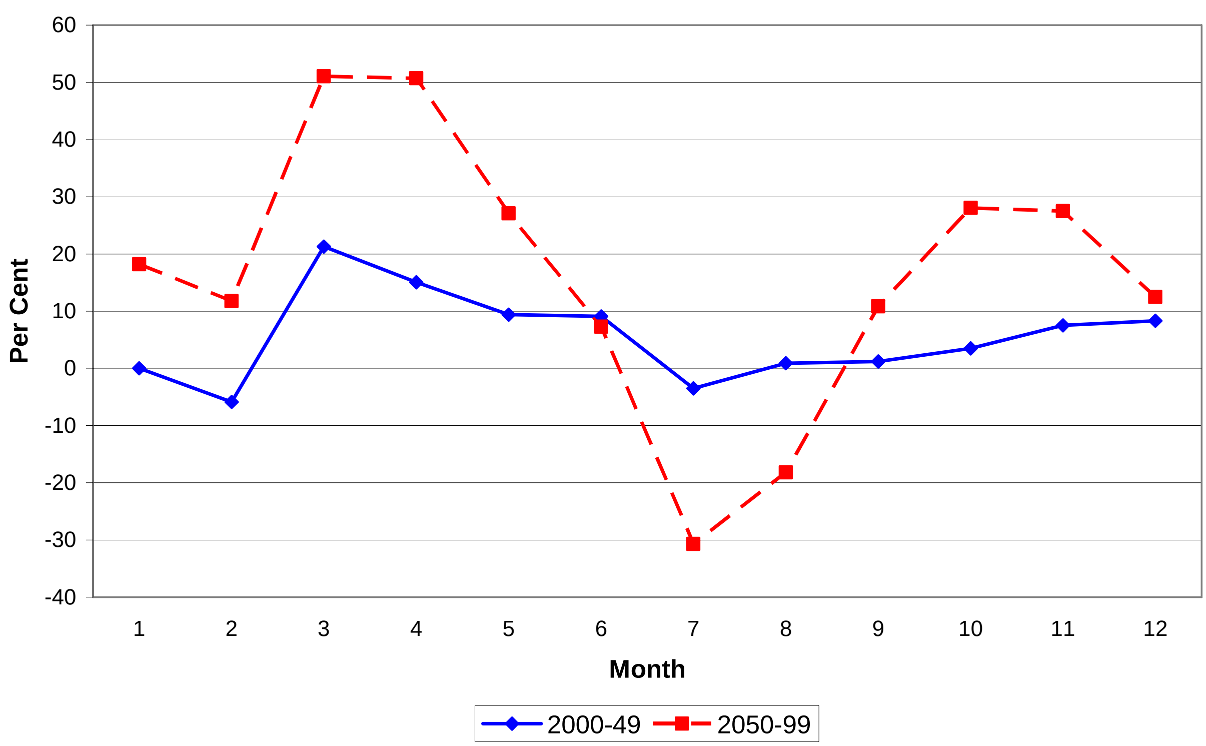
Temperature Change NE Division

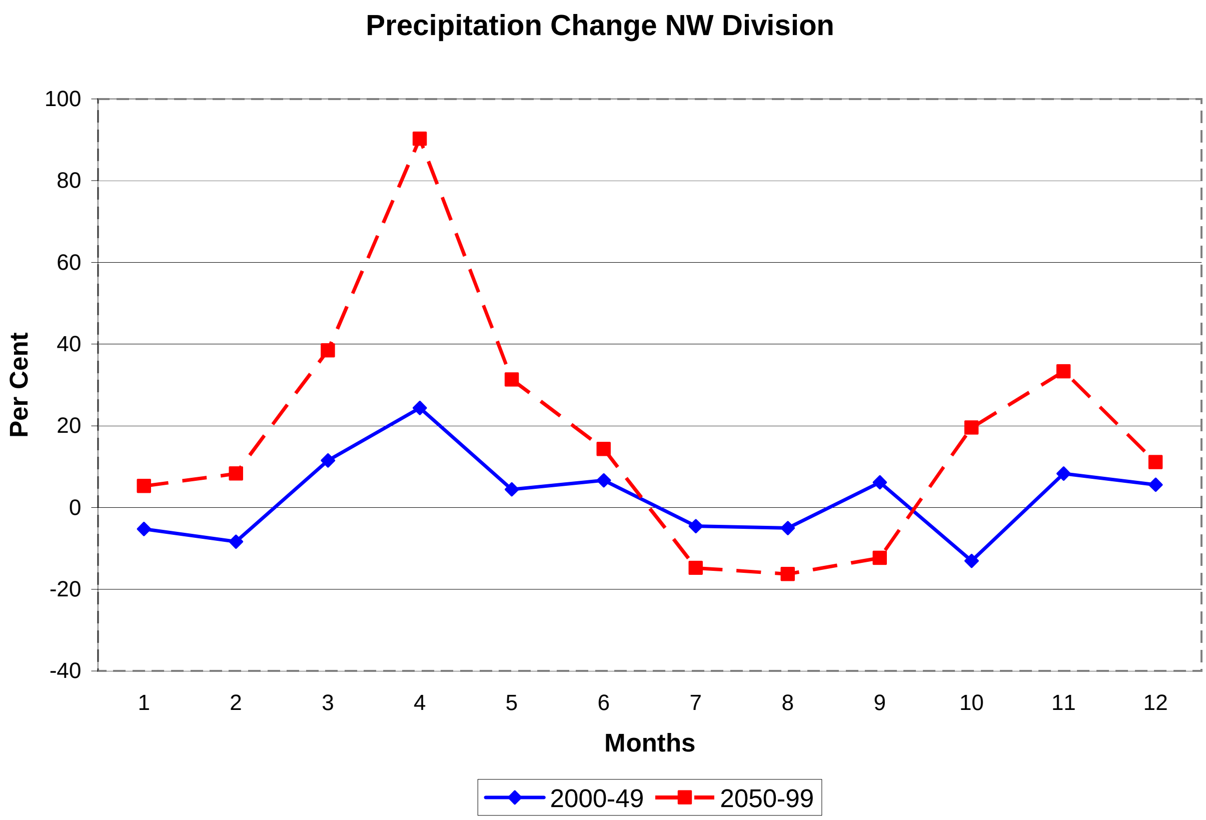


Precipitation Change SW Division



Precipitation Change SE Division




Precipitation Change NW Division
Per Cent
100
80
60
40
20
0
-20
-40
1
2
3
4
5
6
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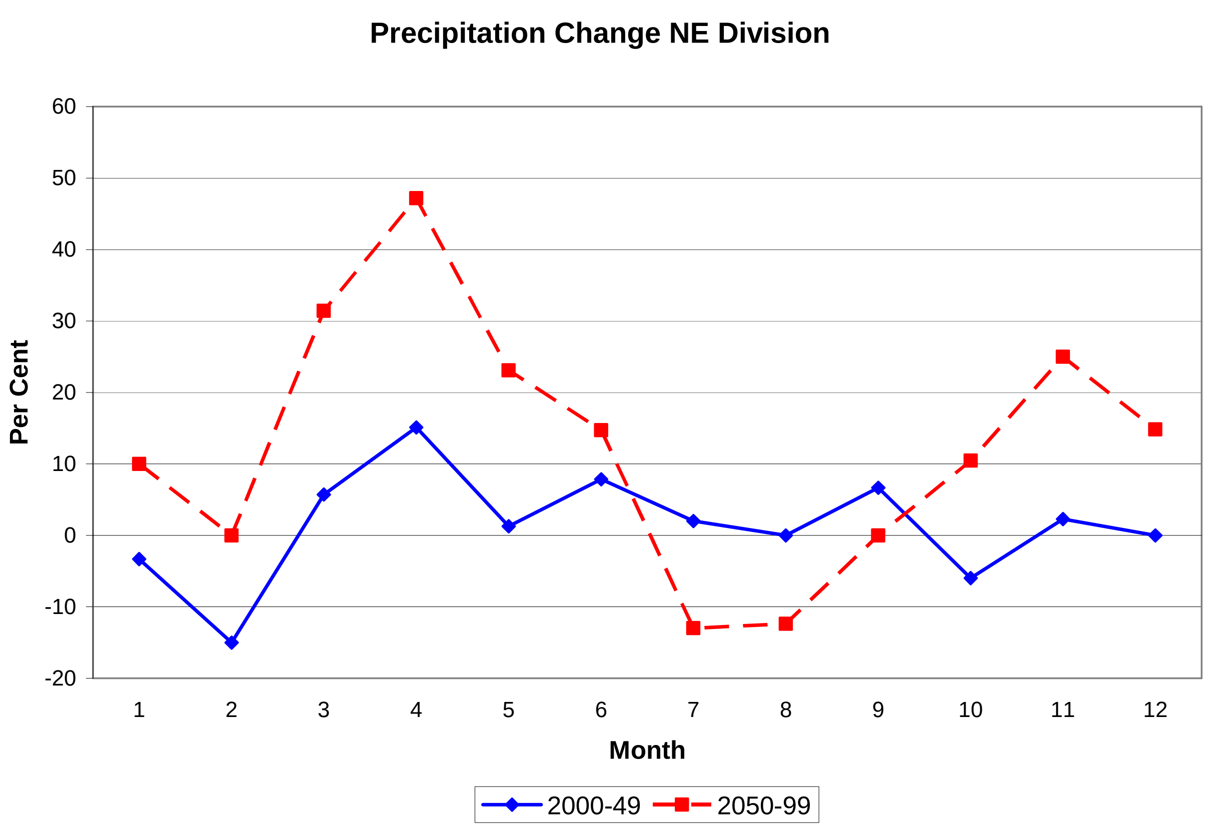
8
9
10
11
12
Months
2000-49
2050-99


Precipitation Change NE Division
Per Cent
60
50
40
30
20
10
0
-10
-20
1
2
3
4
5
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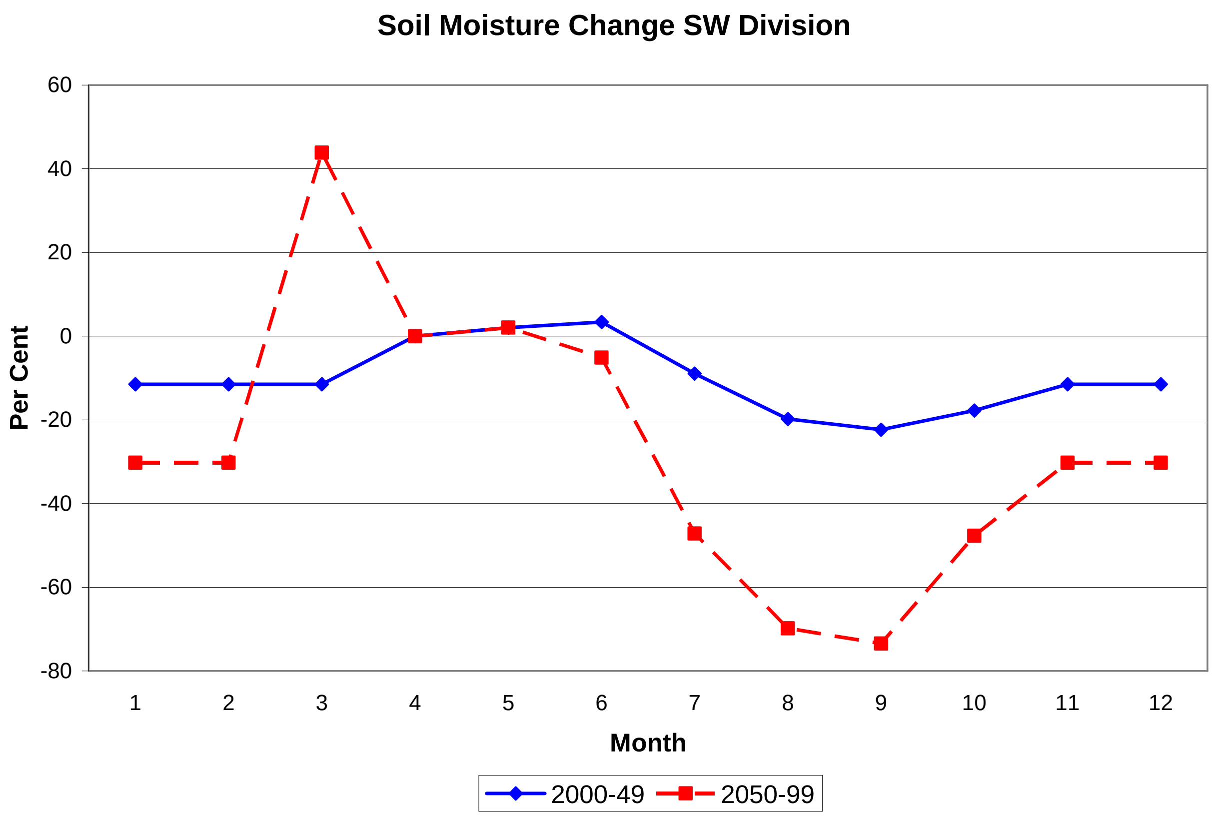
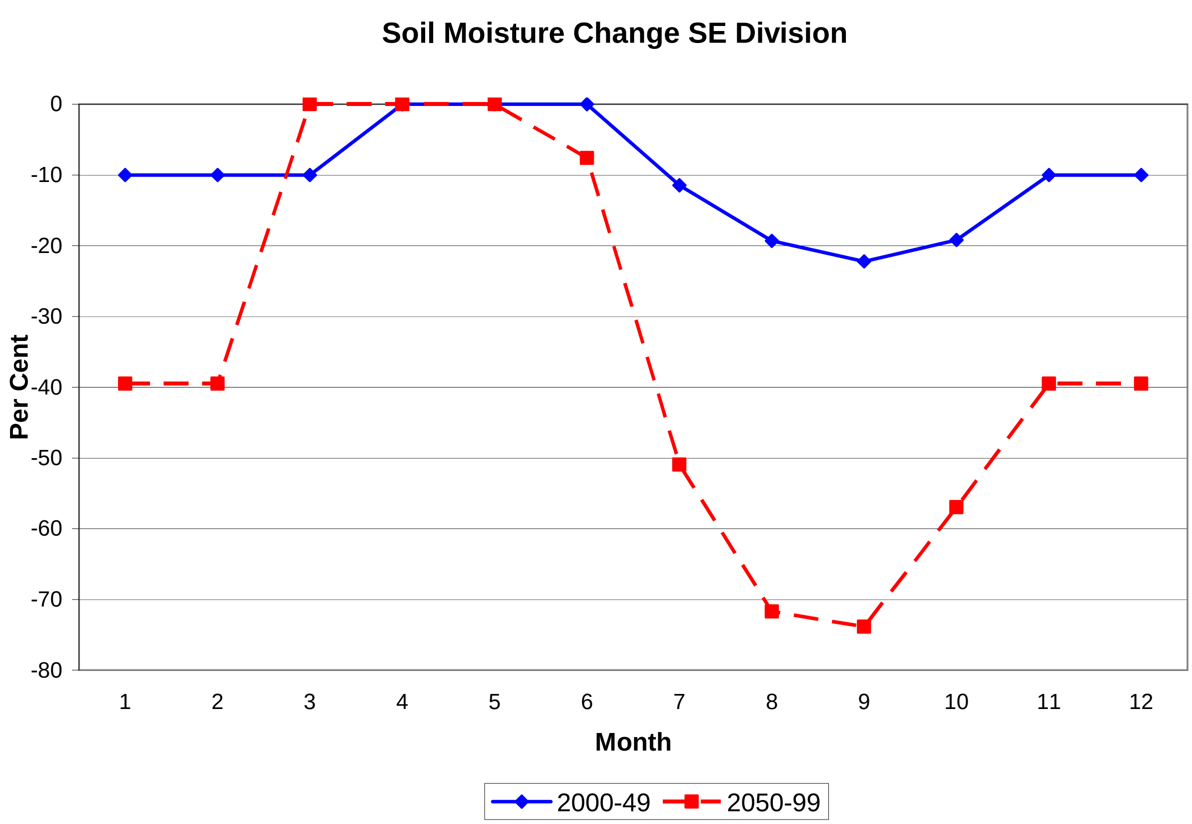
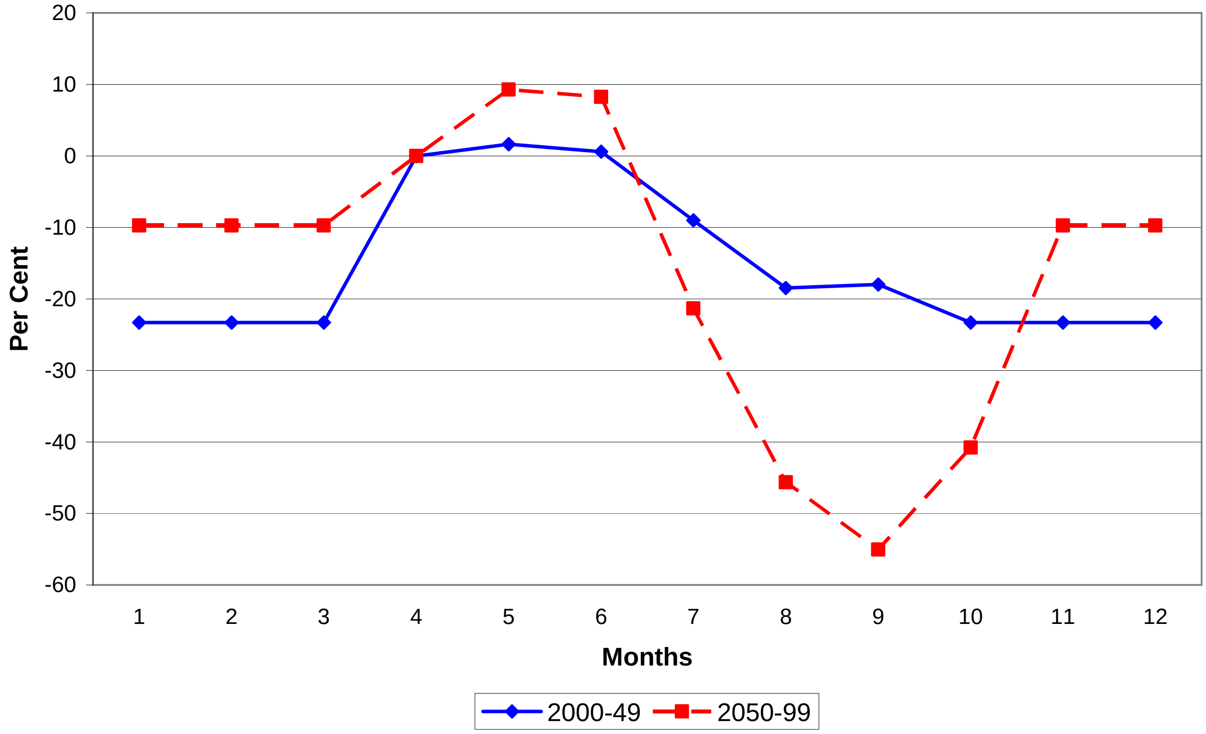
7
8
9
10
11
12
Month
2000-49
2050-99

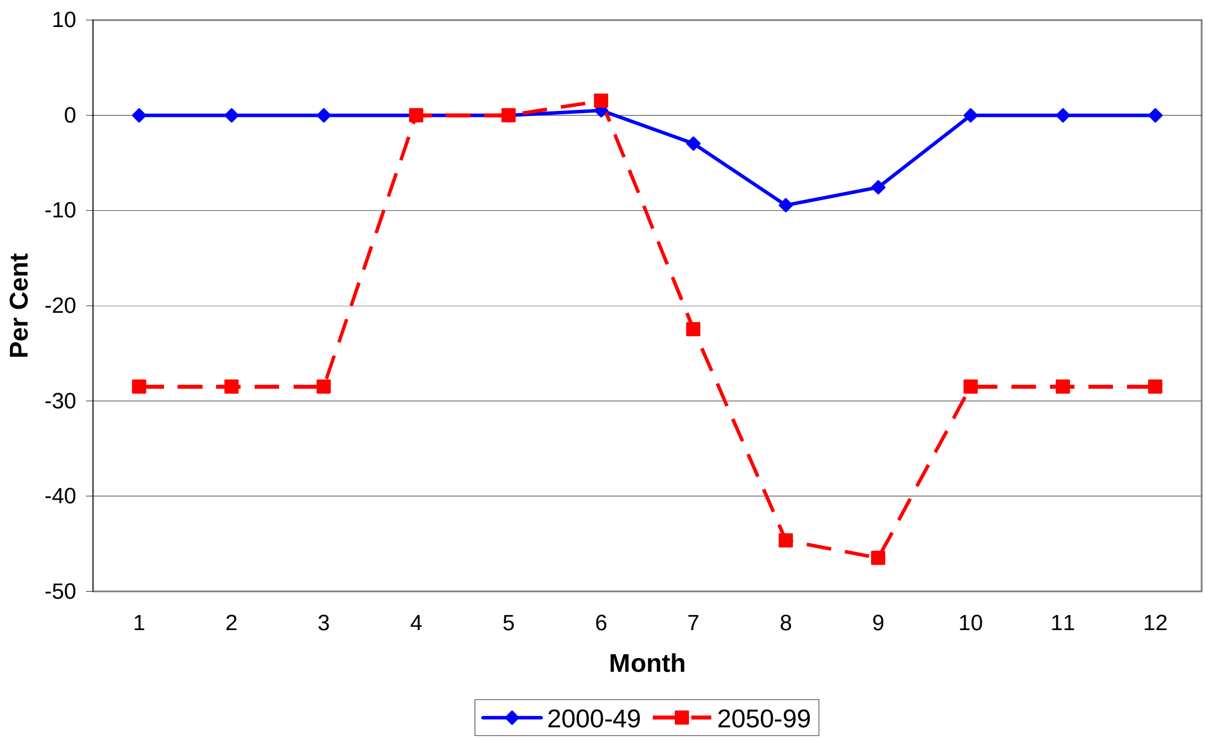

Soil Moisture Change SW Division
60
40
20
0
-20
-40
-60
-80
Per Cent
1
2
3
4
5
6
7
8
9
10
11
12
Month
2000-49
2050-99


Soil Moisture Change SE Division
0
-10
-20
-30
-40
-50
-60
-70
-80
Per Cent
1
2
3
4
5
6
7
8
9
10
11
12
Month
2000-49
2050-99

Soil Moisture Change NW Division



Soil Moisture Change NE Division



Ice-out timing trend analysis for Minnesota lakes 1948-2008

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[3] Metropolitan State University

Data from 71 lakes in MN were used to show trends in both observed and modeled ice out dates (in day-of-year format with Jan 1 = 1). [One observation for Isle Lake (DOW 270040) in 1991 was dropped as a suspected data entry error; it listed ice out day as 460.] To account for repeated measures of lakes over time and correlated annual variation in ice out date among lakes, we used a mixed model (Venables & Ripley,2002) to estimate the temporal trend in ice out date using the *lmer* function from the lme4 package in version 2.8.1 of the R statistical program (R Development Core Team, 2008).

Methods: The model contained fixed intercept and trend parameters in addition to 2 random effects representing a lake-specific intercept and within-year correlations in ice out date:

$$IO_{ij} = \beta_0 + \beta_1 * j + \lambda_i + \psi_j + \varepsilon_{ij}$$

where IO_{ij} was ice out date for the i^{th} lake (i = 1,…, 72) in year j (j = 0,…, 61 representing the years 1948-2008). The fixed intercept and trend parameters, β_0 and β_1 described the overall change in ice out date for the group of lakes. For inference on statewide changes in ice out date, β_1 was the parameter of interest ;i.e., this parameter represented the yearly change in ice out date for the 'population' of lakes in this data set. Since the year data were shifted by subtracting 1948, the intercept parameter, β_0, represented the average ice out date for the lakes in 1948 (excluding the random year effect).

The lake-specific adjustment for the i^{th} lake, λ_i, was assumed to be distributed N(0, σ_L); for model fitting purposes, the only parameter to be estimated concerning the random lake effects is σ_L, though we can get unbiased predictors for the individual λ_i's (usually denoted as BLUPs for 'best linear unbiased predictor').. The λ_i's account for correlations among observed ice out dates for a single lake over time (e.g., a more northerly lake will tend to have a later ice out date); the σ_L parameter represents the variability in ice out date among lakes in the data set. The effect of the j^{th} year, ψ_j, accounts for correlations among lake in ice out date within a single year (e.g., all lakes statewide have early ice out dates because of a particularly early spring) and was assumed to be distributed as N(0, σ_Y); the σ_Y parameter describes the variability in average ice out date among years. We used the ψ_j BLUPs for inference on yearly deviations in ice out date from the long-term fixed trend.

The model was fit with the observed and modeled data separately, both models had practically identical trend estimates and very similar variance estimates as the model fit to the full data set, confirming no differences between the observed and modeled ice out data; all results shown below reflect the full data set with observed and modeled data combined.

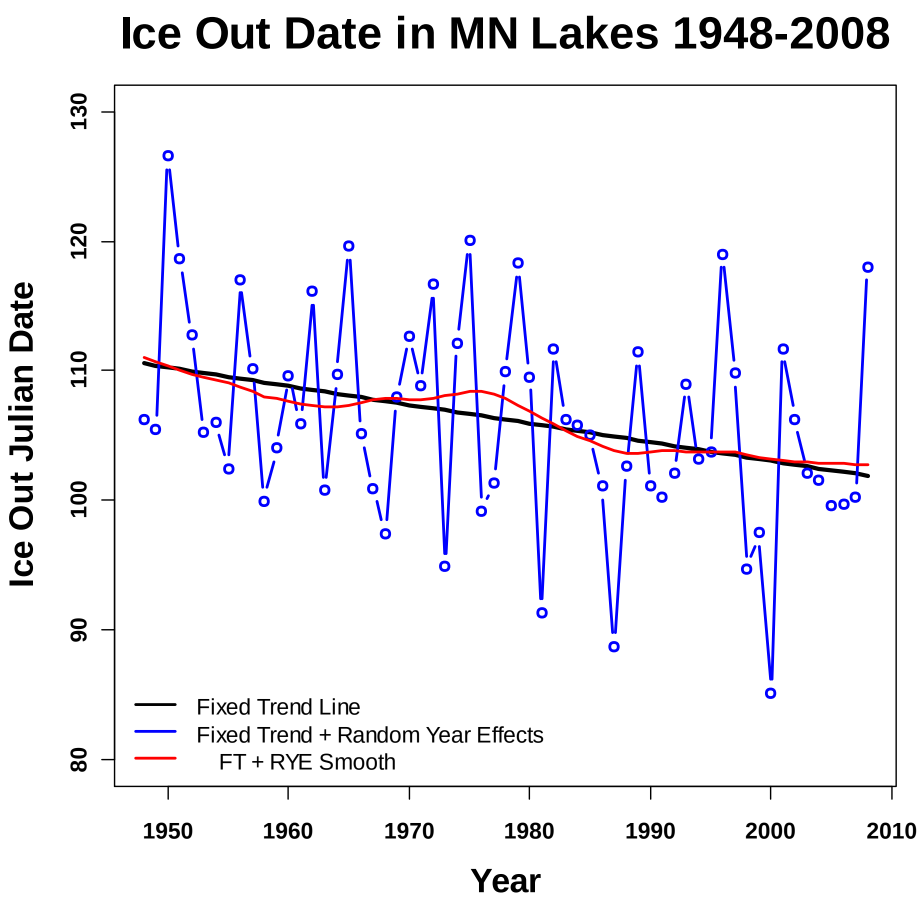
Results: There was a significantly negative estimate of the fixed trend in ice out date; ice out dates were 1.44 days earlier per decade (see Ice Out Date.. Figure). The average ice out date, excluding random year effects, for the earliest measurements (1948-1950) was approximately the 111th day of the year.

There was large deviation from the fixed trend among years in ice out date (σ_Y = 7.6 days). Over time, the year effects show a consistent up & down pattern, with more extreme early ice out events happening in recent years. In addition to the variation among lakes and years, in some years there was an inconsistent geographical split in how the observed ice-out date differed from the predicted date. For example, ice-out was earlier than predicted in the southern parts of MN for 1966, 1987, and 2007, while later than predicted in northern parts of Minnesota for those same years. The reverse occurred in 1951, 1952, and 1993, when ice-out was later than predicted in the southern regions and earlier than predicted in the northern regions.

There was large variation among lakes (σ_L = 7.29 days) which represent the large variation in climate and lake morphologies across the state; however, when compared to spatial location (UTM coordinates) there did not appear to be a spatial pattern in the random lake effects.

There was a slight trend in model residuals versus UTM northing coordinates, more southerly points tended to ice out earlier than predicted and northerly points tended to be a little later than predicted. When a centered UTM northing variable was added to the mixed model, the North-South predictor variable was highly significant: going North 1 km makes ice out tend to be .06 days later. Although the variation among lakes is decreased in this model (much of the random lake effects in the above model likely reflected latitudinal differences in ice out date), the estimated fixed trend in ice-out date is nearly identical to the original model which did not include UTM northing (-0.1448 here, -0.1441 in the previous model).

Figure X: The fixed ice-out trend and year effects (added to show the annual deviations about the trend), in additional to a smooth fit of the trend plus year effects.



Random effects:		
Groups Name	Variance	Std.Dev.
Lakename (Intercept)	53.191	7.2932[a]
year (Intercept)	57.782	7.6015[b]
Residual	13.102	3.6196[c]
Number of obs: 4334, groups: Lakename, 72; year, 61		

[a] Std. Dev is among-lake variation in the mean ice-out date
$\sigma_L = 7.29$
[b] Std. Dev is among year variation in mean ice-out date
$\sigma_Y = 7.6$
[c] Residual Std. Dev = 3.6
[d] Estimated fixed trend in ice out date = - 0.14

Fixed effects:			
	Estimate	Std. Error	t value
(Intercept)	110.5514	2.15268	51.36
yr	- 0.14411d	0.05536	-2.6

Figure XXX. Spatial distribution of random lake effect BLUPs on ice out date. Blue points represent lakes that tend to ice out the earliest, red points are lakes that tend to ice out latest.

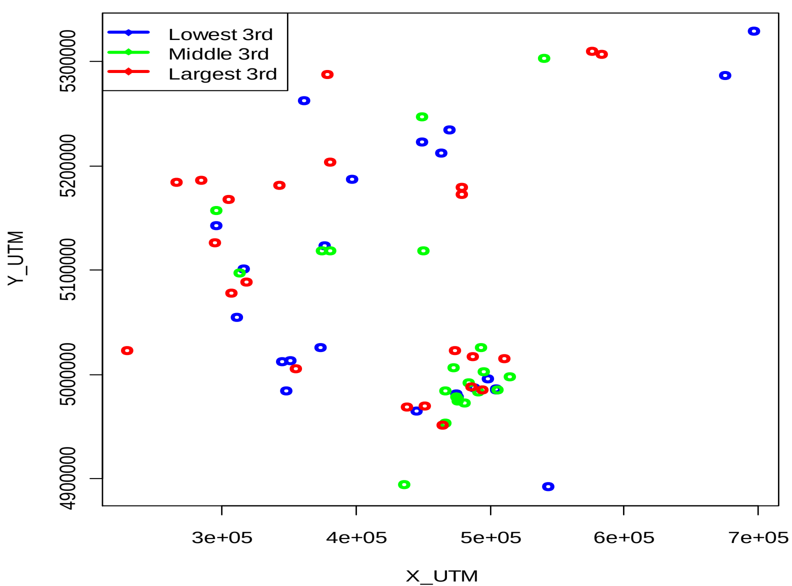


Figure XXX. Random lake effect BLUPs versus $\log_e$ lake area and maximum depth.

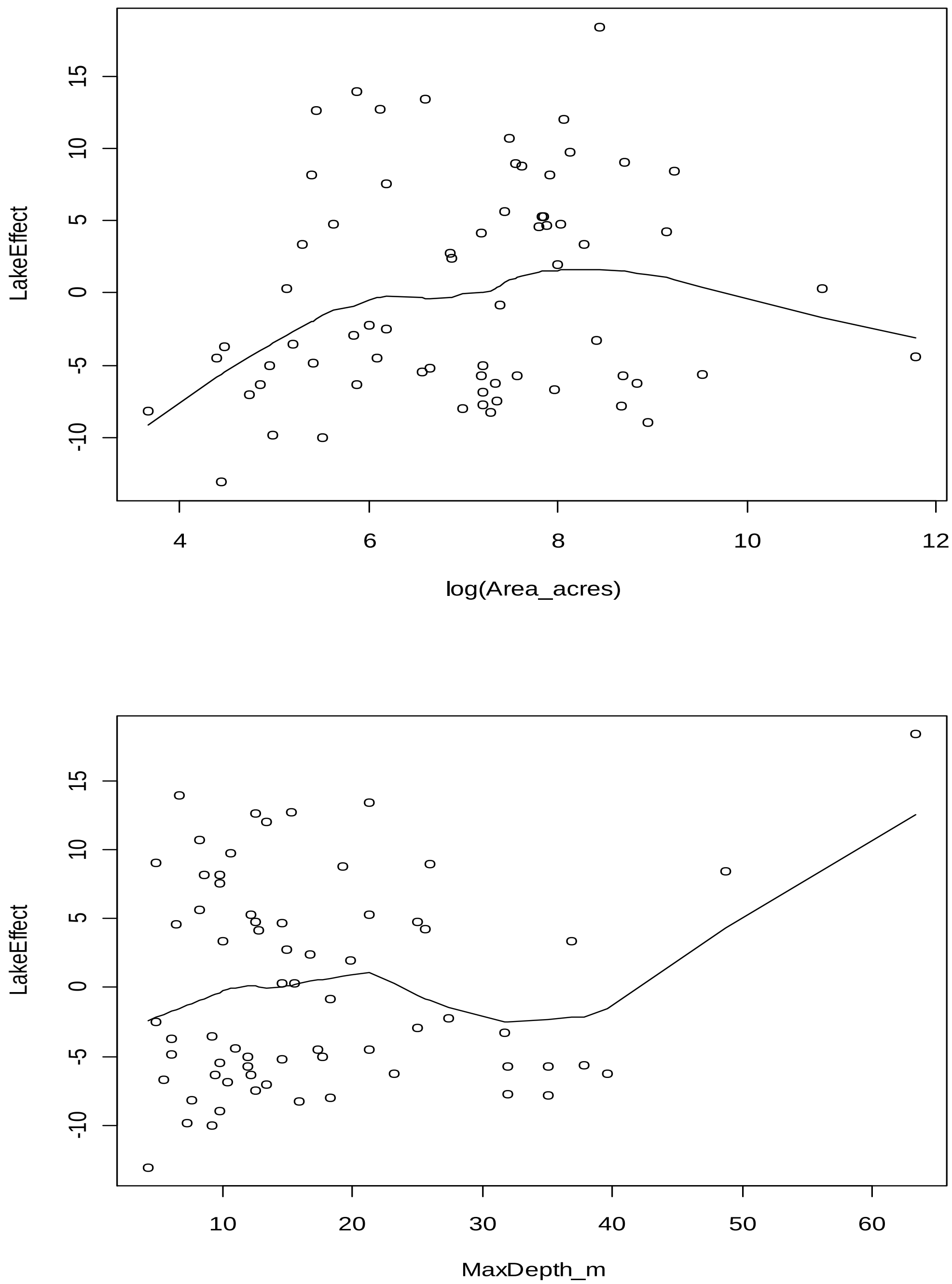


Figure XXX. Mixed model residuals versus year. Note bimodal residual distributions for some years (e.g., 1966 and 1987).

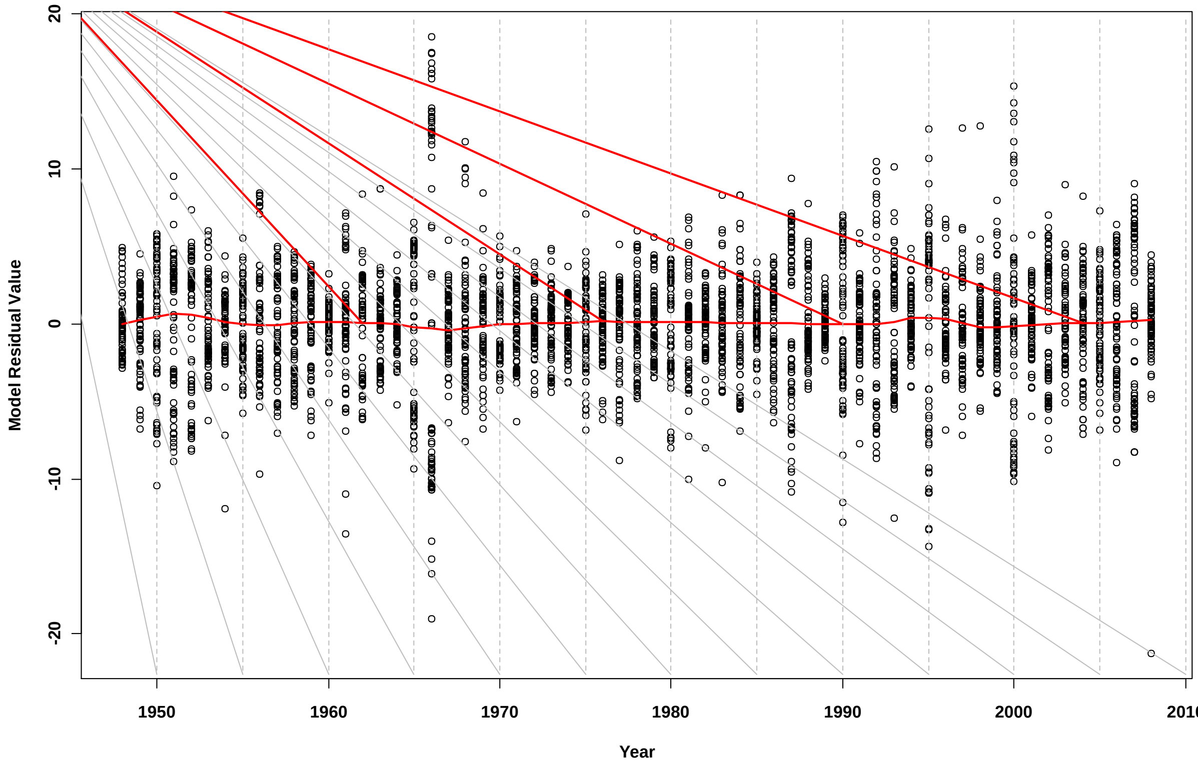
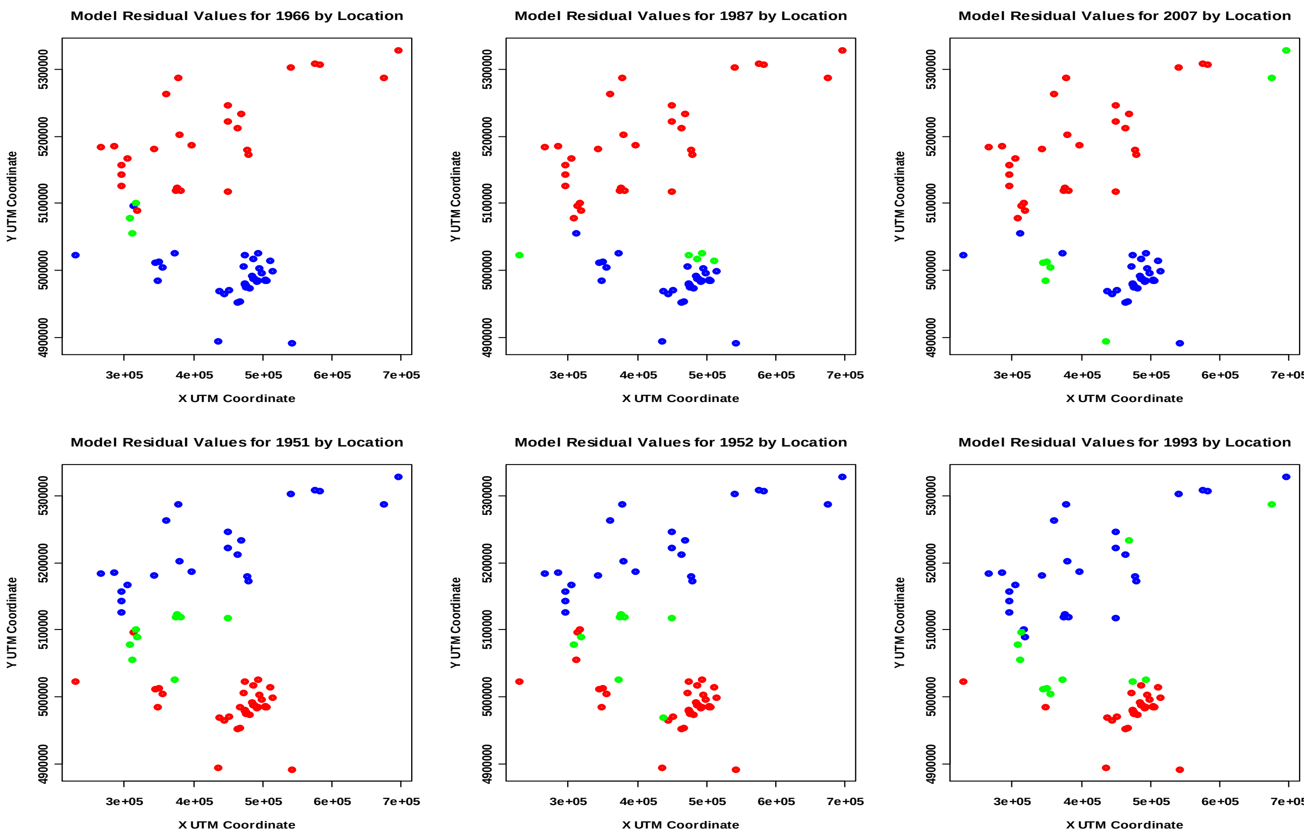


Figure XXX. Spatial plots of model residuals for selected year. There is a spatial split in those years with bimodal residuals; however, the pattern is not consistent. In figure below, ice out was earlier than predicted in the southern parts of MN for 1966, 1987, and 2007. In contrast, ice out in the years 1951, 1952, and 1993 was later than predicted in the southern region.



Blue- Ice out was earlier than predicted; Red- Ice out later than predicted; Green- Ice out with 2 days of predicted

When Y coordinate (UTM) added to the mixed model:

Random effects:		
Groups Name	Variance	Std.Dev.
Lakename (Intercept)	4.9786	2.2313
year (Intercept)	57.601	7.5895
Residual	13.2144	3.6352
Number of obs: 4029, groups: Lakename, 67; year 61		

Fixed effects:		
Estimate	Std. Error	t value
(Intercept) 98.77641	1.99455	49.52
yr -0.14483	0.05528	-2.62
Y_UTM 0.06119	0.00243	25.18

Correlation of Fixed Effects		
	(Intr)	yr
yr	-0.831	
Y_UTM	-0.228	0

The results from the lake ice-out trend analysis are included in a presentation along with the lake surface water trend analyses (see Appendix F.)

UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

Project Report No. 543

Annual Stream Runoff and Climate in Minnesota's River Basins

by

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and

Heinz G. Stefan

September 2010
Minneapolis, Minnesota

ABSTRACT

Stream flows recorded by the USGS from 1946 to 2005 at 42 gauging stations in the five major river basins of Minnesota and tributaries from neighboring states were analyzed and related to associated climate data. Goals of the study were (1) to determine the strength of the relationships between annual and seasonal runoff and climatic variables in these river basins, (2) to make comparisons between the river basins of Minnesota, and (3) to determine trends in stream flows over time. Climatic variables were air temperature, precipitation, the Palmer Drought Severity Index (PDSI), and the Palmer Hydrological Drought Index (PHDI); the latter are common indices of soil moisture. Water year averages showed stronger correlations than calendar year averages. Precipitation was a good predictor of stream flow, but the PDSI was the best predictor and slightly better than PHDI when linear regressions at the annual timescale were used. With an exponential regression PDSI gave a significantly better fit to runoff data than PHDI. Five-year running averages made precipitation almost as good a predictor of stream flow (runoff) as PDSI.

A seasonal time scale analysis revealed a logical stronger dependence of stream flow on precipitation during summer and fall than during the winter and spring, but all relationships for seasonal averages were weaker than for annual (water year) averages. Dependence of stream runoff on PDSI did not vary significantly by season.

On a monthly timescale the strength of correlation between precipitation and runoff dropped off significantly, while PDSI was still a decent predictor in all months but the spring.

Annual stream flow in the Upper Mississippi River Basin, including the Minnesota River Basin, had the strongest dependence on precipitation and PDSI. The Red River of the North Basin showed lower than average dependence on precipitation and average dependence on PDSI.

The Rainy River Basin and the Lake Superior Basin showed the weakest dependence of annual stream flow on precipitation and PDSI.

The relationship between stream flow and precipitation can be expressed most easily by an annual average runoff coefficient, i.e. the ratio of runoff to precipitation in a year. Runoff coefficients vary significantly across the state of Minnesota, from more than 0.4 in the northeast to less than 0.1 in the northwest. Trends in runoff coefficients were estimated from averages for 20-year periods from 1926-1945 to 1986-2005, although data for 1926-1945 were sparse. According to our analysis, runoff coefficients in some of the major river basins of Minnesota have increased significantly during the last 40 years.

The Lake Superior and Rainy River Basins have high and invariant characteristic runoff coefficients around 0.35. The Red River Basin has the lowest characteristic runoff coefficient at ~0.14 but its value has consistently increased from the beginning of the record. The Mississippi Headwaters Basin characteristic runoff coefficient has increased to ~0.24. The Minnesota River Basin runoff coefficient (from the Minnesota River at Jordan, MN station) has also increased significantly and consistently to 0.19. The largest increases in runoff coefficients were found in the Red River and the Minnesota River Basins, the two basins with the lowest runoff coefficients; runoff coefficients in some tributary or sub-watersheds have doubled. In the Lake Superior and Rainy River Basins, and in the St. Croix River watershed, little change in runoff coefficients was found.

Overall runoff coefficients drop significantly from east to west in Minnesota. This distribution does not seem to have changed over time. Increases in runoff coefficients over time have been highest in the west, and lowest in the east of Minnesota. One can hypothesize that changes in stream flow in Minnesota’s west are mainly due to land use changes that have lead to faster and easier surface runoff from the land since the beginning of European settlement. An explanation based on climatological factors can, however, also be offered. Precipitation has increased in all of the river basins of Minnesota over the time period of 1926 to 2005, but the largest changes have occurred in the south and west and little change in the northeast of Minnesota.

Changes in total annual runoff (in/yr) between 1946 - 1965 and 1986 – 2005 increased at 38 of 42 stream gaging stations analyzed. Only 4 gaging stations, 3 in the Lake Superior and Rainy River Basins showed decreases, with all being less than 3%. The largest increases in average annual runoff were at 19 gaging stations in the Red River and Minnesota River Basins; at 17 of these, increases were from 60% to 132%, and at the remaining two stations the increases were 19% and 20%. The southern Minnesota watersheds with the largest increases in runoff also had the largest increases in precipitation.

Overall, stream flow, expresses as annual runoff (in/yr), has increased since the beginning of stream gaging in Minnesota and the Upper Midwest, although periods of substantially lowered stream flows have occurred, e.g. in the drought period of the 1930s. Not only has the runoff (cm/yr) increased, but runoff coefficients, i.e. the ratio of runoff to precipitation, have also increased. When viewed as a percent change of annual runoff, the largest stream flow changes have occurred in the western part and the lowest in the eastern part of Minnesota. Increases in absolute values of annual runoff, percent of runoff, and runoff coefficients have been quantified in this study.

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1. INTRODUCTION

Minnesota is the headwaters region of rivers that drain into the Gulf of Mexico, the Gulf of St. Lawrence and into Hudson Bay. Water originating in Minnesota's river basins is important not only to the state, but also to other U.S. states and Canadian provinces. Historical annual stream flow and climate data of Minnesota and its neighboring states are analyzed in this report.

Stream flow information is needed to assess water balances, to plan water supplies, to design river bank and flood protection works, to manage water quality and recreational water uses, and more. The availability of fresh water is affected by urbanization, agricultural land use changes, and global climate change; freshwater availability is of increasing concern in many regions of the world. Many cities, including several in Minnesota, get their water supply from rivers or groundwater, and discharge treated wastewater into rivers. Streams and rivers in Minnesota are also used for hydropower and recreation (e.g., boating and fishing). The Mississippi and the Minnesota River are navigable waterways. Stream flows depend on climatologic, geographic, geologic, and anthropogenic factors. Land use changes, especially urbanization and agriculture, affect the amount of rainfall that is lost to evapotranspiration and infiltration and therefore affect the amount of runoff and the time over which the runoff occurs. Urban development and agricultural drainage tends to increase runoff and leads to higher flow rates in the streams and rivers that receive the runoff. Stream flow is without doubt important to Minnesota, and analyzing and projecting stream flows is therefore of interest.

The hydrologic cycle is driven by meteorological variables, notably precipitation and evaporation. Precipitation in the form of rain and snow is the major water input for the vast majority of watersheds in the world. Air temperature affects evapotranspiration in many types of watersheds of different climate, vegetation, and land use. Changes in precipitation and air temperature can be expected to play roles in changes of stream flow.

The hydrologic cycle also responds strongly to watershed characteristics. Indices have been developed to assess the overall moisture conditions of regions on different spatial and temporal scales. Some of these indices have been created to determine when an area is experiencing drought and when it is experiencing water surplus. A well known and widely used index is the Palmer Drought Severity Index (PDSI) (Palmer 1965). The PDSI is region-specific and is based on a supply and demand model of soil moisture. PDSI is calculated based on the hydrologic characteristics of the region and on the precipitation and temperature data recorded during and preceding the time period of interest. The PDSI is centered at zero; negative numbers indicate that the region is experiencing drought and positive numbers indicate wetter than normal conditions. It is to be expected that PDSI is correlated with stream flow. Other indices such as the Palmer Hydrological Drought Index (PHDI) and the Standardized Precipitation Index (SPI) also give indications of the moisture availability of a region. Weber and Nkemdirim (1998) reviewed the PDSI and PHDI indices and recommended that PDSI be used for future hydrologic planning such as reservoir operation as it responds at least one month faster to changing moisture conditions. Their study, however, did not look at the relationship between the indices and stream flows.

There has been much speculation on the impact of global climate change on global water resources. Increases in global air temperatures are expected to create a more active hydrologic cycle, leading to more intense and larger precipitation events as well as increasing evapotranspiration rates (IPCC 2007). If strong relationships between climatic variables and stream flows can be determined from past records, the projected climatic variables can be used to estimate future stream flow rates. Kletti and Stefan (1997) attempted to model seasonal flows in three Minnesota streams using just four climatic parameters and no watershed inputs and had disappointing results, although they did obtain some decent fits (max $r^2 = 0.69$). Climate inputs from global circulation models have been used to project climate change effects on runoff (Kletti and Stefan, 1997) and water quality (Hanratty and Stefan, 1998) with differing results. Models for predicting future stream flows from historical relationships with minimal to no model input about the geology, topography, and land use of a basin could be simpler and more reliable than existing process-based hydrologic runoff models, for example the U.S. Department of Agriculture's Soil and Water Assessment Tool (SWAT) or the Army Corps of Engineers Hydrologic Modeling System (HEC-HMS). One of the objectives of this study is to look for direct relationships between flows in Minnesota's streams and rivers, and climatic variables that could be used for future modeling.

Previous studies have shown that stream flows in Minnesota's watersheds and around the United States are changing. Novotny and Stefan (2007) found that peak summer flows in gaged Minnesota streams are increasing, as are the number of high flow days and base flow rates, while spring stream flows fed by snowmelt runoff are remaining relatively constant. Dadaser-Celik and Stefan (2009) analyzed flow duration curves created with daily flow data for two time periods, 1946-1965 and 1986-2005, and found that average annual and low flows in the Minnesota, Upper Mississippi, and Red River basins have increased from mid-1900s flows. Just north of Minnesota, with a major input from the Rainy River basin, mean annual flows in the Winnipeg River have increased by 58% since 1924, due mostly to increased winter flows (St. George, 2007).

In the Great Lakes Region, between 1956 and 1988, Southern Wisconsin and mainland Michigan streams saw linearly increasing mean annual flows due to increases in fall and winter runoff, while New York and eastern Ohio streams displayed sharply increased fall flows (Johnston and Shmagin, 2008). In Indiana, there have been increases in low and medium flows but high flows have remained relatively unchanged (Kumar et al., 2009). In the Pacific Northwest the variance in annual flows has increased, mainly due to lower flows in dry years, however, 75-percentile flows have remained largely unchanged (Luce and Holden, 2009).

We are not only interested in absolute runoff values, but also in runoff coefficients. A runoff coefficient is a dimensionless ratio of the volume of runoff during a time period to the volume of precipitation over the watershed in the same time period. A runoff coefficient shows the relationship between runoff and precipitation in a watershed over a certain time period, e.g. a year. Runoff coefficients can be calculated for individual watersheds over any time period in which flow and precipitation data were measured converted to height (e.g., mm) of water over the entire. Runoff coefficients theoretically vary between 0 and 1.0 and depend on geology, topography, soils, and land use, particularly perviousness and vegetation cover within the watershed, as well as rainfall intensities. Snowfall often produces no immediate runoff, and the short-term runoff coefficient is 0; melting snow will contribute to the long-term runoff coefficient; if precipitation runs off a paved surface without losses, the runoff coefficient is 1.0. Changes in runoff coefficients for given basins with respect to time can give insight into the effects of land use or climate change that have occurred.

An objective of this study is to analyze stream flows, and to determine annual runoff coefficients for the major river basins of Minnesota. We also want to determine if, where and by how much runoff (in/yr) and runoff coefficients (-) have changed over the time that stream flow has been gaged in Minnesota.

Changes in runoff coefficients in the Upper Midwest in the past 150 years are most likely more related to the dramatic land use changes that have occurred rather than climate changes. However, historical stream flow records cover only a much shorter period of 50 to 100 years, including potentially significant climate change effects in the recent 20 years. Our analysis of runoff and runoff coefficients in Minnesota may show significant changes, but may not fully explain the causes of the observed changes, because changes in climate, land use, and water use are potential causes of stream flow changes. Only in watersheds and over time periods in which two of the three have not changed, will the cause of stream flow change be obvious. In other situations, more detailed analysis will be necessary. Brief descriptions of the major river basins and the climate of Minnesota and the Upper Midwest are given in Dadaser-Celik and Stefan (2009) and are reproduced in Appendix A.

This report will present the methods, results, interpretations, and conclusions of an analysis of historic stream flows and climatic data in Minnesota. The report focuses on stream flow and different climatic variables and indices. Strengths of empirical relationships (correlation r^2 values), geographic distributions in Minnesota, and historical trends will be analyzed. Results will be given in terms of absolute values of annual stream flows (runoff) and precipitation, runoff coefficients, and historical trends and changes in terms of absolute values or percentages for the watersheds of Minnesota and portions of surrounding states.

2. OBJECTIVES AND METHODS

Stream flows recorded by the USGS from 1926 to 2005 at gauging stations in the major river basins of Minnesota and its tributaries from neighboring states will be analyzed and related to associated climate data. Goals of the study are (1) to determine the strength of the relationships between annual and seasonal runoff and climatic variables in river basins and tributary watersheds, (2) to determine trends in stream flows over time, and (3) to make comparisons between the major river basins of Minnesotae. In a previous version of this report stream flow was quantified in terms of cfs and precipitation in terms of inches per year. In this study stream flow will be analyzed in terms of runoff in cm/year; a dimensionless annual runoff coefficient will be calculated as the ratio of annual runoff to annual precipitation; change of runoff will be calculated as the difference between different periods, or as a percentage of previous stream flows. Climatic variables will be air temperature, precipitation, the Palmer Drought Severity Index (PDSI), and the Palmer Hydrological Drought Index (PHDI).

One major objective of this study is to determine relationships between climatic variables and stream runoff at different time scales in watersheds across the state of Minnesota. The analysis will be completed using stream flow data from USGS gaging stations across the state and a few from neighboring states. The climatic variables used in the analysis will come from a variety of sources, mostly through the Minnesota State Climatology Office at the University of Minnesota and National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA), and will include precipitation, air temperature, Palmer Drought Severity Index (PDSI), and Palmer Hydrological Drought Severity Index (PHDI).

The easiest way to express the overall relationship between precipitation and runoff in a watershed is by a runoff coefficient. The runoff coefficient is the ratio of runoff to precipitation for a watershed over a time period. It includes the cumulative effects of several watershed and rainfall characteristics, such as topography, surface geology, soil characteristics (permeability, porosity), vegetation cover and land use. The runoff coefficient is a dimensionless number and gives the fraction of the precipitation that runs off from a watershed over a given time period.

The runoff analysis will be completed mainly on the annual time scale, including the annual calendar (January-December) and water year (October-September) scales, but the seasonal and the monthly time scales will not be ignored. Overall period of record (P.O.R.) averages will be calculated as well as time period averages to analyze how runoff and runoff coefficients have changed over time. The time periods used were 1926-1945, 1946-1965, 1966-1985, and 1986-2005 for consistency with past analysis. The 1926-1945 period spans a period largely characterized by widespread and longterm drought. The 1946-1965 and 1986-2005 time periods were used earlier for change analysis as the 40 year difference between the period centers was considered sufficient to highlight changes that have occurred recently (Dadaser-Celik and Stefan, 2009).

Many large land use changes, including the conversion of vast areas of prairie and forests and drainage of wetlands for agriculture, basin wide clear-cut logging, mining, and initial urban development occurred well before the USGS and other agencies began continuously monitoring the stream flows in Minnesota, and thus data is unavailable to calculate historic runoff coefficients, although this information would no doubt be incredibly useful in determining land use change effects and the extent of hydrologic change that human settlement and development have caused.

The analysis will first be conducted for an annual time scales. Annual runoff will be correlated with annual precipitation, annual average temperature, and annual average PDSI and

PHDI for each basin. Correlation strength is described by the coefficient of determination (r^2). In first approximation the data will be described with a best fit linear regression, however exponential fits will also be explored. Running averages of average runoff, precipitation, and PDSI will be computed and analyzed to reveal relationships between multi-year parameter averages. It is hypothesized that total annual precipitation, PDSI, and PHDI are well correlated with annual runoff. There is little expectation that average temperatures would be well correlated with runoff.

The analysis will be expanded to seasonal and monthly time scales. *Cool* months are defined as November through April and *warm* months are defined as May through October. *Winter* months are December, January, and February, when air temperatures are mostly below freezing, and precipitation is in the form of snow which does not immediately run off. Stream flow in the winter is fed mostly by groundwater (baseflow) and infrequent snowmelt events. The relationship between precipitation and runoff in Minnesota in winter is expected to be poor. Stream flows in *spring* are very much controlled by snowmelt runoff and are therefore also not expected to have a good relationship with monthly precipitation and other monthly climatic variables, although air temperature may show correlation due to its role in snowmelt. Stream flow in the *summer* and *fall* months are expected to have the strongest relationships with climatic variables. Precipitation is a major contributor to stream flow and PDSI, calculated on a monthly scale, will be a good measure of general water availability in the region. Analyses will also be completed for individual months.

A gage will be required to have a minimum of 18 years of data for a 20-year period to be considered representative and used in calculations, with the exception of the earliest time period where 15 years will be accepted for the purpose of including more gages in the period when many gages were being installed. Average flow at a gage will be converted to total runoff in height of water (mm) over the watershed by determining the total flow volume and dividing by the watershed area. The total runoff will be divided by the total precipitation (also in mm) to calculate the runoff coefficient during the specific time period.

The accuracy of the runoff coefficient calculations depends on the accuracy of the watershed area. Digital information on watershed boundaries for each stream gage were needed for averaging of climatic variables from multiple weather stations, and for determining drainage areas needed for runoff coefficient calculations. In most cases, the locations of stream gages did not agree well with watershed boundaries defined in readily available GIS datasets (e.g., MN DNR) as the gages were not usually located at the watershed outlet. The USGS's National Elevation Dataset (NED) contains a 30-meter gridded digital elevation model (DEM) that covers the majority of the United States. NED data was obtained and used in ESRI ArcGIS 9.2 for semi-automatic watershed boundary delineation using the gage locations as watershed outlets. GIS tools (e.g., fill) were used to hydrologically correct the DEM. Flow direction and flow accumulation grids were generated and used to generate contributing watersheds for each gage location. The generated watershed shapefiles and calculated areas were compared to watershed boundary shapefiles and information published by the USGS (e.g., 8 digit HUCs) and MN DNR ("Major Watershed Index"). The DEM generated watershed boundaries agreed very well with published watershed boundaries and provided the watershed area contributing to flow at the gage. The calculated areas agreed very well with the gage areas published by the USGS, typically within 1%. To maintain consistency and repeatability, the areas given by the USGS gage information will be used for runoff coefficient calculation.

3. DATA

3.1. Stream Flow Data

Forty-two (42) U.S. Geological Survey (USGS) stream gaging stations in the states of Minnesota, Wisconsin, and North and South Dakota were used in this study. Thirty-six of the stations match those used by Novotny and Stefan (2007) and Dadaser-Celik and Stefan (2009), and six stations were added to better represent the drainage areas contributing to the flow in Minnesota's streams and rivers. The stations were selected based on record length and record completeness. All records used end with 2008, and record lengths vary from 59 to 108 full years of data. The 42 gaging stations are spread across five major river basins of the Upper Midwest. Twelve (12) stations are located in the Minnesota River Basin, five (5) stations in the Mississippi Headwaters Basin (those above the confluence with the Minnesota River), eleven (11) stations in the remaining Upper Mississippi Basin (those below the confluence with the Minnesota River), seven (7) stations in the Red River of the North Basin, five (5) stations in the Rainy River Basin, and two (2) stations in the Lake Superior Basin. Daily stream flow data were extracted from the USGS Water Data website for all 42 gaging stations and averaged into the needed time scales. Annual and monthly averages were calculated only for full records; no incomplete records were used. Monthly flow data was converted into total runoff (in mm) by integrating over time and dividing by the drainage area of the stream gage's watershed. The locations of the stream gaging stations and the major river basins are shown in Figure 1. Figure 2 shows the watershed boundaries that were delineated for each stream gaging station. Table 1 gives the name and general information for each USGS gaging station including drainage area and period of record.

3.2. Climate Data

Historical climatic data for the Upper Midwest are available from a variety of sources. Many of the records are from networks of volunteer observers or small weather stations. Some are short, inconsistent, incomplete, and unverified. After a review of potential sources, data from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) were selected for the analysis. The NCDC uses networks of volunteer observers as well as NOAA weather stations to reliably and accurately estimate precipitation and temperature data as single values across climate divisions on a monthly scale, with records dating back to 1895. The Minnesota State Climatologist's Office (University of Minnesota) makes compilations and analyses of this weather data available via the internet. The NCDC climate division data also include the PDSI and PHDI calculated for each climate division for the length of the record. It is assumed that a single value across a climate division is a good estimate, meaning that on annual or monthly time scales the precipitation and mean temperatures do not vary significantly across each climate division. To estimate the total precipitation and average temperature in the watershed of each USGS stream gage, area-weighted averages of the climate division data were calculated based on the watershed's area fraction in each climate division. The calculations were completed using ArcGIS to overlay the stream gage watersheds (described previously) and the climate division shapefiles to determine the resulting component areas. A few watersheds in northern Minnesota have contributing drainage area in Canada. Because historic monthly climate data for Canada were unavailable, it was assumed that the climate division data for Minnesota Climate Division 3 would be representative of the climate data in Canada. The climate divisions as defined by NOAA in the regions studied are shown in Figure 3 along with the stream gage locations and major river basin boundaries.

An additional source for climate data is the United States Historical Climatology Network (USHCN). The USHCN dataset provides daily and monthly precipitation and temperature data across the US. The stations are not uniformly distributed and do not contain as long a record as the NCDC climate division dataset. Interpolating watershed-specific information for the USGS gaging stations for continuous time periods would be very time consuming and was not completed. In analyses at time scales shorter than a month, however, the USHCN data could be very useful.

4. RESULTS

4.1. Correlations at the Annual (Calendar and Water Year) Time Scale

Annual (January-December) and water year (October-September) average runoff was plotted against mean annual air temperature, total annual precipitation, and average PDSI and PHDI (determined by averaging the monthly values over the course of each year) for all 42 stream gaging stations. The coefficients of determination (r^2) between runoff and each of the climate variables were calculated. Figures 4 to 9 show examples of the plots for precipitation and PDSI for the Mississippi River near Prescott, WI, the Rum River near St. Francis, MN, and the Pigeon River near Grand Portage, MN. The correlations for the Mississippi River near Prescott, WI were among the best observed, those for the Rum River were about average, and those for the Pigeon River were among the worst found in the analysis.

Correlations between average annual air temperature and runoff were always very weak, as had been expected; average and maximum r^2-values of 0.07 and 0.20, respectively, were found. Correlations of runoff against precipitation, PDSI, and PHDI were significantly stronger; PDSI and PHDI were better predictors of runoff than precipitation. The overall average and maximum r^2-values between precipitation and runoff for all 42 stations were 0.39 and 0.57, respectively. The overall average and maximum coefficients of determination between PDSI and runoff were 0.67 and 0.88, respectively (0.67 and 0.87 for PHDI). Table 2 lists the r^2-values of the correlations between water year average climatic variables and runoff for each gaging station as well as basin averages. Water year averages were found, on average, to have slightly better correlations than annual (calendar year) averages (Figure 10). Water year averages were retained for subsequent analysis.

The best correlations between total precipitation or average PDSI or PHDI and runoff were found in the Upper Mississippi River Basin below the confluence with the Minnesota River; the strongest correlations were for stream gaging stations on the main stem of the Mississippi River (e.g., $r^2 = 0.88$ at Prescott, WI and Winona, MN between PDSI and runoff). The importance of average moisture conditions throughout river basin drainage area and the compounded effect of the smaller drainage areas that feed them is illustrated by this result.

In the Minnesota River Basin, runoff showed above average correlation strength with precipitation ($r^2 = 0.44$) and average strength with PDSI ($r^2 = 0.67$). In the Mississippi Headwaters Basin runoff showed below average strength with precipitation ($r^2 = 0.34$) and above average strength with PDSI ($r^2 = 0.72$). The weakest correlations between runoff and precipitation were observed in the Rainy River Basin and the Red River Basin with averages of $r^2 = 0.27$ and 0.38, respectively. The Lake Superior Basin had the lowest average correlation strength between runoff and PDSI, with an $r^2 = 0.47$, while the Rainy River Basin averaged $r^2 = 0.57$, and the Red River Basin had $r^2 = 0.66$.

That runoff correlates more strongly with PDSI than with precipitation reinforces the concept that overall moisture conditions play a larger role in generating runoff than precipitation events alone. Soil infiltration capacity and groundwater levels are controlled by antecedent moisture conditions, and in turn provide baseflow to streams. For example, a rainfall event with significant precipitation will create more surface runoff during a wet time than a drought period because the amount of new water that can be stored in the watershed (in soils, groundwater, wetlands, ponds, etc.) will be lower in a wet period than a dry period.

Precipitation was found to have the highest correlations, on average, with linear regression, while PDSI and PHDI gave the best fit to runoff with exponential regressions, i.e., linear regression with the log of runoff (Figure 11). Exponential regressions were used between the drought indices and runoff for the remainder of the analyses. On average, PDSI and PHDI were equally good predictors of runoff (Figure 12). Because Weber and Nkemdirim (1998) found that PDSI responds at least one month faster than PHDI to changing moisture conditions, PDSI was used in subsequent analyses.

It was found that watershed size, i.e. the contributing drainage area at the stream gage location, had little influence on the strength of correlation between stream runoff and precipitation or PDSI (Figure 13). However, runoff at stream gaging stations with the largest drainage areas did tend to have stronger correlations, especially with PDSI.

Five- , ten- , and twenty-year running averages of the climatic variables and stream flows were also computed and analyzed. The average strength of the correlation between runoff and precipitation rose significantly when water year averages were replaced by 5-year running averages, but did not improve much further when 10- and 20-year running averages were used (Figure 14). Using running averages of PDSI did not change the correlation strengths significantly (Figure 15). The 5-year average of precipitation was, on average, a slightly worse predictor of runoff than the 5-year average of PDSI, and the 10- and 20-year averages of precipitation were slightly better predictors than the 10- and 20-year averages of PDSI (Figure 16).

These results suggest that PDSI and PHDI capture moisture conditions in a watershed well enough for runoff projection at the annual time scale as well as longer time scales. By comparison, precipitation data have to be extended from the annual scale to a multi-year (5-year) scale to become representative of soil moisture conditions in the watershed for runoff projection.

4.2. Correlations at the Seasonal Time Scale

From the annual (calendar year and water year) time scale, our analysis was extended to a seasonal time scale. *Cool* months were defined as November through April and *warm* months were defined as May through October. *Winter* months are December, January, and February, when air temperatures are mostly below freezing, precipitation is in the form of snow and does not immediately run off, and stream flow is fed mostly by groundwater (baseflow) and infrequent snowmelt events. Stream flow in *spring* (March, April, and May) is very much controlled by snowmelt runoff. Stream flow in the *summer* (June, July, and August) and *fall* (September, October, and November) is fed largely by rainfall and stored water.

In the analysis, seasonal runoff was related to seasonal average air temperature, seasonal average PDSI, and total seasonal precipitation for all 42 stream gaging stations. In addition, *winter* and *spring* climate variables were related to spring runoff in an attempt to capture the snowpack that accumulates over the winter and runs off during spring snowmelt. The coefficients of determination (r^2) were determined between the seasonal stream flow and each of the three climate variables.

Figure 17 shows the overall average correlation strengths (as r^2) of air temperature, precipitation, and PDSI against runoff for the seasonal time scales. The average water year r^2-values are given for comparison. In each of the river basins, the average correlation strengths at the seasonal time scale showed the same patterns as those at the annual time scale given in the previous section of this report. The Rainy River and Lake Superior Basins had the weakest correlations and the Upper Mississippi below the Minnesota and the Minnesota River Basins had the strongest. As in the yearly time scale analysis, the correlation strengths for PDSI were obtained by an exponential fit (i.e., linear regression with the log of runoff).

The correlation strengths (r^2-values) between seasonal average air temperature and stream runoff were again very weak. On average, the correlation strengths between precipitation and runoff were slightly higher during the *warm* months than the *cool* months. This is also reflected in the significantly higher average r^2-values between precipitation and runoff in the *summer* and *fall* months, compared to the *winter* and *spring* months, which is due to the importance of precipitation for generating stream flow in *summer* and *fall*. On the other hand, *winter* and *spring* precipitation regressed against *spring* runoff gave significantly higher r^2-values than just *spring* precipitation against *spring* runoff, because the snowpack runs off in *spring*. None of the average correlation strengths between precipitation and runoff at the seasonal time scales were higher than those found for the annual time scale. As in the water year analysis, PDSI was a much better predictor of runoff than precipitation. Average correlation strengths were similar in the *cool* and *warm* months and in *summer* and *spring*. Average correlation strengths in the *fall* were slightly higher, and average correlation strengths in the *winter* were slightly lower, implying a slightly higher importance of moisture conditions in generating fall runoff, and slightly smaller importance for generating winter runoff, which is typical for the Upper Midwest.

4.3. Correlations at the Monthly Time Scale

After analysis of annual and seasonal time scales, the analysis was extended to the monthly time scale, i.e. data were averaged over individual months and analyzed. Average monthly runoff at each of the 42 stream gaging stations was regressed against average monthly air temperature, monthly total precipitation, and monthly PDSI for each month of the year for the entire period of record. Figure 18 shows the overall average correlation strengths (as r^2) of air temperature, precipitation, and PDSI against runoff for individual months with the average water year r^2-values for comparison. Comparison of average correlation strengths by river basin at the monthly time scale and at the annual time scale showed the same patterns, The Rainy River and Lake Superior Basins showed the weakest correlations and the Upper Mississippi below the Minnesota and the Minnesota River Basins showed the strongest.

The best relationships were once again observed between PDSI and stream flow. Overall, r2-values at the monthly time scale were weaker than at the annual time scale. Noticeably stronger correlations were observed in the summer, fall, and winter months than in the spring months. The lower correlation strengths in the spring months are attributed to the fact that the major contributor to stream flow in spring is snow melt runoff, and the amount of snowmelt water is not well correlated with PDSI.

Correlations between precipitation and stream flow were very weak; the best month was June, with an average $r^2 = 0.25$. Lag time between precipitation and runoff at the gaging station was not accounted for in the analysis. The monthly timescale seems too short to capture the precipitation vs. runoff relationship, especially in the larger watersheds. An analysis of watershed time of concentration and appropriate lagging of precipitation events in the analysis could increase the strength of the correlations at the monthly timescale. The r^2-values between precipitation and runoff in the winter months were the very weakest, with averages from 0.01 to 0.04, because precipitation falls as snow in these months and produces little direct runoff.

The r^2-values between air temperature and flow were again very low indicating almost no correlation between runoff and air temperature at the monthly timescale. Small increases were observed in the correlations between temperature and runoff in February and March indicating a very slight dependence; however the average $r^2 = 0.13$ in March. The small increase may reflect the dependence of snowmelt on air temperature.

Overall, the monthly timescale is too short to relate stream runoff in major watersheds to climate variables. On shorter time scales watershed specific topography, ecology, geology, and land use cause a lag, and play much larger roles in determining runoff from precipitation events. More complex hydrologic runoff models must be applied to accurately predict runoff at the monthly time scale.

4.4. Analysis of Runoff Coefficients

The easiest way to express the overall relationship between precipitation and runoff in a watershed is by a runoff coefficient. For each of the 42 stream gaging stations and for each water year of record annual runoff coefficients were calculated by dividing the total observed annual runoff from the watershed during the year by the total annual precipitation. Averages for the period of record (P.O.R.) as well as 20-year averages were calculated. The 20-year periods used were 1926-1945, 1946-1965, 1966-1985, and 1986-2005. In Tables 3, 4, and 5 the average precipitation (cm), the runoff (cm), and the runoff coefficients (dimensionless), respectively, are listed for each stream gage and its associated watershed over the P.O.R. as well as over the shorter time scales. Figures 19 to 23 show the change in runoff coefficients in increments of 20-year periods from 1926 to 2005. Stream gaging stations are divided according to river basins: Tributaries of Lake Superior and the Rainy River Basin (Figure 19), the Red River Basin (Figure 20), the Mississippi Headwaters Basin (Figure 21), the Minnesota River Basin (Figure 22), and the Upper Mississippi Basin below the confluence with the Minnesota River (Figure 23).

A comparison of average runoff coefficients in the six furthest down river (most encompassing) river basins and their changes over the period 1926 to 2005 is given in Figure 24. The trend in runoff coefficients is upward in all river basins, except the Lake Superior Basin.

Annual average precipitation (cm/yr) and average annual average runoff (cm/yr) for the same basins and time periods are given in Figure 25. Note the overall upward trends in both precipitation and runoff in every major basin in Figure 25. For runoff coefficients to increase, the increase in runoff must be more severe than the increase in precipitation.

Figures 26 and 27 display maps that shows the geographic distribution of the runoff coefficients for the 1946-1965 and the 1986-2005 time periods, and Figure 28 shows the associated percent change in runoff coefficient per stream gage from the 1946-1965 period to the 1986-2005 period. Similarly, Figures 29 - 32 show maps of the distribution of values and changes in average annual precipitation (in both cm and percent) in and between the same time periods, and Figures 33 – 36 show the same for average annual runoff.

5. INTERPRETATIONS OF RESULTS

In the Lake Superior Basin both stream gaging stations had high average runoff coefficients (~ 0.43) in the period from 1966-1985 after an increase from the previous period, but subsequently runoff coefficients decreased back to their earlier averages (~ 0.36). Only the Pigeon River has a long enough record to obtain a runoff coefficient for the 1926-1945 period, which was actually higher (~ 0.44) than for the 1966-1985 period, despite considerable overlap with the drought period of the 1930s. The Rainy River Basin was also characterized by high runoff coefficients (0.3 to 0.4), with the maximum values in the 1966-1985 period. The Lake Superior and Rainy River Basins have no doubt seen the least amount of agricultural conversion and urbanization of the watersheds studied and both remain heavily forested. In both basins soil column lengths are short because the most recent glaciation scoured to bedrock, which is exposed in many areas. Both areas are considered part of the Canadian Shield, and have many lakes and wetlands. These features can explain both the high runoff coefficients and the relative lack of change observed over the time periods.

In the Red River Basin runoff coefficients have increased over time, some very significantly. Initial runoff coefficients were much lower than those of the Rainy River and Lake Superior Basin, ranging from ~0.03 to 0.08. Since the 1946-65 period, runoff coefficients have increased significantly to a range between ~0.08 to 0.15; the runoff coefficient for the Sheyenne River increased by 109%. The Red River Basin is characterized by very fine grained soils and flat topography as much of it was once the bottom of glacial Lake Agassiz. The land use in the basin is primarily agricultural. The Red Lake River near Crookston, MN and the Roseau River near Malung, MN watersheds both saw relatively little change in runoff coefficients between the time periods. The Roseau River watershed was the sole exception to low runoff coefficients and provided a value of ~0.33. Both the Red Lake River and the Roseau River watersheds are on the eastern side of the basin and likely have topography, geology, and land use characteristics more similar to the Rainy River and Mississippi Headwaters Basins than the rest of the Red River Basin.

In the Mississippi Headwaters Basin typical runoff coefficients were between 0.20 and 0.26 and were relatively stable between the 1946-1965 and 1986-2005 periods. Notable exceptions to this stability are the Mississippi River at Grand Rapids, MN, which is the only station with a record going back to the 1926-1945 period, and a significant leap from ~0.12 to 0.21 from that period to the next, and the Crow River at Rockford, MN, whose runoff coefficient increased steadily from ~0.12 to 0.21 from 1926-1945 to 1986-2005. Significant urbanization has occurred in the Crow River watershed, and some near Grand Rapids, while the main land uses in the Mississippi Headwaters Basin are forests and agriculture.

The most significant increases in runoff coefficients were obtained for the Minnesota River Basin, where agriculture makes up 92% of the basins area. In the 1946-1965 period, the runoff coefficients were from ~0.06 to 0.15 and many increased slightly or decreased in the 1966-1985 period. In the most recent period (1986-2005), however, the runoff coefficients jumped to between ~0.09 and 0.26. At many stream gaging stations runoff coefficients increased by ~70 to 80%; the Chippewa River at Milan, MN showed a 115% increase. The two stations that have longer records (Minnesota River at Montevideo, MN and Minnesota River at Mankato, MN) show even lower initial runoff coefficients (0.03-0.06) in the 1926-1945 time period. Both the Le Sueur River and the Blue Earth River at Rapidan, MN showed higher initial runoff coefficients than were typical of the Minnesota River Basin for each time period, but both stream gaging sites also had significant increases in runoff coefficients over time.

For stream gaging stations in the Upper Mississippi River Basin below the confluence with the Minnesota River runoff coefficients show two different patterns. The stream gaging stations on the St. Croix River that drains eastern central Minnesota and northwestern Wisconsin and the stations on the Chippewa River that drains western and central Wisconsin showed high runoff coefficients ranging from ~0.34 to 0.42. The St. Croix River watershed is heavily forested but interestingly the Chippewa River watershed is heavily used for agriculture, in particular dairy farming, and thus does not have the same basin characteristics that likely cause the high runoff coefficients found in northern Minnesota. The runoff coefficients in these watersheds have also remained relatively stable with time. The remaining stream gaging stations in the Upper Mississippi Basin below the confluence with the Minnesota River are in the 'Driftless Area', the area of southeastern Minnesota, western Wisconsin, and northern Iowa and Illinois that were not covered by glaciers during the last ice age, including two southern Minnesota streams that flow through Iowa before joining the Mississippi River further downstream. For each of these stream gaging stations runoff coefficients increased over time, from ~0.1 - 0.23 in 1946-1965 to a range of ~0.2 - 0.33 in 1986-2005.

Interesting results emerge by studying the runoff coefficients that are "characteristic" (most down-river) for the major river basins of Minnesota and surrounding states. In the north, the Lake Superior and Rainy River Basins have high and invariant characteristic runoff coefficients around 0.36 and 0.34, respectively. The Red River Basin in northwestern Minnesota and eastern North Dakota has the lowest characteristic runoff coefficient at ~0.14 but has consistently increased from 0.04 near the beginning of the period of record. The Mississippi Headwaters Basin characteristic runoff coefficient has increased to ~0.24 from 0.12 in the earliest time period. The Minnesota River Basin characteristic runoff coefficient (from the

Minnesota River at Jordan, MN station) has also increased significantly and consistently from 0.06 to 0.19. The low runoff coefficients from the Minnesota River combine with the higher runoff coefficients coming out of the Mississippi Headwaters and the even higher runoff coefficients coming out of the St. Croix and Chippewa River watersheds such that the basin characteristic runoff coefficient for the Upper Mississippi River Basin (from the Mississippi River at Winona, MN station) has increased to ~0.27.

Overall runoff coefficients increase significantly from west to east in the Upper Midwest region studied (Figures 26 and 27). This distribution does not seem to have changed over time. Increases in runoff coefficients have, however, been highest in the west, and lowest in the east of the geographic region studied (Figure 28). One can hypothesize that this gradient is mainly due to land use changes that have been more incisive in the west, and have lead to faster and easier surface runoff from the land in the west since the beginning of European settlement. An explanation based on climatological factors may, however, also be reasonable. It was found that precipitation has increased in all of the river basins studied over the time period of 1926 to 2005 (see Figures 25, 31, and 32) with the largest changes occurring in the southernmost of the watersheds studied and very little change being observed in northeastern Minnesota. If the relative increase in runoff is more than the relative increase in precipitation, than the runoff coefficients have increased.

The geographical distribution of average annual runoff (Figures 33 – 36) is similar to the distribution of the runoff coefficients, with the highest values occurring in the east and decreasing values to the west. When the change in total runoff (Figure 35) is expressed as the total difference between the 1946 - 1965 and 1986 – 2005 time periods, the largest changes in runoff are seen in the southernmost watersheds that also saw the largest increases in precipitation. These southern Minnesota watersheds also saw significant changes in runoff coefficients. These observations could lead to the hypothesis that much of the additional precipitation is directly running off into streams and rivers, without much additional infiltration. This can be illustrated using the Root River and the Cedar River watersheds; both have seen very similar increases in average annual precipitation and average annual runoff of 10 - 14 cm.

When the change in runoff is viewed as a percent change from the earlier period (Figure 36), the watersheds in the Red River Basin and the more upriver watersheds in the Minnesota River Basin are seen to have higher relative changes than the watersheds with the largest total runoff. The geographic distribution of the percent change, also displays an obvious east to west gradient, this time with the highest changes occurring in the west and the lowest in the east.

Overall, runoff, i.e. stream flow, has increased since the beginning of stream gaging in Minnesota and the Upper Midwest in the watersheds studied (see Figures 33 – 36), although periods of substantially lower stream flows have occurred, e.g. in the drought period of the 1930s, which is illustrated in the historical flow and precipitation records for the Mississippi River at St. Paul, MN in Figure 37. Not only has the runoff (cm/yr) increased but runoff coefficients, i.e. the ratio of runoff to precipitation, have also increased. Increases in runoff coefficients have been documented in this study. Further study is needed to conclusively determine the underlying causes of these findings, particularly research regarding land use, water use, and climate changes. In a specific watershed with given topography, geology and vegetation cover, runoff coefficients depend both on land use and precipitation (amount and intensity). Figures 38 and 39 show the relationships between 5-year average annual (water year) precipitation and runoff coefficient, and PDSI and runoff coefficient, respectively, for the Mississippi River at St. Paul, MN. A strong positive relationship (r^2 = 0.71 and 0.66, respectively) is observed at this station and similar results are seen at other stations. The strengths of the relationships at each stream gage between precipitation and PDSI against runoff coefficient are compared for the 5-year running averages and annual time scales (Figure 40). It is apparent that the 5-year running averages of precipitation have significantly stronger relationships with the runoff coefficient than at the annual time scale, highlighting the effects that antecedent moisture conditions have on runoff coefficients. At both time scales PDSI is an overall better predictor of runoff coefficient. The dramatic increase in correlation strength is not evident between PDSI and runoff coefficients from annual to 5-year running average scales, which is consistent with earlier findings that 5-year running averages of precipitation approach the general moisture conditions indicated by annual average PDSI. Low runoff coefficients in the 1926-1945 are representative of a dry period. Higher runoff coefficients in the 1986-2005 period may be due to increased precipitation leading to water surplus (and thus higher PDSI) and less available storage in the watershed.

6. SUMMARY AND CONCLUSIONS

Historical stream flow and climate data for major river basins in Minnesota and tributaries from neighboring states were analyzed. Stream flow data came from 42 USGS gauging stations. A goal of the study was to determine the strength of the relationship between runoff and climatic variables. Another goal was to study how stream flow in Minnesota has changed since the beginning of data collection and how changes related to changes in climatic variables. The climatic variables analyzed included precipitation, PDSI and PHDI, two common drought indices. A third goal was to compare streamflow and its changes in the vastly different major river basins of Minnesota. The analysis was conducted at annual (calendar and water year), multi-year (running averages), seasonal, and monthly time scales. The following conclusions were drawn from this study.

6.1 Relationships between Stream Flow and Climate Parameters

1) The drought indices (PDSI and PHSI) were determined to be much better predictors of stream flow (runoff) than precipitation alone; runoff showed a slightly higher dependence on PDSI than PHDI. This result highlights the importance on antecedent moisture conditions on the generation of runoff and stream flows.

2) Correlation strengths were improved significantly by using an exponential fit between runoff and the drought indices; correlations between runoff and precipitation were stronger with a simple linear model.

3) Drainage area does not have a crucial effect on the relationship between runoff (cm/yr) and climatic variables; however some of the strongest dependences were obtained for the furthest downstream gaging stations of the Mississippi River (e.g., Prescott, WI and Winona, MN).

4) Water year (October – September) averages showed slightly stronger correlations between the climatic variables and runoff than calendar year (January – December) averages.

5) Multi-year running averages improve the correlation strengths between precipitation and runoff significantly, but not between PDSI and runoff. Five-year running averages of (water year) precipitation are sufficient. A precipitation average over several years appears to account for the overall soil moisture conditions, as the drought indices do at shorter, e.g. the annual, time scales.

6) The seasonal time scale analysis yielded only some useful results: a strong dependence of runoff on precipitation during summer and fall, but a much weaker dependence during the winter. The correlation strength between PDSI and runoff did not differ greatly by season. PDSI can be a good indicator of moisture conditions when precipitation is falling as snow.

7) At the monthly time scale the dependence of runoff on precipitation was even more decreased. Precipitation was not a good predictor of runoff in any month. The snow melt months February and March had the weakest dependence of runoff on PDSI.

8) Among the river basins studied, the Upper Mississippi River Basin below the confluence with the Minnesota River has the strongest dependence on precipitation and PDSI. Runoff from the Minnesota River Basin showed above average dependence on precipitation and average dependence on PDSI, while runoff in the Mississippi Headwaters Basin showed below average dependence on precipitation and above average dependence on PDSI. The Red River of the North Basin showed lower than average dependence on precipitation and average dependence on PDSI. The Rainy River Basin and the Lake Superior Basin showed the weakest dependences of precipitation and PDSI on runoff. Geology, topography, and land use contribute to the differences observed between river basins.

6.2 Geographic Distribution and Changes in Annual Runoff and Runoff Coefficients

1) Annual average runoff coefficients, i.e. the ratio of runoff to precipitation averaged over at least 50 years, vary significantly across the state of Minnesota, from 0.4 in the northeast to less than 0.1 in the northwest. It was also found that runoff coefficients averaged over 20-year periods have increased during the last 40 years in many of the river basins in Minnesota and the Upper Midwest. The largest increase in runoff coefficients was found in the Red River of the North and the Minnesota River Basins, the two basins with the lowest runoff, located in the former prairie regions. Runoff coefficients in some tributary or sub-watersheds have doubled; there is more runoff and more total stream flow for the same amount of precipitation in these basins in more recent times. The smallest change in runoff coefficients was found in the Lake Superior and Rainy River Basins, and in the St. Croix River and Chippewa River (Wisconsin) watersheds, all in the eastern part of the region studied.

2) The highest observed precipitation and runoff changes in total amount (cm) were in some of the southernmost watersheds studied, while the most relative changes in percent (%) of previous annual precipitation and runoff values were in the western watersheds of Minnesota.

3) Some sub-watersheds in southern Minnesota have experienced increases in total runoff (in cm) that are similar in magnitude to the observed increase in precipitation. This suggests that most of the recently seen increase in precipitation could be running directly off to streams and rivers, with little new loss to infiltration or evapotranspiration.

4) The most significant increases in runoff are in basins that likely saw the largest land use changes in the form of agricultural practices and urbanization during the time period studied (Land use was not part of this study). An increase in average precipitation was, however, also observed in the river basins across the Upper Midwest, and the high correlations found between

precipitation and runoff suggest that this precipitation change has contributed significantly to the increases in stream flows.

5) Future analyses need to examine the combined role of land use changes and climate change on changing runoff. Annual runoff (cm/yr) and annual runoff coefficients (cm of runoff divided by cm of precipitation per year) are influenced by the topography, geology, soils, vegetation cover, land use, and water use of the watershed, but also by climatic variables such as total rain- and snow- fall, rainfall intensities, and dew points. In a given watershed, climate change alters several of the climate parameters, including precipitation amounts and intensities, and antecedent soil moisture conditions, and thereby affects the runoff and steam flow. At the same time, land use changes by agricultural conversion and urbanization, including drainage water withdrawals and applications for irrigation, industrial and domestic uses in several of Minnesota's river basins have been profound. Multi-parameter analysis techniques and hydrologic modeling are two approaches to partition the interactions of climate change and land use.

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Table 1: Information on USGS stream gauging stations studied.

USGS No.	Station Name	Period of Record	Full Years of Record	Drainage Area (km^2)	Contributing Climate Divisions
Tributaries to Lake Superior Basin					
04010500	Pigeon River near Grand Portage, MN	1924-2008	85	1577	MN 3
04024000	St. Louis River at Scanlan, MN	1908-2008	100	8884	MN 2,3,6
Red River of the North Basin					
05054000	Red River of the North at Fargo, ND	1902-2008	107	17612	MN 1,4; SD 3; ND 6,9
05059500	Sheyenne River at West Fargo, ND	1903-2008	81	8003	ND 2,3,5,6,9
05062000	Buffalo River near Dilworth, MN	1931-2008	77	2525	MN 1,4
05079000	Red Lake River at Crookston, MN	1902-2008	107	13649	MN 1,2
05082500	Red River of the North at Grand Forks, ND	1904-2008	104	77959	MN1,2,4; SD3; ND 2,3,5,6,9
05092000	Red River of the North at Drayton, ND	1950-2008	59	90132	MN1,2,4; SD3; ND 2,3,5,6,9
05104500	Roseau River near Malung, MN	1947-2008	62	653	MN 1,2
Rainy River Basin					
05127500	Basswood River near Winton, MN	1931-2008	76	4507	MN 3
05128000	Namakan River at outlet of Lac La Croix, MN	1923-2008	86	13390	MN 3
05130500	Sturgeon River near Chisholm, MN	1943-2008	66	466	MN 2,3
05131500	Little Fork River at Littlefork, MN	1929-2008	85	4351	MN 2,3
05133500	Rainy River at Manitou Rapids, MN	1929-2008	80	50246	MN 2,3
Mississippi Headwaters Basin					
05211000	Mississippi River at Grand Rapids, MN	1912-2008	107	8728	MN 1,2
05227500	Mississippi River at Aitkin, MN	1946-2008	63	15903	MN 1,2,3,6
05280000	Crow River at Rockford, MN	1935-2008	82	6838	MN 4,5,6
05286000	Rum River near St. Francis, MN	1934-2008	76	3522	MN 5,6
05288500	Mississippi River near Anoka, MN	1932-2008	85	49469	MN 1,2,3,4,5,6

Table 1: Continued.

USGS No.	Station Name	Period of Record	Full Years of Record	Drainage Area (km^2)	Contributing Climate Divisions
Minnesota River Basin					
05291000	Whetstone River at Big Stone City, SD	1932-2008	77	1031	SD 3
05292000	Minnesota River at Ortonville, MN	1939-2008	70	3004	MN 4; SD 3
05304500	Chippewa River near Milan, MN	1938-2008	71	4869	MN 4,5
05311000	Minnesota River at Montevideo, MN	1930-2008	87	16006	MN 4,5,7; SD 3,7
05313500	Yellow Medicine River at Granite Falls, MN	1940-2008	72	1720	MN 4,7; SD 7
05315000	Redwood River near Marshall, MN	1941-2008	68	671	MN 7
05316500	Redwood River near Redwood Falls, MN	1936-2008	74	1629	MN 4, 7
05317000	Cottonwood River near New Ulm, MN	1939-2008	74	3367	MN 7,8
05320000	Blue Earth River near Rapidan, MN	1950-2008	65	6242	MN 7,8; IA 1,2
05320500	Le Sueur River near Rapidan, MN	1950-2008	65	2875	MN 8
05325000	Minnesota River at Mankato, MN	1930-2008	87	38591	MN 4,5,7,8; SD 3,7; IA 1,2
05330000	Minnesota River near Jordan, MN	1935-2008	74	41958	MN 4,5,7,8; SD 3,7; IA 1,2
Upper Mississippi River Basin (below Minnesota River)					
05331000	Mississippi River at St. Paul, MN	1907-2008	108	95312	MN 1-9; SD 3,7; IA 1,2
05333500	St. Croix River near Danbury, WI	1914-2008	91	4092	WI 1
05340500	St. Croix River at St. Croix Falls, WI	1902-2008	98	16162	MN 6, WI 1
05344500	Mississippi River at Prescott, WI	1929-2008	79	116032	MN 1-9; SD 3,7; WI 1,4; IA 1,2
05356500	Chippewa River near Bruce, WI	1913-2008	94	4274	WI 1,2
05365500	Chippewa River at Chippewa Falls, WI	1888-2008	93	14634	WI 1,2,4
05369500	Chippewa River at Durand, WI	1928-2008	80	23336	WI 1,2,4
05378500	Mississippi River at Winona, MN	1929-2008	80	153328	MN1-9; SD 3,7; WI 1,2,4; IA 1,2
05385000	Root River at Houston, MN	1909-2008	75	3238	MN 9
05457000	Cedar River near Austin, MN	1945-2008	69	1033	MN 8,9
05476000	Des Moines River at Jackson, MN	1936-2008	73	3238	MN 7

Table 2: Coefficients of determination (r^2) for regressions between water year average climatic variables and stream runoff at USGS stream gaging stations. Basin averages are also given.

USGS No	Station Name	Temp vs. Runoff	Precip vs. Runoff	PDSI vs. Runoff	PHDI vs. Runoff
		Linear Regression	Linear Regression	Exp. Regression	Exp. Regression
		r^2	r^2	r^2	r^2
Tributaries to Lake Superior Basin					
04010500	Pigeon River near Grand Portage, MN	0.15	0.26	0.37	0.33
04024000	St. Louis River at Scanlan, MN	0.03	0.40	0.57	0.58
	Basin Averages	**0.09**	**0.33**	**0.47**	**0.46**
Red River of the North Basin					
05054000	Red River of the North at Fargo, ND	0.01	0.28	0.67	0.69
05059500	Sheyenne River at West Fargo, ND	0.01	0.26	0.72	0.72
05062000	Buffalo River near Dilworth, MN	0.01	0.24	0.60	0.62
05079000	Red Lake River at Crookston, MN	0.01	0.22	0.61	0.66
05082500	Red River of the North at Grand Forks, ND	0.00	0.27	0.69	0.72
05092000	Red River of the North at Drayton, ND	0.04	0.29	0.72	0.74
05104500	Roseau River near Malung, MN	0.09	0.38	0.58	0.53
	Basin Averages	**0.02**	**0.28**	**0.66**	**0.67**
Rainy River Basin					
05127500	Basswood River near Winton, MN	0.15	0.21	0.55	0.52
05128000	Namakan River at outlet of Lac La Croix	0.12	0.19	0.51	0.51
05130500	Sturgeon River near Chisholm, MN	0.20	0.30	0.63	0.60
05131500	Little Fork River at Littlefork, MN	0.11	0.40	0.52	0.44
05133500	Rainy River at Manitou Rapids, MN	0.18	0.26	0.62	0.54
	Basin Averages	**0.15**	**0.27**	**0.57**	**0.52**
Mississippi Headwaters Basin					
05211000	Mississippi River at Grand Rapids, MN	0.01	0.15	0.49	0.53
05227500	Mississippi River at Aitkin, MN	0.10	0.30	0.82	0.80
05280000	Crow River at Rockford, MN	0.02	0.47	0.76	0.77
05286000	Rum River near St. Francis, MN	0.01	0.37	0.67	0.75
05288500	Mississippi River near Anoka, MN	0.01	0.43	0.84	0.86
	Basin Averages	**0.03**	**0.34**	**0.72**	**0.74**

Table 2: Continued.

USGS No	Station Name	Temp vs. Runoff	Precip vs. Runoff	PDSI vs. Runoff	PHDI vs. Runoff
		Linear Regression	Linear Regression	Exp. Regression	Exp. Regression
		r^2	r^2	r^2	r^2
Minnesota River Basin					
05291000	Whetstone River at Big Stone City, SD	0.19	0.32	0.56	0.55
05292000	Minnesota River at Ortonville, MN	0.16	0.31	0.65	0.67
05304500	Chippewa River near Milan, MN	0.04	0.28	0.60	0.63
05311000	Minnesota River at Montevideo, MN	0.09	0.35	0.81	0.80
05313500	Yellow Medicine River at Granite Falls, MN	0.11	0.43	0.56	0.56
05315000	Redwood River near Marshall, MN	0.09	0.47	0.60	0.63
05316500	Redwood River near Redwood Falls, MN	0.08	0.53	0.58	0.60
05317000	Cottonwood River near New Ulm, MN	0.09	0.56	0.68	0.69
05320000	Blue Earth River near Rapidan, MN	0.09	0.57	0.75	0.79
05320500	Le Sueur River near Rapidan, MN	0.09	0.54	0.63	0.67
05325000	Minnesota River at Mankato, MN	0.09	0.50	0.83	0.82
05330000	Minnesota River near Jordan, MN	0.08	0.47	0.81	0.80
	Basin Averages	**0.10**	**0.44**	**0.67**	**0.68**
Upper Mississippi River Basin (below Minnesota River)					
05331000	Mississippi River at St. Paul, MN	0.03	0.50	0.85	0.86
05333500	St. Croix River near Danbury, WI	0.03	0.37	0.58	0.57
05340500	St. Croix River at St. Croix Falls, WI	0.01	0.45	0.69	0.66
05344500	Mississippi River at Prescott, WI	0.06	0.51	0.88	0.87
05356500	Chippewa River near Bruce, WI	0.03	0.49	0.75	0.70
05365500	Chippewa River at Chippewa Falls, WI	0.04	0.47	0.81	0.74
05369500	Chippewa River at Durand, WI	0.05	0.46	0.84	0.81
05378500	Mississippi River at Winona, MN	0.05	0.49	0.88	0.86
05385000	Root River at Houston, MN	0.00	0.43	0.63	0.61
05457000	Cedar River near Austin, MN	0.01	0.52	0.64	0.61
05476000	Des Moines River at Jackson, MN	0.09	0.53	0.67	0.72
	Basin Averages	**0.04**	**0.47**	**0.75**	**0.73**
Overall Averages		**0.07**	**0.39**	**0.67**	**0.67**

Table 3: Average annual (water year) precipitation in the watershed of each USGS stream gaging station for different time periods and the period of record (P.O.R.). Change in average runoff from the 1946-1965 to the 1986-2005 period is also given.

USGS No.	Station Name	Water Year Average (St. Dev.) Precip (cm)					% Change from 1946 - 1965 to 1986 - 2005
		1926-1945	1946-1965	1966-1985	1986-2005	P.O.R	
Tributaries to Lake Superior Basin							
04010500	Pigeon River near Grand Portage, MN	25.65 (3.23)	27.84 (3.19)	28.67 (3.34)	28.25 (3.94)	27.74 (3.62)	1.46
04024000	St. Louis River at Scanlan, MN	25.65 (3.27)	27.78 (3.15)	28.65 (3.35)	28.31 (3.88)	27.72 (3.61)	1.91
Red River of the North Basin							
05054000	Red River of the North at Fargo, ND	20.21 (4.19)	22.20 (3.11)	21.65 (3.25)	23.67 (4.33)	21.78 (3.62)	6.61
05059500	Sheyenne River at West Fargo, ND	17.40 (3.92)	18.50 (2.49)	18.12 (2.48)	20.20 (3.47)	18.66 (3.05)	9.17
05062000	Buffalo River near Dilworth, MN	20.58 (4.00)	22.46 (2.97)	22.73 (3.30)	23.98 (3.95)	22.50 (3.51)	6.76
05079000	Red Lake River at Crookston, MN	21.95 (4.04)	23.43 (3.05)	24.09 (3.43)	24.81 (3.85)	23.69 (3.59)	5.85
05082500	Red River of the North at Grand Forks, ND	19.67 (3.96)	21.18 (2.66)	21.14 (2.84)	22.85 (3.47)	21.25 (3.21)	7.90
05092000	Red River of the North at Drayton, ND	19.53 (3.92)	20.97 (2.66)	20.95 (2.77)	22.63 (3.44)	21.08 (3.17)	7.91
05104500	Roseau River near Malung, MN	21.3 (4.01)	22.81 (3.04)	23.42 (3.43)	24.33 (3.91)	23.10 (3.57)	6.66
Rainy River Basin							
05127500	Basswood River near Winton, MN	25.65 (3.23)	27.84 (3.19)	28.67 (3.34)	28.25 (3.94)	27.74 (3.62)	1.46
05128000	Namakan River at outlet of Lac La Croix	25.65 (3.23)	27.84 (3.19)	28.67 (3.34)	28.25 (3.94)	27.74 (3.62)	1.46
05130500	Sturgeon River near Chisholm, MN	25.45 (3.29)	27.55 (3.12)	28.38 (3.31)	28.01 (3.88)	27.48 (3.59)	1.69
05131500	Little Fork River at Littlefork, MN	24.76 (3.60)	26.59 (3.07)	27.41 (3.32)	27.25 (3.77)	26.62 (3.61)	2.50
05133500	Rainy River at Manitou Rapids, MN	24.83 (3.57)	26.69 (3.07)	27.51 (3.31)	27.33 (3.78)	26.71 (3.60)	2.42
Mississippi Headwaters Basin							
05211000	Mississippi River at Grand Rapids, MN	23.58 (4.24)	25.01 (3.38)	25.80 (3.61)	26.00 (3.90)	25.19 (3.83)	3.99
05227500	Mississippi River at Aitkin, MN	24.33 (4.18)	25.75 (3.24)	26.78 (3.66)	27.19 (3.84)	26.04 (3.83)	5.60
05280000	Crow River at Rockford, MN	24.22 (4.52)	27.01 (4.50)	28.25 (4.54)	28.88 (5.65)	26.76 (4.82)	6.92
05286000	Rum River near St. Francis, MN	26.20 (4.70)	27.75 (4.11)	29.42 (4.48)	30.55 (5.34)	28.26 (4.67)	10.08
05288500	Mississippi River near Anoka, MN	24.33 (4.24)	26.39 (3.48)	27.49 (3.93)	28.15 (4.44)	26.43 (4.12)	6.69

Table 3: Continued.

USGS No	Station Name	Water Year Average (St. Dev.) Precip (cm)					% Change from 1946-65 to 1986-05
		1926-1945	1946-1965	1966-1985	1986-2005	P.O.R	
Minnesota River Basin							
05291000	Whetstone River at Big Stone City, SD	19.67 (4.16)	20.01 (3.47)	19.42 (3.56)	23.10 (4.70)	20.16 (3.95)	15.46
05292000	Minnesota River at Ortonville, MN	20.02 (4.18)	20.89 (3.43)	20.28 (3.55)	23.53 (4.68)	20.81 (3.90)	12.61
05304500	Chippewa River near Milan, MN	21.77 (4.53)	24.87 (3.71)	24.31 (4.15)	25.63 (4.93)	23.88 (4.25)	3.03
05311000	Minnesota River at Montevideo, MN	21.12 (4.33)	23.60 (3.52)	23.03 (3.88)	24.92 (4.74)	22.85 (4.02)	5.58
05313500	Yellow Medicine River at Granite Falls, MN	23.03 (3.92)	25.07 (3.66)	25.59 (4.32)	26.75 (5.05)	24.74 (4.18)	6.71
05315000	Redwood River near Marshall, MN	23.89 (3.90)	25.29 (3.96)	26.55 (4.87)	27.57 (5.51)	25.39 (4.49)	9.01
05316500	Redwood River near Redwood Falls, MN	23.88 (3.90)	25.29 (3.96)	26.54 (4.87)	27.56 (5.50)	25.38 (4.48)	9.00
05317000	Cottonwood River near New Ulm, MN	24.65 (3.90)	25.96 (3.80)	27.27 (4.45)	28.50 (5.57)	26.18 (4.40)	9.78
05320000	Blue Earth River near Rapidan, MN	27.57 (4.25)	28.38 (3.88)	29.99 (3.61)	31.63 (6.07)	29.10 (4.45)	11.44
05320500	Le Sueur River near Rapidan, MN	27.53 (4.38)	28.5 (4.03)	30.01 (3.56)	32.04 (6.27)	29.20 (4.58)	12.39
05325000	Minnesota River at Mankato, MN	23.72 (4.00)	25.61 (3.38)	26.08 (3.61)	27.70 (5.01)	25.45 (4.00)	8.17
05330000	Minnesota River near Jordan, MN	23.87 (4.02)	25.77 (3.41)	26.32 (3.62)	27.90 (5.04)	25.64 (4.03)	8.26
Upper Mississippi River Basin (below Minnesota River)							
05331000	Mississippi River at St. Paul, MN	24.18 (4.06)	26.16 (3.33)	27.04 (3.7)	28.12 (4.58)	26.14 (3.98)	7.48
05333500	St. Croix River near Danbury, WI	29.42 (4.32)	29.88 (4.48)	32.42 (3.84)	31.64 (4.87)	30.73 (4.31)	5.89
05340500	St. Croix River at St. Croix Falls, WI	27.89 (4.42)	28.82 (4.05)	30.95 (4.01)	31.19 (4.98)	29.55 (4.35)	8.19
05344500	Mississippi River at Prescott, WI	24.88 (4.04)	26.65 (3.32)	27.77 (3.7)	28.70 (4.55)	26.78 (3.96)	7.70
05356500	Chippewa River near Bruce, WI	30.05 (4.31)	30.11 (4.28)	32.54 (3.78)	31.71 (4.71)	31.02 (4.17)	5.30
05365500	Chippewa River at Chippewa Falls, WI	30.92 (4.40)	30.42 (4.09)	32.69 (3.79)	31.81 (4.58)	31.42 (4.07)	4.55
05369500	Chippewa River at Durand, WI	30.67 (4.40)	30.18 (4.04)	32.73 (3.75)	32.08 (4.33)	31.37 (4.00)	6.27
05378500	Mississippi River at Winona, MN	26.20 (3.95)	27.41 (3.26)	28.95 (3.51)	29.65 (4.39)	27.86 (3.80)	8.16
05385000	Root River at Houston, MN	29.49 (5.09)	29.02 (4.66)	32.5 (4.27)	33.59 (5.66)	30.92 (4.83)	15.76
05457000	Cedar River near Austin, MN	28.72 (4.60)	28.81 (4.16)	31.52 (3.72)	32.98 (5.58)	30.24 (4.51)	14.44
05476000	Des Moines River at Jackson, MN	23.89 (3.90)	25.29 (3.96)	26.55 (4.87)	27.57 (5.51)	25.39 (4.49)	9.01

Table 4: Average annual (water year) runoff at each USGS stream gaging station for different time periods and the period of record (P.O.R.). Change in average runoff from the 1946-1965 to the 1986-2005 period is also given.

USGS No	Station Name	Water Year Average (St. Dev.) Runoff (cm)					% Change from 1946 - 1965 to 1986 - 2005
		1926-1945	1946-1965	1966-1985	1986-2005	P.O.R	
Tributaries to Lake Superior Basin							
04010500	Pigeon River near Grand Portage, MN	11.20 (2.45)	10.51 (3.84)	12.51 (3.15)	10.30 (3.19)	11.04 (3.40)	- 2.03
04024000	St. Louis River at Scanlan, MN	8.62 (2.42)	9.53 (2.83)	11.03 (3.42)	10.40 (3.04)	9.42 (3.16)	9.12
Red River of the North Basin							
05054000	Red River of the North at Fargo, ND	0.57 (0.68)	1.31 (0.78)	1.45 (0.87)	2.50 (1.39)	1.44 (1.15)	90.74
05059500	Sheyenne River at West Fargo, ND	0.47 (0.32)	0.77 (0.52)	1.02 (0.48)	1.78 (1.11)	1.05 (0.82)	132.02
05062000	Buffalo River near Dilworth, MN		2.06 (1.01)	2.13 (1.38)	3.31 (1.83)	2.30 (1.56)	60.42
05079000	Red Lake River at Crookston, MN	1.69 (1.30)	3.18 (1.81)	4.13 (1.67)	3.82 (2.32)	3.11 (1.91)	20.22
05082500	Red River of the North at Grand Forks, ND	0.73 (0.58)	1.48 (0.85)	1.90 (0.90)	2.52 (1.38)	1.59 (1.09)	70.12
05092000	Red River of the North at Drayton, ND		1.45 (1.04)	1.87 (0.90)	2.45 (1.35)	1.98 (1.16)	68.81
05104500	Roseau River near Malung, MN		7.26 (4.31)	8.19 (5.18)	8.64 (5.82)	7.91 (5.04)	19.00
Rainy River Basin							
05127500	Basswood River near Winton, MN		10.53 (4.20)	12.37 (3.45)	10.24 (3.05)	10.74 (3.62)	- 2.78
05128000	Namakan River at outlet of Lac La Croix	9.20 (2.86)	10.21 (3.56)	11.60 (3.39)	9.92 (2.94)	10.02 (3.50)	- 2.92
05130500	Sturgeon River near Chisholm, MN		8.47 (2.56)	10.13 (2.92)	9.42 (3.09)	9.33 (2.88)	11.26
05131500	Little Fork River at Littlefork, MN	7.17 (2.83)	8.24 (2.71)	10.22 (3.36)	8.59 (2.91)	8.54 (3.11)	4.33
05133500	Rainy River at Manitou Rapids, MN	7.60 (2.66)	9.08 (2.66)	10.25 (3.18)	9.14 (2.91)	9.05 (2.99)	0.65
Mississippi Headwaters Basin							
05211000	Mississippi River at Grand Rapids, MN	2.79 (1.97)	5.17 (1.98)	5.97 (2.10)	5.92 (2.16)	4.94 (2.30)	14.53
05227500	Mississippi River at Aitkin, MN		6.14 (2.23)	6.82 (2.36)	6.65 (2.16)	6.44 (2.24)	8.33
05280000	Crow River at Rockford, MN		3.30 (2.25)	5.01 (2.93)	6.20 (3.37)	4.30 (3.00)	88.04
05286000	Rum River near St. Francis, MN		5.96 (2.75)	7.65 (2.83)	6.93 (3.02)	6.41 (2.96)	16.38
05288500	Mississippi River near Anoka, MN		5.52 (2.01)	6.76 (2.34)	6.80 (2.21)	5.80 (2.39)	23.33

Table 4: Continued.

USGS No	Station Name	Water Year Average (St. Dev.) Runoff (cm)					% Change from 1946 - 1965 to 1986 - 2005
		1926-1945	1946-1965	1966-1985	1986-2005	P.O.R	
Minnesota River Basin							
05291000	Whetstone River at Big Stone City, SD		1.80 (1.37)	1.8 (1.46)	2.97 (2.47)	2.07 (1.82)	65.34
05292000	Minnesota River at Ortonville, MN		1.30 (1.04)	1.11 (1.05)	2.27 (1.91)	1.62 (1.46)	74.95
05304500	Chippewa River near Milan, MN		1.94 (1.40)	2.69 (1.77)	4.25 (2.45)	2.77 (2.07)	119.29
05311000	Minnesota River at Montevideo, MN	0.72 (0.76)	1.83 (1.13)	1.98 (1.37)	3.39 (2.24)	2.05 (1.69)	85.29
05313500	Yellow Medicine River at Granite Falls, MN		2.42 (1.86)	2.83 (2.66)	4.13 (3.06)	2.94 (2.52)	71.00
05315000	Redwood River near Marshall, MN		2.55 (1.71)	3.13 (3.22)	5.51 (5.12)	3.70 (3.61)	116.25
05316500	Redwood River near Redwood Falls, MN		2.56 (1.70)	3.22 (2.96)	5.14 (3.91)	3.36 (2.99)	101.14
05317000	Cottonwood River near New Ulm, MN		2.85 (1.93)	3.98 (3.52)	5.97 (4.31)	4.05 (3.41)	109.72
05320000	Blue Earth River near Rapidan, MN		4.20 (2.95)	5.94 (3.92)	7.94 (5.51)	6.20 (4.33)	88.89
05320500	Le Sueur River near Rapidan, MN		4.48 (3.53)	6.99 (3.89)	8.86 (5.19)	6.85 (4.41)	97.86
05325000	Minnesota River at Mankato, MN	1.52 (1.27)	2.81 (1.58)	3.53 (2.12)	5.23 (3.12)	3.34 (2.44)	86.37
05330000	Minnesota River near Jordan, MN		2.92 (1.57)	3.78 (2.17)	5.45 (3.24)	3.82 (2.53)	86.73
Upper Mississippi River Basin (below Minnesota River)							
05331000	Mississippi River at St. Paul, MN	2.76 (1.60)	4.21 (1.67)	5.26 (2.05)	6.06 (2.49)	4.43 (2.18)	43.71
05333500	St. Croix River near Danbury, WI	10.44 (2.34)	11.84 (2.29)	11.94 (1.84)	11.73 (2.12)	11.27 (2.24)	- 0.97
05340500	St. Croix River at St. Croix Falls, WI	8.26 (2.96)	9.92 (2.80)	11.17 (2.7)	10.62 (2.92)	9.51 (3.05)	7.08
05344500	Mississippi River at Prescott, WI	3.75 (1.88)	5.24 (1.76)	6.26 (1.99)	6.78 (2.39)	5.57 (2.24)	29.32
05356500	Chippewa River near Bruce, WI	11.89 (3.80)	11.45 (2.96)	13.71 (2.28)	12.52 (3.52)	12.16 (3.25)	9.30
05365500	Chippewa River at Chippewa Falls, WI	12.26 (4.09)	11.28 (3.00)	13.29 (2.76)	11.92 (3.16)	12.03 (3.29)	5.69
05369500	Chippewa River at Durand, WI	11.40 (3.69)	10.41 (2.44)	12.87 (2.16)	11.92 (2.71)	11.56 (2.87)	14.54
05378500	Mississippi River at Winona, MN	5.09 (1.97)	6.08 (1.74)	7.56 (1.94)	8.18 (2.39)	6.78 (2.29)	34.51
05385000	Root River at Houston, MN	7.23 (2.06)	6.68 (1.91)	8.89 (3.53)	11.24 (2.67)	8.31 (3.06)	68.22
05457000	Cedar River near Austin, MN		5.77 (2.72)	8.68 (4.38)	11.18 (5.31)	8.53 (4.70)	93.74
05476000	Des Moines River at Jackson, MN		2.77 (1.98)	4.17 (4.02)	6.07 (5.07)	4.32 (3.88)	118.69

Table 5: Average annual (water year) runoff coefficients for the watersheds of the USGS stream gaging stations for different time periods and the period of record (P.O.R.). Change in average runoff from the 1946-1965 to the 1986-2005 period is also given.

USGS No.	Station Name	Water Year Average (St. Dev.) Runoff Coefficients					% Change from 1946 - 1965 to 1986 - 2005
		1926-1945	1946-1965	1966-1985	1986-2005	P.O.R	
Tributaries to Lake Superior Basin							
04010500	Pigeon River near Grand Portage, MN	0.44 (0.09)	0.38 (0.12)	0.44 (0.1)	0.36 (0.09)	0.40 (0.11)	-4.05
04024000	St. Louis River at Scanlan, MN	0.34 (0.08)	0.34 (0.09)	0.38 (0.1)	0.36 (0.07)	0.34 (0.09)	6.25
Red River of the North Basin							
05054000	Red River of the North at Fargo, ND	0.03 (0.03)	0.06 (0.03)	0.07 (0.04)	0.1 (0.05)	0.06 (0.05)	77.58
05059500	Sheyenne River at West Fargo, ND	0.03 (0.02)	0.04 (0.02)	0.06 (0.03)	0.08 (0.05)	0.05 (0.04)	108.97
05062000	Buffalo River near Dilworth, MN		0.09 (0.04)	0.09 (0.06)	0.13 (0.07)	0.10 (0.06)	48.43
05079000	Red Lake River at Crookston, MN	0.07 (0.06)	0.13 (0.07)	0.17 (0.07)	0.15 (0.08)	0.13 (0.07)	10.47
05082500	Red River of the North at Grand Forks, ND	0.04 (0.03)	0.07 (0.03)	0.09 (0.04)	0.11 (0.05)	0.07 (0.04)	55.07
05092000	Red River of the North at Drayton, ND		0.07 (0.04)	0.09 (0.04)	0.1 (0.05)	0.09 (0.05)	56.06
05104500	Roseau River near Malung, MN		0.31 (0.16)	0.34 (0.2)	0.33 (0.21)	0.32 (0.19)	8.28
Rainy River Basin							
05127500	Basswood River near Winton, MN		0.38 (0.13)	0.43 (0.11)	0.36 (0.09)	0.38 (0.11)	-3.97
05128000	Namakan River at outlet of Lac La Croix	0.36 (0.11)	0.37 (0.11)	0.4 (0.11)	0.35 (0.1)	0.36 (0.11)	-3.98
05130500	Sturgeon River near Chisholm, MN		0.31 (0.08)	0.36 (0.09)	0.33 (0.09)	0.33 (0.09)	8.11
05131500	Little Fork River at Littlefork, MN	0.29 (0.09)	0.31 (0.08)	0.37 (0.11)	0.31 (0.08)	0.32 (0.1)	0.98
05133500	Rainy River at Manitou Rapids, MN	0.31 (0.1)	0.34 (0.09)	0.37 (0.1)	0.33 (0.09)	0.34 (0.1)	-2.26
Mississippi Headwaters Basin							
05211000	Mississippi River at Grand Rapids, MN	0.12 (0.08)	0.21 (0.07)	0.23 (0.08)	0.22 (0.07)	0.2 (0.09)	9.09
05227500	Mississippi River at Aitkin, MN		0.24 (0.07)	0.25 (0.08)	0.24 (0.06)	0.24 (0.07)	2.53
05280000	Crow River at Rockford, MN		0.12 (0.06)	0.17 (0.08)	0.21 (0.09)	0.15 (0.09)	78.75
05286000	Rum River near St. Francis, MN		0.21 (0.08)	0.26 (0.09)	0.22 (0.08)	0.22 (0.09)	7.20
05288500	Mississippi River near Anoka, MN		0.21 (0.06)	0.24 (0.07)	0.24 (0.05)	0.21 (0.07)	16.32

Table 5: Continued.

USGS No.	Station Name	Water Year Average (St. Dev.) Runoff Coefficients					% Change from 1946 - 1965 to 1986 - 2005
		1926-1945	1946-1965	1966-1985	1986-2005	P.O.R	
Minnesota River Basin							
05291000	Whetstone River at Big Stone City, SD		0.09 (0.07)	0.09 (0.06)	0.12 (0.09)	0.09 (0.07)	38.57
05292000	Minnesota River at Ortonville, MN		0.06 (0.05)	0.05 (0.05)	0.09 (0.07)	0.07 (0.06)	49.99
05304500	Chippewa River near Milan, MN		0.08 (0.05)	0.11 (0.06)	0.16 (0.08)	0.11 (0.07)	115.35
05311000	Minnesota River at Montevideo, MN	0.03 (0.03)	0.08 (0.05)	0.08 (0.05)	0.13 (0.08)	0.08 (0.06)	74.00
05313500	Yellow Medicine River at Granite Falls, MN		0.09 (0.07)	0.1 (0.09)	0.15 (0.09)	0.11 (0.08)	56.55
05315000	Redwood River near Marshall, MN		0.1 (0.06)	0.11 (0.1)	0.18 (0.13)	0.13 (0.1)	87.99
05316500	Redwood River near Redwood Falls, MN		0.1 (0.06)	0.11 (0.09)	0.17 (0.1)	0.12 (0.09)	78.08
05317000	Cottonwood River near New Ulm, MN		0.11 (0.06)	0.14 (0.11)	0.2 (0.11)	0.14 (0.1)	86.10
05320000	Blue Earth River near Rapidan, MN		0.14 (0.08)	0.19 (0.11)	0.23 (0.12)	0.19 (0.11)	67.15
05320500	Le Sueur River near Rapidan, MN		0.15 (0.1)	0.23 (0.12)	0.26 (0.11)	0.21 (0.12)	78.50
05325000	Minnesota River at Mankato, MN	0.06 (0.04)	0.11 (0.05)	0.13 (0.07)	0.18 (0.09)	0.12 (0.08)	69.84
05330000	Minnesota River near Jordan, MN		0.11 (0.05)	0.14 (0.07)	0.19 (0.09)	0.14 (0.08)	69.96
Upper Mississippi River Basin (below Minnesota River)							
05331000	Mississippi River at St. Paul, MN	0.11 (0.05)	0.16 (0.05)	0.19 (0.06)	0.21 (0.07)	0.16 (0.07)	33.51
05333500	St. Croix River near Danbury, WI	0.35 (0.05)	0.4 (0.06)	0.38 (0.06)	0.37 (0.05)	0.37 (0.06)	-6.39
05340500	St. Croix River at St. Croix Falls, WI	0.29 (0.08)	0.34 (0.07)	0.36 (0.08)	0.34 (0.06)	0.32 (0.08)	-0.85
05344500	Mississippi River at Prescott, WI	0.15 (0.06)	0.19 (0.05)	0.22 (0.06)	0.23 (0.06)	0.2 (0.06)	20.38
05356500	Chippewa River near Bruce, WI	0.39 (0.1)	0.38 (0.07)	0.42 (0.07)	0.39 (0.08)	0.39 (0.08)	3.46
05365500	Chippewa River at Chippewa Falls, WI	0.39 (0.1)	0.37 (0.07)	0.41 (0.08)	0.38 (0.07)	0.38 (0.08)	2.35
05369500	Chippewa River at Durand, WI	0.37 (0.09)	0.34 (0.06)	0.4 (0.07)	0.37 (0.06)	0.37 (0.07)	7.83
05378500	Mississippi River at Winona, MN	0.19 (0.06)	0.22 (0.05)	0.26 (0.06)	0.27 (0.06)	0.24 (0.06)	24.48
05385000	Root River at Houston, MN	0.24 (0.05)	0.23 (0.06)	0.27 (0.09)	0.33 (0.05)	0.26 (0.07)	41.79
05457000	Cedar River near Austin, MN		0.2 (0.08)	0.27 (0.12)	0.33 (0.11)	0.27 (0.12)	67.58
05476000	Des Moines River at Jackson, MN		0.1 (0.07)	0.15 (0.12)	0.2 (0.13)	0.15 (0.11)	93.69

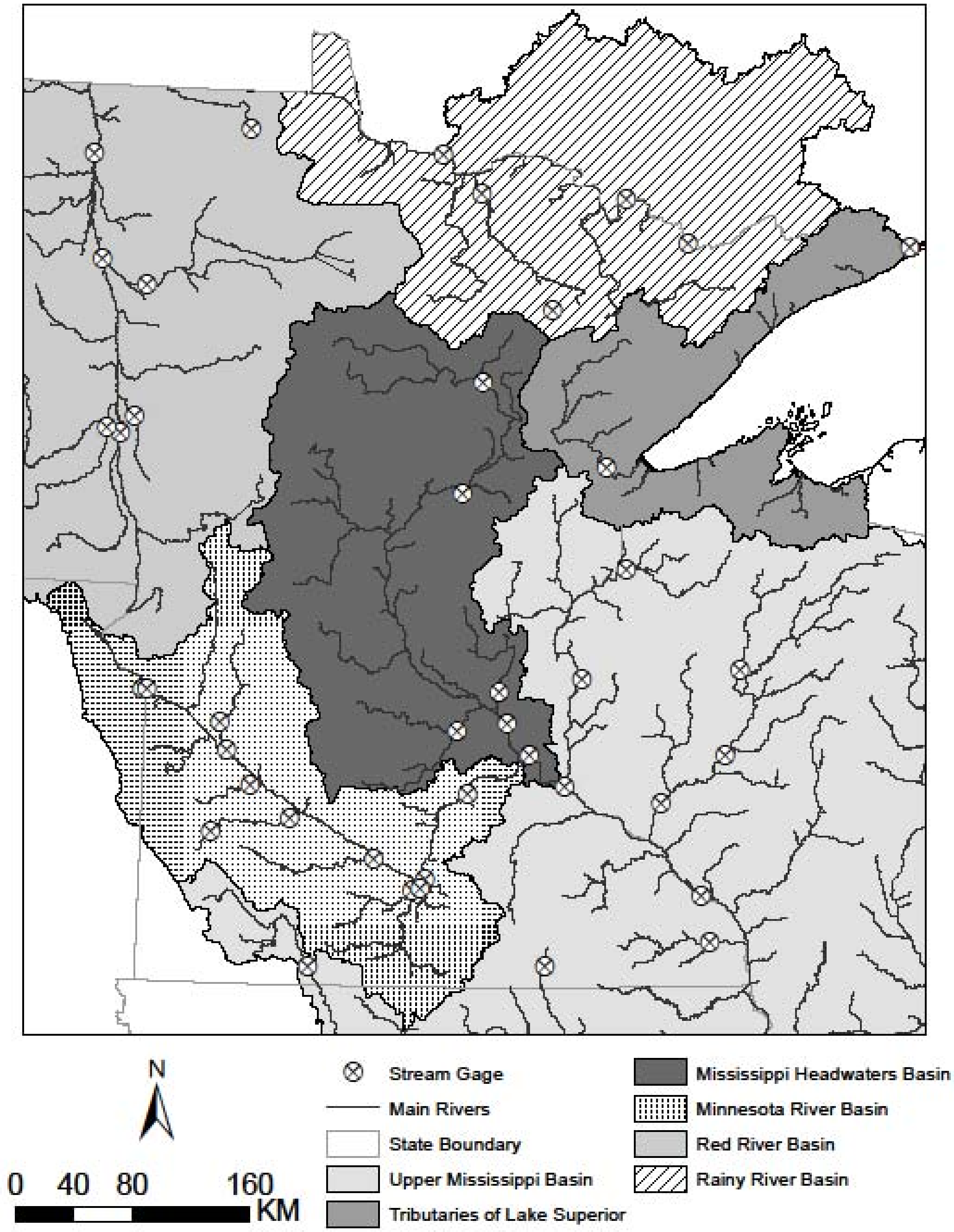


Figure 1: Major river basins of the Upper Midwest and USGS stream gage locations. Mississippi Headwaters and the Minnesota River Basins are part of the Upper Mississippi River Basin.

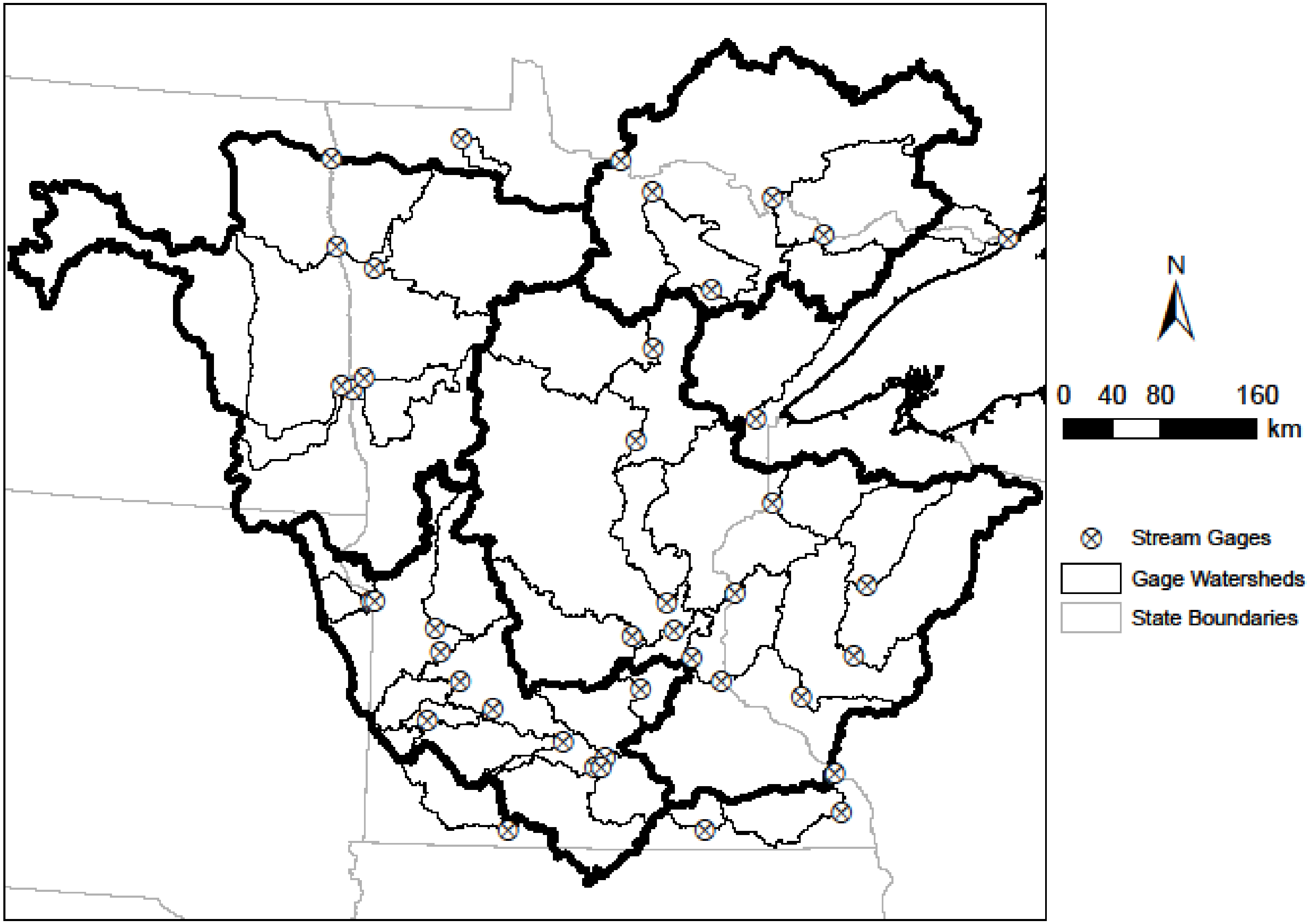


Figure 2: Watershed boundaries for each USGS stream gage. Major river basins (bold lines) are divided into tributary watersheds (thin lines).

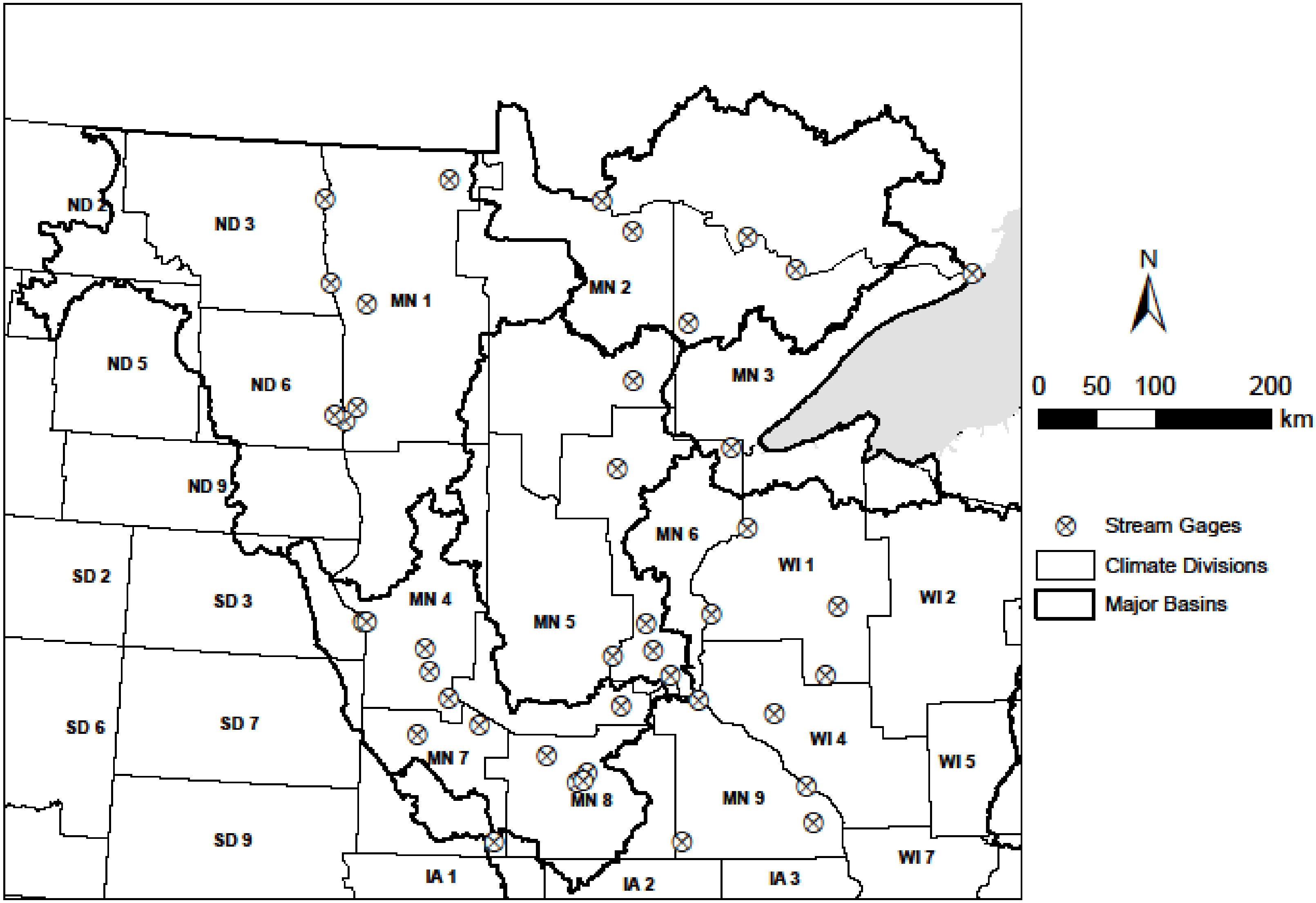


Figure 3: Upper Midwest climate divisions (NOAA), major river basins, and USGS stream gaging stations studied.

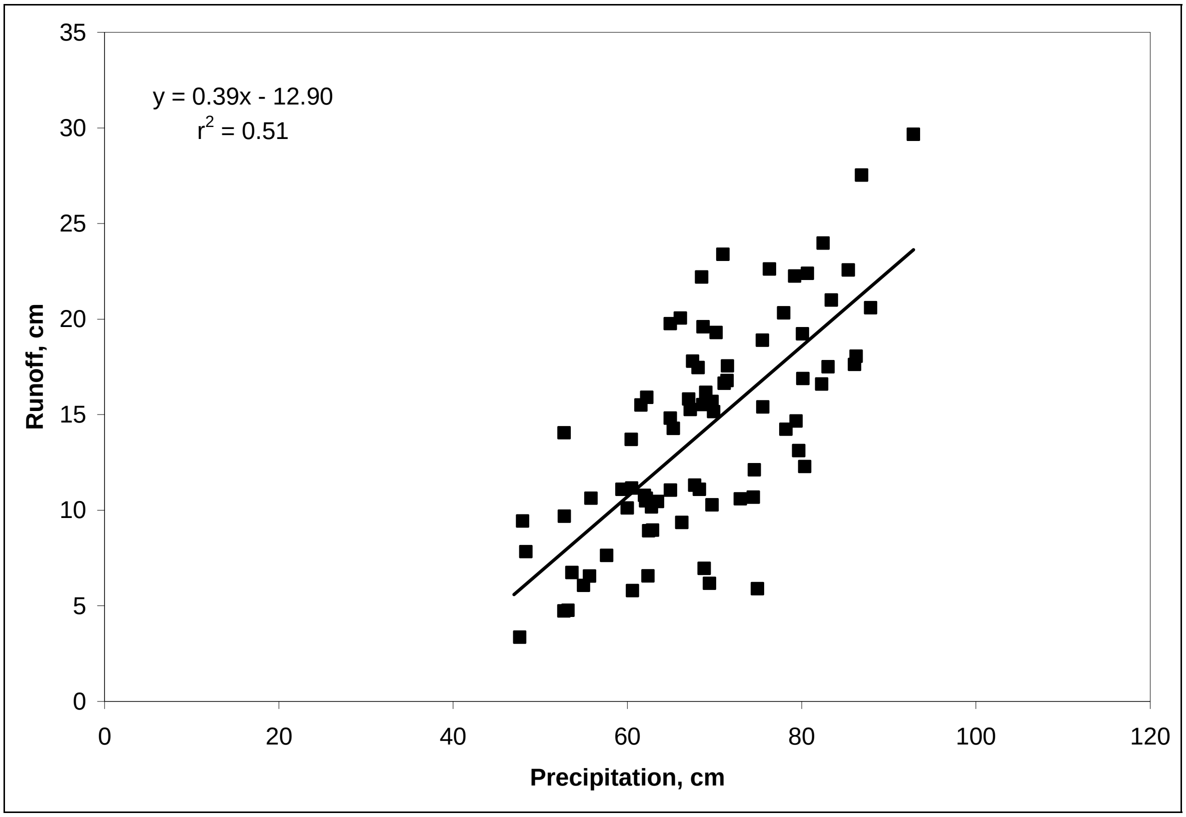


Figure 4: Annual average runoff in the Mississippi River near Prescott, WI, vs. annual precipitation in the watershed at the water year time scale.

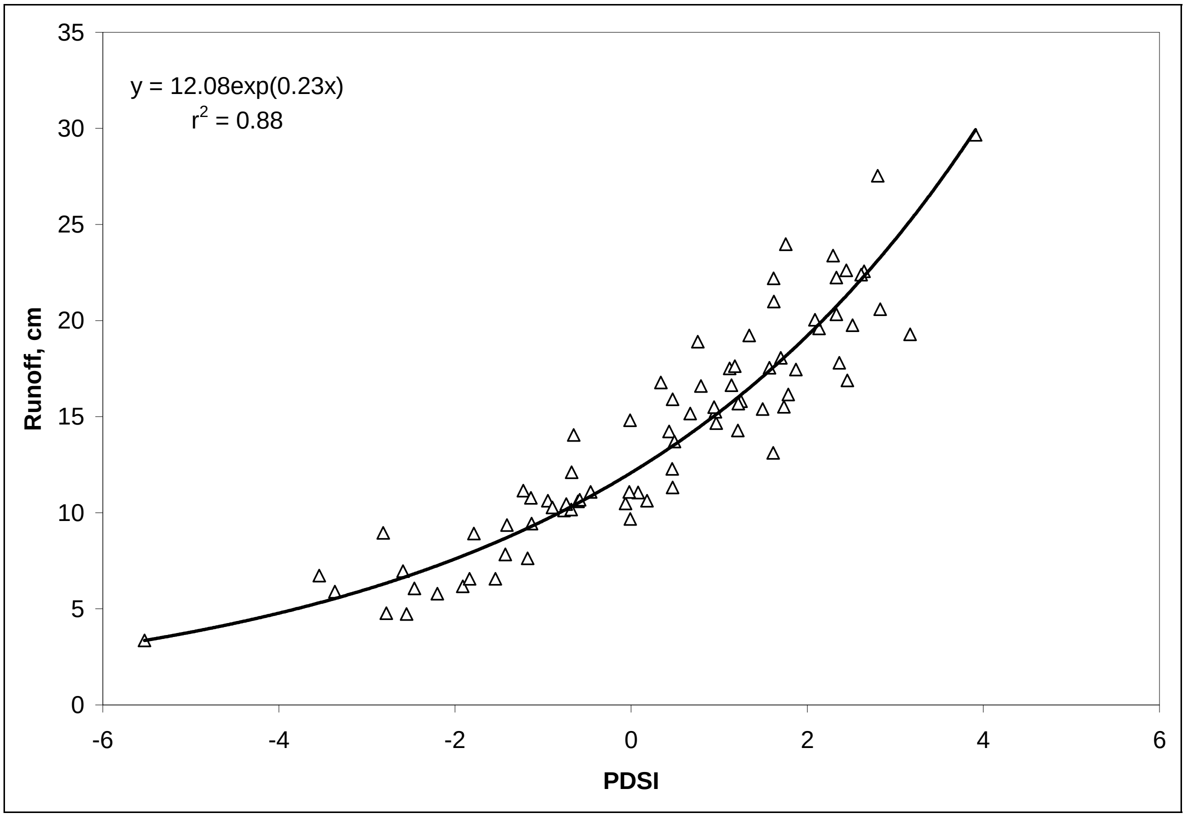


Figure 5: Annual average runoff in the Mississippi River near Prescott, WI, vs. annual average PDSI in the watershed at the water year time scale.

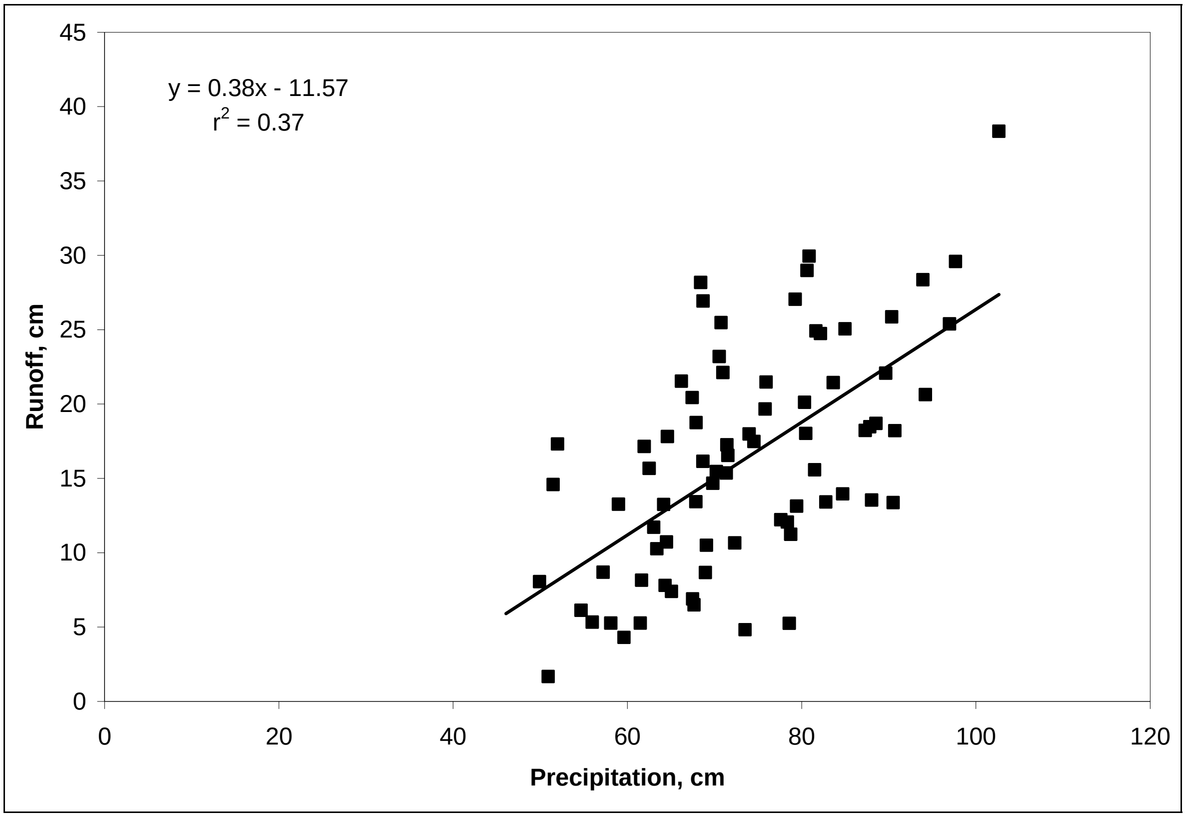


Figure 6: Annual average runoff in the Rum River near St. Francis, MN, vs. annual precipitation in the watershed at the water year time scale.

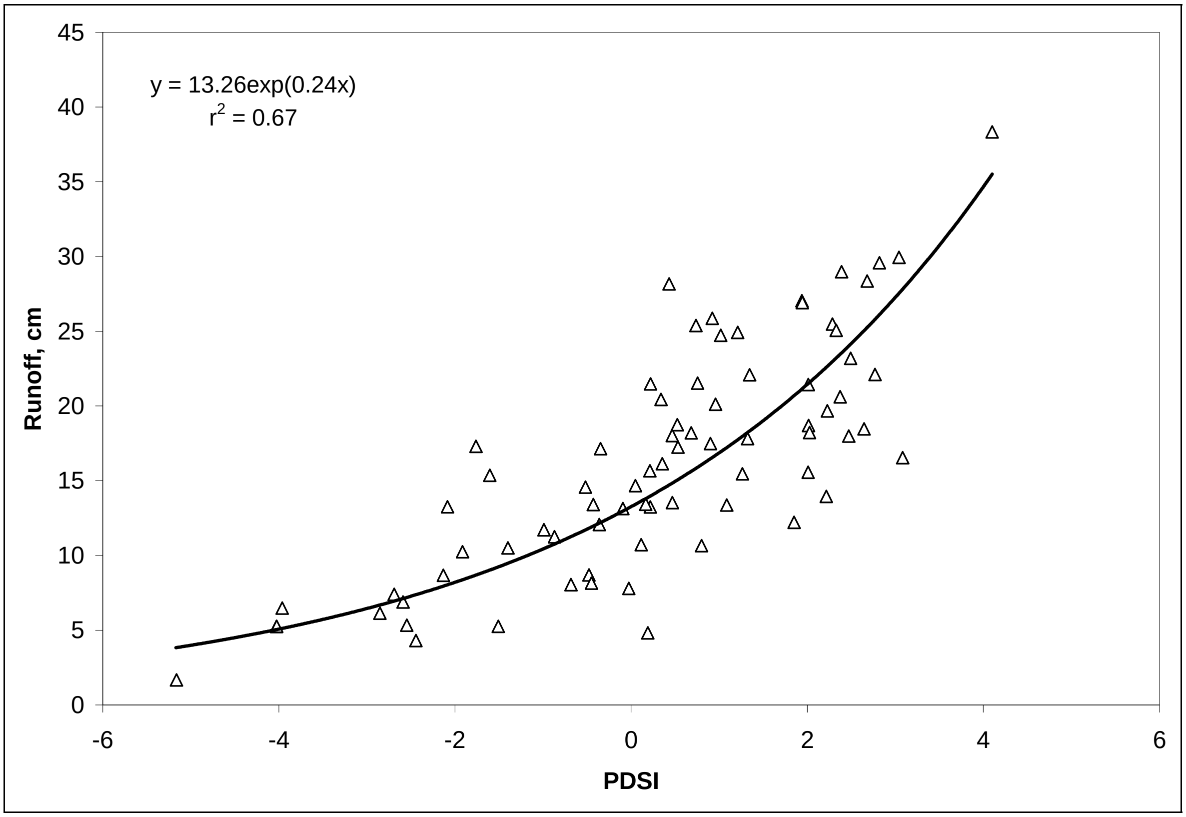


Figure 7: Annual average runoff in the Rum River near St. Francis, MN, vs. annual average PDSI in the watershed at the water year time scale.

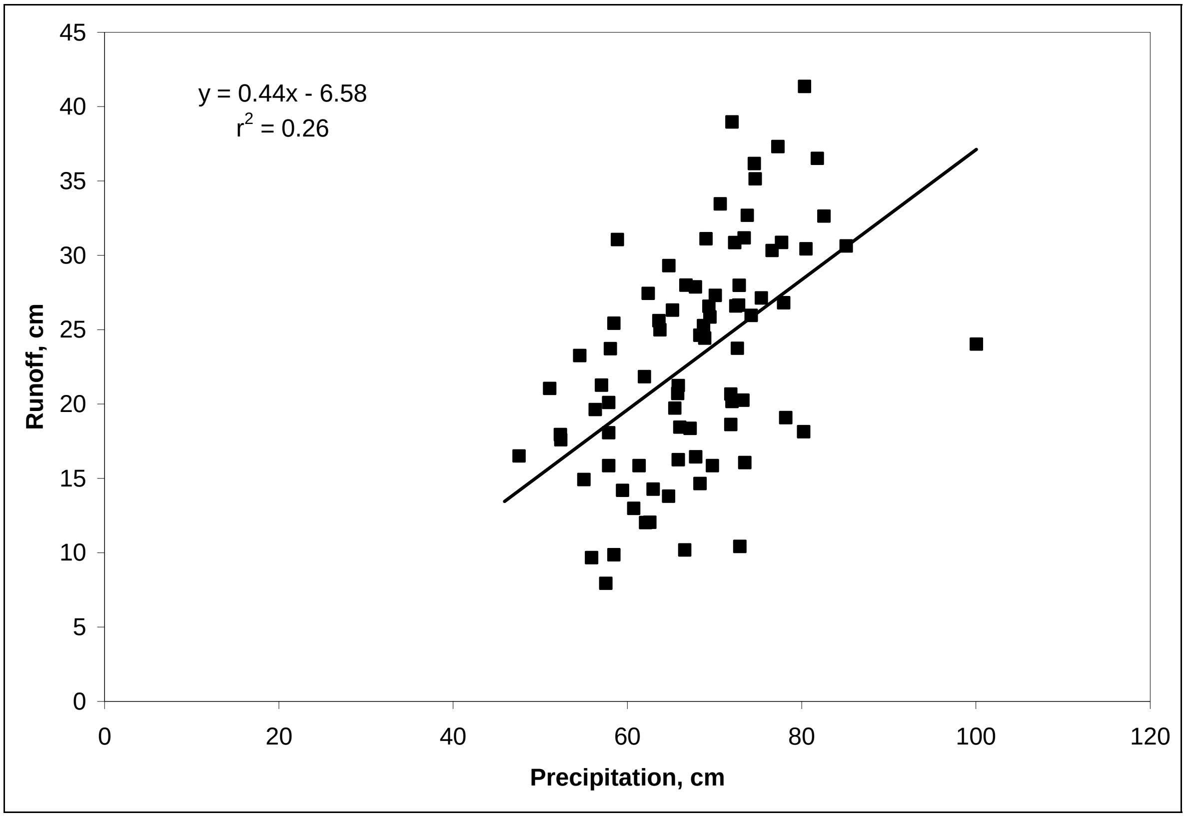


Figure 8: Annual average runoff in the Pigeon River at Grand Portage, MN, vs. annual precipitation in the watershed at the water year time scale.

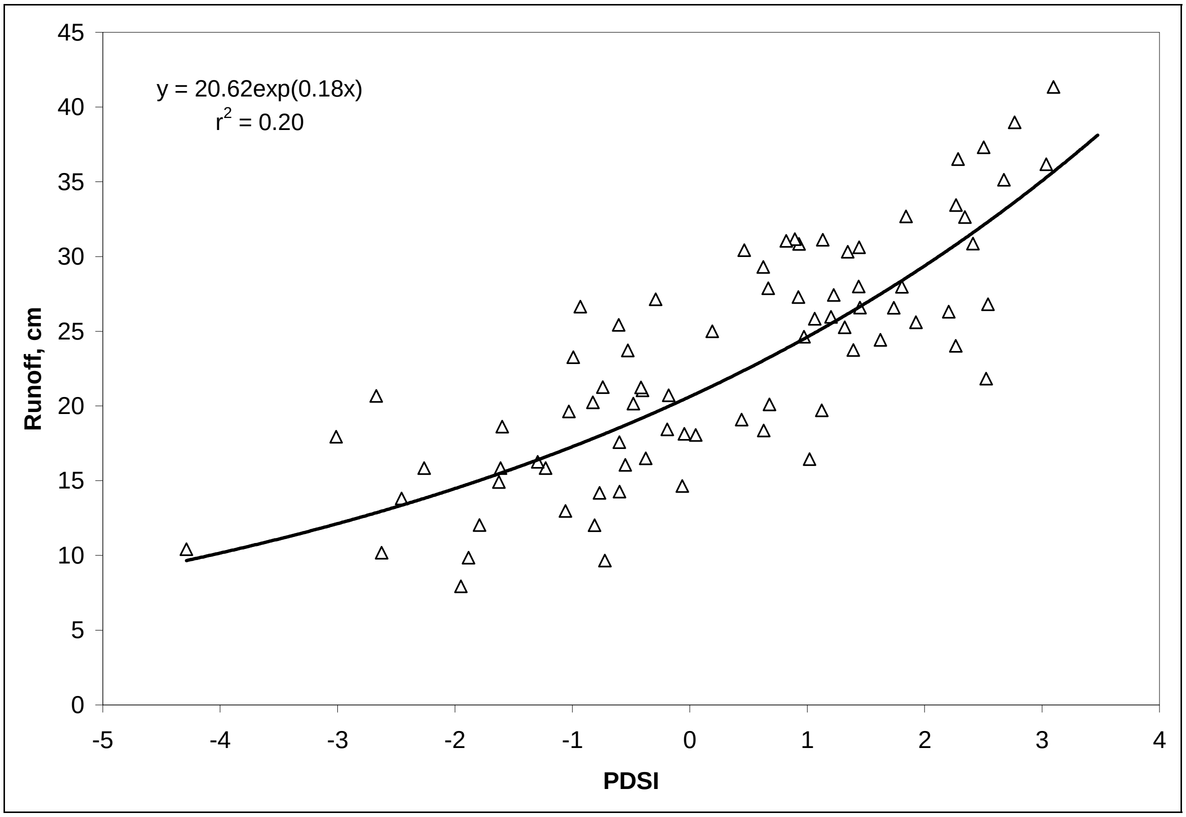


Figure 9: Average annual runoff in the Pigeon River at Grand Portage, MN, vs. annual average PDSI in the watershed at the water year time scale.

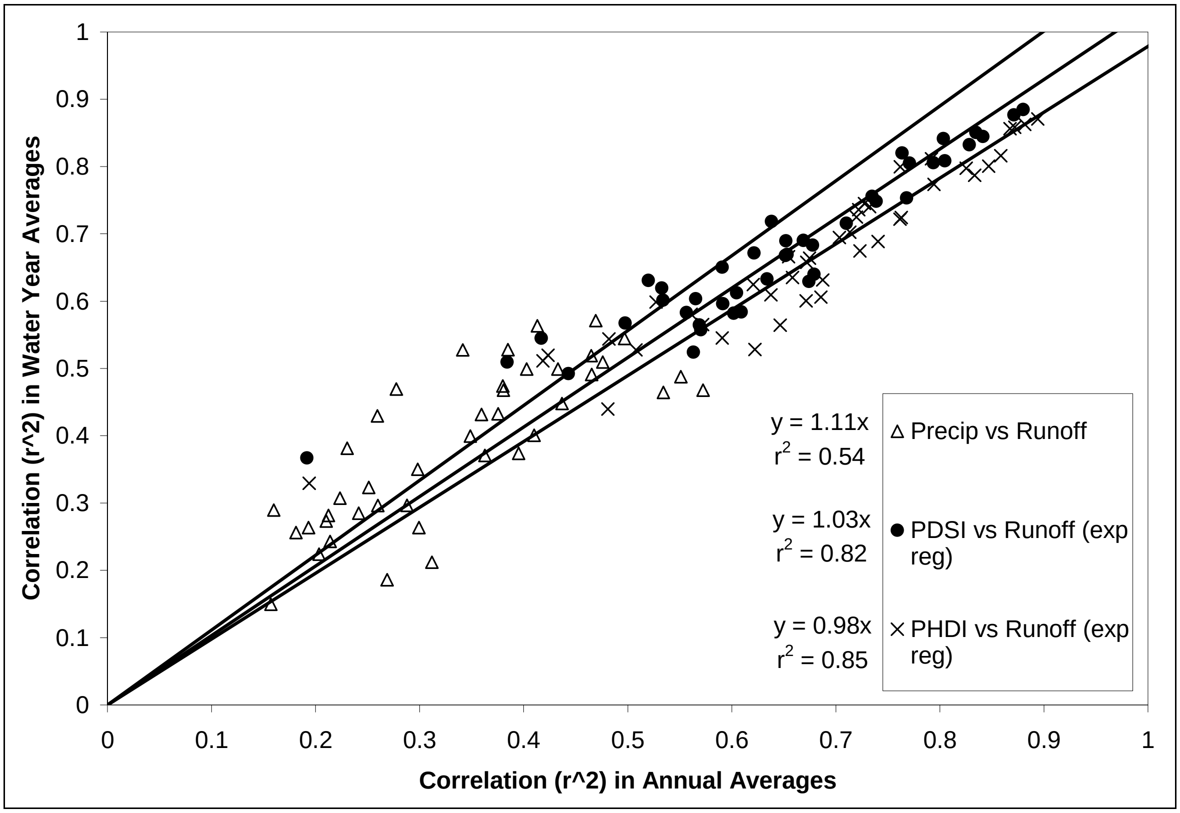


Figure 10: Average water year vs. calendar year correlation strengths between runoff and precipitation, PDSI, or PHDI.

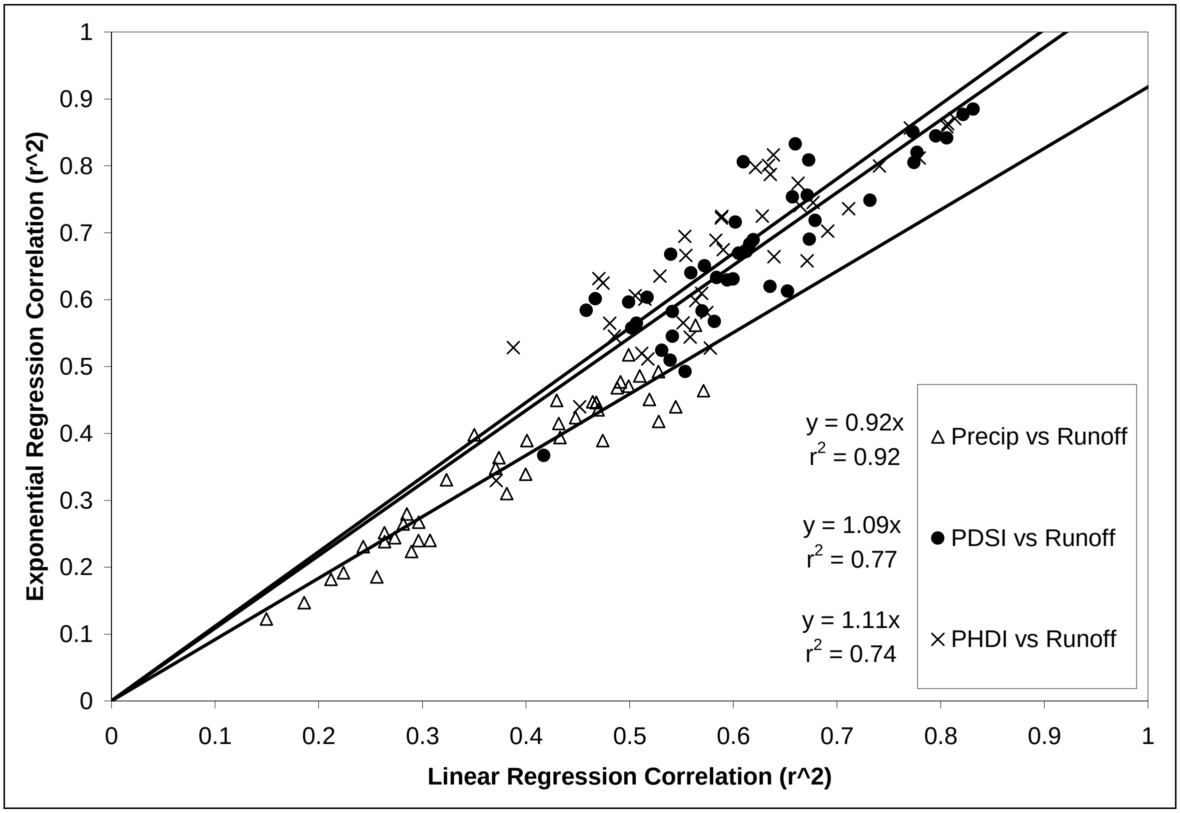


Figure 11: Exponential regression correlation vs. linear regression correlation strengths between runoff and precipitation, PDSI and PHDI at the water year time scale.

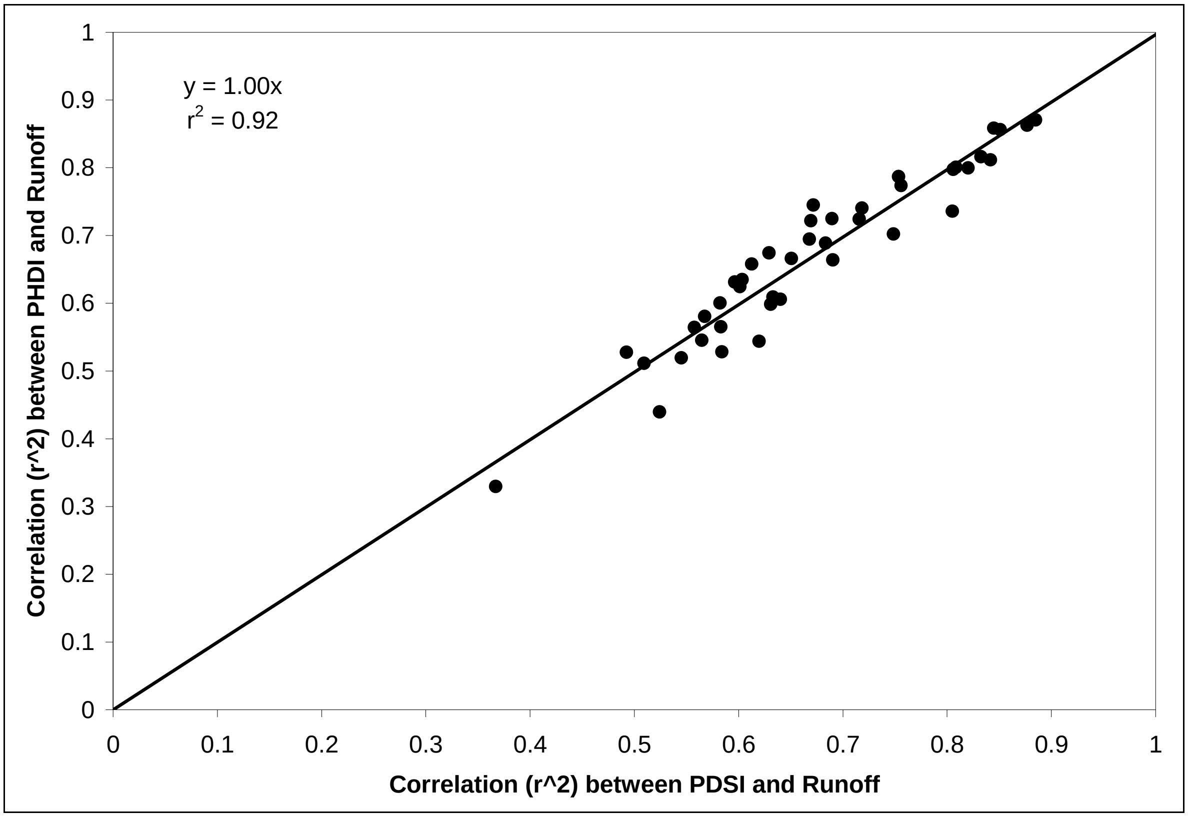


Figure 12: PHDI vs. PDSI correlation strengths as predictors of runoff at the water year time scale.

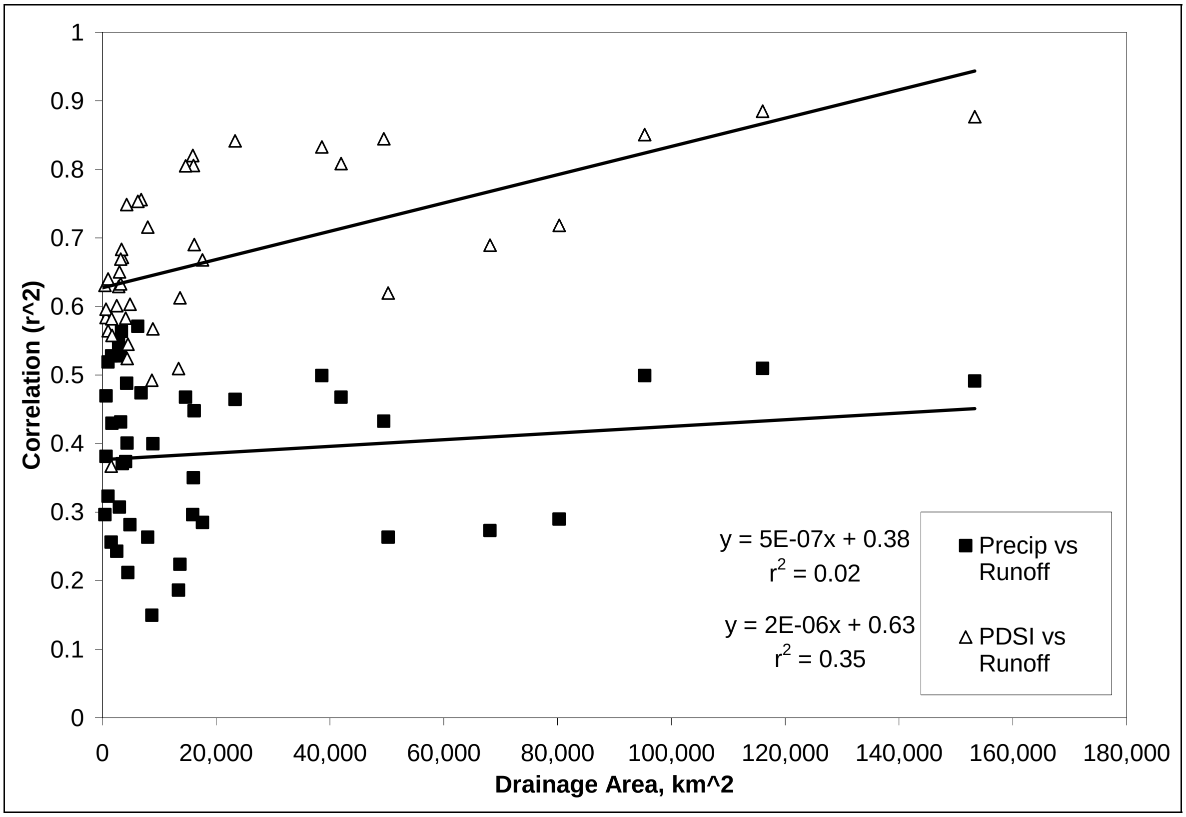


Figure 13: Correlation strength between runoff and precipitation or PDSI vs. drainage area at the water year time scale.

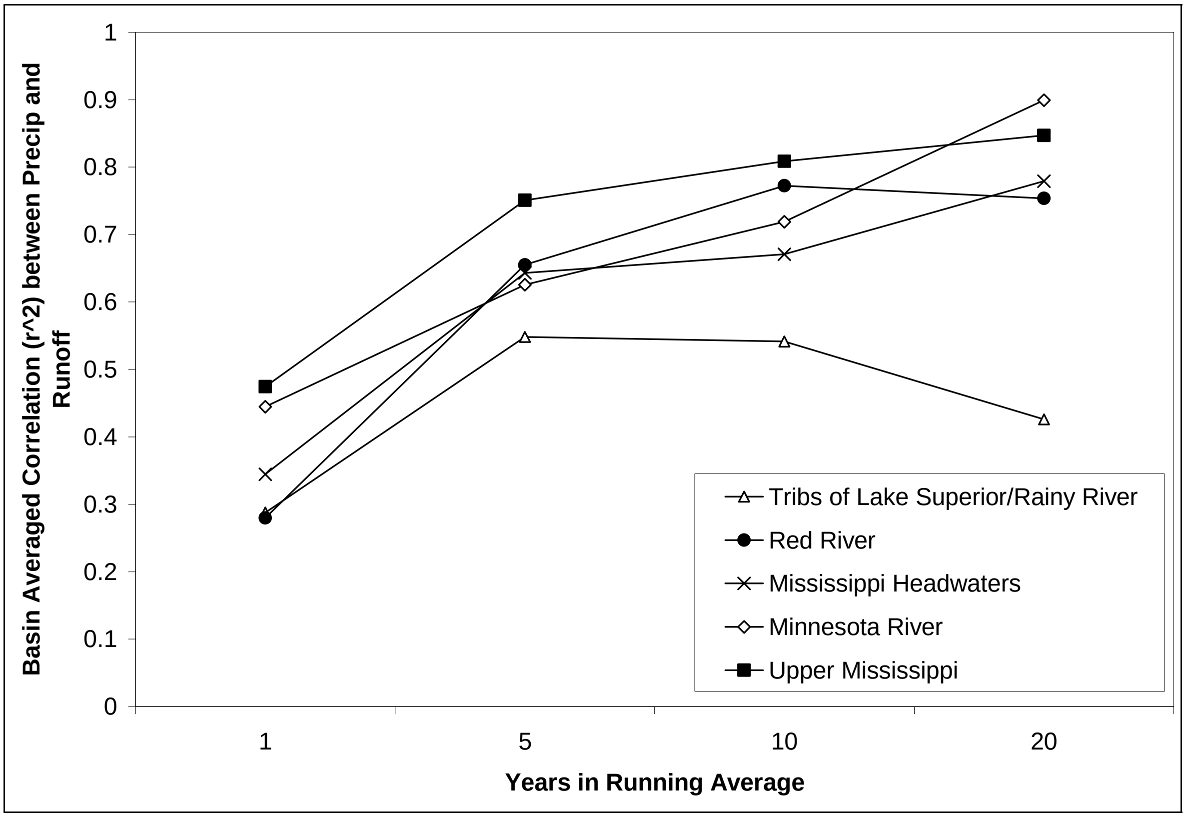


Figure 14: Basin average strengths of correlations between running average runoff and precipitation at the 1-year to 20-year running average time scales.

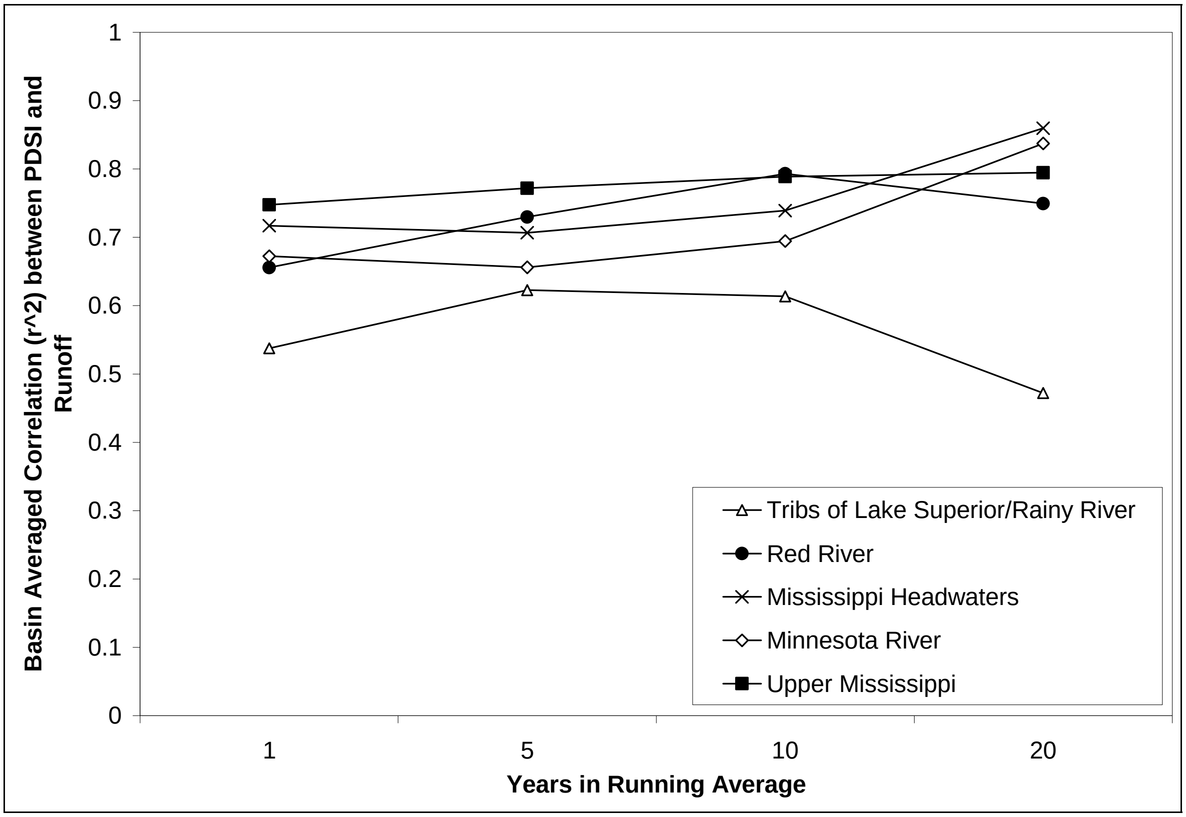


Figure 15: Basin average strengths of correlations between running average runoff and PDSI at the 1-year to 20-year running average time scale.

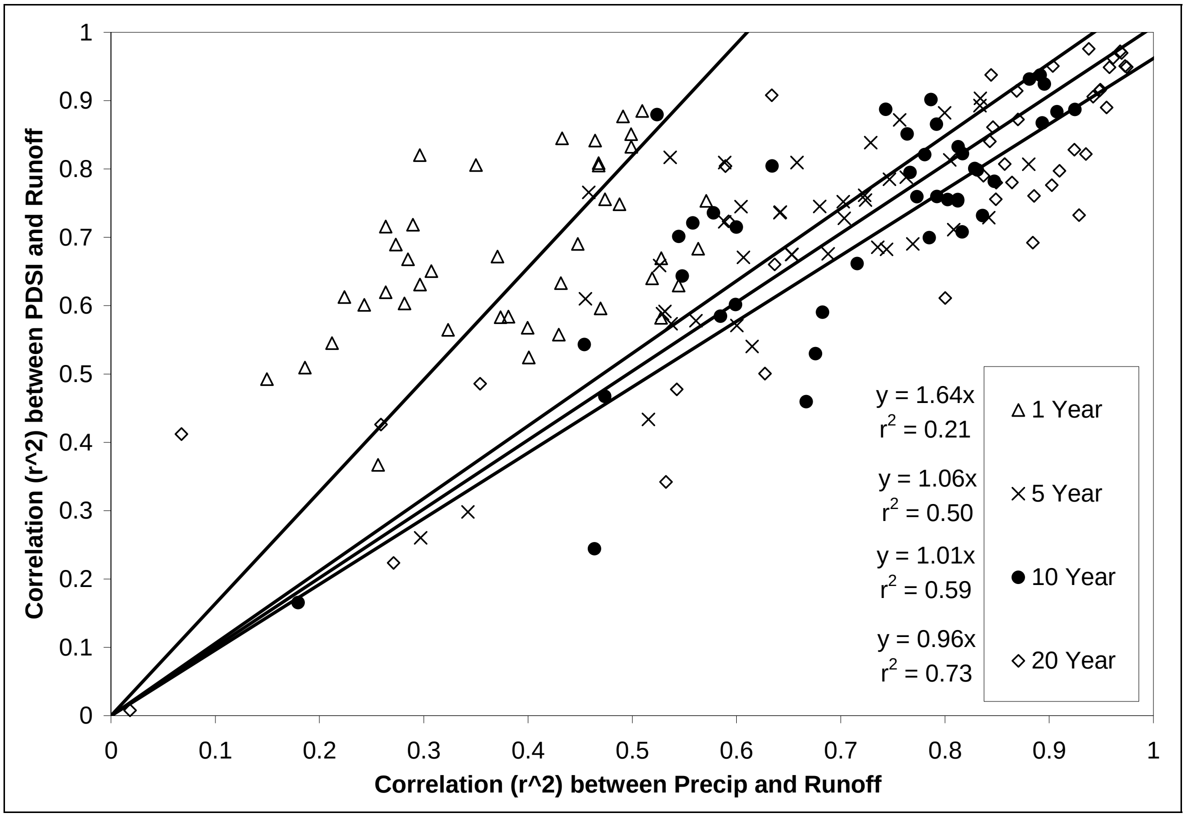


Figure 16: Strengths of correlation between average runoff and PDSI vs. strengths of correlation between average runoff and precipitation at the 1-year to 20-year running average time scales.

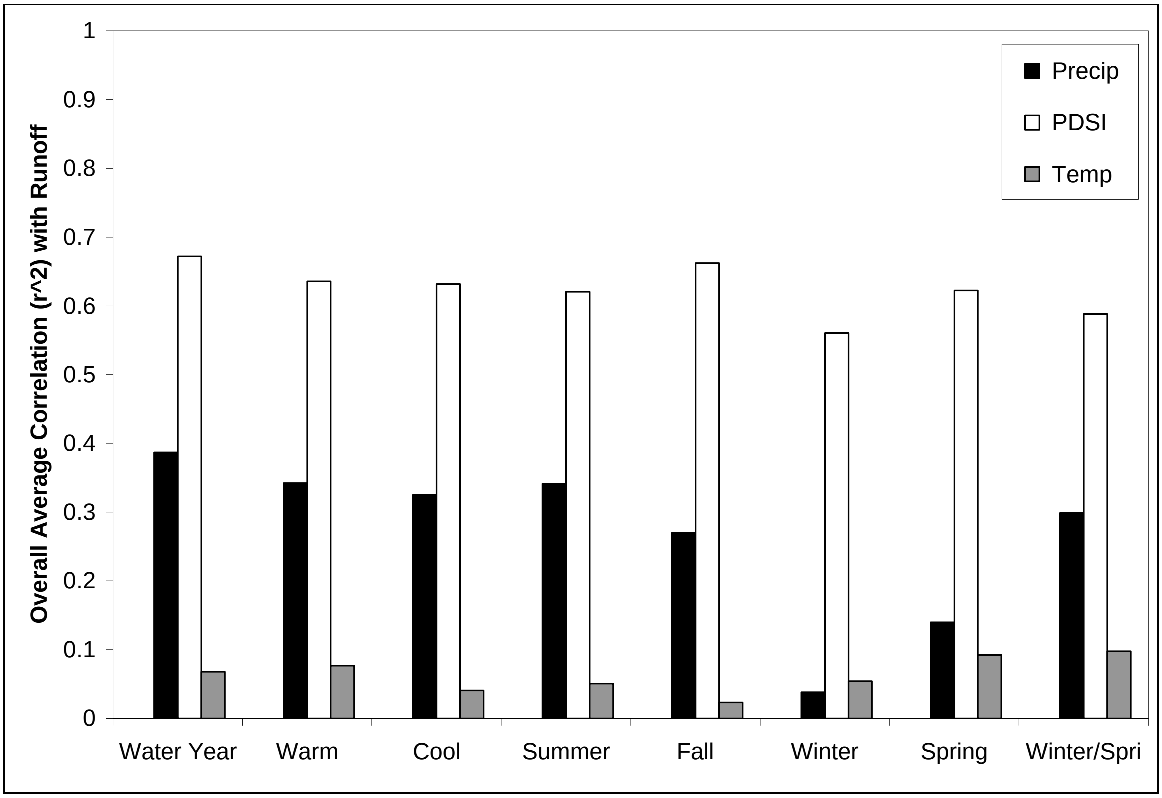


Figure 17: Overall average correlation strengths between climatic variables and runoff at seasonal time scales. Earlier results for the annual time scale are given on the left for comparison.

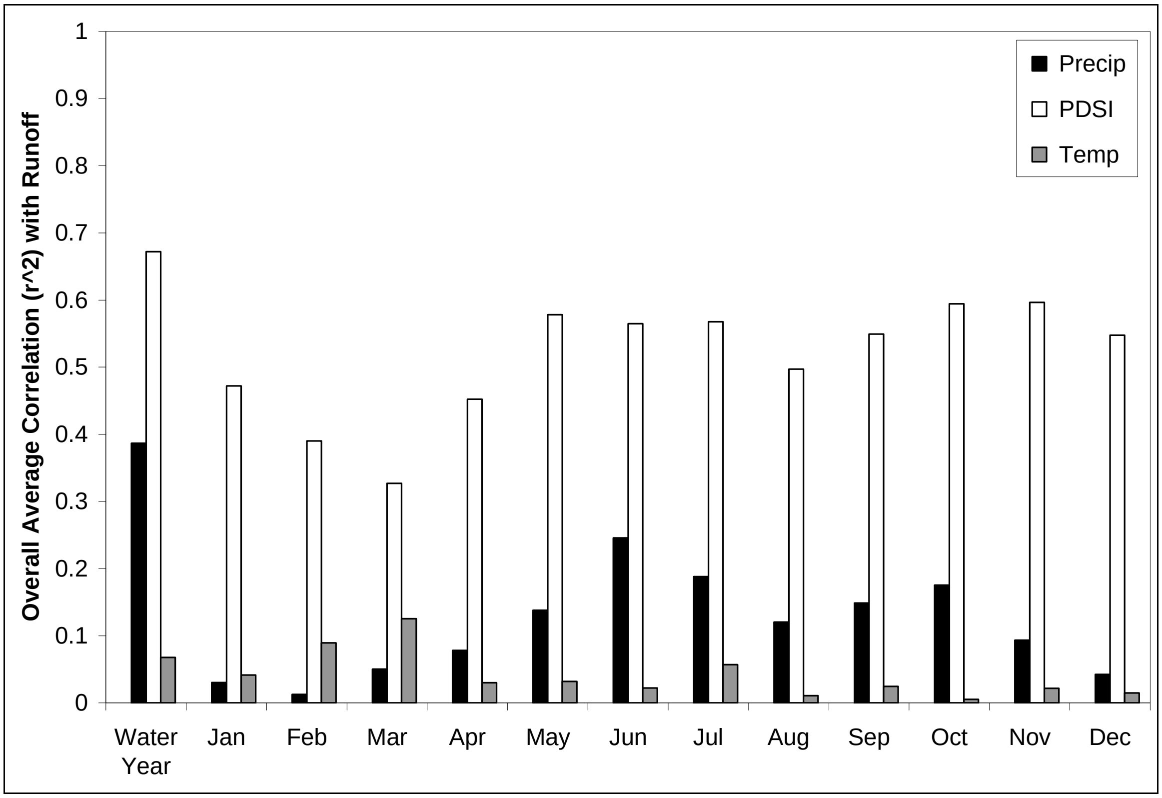
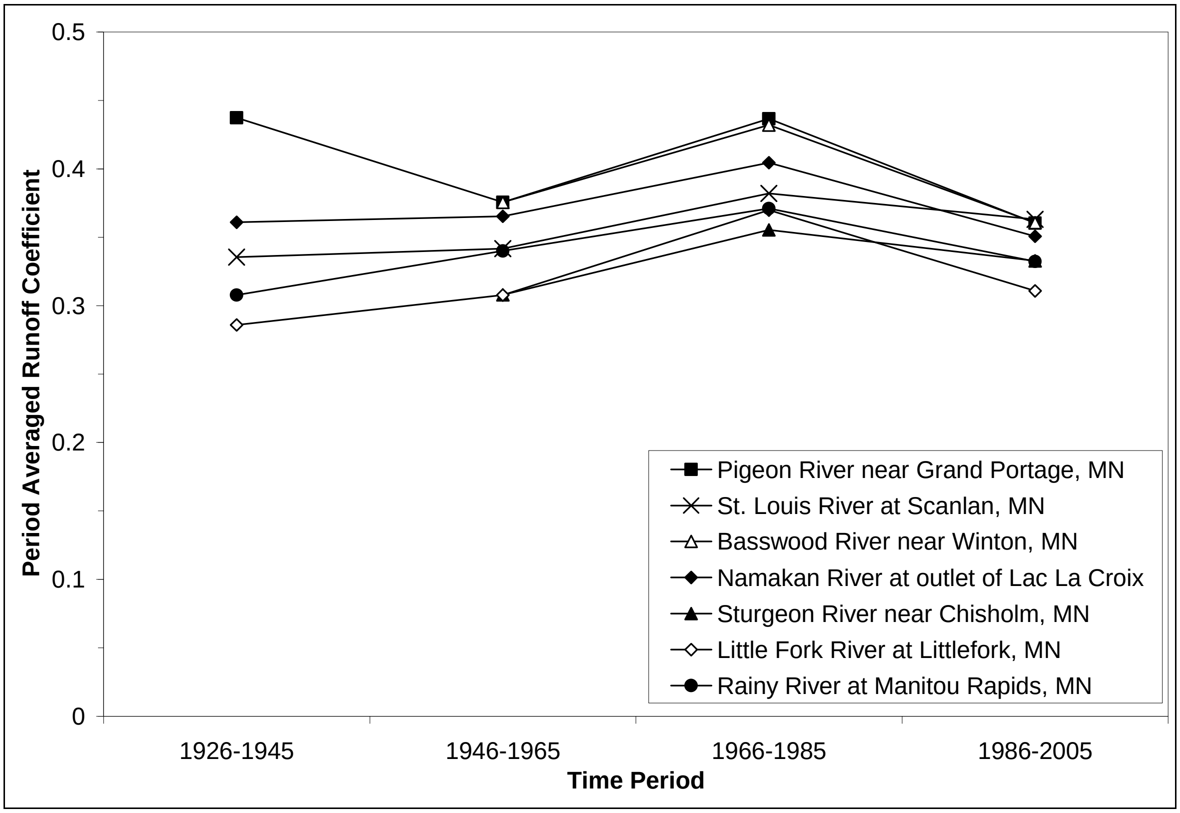


Figure 18: Overall average correlation strengths between climatic variables and stream runoff at the monthly time scale. Earlier results for the annual time scale are given on the left for comparison.



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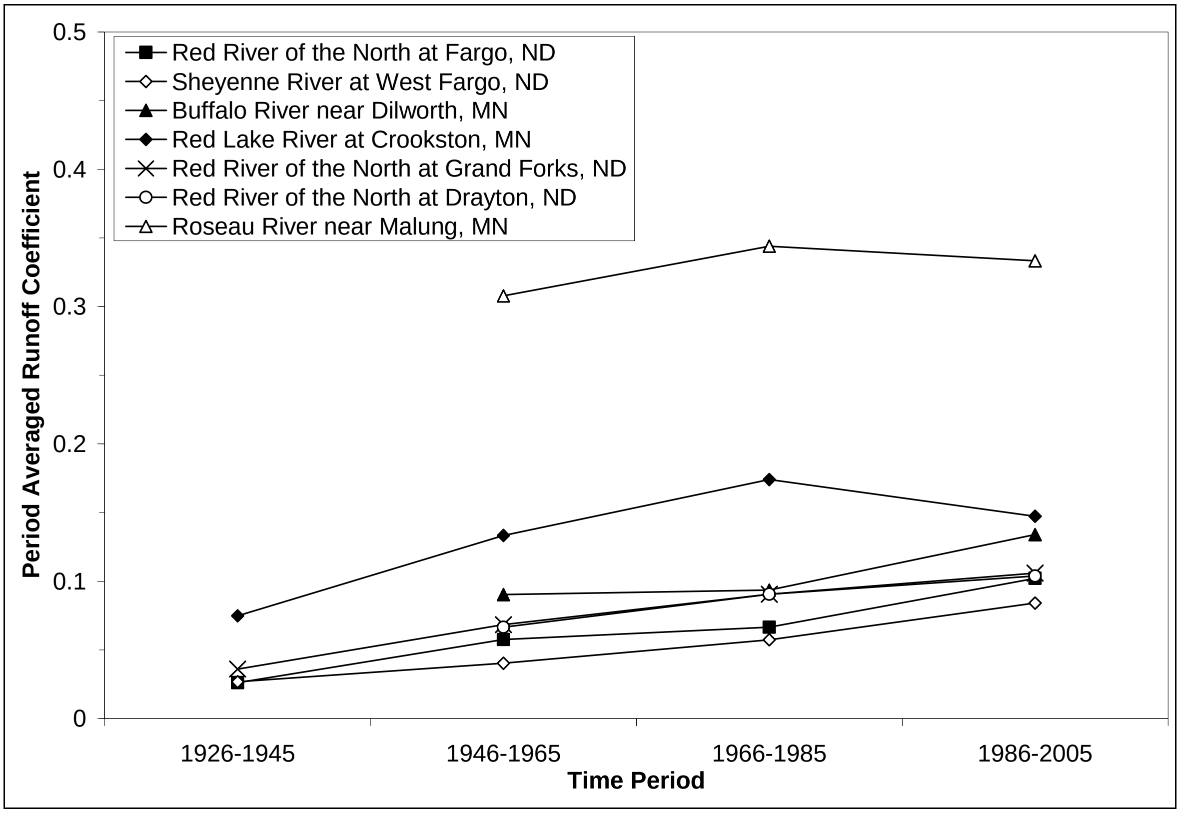

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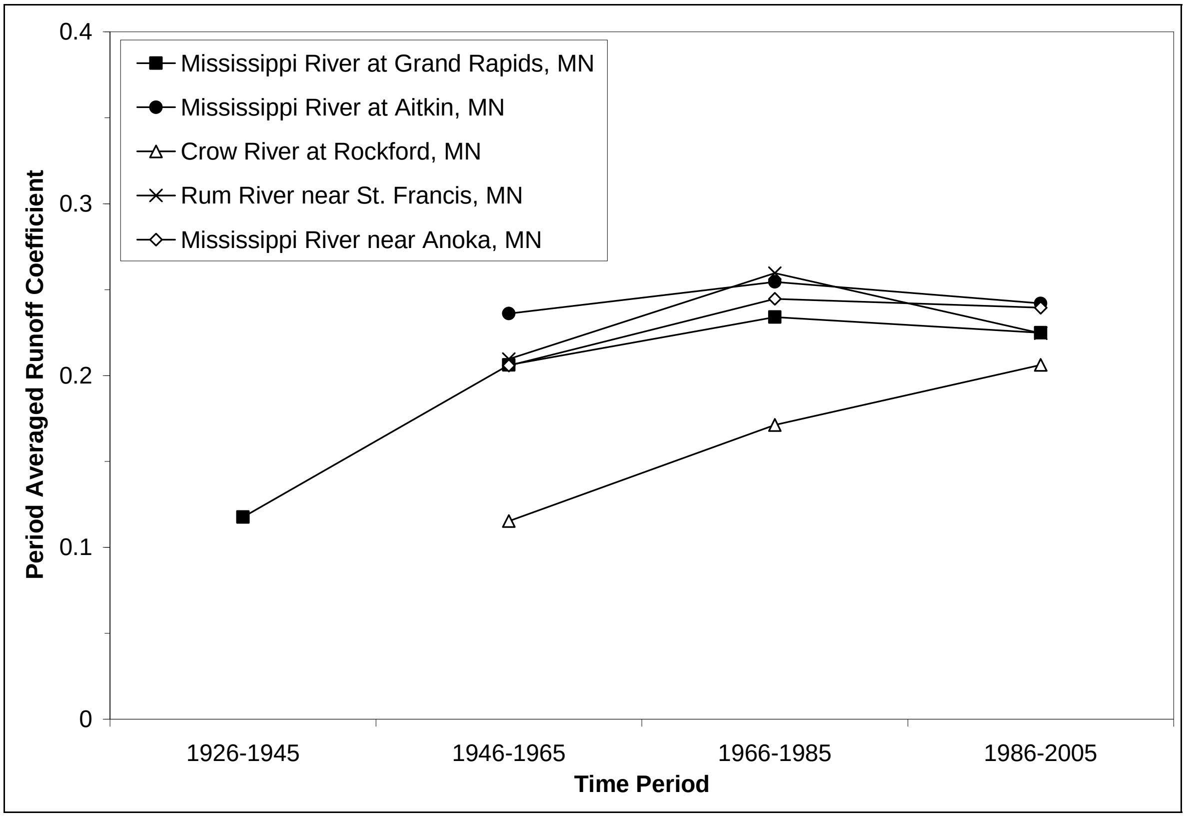

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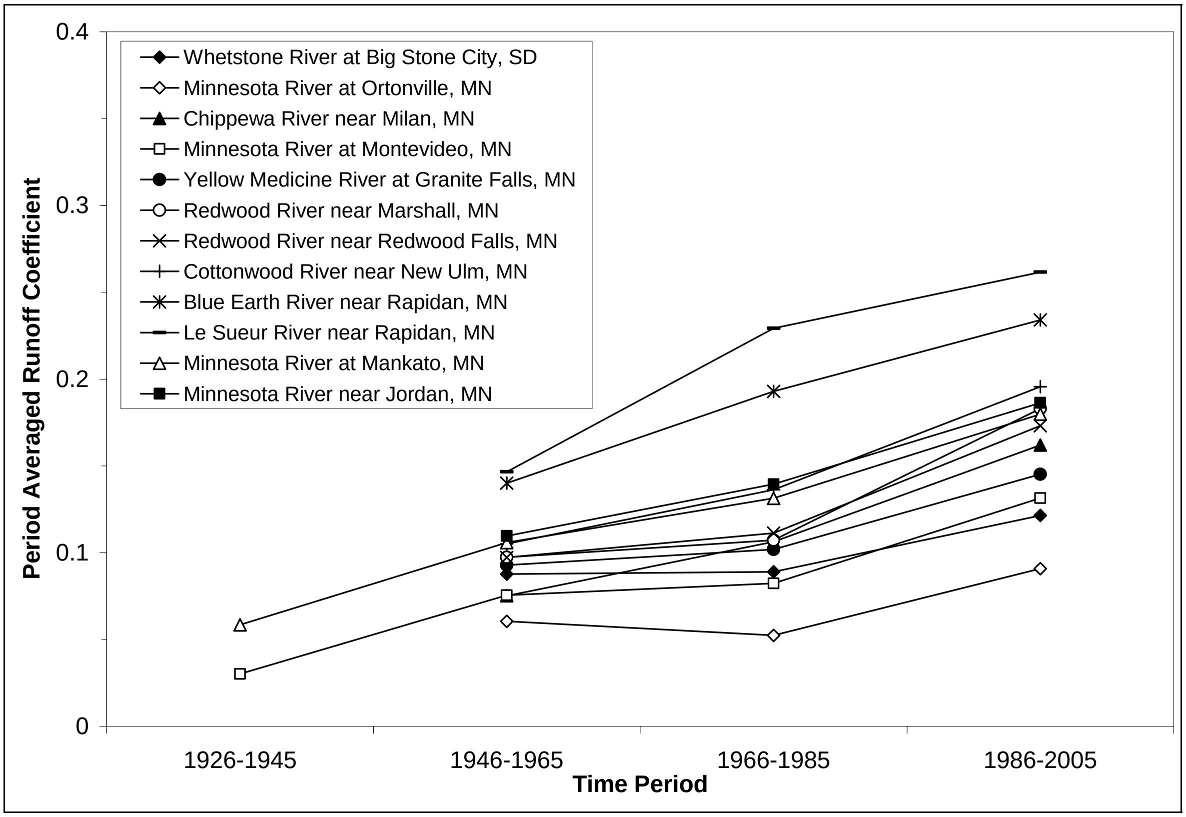

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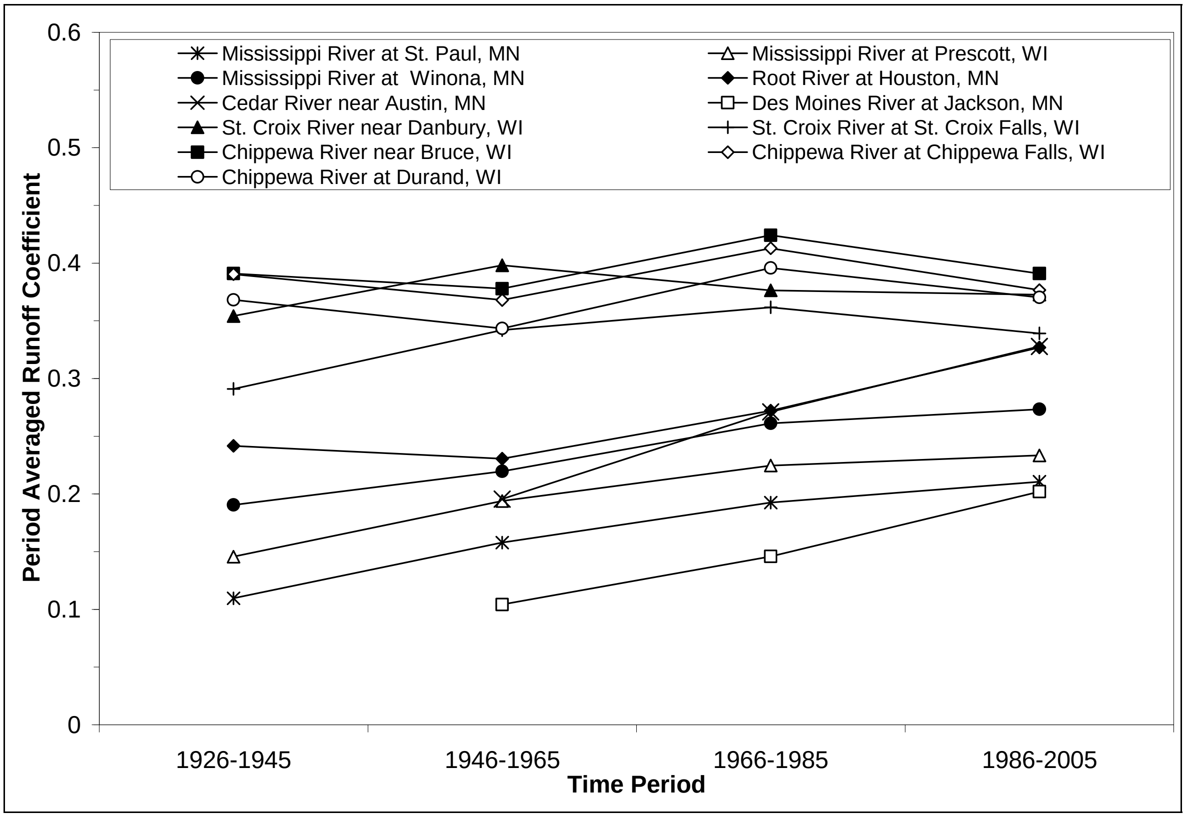

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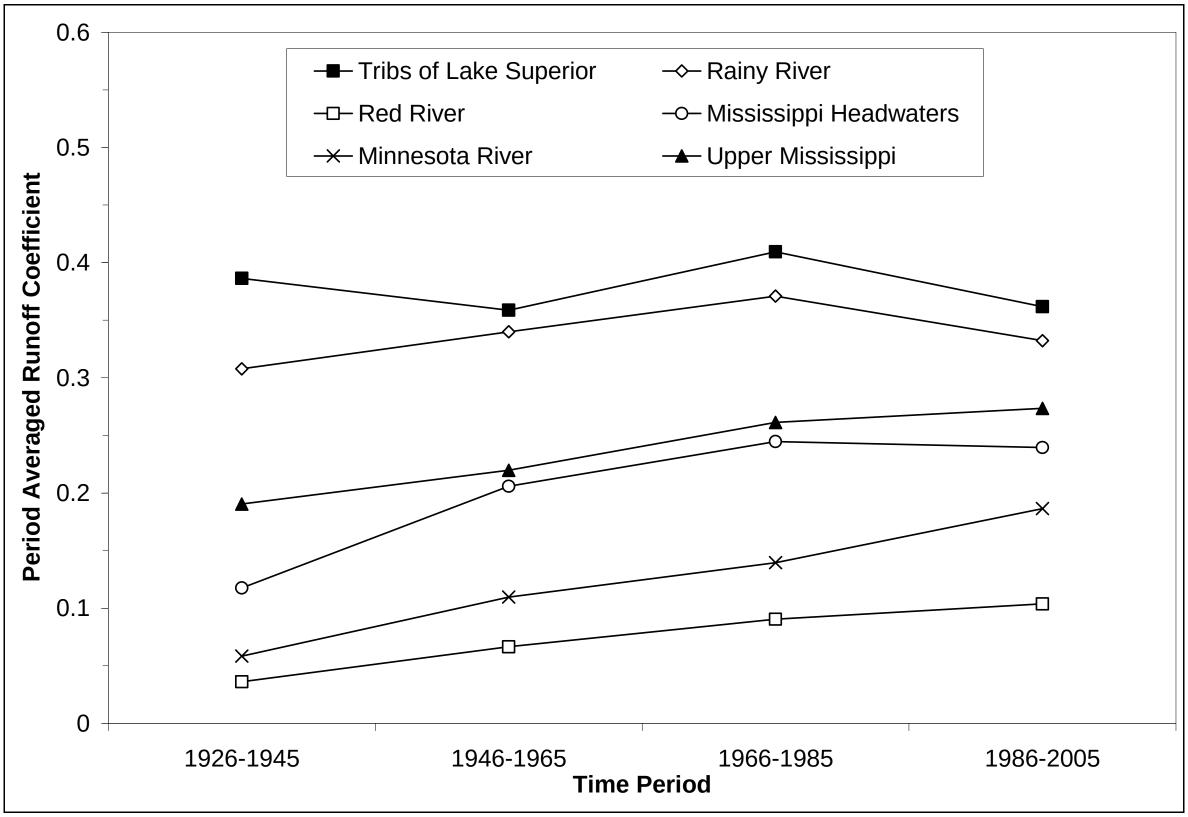

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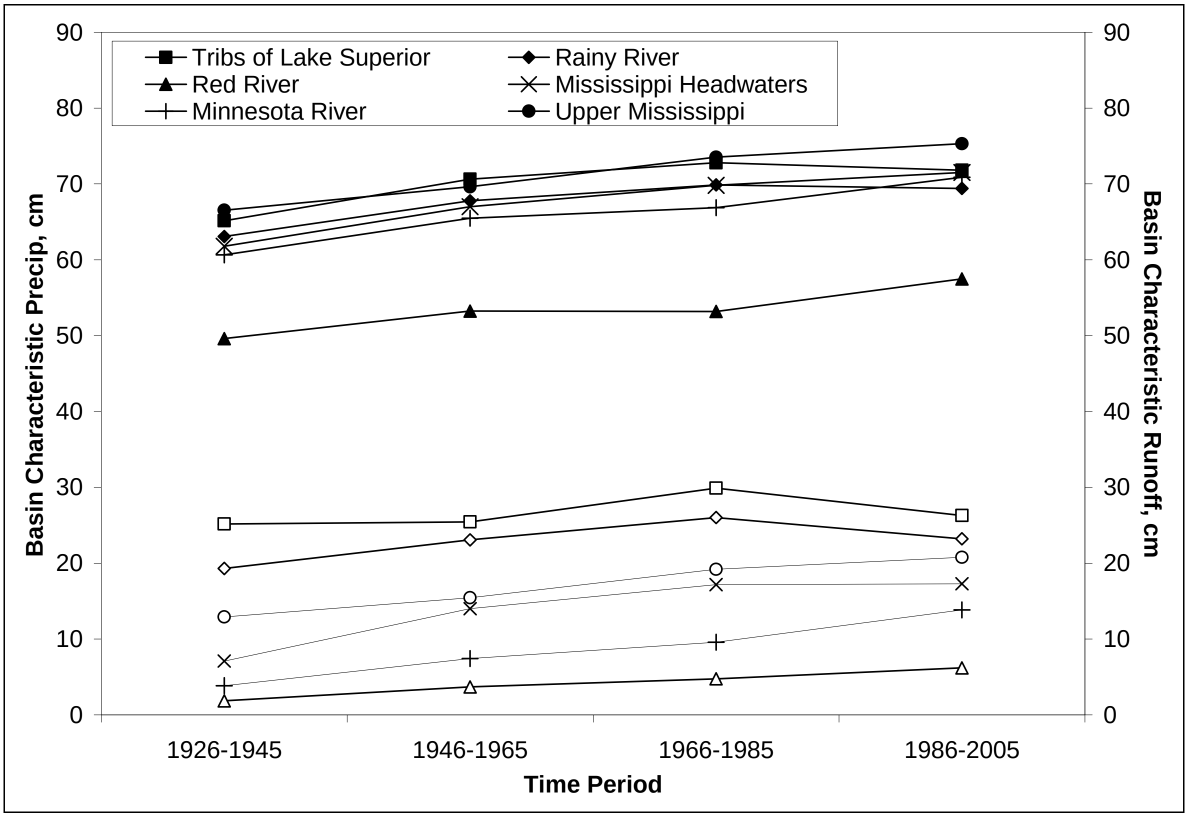

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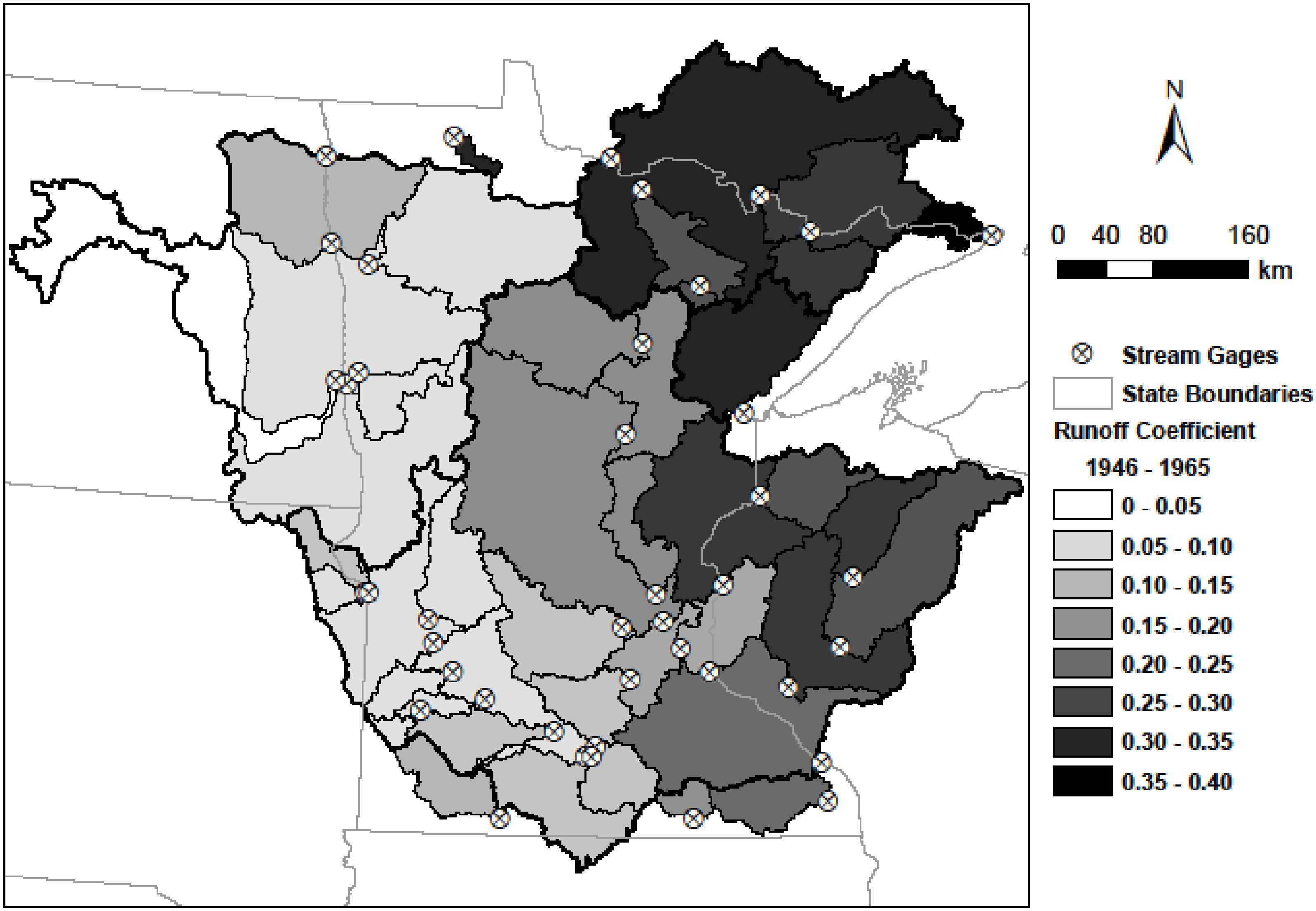

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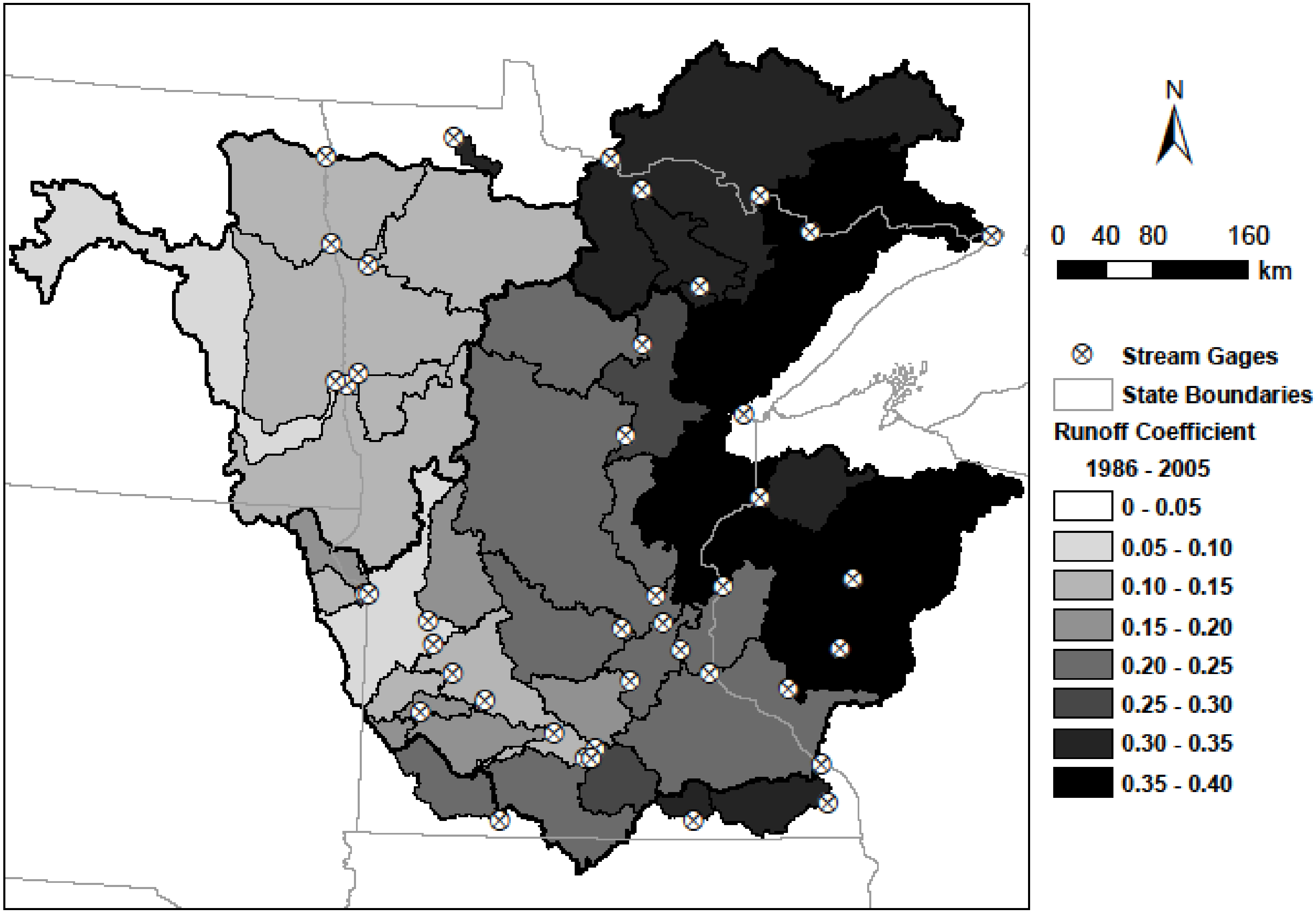

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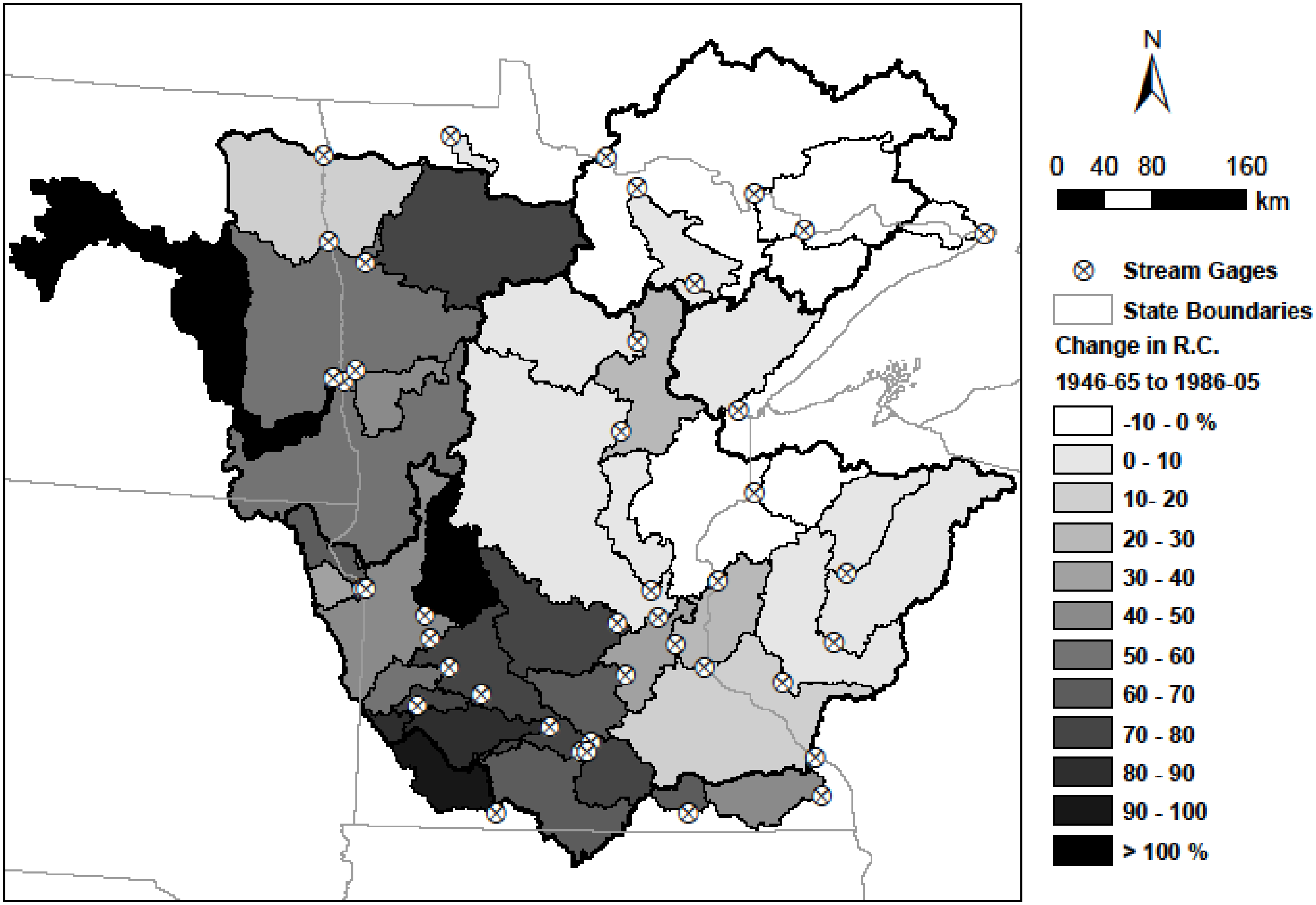

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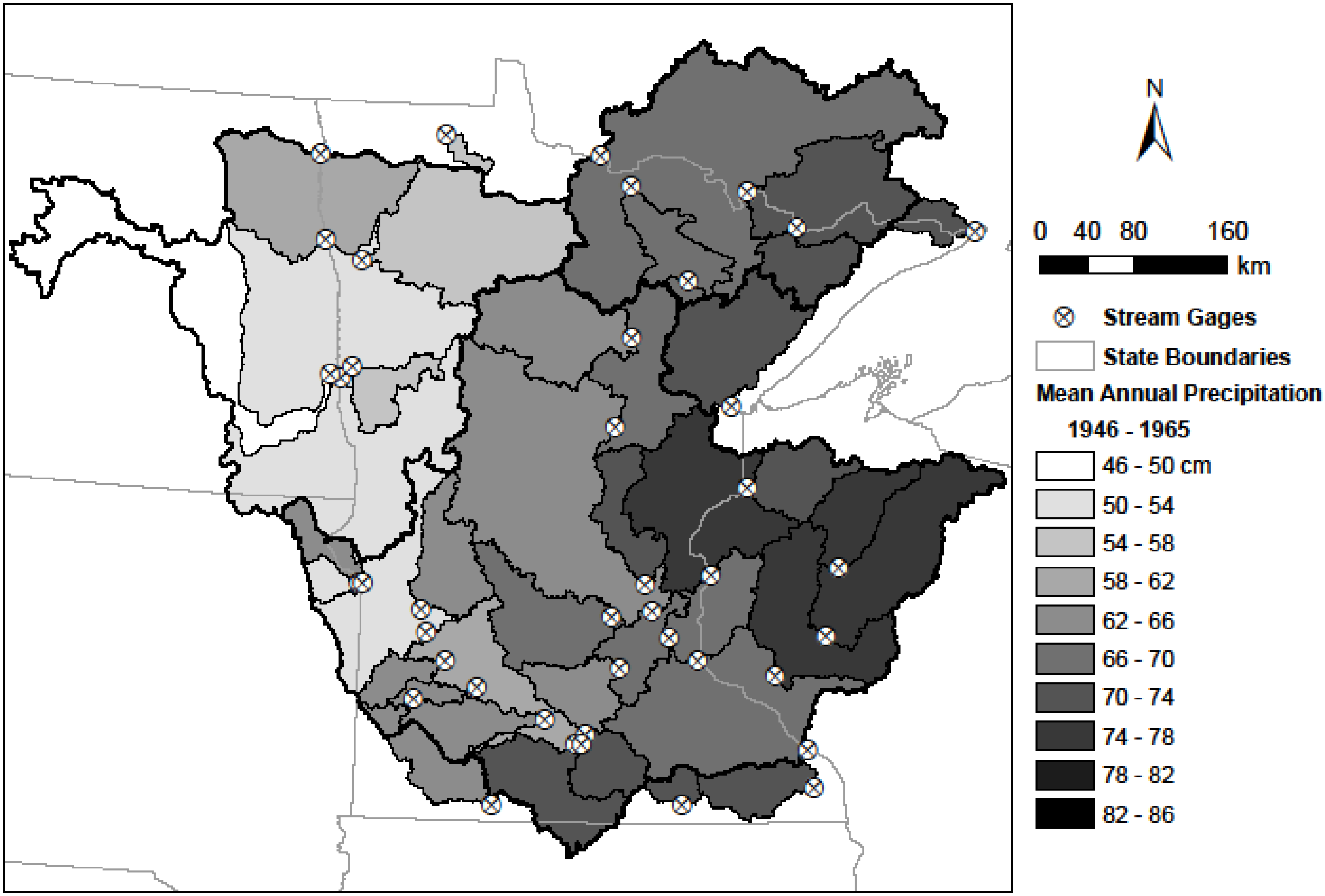

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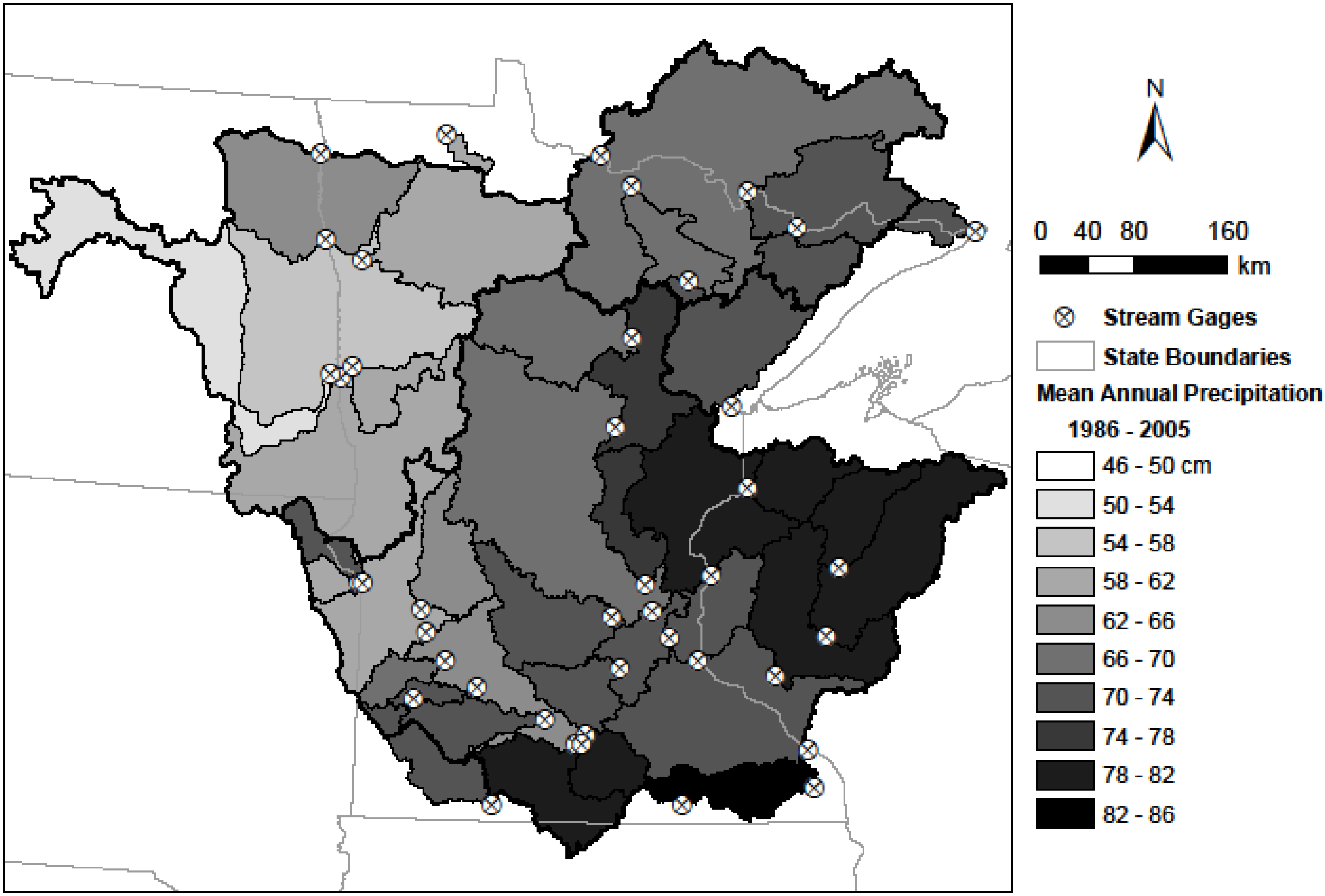

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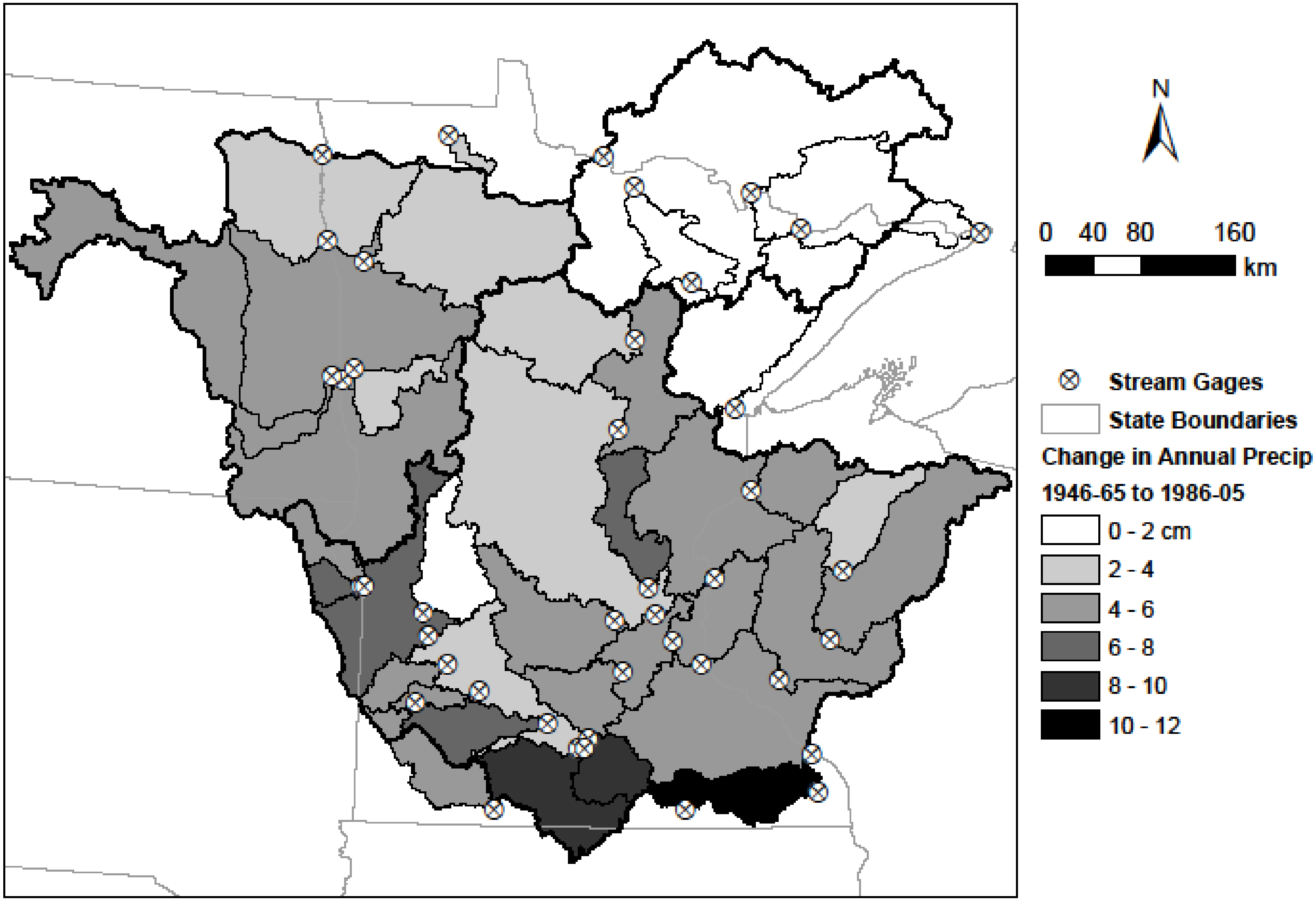

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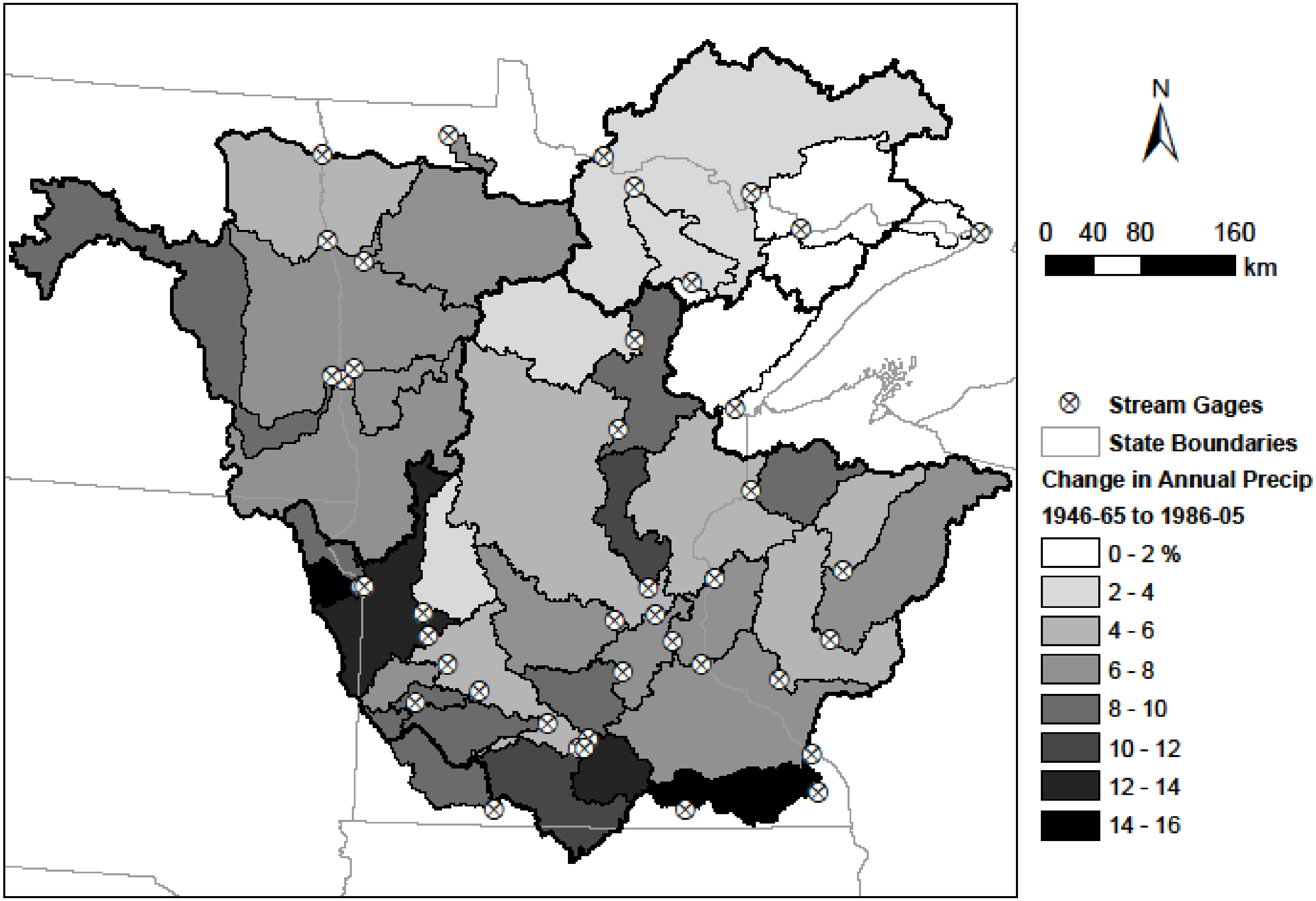

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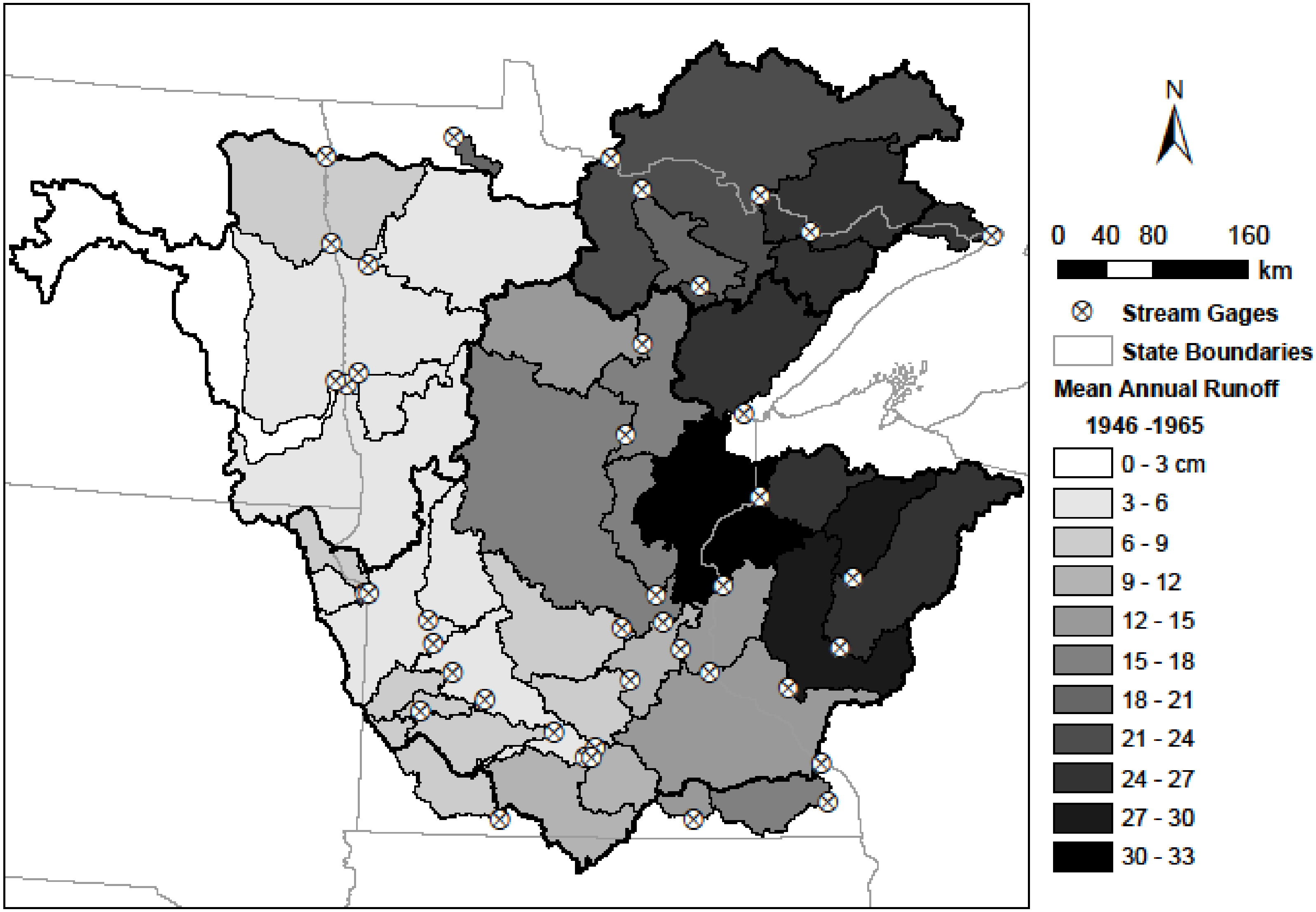

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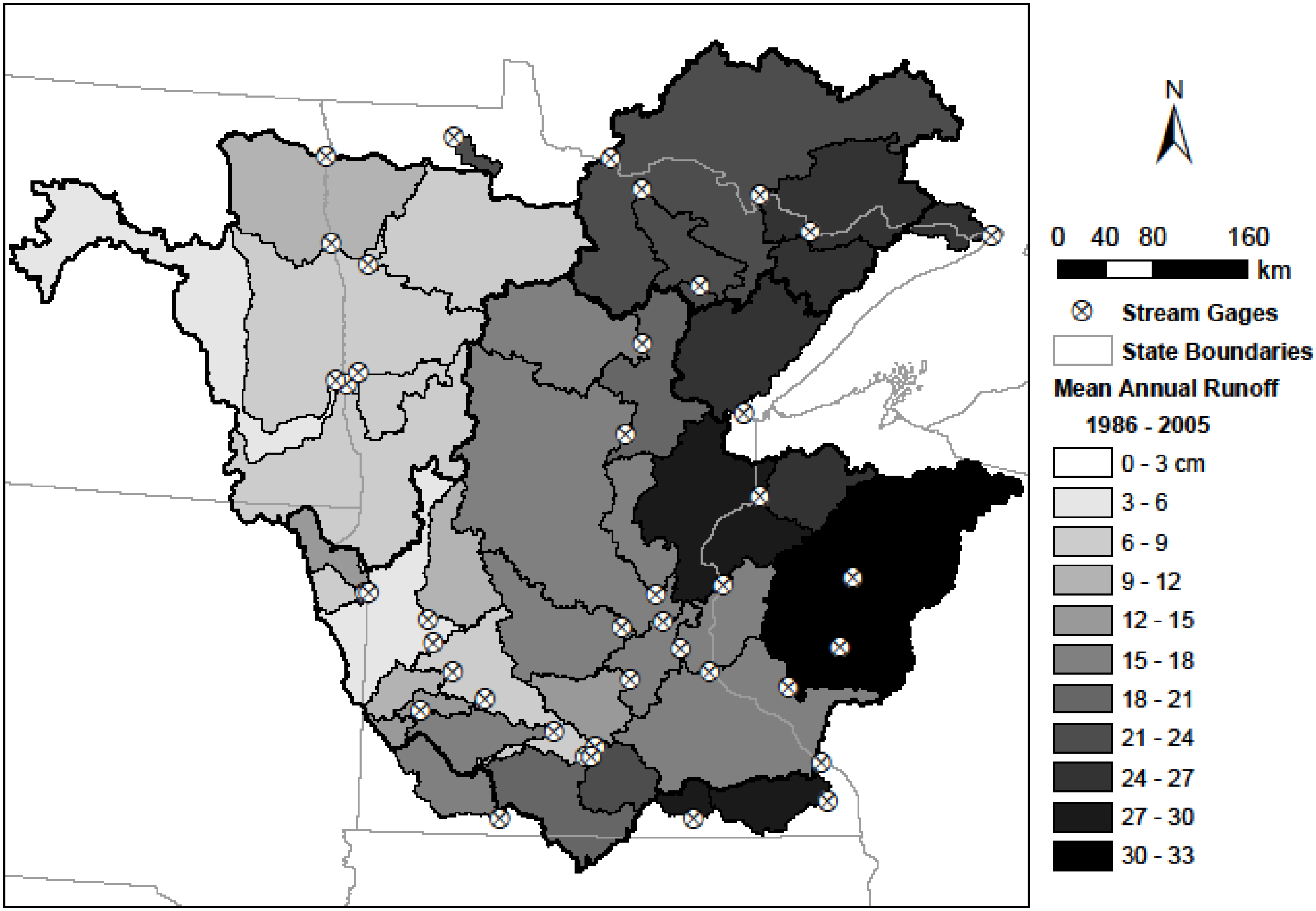

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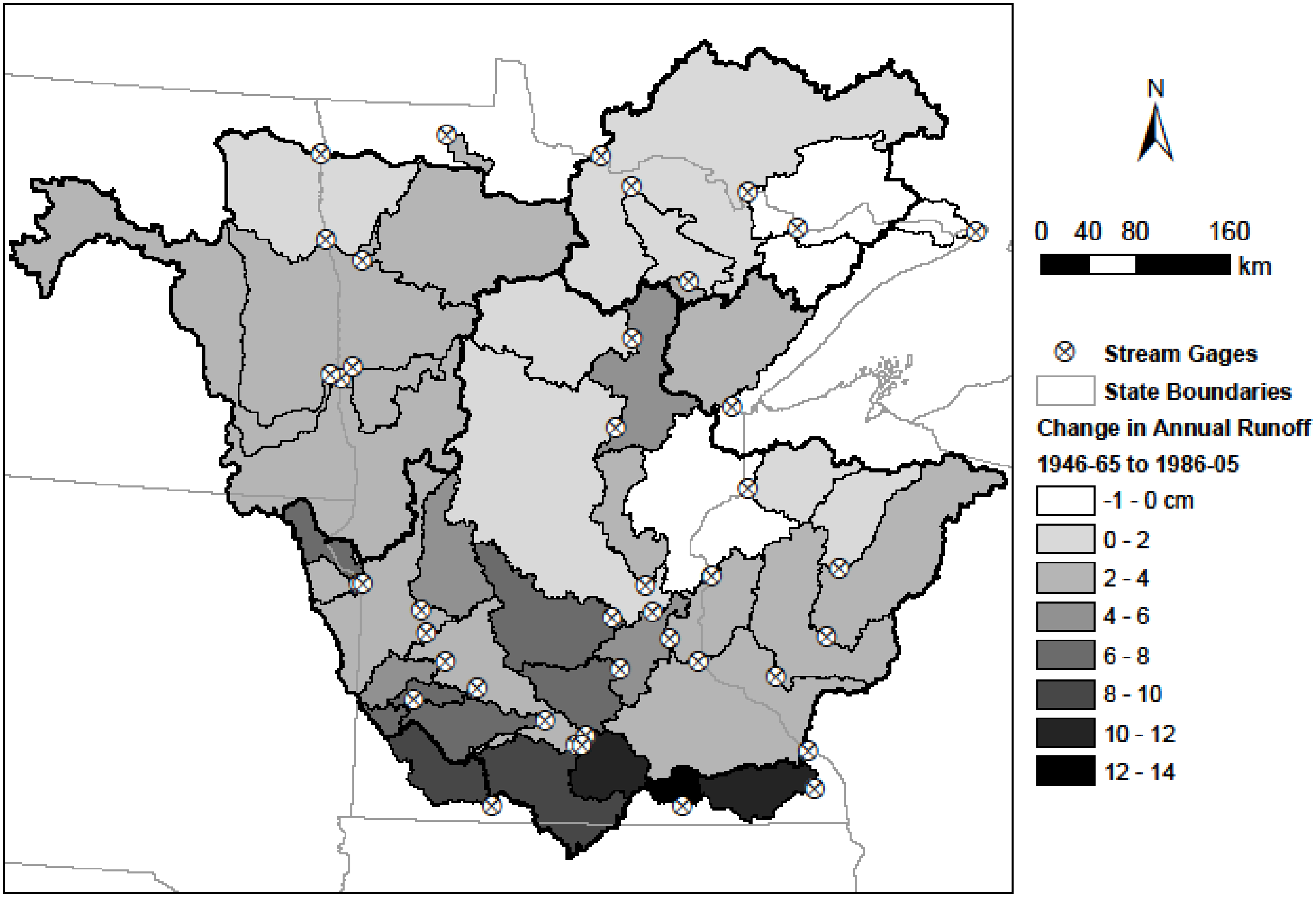

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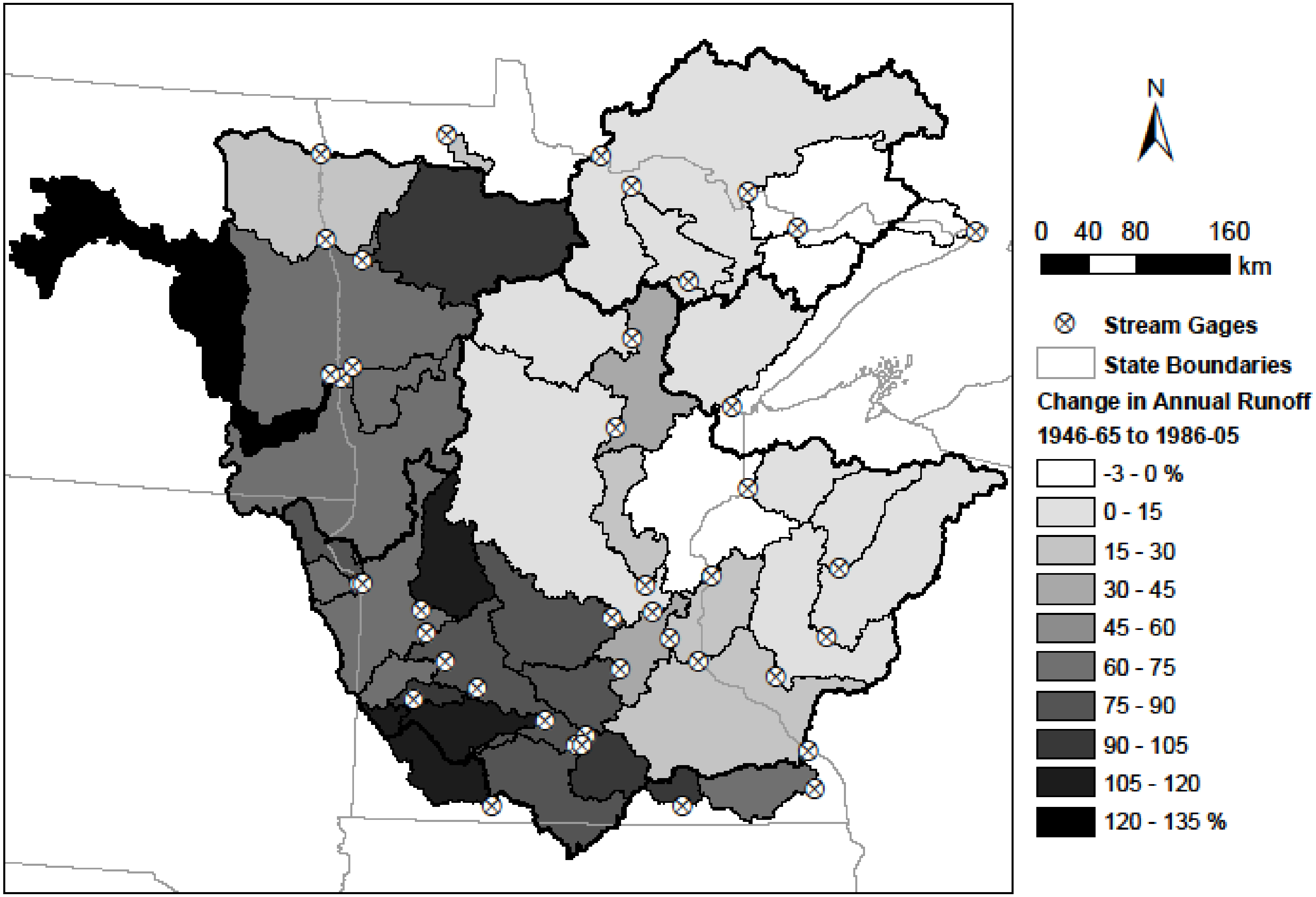

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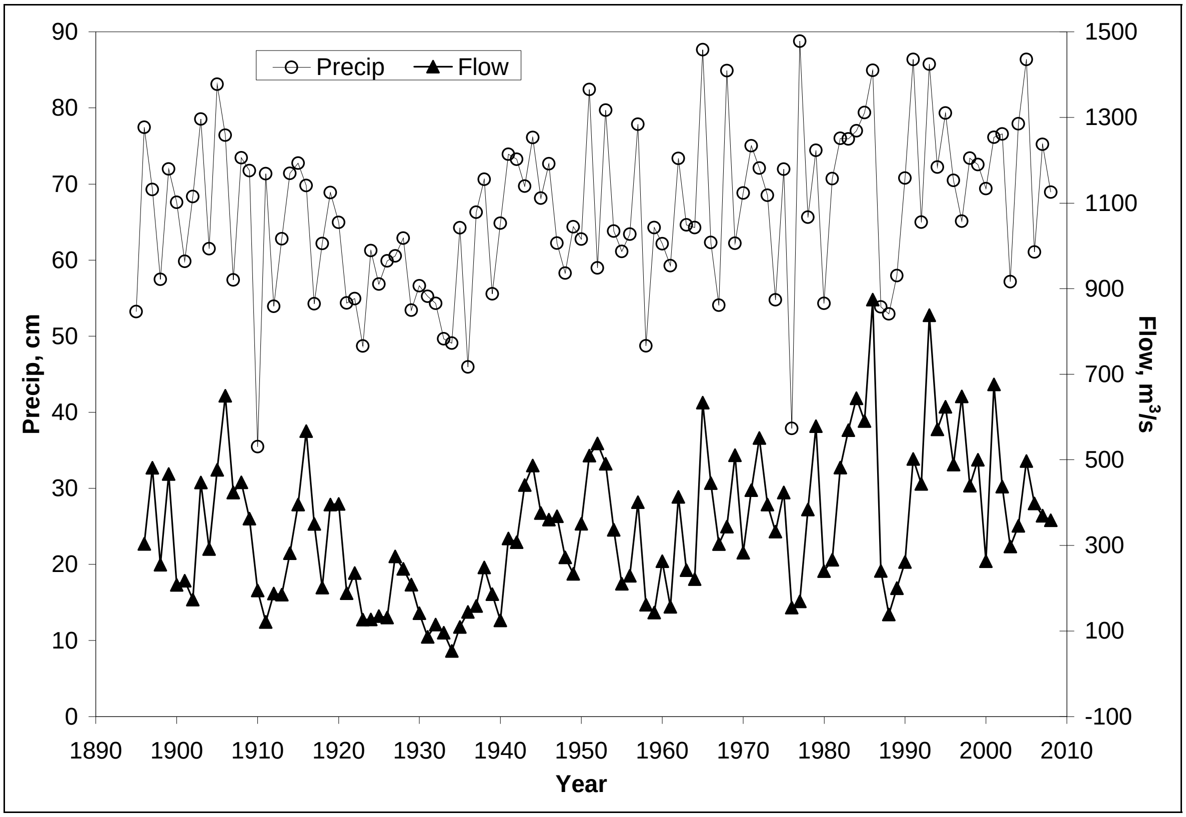

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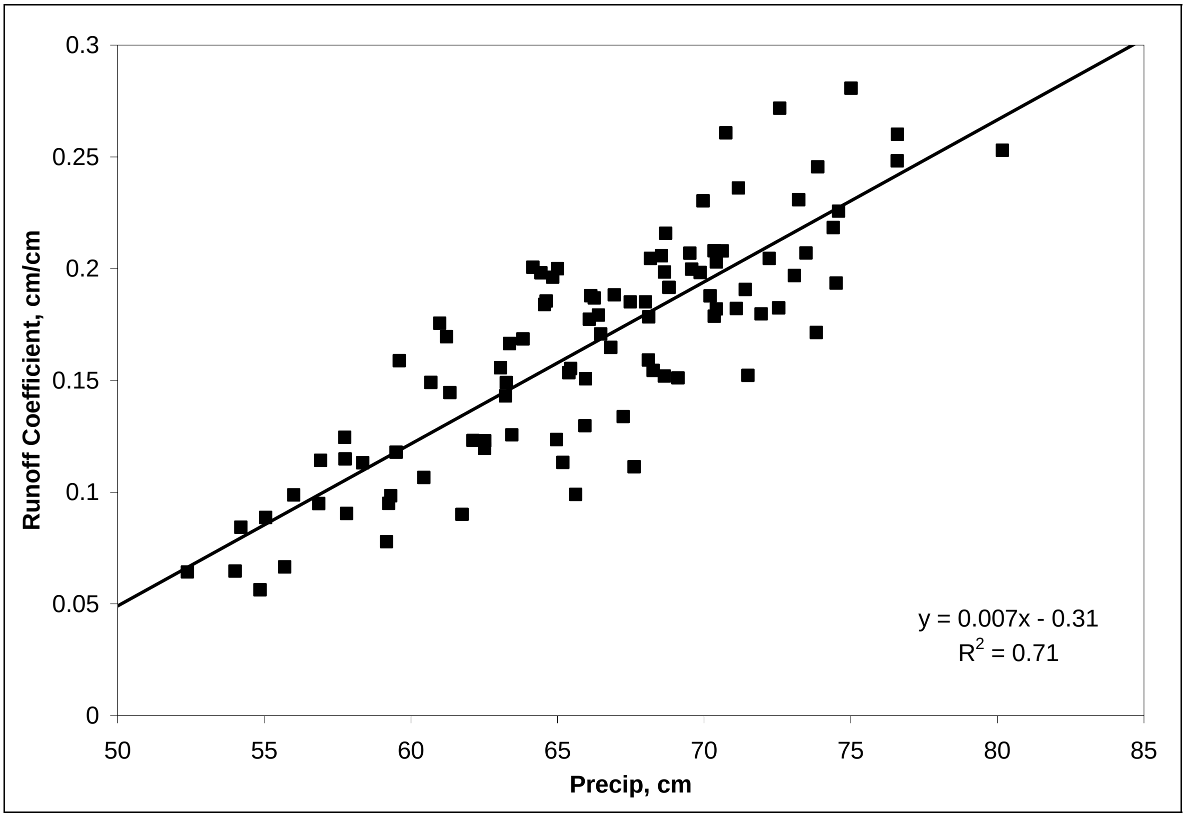

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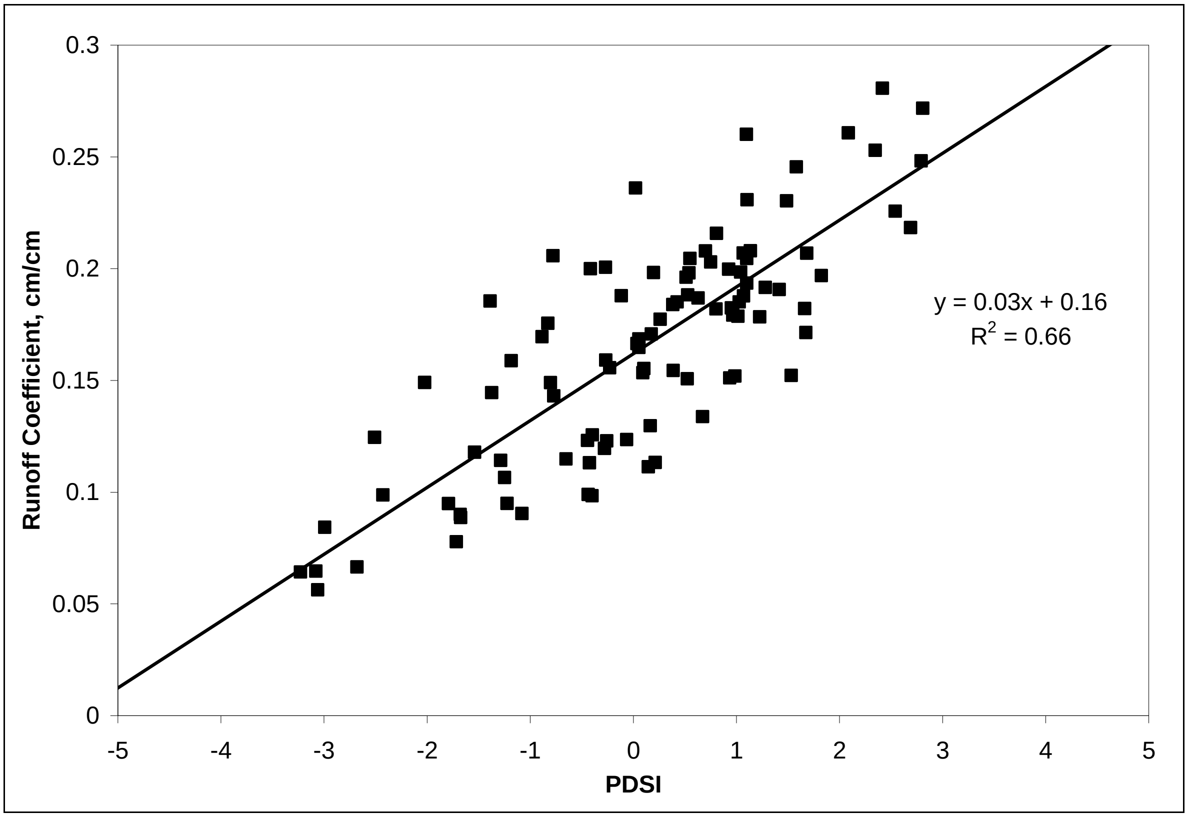

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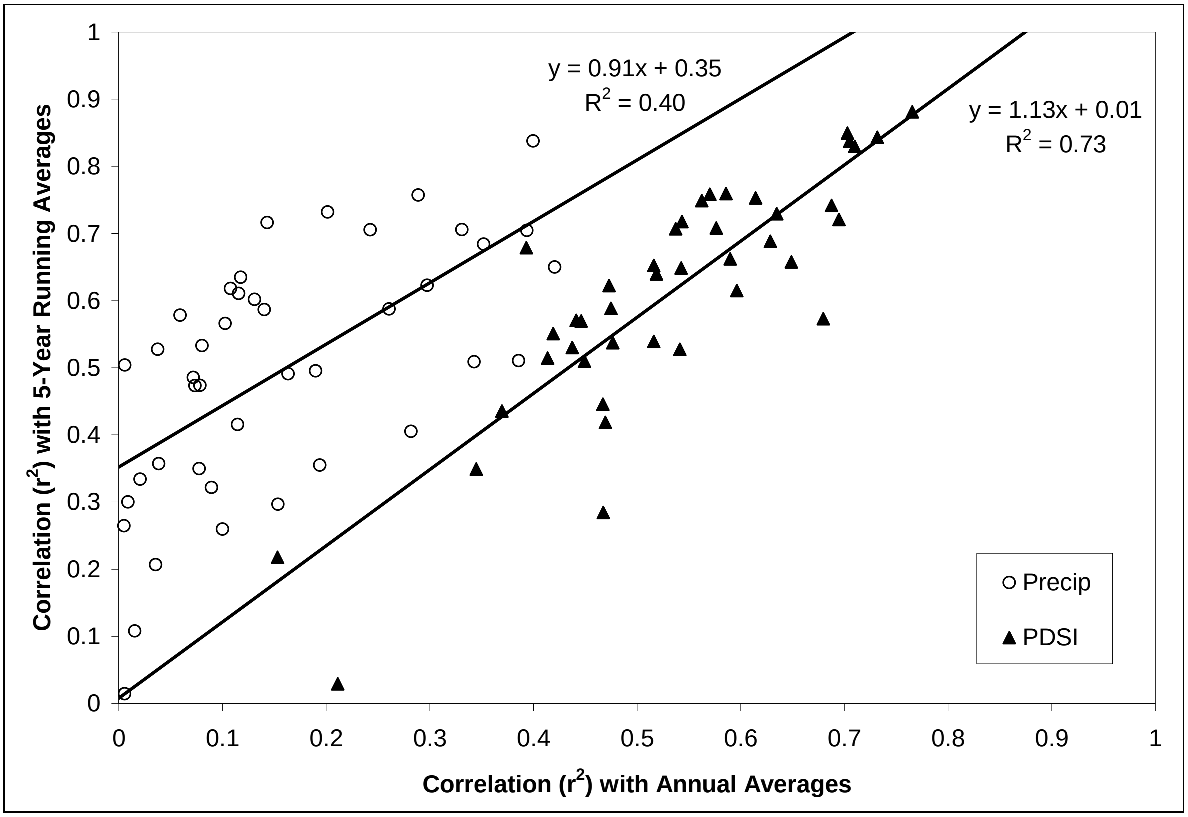

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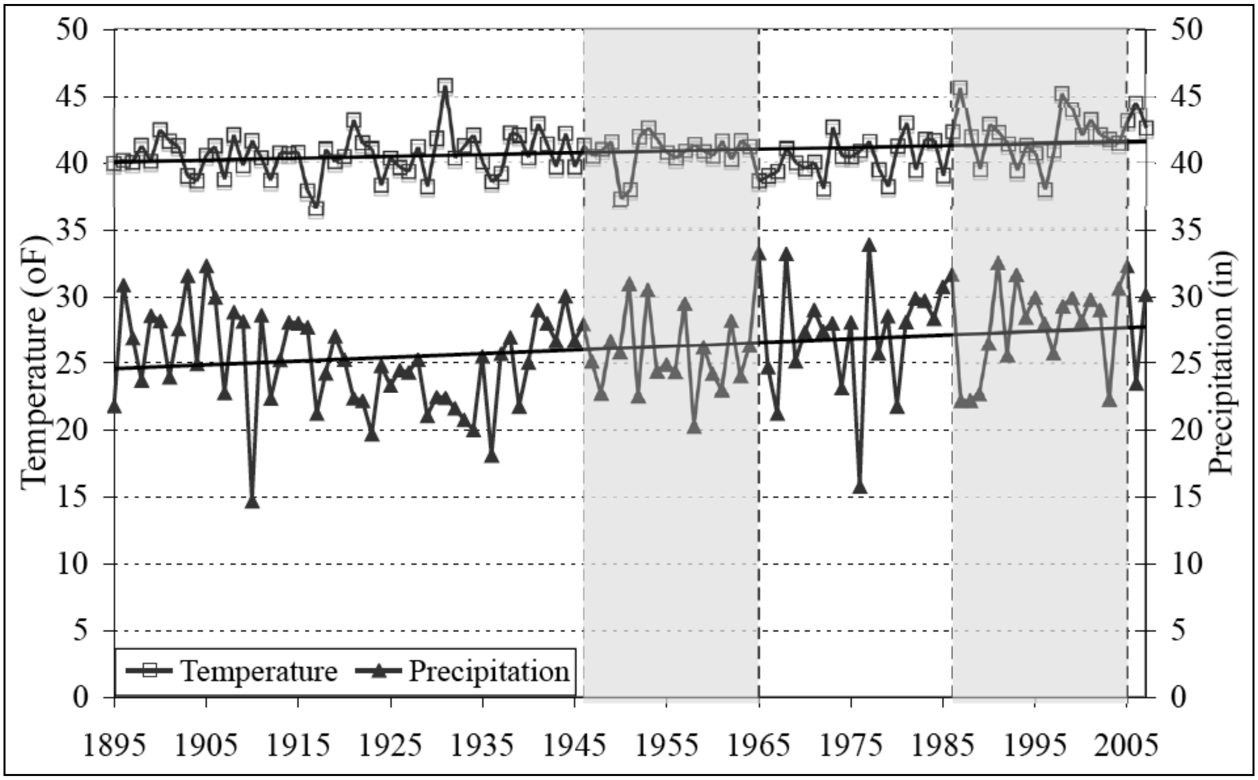

Note: 1 in = 25.4 mm and 1.8 ^{o}F = 1.0 ^{o}C

Figure A.1: Annual average temperatures and annual precipitation in Minnesota for the period 1895-2007. Study time periods 1946-1965 and 1986-2005 are highlighted in gray. (From Dadaser-Celik and Stefan (2009)).

APPENDIX: DESCRIPTION OF MINNESOTA'S RIVER BASINS AND CLIMATE

The following descriptions of Minnesota's major river basins and climate are provided by Dadaser-Celik and Stefan (2009)**.**

A.1 Study Area

Minnesota is located in the Upper Midwest of the U.S. is in the headwaters of three continental drainage systems, although its elevation is relatively low, ranging from about 180 m (600 ft) to 690 m (2300 ft) amsl. The state's drainage area is 223,000 km^2 (87,000 square miles). Major rivers and river basins, as well as USGS stream gauging stations are shown in Figure 1. Ice sheets sculpted most of the states current landscape; the last glaciation ended 12,000 years ago. Glaciers covered all of Minnesota except the far southeast, known as the Driftless Area and left behind 15 m (50 ft) or more of glacial till as they retreated (Ojakangas, 2001).

Besides being the *Land of 10,000 Lakes* (11,840 lakes over 10 acres in size) Minnesota also has about 42,900 km^2 of wetlands, and 6,560 natural streams and rivers that cumulatively flow for 111,000 km (69,000 miles). Because continental divides meet in north-central Minnesota, surface runoff can follow the Mississippi River south to the Gulf of Mexico, the St. Lawrence Seaway east to the Atlantic Ocean, or the Hudson Bay watershed to the Arctic Ocean. The Mississippi River begins at Lake Itasca and is joined by the Minnesota River at Fort Snelling, by the St. Croix River near Hastings, by the Chippewa River at Wabasha, and by many smaller streams. The Red River of the North drains the northwest part of the state northward toward Hudson Bay and the Rainy River forms the U.S. border with Canada.

Minnesota's streams and rivers were described by Waters (1977), and are important as wildlife habitat, for recreation, as a source of water supply, and as recipients of waste water. There are five major river basins of substantially different geologic, topographic, ecologic and land use characteristics. The five basins are named after the Minnesota River, the Red River of the North, the Rainy River, Lake Superior and the Upper Mississippi River, and are hydrologically quite different. They will be described and analyzed below.

The ***Minnesota River Basin*** covers about 16,770 square miles, and is located in southern Minnesota (http://mrbdc.mnsu.edu/mnbasin/fact_sheets/fastfacts.html), except for small portions that extend into South Dakota and Iowa (Figure 1). 92% of the basin area is used for agriculture. A large range of climatic, hydrologic, landscape and soil characteristics can be seen in the Minnesota River Basin. Annual precipitation ranges from 22 inches in the northwestern to 32 inches in the southeastern portion of the basin. Annual runoff ranges from 2 inches in the west to 6 inches in the east (http://www.soils.umn.edu/research/mn-river/doc/mbtext.html). Soil drainage ranges from well drained to poorly-drained. The basin includes an extensive network of agricultural drainage tiles and man-made ditches. Other hydrologic features include lakes, wetlands, and permanent and intermittent streams. Sediments deposited during recent glacial recessions are continuing to be eroded. Erosion potential of agricultural cropland and stream banks is significant. The Minnesota River valley was formed by the post-glacial River Warren which drained the former gigantic Lake Agassiz southward towards the Mississippi River.

The ***Red River of the North Basin*** comprises 37,100 square miles of land in Minnesota, South Dakota and North Dakota. 17,730 square miles of it is in Minnesota. The majority of the land in the Minnesota is used for agriculture (66%), some land on the fringes of the basin is covered by forests (12%), and some is urban land (8%) mostly in North Dakota (Paakh et al., 2006). The Red River flows towards the north across the lakebed of the former Lake Agassiz. The river itself began after Lake Agassiz drained, about 9,500 years ago. The river's floodplain is remarkably flat and has a gradient of about 1:5000 from its origin in Minnesota to the international border. When water levels of Red River rise, "overland flooding" appears across the floodplain. Several floods occurred in the Red River of the North Basin in the past following heavy snows or rains on saturated or frozen soil and they were often made worse when snowmelt started in the warmer south, and northward flowing water was dammed or slowed by ice (http://en.wikipedia.org/wiki/Red_River_of_the_North).

The ***Rainy River Basin*** covers a total area of 27,114 square miles, of which 11,244 square miles are located in northern Minnesota, and the remainder in Ontario, Canada. The majority of the Rainy River Basin is covered by forests, lakes, and wetlands (MPCA, 2001). The Rainy River drains Rainy Lake and discharges into Lake of the Woods, a distance of about 135 km (85 miles). The basin is in the Canadian Shield region, and is characterized by thin soil covers. Most of the water storage is in surface water bodies.

The ***Lake Superior Watershed Basin*** in Minnesota is 6,200 square miles in size, and is covered mainly by forests, with little agriculture and several urban areas. It is also in the Canadian Shield formation.

The ***Upper Mississippi River Basin*** covers 30,800 square miles entirely within the state of Minnesota. Land cover in this part of the Upper Mississippi River Basin ranges from conifer and hardwood forests to agriculture where corn, soybean, and forage crops are cultivated (MPCA, 2000). In St. Paul the Minnesota River discharges into the Mississippi River and puts its imprint on Mississippi River flows. Downstream from St. Paul the St. Croix River, which drains portions of eastern Minnesota and western Wisconsin, enters the Mississippi River at Prescott, WI. Downstream from Prescott additional portions of western Wisconsin and southeastern Minnesota become part of the Mississippi River drainage (Figure 1). The Twin Cities metropolitan area is in the Mississippi River drainage.

A small piece of southwestern Minnesota (Figure 1) drains into the Missouri River, and another into the Upper Mississippi River through Iowa; both are not included in the study.

A.2 Climate

Minnesota has a continental climate with cold winters and warm summers. The state's location in the Upper Midwest causes a wide variety of weather with four distinct seasons. Normal precipitation is lowest in winter (1-3 inches in Dec to Feb) and highest in summer (9 to 13 inches in June to Aug). Mean annual precipitation for the entire state has been on the rise (Figure A.1) and has reached approximately 28 inches/yr. The lowest annual average precipitation (510 mm or 20 in/yr) occurs in the northwest of the state and the highest (890 mm or 35 in/yr) in the southeast. Snow is the main form of precipitation from Nov to March, and a snow cover of 1inch (25mm) or more exists for 110 days per year on average.

Average annual air temperature for the state has risen to 5.5 ^{o}C or 42 ^{o}F, but mean annual air temperatures in the north (3^{o}C or 37.4 ^{o}F in International Falls) and in the south (9 ^{o}C or 49 ^{o}F in Winona) are substantially different. Minnesota extends from 43^{o}34’ to 49^{o}23’ latitude, a distance of 650 km (407 miles), and is divided into 9 climate divisions shown in Figure 3. Climate (precipitation and air temperature) in the five major river basins differs substantially because of geographic location, and seasonal variations are significant as well.

ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

Project Report No. 546

Projecting the impact of climate change on coldwater stream temperatures in Minnesota using equilibrium temperature models

by

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Prepared for

The Legislative-Citizens Commission on Minnesota Resources
St. Paul, Minnesota

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Minneapolis, Minnesota

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Executive Summary

Coldwater streams are valued because they provide unique habitat for coldwater fish such as trout, and other animal species. Water temperature is the most important characteristic of coldwater stream habitat. Stream temperature is controlled by the balance of the heat fluxes across the water surface and the heat fluxes across the sediment surface (groundwater inflow and conduction to the sediment). In this study, a modified equilibrium temperature model was developed for coldwater streams, including the effects of both climate and groundwater inflow on stream temperature. It gives an upper bound, and in some cases, good prediction of, daily average temperature based on climate conditions, riparian shading, stream width, and groundwater inputs.

The modified equilibrium temperature models developed in this study are intended to be applicable to stream-average (generic) analyses with minimal in-situ data on stream geometry, rather than for detailed analyses of individual stream reaches. Additional expressions are derived and tested for distances and times required to reach thermal equilibrium, and for diurnal temperature amplitude. For a small tributary stream with relatively uniform riparian shading (South Branch), the modified equilibrium temperature gave good predictions of daily average stream temperature. The modified equilibrium temperature model also gave good estimates of daily average stream temperature for the mainstem of the Vermillion when riparian shading was averaged over sufficiently long distances.

The stream temperature models were then used to characterize the response of water temperatures in three Minnesota coldwater stream basins to two projected climate change scenarios. Two of the study streams, Miller Creek and Chester Creek, are located in Duluth, Minnesota, and are primarily fed by upland wetlands. The third stream, the South Branch of the Vermillion River, is located south of the Twin Cities, Minnesota, and is primarily fed by shallow groundwater. Two climate change scenarios were run: the Canadian Global Climate Model (CGCM) version 2.0 for a doubling of atmospheric CO_2, and the Canadian Global Climate Model version 3.1 A1B scenario.

A sensitivity analysis conducted with the modified equilibrium temperature model confirms that water temperature in coldwater streams varies strongly with riparian shading, stream width, and both groundwater inflow rate and temperature. This sensitivity of stream temperature to groundwater parameters needs to be taken into account in climate change studies, since groundwater temperatures are expected to rise with air temperatures.

Overall, water temperatures in the streams were projected to increase between 4 and 5°C for the CGCM 2.0 CO_2 doubling climate change scenario, and between 3 and 4°C for the CGCM 3.1 A1B scenario. These stream temperature increases are larger than temperature increases projected by previous climate change studies based on air temperature – stream temperature regression analysis (2 to 3°C). Estimated increases in source water temperatures of groundwater due to climate change contributed about 60% of the total stream temperature increase, and the remaining 40% were provided by increases in atmospheric heat transfer. The ratio of the stream

temperature increment to air temperature increment was found to vary from 0.8 to 1.08, larger than the slope of the observed stream temperature versus air temperature relationship.

Increases in source water temperatures were therefore found to contribute significantly to the response of stream temperatures to climate change. For the streams in Duluth, wetland temperatures were predicted to increase 2.7 to 3.5 °C, based on a separate, calibrated heat transfer model. For the South Branch of the Vermillion River, groundwater temperatures were assumed to match long term increases in air temperature, ranging from 4 to 5 °C. These results suggest that source water temperatures need to be considered in predicting the response of stream temperature to climate change. More work is needed to characterize groundwater and other water sources for coldwater streams.

Notation

A	stream cross-section, m^2
B	stream width, m
C_p	specific heat of water, J/kg/°C
CR	cloud cover ratio, 0-1
C_{sh}	shading coefficient, 0-1
C_{ws}	wind sheltering coefficient, 0-1
d	water depth, m
e_a	ambient vapor pressure,
e_s	saturated vapor pressure,
h_{atm}	net atmospheric heat tranfer, W/m^2
h_{conv}	convective heat transfer, W/m^2
h_{evap}	evaporative heat transfer, W/m^2
h_{li}	incoming long wave radiation, W/m^2
h_{lo}	outgoing long wave radiation, W/m^2
h_s	solar heat transfer, W/m^2
h_{sed}	sediment heat transfer, W/m^2
K	bulk atmospheric heat transfer coefficient, W/m^2/°C
K_s	sediment thermal conductivity, W/m^2/°C
K_s*	combined sediment/groundwater heat transfer coefficient, W/m^2/°C
Q	stream discharge, m^3/s
q_g	groundwater inflow rate, m^2/s
R_s	incoming solar radiation, W/m^2
t	time, s
T	stream temperature, °C
T_a	air temperature, °C
T_d	dew point temperature, °C
T_e	equilibrium temperature, °C
T_e*	modified equilibrium temperature, °C
T_g	groundwater temperature, °C
T_{max}	daily maximum stream temperature, °C
V	flow velocity, m/s
W_p	wetted perimeter, m
x	streamwise distance, m
a	water surface albedo
δT	diurnal temperature change, °C
δ	depth of penetration, m
λ	characteristic length scale, m
τ	characteristic time scale, s
ρ	density, kg/m^3
ω	frequency, rad/s

Part I. Modified equilibrium temperature model for coldwater streams: Model formulation, verification, and sensitivity analysis

1.1 Introduction

Water temperature is a very important characteristic of aquatic habitats, particularly those supporting coldwater fish species such as trout [*Eaton et al.* 1995]. Stream temperature not only controls the survival of juvenile and adult coldwater fish, but also affects their reproduction and food sources such as macroinvertebrates [*Durance and Ormerod* 2007]. Hydrogeologic and climate settings constrain the existence of coldwater streams. In Minnesota, for example, trout streams are created by (1) karst springs in the southeast region of the state, near Rochester, 2) by cold wetlands in the northeast region of the state, near Duluth, and 3) by shallow groundwater aquifers in other regions of the state. The hydrological and climatological processes that maintain coldwater stream habitat vary between these regions, but involve a combination of cold water sources from groundwater or wetlands, riparian shading, and/or temperate climate. In other regions of the USA and the world, alpine settings with coldwater sources from snow or ice and cold mountain climate provide another important category of trout streams [*Brown and Hannah* 2007; *Clark et al.* 2001; *Hari et al*. 2006].

Both land development and climate change have the potential to increase stream temperatures and degrade coldwater habitat. Potential impacts on water temperatures have been estimated using field investigations and model studies [*Caissie* 2006; *Hari et al.* 2006; *Nelson and Palmer* 2007; *Webb et al.* 2008]. Deterministic, numerical stream temperature models can be used to predict the temperature response of specific streams to land use and climate change [*Herb and Stefan* 2008a, 2008b; *Kim and Chapra* 1997; *Sinokrot and Stefan* 1994]. Analytical models have been applied with some success for steady state and transient stream temperature prediction [Edinger et al. 1974; *Tang and Keen* 2009]. Regional regression models have also been created to study the impacts of land use and climate change on stream temperature [*Mohseni et al.* 1999; *Wang et al.* 2003]. Stream temperature – air temperature regression models can be used to characterize stream temperature in current conditions [e.g. *Webb et al.* 2003] and make estimates of the sensitivity of stream temperature to future increases in air temperature predicted by global climate models [*Erickson and Stefan* 2000; *Mohseni and Stefan* 1998, 1999]. These relationships can be improved by considering equilibrium temperature, which takes into account atmospheric moisture, wind and radiation in addition to air temperature [*Bogan et al.* 2003; *Edinger et al.* 1968]. However, even equilibrium temperature is often not a sufficient predictor of stream temperature because urban storm- and wastewater, as well as groundwater and tributary inputs can contribute significantly to a streams heat budget [*Bogan et al.* 2004].

Limited information is currently available to characterize the general response of stream temperature to a combination of surface (atmospheric) and subsurface (groundwater) heat inputs, which is particularly important for coldwater streams which typically drain small watersheds. The aim of this study was to evaluate relatively simple, process-based stream temperature models based on the equilibrium temperature concept which include riparian shading and groundwater inputs. Previously developed relationships for equilibrium temperature were augmented by additional terms to take into account groundwater inputs and heat conduction to the sediment. A trout stream in Minnesota was used to evaluate the ability of these models to predict daily average stream temperature. A sensitivity analysis was used to characterize the relative importance of climate parameters, groundwater inputs, and stream channel characteristics for determining stream temperatures.

1.2. Model Formulation

1.2.1 Heat balance for a stream reach

A one-dimensional equation for stream temperature at some cross-section of a stream can be written as

$$\frac{\partial}{\partial t}(AT)+\frac{\partial}{\partial x}(QT)=\frac{B\,h_{atm}(T)}{\rho C_p}+q_g T_g+\frac{W_p\,h_{sed}(T)}{\rho C_p} \qquad (1)$$

where A = flow cross-sectional area, B = stream width, h_{atm}= atmospheric heat transfer rate, h_{sed}= sediment heat transfer rate (W/m^2), q_g = groundwater inflow rate (m^2/s), Q = stream discharge, t = time, T_g= groundwater temperature, T = stream temperature, W_p= wetted perimeter, x= streamwise distance and $\rho\, C_p$= product of density and specific heat for water. A longitudinal dispersion term is not necessary in this equation because the longitudinal temperature gradients are usually small (zero in the case of equilibrium temperature). For the purposes of this study, lateral inflows are assumed to be entirely due to groundwater inputs. If surface inflows are present,, they can be accommodated by a modified inflow temperature. For steady flow conditions, $\partial A/\partial t = 0$. The second term on the LHS of Equation 1 can be expressed as $Q\cdot\partial T/\partial x$ + $T\cdot q_g$. The first term on the RHS of Equation 1 is the heat flux across the water surface of the stream, and the second term on the RHS is the groundwater heat input to the stream. The third term on the RHS is the heat transfer between the streambed and the flowing water, which can be estimated by a heat conduction equation, $h_{sed} = (K_s/\delta)\cdot(T_g-T)$, where K_s is the effective thermal conductivity of the sediment, δ is a characteristic length scale for the conduction process, and the sediment temperature has been assumed equal to the groundwater inflow temperature. Using these assumptions, Equation 1 can be simplified to the form:

$$A\frac{\partial T}{\partial t}+Q\frac{\partial T}{\partial x}=\frac{B\,h_{atm}}{\rho C_p}+\left(q_g+\frac{W_p\,K_s}{\rho C_p \delta}\right)\left(T_g-T\right) \qquad (2)$$

A key to determining stream temperatures are appropriate formulations for the atmospheric heat transfer as a function of climate parameters. The net heat transfer rate at the water surface (h_{atm}(T)) is the sum of components due to solar radiation (h_s), incoming longwave radiation (h_{li}), back radiation (h_{lo}), evaporation (h_{evap}), and convection (h_{conv}):

$$h_{atm}=h_s+h_{li}-h_{lo}-h_{evap}-h_{conv} \qquad (3)$$

The heat transfer formulations used in this study are based on those given by *Edinger et al.* [1968 and 1974] for lake and reservoir surfaces.

$$h_{evap}=C_o\,f(W)\,\beta\left(T-T_d\right) \qquad (4)$$

$$h_{conv}=C_o\,f(W)\left(T-T_a\right) \qquad (5)$$

$$\beta = \frac{e_s - e_a}{T - T_a} \quad (\text{mmH}_g/°\text{C}) \tag{6}$$

$$f(W) = a_o + a_1 W \quad (\text{W/m}^2/\text{mmH}_g) \tag{7}$$

$$h_s = (1 - \alpha)(1 - C_{sh})R_s \tag{8}$$

$$h_{li} = \sigma\left(CR + 0.67 \cdot (1 - CR)e_a^{\ 0.08}\right)(T_a + 273.15)^4 \tag{9}$$

$$h_{lo} = \varepsilon\sigma(T + 273.15)^4 \tag{10}$$

where C_o is Bowen's ratio (0.47 mm Hg/°C) α is the water surface albedo, R_s is incident solar radiation, C_{sh} is the shading coefficient (1=full shading), σ is the Stefan-Boltzmann constant, ε is the emissivity, *CR* is the cloud cover fraction (0-1), and e_s and e_a (mm Hg) are the saturated vapor pressure at *T* and the atmospheric vapor pressure, respectively. Equation 7 gives the form of the wind speed function used in this study. In general, the wind speed function *f(W)* can include constant, linear, and quadratic wind speed coefficients (*Edinger et al.,* 1974), and/or account for atmospheric stability which becomes important for artificially heated water bodies (Ryan and Harleman, 1973; Stefan et al.,1980). The observed wind velocity (W_o) was adjusted based on a wind sheltering coefficient, C_{ws}, i.e. $W = (1-C_{ws})\cdot W_o$.

1.2.2 Equilibrium temperature

The equilibrium temperature (T_e) of a surface water body is defined as the water temperature at which the water body reaches thermal equilibrium with the atmosphere, e.g. zero net heat flux across the water surface. Equilibrium temperature can be used to predict analytically or numerically the temperature of surface water bodies, e.g. lakes and streams [*Edinger et al.* 1968, 1974]. In general, actual water temperatures approach equilibrium temperature asymptotically, and the lag time is inversely proportional to water depth; therefore the assumption that water temperature equals equilibrium temperature cannot be used to describe short term thermal behavior, e.g. diurnal fluctuations in stream temperature, but it is appropriate for daily time scales and longer. The SNTEMP stream temperature model [*Theurer et al.* 1984] uses equilibrium temperature as a basis for predicting daily average stream temperature using similar formulations to those given here.

By definition, the equilibrium temperature is the stream temperature which causes the surface heat transfer term (h_{atm}) in Equation 2 to be zero. One approach to determine equilibrium temperature is to calculate the components of surface heat transfer (radiation, convection, evaporation) as a function of climate parameters (air temperature, humidity, solar radiation, wind speed, cloud cover) and then find the water temperature at which the sum or net surface heat transfer is zero. This process requires an iterative solution, since some heat transfer terms are a non-linear function of water temperature, e.g. Equation 10. *Edinger et al.* [1974] give several simplified formulations to estimate equilibrium temperature and introduce a bulk coefficient for surface heat transfer, *K*. In that process the back radiation term is expressed as

$$h_{lo} \approx 306 + 4.48T + 0.025T^2 \tag{11}$$

A relatively accurate estimate of equilibrium temperature (T_e) is

$$T_e = \frac{\left(h_s + h_{li} - 306 + (K - 4.48)T_d^{'}\right)}{K + 0.05T_d^{*} - 0.025\,T_e} \tag{12}$$

$$K = 4.5 + 0.05\,T + \left(0.47 + \beta\right) f(W) \qquad (\mathrm{W/m^2/^\circ C}) \tag{13}$$

$$T_d^{'} = T_d + \frac{0.47\left(T_a - T_d\right)}{\beta + 0.47} \tag{14}$$

Since T_e appears on the RHS of Equation 12, an iterative solution can be used to improve accuracy. When T_a was used as the initial guess for T_e in this study, only a few iterations were required to converge to a solution.

1.2.3 Modified equilibrium temperature - shift due to groundwater inflow and streambed heating

Equilibrium temperature, in the original sense, considers only atmospheric heat inputs. The effect of a groundwater input (per unit stream length) on stream temperature can be analyzed by introducing the modified equilibrium temperature concept. Heat transfer by conduction from the stream to the streambed can also be included with the assumption that the sediment temperature is equal to a groundwater temperature:

$$h_{sed} = \frac{K_s}{\delta}\left(T - T_g\right) \tag{15}$$

where K_s is the effective thermal conductivity of the sediment bed, and δ is the characteristic length scale for conduction. A modified equilibrium temperature, T_e*, is found by setting the entire RHS of Equation 2 equal to zero. The * notation distinguishes this groundwater adjusted temperature from the standard equilibrium temperature based on atmospheric heat transfer only (T_e).

$$h_{atm}\left(Te^{*}\right) + \left(\rho C_p \frac{q_g}{B} + \frac{W_p K_s}{B\delta}\right)\left(T_g - T_e{}^{*}\right) = 0 \tag{16}$$

Since B is the stream width, the term (q_g/B) is the groundwater inflow rate per unit area of stream bed. The temperature T_e* found by solving Equation 16 represents a modified equilibrium temperature for which the atmospheric heat transfer balances the heat input due to groundwater inflow and conduction into the streambed. A stream receiving groundwater will tend toward that modified equilibrium temperature given sufficient time (and spatial distance). In mid-summer, atmospheric heat flux would typically be into the stream tending to heat the water, while the incoming groundwater would tend to cool the stream ($T_g < T$). In winter, the groundwater would heat the stream, and the heat flux to the atmosphere would cool it.

Equation 16 can be solved for the modified equilibrium temperature T_e*. Using methods from *Edinger et al.* [1974], Equations 17, equivalent to Equation 12 can be found for the modified equilibrium temperature.

$$T_e^* = \frac{\left(h_s + h_{li} - 306 + (K - 4.48)T_d^{'}\right) + K_s^* T_g}{K + K_s^* + 0.05T_d^* - 0.025T_e^*} \tag{17}$$

$$K_s^* = \frac{K_{sed}}{\delta} + \frac{W_p}{B}\frac{\rho C_p q_g}{B} \tag{18}$$

In many shallow streams, the wetted perimeter W_p can be approximated by stream width B. The parameter K_s* is a combined heat transfer coefficient for the groundwater and sediment. For q_g= 0.01 m^3/s/km (0.17 cfs/mile), K_s = 1 W/m/°C, δ=1 m, and a stream width of 5 m, $K_s* \approx 14$ (W/m^2/°C), which is of the same order of magnitude as the bulk atmospheric heat transfer coefficient, *K*. Additional examples of the magnitude of *K* and K_s* are given in Table 1.2 for two reaches of the Vermillion River.

Although the modified equilibrium temperature is intended to be applied to relatively uniform stream reaches, the assumed uniform groundwater inflow rate introduces a systematic increase of flow rate with downstream distance. As the stream width *B* also increases with increasing flow downstream, the relative effect of groundwater inputs on stream temperature is reduced with distance. For a fixed rate of groundwater inflow per unit length (q_g), an increase in stream flow and width leads to a slight positive streamwise temperature gradient. For the South Branch reach of the Vermillion River described later, the streamwise gradient in temperature is small, about 0.02 °C/km in mid-summer. On the other hand, if the groundwater inflow rate per unit surface area (q_g/B) is held constant, T_e* is invariant over streamwise distance (assuming shading, etc. are also constant).

1.2.4 Length and time scales required to reach equilibrium temperature

Stream temperature responds to changes in heat inputs over length and time scales which can be estimated using relatively simple relationships. If a slug of water is followed downstream along a characteristic path, it can be shown that Equation 2 can be simplified to the following form [*Theurer et al.* 1984]:

$$\frac{\partial T}{\partial x} = \frac{B\, h_{atm}}{\rho C_p Q} + \left(\frac{q_g}{Q} + \frac{W_p\, K_s}{\rho C_p Q \delta}\right)(T_g - T) \tag{19}$$

Equation 19 can be rewritten in terms of the parameters used in the equilibrium temperature formulations as

$$\frac{\partial T}{\partial x} = \frac{K\,\mathrm{B}}{\rho C_p Q}\left(T_e - T\right) + \frac{K_s^* B}{\rho C_p Q}(T_g - T) \tag{20}$$

Equation 20 can be solved for *T*(*x*), the longitudinal variation in the mean stream temperature, with the result given by Equation (21).

$$T(x) = T_e{}^* + \left(T_o - T_e{}^*\right)\exp\left(-\frac{x}{\lambda}\right) \tag{21}$$

$$T_e{}^* = \frac{K\,T_e + K_s^*\,T_g}{K + K_s^*} \tag{22}$$

$$\lambda = \frac{\rho C_p Q}{B\left(K + K_s^*\right)} \quad (23)$$

where T_o is the upstream temperature (at $x=0$) and λ is the length scale for the response of stream temperature to a step change in temperature or heat flux at $x=0$. The corresponding characteristic time scale or time constant (τ) can be found by dividing the length scale by flow velocity $V=Q/A$.

$$\tau = \frac{\lambda}{V} = \frac{\rho C_p d}{K + K_s^*} \quad (24)$$

While the equilibrium temperature (T_e *or* T_e*) does not explicitly depend on the streamflow (Q), it is noteworthy that the thermal length scale λ has a linear dependence on (Q/B). A stream with higher flow, and in particular, greater depth, therefore requires a greater distance to respond to a water temperature disturbance. Equations 23 and 24 can be applied to a variety of perturbations on stream temperature, including changes in riparian shading, changes in the groundwater inflow rate, and concentrated surface inflows.

For the mainstem reach of the Vermillion River, described in a later section, λ is found to vary from 3 to 45 km, and τ from 7 to 50 hours, for stream flows from to 0.43 to 5.8 m^3/s (15 to 205 cfs) during the summer period. Streams are more likely to approach equilibrium conditions during periods of low flow. The length scale parameter, λ, can be used to determine the distance upstream of a monitoring point that will have influence on the temperature at that point. For example, the length scale can be used to determine over what upstream distance riparian shading needs to be averaged to estimate stream temperature at a point.

1.2.5 Diurnal stream temperature fluctuation and daily maximum stream temperature

Diurnal temperature fluctuations can be a determining factor for the quality of aquatic habitat in a stream reach. Some stream temperature studies, such as TMDL (Total Maximum Daily Load) studies, use maximum, rather than average, daily stream temperature as a basis for quantifying temperature impacts. It is possible to find estimates for both the amplitudes of diurnal temperature variations and the maximum daily stream temperature, using an approach similar to the foregoing analysis of equilibrium temperature.

Diurnal stream temperature variations are driven by atmospheric heat transfer across the water surface. Figure 1.1 gives an illustration of the calculated diurnal fluctuations of solar radiation, incoming log wave radiation, evaporation, and convection for a stream reach with 50% shading, using the previously given heat transfer Equations 4 to 11. The convection and evaporation terms were calculated based on the equilibrium temperature, rather than the actual, stream temperature to give a better representation of the magnitude of these heat transfer components. The example in Figure 1.1 is for a two-week period in July. Over the time period June 1 to October 1, 2008, the diurnal fluctuations averaged 307, 66, 59, and 47 W/m^2 for solar radiation, incoming long wave radiation, evaporation, and convection, respectively. Incoming long wave radiation and convection have a correlation to solar radiation (correlation coefficients = 0.35, 0.70, respectively), while evaporation is poorly correlated to solar radiation (correlation coefficient = 0.08). For this reason, diurnal fluctuations of stream temperature driven by evaporation are not considered.

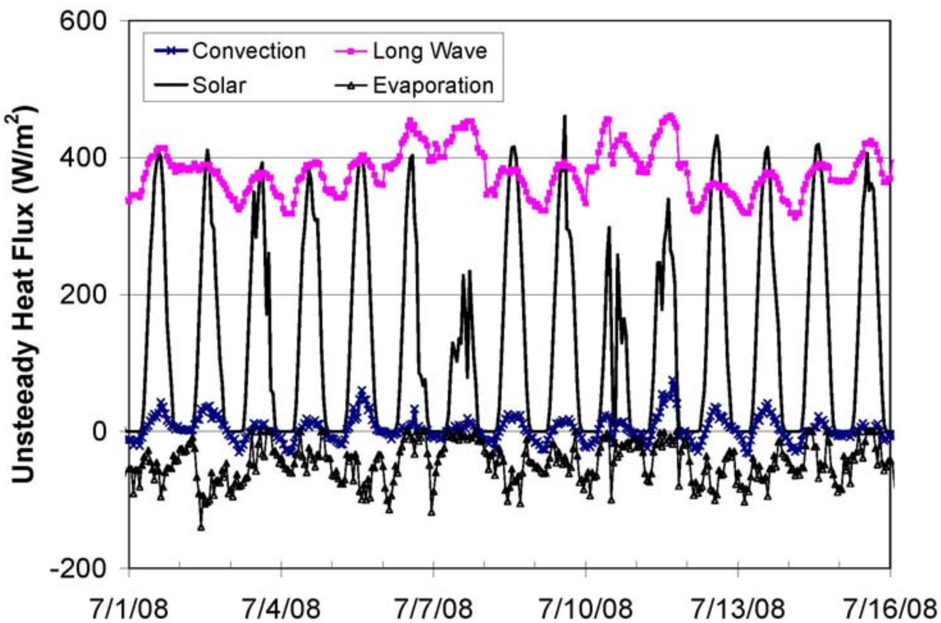

Figure 1.1. Example of time series of solar radiation, incoming long wave radiation, convection, and evaporation for a water body at equilibrium temperature in Minneapolis, 45°N latitude, 93°W longitude).

To find analytic expressions for the diurnal temperature variations of a stream, sinusoidal variations of stream temperature, solar radiation, and air temperature are assumed:

$$T(t) = \overline{T} + \hat{T}\exp(j\omega t) \qquad (25)$$

$$h_s(t) = \overline{h}_s(1 + \exp(j\omega t)) \qquad (26)$$

$$T_a = \overline{T}_a + \hat{T}_a\exp(j\omega t) \qquad (27)$$

where $\overline{T}$, $\overline{T}_a$ and $\overline{h}_s$ are the daily mean values of stream temperature, air temperature and solar heat flux, $\hat{T}$ and $\hat{T}_a$ are the amplitude of stream temperature and air temperature, respectively, ω is the frequency of oscillation (7.27x10^{-5} rad/s for a period of 1 day), and $j = \sqrt{-1}$. Note that it is not necessary to specify a fluctuating component of the solar heat flux, because for a simple sinusoid, $\hat{h}_s$ must be equal to $\overline{h}_s$ for the function to oscillate between zero and the maximum value. Complex number notation is used to simplify solution procedures; the actual temperature fluctuations are represented by the real part of the solution. Substituting Equations 25 - 27 into Equation 2 and solving for the fluctuating components only, gives the following expression for fluctuating stream temperature:

$$\hat{T} = \left(\frac{\overline{h}_s + \left(0.47 f(W) + 4.6\varepsilon_a\right)\hat{T}_a}{\rho C_p d\ j\omega + K_s^* + 0.47\ f\left(W\right) + 4.48} \right) \tag{28}$$

where d is the mean water depth. $\hat{T}$ is a complex number that represents both the magnitude of the stream temperature oscillation and the phase with respect to the solar gradation driver. For the purposes of this study, it is sufficient to predict the total diurnal change in temperature ($\delta T = T_{max} - T_{min}$), which can be found as:

$$\delta T = 2\left|\hat{T}\right| = \frac{2\left(\overline{h}_s + \left(0.47 f(W) + 4.6\varepsilon_a\right)\hat{T}_a\right)}{\left[\left(\rho C_p d\ \omega\right)^2 + \left(K_s^* + 0.47\ f\left(W\right) + 4.48\right)^2\right]^{1/2}} \tag{29}$$

If the convection, long wave radiation, and groundwater terms are dropped, Equation 29 simplifies substantially to an expression that considers only solar radiation as the driver:

$$\delta T = \frac{2\,\overline{h}_s}{\rho C_p d\ \omega} \tag{30}$$

1.3 Model Validation

The analytic expressions for equilibrium stream temperature and diurnal temperature fluctuations provide estimates of stream temperature in uniform stream reaches. Real stream reaches have natural variations of stream characteristics with downstream distance, inflows from tributaries, and are impacted by land use and development which can cause abrupt changes in channel width, stream depth, riparian shading etc. The expressions for the longitudinal variation of stream temperature in non-equilibrium conditions provide some opportunity to correct for non-uniform stream characteristics in terms of geometry, shading, and groundwater inflow, but they require additional information, e.g. the upstream temperature. To test the impact of these discrepancies, the temperatures predicted by the analytic (simplified) models will be compared to observed stream temperature data, and to simulation results from a detailed numerical stream temperature model.

1.3.1 Stream reaches and data for model validation

The comparison of analytic and numerical temperature model results was made for two reaches of the Vermillion River, a tributary of the Mississippi, and a designated trout stream about 20 miles south of the Twin Cities (Minneapolis and St. Paul) in Minnesota (Figure 1.2). The upper Vermillion River has numerous groundwater-fed coldwater reaches. Substantial temperature and flow monitoring has occurred on the Vermillion over several years, and numerical models for stream flow and temperature have been developed [*Herb et al.* 2008a, b]. For the present study, a 4.3 km reach of the South Branch, a tributary to the Vermillion, and a 8 km reach of the Vermillion mainstem upstream of the USGS (United States Geological Survey) flow monitoring station at Empire, MN were selected (Figure 1.2). Water temperature has been monitored in these reaches in 2006, 2007, and 2008. The 2008 data will be used in this study, because 1) additional parameters related to groundwater inputs have been measured in 2008, and 2) the confounding effect of a wastewater input from the Empire wastewater treatment plant is no longer present in 2008 because of a permanent wastewater diversion.

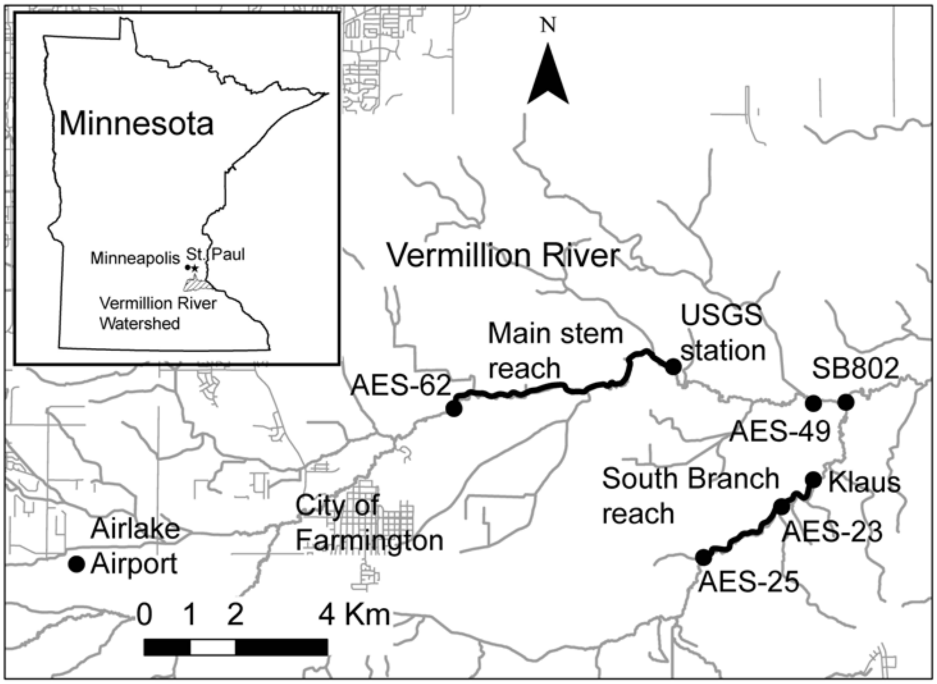

Figure 1.2. Map of the test reaches and temperature monitoring stations in the South Branch and in the mainstem of the Vermillion River. The Vermillion River is a tributary of the Mississippi, and is located about 30 km south of the Twin Cities (Minneapolis and St. Paul) in Minnesota.

Continuous 15 minute stream flow data for 2008 were obtained for the USGS gaging site on the Vermillion River main stem at Empire and for the SB802 site on the South Branch of the Vermillion River (Figure 1.2). Stream temperature recorded at 15-minute intervals were obtained for the USGS site and for a site 8 km upstream at Biscayne Ave (AES-62 site in Figure 1.2). Stream temperature data were also obtained for three sites on the South Branch (SB802, AES-23, AES-25, Figure 1.2). Stream temperatures were monitored by the Dakota County Soil and Water Conservation District and the Minnesota Department of Natural Resources using Onset Hobo temperature loggers. Streambed temperature was also monitored at other sites in the Vermillion River watershed, including a site approximately 6 km downstream of the USGS site (AES-49) and a site on the South Branch (AES-23), shown in Figure 1.2. Streambed temperatures were monitored at a depth of about 40 cm into the sediment bed using piezometers equipped with Onset Hobo temperature loggers. This monitoring work was performed by Applied Ecological Services, Inc. in St. Paul, MN. Both monitored reaches are "gaining reaches", i.e. they have significant groundwater inflow [*Janke et al. 2008*]; streambed temperatures give a good estimate of the groundwater inflow temperature. Climate data were available from the Airlake Airport near Lakeville, including air temperature, relative humidity, and wind speed at 1-hour intervals. 10-minute solar radiation data were recorded at the St. Anthony Falls Laboratory, University of Minnesota, in Minneapolis, approximately 30 km north of the Vermillion River.

1.3.2 Comparisons with numerical 1-D model simulation results

A numerical stream temperature model for the Vermillion River basin was previously developed at the University of Minnesota to study the impact of land use changes on stream temperature [*Herb et al.* 2008a, b]. The stream temperature model is 1-D and unsteady; it includes surface heat transfer, sediment heat transfer, uniform or spatially varying groundwater inputs, surface runoff inputs, and riparian shading. The spatial resolution of the model is 100 m and the time resolution is 5 to 60 minutes, depending on the size of the reach. For the stream reaches of the present study, a 1-hour time step was found to be adequate for the numerical simulations. Unsteady stream flow and cross-sectional areas are supplied as an external model input. The EPD-riv1 model [*US EPA* 2005] was used to generate hourly stream flows in the mainstem and in reaches of the South Branch based on the observed flow at the USGS and SB802 flow gaging sites, respectively.

<u>Stream reach in the South Branch of the Vermillion River</u>

The South Branch reach was selected as a test case for model validation because stream temperatures recorded at three sequential stations (AES-25, AES-23, Klaus in Figure 1.2) were nearly identical (root-mean-square difference of 1.0^{o}C), indicating that the analytic models for equilibrium temperature and diurnal temperature variation should be applicable to this reach. The numerical stream temperature model was calibrated for the South Branch reach for the period June 1 to September 30, 2008 using the observed stream temperature at (AES-25) as the upstream boundary condition. The groundwater inflow rate (q_g) was set to 12 L/s per km (0.68 cfs/mile). The actual groundwater inflow rate from a shallow sand aquifer would be expected to vary at weekly to monthly time scales, but adequate results for the study period were obtained using a constant input rate. Monthly precipitation and stream discharge during the period June 1 to September 30, 2008 was relatively uniform, except for higher flow in June (Figure 1.3). The shading coefficient (C_{sh}) was assumed to be equal to the wind sheltering coefficient (C_{ws}) and was calibrated to be 0.63. The numerical stream temperature model gave a good fit of the observed downstream temperature at the Klaus station (Figure 1.4). The overall RMSE of the simulated 1-hour temperatures was 0.8°C over the 4 month period.

<u>Stream reach in the Vermillion River mainstem</u>

A stream temperature model was also developed and calibrated for the mainstem reach of the Vermillion River. The observed hourly stream temperatures at the AES-62 site (Biscayne Ave.) were used as the upstream boundary condition and the riparian shading coefficient and the groundwater inflow rate were adjusted to best match the observed downstream temperature at the USGS station. The streambed temperature observed at station AES-49, 6 km downstream of the USGS station, was used as the groundwater temperature; it varied seasonally from 9 °C in June to 11.5 °C in September. The shading coefficient (C_{sh}) was calibrated to a value of 0.35, and set equal to the sheltering coefficient. The calibrated groundwater inflow rate (q_g) for the Vermillion River main stem reach was 13.2 L/s per km (0.75 cfs/mile). The stream temperature simulation results are compared to observed stream temperatures at the USGS station in Figure

1.5. Good accuracy was achieved for both daily mean temperatures and diurnal temperature fluctuations, with root-mean square errors (RMSEs) of about 1°C.

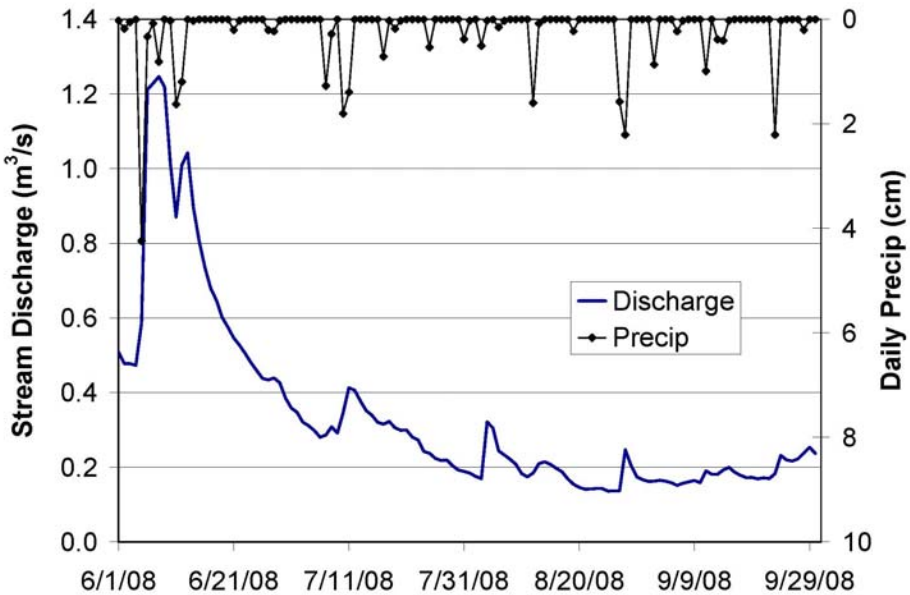

Figure 1.3. Daily stream discharge and precipitation for the South Branch of the Vermillion River, 2008.

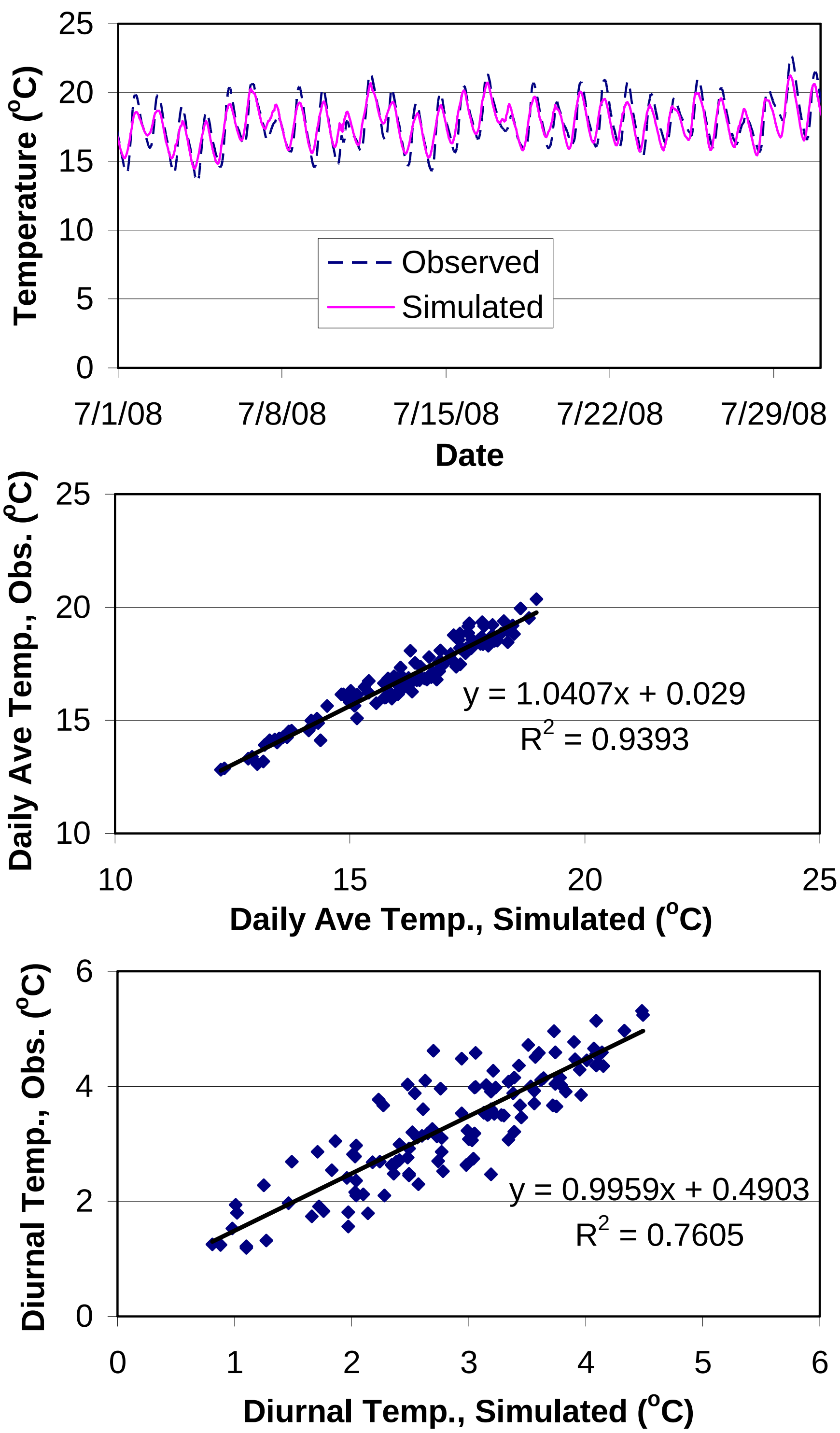

Figure 1.4. Time series of numerically simulated and observed hourly stream temperatures in the South Branch reach (upper panel), observed vs. simulated daily average stream temperature (center panel), and observed vs. simulated diurnal temperature variation (δT, lower panel). The overall RMSE of the 1-hour temperature simulation is 0.8°C.

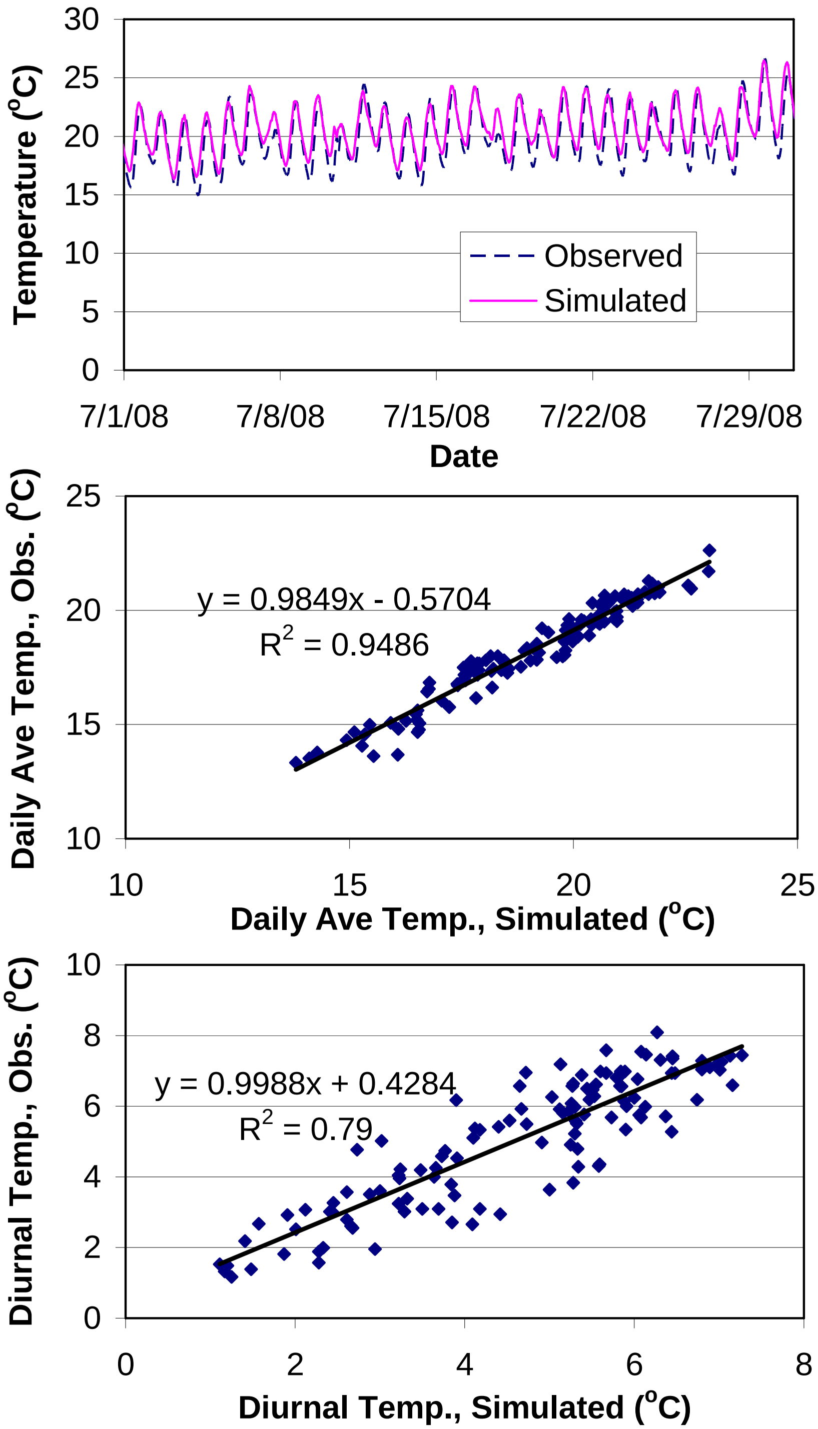

Figure 1.5. Time series of numerically simulated and observed hourly stream temperatures in the mainstem reach (upper panel), observed vs. simulated daily average temperature (center panel), and observed vs. simulated diurnal temperature variation (δT, lower panel). The overall RMSE of the 1-hour temperature simulation is 1.2 °C.

1.3.3 Modified equilibrium temperature model results

The analytic, modified equilibrium temperature model (Equations 17 and 18) was used to predict daily average stream temperatures in the South Branch and mainstem reaches of the Vermillion River for the period June 1 to September 30, 2008. The groundwater input rates and temperatures, and the riparian shading and wind sheltering coefficients were set equal to the calibrated values from the numerical model study. The stream width was set for each day based on the observed discharge using power law relationships.

Statistics of the predicted and observed mean daily temperatures are summarized in Table 1.1. For the South Branch of the Vermillion River, modified equilibrium temperature was a good predictor of daily stream temperature with an RMSE of 1.2°C. For the mainstem reach, equilibrium temperature was also a reasonable of mean daily stream temperature; the RMSE was 1.4 °C.

The average values of the atmospheric bulk heat transfer coefficient (K) and the sediment/groundwater coefficient (K_s*) are given in Table 1.2. For the wider mainstem reach, the average value of K (13.1 W m^{-2} $^oC^{-1}$) is 2.5 times higher than K_s* (5.8 W m^{-2} $^oC^{-1}$); for the South Branch reach, K (9.0 W m^{-2} $^oC^{-1}$) is 1.7 times lower than K_s* (15.2 W m^{-2} $^oC^{-1}$).

The analytic diurnal equilibrium temperature model (Equation 29) was used to predict diurnal stream temperature fluctuations in the two Vermillion River reaches for the period June1 to September 30, 2008. For both the mainstem and South Branch reaches, Equation 29 was a good predictor of diurnal stream temperature changes. Statistics of the predicted and observed mean diurnal temperature fluctuations are summarized in Table 1.3. The analytic model results compared to observations had a slightly higher RMSE than the numerical model results.

<u>Stream reach in the South Branch of the Vermillion River.</u>

The mean flow rate for South Branch was 0.34 m^3/s (12 cfs) for the period June 1 to September 30, 2008. For SB802 on the South Branch of the Vermillion River, the daily equilibrium temperature computed from Equation 17 was a good predictor of the observed daily average stream temperature (Figure 1.6). The RMSE was 1.2°C. Statistics of the predicted and observed mean daily temperatures are given in Table 1.1.

<u>Stream reach in the Vermillion River mainstem</u>

The mainstem of the Vermillion River at the USGS gaging station site is substantially larger than South Branch, with a mean flow of 0.34 m^3/s (12 cfs). Three cases were run for the mainstem segment, which demonstrate the abilities and limitations of the modified equilibrium temperature model:

1. Modified equilibrium temperature, local shading conditions. For the reach between Biscayne Ave (AES-62) and the USGS station, the calibrated shading coefficient from the numerical model was 0.35. Using this shading coefficient, the equilibrium temperature model systematically over-predicted daily average stream temperatures (Figure 1.7, lower panel), with RMSE = 3.1°C. The main reason for this overprediction is that this stream reach is not in thermal

equilibrium. Stream temperature in that reach increases systematically with distance ($dT/dx > 0$), due to low riparian shading ($C_{sh} = 0.35$) relative to upstream reaches ($C_{sh} = 0.5$ to 0.8). According to Equation 23, the characteristic length (λ) required to reach equilibrium in that stream reach is about 12 km at low flow (0.5 m^3/s) and 100 km at high flow (6 m^3/s).

2. Modified equilibrium temperature with spatially averaged shading conditions.
Riparian shading conditions were spatially averaged over 20 km upstream of the USGS site, based on calibrated shading from previous numerical model results (Herb et al. 2008a), yielding a mean shading of 0.70. If this mean value is then used in the modified equilibrium temperature model (eq. 17), predicted temperatures match observations at the USGS site reasonably well (RMSE =1.4 C, Figure 1.7 center panel).

3. Modified equilibrium temperature with spatial correction, local shading conditions. If Equations 21 and 22 are used to adjust the modified equilibrium temperatures based on the observed stream temperature at Biscayne Ave, the calculated modified equilibrium temperatures match measured stream temperatures quite well (Figure 1.7, upper panel). The longitudinal variation of stream temperature predicted by the analytic model (Equations 21 to 23) also agrees well with those simulated by the numerical model (Figure 1.8).

The analytic diurnal temperature fluctuation model (Equation 29) was a good predictor of diurnal stream temperature changes (Figure 1.9); the RMSE was 0.86°C for the South Branch reach, and 1.0°C for the mainstem reach, respectively. For both the SB802 and USGS stations, the analytic model for diurnal temperature fluctuations had a slightly (order 0.1°C) higher RMSE to observations than the numerical model (Table 1.3). The RMSE values for the numerical model were 0.94°C and 0.68°C for the mainstem reach and the South Branch reach, respectively.

Table 1.1. Summary statistics of mean daily stream temperatures (°C) in the mainstem and South Branch reaches of the Vermillion River, June 1 - September 30, 2008.

Parameter	Mainstem	South Branch
Average, Observed	18.2	16.9
St. Dev., Observed	2.1	1.7
Average, Numerical	19.1	16.3
St. Dev., Numerical	2.1	1.6
RMSE, Numerical	1.3	0.8
Average, Analytic	18.5	15.6
St. Dev., Analytic	2.4	1.5
RMSE, Analytic	1.4	1.2

Table 1.2. Magnitude and variability of the atmospheric heat transfer coefficient (*K*) and the sediment/groundwater bulk heat transfer coefficient (K_s*) for the mainstem and South Branch reaches of the Vermillion River for June 1 – September 30, 2008. In all cases, K_s = 1 W/m/°C and δ=2 m.

Parameter	Mainstem	South Branch
q_{gw} (L/s/km)	13.2	12.7
B (average, m)	3.8	11.2
K_s* (average, W/m^2/ºC)	5.8	15.2
K_s* (stan dev,W/m^2/ºC)	0.25	1.5
K (average, W/m^2/ºC)	13.1	9.0
K (stan dev, W/m^2/ºC)	4.2	2.4

Table 1.3. Summary statistics of diurnal stream temperature fluctuations (°C) in the mainstem and South Branch reaches of the Vermillion River, June 1 - September 30, 2008.

Parameter	Mainstem	South Branch
Average, Observed	5.0	3.3
St. Dev., Observed	1.8	0.99
Average, Numerical	4.6	2.8
St. Dev., Numerical	1.6	0.87
RMSE, Numerical	0.94	0.68
Average, Analytic	4.2	2.8
St. Dev., Analytic	1.6	1.0
RMSE, Analytic	1.0	0.86

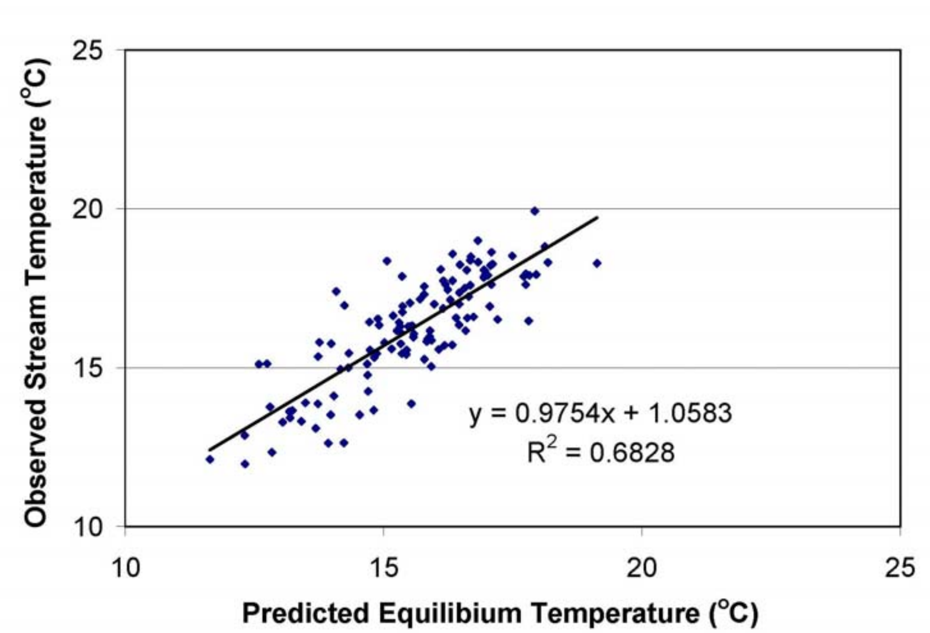

Figure 1.6. Observed daily average stream temperature vs. modified equilibrium temperature from Eq. 17 for the SB802 site, June 1 – September 30, 2008. RMSE =1.2 °C.

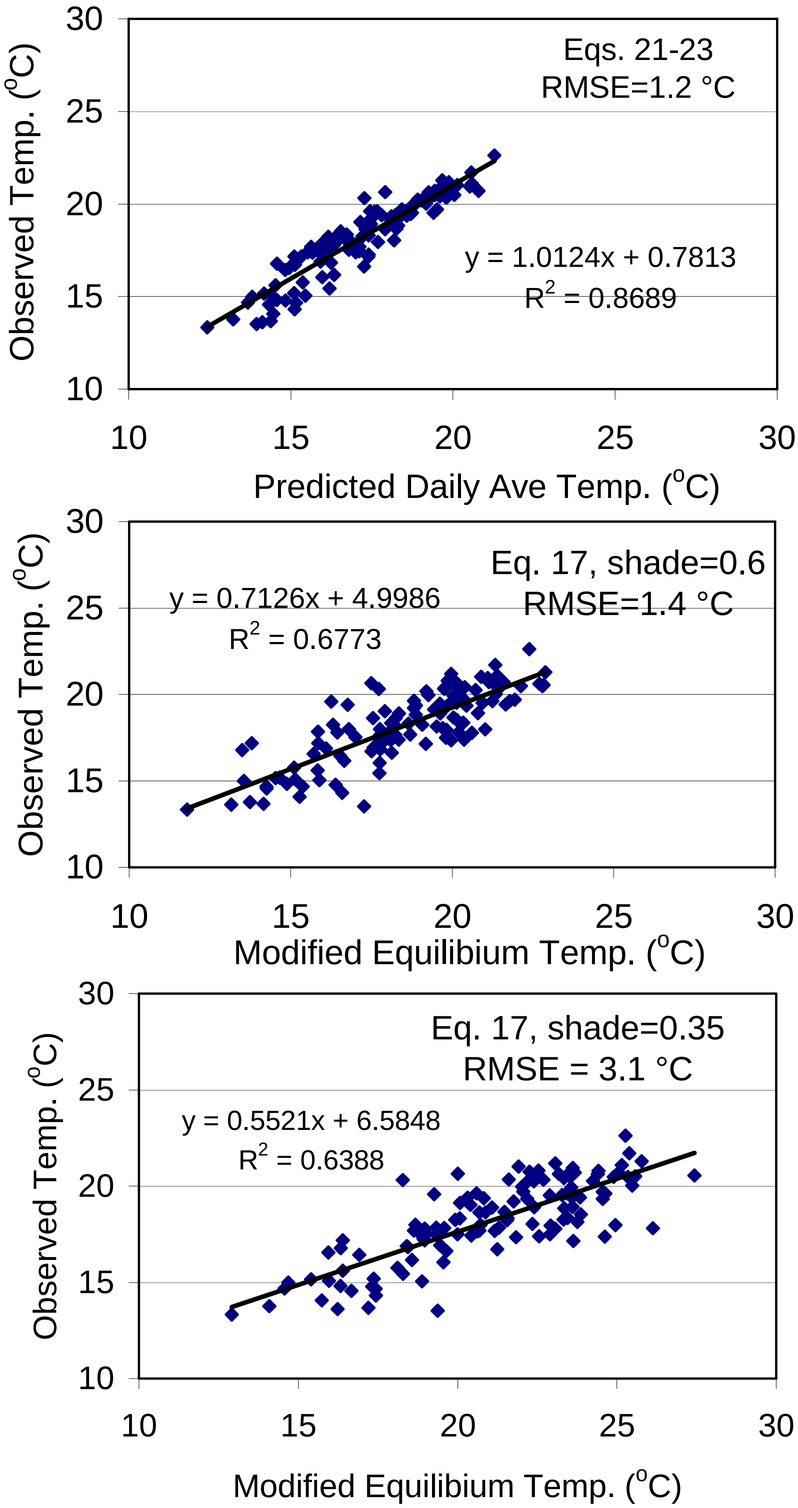

Figure 1.7. Observed daily average stream temperature vs. modified equilibrium temperature from Eq. 17 (lower and center panel) and observed daily average stream temperature vs. daily average temperature from Eq. 21-23 (upper panel) for the USGS stream gaging site on the mainstem, June 1 – September 30, 2008.

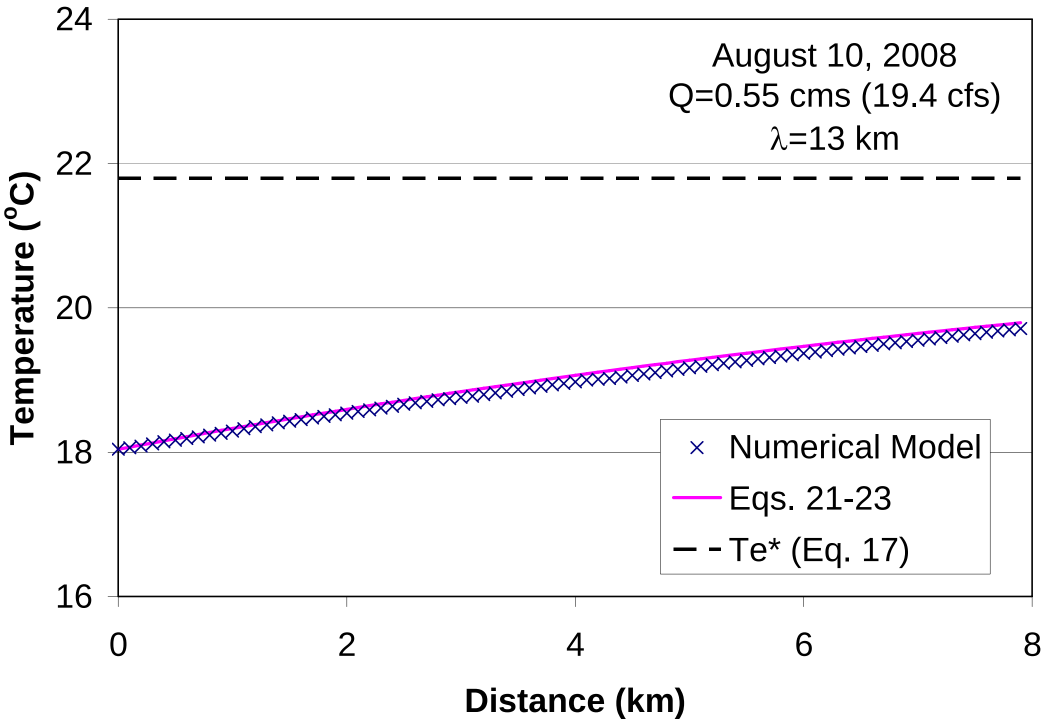

Figure 1.8. Daily average stream temperature vs. distance from the analytic solution (Equations 21-23) and the numerical model for the mainstem reach, August 10, 2008.

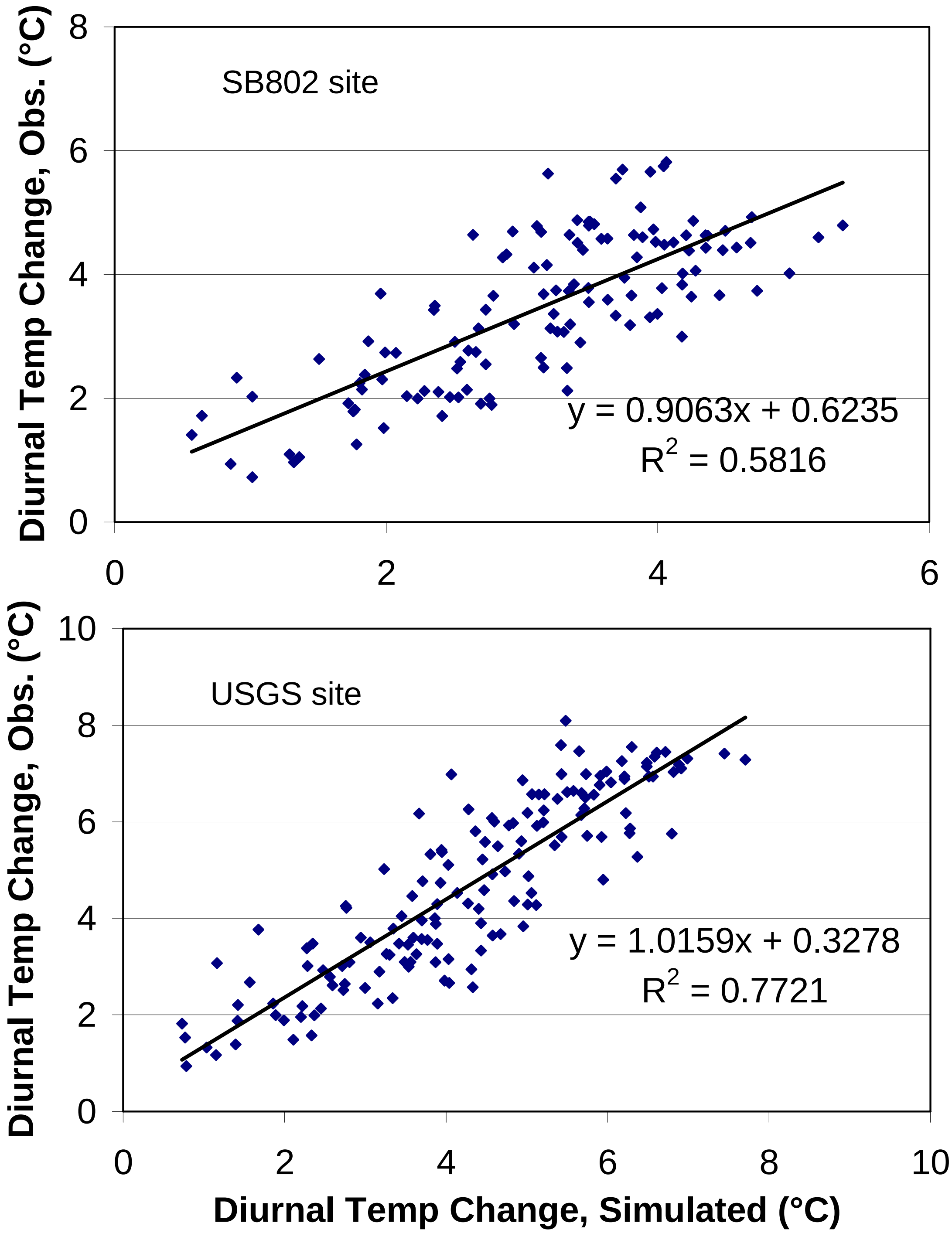

Figure 1.9. Observed vs. predicted diurnal temperature change (δT) from Eq. 29 for the SB802 (upper panel) and the USGS (lower panel) stream gaging stations, June 1 – September 30, 2008. RMSE = 0.9°C and RMSE = 1.0°C, respectively.

1.4. Model Sensitivity Analysis

The analytic modified equilibrium temperature model for mean daily stream temperature and diurnal temperature variations can be used to examine the sensitivity of stream temperatures to hydraulic, riparian and climatic parameters. The sensitivity of the modified equilibrium temperature (T_e*) was investigated for stream reaches with nominal parameters corresponding to the South Branch and mainstem reaches of the Vermillion River summarized in Table 1.4. In all cases, T_e* was calculated using daily climate data for 2008, and averaged over the period June 1 - September 30. Non-temperature parameters were increased by 10%, i.e. multiplied by a factor of 1.1, and the resulting change in modified equilibrium temperature (T_e*) was documented as ΔT^*_e. Temperature parameters (T_g ,T_d ,T_a) were increased by 1°C above the nominal value. An adjustment to stream discharge (Q) produced corresponding changes to width, based on power law relationships for each reach, while an adjustment to stream width (B) did not affect any other parameters.

For a stream with the characteristics of the South Branch reach, the modified daily equilibrium temperature was found to be most sensitive (Table 1.4a) to the shading coefficient (C_{sh}). A 10% increase in shading produced a stream temperature change ΔT^*_e = - 0.55°C. A change in the groundwater inflow rate or groundwater temperature gave stream temperature changes of ΔT^*_e = - 0.27°C and 0.61°C, respectively. Stream width and average daily air temperature changes gave ΔT^*_e= 0.29°C and ΔT^*_e = 0.56°C, respectively. Sensitivity to stream flow (Q) was found to be small (ΔT^*_e= 0.053°C) and due to the change in stream width with flow. All changes were either a 10% or a 1°C increase in the model input parameter.

Table 1.4a. Mean change (Δ) and standard deviation of change (SD) in three estimated stream temperature response parameters (modified equilibrium temperature =T_e*, diurnal temperature change = δT, and daily maximum temperature = T_{max}, in response to a 10% or a 1°C increase in model input parameter values. Results are calculated changes for the period June 1 to September 30, 2008. Nominal parameter values (T^*_e=15.4°C, δT = 3.0°C, T_{max} = 16.9°C) are for the South Branch reach of the Vermillion River.

Input Parameter (units)	Nominal Value	Modified Value	Response: Mean Change (Standard Deviation), (°C)		
			ΔT^*_e (SD)	$\Delta\ \delta T$ (SD)	ΔT_{max} (SD)
C_{sh}	0.625	0.688	-0.546 (0.219)	-0.344 (0.065)	-0.719 (0.27)
C_{ws}	0.625	0.688	-0.016 (0.05)	0 (0)	-0.016 (0.05)
q_g (L/s/km)	12.7	14.0	-0.273 (0.102)	-0.026 (0.008)	-0.286 (0.101)
T_g (°C)	10.5	11.5	0.61 (0.058)	0 (0)	0.61 (0.058)
Q (m^3/s)	0.339	0.373	0.053 (0.02)	-0.096 (0.015)	0.004 (0.019)
B (m)	3.8	4.1	0.294 (0.11)	0.042 (0.013)	0.315 (0.108)
d (m)	0.23	0.25	0 (0)	-0.208 (0.032)	-0.104 (0.032)
T_a (°C)	20.2	21.2	0.280 (0.05)	0 (0)	0.280 (0.05)
T_d (°C)	13.7	14.7	0.143 (0.042)	0 (0)	0.143 (0.042)

Results were similar for the mainstem reach (Table 1.4b). Considering that a 10% change in shading is ΔC_{sh} = 0.035 for the mainstem reach, but ΔC_{sh} = 0.0625 for the South Branch reach, the sensitivity of T^*_e to shading is similar for the two reaches. The larger stream width of the mainstem (B = 11.2 m versus 3.4 m for South Branch) reduces the sensitivity to groundwater temperature (ΔT^*_e= 0.29°C and 0.61°C, respectively), but increases the sensitivity to air temperature. ΔT^*_e=0.80°C for the mainstem and ΔT^*_e=0.56°C for South Branch.

Table 1.4b. Mean change (Δ) and standard deviation of change (SD) in three estimated stream temperature response parameters (modified equilibrium temperature =T_e*, diurnal temperature change = δT, and daily maximum temperature = T_{max}, in response to a 10% or a 1°C increase in model input parameter values. Results are calculated changes for the period June 1 to September 30, 2008. Stream temperature response (°C) to 10% or 1°C increases in model input parameters. Nominal parameter values (T^*_e= 21.3°C, δT = 4.2°C, T_{max} = 23.5°C) are for the mainstem reach of the Vermillion River.

Input Parameter (units)	Nominal Value	Modified Value	Response: Mean Change (Standard Deviation), (°C)		
			Δ T^*_e (SD)	Δ δT (SD)	Δ T_{max} (SD)
C_{sh}	0.35	0.385	-0.387 (0.159)	-0.19 (0.037)	-0.482 (0.185)
C_{ws}	0.35	0.385	0.102 (0.039)	0 (0)	0.102 (0.039)
q_g (L/s/km)	13.2	14.5	-0.287 (0.117)	-0.006 (0.002)	-0.291 (0.117)
T_g (°C)	10.5	11.5	0.285 (0.056)	0 (0)	0.285 (0.056)
Q (m^3/s)	1.068	1.175	0.022 (0.009)	-0.206 (0.037)	-0.081 (0.035)
B (m)	11.2	12.3	0.29 (0.12)	0.004 (0.003)	0.294 (0.12)
d (m)	0.26	0.29	0 (0)	-0.372 (0.067)	-0.186 (0.067)
T_a (°C)	20.2	21.2	0.402 (0.053)	0 (0)	0.402 (0.053)
T_d (°C)	13.7	14.7	0.255 (0.057)	0 (0)	0.255 (0.057)

The sensitivity of the diurnal stream temperature amplitude (δT) and of the daily maximum stream temperature (T_{max}) to stream morphologic and climate parameters was also explored. Daily maximum stream temperature can be estimated as

$$T_{\max} = T_e * + \frac{\delta T}{2} \tag{31}$$

Sensitivity analysis results for δT and T_{max} are also summarized in Tables 1.4a and 1.4b. The diurnal stream temperature amplitude δT in the stream reach of the South Branch, was found to be sensitive to shading ($\Delta\delta T$ = - 0.34°C), to stream depth ($\Delta\delta T$ = - 0.21°C), and to stream discharge ($\Delta\delta T$ = - 0.10°C). Diurnal amplitude is notably insensitive to the groundwater inflow rate and groundwater temperature ($\Delta\delta T$ = - 0.026°C and 0, respectively).

The sensitivity of T_{max} to a parameter is the sum of the sensitivity to T_e* and δT. T_{max} was found to be sensitive to shading (ΔT_{max} = - 0.72), groundwater temperature (ΔT_{max} = 0.61), air temperature (ΔT_{max} = 0.56), stream width (ΔT_{max} = - 0.32), and groundwater inflow rate (ΔT_{max} = - 0.29).

The sensitivity of T_e* and T_{max} to groundwater inflow rate (q_g) and shading coefficient (C_{sh}) is illustrated with 2008 climate data in Figure 1.10 for the South Branch reach and Figure 1.11 for the mainstem reach. Calculated time series of T_e* in 2008 are given for varying values of q_g and C_{sh}, keeping other parameters at their nominal values given in Table 1.4a and b. Very low shading or very low groundwater inputs can result in equilibrium temperatures approaching and exceeding 30°C in the South Branch reach and 40°C in the mainstem reach. This is noteworthy because these temperatures substantially exceed temperature tolerances of all trout (salmonid) species. Compared to the South Branch reach, the wider mainstem reach with lower shading requires more groundwater input to reduce stream temperatures.

Figure 1.12 illustrates the tradeoff between stream shading and groundwater inputs to achieve particular values of equilibrium stream temperature. Results are given for temperatures averaged over July, 2008. The groundwater inflow rate is specified as (q_g/B), the average velocity of the groundwater inflow normal to the stream bottom (mm/s). In this way the plot can be applied to streams of any width. However, Figure 1.12 is specific for July 2008 climate and groundwater temperature of 10°C and 12°C.

Figure 1.13 gives information on the relationships between stream shading, groundwater inputs, and stream temperatures in a slightly different form compared to Figure 1.12. Stream equilibrium temperature is plotted against shading for lines of constant groundwater input velocity (q_g/B). Plots are given for mean climate conditions in July and September in the Twin Cities area, with July stream temperatures substantially higher for the same shading and groundwater inputs. Note that for higher groundwater input rates, stream temperature is less sensitive to changes in shading. If groundwater inputs for a stream reach are considered fixed, the effect of riparian shading management on stream temperature can be easily found using such a figure.

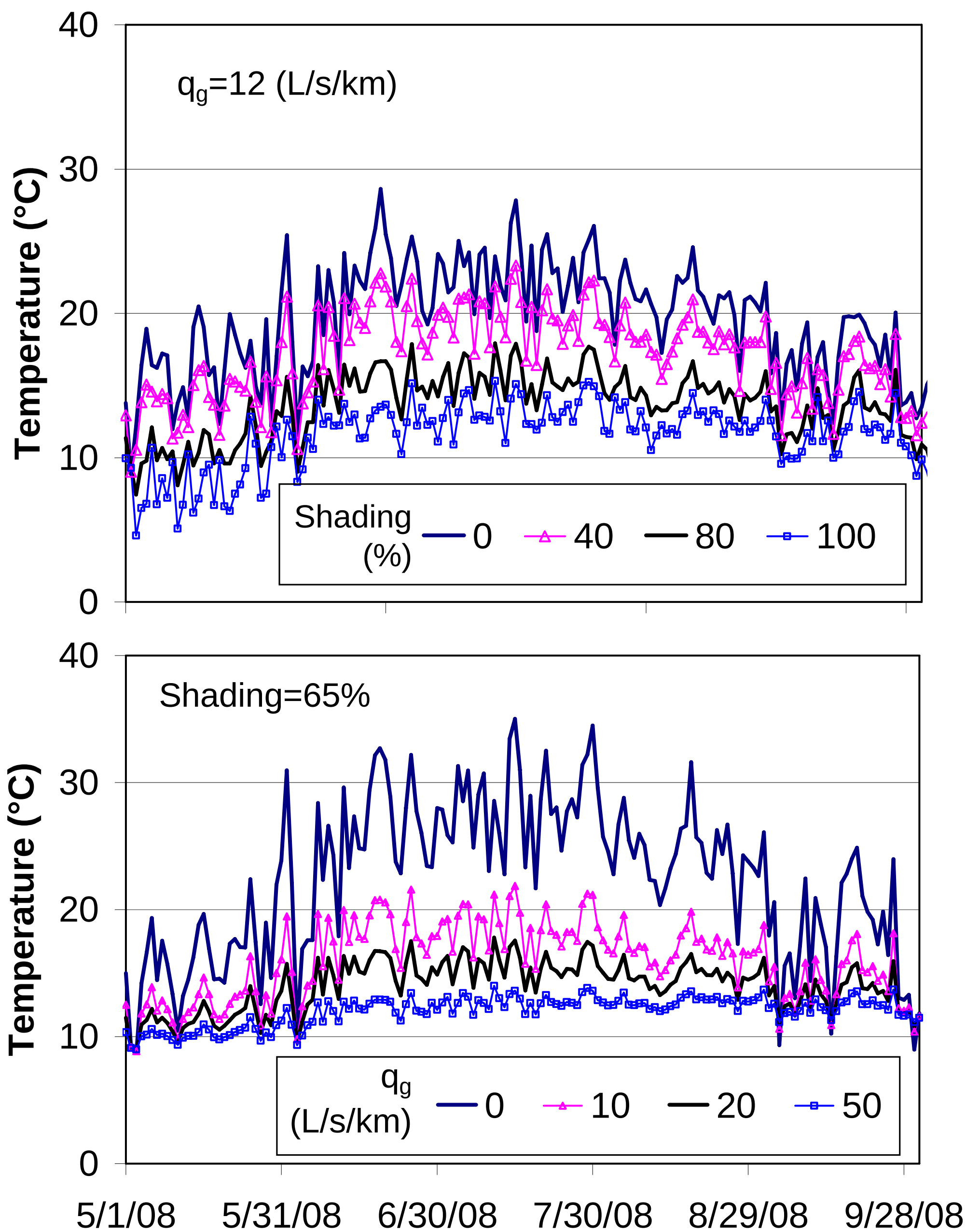

Figure 1.10. Sensitivity of daily adjusted equilibrium temperature (T_e*) to the shading coefficient (upper panel) and groundwater inflow rate (lower panel) for the South Branch reach (*B*=3.7m) and 2008 climate data. The wind sheltering coefficient was set equal to the shading coefficient in all cases.

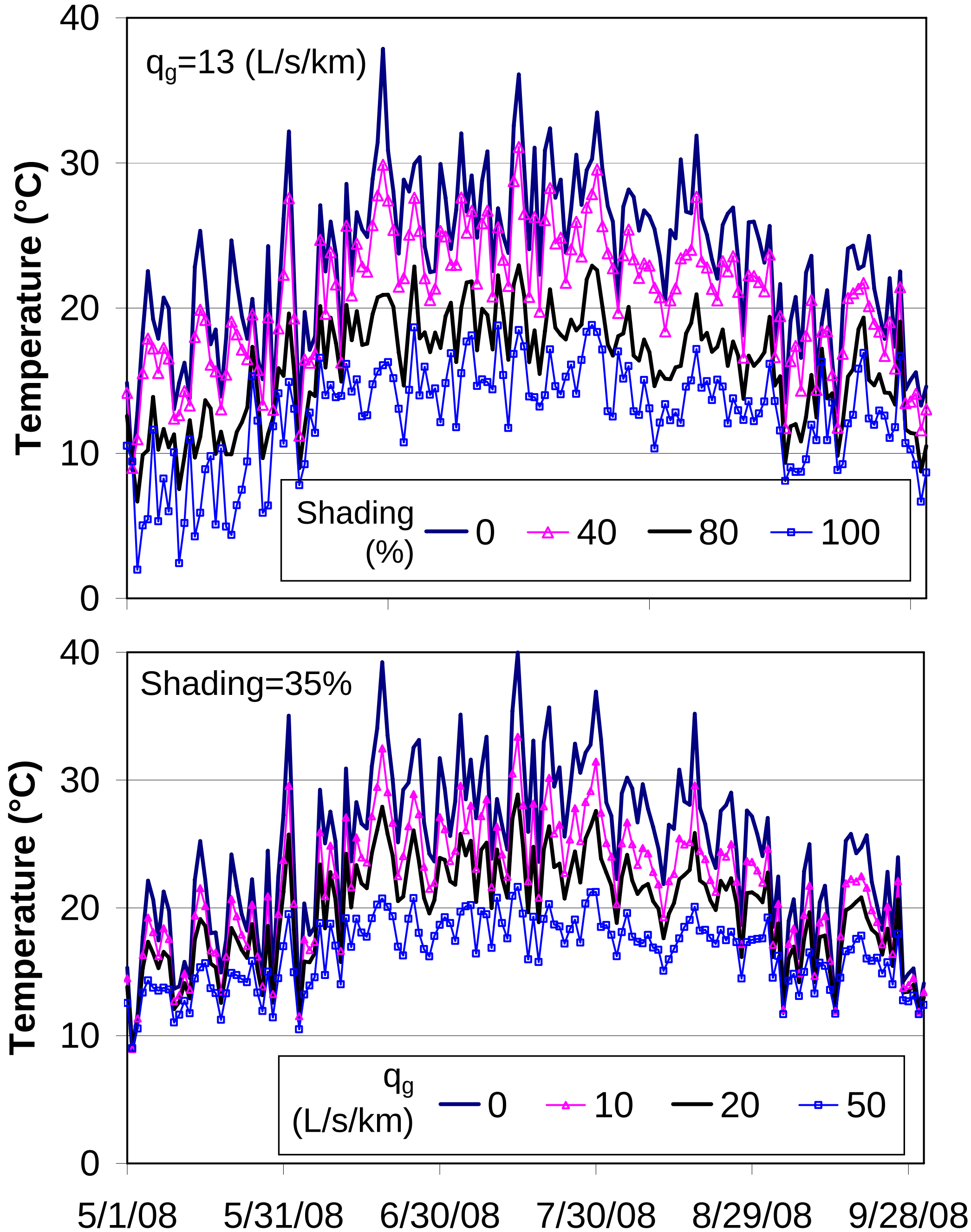

Figure 1.11. Sensitivity of daily adjusted equilibrium temperature (T_e*) to the shading coefficient (upper panel) and groundwater inflow rate (lower panel) for the mainstem reach (B = 11.2m) and 2008 climate data. The wind sheltering coefficient was set equal to the shading coefficient in all cases.

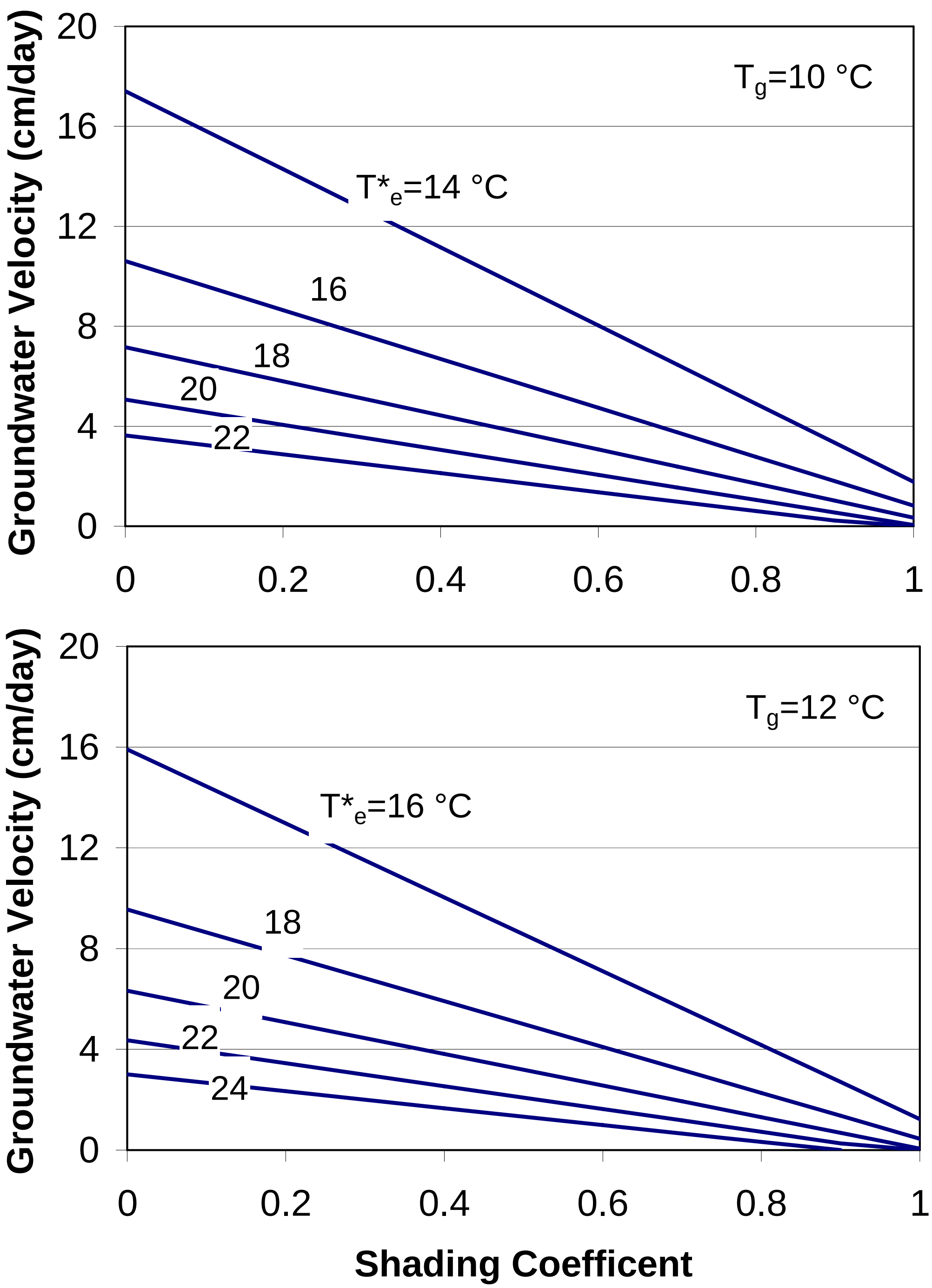

Figure 1.12. Equilibrium temperature (T_e*) isotherms in a plot of groundwater inflow velocity (q_g/B) vs. shading coefficient. All temperature values are averaged over July, 2008. Groundwater inflow temperatures are T_g = 10°C (upper panel) and T_g = 12°C (lower panel).

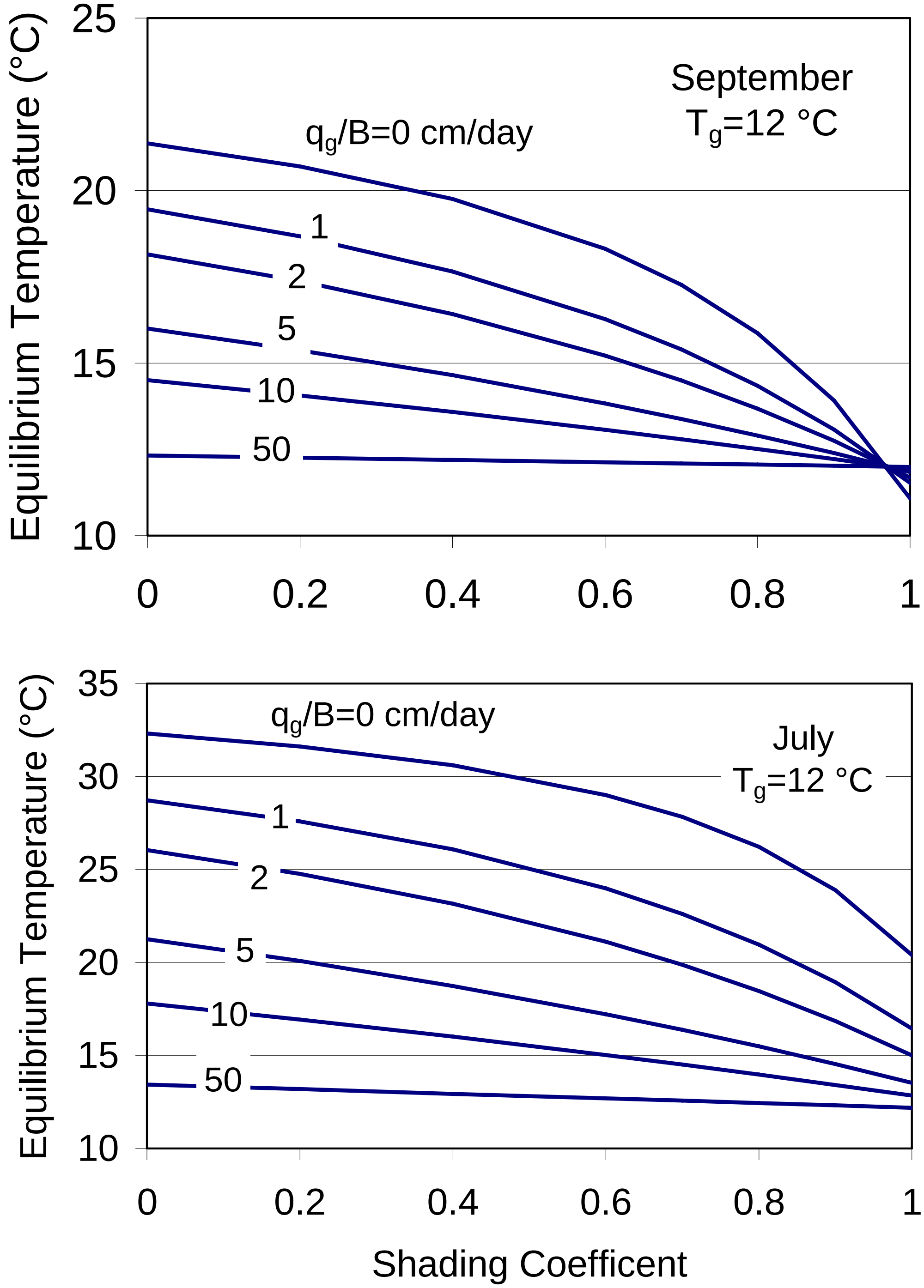

Figure 1.13. Equilibrium temperature versus shading and groundwater inflow velocity for averaged climate in July 2008 (lower panel) and September 2008 (upper panel). Groundwater inflow temperatures is $T_g = 12°C$.

1.5 Summary and Conclusions (Part I)

The temperature of a coldwater stream depends on the balance of the heat fluxes across the water surface (short and long wave radiation, convection and evaporation) and the heat fluxes across the sediment surface (groundwater inflow and conduction to the sediment). Previous equilibrium temperature models have reduced the complex heat transfer across the water surface to a net transfer rate that depends on a bulk heat transfer coefficient (K) and a temperature difference between the water and the equilibrium temperature [*Edinger et al.* 1968]. A modified (extended) equilibrium temperature (T_e*) model for coldwater streams has been developed and tested. The new model adds a second bulk coefficient (K_s*) and the streambed temperature (T_g) to modulate the influence of the groundwater inflow and sediment temperature on stream temperature.

For small, groundwater-fed streams, the surface and subsurface heat transfer coefficients, K and K_s^*, respectively, can be of similar magnitude. For a given rate of groundwater input (flow rate per unit stream length), the degree of influence of groundwater on stream temperature scales inversely with stream width, so that a given groundwater inflow (flow/length) will have less impact on stream temperature for wider streams. Typical trends of increasing stream temperature with downstream distance observed in field studies of trout streams [*Caissie* 2006] can be attributed to a combination of this groundwater effect and the typical reduction in riparian shading as channel width increases.

The modified equilibrium temperature model for coldwater streams formulated and used in this study gives an upper bound for daily average temperature based on climate conditions, riparian shading, stream width, and groundwater inputs. Two reaches of the Vermillion River were successfully modeled in this study. For streams with non-uniform shading due to development or other factors, riparian shading needs to be averaged over appropriate length scales for equilibrium conditions. For the main stem of the Vermillion, this length scale was estimated with Equation 23 as 20 km.

The amplitudes of diurnal temperature fluctuations of streams depend on the daily solar radiation and air temperature cycles, and can be estimated with relatively simple analytic models. The diurnal temperature variation also depends on stream depth, since depth determines the thermal mass of water per unit surface area. Groundwater inflows to a stream were found to have relatively little effect on diurnal temperature variation in the two stream reaches studied. Hyporheic exchange flows can have a measureable influence on diurnal temperature changes in streams with alluvial substrates because they increase the mass of water to be heated and cooled in the diurnal cycle increase, similar to stream depth [*Burkholder* 2008; *Story et al.* 2003]. Hyporheic exchange flows were not included in the modified equilibrium temperature model, because they depend on morphological features such as permeability of the stream bed [*Burkholder* 2008]; stream depth can, however, be considered as a surrogate for hyporheic effects. The equilibrium temperature and diurnal temperature variation models were combined to give an estimate of daily maximum stream temperatures.

A sensitivity analysis of the equilibrium temperature model confirms that water temperatures in coldwater streams vary strongly with riparian shading, stream width, and both groundwater inflow rate and temperature. While increased wind sheltering can reduce evaporative (latent) and convective (sensible) heat fluxes, the sensitivity of stream temperature to wind sheltering was found to be an order of magnitude lower than the sensitivity to shading changes. This result is in agreement with previous studies showing that convective/evaporative heat fluxes tend to be smaller than radiation fluxes [e.g. *Johnson* 2004].

The decreased sensitivity of stream temperature to air temperature for streams with larger groundwater inputs predicted in this study is in qualitative agreement with previous studies [*Caissie* 2006]. However, groundwater-fed stream reaches will be sensitive to increases in groundwater temperature, which can be expected to rise with mean annual air temperature. The models developed in this study provide a convenient means to estimate the stream temperature–air temperature slope, and are appropriate for studying the regional response of stream temperature to climate change.

The modified equilibrium temperature model is applicable to the study of specific coldwater stream reaches. Benefits of additional riparian shading or changes in stream morphology can be explored (simulated) with the model before management decisions are made. Trends in daily average and daily maximum stream temperatures in the warmest months can be studied with a minimum of in-situ stream geometry and flow data, yet the model is fairly realistic and allows for extrapolations because it is built on deterministic relationships. Basic information such as the shading-groundwater relationships given in Figure 1.12 can be used to quantify the importance of riparian cover and groundwater inputs in maintaining acceptable stream temperatures. The stream temperature model can be run with input provided by GIS analysis tools. Smaller stream systems may require aerial imagery for stream geometry and riparian shading, when satellite imagery has insufficient spatial resolution. Further work is needed to build data bases of coldwater stream morphology and hydrology and to estimate groundwater inputs so that the coldwater stream temperature projection tool developed in this study can be applied at a regional scale.

Part II. Projected impact of climate change on coldwater stream temperatures in Minnesota: Model simulations

2.1 Introduction

Coldwater fish species such as trout are found only in streams that meet certain temperature criteria because water temperature regulates the rates of biological and chemical processes, and is therefore an important aquatic habitat parameter (Eaton *et al.* 1995). The water temperature in streams and rivers is usually controlled by surface heat transfer processes with the atmosphere (Edinger *et al.* 1968, Sinokrot and Stefan 1993). Coldwater reaches of streams typically have substantial riparian shading and are fed by a cold water source, e.g. groundwater, deep reservoirs, ice- or snowmelt-water, or wetlands. Long term climate change, particularly increases in air temperature, is expected to lead to increases in stream and river water temperatures because of its direct effect on the heat transfer processes on the water surface. Stream temperature increases due to climate change may impact coldwater fish populations through a number of mechanisms, including metabolic changes, decreases in dissolved oxygen and increased uptake of contaminants (Ficke *et al.* 2007). Streams that are already impacted by land development may be particularly susceptible to climate changes (Webb *et al.* 2008). A second effect which has received relatively little attention is the warming of the source waters due to climate change (Meisner 1988). This dual effect of climate change on stream temperature will be investigated in this paper for Minnesota coldwater streams and climate conditions.

The change in stream temperatures due to climate and land use changes has been estimated using both empirical and deterministic models (Caissie 2006; Hari *et al.* 2006; Nelson and Palmer 2007; Webb *et al.* 2008). Deterministic, numerical stream temperature models can be used to predict the temperature response of a specific stream to climate change (Kim and Chapra 1997; Sinokrot and Stefan 1994). Such models require a substantial input of weather and stream parameters to quantify the different heat transfer processes. Stream-specific or regional regression models can also been created to study the impact of climate change on stream temperature (Clark *et al.* 2001; Mohseni *et al.* 1999). Stream temperature – air temperature regression models that characterizes stream temperature for past conditions can give the sensitivity of stream temperature to air temperature (e.g. Stefan and Preud'homme, 1993; Webb *et al.* 2003) , which in turn can be used to estimate future stream temperature from air temperature projected by global climate models (Erickson and Stefan 2000; Mohseni and Stefan 1998, 1999, Morrill *et al.* 2005). These regression models characterize the response of stream temperature to atmospheric heating using air temperature as a surrogate, but do not take into account long term changes in source water, e.g. groundwater temperatures in response to air temperature changes.

If equilibrium temperature (Edinger *et al.* 1968) is used as the independent variable instead of air temperature, the atmospheric heat transfer components are more explicitly taken into account in the projection of the stream temperature response to climate change (Bogan *et al.* 2003). However, equilibrium temperature or air temperature alone are not necessarily good predictors of stream temperature, especially coldwater streams because surface and subsurface water and heat inputs of source water can contribute significantly to a coldwater streams heat budget (Bogan *et al.* 2004).

Previous research on the effects of climate change on stream temperature has focused on atmospheric heat transfer components and ignored source water input. For many coldwater stream reaches in Minnesota that input is crucial in summer to maintain moderate temperatures. Soil and groundwater temperatures can be expected to increase with long term air temperature increases (Meisner *et al.* 1988), providing an additional mechanism for stream temperature response to climate change. Wetland systems acting as a water source for streams can also be expected to increase in temperature. In this paper, a previously developed stream temperature model based on equilibrium temperature is used to assess the response of stream temperature to climate change scenarios, taking into account both changes in atmospheric heat transfer and source water temperature. Two wetland-fed, coldwater trout streams near Duluth, MN and a groundwater-fed coldwater trout stream south of Minneapolis/St. Paul, MN are considered. The response of each stream to climate change is assessed in terms of 1) changes in direct atmospheric heat transfer to the stream, 2) changes in the temperature of water sources (groundwater, wetlands) and 3) the combined effects of changes in both atmospheric heat transfer and source temperatures.

2.2 Study Sites

The three study streams include an example of a groundwater-fed coldwater stream south of Minneapolis/St. Paul, MN (South Branch of the Vermillion River) and examples of two wetland-fed streams in Duluth, MN (Miller Creek and Chester Creek). The locations of the three sites are shown in Figure 2.1. South Branch, Miller Creek, and Chester Creek have watershed areas of 84, 24, and 18 km^2, respectively. All three are designated trout streams.

The Vermillion River flows through a relatively flat region covered by several major glacial moraines. The watershed is mostly made up of glacial drift from two separate glacial advancements (Superior and Des Moines lobes). The Vermillion River receives groundwater discharge from a quaternary surface aquifer that has a typical thickness from 7 to 35 m. There are also localized connections to two deeper aquifers – the Prairie du Chien and Jordan aquifers. The river sits in buried valleys filled with sand and gravel with high hydraulic transmissivity and recharge potential near the stream (EOR, 2007; Erickson and Stefan, 2009), and in particular, near portions of the river that are designated trout stream, including portions of South Branch. Although the Vermillion River watershed has some areas of increasing residential and commercial development, the study area (South Branch) has primarily agricultural land use (78%).

Miller Creek and Chester Creek have hydrogeologic features typical of streams in the Duluth area and northeastern Minnesota. The upper watersheds are relatively flat, covered with thin glacial deposits (Fitzpatrick *et al.* 2006), and with prominent wetland areas. Lower sections of the watersheds have steep slopes, very little soil coverage and are confined or entrenched valleys carved through bedrock. Groundwater storage is not well characterized, but it is believed that wetlands in the upper portions of the watersheds provide most of the hydrologic storage. Miller

Creek, in particular, has been impacted by development, with historical wetland loss and increased impervious surface area, currently about 23%.

Substantial temperature and flow monitoring has occurred on the Vermillion River over several years, and numerical models for stream flow and temperature have been developed (Herb *et al.* 2008a, b). For the present study, South Branch, a tributary of the Vermillion River, was selected (Figure 2.1). Water temperature has been monitored in stream reaches in 2006, 2007, and 2008. The 2008 data were used in this study to calibrate a stream temperature model, because additional parameters related to groundwater inputs were measured in 2008. Continuous 15-minute stream flow data for 2008 were obtained for the AES-21 (SB802) site on the South Branch of the Vermillion River (Figure 2.1). Representative stream temperature data for the South Branch was obtained from the Klaus monitoring station (Figure 2.1). Stream temperature was monitored by the Dakota County Soil and Water Conservation District and the Minnesota Department of Natural Resources using Onset Hobo temperature loggers. 2008 climate data for the South Branch stream temperature model calibration were available from the Airlake Airport near Lakeville, including air temperature, humidity, and wind speed at 1-hour interval. 10-minute solar radiation data were recorded at the St. Anthony Falls Laboratory, University of Minnesota, in Minneapolis, approximately 30 km north of the Vermillion River. For climate change analysis, a longer time record was obtained for the Minneapolis/St. Paul International Airport, which is about 25 km north of South Branch. This data set includes simulated solar radiation and was obtained for the period 1961-2005 from the National Renewable Energy Laboratory (NREL) (http://rredc.nrel.gov/solar/old_data/nsrdb/).

Substantial stream temperature monitoring data was also available for Miller Creek, in Duluth, MN (Figure 2.1), including sites in the main stem, tributaries, and stormwater inlets. Stream temperature data was taken by the South St. Louis Soil and Water Conservation District, mainly using Onset Tidbit temperature loggers. Flow data (1-hour) was available from a gaging station near the outlet of Miller Creek (Figure 2.1) for 1997, 1998, 2007, and 2008. Stream temperature and discharge data for Chester Creek were obtained from the Duluthstreams web site <www.duluthstreams.org>. Climate data for the Duluth area streams was obtained from Duluth International Airport, which is at the upper end of the Miller Creek watershed. For 2008 only, 1-hour observed solar radiation data were obtained from the Minnesota Pollution Control Agency from a station in the lower portion of the Miller Creek watershed. For other years (1961-2005), simulated hourly solar radiation data were obtained from the NREL for Duluth International Airport.

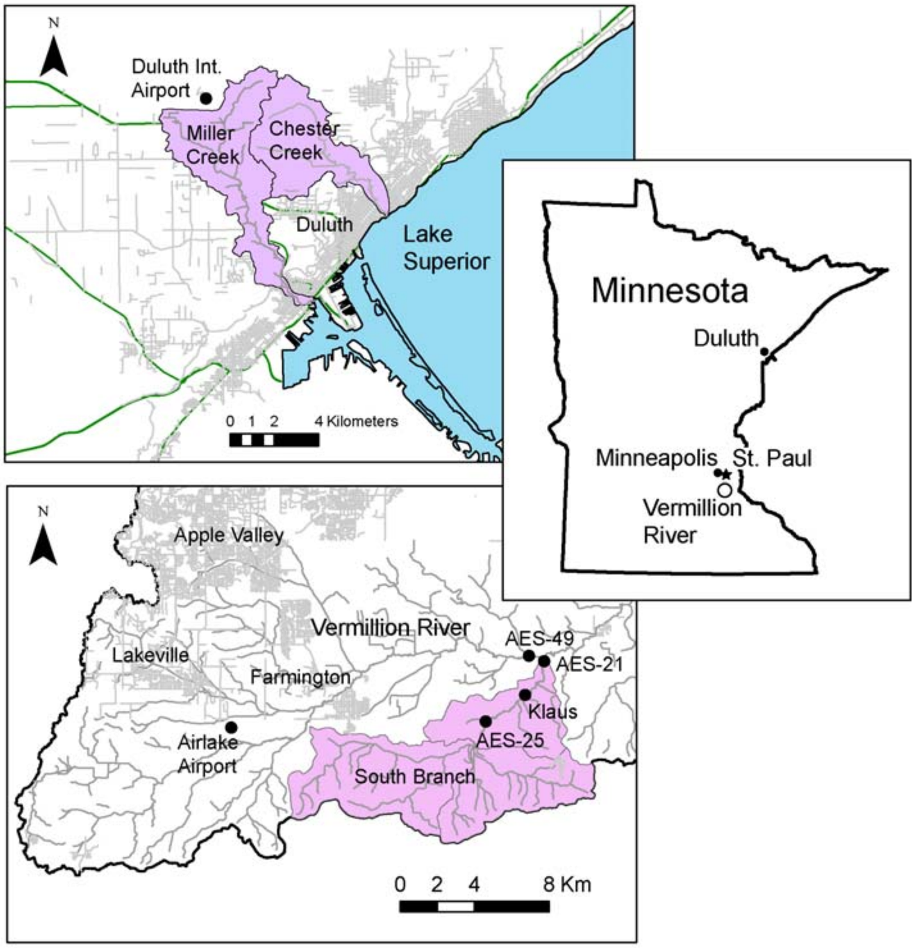

Figure 2.1. Study streams in Duluth, MN (Miller Creek, Chester Creek) and south of Minneapolis/St. Paul (Vermillion River).

2.3 Source Water Temperatures

2.3.1 Wetland temperatures

The North Shore region of Lake Superior in Minnesota has over 100 designated trout streams. This region does not have large groundwater aquifers, due to the presence of shallow and surface bedrock. Wetlands and lakes are a significant source of hydrologic storage in these watersheds (Detenbeck *et al.* 2003). Very little information is available on the storage characteristics of the North Shore wetland systems, other than what can be discerned from observed stream discharge. Comparison of hydrographs from streams in the Duluth, MN area to a similarly sized tributary of the Vermillion River, south of Minneapolis/St. Paul, MN clearly shows the relative lack of hydrologic storage in the North Shore systems (Figure 2.2).

Visual inspections of the wetlands in the Miller Creek watershed show relatively little standing surface water and surface channelization connecting the wetlands to the stream channel of Miller Creek. As a result, it is assumed that much of the connection between wetlands providing hydrologic storage and the stream channel is mainly by subsurface flow.

Source water temperatures for the Duluth area streams were obtained from 1) several years of monitored temperatures in wetland (standing) water in the Miller Creek watershed at Ridgeview Rd and 2) a previously developed computer model for the temperature of surface and subsurface water in wetlands (Herb *et al.* 2007). The model includes the effect of emergent vegetation on surface heat transfer processes. Using observed climate data from the Duluth International Airport, the wetland model was able to reproduce the observed surface water temperature time series (Figure 2.3) with a root-men-square error (RMSE) =1.4ºC. The primary calibration parameter for the wetland temperature model is a vegetation density parameter which varies from 0 to 1 and impacts shading and evaporation. For the Duluth wetland simulations, a relatively high vegetation density parameter (0.95) was determined by temperature calibration.

Simulated (or observed) wetland temperatures used as a source temperature for stream temperature simulations tended to give an excessive response of stream temperature to weather (climate) parameters when used at a daily time scale. Better results were obtained by using, e.g. a 7-day running average of wetland temperature or a second order polynomial fit of the seasonal variation of wetland temperature as the source temperature. A polynomial fit of the 10-year average (1997-2005, 2008) simulated daily wetland temperature also produced good stream temperature simulation results for 2008 data (Figure 2.4). The maximum summer source water (wetland) temperatures are reached at the end of July, approximately. The 10-year average source temperature was subsequently used for all simulations of Duluth-area streams, because it gives good temperature simulation results for current conditions and provides a good basis for estimating future source temperatures for these systems.

To specify climate change, Duluth climate data (1997-2005, 2008) was incremented using two future climate scenarios (GCMM 2.0 and 3.1 described in Section 2.5), and the wetland temperature model was also run for these scenarios. In addition to running incremented future climate scenarios above the wetland, the soil temperature at the lower boundary of the wetland model (10 m into the ground) was incremented by the projected change in mean annual air temperature for the region (5.0ºC for CGCM 2.0, 4.0ºC for CGCM 3.1). The projected change in wetland source water temperature with average increments of 2.7ºC and 3.5ºC and maximum increments of 4.3ºC and 3.2ºC for CGCM 2.0 and 3.1, respectively. These temperature increments are lower than the specified air temperature increments during the summer months, mainly due to evaporative cooling.

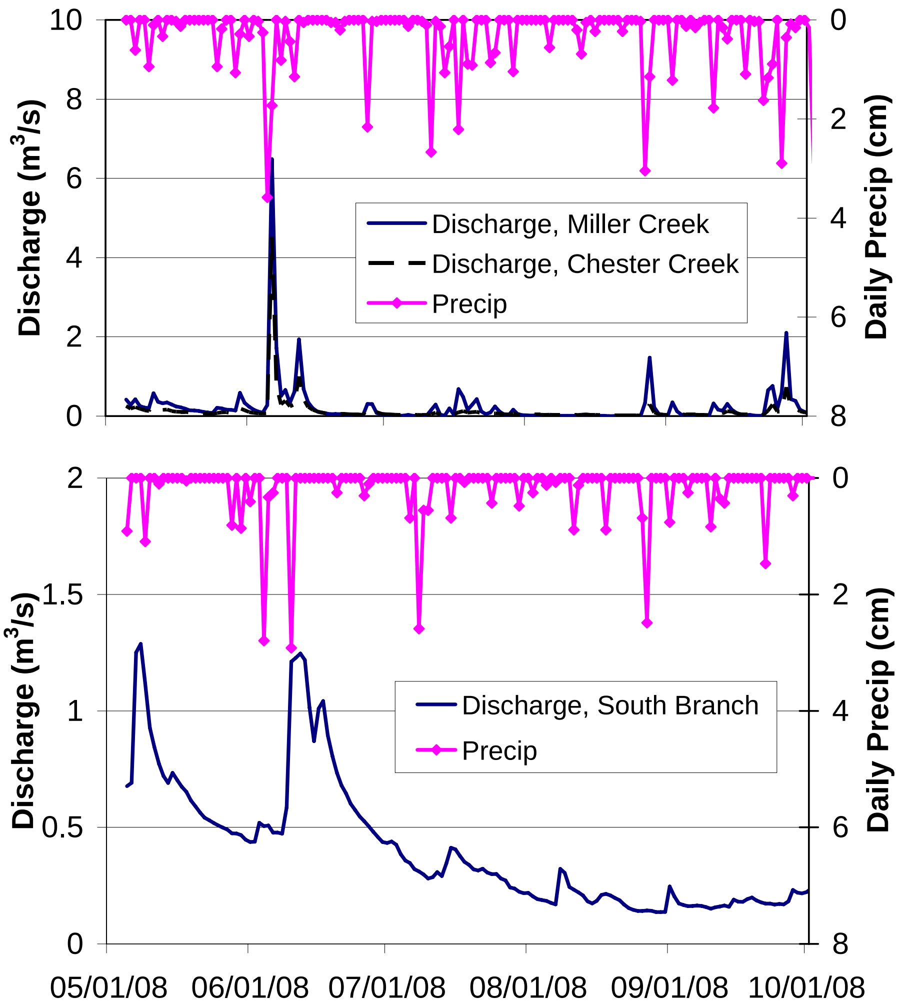

Figure 2.2. Precipitation and stream discharge timeseries for two North Shore trout streams in Duluth, MN (Miller and Chester Creek), and a groundwater-fed trout stream south of Minneapolis/St. Paul (South Branch of the Vermillion River).

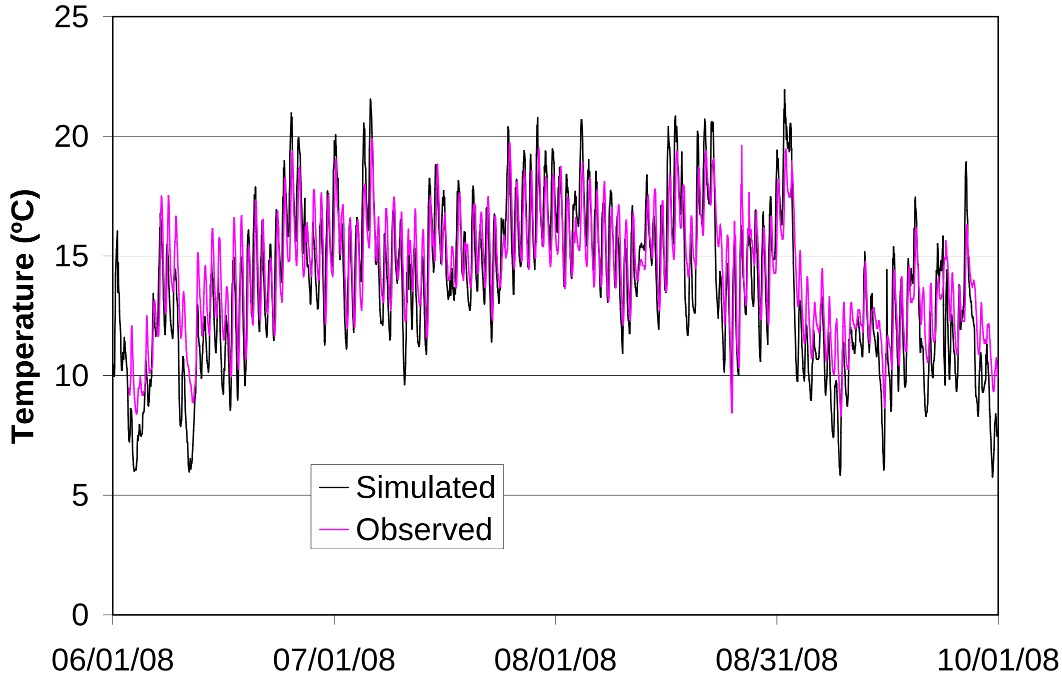

Figure 2.3. Simulated and observed wetland temperatures for the Ridgeview Rd. monitoring point in 2008. The simulations are at a 1-hour time step and have an RMSE = 1.4ºC.

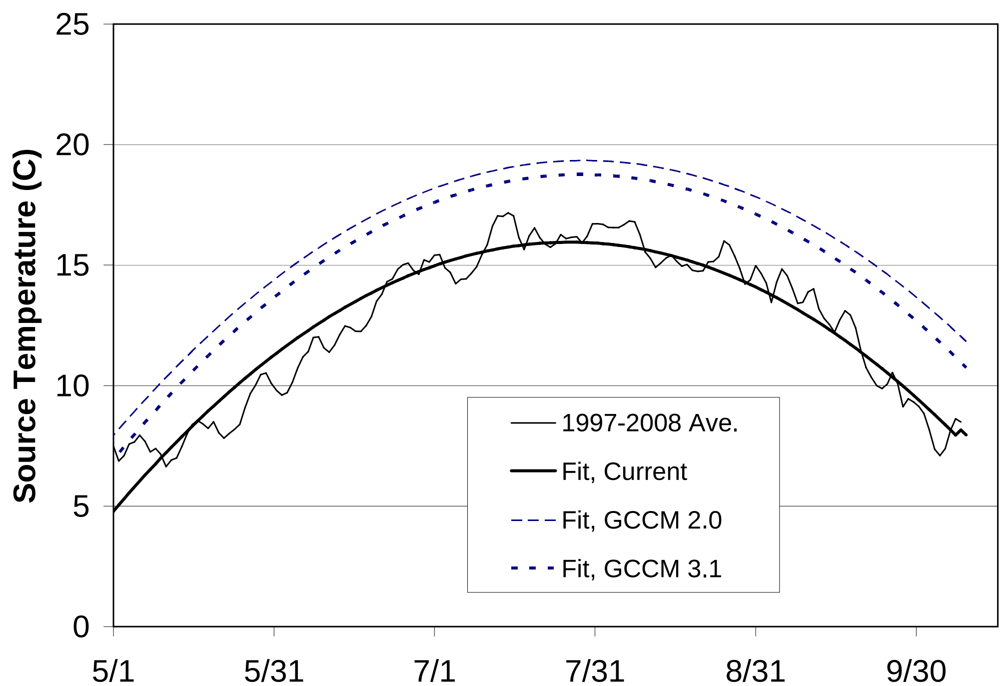

Figure 2.4. Simulated source water (wetland) temperatures for current conditions (average of 1997-2005, 2008) and for the CGCM 2.0 and 3.1 climate scenarios.

2.3.2 Groundwater temperatures

Groundwater temperatures depend on the depth of the aquifer. Water temperatures in shallow aquifers in Minnesota, down to depths on the order of 10m, respond to seasonal temperature changes on the ground surface; amplitudes and lag times vary with depth (Taylor and Stefan 2009). Groundwater from deep aquifers is isothermal year around. Its temperature is imposed by the long-term (multi-year) average ground surface temperature.

The Vermillion River is an example of a groundwater-fed Minnesota trout stream. Direct measurements of source water (groundwater) temperatures were available from 1) temperature measurements in the streambed of gaining stream reaches, i.e. stream reaches that receive groundwater, and 2) temperature measurements in several shallow groundwater wells in the watershed. Streambed temperatures were monitored at a depth of about 40 cm into the sediment bed using piezometers equipped with Onset Hobo temperature loggers. The monitoring work was installed and operated by Applied Ecological Services, Inc. in St. Paul, MN. Examples of streambed temperatures plotted in Figure 2.5 show that the AES-21 site had a constant streambed temperature, suggesting that the groundwater came from a depth where temperatures are unaffected by seasonal changes; the constant 9°C temperature is close to the 7.4°C mean annual air temperature in the Twin Cities area. The streambed temperatures at sites AES-25 and A-49 varied by several degrees over the summer period, and reached maximum values from August to September (Figure 2.5).

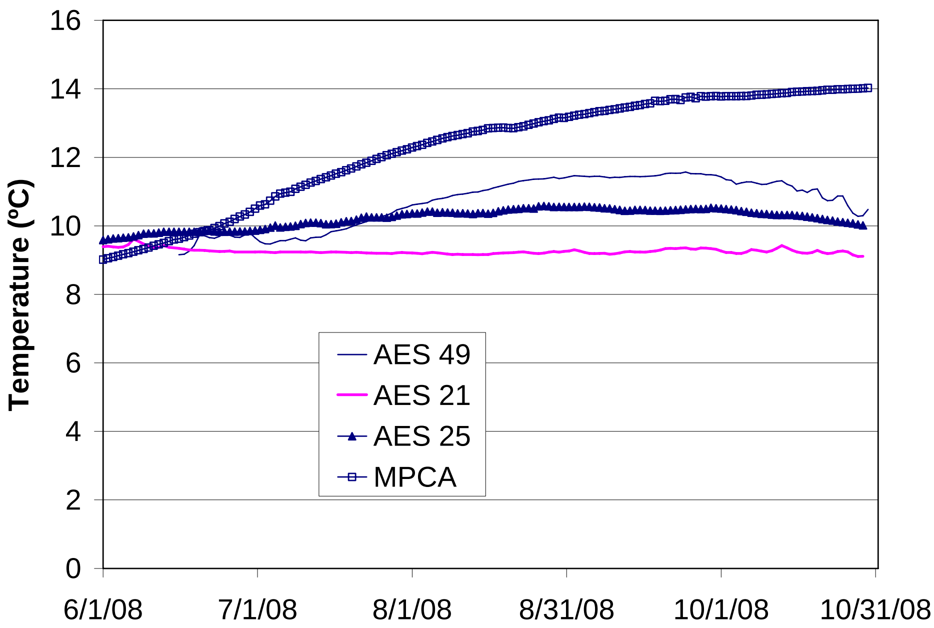

Figure 2.5. Observed streambed temperatures at 3 sites (AES 21, 25, 49) in the Vermillion River and observed temperature from a shallow groundwater well (MPCA). The locations of the sites are shown in Figure 2.1.

Shallow groundwater temperatures from 3m depth in a well in Farmington, MN, were obtained from the Minnesota Pollution Control Agency. The seasonal temperature excursion is 5°C, and a maximum temperature is reached in October.

Using the various streambed temperatures as source water temperatures, the AES 49 site temperature gave the best prediction of stream temperature at the South Branch site as will be shown in a later section. To project an increase in source water (groundwater) temperature due to climate change, the observed 2008 groundwater temperature was incremented by the projected change in mean annual air temperature (5.0ºC for CGCM 2.0, and 4.0ºC for CGCM 3.1) for the future climate scenarios.

2.4. Stream Temperature Model Calibration and Sensitivity

2.4.1 Stream temperature model calibration

The modified equilibrium stream temperature model described in Part I of this report was applied to simulate daily summer temperatures in the three study streams. Individual models were calibrated for the South Branch of the Vermillion River, for Miller Creek, and for Chester Creek using recorded time series of source temperatures described in Section 2.2. The calibration parameters were the shading and wind sheltering coefficients, and the source water (groundwater) inflow rate (q_g) and source water (groundwater) temperature (T_g). These calibration parameters were varied to achieve the lowest root-mean-square error (RMSE) between the predicted daily stream temperatures and the observed daily stream temperatures for June – September 2008. In addition, the slopes and intercepts of the air temperature – stream temperature relationships were compared for simulated and observed stream temperatures, to ensure that the model was correctly predicting the response of stream temperatures to air temperature variations. The stream width was calculated for each day based on the observed stream discharge using a power law relationship. The calibration parameter values, and the RMSE statistics are summarized in Table 2.1. The stream temperature simulations had an RMSE close to 1°C for all three streams, which is typical for stream temperature simulations. The simulated and observed daily stream temperatures are plotted in Figures 2.6 and 2.7 for Miller Creek and South Branch, respectively.

Table 2.1. Stream temperature model fit parameters.
The groundwater inflow rate is given in units of liters/second/kilometer.

	Shading coeff. C_{sh}	Sheltering coeff. C_{ws}	GW inflow rate q_g (l/s/km)	RMSE (°C)
Miller	0.59	0.59	11.8	1.04
Chester	0.60	0.60	14.7	1.02
South Branch	0.50	0.50	13.0	0.90

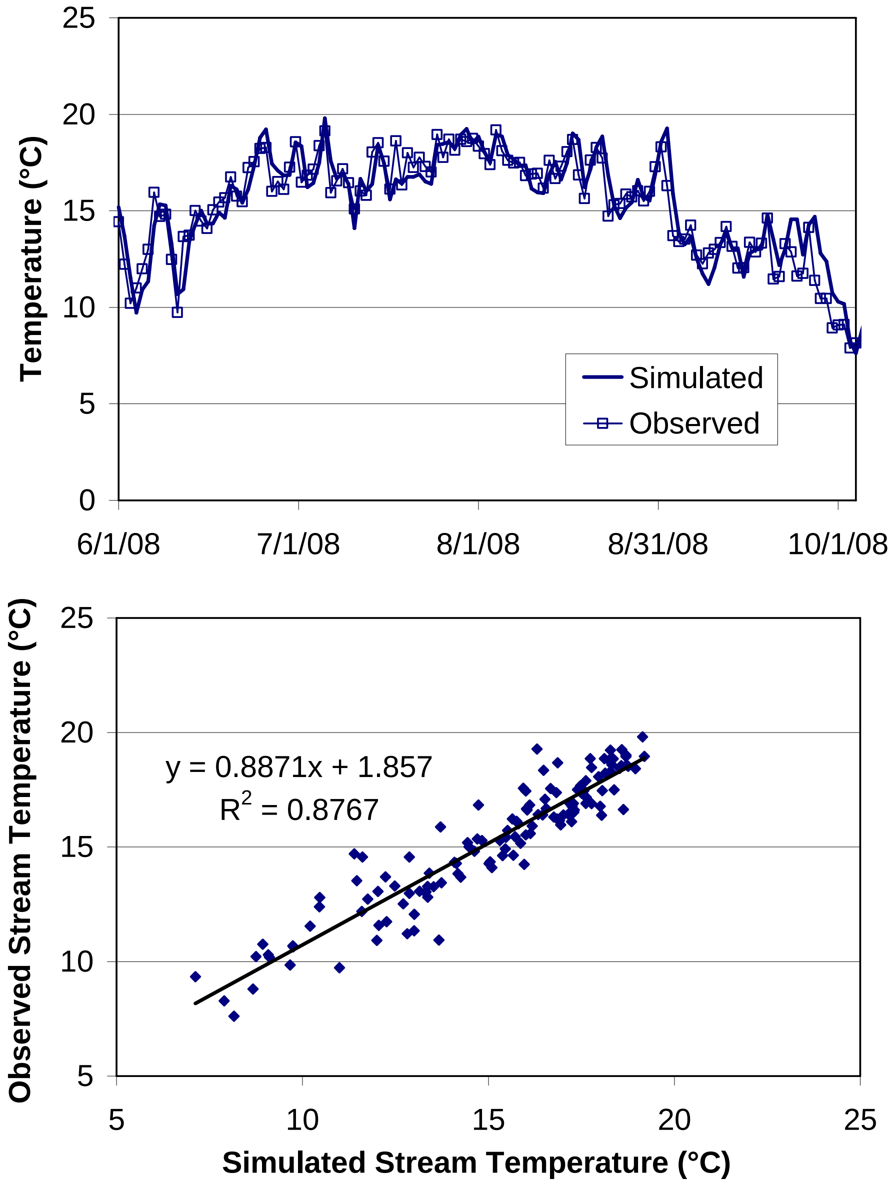

Figure 2.6. Time series of simulated and observed daily average stream temperature (upper panel) and observed vs. simulated daily average stream temperature (lower panel) for Miller Creek, June – September 2008.

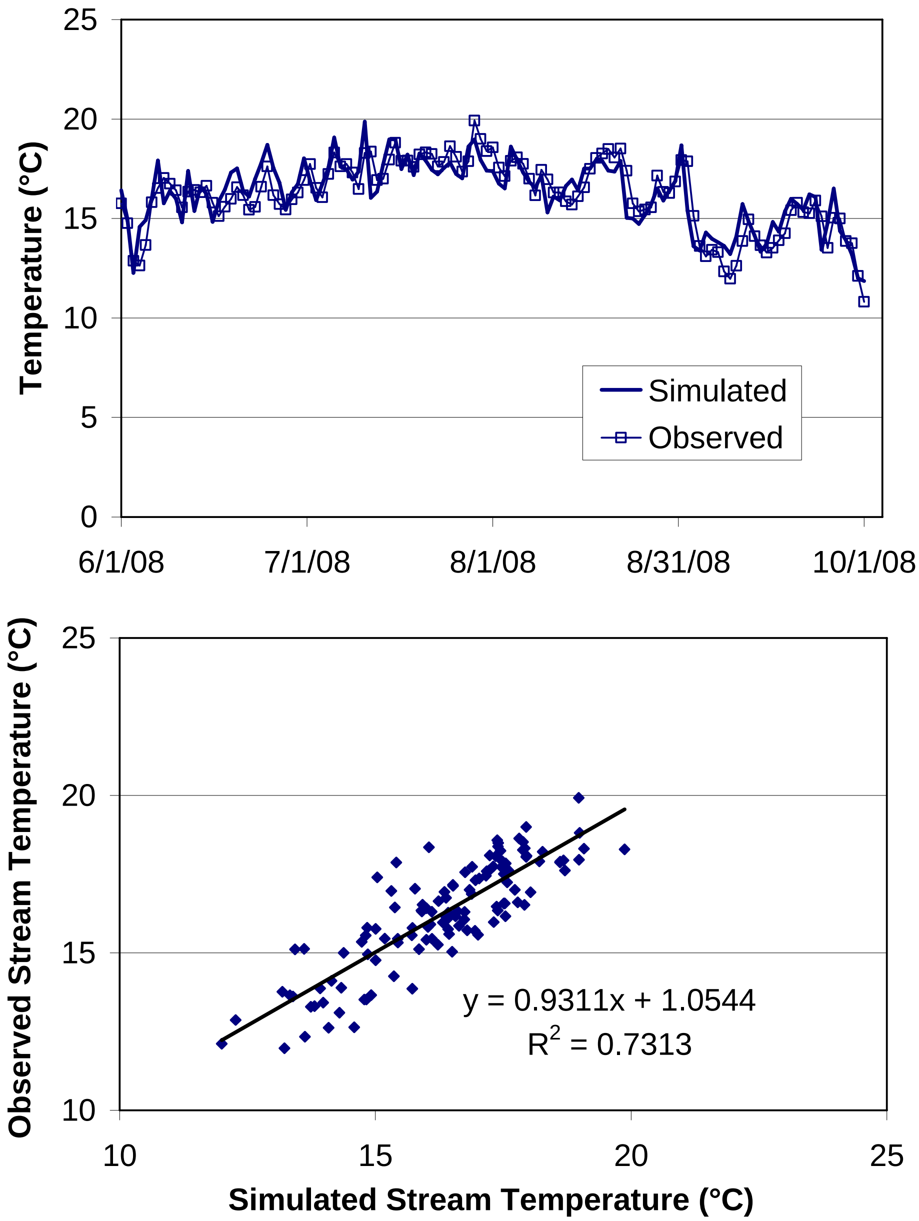

Figure 2.7. Time series of simulated and observed daily average stream temperature (upper panel) and observed vs. simulated daily average stream temperature (lower panel) for South Branch, June – September 2008.

2.4.2 Stream temperature sensitivity to air temperature

The response of stream temperatures to climate change is mainly driven by changes in air temperature. The slope and the intercept of the linearized stream temperature – air temperature relationship are therefore important elements of stream temperature projection. An example of these relationships for observed data and simulated values is given in Figure 2.8 for Miller Creek. The slopes and intercepts of the linearized air temperature – stream temperature relationships are summarized in Table 2.2 for all three streams. In general, the simulated daily stream temperatures tended to give slightly higher slopes and slightly lower intercepts with air temperature compared to observed stream and air temperatures. The level of agreement of these slopes and intercepts between simulated and observed stream temperature was used to determine the most appropriate seasonal variation of source temperatures (see Section 2.3)

Table 2.2. Stream temperature vs. air temperature relationships for Miller Creek, Chester Creek, and South Branch for observed and simulated stream temperatures.

	Observed		Simulated	
	Slope	Intercept (^oC)	Slope	Intercept (^oC)
Miller	0.60	5.8	0.65	4.9
Chester	0.43	7.6	0.45	7.2
South Branch	0.43	7.6	0.44	7.2

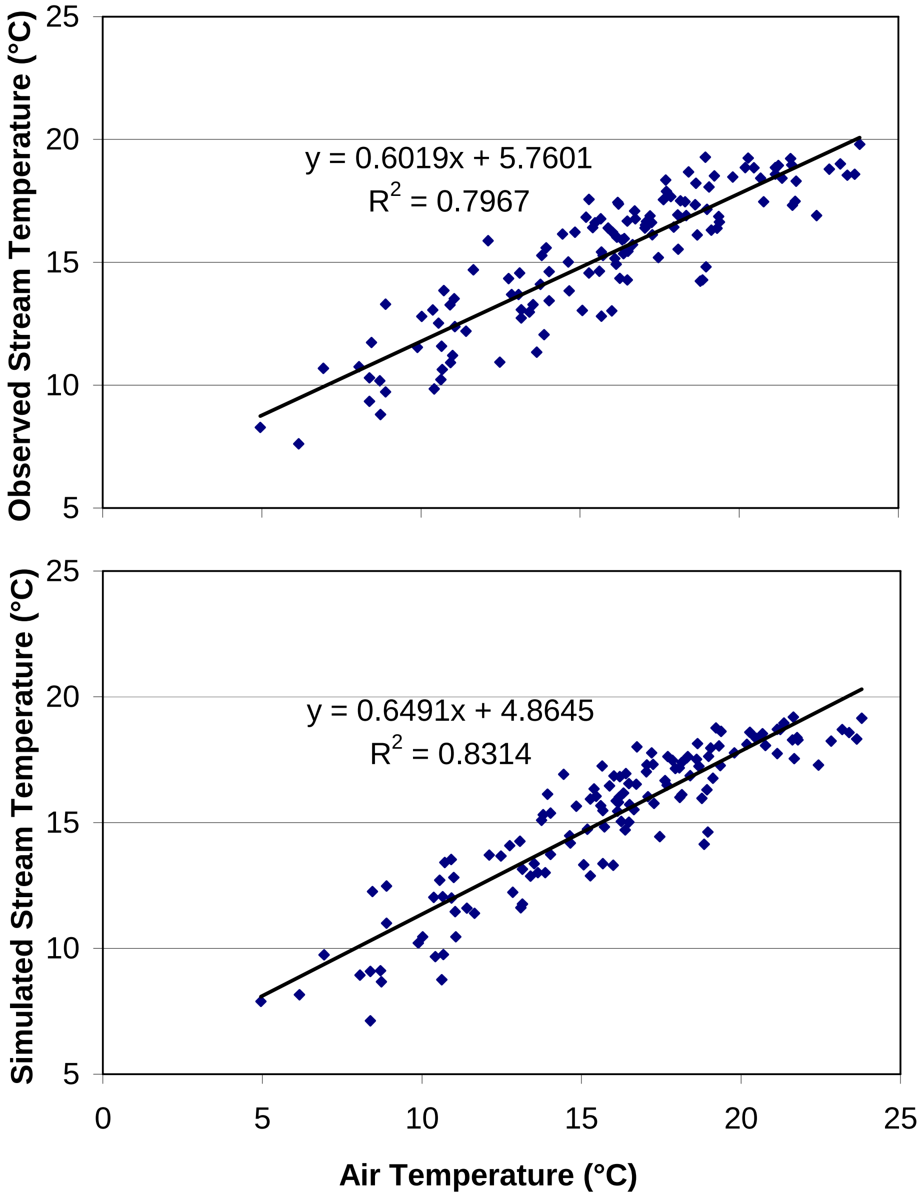

Figure 2.8. Observed (upper panel) and simulated (lower panel) daily average stream temperature vs. observed daily average air temperature for Miller Creek, June – September 2008.

2.5 Climate Change Scenarios

Climate change scenarios from the Canadian Centre for Climate Modeling were used. Two scenarios were used: the 2xCO2 doubling scenario from the CGCM version 2.0 model results, and the A1B scenario (rapid economic growth) from the CGCM version 3.1 results. The CGCM version 2.0 was selected to allow direct comparisons to previous fish habitat studies for Minnesota (e.g. Mohseni *et al.* 1999), while the CGCM 3.1 version includes more recent results with higher spatial resolution. Climate parameters for both scenarios were downloaded from the Intergovernmental Panel on Climate Change (IPCC) data center. Monthly average increments to air temperature, humidity, solar radiation, cloud cover, and precipitation were calculated for the spatial model nodes closest to Duluth and Minneapolis/St. Paul, MN. The climate parameter increments were calculated and provided by Prof. Xing Fang, Dept. of Civil Engineering, Auburn University. The monthly increments for each scenario and climate parameter are summarized in Tables 2.3 to 2.5.

Table 2.3. Monthly increments of climate parameters for Minneapolis and Duluth, MN from scenario CGCM 2.0. (+) indicates an additive increment, (x) indicates a multiplicative factor.

Month	Air temp T_a (°C) (+)	Spec.humidity q (x)	Solar rad. h_s (x)	Wind speed W_o (x)	Precipitation (x)
1	8.17	1.85	0.94	1.08	1.23
2	8.50	1.94	0.92	1.10	1.26
3	4.37	1.53	0.95	0.88	1.22
4	5.76	1.78	0.95	1.01	1.50
5	5.39	1.46	0.97	0.97	1.05
6	4.27	1.32	0.96	0.85	0.99
7	3.54	1.23	0.96	0.80	0.87
8	5.24	1.35	0.99	0.83	0.87
9	4.51	1.29	0.99	0.90	0.79
10	2.71	1.19	0.98	1.01	0.96
11	2.90	1.29	1.01	1.02	0.96
12	4.38	1.25	1.00	0.91	0.97
Average	4.98	1.46	0.97	0.95	1.06

Table 2.4. Monthly increments of climate parameters for Minneapolis, MN from scenario CGCM 3.1. All increments are additive (+), with indicated units.

Month	Air temp T_a (°C)	Relative Humidity RH	Solar rad. h_s (W/m^2)	Wind speed W_o (m/s)	Precipitation (cm)
1	4.84	0.0009	-3.63	0.53	0.021
2	8.09	0.0011	-18.51	0.43	0.055
3	6.25	0.0010	-26.67	0.17	0.053
4	3.60	0.0011	-12.59	0.71	0.038
5	3.47	0.0015	-9.67	0.57	0.043
6	3.28	0.0019	1.10	0.46	-0.023
7	3.25	0.0022	7.16	0.21	-0.029
8	3.32	0.0022	1.77	0.34	-0.026
9	3.34	0.0020	0.17	0.17	-0.007
10	3.39	0.0016	-0.57	0.37	0.027
11	3.06	0.0011	-1.05	0.17	0.075
12	2.91	0.0008	-0.64	0.36	0.082
Average	4.07	0.0015	-5.26	0.37	0.026

Table 2.5. Monthly increments of climate parameters for Duluth, MN from scenario CGCM 3.1. All increments are additive, with indicated units.

Month	Ta (°C)	RH	Solar (W/m^2)	Wind (m/s)	P (cm)
1	6.89	0.0006	-2.76	0.42	0.023
2	5.07	0.0005	-4.61	0.25	0.034
3	3.90	0.0004	0.89	0.10	0.013
4	4.31	0.0011	-9.09	0.42	0.087
5	4.12	0.0017	-14.24	0.31	0.064
6	4.59	0.0023	4.66	0.77	0.032
7	3.80	0.0022	6.99	0.24	0.002
8	3.30	0.0018	3.69	0.20	0.026
9	3.49	0.0016	5.18	0.46	-0.020
10	3.19	0.0012	1.91	0.30	0.049
11	2.89	0.0007	-0.88	0.28	0.033
12	4.14	0.0005	-2.36	0.37	0.059
Average	4.14	0.0012	-0.88	0.34	0.033

2.6 Simulated Scenarios

To project climate change impact on coldwater stream temperatures the calibrated stream temperature models for Miller Creek, Chester Creek and South Branch discussed in Section 2.4 were each run for 7 cases summarized in Table 2.6. the cases are combinations of climate scenarios. The stream temperature model was run using either baseline (observed) climate data for the years 1961-2005 or incremented climate data to calculate surface heat transfer. The climate record length used for this study was limited by the availability of solar radiation data. Source water temperatures were either baseline temperatures or incremented temperatures, as described in Section 2.3 and 2.5. In this way, the effects of incremented surface heat transfer and incremented source water temperatures were analyzed both separately and combined.

Simulations for Miller Creek and Chester Creek were run using climate data from Duluth International Airport, while simulations for the South Branch of the Vermillion River were run using climate data from the Minneapolis/St. Paul International Airport. In all cases, simulations were made for 45 years (1961-2005) of climate data, using either the baseline or incremented data.

Table 2.6. Summary of stream temperature analysis cases. Surface heat transfer and source water temperatures were determined for either baseline climate or incremented climate.

Case	Surface Heat Transfer	Source Water Temperature	Average Stream Temperature Increase (ºC)		
			Miller Creek	Chester Creek	South Branch
1	Baseline	Baseline	-	-	-
2	CGCM 2.0	Baseline	1.5	1.3	1.8
3	Baseline	CGCM 2.0	2.5	2.8	2.7
4	CGCM 2.0	CGCM 2.0	4.1	4.1	4.6
5	CGCM 3.1	Baseline	1.4	1.2	1.5
6	Baseline	CGCM 3.1	2.1	2.3	2.2
7	CGCM 3.1	CGCM 3.1	3.4	3.5	3.6

Stream discharge was estimated for each case based on precipitation data, using relationships between discharge and precipitation developed for each stream. An example of the stream discharge vs. precipitation relationship is given in Figure 2.9 for Miller Creek. The RMSE (root-mean-square error) between the discharge vs. precipitation relationships in Figure 2.9 and actual discharges is 0.3 m^3/s. This significant error resulted in relative little error in simulated temperatures because the results were much more sensitive to stream morphometry, especially stream width and climate parameters, than to streamflow. For 2008 data, daily stream temperatures simulated using 1) observed discharge data and 2) estimated discharges using the relationship given in Figure 2.9 differed only by 0.3 ºC (root-mean-square difference). The groundwater inflow rates calibrated for 2008 (Table 2.1) were used for all analyses, because no good basis was found to predict e.g. monthly variations of groundwater inflow rates.

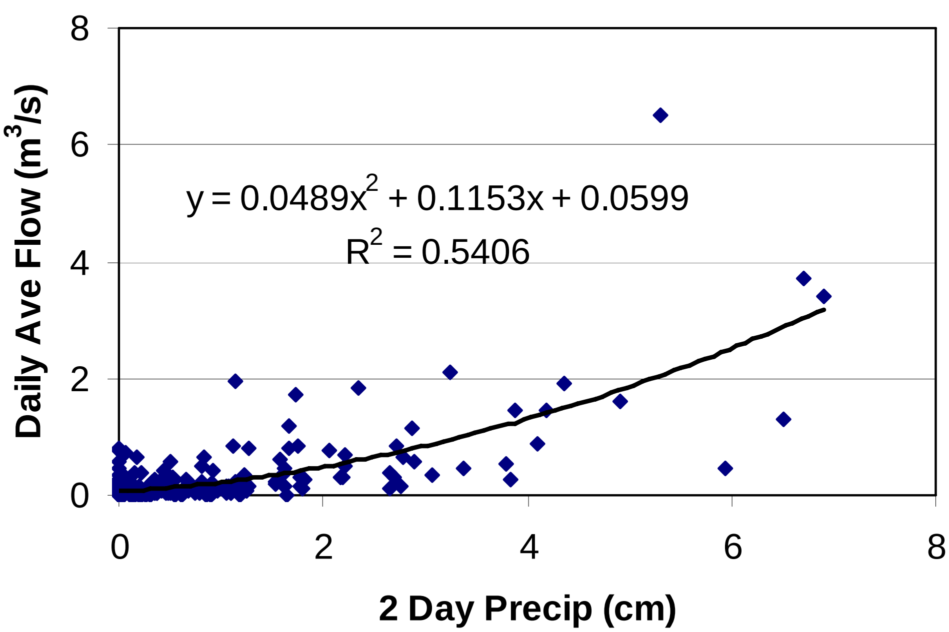

Figure 2.9. Daily average streamflow vs. 2-day antecedent total precipitation for Miller Creek, 1997-1998 and 2007-2008.

2.7 Simulation Results

The simulated stream temperature increases, averaged over all days, months (May to September) and years (1961-2005) of the entire simulation period are given for each of the seven simulated cases (scenarios) and each stream in Table 2.6. Overall, the three study streams showed similar temperature increases. The full CGCM 2.0 scenario (case 4) gave an average increase in stream temperature from 4.1 to 4.6ºC, whereas the full CGCM 3.1 scenario (case 7) gave only from 3.4 to 3.6ºC for the three streams. This is not surprising given that the average air temperature increase (Duluth and Minneapolis/St/Paul) was 4.1C for CGCM2.0 and 5.0 for CGCM 3.1 (Tables 2.3, 2.4 and 2.5).

Increases in direct atmospheric heat transfer to the stream as well as increases in source water temperatures figure prominently in the overall stream temperature response. Source water temperature changes give the larger response in stream temperature for all three study streams and both climate scenarios. South Branch had slightly higher total stream temperature increases compared to the Duluth streams (Miller Creek and Chester Creek), mainly because of lower effective riparian shading (Table 2.1). For the CGCM 3.1 scenario, the lower shading of South Branch was somewhat offset by the lower air temperature increments for Minneapolis compared to Duluth, with the result that the three study streams had very similar temperature increases.

Detailed information on monthly stream temperature simulation results is given in Tables 2.7 to 2.12 for each of the three study streams and the two climate change scenarios. The seasonal variation of stream temperatures and of temperature increases has been plotted in Figures 2.10 to 2.13. For each study stream and climate scenario, the stream temperature increase varied from month to month, driven by corresponding increments in climate parameters. The standard deviations of the daily stream temperature increments are quite small (< 0.5ºC) in all cases. This suggests that the coldwater stream temperature increases due to climate change are relatively uniform, independent of the daily variations in flow and baseline climate conditions.

For the CGCM 3.1 climate scenario, the highest stream temperature increase occurred in June for Miller Creek and Chester Creek and in July/August for South Branch. Overall, the stream temperature increments were slightly lower than the air temperature increments. The exception is the response of South Creek to climate scenario CGCM 3.1; South Creek's stream temperature increases due to the combined effects of surface heat transfer and source water temperature increases were up to 0.5ºC higher than the associated air temperature increments (Figure 2.13). For the CGCM 2.0 scenario, temperature increments for all three study streams were slightly higher than the air temperature increment in July. While atmospheric heat transfer causes stream temperature to track air temperature at the daily time scale, the less variable seasonal distribution of the source water temperature increments tends to give more uniform stream temperature increases.

The ratio of the average stream temperature increment to the average air temperature increment given in this section is 0.9 for Miller Creek and Chester Creek for both climate scenarios. This is substantially higher than the slope of the observed daily stream temperature vs. daily air temperature slopes given in Table 2.2 (0.60 for Miller Creek, 0.43 for Chester Creek). For South

Branch, the average stream temperature – air temperature increment ratio is 1.0 for CGCM 2.0 and 1.1 for CGCM 3.1, more than double the slope (0.43) of the observed stream temperature – air temperature plot. This suggests that observed, short term (daily) variations in stream temperature with air temperature are not representative of, and under-predict the long term response of stream temperatures to air temperature increases, mainly because of changes in source water temperature that do not appear at short times scales.

Table 2.7. Projected stream temperatures of Miller Creek in response to the CGCM 2.0 climate scenario. SD = standard deviation of daily values.

Mean Monthly Stream Temperatures (^oC)								
	Case 1 (Baseline)				Case 2			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	9.3	2.5	16.1	1.8	11.1	2.6	18.5	3.6
June	14.8	1.9	20.9	8.9	16.2	1.9	23.0	10.7
July	17.6	1.4	21.2	12.7	18.8	1.3	22.5	14.1
August	16.9	1.4	22.0	12.5	18.6	1.5	24.5	14.1
September	12.9	2.2	19.7	7.6	14.4	2.3	21.6	8.9
	Case 3				Case 4			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	12.0	2.5	18.7	4.3	13.8	2.6	20.8	6.1
June	17.3	1.9	23.0	11.5	18.8	1.9	25.1	13.3
July	20.1	1.3	23.3	14.9	21.4	1.3	24.8	16.5
August	19.3	1.4	24.1	15.0	21.2	1.5	26.5	16.8
September	15.4	2.1	21.9	9.9	16.9	2.2	23.8	11.4
Mean Monthly Stream Temperature Increments (^oC)								
	Case 2 - Case 1				Case 3 - Case 1			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	1.8	0.3	2.7	1.1	2.7	0.2	3.2	2.1
June	1.4	0.2	2.2	0.9	2.6	0.2	3.1	2.0
July	1.2	0.2	2.0	0.7	2.5	0.2	3.0	2.0
August	1.8	0.2	2.5	0.9	2.5	0.2	3.0	1.9
September	1.5	0.2	2.2	0.6	2.5	0.2	3.0	1.9
	Case 4 - Case 1							
Month	Mean	SD	Max	Min				
May	4.4	0.2	5.0	3.9				
June	4.1	0.1	4.8	3.6				
July	3.8	0.1	4.5	3.4				
August	4.3	0.1	4.6	3.7				
September	4.0	0.1	4.4	3.2				

Table 2.8. Projected stream temperatures of Miller Creek in response to the CGCM 3.1 climate scenario. SD = standard deviation of daily values.

Mean Monthly Stream Temperatures

	Case 1 (Baseline)				Case 2			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	9.3	2.5	16.1	1.8	10.6	2.6	18.0	3.2
June	14.8	1.9	20.9	8.9	16.5	2.0	23.7	10.1
July	17.6	1.4	21.2	12.7	19.0	1.5	23.0	14.0
August	16.9	1.4	22.0	12.5	18.1	1.5	23.9	13.5
September	12.9	2.2	19.7	7.6	14.1	2.3	21.5	8.5

	Case 3				Case 4			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	11.5	2.5	18.3	3.8	12.8	2.6	20.1	5.2
June	17.0	1.9	22.7	11.1	18.5	2.0	25.3	12.2
July	19.8	1.3	23.0	14.6	21.2	1.4	24.9	16.0
August	19.0	1.4	23.8	14.5	20.1	1.5	25.6	15.6
September	14.9	2.2	21.5	9.3	16.0	2.3	23.3	10.2

Mean Monthly Stream Temperature Increments

	Case 2 - Case 1				Case 3 - Case 1			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	1.3	0.2	2.0	0.8	2.2	0.1	2.6	1.7
June	1.7	0.3	2.7	1.0	2.2	0.2	2.6	1.7
July	1.4	0.2	2.1	0.9	2.2	0.2	2.6	1.7
August	1.2	0.2	1.9	0.8	2.1	0.2	2.6	1.6
September	1.2	0.2	1.9	0.7	2.0	0.1	2.4	1.5

	Case 4 - Case 1			
Month	Mean	SD	Max	Min
May	3.5	0.1	4.2	3.2
June	3.8	0.2	4.4	3.3
July	3.6	0.1	3.9	3.2
August	3.3	0.1	3.6	3.0
September	3.1	0.2	3.6	2.7

Table 2.9. Projected stream temperatures of Chester Creek in response to the CGCM 2.0 climate scenario. SD = standard deviation of daily values.

Mean Monthly Stream Temperatures

	Case 1 (Baseline)				Case 2			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	8.9	2.4	15.1	2.0	10.4	2.5	17.2	3.6
June	14.3	1.7	19.9	9.1	15.5	1.7	21.7	10.6
July	17.1	1.2	20.4	12.9	18.1	1.2	21.4	14.1
August	16.5	1.2	21.1	12.7	18.0	1.3	23.1	14.1
September	12.8	2.0	18.8	7.9	14.0	2.1	20.4	9.1
	Case 3				Case 4			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	11.8	2.4	17.9	4.8	13.3	2.4	19.8	6.3
June	17.2	1.7	22.3	11.9	18.4	1.7	24.1	13.4
July	19.9	1.1	22.7	15.3	21.0	1.1	24.0	16.8
August	19.2	1.2	23.5	15.4	20.8	1.3	25.5	17.0
September	15.5	2.0	21.3	10.5	16.7	2.0	22.9	11.8

Mean Monthly Stream Temperature Increments

	Case 2 - Case 1				Case 3 - Case 1			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	1.5	0.2	2.4	0.9	2.9	0.2	3.4	2.4
June	1.2	0.2	1.9	0.7	2.8	0.2	3.3	2.3
July	1.0	0.1	1.7	0.6	2.8	0.2	3.2	2.3
August	1.5	0.2	2.1	0.8	2.7	0.2	3.2	2.2
September	1.2	0.2	1.8	0.5	2.7	0.2	3.2	2.1
	Case 4 - Case 1							
Month	Mean	SD	Max	Min				
May	4.4	0.1	4.9	4.0				
June	4.1	0.1	4.6	3.6				
July	3.8	0.1	4.4	3.5				
August	4.3	0.1	4.5	3.7				
September	4.0	0.1	4.4	3.3				

Table 2.10. Projected stream temperatures of Chester Creek in response to the CGCM 3.1 climate scenario. SD = standard deviation of daily values.

Mean Monthly Stream Temperatures

	Case 1 (Baseline)				Case 2			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	8.9	2.4	15.1	2.0	10.0	2.5	16.7	3.2
June	14.3	1.7	19.9	9.1	15.8	1.8	22.4	10.1
July	17.1	1.2	20.4	12.9	18.4	1.3	21.9	14.0
August	16.5	1.2	21.1	12.7	17.5	1.3	22.7	13.6
September	12.8	2.0	18.8	7.9	13.8	2.1	20.3	8.8
	Case 3				Case 4			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	11.3	2.4	17.5	4.3	12.4	2.5	19.1	5.4
June	16.8	1.7	22.0	11.5	18.1	1.8	24.3	12.5
July	19.5	1.1	22.4	15.0	20.7	1.2	24.1	16.3
August	18.8	1.2	23.2	14.9	19.8	1.3	24.7	15.8
September	14.9	2.0	20.9	9.9	15.9	2.1	22.3	10.7

Mean Monthly Stream Temperature Increments

	Case 2 - Case 1				Case 3 - Case 1			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	1.1	0.2	1.8	0.7	2.4	0.1	2.8	2.0
June	1.5	0.2	2.5	0.9	2.4	0.1	2.8	1.9
July	1.2	0.2	1.8	0.8	2.4	0.1	2.8	1.9
August	1.0	0.1	1.7	0.6	2.3	0.1	2.8	1.8
September	1.0	0.2	1.7	0.5	2.1	0.1	2.5	1.7

	Case 4 - Case 1			
Month	Mean	SD	Max	Min
May	3.5	0.1	4.2	3.2
June	3.8	0.2	4.4	3.4
July	3.6	0.1	4.0	3.3
August	3.3	0.1	3.7	3.1
September	3.1	0.1	3.7	2.7

Table 2.11. Projected stream temperatures of South Branch in response to the CGCM 2.0 climate scenario. SD = standard deviation of daily values.

Mean Monthly Stream Temperatures

	Case 1 (Baseline)				Case 2			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	12.8	2.2	19.4	6.2	15.0	2.4	23.0	8.0
June	15.9	2.0	22.0	9.4	17.6	2.1	24.3	11.5
July	17.5	1.7	23.5	12.0	18.8	1.7	25.0	13.3
August	16.9	1.7	21.9	12.3	19.0	1.8	24.6	14.3
September	14.3	2.2	20.2	8.3	16.1	2.3	22.7	10.3

	Case 3				Case 4			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	15.5	2.2	21.6	8.7	17.7	2.4	24.8	10.7
June	18.5	1.9	24.0	11.7	20.4	2.0	26.7	13.9
July	20.2	1.6	25.5	15.0	21.6	1.6	27.2	16.5
August	19.6	1.6	24.2	14.8	21.8	1.7	26.9	17.2
September	17.1	2.1	22.6	10.6	18.8	2.2	24.8	12.7

Mean Monthly Stream Temperature Increments

	Case 2 - Case 1				Case 3 - Case 1			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	2.3	0.4	3.8	1.2	2.7	0.3	3.7	1.8
June	1.8	0.3	3.1	1.0	2.7	0.3	3.6	1.7
July	1.3	0.2	2.6	0.8	2.7	0.3	3.6	1.5
August	2.1	0.3	2.8	1.1	2.7	0.3	3.8	1.8
September	1.7	0.3	2.6	0.7	2.8	0.3	3.7	1.8

	Case 4 - Case 1			
Month	Mean	SD	Max	Min
May	4.9	0.3	6.0	4.3
June	4.5	0.2	5.5	3.8
July	4.1	0.2	5.0	3.5
August	4.9	0.1	5.2	3.9
September	4.5	0.1	5.0	3.5

Table 2.12. Projected stream temperatures of South Branch in response to the CGCM 3.1 climate scenario. SD = standard deviation of daily values.

Mean Monthly Stream Temperatures

	Case 1 (Baseline)				Case 2			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	12.8	2.2	19.4	6.2	14.1	2.4	21.6	7.1
June	15.9	2.0	22.0	9.4	17.4	2.1	24.1	11.0
July	17.5	1.7	23.5	12.0	19.2	1.8	25.5	13.2
August	16.9	1.7	21.9	12.3	18.5	1.8	24.2	13.6
September	14.3	2.2	20.2	8.3	15.8	2.4	22.4	9.7
	Case 3				Case 4			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	14.9	2.2	21.2	8.2	16.2	2.4	23.1	9.2
June	18.0	1.9	23.6	11.3	19.5	2.1	25.8	12.8
July	19.7	1.6	25.1	14.5	21.2	1.7	27.1	15.6
August	19.1	1.6	23.8	14.3	20.6	1.7	25.8	15.7
September	16.5	2.1	22.1	10.1	17.9	2.3	24.1	11.6

Mean Monthly Stream Temperature Increments

	Case 2 - Case 1				Case 3 - Case 1			
Month	Mean	SD	Max	Min	Mean	SD	Max	Min
May	1.4	0.3	2.4	0.6	2.2	0.2	3.0	1.5
June	1.6	0.2	2.5	0.9	2.1	0.2	2.8	1.3
July	1.6	0.2	2.5	1.1	2.1	0.2	2.9	1.2
August	1.6	0.2	2.3	0.9	2.2	0.2	3.1	1.5
September	1.5	0.2	2.2	0.8	2.2	0.2	3.0	1.5

	Case 4 - Case 1			
Month	Mean	SD	Max	Min
May	3.4	0.2	4.1	3.0
June	3.6	0.2	4.1	3.1
July	3.7	0.1	4.1	3.4
August	3.7	0.1	4.1	3.3
September	3.6	0.1	4.0	3.2

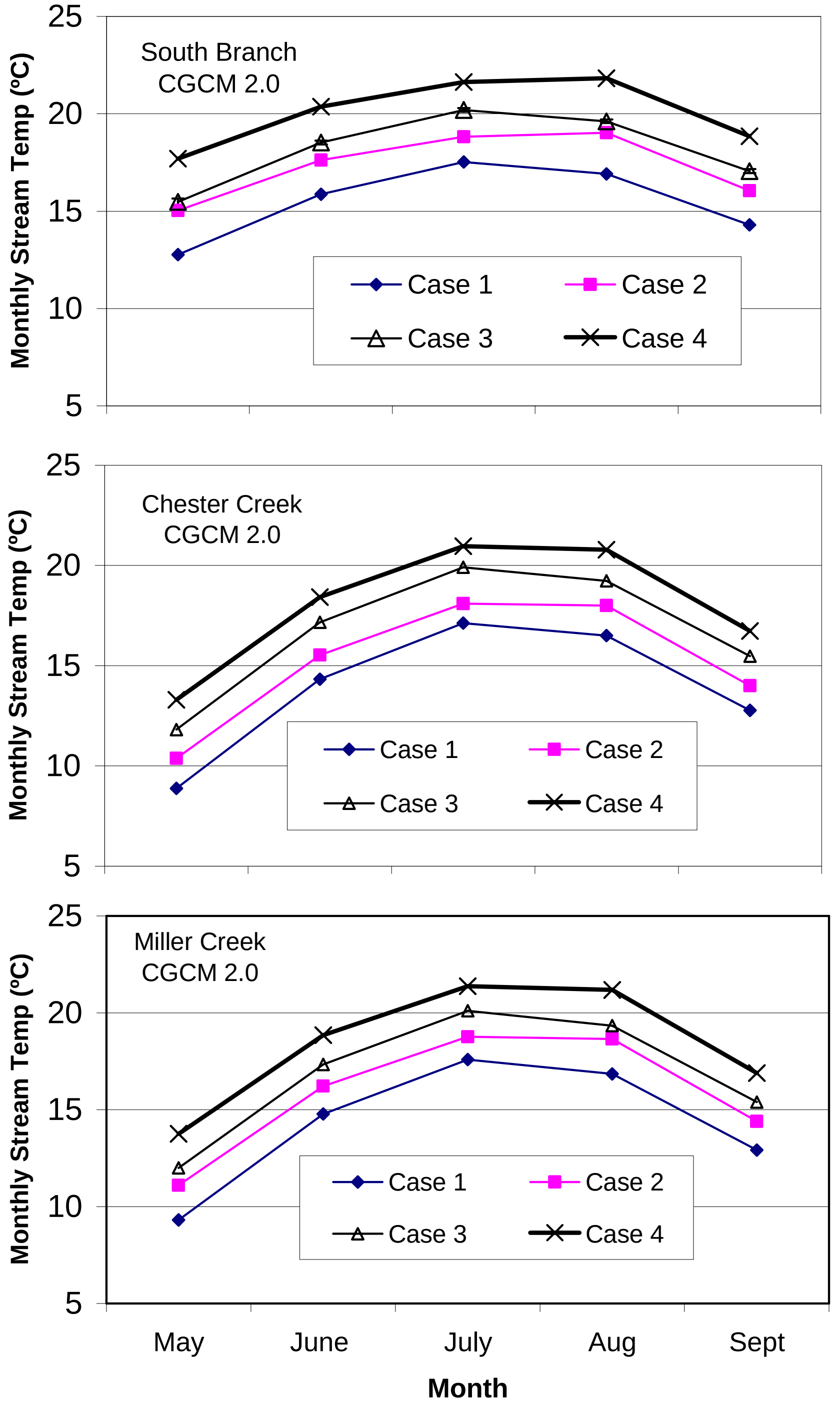

Figure 2.10. Mean monthly stream temperatures for the CGCM 2.0 scenario (Cases 2, 3, 4) and baseline (Case 1) for South Branch, Chester Creek, and Miller Creek.

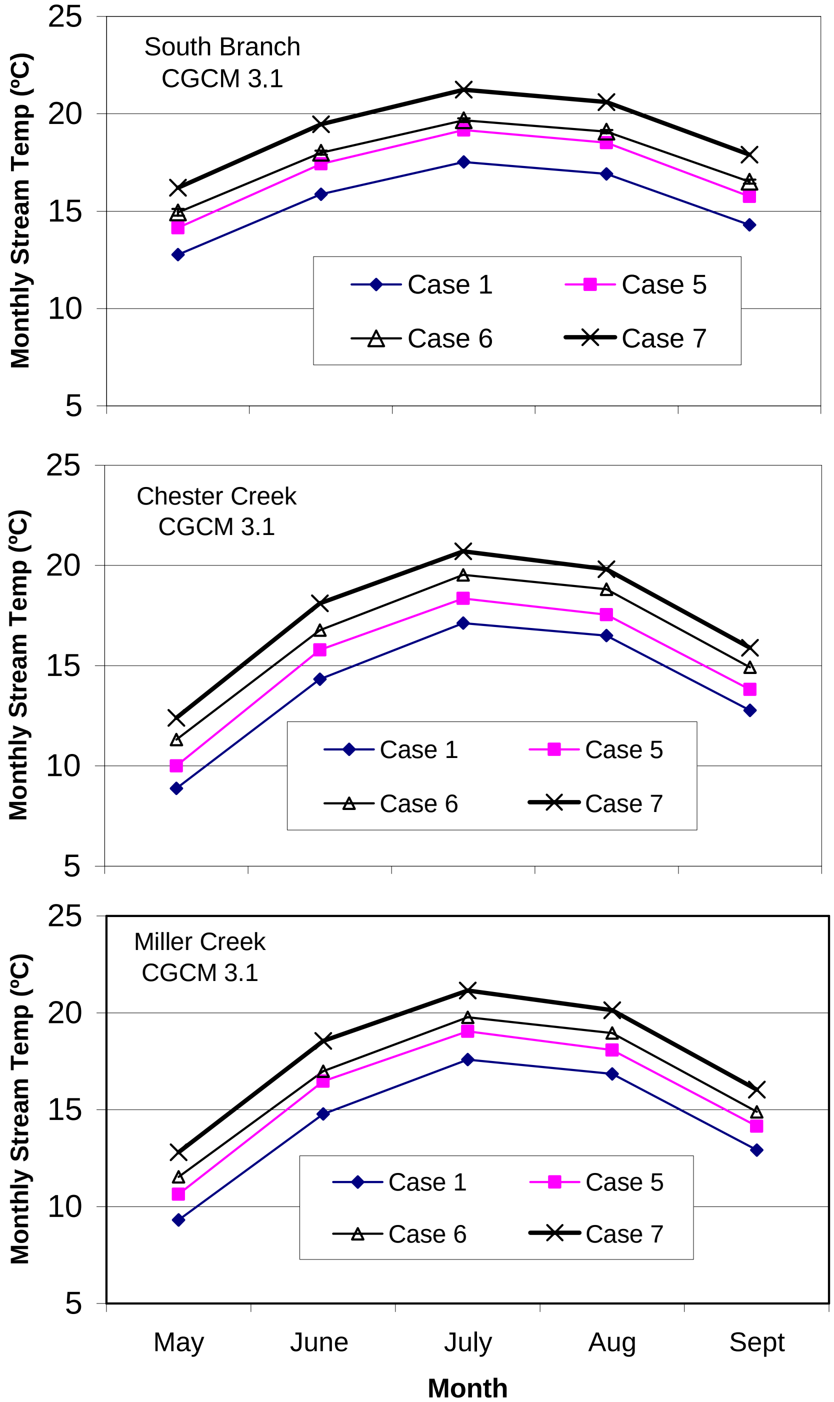

Figure 2.11. Mean monthly stream temperatures for the CGCM 3.1 scenario (Cases 5, 6, 7) and baseline (Case 1) for South Branch, Chester Creek, and Miller Creek.

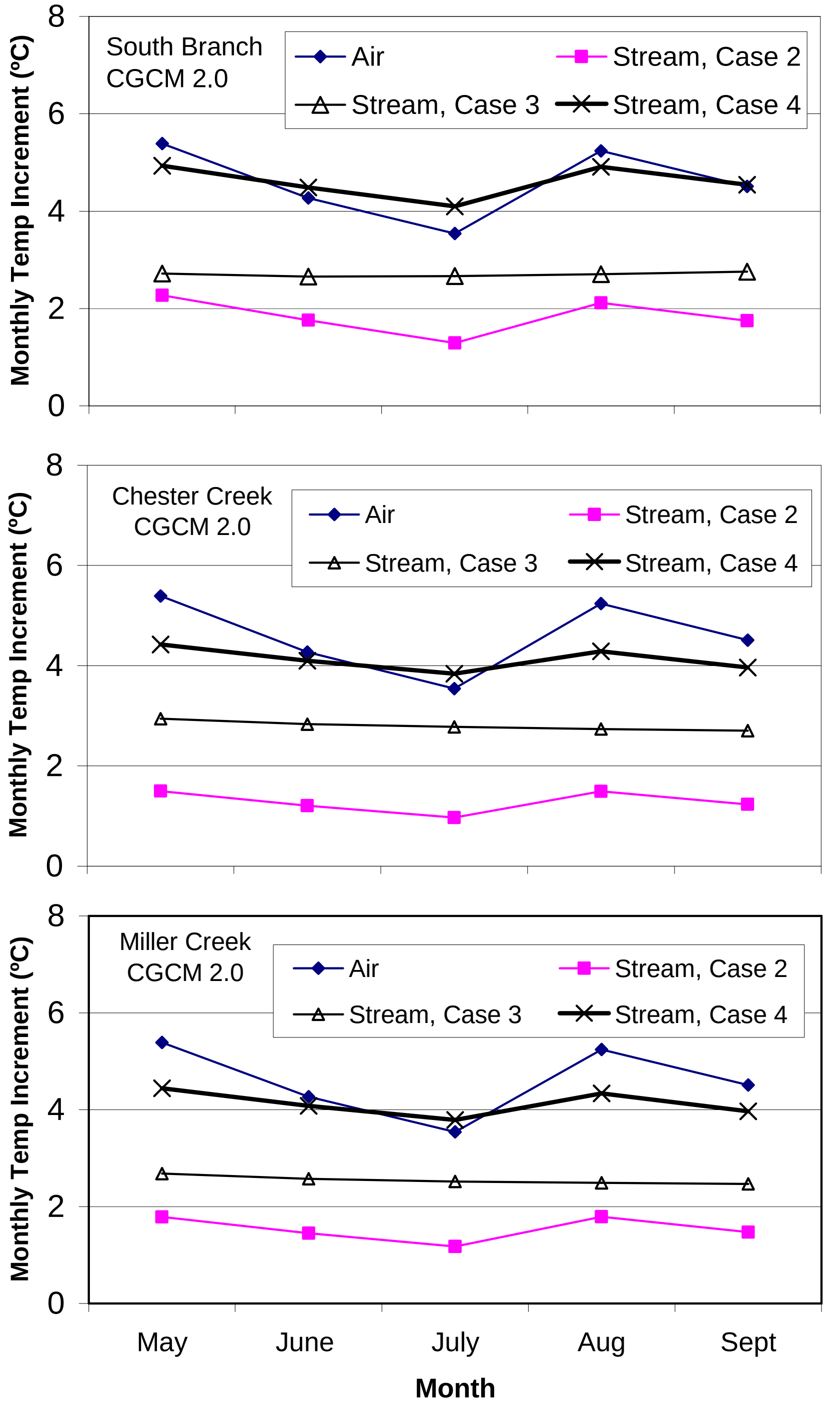

Figure 2.12. Mean monthly air and stream temperature increments for the CGCM 2.0 scenario (Cases 5, 6, 7) for South Branch, Chester Creek, and Miller Creek.

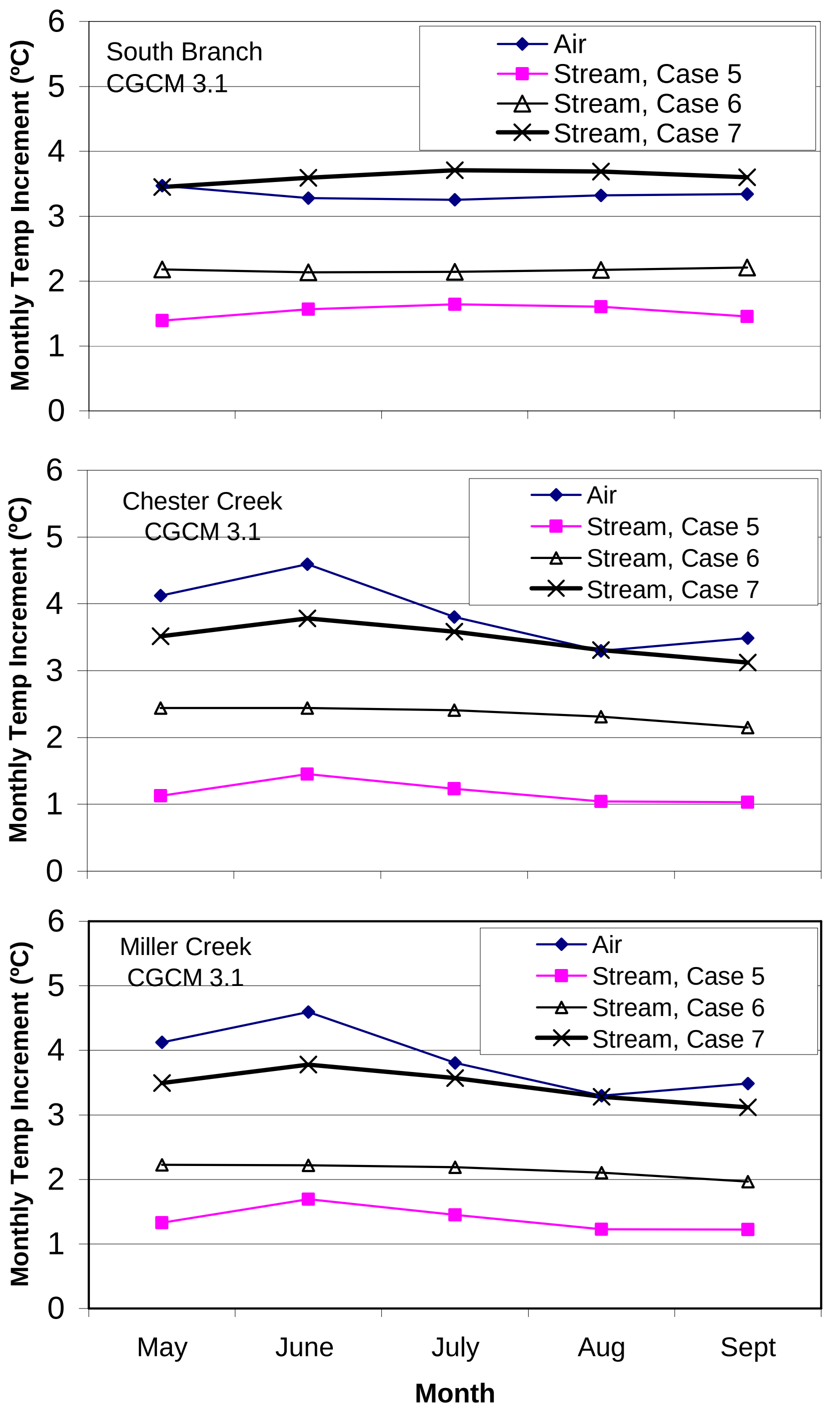

Figure 2.13. Mean monthly air and stream temperature increments for the CGCM 3.1 scenario (Cases 5, 6, 7) for South Branch, Chester Creek, and Miller Creek.

2.8 Summary and Conclusions, Part II

Coldwater streams in Minnesota provide habitat to valuable trout populations, and climate change poses a threat to this habitat. A study of three coldwater streams, which are designated trout streams in Minnesota, has therefore been conducted to assess the potential magnitude of stream temperature changes in these streams. Two of these study streams, Miller Creek and Chester Creek, are located in Duluth and one, the South Branch of the Vermillion River is located south of the Twin Cities. Deterministic stream temperature models were used to characterize the response of the water temperatures in the three streams to projected climate change scenarios. The models include both the heat transfer between the streams and the atmosphere and the potential warming of the cold water sources. These coldwater sources are groundwater in the Vermillion River basin for the South Branch, and wetlands for the two North Shore streams.

Overall, water temperatures in the streams were projected to increase between 4 and 5°C for the CGCM 2.0 (doubling of atmospheric CO_2) climate change scenario, and between 3 and 4°C for the CGCM 3.1 A1B (rapid economic growth) climate change scenario. Estimated increases in source water temperatures accounted for approximately 60% of the total stream temperature increase due to climate change; increases in atmospheric heat transfer provided approximately 40%. The source water temperature in the (shallow) groundwater aquifer was assumed to increase the same as the mean annual air temperature (4 to 5°C) over a period of many years because mean annual ground temperatures are known to be similar to mean annual air temperatures above the ground (Taylor and Stefan 2009); the increase in wetland temperature was predicted by a wetland temperature model (Herb et al. 2007).to be 3 to 4°C, i.e. less than the groundwater temperature increase because of evaporative cooling.

The ratio of the stream temperature increment to air temperature increment was found to vary from 0.8 to 1.08, much larger than the slope of the observed daily stream temperature versus daily air temperature relationship. For the CGCM 2.0 CO_2 scenario (doubling of atmospheric CO_2), stream temperature increments projected by this study are 4 to 5°C. These increments are larger than those projected by previous climate change studies based on air temperature – stream temperature regression analysis (2 to 3°C) (Mohseni et al. 1999, Morrill et al. 2005).

It has been demonstrated that a deterministic stream temperature model based on the equilibrium temperature concept can reveal the response of coldwater stream temperatures to climate change at local scales. To project stream temperatures, the model requires climate data, stream width, source water (e.g. groundwater) input rates and temperatures. It is necessary to characterize the response of source water quantities and temperatures to climate change for each hydrogeologic setting.

It has also been demonstrated in this study that source water temperatures figure prominently in the response of stream temperatures to long term climate change. Although the field measurements and model calibration procedures give some evidence that the seasonal source water temperatures used in this study are appropriate, further work is needed on both groundwater and wetland systems to better characterize both the hydrology and heat transfer processes that control these systems.

Karst systems, e.g. in the driftless area of southeastern Minnesota and southwestern Wisconsin, may act quite differently from the shallow sand aquifer (Vermillion River) or wetland systems (Duluth streams) considered in this study . Possible changes in available source water quantities and input rates in addition to source water temperatures should also be investigated, as changes in precipitation patterns and evapotranspiration are expected to accompany long term climate change.

Winter conditions were not considered in this study. Long term changes in groundwater temperatures and air temperatures may markedly affect winter water temperatures and ice cover conditions, and therefore impact winter habitat for fish and invertebrates.

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BIOLOGICAL INDICATORS OF CLIMATE CHANGE: TRENDS IN FISH COMMUNITIES AND THE TIMING OF WALLEYE SPAWNING RUNS IN MINNESOTA

A THESIS SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF THE UNIVERSITY OF MINNESOTA
BY

KRISTAL N. SCHNEIDER

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FOR THE DEGREE OF
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I dedicate this thesis to my mother and stepdad whose unending support and encouragement played a major role in this accomplishment. I cannot simply put into words how much I appreciate them.

ABSTRACT

I conducted research on two projects to examine effects of climate change on Minnesota's aquatic communities. I used walleye egg-take records from the Minnesota Department of Natural Resources for 12 spawning locations and historical ice-out data to determine if the timing of these events is changing. I used ice-out data instead of temperature for our analyses because historical temperature data is not available and ice-out has been previously related to climate change. Because ice-out has been previously related to climate change, I regressed the dates of first egg-take against ice-out dates to determine if the timing of walleye spawning runs could be a useful biological indicator of climate change. For the second project to determine if fish species abundances are changing in response to climate change, I used historical lake survey records for 34 lakes, each with 15 to 43 years of data, and regressed catch-per-unit-effort (CPUE) against year. I examined species distributions by regressing mean latitude against year. I regressed slopes of CPUE over time against 5 local air temperature variables to determine if changes in abundance were associated with air temperature. I also used stepwise regressions (forward and backward selection) and one-way analysis of variance (ANOVA) to determine if variability in trends could be explained by lake physical and chemical characteristics. Results were reported for 7 species with the strongest trends: Centrarchids (*Micropterus salmoides*, *Micropterus dolomieu*, and *Lepomis macrochirus*); Ictalurids (*Ameiurus melas* and *Ameiurus natalis*); Whitefish (*Coregonus artedi* and *Coregonus clupaeformis*).

For the walleye spawning analyses I found that spawning runs and ice-out are occurring earlier in some lakes but not all. However, there was a strong relationship between first egg-take and ice-out dates, and walleye egg-take appears to provide a good biological indicator of climate change. For the lake survey analysis, centrarchid abundance in lakes was increasing over time, black bullhead abundance was decreasing, and other species were increasing in some lakes and decreasing in others. Slopes of CPUE versus year increased more quickly over time in smaller lakes and more quickly moving east across the state than in larger lakes toward the west. All species' ranges were significantly advancing northward except smallmouth bass and whitefish. Regressions of CPUE versus air temperature showed that centrarchids are increasing in lakes as summer air temperatures increase, and whitefish are decreasing in lakes as air temperatures increase. In summary, the abundances and distributions of these 7 species over time may be responsive to climate change, and trends for species abundances may be influenced by lake characteristics. Centrarchids and bullhead may be good indicators, and thus, further research is warranted. Also, because there is a strong relationship between dates of first egg-take and ice-out, and because ice-out has previously been related to climate change, the timing of walleye spawning runs may be a useful biological indicator of climate change.

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CHAPTER 1

PROLOGUE

Climate change and its effects are important topics that are arousing interests and concerns in fisheries and related disciplines (McGinn 2002: American Fisheries Society Symposium 32). Climate change is affecting physical processes such as altered streamflows and the timing of ice-out with effects on both human infrastructure and biota (Melillo et al. 1993; Magnuson et al. 2000; Walther et al. 2002; Koster et al. 2005; Schindler et al. 2005; Hodgkins and Dudley 2006; Parmesan 2006). Climate change is also affecting biological processes that influence community structure and species composition in aquatic systems (e.g., Gerten and Adrian 2000; Sundby and Nakken 2008; Wingate and Secor 2008). Evidence of climate change and its effects has been documented using a range of both physical and biological responses.

Primarily, climate change is indicated by changes in global average air temperatures, which have increased 0.6°C (± 0.2°C) since the late 1800s (IPCC 2001; Walther et al. 2002). The years 1970-forward have been recognized as a distinct period of increased warming. Local effects have been observed ranging from summer extremes to shorter winters; in the Midwest large heat waves have been recorded more frequently in the period 1980-forward than for any other time period in the past century (U. S. Global Change Research Program, 2009), and the length of the frost-free season is increasing (Easterling 2002; Frich et al. 2002). Lake and stream temperatures are increasing (Johnson and Stefan 2006; Austin and Colman 2007), and ice-out (ice break-up on lakes) is occurring earlier over time (Magnuson et al. 2000; Jensen et al. 2007). Evidence that climate change is affecting biological systems around the world spans both aquatic and terrestrial systems; studies have documented climate-driven range shifts for more than 300 species in terrestrial and aquatic habitats (Parmesan et al. 1999; Parmesan and Yohe 2003; Chu et al. 2005; Hickling et al. 2005). Numerous others have shown that climate variables, such as temperature, influence species reproduction (Reading 1998; Dunn and Winkler 1999, Sundby and Nakken 2008), migration (Bohlin et al. 1993; Both et al. 2005), and abundance (Shuter et al. 1980; Shuter et al. 2002; Wingate and Secor 2008).

Changes in biological systems raise questions about the fate of species affected, and for this thesis I will focus on those related to fisheries. For example, will range expansion of warm-water fish such as bluegill (*Lepomis macrochirus*) or smallmouth bass (*Micropterus dolomieu*) become more frequent in lakes and across regions? Will there no longer be suitable habitat for some cold-water species such as tullibee (*Coregonus artedi*) or lake whitefish (*Coregonus clupeaformis*)? If the answer to the previous two questions is "yes", will we observe more species extinctions? Some studies have already documented species invasions and predicted local extinctions associated with climate change (Chu et al. 2005; Daufresne and Boet 2007; Rahel and Olden 2008). For example, Stefan et al. (2001) predicted that warming temperatures would reduce the number of lakes in the United States with suitable cold-water fish habitat by up to 45%, and some Canadian studies have shown that one warm-water species, smallmouth bass, is already expanding its range northward as temperatures warm (Shuter et al. 2002, Vander Zanden et al. 2004). The introduction of non-native species could be detrimental to populations of native species in aquatic habitats (Findlay et al. 2000; Jackson and Mandrake 2002). For example, the introduction of a warm-water species to a cool-water habitat could alter predator-prey interactions and as a result, cause reductions in diversity and prey species abundances (Robinson and Tonn 1989; Jackson et al. 2001; Vander Zanden et al. 2004). In a study of competition between Sacramento perch (*Archoplites interruptus*) and bluegill, Marchetti (1999) suggested that introduced centrarchids might be responsible for present and future extirpations of Sacramento perch in California. Jackson (2002) showed that there was a strong negative association between abundances of small-bodied fishes and black basses in south-central Ontario lakes. He also mentioned that changes in fish diversity and prey (small-bodied) species abundances could negatively affect water quality by altering planktonic communities via a trophic cascade. Processes such as these are important to consider for future projections and management of local resources. Moreover, aside from community and ecosystem changes via invasions and extinctions, we should also consider economic effects. Many aquatic species such as walleye (*Sander vitreus*) and largemouth bass (*Micropterus salmoides*) are important commercially and recreationally as a source of food and revenue (i.e. bait and tackle sales, commercial fish sales, etc.) for the economy. Therefore, reductions of these important species could result in negative economic as well as biological consequences (Roessig et al. 2004; Brander 2007).

From examination of previous studies we can see that climate change could significantly affect our aquatic resources. Because of this, it would be useful to have climate change indicators that could help researchers and agencies develop future projections and management plans. Moreover, biological indicators would be particularly useful to natural resource management agencies because they could act as a response variable or a predictor depending on the goal of the analyses. Previous studies have shown that species including Atlantic cod (*Gadus morhua*), the common toad (*Bufo bufo*), and some insects may be good biological indicators of climate change (e.g. Reading 1998; Larocque et al. 2001; Balanya et al. 2006, Sundby and Nakken 2006). For aquatic resources, a good candidate for a biological indicator may be a species that is responsive to climate change in an easily observable manner and is important commercially or recreationally. The availability of long-term records and the chance that the species would continue to be monitored over time would probably be greatest for these species. A good candidate for a biological indicator would also benefit from being economically important so that value is perceived across different components of society, thus making its response to climate change of more interest to various stakeholders.

To find an indicator we must determine if there are changes in aquatic populations that are associated with climate change and determine if the population can be characterized by the attributes discussed previously in order to promote scientifically sound results that will benefit multiple components of society. By following these guidelines, not only may we find a good indicator, but we'll also get some idea of changes we can expect in the future.

My research goals were to identify a good aquatic biological indicator of climate change (Chapter 2) and to examine changes in Minnesota's fish communities associated with climate change and identify additional indicators (Chapter 3). The thesis is organized into chapters with this introductory chapter followed by two chapters written as manuscripts for publication. A concluding (Epilogue) chapter summarizes my overall findings and conclusions. Below I give brief descriptions of each chapter. For chapters 2 and 3 I give likely co-authors for manuscripts in press or to be submitted, and within these chapters I use the plural “we” instead of “I” because these chapters had contributing co-authors.

Chapter 2: Schneider, K. N., R. M. Newman, V. Card, S. Weisberg, and D. L. Pereira. The timing of walleye spawning as an indicator of climate change. Accepted 24 March 2010 for publication in Transactions of the American Fisheries Society.

In Chapter 2, I proposed that the timing of walleye (*Sander vitreus*) spawning runs might be a good biological indicator of climate change, and I examined changes in the timing of walleye spawning and ice-out over time. To determine if walleye spawning was a good indicator, I regressed the date of first egg-take against the date of ice-out. I used egg-take data from 12 hatcheries across Minnesota and ice-out data from lakes within 48 km of each egg-take site. I used ice-out data instead of air temperature for our analyses because walleye often spawn soon after ice-out and because ice-out has been previously related to climate change (Scott and Crossman 1973; Becker 1983; Magnuson et al. 1997; Magnuson et al. 2000; Jensen et al. 2007). I also determined if there were changes in the timing of walleye spawning runs and ice-out over time.

Chapter 3: Schneider, K. S., R. M. Newman, S. Weisberg, and D. L. Pereira. Changes in Minnesota fish species abundance and distribution associated with local climate and lake characteristics. Target journal not yet determined.

In Chapter 3, I examined changes in Minnesota fish communities over time and responses of fish communities to changes in local climate. I analyzed historical Minnesota fisheries lake survey data (gillnet and trapnet) for 34 lakes, each with 15 to 43 years of data, to determine if fish distributions and abundances were changing over time. I also analyzed trends to determine the relationship between five air-temperature variables and fish abundance and to determine if lake physical and chemical characteristics influenced trends in catch-per-unit-effort over time. Results were summarized for 7 fish species with the strongest trends: Centrarchids (*Micropterus salmoides*, *Micropterus dolomieu*, and *Lepomis macrochirus*); Ictalurids (*Ameiurus melas* and *Ameiurus natalis*); Whitefish (*Coregonus artedi* and *Coregonus clupaeformis*).

Chapter 4 is the final chapter where I summarize results from previous chapters (2 and 3), and further discuss the importance and application of these findings for aquatic resource management. Chapter 2 was accepted for publication in Transactions of the American Fisheries Society, and Chapter 3 is undergoing revisions so that it can be submitted to a journal upon completion.

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CHAPTER 2

Timing of Walleye Spawning as an Indicator of Climate Change

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Thank you,

Kristal N. Schneider

CHAPTER SUMMARY

We obtained walleye *Sander vitreus* historical egg-take records for 12 spawning locations from the Minnesota Department of Natural Resources to determine if the timing of walleye spawning runs could be used as an indicator of climate change. We used ice-out data instead of temperature for our analyses because walleye often spawn soon after ice-out, and ice-out has been previously related to climate change. We used linear regressions to determine the relationship between the start of spawning (based on first egg-take) or peak of spawning run (greatest egg-take) and ice-out date and to determine if there were long-term trends in ice-out and date of spawning over time. Linear regressions of the date of first walleye egg-take versus ice-out date showed that for each day ice-out gets earlier, walleye spawning begins 0.5 to 1 day earlier. All but 2 regressions had slopes less than 1. Similar results were found for peak of spawning runs. Regressions of egg-take and ice-out date versus year showed trends toward earlier spawning and earlier ice-out. For regressions of first egg-take versus year (16 total with restricted datasets), significant negative slopes ($P<0.1$) were observed in 5 out of 16 regressions; for peak egg-take, 6 regressions had significant negative slopes. For regressions of ice-out date versus year, 25 of 26 regressions were negative; there were 9 significant negative slopes ($P<0.1$). Overall, ice-out and walleye spawning are getting earlier in Minnesota, and the timing of walleye spawning may be a good biological indicator of climate change.

INTRODUCTION

As interest in climate change increases, there is a growing concern for its effects on the distribution and reproduction of species as well as an increasing need for biological indicators of climate change. Defining multiple parameters as indicators of climate change allows us to compare trends that can be used to predict future changes or reconstruct past changes in climate and allows us to choose cost-effective methods to monitor effects of climate change. Past research has documented climate trends by analyzing hydrologic parameters such as freeze and ice-out dates (Robertson et al. 1992; Magnuson et al. 1997; Jensen et al. 2007), climatic variables such as temperature and precipitation (Karl et al. 1996; IPCC 2001), and biological parameters such as changes in algal assemblages (Smol and Cumming 2000), diatom community structure (Kilham et al. 1996), and species distributions (Larocque et al. 2001; Chu et al 2005; Balanya et al. 2006). Indicators such as these help to answer questions from researchers, policy-makers, and the public about future climate projections, the effects of climate change on species and ecosystems, and anthropogenic forces that may be driving climate change.

The purpose of our study was to determine if climate change is affecting an aquatic species that is an important commercial and recreational resource in Minnesota and to determine if that species may be a useful biological indicator of climate change. Biological indicators are important because they provide us with a response that is a function of some stimulus over time instead of just a snapshot that may record a single extreme event (such as one random day with record high temperatures). By choosing walleye *Sander vitreus*, a species important both commercially and recreationally, we were able to obtain long-term records to determine if the timing of walleye spawning runs was related to ice-out and to identify any long-term trends in walleye spawning and ice-out data.

Walleye egg-take for hatcheries in Minnesota started in the late 1800s, and by 1923 seven walleye hatcheries and collection sites were established (Minnesota Department of Natural Resources 1996). Fish trapping sites are used to capture walleye for egg collection. Walleye spawning typically occurs soon after ice-out when ambient water temperatures are between 4-11°C (Scott and Crossman 1973; Wolfert et al. 1975; Becker 1983) and is partly dependent on these conditions and photoperiod to induce gonadal and hormonal changes that prepare the fish for spawning (Hokanson 1977; Malison et al. 1994; Malison and Held 1996). Thus some climate variable(s) likely influence the timing of the spawning run. Earlier studies of fishes have shown that climate change has significant relationships with species range shifts (Chu et al. 2005), recruitment (Shuter et al. 2002), fecundity (Sundby and Nakken 2008), and abundance (Kallemeyn 1987; Wingate and Secor 2008), but few have documented climate change effects on the timing of spawning in fishes.

Air temperature (e.g., mean monthly or maximum daily) has been used frequently in previous studies to examine the effects of climate change on various organisms (e.g. Winkel and Hudde 1997; Reading 1998; Dunn and Winkler 1999; Blaustein et al. 2001; Both et al. 2005). For our study we decided to focus on the relationship between the timing of walleye spawning runs and ice-out instead of air or water temperature. Ice-out is generally described as the time when a lake is free of all ice. We used ice-out because walleye spawning generally occurs soon after ice-out (Scott and Crossman 1973; Becker

1983) and because previous research has documented changes toward earlier ice-out, which may be evidence of climate change (Magnuson et al. 1997; Magnuson et al. 2000; Jensen et al. 2007). We also chose to use ice-out data because it is broadly available geographically and historically (more than 100 years of data in some cases) whereas air and water temperature data are not. In our datasets, temperature (air and water) was not recorded for every day of sampling, and record format was inconsistent across locations. For example, some locations recorded minimum and maximum daily temperatures, but others recorded only one measurement per day. Also, although spawning has been documented to occur when ambient water temperatures are between 4-11°C (Scott and Crossman 1973; Wolfert et al. 1975; Becker 1983) as previously noted, spawning temperature and temperature measurements taken with a thermometer are quite variable. Thus the timing of the spawning run is probably better related to ice-out than temperature. Robertson et al. (1992) suggest that the climate signal is amplified by using ice cover as a response. Based on their analyses, a 1°C change in air temperature should result in a 5.1 ± 0.4 (95% confidence limit) day change in mean ice-out dates. Other research suggests that the timing of ice-out may be a good indicator of climate change because it is strongly correlated with air temperatures (Palecki and Barry 1986; Johnson and Stefan 2006). Previous studies also suggest that the period 1970-onward is a distinct period of warming with increases in temperature occurring at a rate that is nearly double that of the previous period (IPCC, 2001; Walther et al. 2002). In agreement, a shift toward earlier ice-out in North America was documented during that same time period (Robertson et al. 1992; Johnson and Stefan 2006).

In this paper we determine the relationship between the timing of walleye spawning runs and ice-out, and we determine if there are trends in timing and duration of walleye spawning and in the timing of ice-out over time in Minnesota lakes. If the timing of walleye spawning is related to ice-out, it may provide a convenient biological indicator of climate change. Also, an observed relationship between walleye spawning and ice-out may demonstrate how walleye are responding to climate change. This information would be useful in future management plans for aquatic resources and in future climate change studies.

METHODS

We obtained walleye spawning records from the Minnesota Department of Natural Resources (MN DNR) and acquired Minnesota ice-out records from the Minnesota Ice Cover Database, the Minnesota Historical Society, and the Cook Herald News. For three of our spawning locations, we used ice-out data (measured as the number of days ice-out occurred after April 1st; January 1st for time series) from the same lake where walleye spawning data were collected (Table 1). Two spawning sites were in streams that flowed directly into the ice-out lakes, one site was in a system indirectly connected to the ice-out lake, and six sites were in water bodies not connected to the ice-out lakes but within 17 to 48 km. For Lake Sallie we evaluated two different ice-out datasets, Lake Sallie and Detroit Lake (connected to Lake Sallie) because the Detroit Lake ice-out record had 8 more sampled years than the Lake Sallie ice-out record. Statistical analyses were performed using R version 2.5.1, except Microsoft Excel was used to calculate some correlations. All statistical results were judged significant at the $P<0.05$ level unless otherwise stated. ArcGIS 9 (ESRI 2004) was used to map walleye spawning and ice-out locations and to measure the distance between spawning and ice-out data collection sites.

Walleye Spawning Records

Walleye spawning records collected by the MN DNR contained information on egg-take (number of eggs stripped from ripe walleye females) and individual fish counts obtained from twelve walleye egg collection operations conducted by various Minnesota hatcheries from 1938 to 2007 (Table 1). The timing of the walleye spawning runs could be described by the beginning of spawning, peak of spawning, or the end of spawning. From 1987 to 2007, the data recorded included number of walleye captured by sex and reproductive state of females (green, ripe, or spent), along with egg-take on each date. Prior to 1987, data on individual walleyes were generally not recorded, and only data on egg-take were available. Because egg collection quotas were common among hatcheries and tended to halt egg collections before the actual end of walleye spawning runs, we decided to focus on the dates for beginning and peak of spawning only. We wanted to know if we could use these dates interchangeably or if one response was a better indicator of the timing of spawning runs. We also needed to determine if the selected response was correlated with egg-take records so that data prior to 1987 could be used. We chose to use ripe females rather than green or spent females because these fish were ready to spawn.

We first needed to determine if peak capture dates or dates of first capture better described the timing of the spawning run. Coefficient of determination (R^2) values from regressions of the peak of spawning runs versus the start of spawning runs for ripe females ranged from 0.16 to 0.94, and at all but two locations, Otter Tail River and Rice Lake, regressions were significant. On average, peak capture of ripe females occurred 2 to 8 days later than first occurrence of ripe females. When correlations were computed separately across locations for the start of spawning runs and for the peak of spawning runs, correlations were larger on average for the start of spawning versus year than for the peak of spawning versus year. Thus, we focus on dates of first capture of ripe females.

To determine if egg-take (which greatly extended the data set) could be used instead of ripe females, we computed correlations between dates of first egg collection and dates of first ripe female sightings at all locations. They were highly correlated, with correlations (r) ranging from 0.78 to 0.99, and Rice Lake and Otter Tail River were the only locations with correlations less than 0.97. This allowed us to greatly extend our datasets by using egg-take data instead of data on adult walleyes that were typically not available prior to 1987.

Spawning and Ice-out Regressions and Time Series

We regressed the dates for the beginning of walleye spawning runs against ice-out dates for all 12 spawning locations to determine if there was a relationship between the two variables. For these regressions April 1st was designated as day 0 to magnify plots. The slopes and intercepts were compared across latitudes to determine if there were obvious spatial trends and were also compared using the "lmList" function in R (Pinhero and Bates, 2000) to create a list of slopes and intercepts as objects with 95% confidence intervals. T-tests were used to test the null hypothesis at each location that the slope was equal to one. We also regressed dates of peak egg-take versus ice-out to compare trends with first egg-take. To test for serial dependence in the datasets (Oehlert, 2000), the “acf” function in R was used to plot residuals from the regressions of walleye spawning versus ice-out date. We used a Bonferroni correction to control the family-wise error rate and report these results separately for each analysis. To determine if there were long-term trends in the timing of walleye spawning runs, we computed regressions of the beginning of walleye spawning (first egg-take) and the peak of walleye spawning (peak egg-take) versus year for each location. Because Pike and Pine Rivers both had about a twenty year gap in data, regressions were also computed for these locations that restricted the analyses to those years after 1970. We used the “pbinom” function in R to test the probability of getting our observed number of negative slopes.

Although there were likely constraints due to egg-take quotas, we present the results of regressions of peak egg-take versus ice-out and peak egg-take versus year for comparison with first egg-take results. Because changes in dates of first and peak egg-take may also indicate or be influenced by changes in the duration of spawning, we also present the results of regressions of the duration of spawning versus year and the duration of spawning versus ice-out. The duration of spawning was defined as number of days occurring from first to peak egg-take.

To determine if there were long-term trends in ice-out, we computed the regressions of ice-out dates versus year for all locations. Regressions were computed using full ice-out datasets at each location and using ice-out data that were matched to the sampling years represented in the spawning datasets (referred to as “restricted datasets”). More than half of the ice-out locations had records that started around 1970 or later. To determine if significant trends were present for that period, the datasets with longer-term records (prior to 1970) were restricted to the years 1970-onward (referred to as "restricted datasets"). We then used the "pbinom" function in R to test the probability of getting our observed number of negative slopes.

The "lowess" function in R, an algorithm based on the Ratfor original by W.S. Cleveland (1981), was used to compute a LOWESS smooth (SPAN=2/3) for each time series (spawning and ice-out). These were then compared to the linear regressions by computing the G-test statistic for lack of fit in R (Weisberg, 2005) to determine if the LOWESS smooth improved the fit. All time series datasets were tested for autocorrelation using the "acf" function in R, and a Bonferroni correction was used to control family-wise error rate.

RESULTS

Relationship Between Spawning and Ice-out

The timing of walleye spawning runs was highly correlated with the timing of ice-out, and there was no evidence of autocorrelation. Slopes from linear regressions of first egg-take versus ice-out date were significant at all locations, and all R^2 values were greater than 0.30 (Table 2, Figure 1). After a Bonferroni correction, 10 of 13 regressions were significant; only Bucks Mill, Otter Tail River, and Rice Lake were not significant. The relationships described by linear regression suggested that walleye spawning gets half a day to one day earlier for each day that ice-out gets earlier (Table 2). All but 2 locations, Lake Koronis and the St. Louis River, had slopes significantly less than 1 (t-tests H_0: Slope=1). We found no obvious trends across Minnesota latitudes to explain the differences in slopes.

Regressions of peak egg-take versus ice-out date showed similar results (Table 2); Bucks Mill and Rice Lake were not significant after a Bonferroni correction. However, the slope for Otter Tail River, which wasn't significant in first egg-take regressions, was significant using peak egg-take. The slopes for peak egg-take were usually similar to (differences of 0.02 to 0.33), but lower than the slopes for first egg-take at all locations except Little Cut Foot Sioux Lake, Bucks Mill, and Otter Tail River (Table 2). For regressions of the duration of spawning versus ice-out, significant negative slopes ($P<0.1$) were observed for Boy River, Dead River, Little Cut Foot Sioux Lake, Rice Lake, and St. Louis River. After a Bonferroni correction, only regressions from Boy River and Dead River were significant.

Spawning and Ice-out Time Series

The regressions of first egg-take versus year revealed significant negative slopes at Otter Tail River and at Lake Koronis (Figure 2, Table 3). Marginally significant ($P<0.1$) negative slopes were observed at Lake Sallie and for the restricted Pine River and Pike River datasets (Table 3). After a Bonferroni correction, Lake Koronis was the only location where the regression of first egg-take versus year was significant ($P<0.0063$). However, the probability of getting 14 negative slopes out of 16 was 0.0018. The LOWESS function improved the fit of the data ($P<0.05$) compared to linear regression at only Pike River, Pine River, and Rice Lake, which implied that data were well represented by the fit of the linear regressions at most locations. For peak egg-take regressions, significant ($P<0.05$) negative slopes were observed for Big Lake Creek, Lake Koronis, Otter Tail River, and for the restricted (1971-2007) Pine River dataset (Table 3).

Marginally significant (*P*<0.1) negative slopes were observed from Little Cut Foot Sioux and Pine River. After a Bonferroni correction, no regressions of peak egg-take versus year were significant, however, the probability of getting 14 of 16 negative slopes due to chance was 0.0018.

For regressions of the duration of spawning versus year, significant negative slopes (P<0.1) were observed for Big Lake Creek, Little Cut Foot Sioux Lake, and Pine River. A significant positive slope was observed at Lake Sallie. After a Bonferroni correction, there was one significant negative slope (Big Lake Creek) and one significant positive slope (Lake Sallie).

For ice-out regressions there were 25 negative slopes and 1 positive slope (Table 4). Significant negative slopes (*P* < 0.1) were observed in 8 of 26 regressions (Table 4, Figure 3). No slopes were significant with the Bonferroni correction (*P*<0.0038). However, even if there were no significant relationships between ice-out date and year, the probability of getting 25 negative slopes out of 26 regressions was <0.0001. Linear regressions described the ice-out datasets better than LOWESS fits at most locations (Figure 3). Lack of fit G-test statistics to test if the LOWESS improved the fit compared to linear regressions were only significant (*P*<0.05) for Lake Vermilion (full dataset) and for the Lake Vermilion dataset that was restricted to the range of years represented in the Pike River egg-take dataset.

DISCUSSION

There was a significant positive relationship between the timing of walleye spawning runs and ice-out at all locations. Even with the Bonferroni correction, 10 of 13 regressions for start of the runs were significant. Walleye spawning runs started 0.5 to 1 day earlier for every day ice-out occurred earlier. Although it is typically reported that spawning occurs soon after ice-out (see Scott and Crossman 1973; Wolfert et al. 1975; Becker 1983), our results indicate that in many cases the spawning run may be initiated just before ice-out. This may be a result of using the first occurrence of ripe females (or eggs) as an indicator of the start of spawning runs (i.e. individual vs. population response). The peak occurrence of ripe females and peak egg-take occurred 0 to 25 days after the first sighting of ripe females and first egg-take. The first sighting of ripe females and first egg-take occurred 20 days before to 27 days after ice-out (average of 3.3 days after ice-out). Neither spawning habitat (river versus lake spawning), nor location (location of egg-take site or distance to corresponding ice-out location) could explain the higher slopes at St. Louis River and Lake Koronis (slopes not significantly different from 1), which may mean that other lake characteristics are affecting slopes. Photoperiod and prior thermal history also determine timing of spawning (see Hokanson 1977; Malison et al. 1994; Malison and Held 1996) and likely constrain the dates of spawning.

Previous studies have shown a strong relationship between ice-out and air temperature (Palecki and Barry 1986; Robertson et al. 1992; Johnson and Stefan 2006), and temperature has significant relationships with life history traits of fishes (Bohlin et al. 1993; Shuter et al. 2002; Sundby and Nakken 2008). In a study of the effects of temperature and climate change on year-class production of fishes in the Great Lakes Basin, Casselman (2002) noted that although the time of spawning in lake trout *Salvelinus namaycush*, a cold-water fish, had been relatively consistent over time, an increase in fall temperatures at spawning time had a negative impact on year-class strength. Casselman also observed that year-class strength of northern pike *Esox lucius*, a cool-water fish, showed a curvilinear relationship with July-August temperatures and a similar reduction at high temperatures but observed a general positive effect for smallmouth bass. Moreover, Sundby and Nakken (2008) observed that increasing temperatures induced a northward shift of spawning areas and an increase in fecundity for Arcto-Norwegian cod *Gadus morhua*. Studies of walleye have shown that temperature affects the production and yield of walleye (Christie and Regier 1988; Schupp 2002) and that the timing of walleye spawning depends on water temperature and location (Scott and Crossman 1973; Hokanson 1977; Becker 1983), but the exact relationship between the timing of walleye spawning and temperature has not been well documented. Because our results show that there is a strong relationship between the timing of walleye spawning runs and ice-out, and ice-out has extensive evidence for its use as an indicator of climate change (e.g., Magnuson et al. 2000; Johnson and Stefan 2006), we believe the timing of walleye spawning is a useful biological indicator of climate change.

As with many sampling procedures, there is potential for sampling bias. For example, it's possible that the relationship observed between dates of first egg-take and ice-out is a result of sampling constraints (i.e., if sampling does not begin until after ice-out). However, in our study only 3 of 13 regressions paired egg-take data with ice-out data from the same location, and out of 10 spawning datasets with adequate records, only 23% of first egg-take dates occurred on the first day of sampling. Also, slopes from regressions of peak egg-take versus ice-out date were significant and similar to slopes from first egg-take regressions (Table 2). Peak egg-take occurred 0 to 25 days (mean 5.8

days) after first egg-take; 3% of peak egg-take dates were the same date as first egg-take, and 5% of peak egg-take dates were the day after first egg-take. Furthermore, although spawning duration was negatively related to ice-out for 5 lakes, there was no relation in the other 8 comparisons and no suggestion that duration was constrained by inability to sample spawning fish due to the presence of ice. These results suggest that spawning is related to ice-out but it is unlikely that sampling constraints due to the timing of ice-out were driving the relationships.

The negative relationship of spawning duration with ice-out date at some lakes may reflect biological constraints. With later ice-outs most fish may have mature gametes and be ready to spawn, but with earlier ice-out more individual variation in maturation may be seen. Earlier ice-out therefore might be expected to result in extended spawning runs, however, there was no indication that run duration was generally increasing in Minnesota; duration was increasing at Big Lake Creek and decreasing at Lake Sallie with no change at the other 10 locations. Further consideration of the implications of increased duration of spawning with earlier ice-out is warranted.

Regressions of start of walleye spawning versus year indicated that walleye spawning is getting significantly earlier at some locations in Minnesota, but not all. If we applied a Bonferroni correction, only 1 (Lake Koronis) of 16 regressions would be significant. However, the probability of getting 14 negative slopes out of 16 regressions was very low (0.0018). Similar results were seen with peak of spawning. Walleye spawning regressions with more than 30 years of data contributed 80% of significant negative slopes. Four of the 5 significant regressions were for lakes where spawning records started in 1970 or later. Otter Tail River was the only significant relationship with records prior to 1970. We were unable to detect any spatial trends that would explain variability in relationships among locations.

The trends that we documented in earlier spawning over time could have resulted from artificial selection by stocking artificially hatched walleye fry into these lakes. A MN DNR policy requires that 10% of hatchery production be returned to the waters where the parental fish came from (MN DNR 1997). This policy is intended to compensate for natural production that the artificially hatched fish would have provided if they were not intercepted in the spawn-taking operation. Egg-take at some hatcheries may have been biased toward earlier spawning fish in some years and locations because the operations of trapping and artificially fertilizing fish were often terminated after hatchery production needs (i.e. egg quotas) were met. However, for selection to occur, the stocked recruits would need to make up a greater proportion of the spawning population than did naturally hatched and recruited fish. Although there is potential for some selection bias to arise from this mechanism, it is unlikely that the artificially hatched and stocked fish would contribute disproportionately to the spawning population, especially in spawning runs emanating from the larger lakes where a smaller proportion of the spawning biomass will be intercepted by the spawning run trap.

For ice-out, our results were consistent with previous studies that documented ice-out occurring earlier over time (Schindler et al. 1990; Robertson et al. 1992; Magnuson et al. 2000; Johnson and Stefan 2006). In our study, 25 of 26 regressions were negative, and although a Bonferroni correction would result in no significant regressions, the probability of getting 25 negative slopes out of 26 regressions was very low (<0.0001). Ice-out regressions with more than 30 years of data contributed 75% of significant negative slopes. Six of the 9 significant regressions were for locations where ice-out records started in 1970 or later; Lake Koronis, McDonald Lake restricted to Dead River walleye sampling years, and McDonald Lake restricted to Otter Tail River walleye sampling years were the only significant relationships with records prior to 1970. Some literature (IPCC, 2001; Walther et al. 2002) suggests that 1970-forward is a period of distinct warming that is occurring at rates nearly double those of previous years. There was some indication of accelerating ice-out in our datasets.

Our results suggest that the timing of walleye spawning runs can be used as a biological indicator of climate change because it has a strong relationship with ice-out. Both walleye spawning and ice-out in Minnesota seem to be occurring earlier over time. Although all slopes were not negative and those that were negative were not all significant, both variables (spawning and ice-out) show mostly negative trends over time. Moreover, the very low likelihood of getting so many negative slopes and few positive slopes for both spawning and ice-out suggest the trends are real. Finding no relationship between two variables (egg-take and year or ice-out and year) can reflect either that no such relationship exists, or that the design, either through the variation in the values of the predictors or the sample size, is such that the power of detecting a significant relationship is low for any particular location. That the signs of almost all the coefficients were in the expected direction (moving toward earlier egg-take and ice-out) is indicative that power of detection was too low to detect a significant relationship in any particular lake or river, but taken as a whole, the test we used on the signs of the coefficients suggests against the hypothesis of independence.

Aside from being used as an indicator of climate change, the relationship between walleye spawning and ice-out may provide information about how climate change could affect walleye populations. One potential consequence of earlier spawning may be a mismatch in the timing of larval walleye abundance and peak prey availability, assuming prey populations do not respond to climate change by hatching earlier. This mismatch could cause negative consequences for walleye populations, and should perhaps be examined in future studies. Gotceitas et al. (1996) showed that larval Atlantic cod *Gadus morhua* tended to exhibit poorer growth and survival when there was a temporal mismatch in peak larvae abundance and peak prey availability compared to match conditions. This type of interaction has also been documented outside of the laboratory. Winder and Schindler (2004) found that there was a temporal mismatch in diatom and zooplankton blooms due to differences in sensitivity to warming in Lake Washington. *Daphnia* densities declined because the peak diatom bloom occurred too early to allow for maximum foraging by *Daphnia* populations. Because zooplankton availability significantly influences the survival and growth of larval walleye (Mayer and Wahl 1997; Hoxmeier et al. 2004), a temporal mismatch between peak larvae abundance and peak zooplankton (or other prey) availability may also significantly affect walleye populations. Additionally, change in the timing of walleye spawning runs may also affect recruitment if there is a temporal mismatch between the timing of peak larval emergence and optimal discharge events. There is strong evidence that discharge affects larval walleye survival (Becker 1983; Mion et al. 1998; Jones et al. 2006) and that discharge events may be significantly affected by climate change (Middelkoop et al. 2001; Peterson et al. 2002; Graham 2004).

We have presented evidence that the timing of walleye spawning runs may be a good biological indicator of climate change that could also provide insight into how climate change is affecting walleye populations. The timing of walleye spawning runs is a convenient indicator because walleye are an important sport and commercial fish that are continually monitored and managed in Minnesota. Further research investigating lake and river characteristics is needed to identify factors that could be influencing the relationship between the timing of walleye spawning and ice-out. This information would be useful for developing models to reliably predict the timing of walleye spawning. It would also be useful for creating a universal climate change model instead of several models that vary based on individual locations.

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Table 1. Summary of spawning locations and associated ice-out locations in Minnesota. Distance from spawning location to associated ice-out location was measured, and the number of years (N pairs) were counted where both spawning and ice-out data were available. Sampling range of years for both spawning and ice-out records is shown. The overlap range represents the range of years when spawning and ice-out data were both available, and superscripts identify the type of connectivity, if any, between spawning and ice-out locations. Synthetic records for Rice Lake were created by neighbor-lake modeling.

Spawning location	Spawning range (years)	Ice-out location	Ice-out range (years)	Site-to-site distance (km)	N pairs	Overlap range
Big Lake Creek	1971-2006	Big Turtle Lake[4]	1965-2008	21.86	29	1971-2005
Boy River	1970-2006	Long Lake (Cass)[4]	1974-2008	14.25	32	1974-2005
Bucks Mill	1985-1993	Long Lake[3] (Becker)	1980-2003	10.49	9	1985-1993
Dead River	1966-2007	McDonald Lake[4]	1968-2005	18.56	35	1969-2005
Lake Koronis	1996-2007	Lake Koronis[1]	1950-2005	NA	8	1996-2007
Lake Sallie	1971-2007	Lake Sallie[a]	1970-2007	NA	29	1971-2007
Lake Sallie		Detroit Lake[c]	1970-2007	1.2	37	1971-2007
Little Cut Foot Sioux L.	1942-2007	Leech Lake[d]	1936-2007	48.10	61	1942-2007
Otter Tail River	1954-2002	McDonald Lake[d]	1968-2005	19.91	24	1971-2002
Pike River	1938-1946, 1971-2007	Lake Vermilion[b]	1906-2007	10.23	44	1938-2007

Table 1 (continued).

Pine River	1925-1942, 1970-2006	Lake Edna[d]	1980-2005	17.33	26	1980-2005
		Ponto Lake[d]		20.72		
		Gull Lake[d]		26.99		
Rice Lake	1987-2007	Rice Lake[a] (& synthetic)	1962-2005	NA	10	1987-2005
St. Louis River	1992-2006	Fond du Lac[b]	1996-2007	< 1	11	1996-2006

[a]Same location as egg-take

[b]Egg-take location runs into ice-out lake

[c]Connected to egg-take site through a system of lakes and streams

[d]No connection to egg-take location

Table 2. Summary of linear regressions of first and peak egg-take versus ice-out date. The y-intercept, slope, R^2, *P*-value, and number of years with egg-take and ice-out data (N) are shown for each location. The number of years with egg-take and ice-out data are the same for both first and peak-eggtake at each location. The origin is April 1.

Spawning location	Ice-out location		Y-intercept	Slope	R^2	*P*	N (pairs)
St. Loius River	*Fond du Lac*	First Egg-take	0.47	1.095	0.918	<0.001	10
		Peak Egg-take	5.83	0.912	0.809	<0.001	
Lake Koronis	*Lake Koronis*	First Egg-take	4.95	0.906	0.809	0.002	8
		Peak Egg-take	8.05	0.829	0.890	<0.001	
Little Cut Foot Sioux	*Leech Lake*	First Egg-take	3.17	0.731	0.739	<0.001	61
		Peak Egg-take	7.85	0.752	0.834	<0.001	
Boy River	*Long Lake (Cass)*	First Egg-take	5.5	0.631	0.806	<0.001	32
		Peak Egg-take	18.01	0.301	0.422	<0.001	

Table 2 (continued)

Pike River	*Lake Vermilion*	First Egg-take	2.31	0.629	0.556	<0.001	44
		Peak Egg-take	9.2	0.564	0.604	<0.001	
Pine River	*Edna, Ponto, and Gull*	First Egg-take	2.92	0.598	0.476	<0.001	24
		Peak Egg-take	10.99	0.470	0.439	<0.001	
Big Lake Creek	*Big Turtle Lake*	First Egg-take	7.54	0.570	0.692	<0.001	29
		Peak Egg-take	15.19	0.485	0.635	<0.001	
Lake Sallie	*Lake Sallie*	First Egg-take	4.17	0.567	0.675	<0.001	29
		Peak Egg-take	10.6	0.476	0.462	<0.001	
Lake Sallie	*Detroit Lake*	First Egg-take	4.62	0.537	0.713	<0.001	36
		Peak Egg-take	10.86	0.468	0.552	<0.001	

Table 2 (continued).

Dead River	*McDonald Lake*	First Egg-take	5.79	0.567	0.668	<0.001	35
		Peak Egg-take	17.72	0.355	0.486	<0.001	
Rice Lake	*Rice Lake / Synthetic*	First Egg-take	8.11	0.566	0.567	0.012	10
		Peak Egg-take	10.88	0.56	0.556	0.021	
Bucks Mill	*Long Lake (Becker City)*	First Egg-take	5.29	0.492	0.472	0.041	9
		Peak Egg-take	5.8	0.733	0.574	0.018	
Otter Tail River	*McDonald Lake*	First Egg-take	12.37	0.394	0.319	0.004	24
		Peak Egg-take	16.49	0.466	0.398	<0.001	

Table 3. Summary of linear regressions of first and peak egg-take versus year. The y-intercept, slope, *P*-value, and number of years with egg-take data (N) are shown for each spawning location. The number of years with egg-take data is the same for both first and peak egg-take at each location. Years for restricted regressions are given in parentheses.

Spawning location	Y-intercept	Slope	*P*	N
Big Lake Creek				
First Egg-take	135.36	-0.013	0.891	33
Peak Egg-take	384.04	-0.180	0.030	
Boy River				
First Egg-take	240.07	-0.067	0.453	37
Peak Egg-take	193.45	-0.040	0.608	
Bucks Mill				
First Egg-take	-692.71	0.400	0.433	9
Peak Egg-take	-1351.49	0.733	0.277	
Little Cut Foot Sioux L.				
First Egg-take	195.50	-0.042	0.363	66
Peak Egg-take	268.20	-0.076	0.058	
Little Cut Foot Sioux L. (1970-2007)				
First Egg-take	474.13	-0.182	0.108	38
Peak Egg-take	380.28	-0.132	0.158	
Dead River				
First Egg-take	238.50	-0.067	0.388	39
Peak Egg-take	308.23	-0.098	0.094	

Table 3 (continued).

Lake Koronis				
First Egg-take	3540.21	-1.714	0.005	8
Peak Egg-take	2779.29	-1.333	0.024	
Lake Sallie				
First Egg-take	419.29	-0.158	0.053	37
Peak Egg-take	153.62	-0.022	0.789	
Otter Tail River				
First Egg-take	442.60	-0.168	0.037	32
Peak Egg-take	703.73	-0.297	0.006	
Otter Tail River (1971-2002)				
First Egg-take	474.20	-0.184	0.213	23
Peak Egg-take	561.76	-0.225	0.147	
Pike River				
First Egg-take	152.69	-0.022	0.640	46
Peak Egg-take	135.65	-0.011	0.788	
Pike River (1971-2007)				
First Egg-take	493.09	-0.193	0.070	36
Peak Egg-take	362.40	-0.125	0.153	
Pine River				
First Egg-take	122.36	-0.009	0.781	55
Peak Egg-take	212.04	-0.051	0.085	

Table 3 (continued).

Pine River (1970-2006)				
First Egg-take	527.90	-0.213	0.061	37
Peak Egg-take	507.76	-0.200	0.027	
Rice Lake				
First Egg-take	-218.55	0.160	0.484	12
Peak Egg-take	-224.41	0.164	0.469	
St. Loius River				
First Egg-take	788.60	-0.339	0.383	15
Peak Egg-take	669.26	-0.279	0.427	

Table 4. Summary of linear regressions of ice-out date versus year for full and restricted datasets. The y-intercept, slope, *P*-value, and number of years with ice-data (N) are shown for each location. Parentheses indicate datasets restricted to a range of years or restricted to years sampled at the corresponding spawning location. Brackets indicate county names for lakes with identical names. Synthetic records for Rice Lake were created by neighbor-lake modeling.

Ice-out location	Y-intercept	Slope	*P*	N
Big Turtle Lake	383.00	-0.137	0.192	42
Big Turtle Lake (Big Lake Creek)	401.52	-0.146	0.387	30
Big Turtle Lake (1970-2007)	388.19	-0.139	0.276	37
Detroit Lake	558.91	-0.227	0.064	38
Detroit Lake (Lake Sallie)	509.32	-0.202	0.121	37
Edna, Ponto, and Gull	-124.09	0.116	0.500	26
Fond du Lac	1255.88	-0.573	0.283	12
Fond du Lac (St. Louis River)	1690.70	-0.791	0.211	11
Lake Koronis	437.74	-0.169	0.027	56
Lake Koronis (Lake Koronis)	2964.18	-1.429	0.041	8
Lake Koronis (1970-2005)	680.02	-0.291	0.084	36
Lake Sallie	512.55	-0.204	0.101	30
Lake Sallie (Lake Sallie)	551.48	-0.223	0.095	29
Leech Lake	256.29	-0.071	0.137	72

Table 4 (continued).

Leech Lake (1970-2007)	533.39	-0.210	0.069	38
Long Lake [Cass]	239.97	-0.066	0.640	34
Long Lake [Becker]	120.84	-0.007	0.974	24
McDonald Lake	486.45	-0.191	0.125	38
McDonald Lake (Dead River)	580.99	-0.238	0.082	35
McDonald Lake (Otter Tail River)	912.34	-0.405	0.007	27
Rice Lake (and synthetic)	372.96	-0.137	0.225	43
Rice Lake (1970-2005)	563.48	-0.233	0.042	36
Lake Vermilion	130.30	-0.0064	0.846	89
Lake Vermilion (1970-2007)	467.03	-0.176	0.106	38
Lake Vermilion (Pike River)	468.72	-0.177	0.243	32

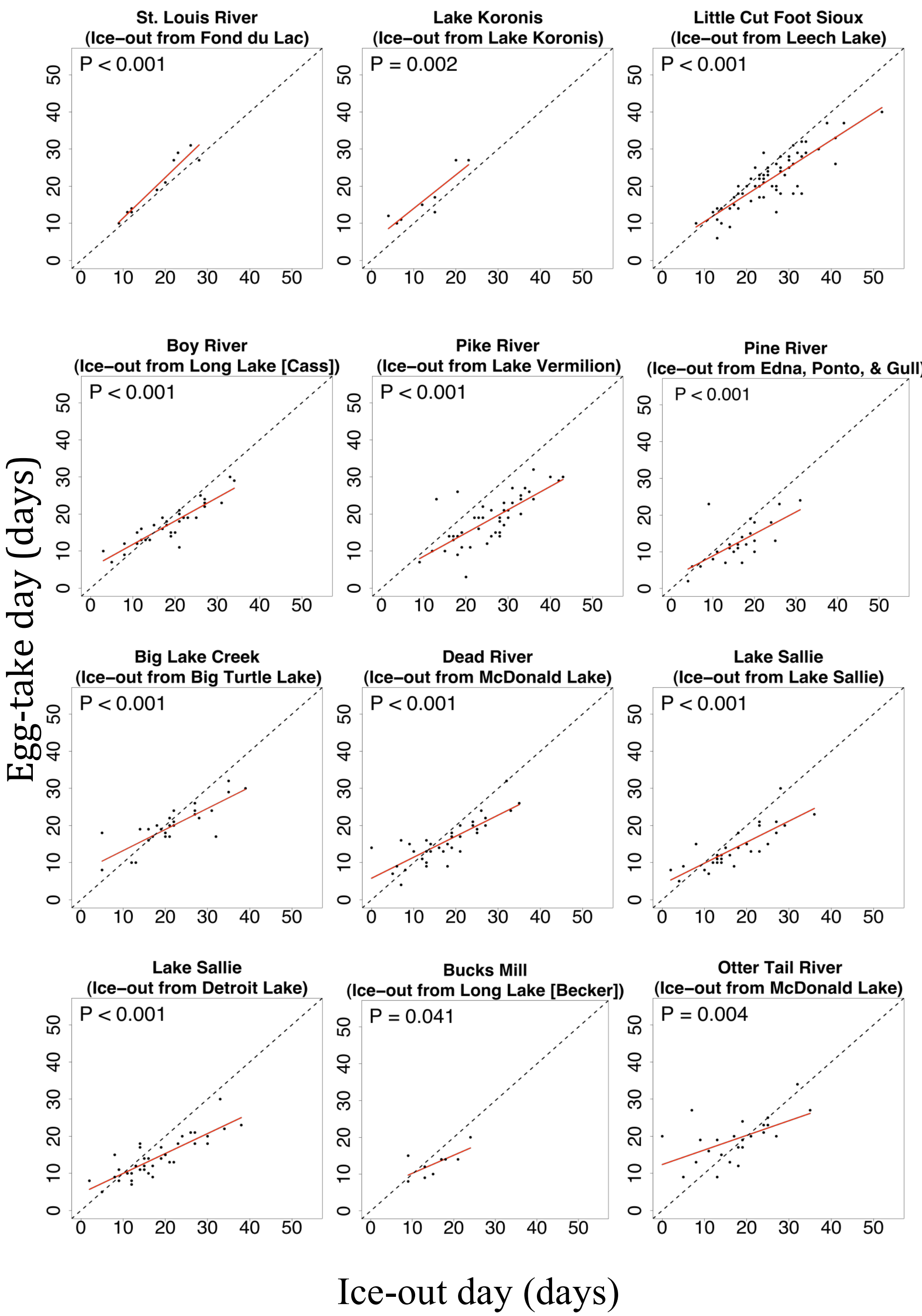

Figure 1. Regressions of first day of egg-take versus ice-out day in order of decreasing slope. All slopes were significant at the 0.05 level. The solid line is the linear regression. The dashed line is y=x. Each point represents one year, and the origin is April 1st.

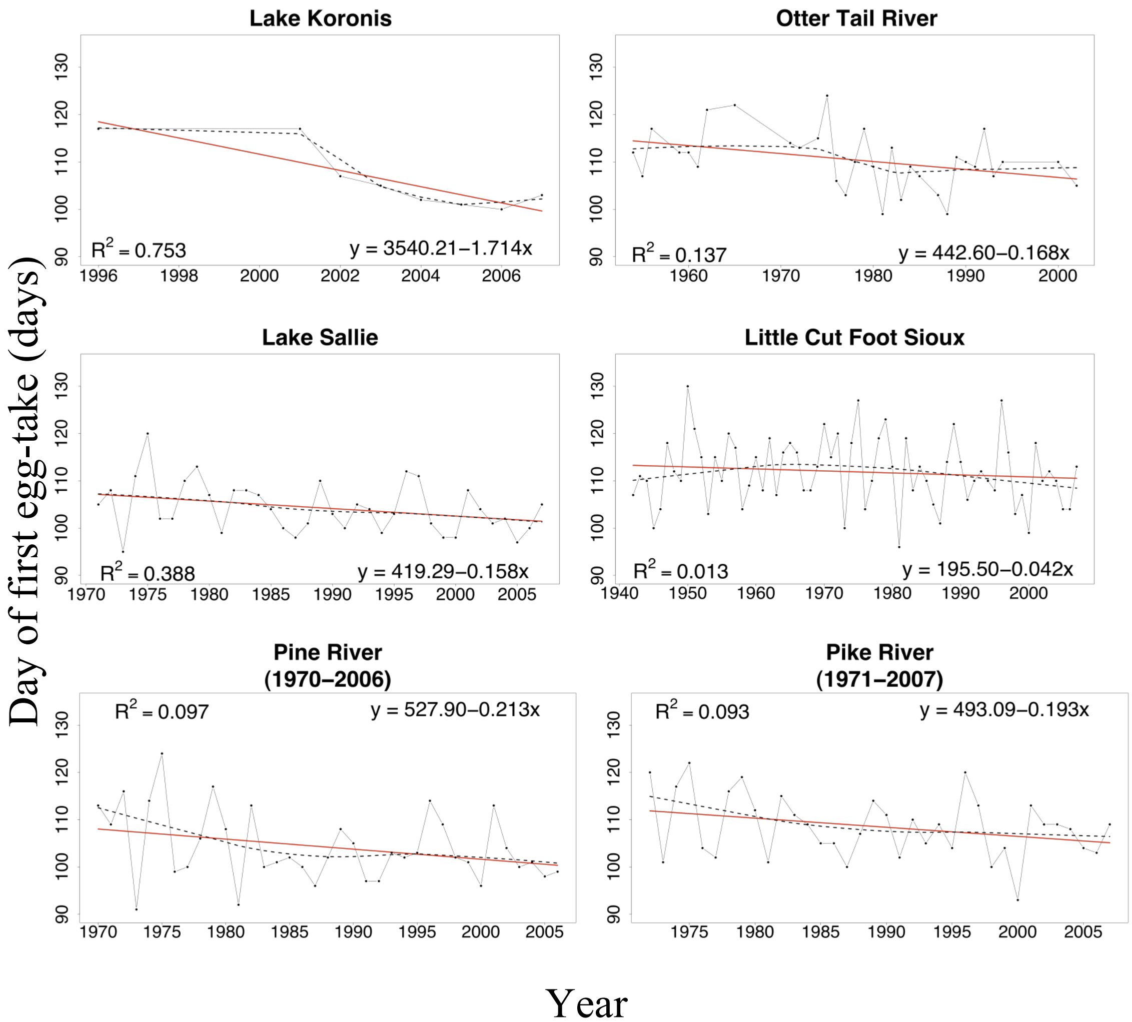

Figure 2: Example relationships of walleye first egg-take versus year. First egg take is recorded as the number of days from 1 January. The solid line is the linear regression, and the dashed line is the LOWESS fit. The linear regression was a better fit than the LOWESS smooth at all locations shown except Lake Koronis. All slopes shown except Little Cut Foot Sioux Lake were significant at the 0.1 level. Little Cut Foot Sioux Lake is shown as an example of a long-term time series that didn't have a significant slope.

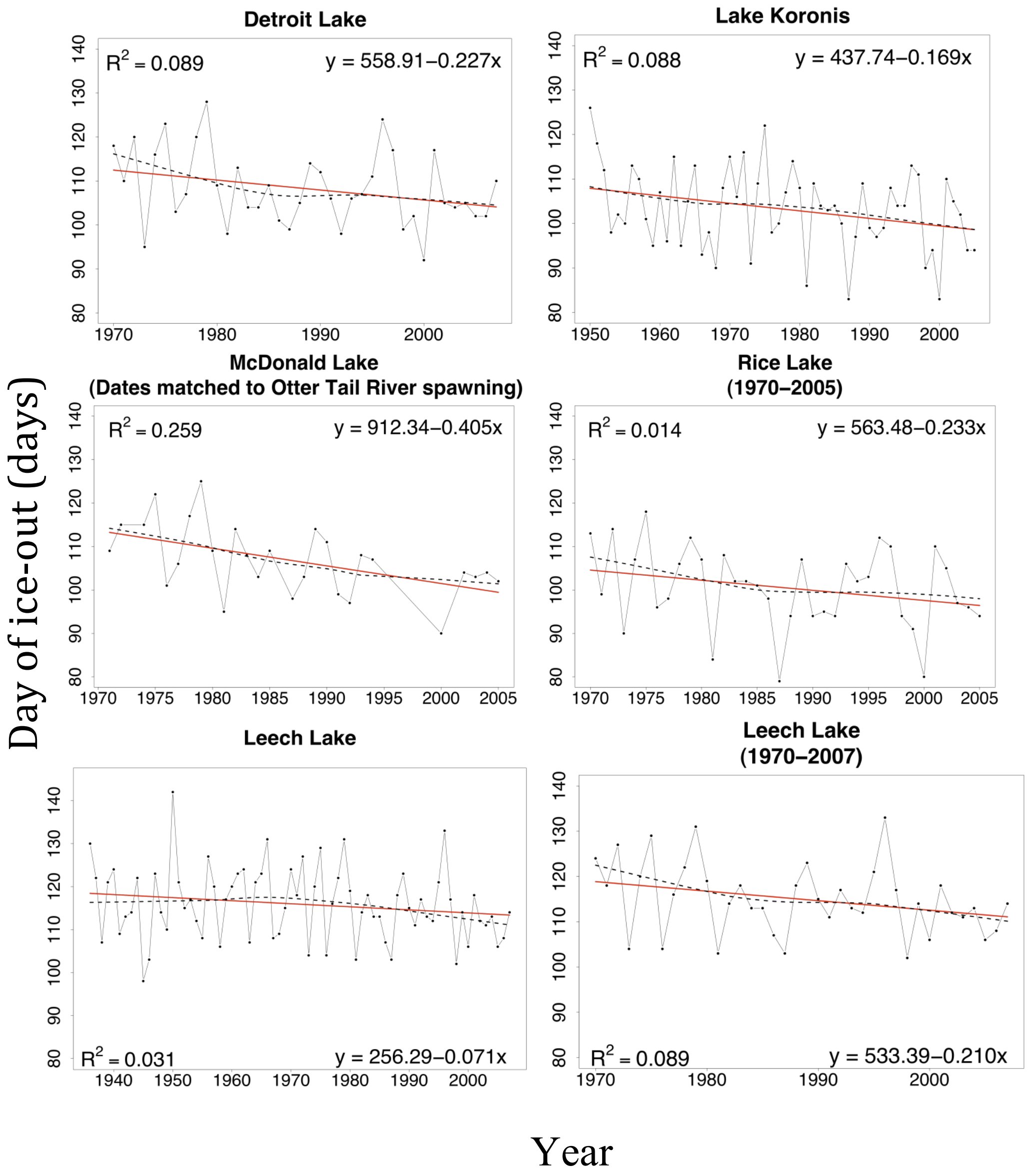

Figure 3. Example regressions of ice-out date over time. Ice-out is recorded as the number of days from 1 January. The solid line is the linear regression, and the dashed line is the LOWESS fit. All slopes shown except Leech Lake (full dataset) were significant at the 0.1 level. The Leech Lake time series is shown as an example of a long-term dataset that didn't have a significant slope. The LOWESS smooth did not improve the fit of the data compared to linear regression for all time series shown.

CHAPTER 3

Changes in Minnesota fish species abundance and distribution associated with local climate and lake characteristics

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CHAPTER SUMMARY

We analyzed historical Minnesota fisheries lake survey data (gillnet and trapnet) for 34 lakes, each with 15 to 43 years of data, to determine if fish distributions and abundances were changing over time. We then analyzed trends to determine effects of local climate on fish abundance and to determine if lake characteristics influenced trends in catch-per-unit-effort (CPUE) over time. Seven fish species from three families showed the strongest trends: centrarchids (*Micropterus salmoides*, *Micropterus dolomieu*, and *Lepomis macrochirus*); ictalurids (*Ameiurus melas* and *Ameiurus natalis*); whitefish (*Coregonus artedi* and *Coregonus clupaeformis*). We used simple linear regression to analyze CPUE over time, and we regressed mean latitudes of species occurrence against year to determine if ranges were advancing northward or contracting. Linear regressions were used to analyze the relationship between fish species' CPUE by lake and the following 5 temperature variables: maximum 7-day max temperature, average annual temperature, average summer temperature, average winter temperature, and degree-days above 5°C. We used stepwise regressions to determine if variability in slopes of CPUE vs. year could be explained by lake surface area, maximum depth, latitude, or longitude, and ANOVA to determine if variability in slopes could be explained by Schupp's lake classes. Linear regressions of CPUE vs. year indicated that centrarchid abundance was increasing, black bullhead (*Ameiurus melas*) abundance was decreasing, and other species were increasing in some lakes and decreasing in others. The ranges of all species were significantly advancing northward except smallmouth bass and whitefish. Regressions of CPUE versus air temperature showed that bass and sunfish were increasing in lakes as summer air temperatures increased, and whitefish were decreasing in lakes as air temperatures increased. Location, lake surface area, and lake class may explain some variability in slopes of CPUE versus year. In summary, temporal trends in the abundance and distribution of some centrarchids, ictalurids, and whitefish may be responding to climate change, and trends may be affected by lake characteristics.

INTRODUCTION

Climate change is expected to affect aquatic ecosystems around the world. Studies of the potential effects of climate change on fish have predicted a northward shift in species distributions (Magnuson et al. 1990; Meisner 1990; Stefan et al. 2001; Chu et al. 2005), and some studies have already documented occurrences of climate-related distribution shifts in fishes (Jackson and Mandrak 2002; Perry et al. 2005; Sundby and Nakken 2008). In a study of reef fish assemblages in the Southern California Bight, Holbrook et al. (1997) observed an increased abundance of southern species and a decreased abundance of northern species with the onset of ocean warming. In France, Daufresne and Boët (2007) similarly observed a significant increase in southern fish species and an increase in the proportion of warm-water species in large rivers that was related to water warming.

Most of the studies cited above observed a relationship between changes in water temperature and changes in fish communities (e.g., increased temperatures led to increased fishes from warmer areas). In Minnesota, lake and stream temperatures are increasing (Johnson and Stefan 2006; Austin and Colman 2007), and ice-out is occurring earlier (Magnuson et al. 2000; Jensen et al. 2007; Schneider et al. In press). Because of these changing conditions and the relationships previously observed between fish communities and water temperatures, climate change may have profound effects on fish communities in Minnesota. However, fish species composition and abundance is often influenced by other chemical and physical characteristics of the lake environment they inhabit (Tonn and Magnuson 1982; Robinson and Tonn 1989; Rodriguez and Lewis Jr. 1997). For example, Marshall and Ryan (1987) showed that mean depth influenced salmonid and percid abundance in Northwest Ontario, and Jackson and Harvey (1989) showed significant correlations between species richness and lake area in the Laurentian Great Lakes basin of Ontario. Thus, fish responses to climate change may be influenced by lake physical and chemical characteristics.

In this study we address 3 questions. (1) Are fish species distributions and relative abundances changing in Minnesota (e.g., are southern species increasing in northern lakes?), and (2) are changes in distributions and abundances related to climatic variables? Also, because lake physical and chemical characteristics are important factors that influence species composition (e.g., Jackson and Harvey 1989; Rodriguez and Lewis Jr. 1997), (3) could location of the lake and other lake physical and chemical properties affect observed trends in abundance and distribution?

METHODS

We obtained fisheries lake survey data from the Minnesota Department of Natural Resources (MN DNR) for 4,145 lakes with data ranging from 1940 to 2007. We initially chose to analyze 20 lakes sampled annually with 18 or more years of gillnet data (Table 1) and 20 lakes with 15 or more years of trapnet data (Table 2). There were 34 individual lakes within this subset because some lakes had both gillnet and trapnet data. Gillnet data ranged from 1941-2007, and trapnet data ranged from 1948-2007. The fisheries surveys used standardized sampling methods (MN DNR 1993) to collect information about fish communities (i.e., species present, number of individuals captured, etc.,) and lake physical and chemical properties. Nets were set overnight during the summer and emptied the next day. Gillnets were 76.20-m long and 1.83-m deep and constructed of #104 twisted nylon fibers. Each net had five 15.2-m panels of varying size bar mesh (1.9, 2.54, 3.18, 3.81, and 5.08 cm), and effort was based on the size of each lake (e.g. 9 nets were used for lakes with areas from 1.2 to 2.4 km^2 and 15 nets were used for lakes larger than 6 km^2). Trapnets were constructed of 1.9-cm nylon mesh and were 12.19-m long and about 1.07-m deep with two 1.83 m X 0.91 m frames and six 76.2-cm hoops. Throat openings were about 12.7-cm diameter (MN DNR 1993).

We analyzed catch-per-unit-effort (CPUE) to determine if species were changing in abundance within lakes, expanding their ranges into new lakes, or disappearing from other lakes. To determine if there were significant trends in species abundances, we computed linear regressions of CPUE versus year by gear, lake, and species. We also examined the percentage and distribution of lake surveys each species appeared in over time by partitioning data so that the total number of surveys was evenly distributed between 5 time periods: 1940 to 1970, 1971 to 1980, 1981 to 1990, 1991 to 2000, and 2001 to 2008. To graphically examine changes in fish communities, we plotted species occurrence over time by lake for gillnets and for trapnets. To determine if species distributions were significantly advancing northward or southward, we averaged latitudes from the lakes each species occurred in each year and regressed the mean latitude against year.

To determine if changes in abundance (and indirectly, changes in distribution) were affected by climatic variables, we chose 5 air temperature variables to analyze. Air temperature was used instead of water temperature because of its broad distribution and availability of long-term records. We obtained air temperature data from National Weather Service Cooperative daily measurements (Zandlo 2008) from weather stations within 45 km of our lakes. We used the following temperature variables in regressions by species to determine if there was a relationship between CPUE and air temperatures across lakes: maximum 7-day maximum (max) temperature each year, average annual temperature, average summer temperature (June-August), average winter temperature (November-March), and degree days above 5°C.

Some of the variability in trends of abundance over time (and in relationships between CPUE and temperature) may be explained by lake characteristics. To investigate this, for each species we computed stepwise regressions that examined the relationship between the slope of CPUE over time and the following independent variables: maximum lake depth, lake location (latitude and longitude), and lake surface area. The full model was:

$$\text{Slope} = \beta_0 + \beta_1\text{MaxD}+\beta_2\text{X\_UTM} + \beta_3\text{Y\_UTM} + \beta_4\log(\text{Area})$$

Slope was the slope from regressions of CPUE versus year for each lake. β_0 was the intercept, and MaxD was the maximum depth of each lake. X_UTM and Y_UTM were the Universal Transverse Mercator (UTM) coordinates for the location of each lake, and log(Area) was the natural log of lake surface area. We used both forward selection and backward elimination and chose models by selecting regressions with the smallest AIC (Akaike Information Criterion). We also used one-way ANOVAs to determine if slopes of CPUE over time for each species varied with Schupp's (1992) lake classes. Schupp's lake classes are based on 8 physical and chemical variables: area, maximum depth, littoral area (percentage), total alkalinity, Secchi depth, the Morphoedaphic Index (MEI), Carlson's Trophic Status Index (TSI), and shoreline development factor. Because our dataset was relatively small and there are 44 lake classes, we used both Schupp's lake classes and a variation of Schupp's classes that grouped the 44 classes into 9 groups (referred to as Schupp's groups) that were the result of a K-means cluster analysis (Schupp unpublished).

RESULTS

Abundance and distribution

Significant relationships ($P < 0.10$) from regressions of CPUE versus year by species were observed in 28 lakes (N = 34). Centrarchids showing trends most frequently were largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), and bluegill (*Lepomis macrochirus*). Largemouth bass distribution and abundance in Minnesota lakes has been increasing over time. Before 1980, largemouth bass appeared in less than 31% of Minnesota lakes surveyed by the MN DNR (Table 3). By the next time period (1981 to 1990), the percentage of lakes with largemouth bass records doubled to 62% and largemouth persisted in > 50% of lakes through 2008 (Appendix B). For regressions of largemouth bass gillnet and trapnet CPUE versus year, there were 20 positive slopes and 10 negative slopes; there were 3 significant positive slopes ($P < 0.1$) and 2 significant negative slopes. In addition to increased abundance within and among lakes, the regression of largemouth bass mean latitude versus year (Figure 1) showed that largemouth were expanding their distribution northward in Minnesota (Appendix A1) by about 2.3 km each year ($P < 0.001$).

Regressions of smallmouth bass CPUE versus year also showed increasing abundance over time. There were 14 positive slopes and 2 negative slopes; eight positive slopes were significant ($P < 0.1$). Although smallmouth seemed to be increasing in individual lakes, the percentage of surveyed lakes with smallmouth bass remained between 26-38% over time (Table 3). There were no obvious changes in smallmouth bass ranges in Minnesota (Appendix A2), and the regression of mean latitude versus year (Figure 1) was positive but not significant (P = 0.82).

Bluegill abundance also significantly increased over time in Minnesota. Regressions of bluegill CPUE versus year, showed 31 positive slopes and 4 negative slopes; sixteen positive slopes were significant and 2 negative slopes were significant ($P < 0.1$). Bluegill were in 58% of surveyed lakes throughout the first 30 years of sampling, but they are now found in 85% of surveyed lakes (Table 3). In addition to increased abundance, bluegill also seemed to be advancing northward (Appendix A3). There was a significant positive relationship ($P < 0.001$) between mean latitude and year that indicated bluegill distributions were expanding northward by about 2.4 km each year (Figure 1).

There were also changes in bullhead abundance and distributions (Appendix A4 and B5). For regressions of black bullhead CPUE versus year, there were 8 positive slopes and 27 negative slopes; there was 1 significant positive slope and 11 significant negative slopes ($P < 0.1$). Although regressions of CPUE versus year indicated mostly decreasing abundances, the number of lakes with recorded black bullhead occurrences was increasing prior to 2001. Black bullhead were in 58% of surveyed lakes (Table 3) during the first period of sampling (1940-1970). Their occurrence increased over the next 20 years; they occurred in 85% of lakes from 1991 to 2000 before decreasing to 65% in the last time period (2001 to 2008). The regression of mean latitude versus year had a significant positive slope ($P < 0.001$) that indicated black bullhead distributions were expanding northward by about 2.6 km per year (Figure 1).

Yellow bullhead showed similar trends for distribution but not abundance. Regressions of CPUE versus year suggested that yellow bullhead were increasing in about half of the sampled lakes and decreasing in the other half; there were 14 positive slopes (6 significant) and 12 negative slopes (3 significant) ($P < 0.1$). Yellow bullhead occurred in only 32% of surveyed lakes (Table 3) during the first period of sampling. Occurrences of yellow bullhead increased to 62% of surveyed lakes from 1991 to 2001 and remained at 56% of lakes from 2001-2008. Regressions of mean latitude versus year suggested that yellow bullhead distributions were expanding northward by about 1.6 km per year (Figure 1).

Black bullhead and yellow bullhead have different temperature and habitat preferences so that one is known to replace the other under certain conditions (Scott and Crossman 1973; Becker 1983; Hubbs and Lagler 2004). Yellow bullhead have a higher thermal maximum (Reynolds and Casterlin 1978; Carveth et al. 2006) than black bullhead (Black 1953; Cvancara et al. 1977; Kayes 1977), and because of this, the replacement of one species by the other may be a response to climate change. To determine if one species was replacing the other, we regressed the ratio of yellow to black bullhead against year. Our results indicated that ratio of yellow to black bullhead increased over time. There were 21 positive slopes and 5 negative slopes; 10 positive slopes were significant and there were no significant negative slopes.

Tullibee showed less evidence of changes. For regressions of CPUE versus year, there were 7 positive slopes and 7 negative slopes; there was 1 significant positive slope and 2 significant negative slopes ($P < 0.1$). Tullibee occurred in 26% of surveyed lakes (Table 3) during the first time period (1940 to 1970) and in 30 to 35% of lakes from 1971 to 2008. There was no evidence of tullibee range expansion or contraction across Minnesota latitudes (*P* = 0.856) (Figure 1, Appendix A6).

Lake whitefish were increasing in some locations and decreasing in others. For regressions of CPUE versus year, there were 6 positive slopes and 5 negative slopes; there were 4 significant positive slopes and 3 significant negative slopes ($P < 0.1$). Lake whitefish occurred in an increasing percentage of surveyed lakes over time (from 10 to 27%; Table 3), but there was no evidence of range expansion or contraction across Minnesota latitudes (*P* = 0.116) (Figure 1, Appendix A7).

Relationships with temperature

To assess relationships between CPUE and air temperature variables, regressions of CPUE versus each temperature variable were computed by species for each lake and gear type. For regressions of largemouth bass CPUE versus temperature for each lake, most significant ($P<0.1$) positive relationships were observed using maximum 7-day max temperature, average summer temperature, and degree-days above 5°C (Table 4). Most significant negative relationships were from using average annual and average winter temperatures. For regressions of smallmouth bass CPUE versus temperature, most significant positive slopes were observed using each temperature variable except average winter temperature (Table 4), which had 1 positive and 1 negative relationship. For bluegill, significant positive slopes occurred more often than significant negative slopes in all regressions of CPUE versus each temperature variable. Overall, centrarchid CPUE responded positively to warming temperatures.

For regressions of black bullhead CPUE versus temperature, most significant positive slopes were observed in regressions of CPUE versus maximum 7-day max, and most negative slopes were observed in regressions with average annual temperature (Table 4). Black bullhead regressions with other temperature variables resulted in equal numbers of significant positive and negative relationships (e.g. 1 positive slope from one lake and 1 negative slope from another lake). For regressions of yellow bullhead CPUE versus temperature, more significant negative slopes than positive slopes were observed with average summer temperature and degree-days above 5°C (Table 4). More significant positive slopes than negative slopes were observed with average winter temperature. Regressions with all other temperature variables resulted in equal numbers of significant positive and negative slopes.

Regressions of tullibee CPUE versus temperature showed few significant positive relationships with air temperature variables, and no significant relationships were observed with average winter temperature. For all variables except average annual temperature, the significant slopes were negative (Table 4). For regressions of lake whitefish CPUE versus temperature, most significant positive slopes were observed with average annual and average summer temperature, and most significant negative slopes were observed in regressions with maximum 7-day max and average winter temperature (Table 4). Overall, whitefish CPUE responded negatively to warming temperatures.

Relationships with lake characteristics

To determine if lake characteristics were influencing the trends in abundance, slopes from the regressions of CPUE versus year were regressed against lake characteristics. In general, location and lake surface area seemed to influence slopes of centrarchid CPUE versus year, however, for largemouth bass, no lake characteristics explained variability in trends. For smallmouth bass, regressions suggested that lake surface area, latitude, and longitude explained some variability in slopes (Table 5). All three were associated with more negative slopes of smallmouth bass CPUE over time. ANOVAs were significant for both Schupp's lake classes and Schupp's groups. Greater significance (lower p-value) was observed in ANOVAs using Schupp's lake class. For bluegill, stepwise regressions suggested that lake surface area might explain some variability in slopes of CPUE versus year (Table 5); the relationship between surface area and slopes of bluegill CPUE over time was negative. ANOVAs suggested that lake groups (not Schupp's 44 individual classes) might explain some variability in slopes of bluegill CPUE over time.

For black bullhead, lake surface area and latitude explained some variability in the slopes from regressions of CPUE versus year (Table 5). Slopes were more positive as latitude increased and more negative as lake surface area increased. ANOVA's suggested that slopes also varied by Schupp's lake classes and lake groups; greater significance was observed using Schupp's groups. No variability in yellow bullhead slopes could be explained by the lake characteristics we chose for this study or by lake classes.

DISCUSSION

Fish thermal niches are typically established for physiological, ecological, and reproductive optimal performance (Coutant 1987), and because their distributions vary by temperature (Brandt et al. 1980; Holbrook et al. 1997; Daufresne and Boët 2007), changes in species ranges may be indicative of climate change. Studies have also shown that abundance or CPUE may change in response to climate change (Meisner et al. 1987; Willis and Magnuson 2006). In our study, centrarchids were increasing in abundance (Appendix B) and expanding their ranges northward in Minnesota over time, and these changes were associated with air temperatures. Other studies have documented relationships between centrarchid thermal structure and air temperatures (Schlesinger and Regier 1982, Sharma et al. 2007), and except for smallmouth bass, our results were consistent with other studies that predict warm-water and southern species will expand their ranges northward as temperatures increase (Jackson and Mandrak 2002; Chu et al 2005). Several Canadian studies have shown that smallmouth bass are expanding their ranges northward in Canada (Shuter et al. 2002, Vander Zanden et al. 2004). The lack of a significant change in Minnesota smallmouth bass distributions may be a result of their already widespread occurrence in Minnesota lakes by the 1940s (Appendix A2) and the absence of records prior to that time period. Changes in largemouth bass and bluegill populations were associated with increases in summer air temperatures and are likely due to warmer temperatures creating additional suitable habitat available to promote increases in abundance and northern range expansions (Regier and Meisner 1990; Chu et al. 2005; Sharma et al. 2007).

Analysis of ictalurid abundance and distribution showed varying results. Black bullhead were generally decreasing in lakes, and yellow bullhead were increasing in some lakes but decreasing in others. Both species' distributions were advancing northward. Changes in temperature may also be influencing changes in bullhead abundances by altering the amount of available suitable habitat as mentioned previously. Their temperature preferences and sensitivities to different temperature variables may explain the varying trends in CPUE over time. Yellow bullhead have a higher thermal maximum than black bullhead (Reynolds and Casterlin 1978; Carveth et al. 2006) and thus may tolerate warmer temperatures and for longer periods of time than black bullhead. This is a reasonable assumption for a period of warming considering that black bullhead were expanding their ranges northward more quickly than yellow bullhead (2.6 km/yr versus 1.6 km/yr respectively), and although yellow bullhead seemed to have variable changes in abundance, the majority of black bullhead abundances were decreasing.

There was no evidence of range contraction or expansion by cold-water species (whitefish), and their abundances were increasing in some lakes and decreasing in others. However, this does not necessarily indicate a lack of response to climate change. Whitefish (tullibee and lake whitefish) relationships with air temperatures were mostly negative, but lake whitefish abundances responded positively to average annual and average summer temperatures. Meisner et al. (1987) reported increases in whitefish abundance related to increased temperatures, and Fang et al. (2004) projected an increase in the good-growth period for cold-water species by up to 42 days in some of Minnesota's deep stratified lakes and a decrease in the good-growth period in medium-depth lakes. On the other hand, although we found no evidence of trends in 12 tullibee lakes, Jacobson *et al*. (unpublished) reported decreases in mean abundances of tullibee (cisco) statewide in Minnesota that coincided with increases in temperatures. Other than reduced good-growth periods, decreases in abundance may be due to local mortality events caused by reductions in suitable thermal habitat for cold-water fish, which could be further amplified by lethal combinations of oxygen and temperature (Regier and

Meisner 1990; Jacobson et al. 2008). Continued assessment of the response of tullibee and whitefish to climate change is warranted.

Lake characteristics

Some of the variation in abundance and distribution trends may be explained by lake characteristics. Jackson (2002) showed that lake surface area was significantly associated with total species richness in south-central Ontario. Whittier and Kincaid (1999) showed that lake area and depth were significantly related to species richness in northeastern USA, and that correlations between lake characteristics and species richness were highest for lake area. For our study, some lake characteristics explained variation in abundance and distribution trends. For smallmouth bass, abundance generally increased more in smaller lakes and moving southeast across the state. For bluegill, larger increases in abundance typically occurred in smaller lakes. Consistent with other studies (e.g. Marshall and Ryan 1987; Robinson and Tonn 1989; Rodriguez and Lewis Jr. 1997), it's not surprising that these lake characteristics influenced CPUE over time, but why was CPUE increasing more rapidly given these conditions? Perhaps fish abundances aren't decreasing in larger lakes, but instead are only increasing in smaller lakes in our sample. For bass and sunfish, smaller, southern lakes may provide more good-growth habitat than larger, northern lakes (Bennett 1978, Schindler et al. 1996; King et al. 1999). Also in regard to location, CPUE was increasing in lakes further east that were typically clearer than other lakes. Clearer lakes tend to have deeper epilimnia than lakes with shallower secchi depths (Mazumder and Taylor 1994; Fee et al. 1996), thus providing more good-growth habitat for warm-water species when temperatures are warming.

For black bullhead, CPUE over time increased more in smaller lakes, and their range is expanding northward across Minnesota. Because black bullhead prefer warm temperatures (Cvancara et al. 1977; Kayes 1977), smaller lakes would probably provide more optimum habitat as temperatures increase over time than large lakes (see explanation above). However, the negative relationship with surface area may be an artifact of black bullhead abundances decreasing in most lakes and our sample size consisting of predominantly larger lakes (mean = 34,070 acres, min. = 18 acres, max = 305,907 acres). The lake characteristics we chose for our study did not explain any variation in yellow bullhead abundance over time. It's possible that some other factor (e.g. sampling effort, land use, interactions with black bullhead, etc…) may be influencing changes in yellow bullhead populations, or that lake class may be important, but our dataset lacked influential classes. On the other hand, it could mean that yellow bullhead are simply less sensitive to environmental changes than black bullhead, and the increasing ratio of yellow to black bullhead over time may be occurring because yellow bullhead populations may be less restricted as they advance northward.

For tullibee (cisco), no lake characteristics explained variation in abundance over time, which was decreasing in some lakes and increasing in other lakes. We may not have had enough data to get a strong response, or perhaps the limited distribution of tullibee lakes in our samples restricted the variation in lake characteristics. Our records from tullibee lakes only covered 3 lake classes, and no tullibee have shown up in new lakes (lakes without tullibee previously) since the 1980s (Appendix B6). Perhaps tullibee ranges began constricting to the northern-most part of their range in years not well represented by our records. Effects of climate change on species have been documented around the world since the earliest part of the twentieth century (Parmesan 2006), and Jacobson et al. (2008) have documented tullibee lake mortality events in north-central Minnesota. They reported that 16 north-central Minnesota lakes experienced tullibee midsummer mortality events in 2006, and in all of these mortality event lakes, tullibee had only two choices of habitat: cool hypoxia or normoxia at lethally warm temperatures. In our lakes, it's possible that temperature changes were great enough to allow centrarchids to increase their production but not enough yet to cause tullibee extirpations.

For lake whitefish, no variability in slopes of CPUE versus year could be explained by lake characteristics or lake class. For this species, the strongest response to climate change may be in the colder regions of Northeast Minnesota. In these regions, warming temperatures may not increase water temperatures enough to cause summer kill, but instead could alter important processes such as the timing of ice-out and spawning so that temperatures are closer to optimum and the good-growth season is extended (Fang et al. 1999; Stefan et al. 2001, Fang et al. 2004, Schneider et al. in press). In our dataset, lake whitefish were documented in only five lakes from this region, and only three had records prior to 1980 (Appendix A7). The small sample size (only 10 lake whitefish lakes) and relatively short timespan of the data probably limited the power to detect significant relationships.

Additional considerations: sampling effort, stocking, and land use

It is important to note a few possible sources of variation in abundance and distribution data. One potential source of variation in trends we observed could be from the timespan of the data and the sample size (Wiley et al. 1997). In our dataset, sampling effort varied by lake, and the number of lakes surveyed per year varied over time. This could cause variation in CPUE estimates and a lack of significant trends or false detection of trends. To investigate changes in the number of lakes surveyed per year, we regressed the mean latitude of lakes surveyed (both gillnet and trapnet) against year (Appendix C). The slope was significant (1.51km/year; $P < 0.05$) and suggests that some of the change in species' distributions may be due to changes in the number (and location) of lakes surveyed over time. However, in regressions of each species mean latitude versus year, all slopes were greater than 1.51 (significant slopes ranged from 1.60 to 2.59) and were more significant ($P < 0.001$) than the regression of mean latitude of surveyed lakes versus year.

Sampling effort within individual lakes may also influence trends. In 1993 there was a change in sampling effort that increased the number of nets used in many Minnesota lakes (MN DNR 1993), and an increase in effort could potentially bias records of fish abundance over time. To investigate changes in effort within lakes we examined box plots and computed t-tests for two subsamples of each dataset by lake and species: CPUE from 1983 to 1992 and CPUE from 1993 to 2002. We found no evidence to suggest that observed trends were a function of changing effort within lakes.

Stocking may also play an important role in structuring fish communities. Radomski and Goeman (1995) compared species presence and absence data in Minnesota and showed that species richness within stocked lakes was positively correlated with the number of years stocked ($P < 0.05$). However, they also observed a decrease in community diversity (across-lake diversity) that corresponded with extensive fish stocking. For our lakes, we know that Rebecca (Dakota County), Big Stone, Cass, Leech, Vermilion, and Winnibigoshish have been stocked in the past 10 years with walleye, lake whitefish, or smallmouth bass. During the last 10 years, some of the 7 species used for this study decreased in these lakes and some increased. There doesn't appear to be a direct effect on the species stocked because lake whitefish significantly increased in Cass Lake but decreased in Leech Lake, and there was no significant change in smallmouth bass abundance in any of those five lakes. However, without analyzing the entire fish community in each lake (we chose to run analyses on only 7 of about 70 species occurring in lake survey records) it's unclear if stocked species significantly influenced the changes observed in our study. Further analyses on stocking and diversity in Minnesota lakes would useful to determine if there have been changes in within-lake and across-lake diversity that have influenced populations in this study.

Land use is another factor that may affect fish communities. Evans et al. (1996) linked lake trout, lake whitefish, and lake herring declines in Lake Simcoe, Canada to phosphorous loading in lakes caused by changes in land use. Similarly, Harding et al. (1998) showed that past land use was an important factor in determining present species diversity in streams. Wagner et al. (2006) showed that lakeshore development affected the probability of black bass nest success; nest success decreased with increasing lakeshore development. Numerous other studies have identified ways that land use has altered aquatic habitats that in turn affected resident fish communities (Rodomski and Goeman 1995; Whittier and Kincaid 1999; Wang et al. 2001; Jennings et al. 2003).

Additional research is needed to determine other factors that may be responsible for the relationships observed in our analysis. From this study and examples from others, we showed that there is growing evidence of species range expansions in temperate lakes and changes in abundance that are associated with local climate and lake characteristics. Most notable may be the expansion of ranges and increase in abundances of centrarchids. Numerous studies have predicted or documented substantial population declines of cyprinid and other small-bodied fish, which are important prey species, after bass or bluegill introductions (Marchetti 1999; Findlay et al. 2000; Jackson 2002; Jackson and Mandrak 2002; Vander Zanden et al. 2004; Sharma et al. 2007). From a management perspective, these changes could shift sport fisheries in Minnesota, and thus, shift fisheries management from historical sport fish, such as walleye, to sport fish more recently appearing in lakes, such as bass. In some areas, management has already shifted to include centrarchids, which have been stocked in more than 500 Minnesota lakes since the late 1980s (MN DNR Section of Fisheries, public stocking records, October 8, 2009). Angler perspectives about desirable species may also change if invasive species such as bass become the more common and popular sport fish.

Fisheries management agencies in Minnesota may face many challenges in the future if warming trends continue. Therefore, it's important that management agencies consider the effects of climate change and other variables that are driving or influencing these changes. Information from this and other studies about how temperature and lake characteristics influence fish species abundance and distributions will benefit state and local agencies as they develop future management plans for Minnesota's aquatic resources. The ability to define these relationships will become even more important if we continue to observe trends of warming temperatures.

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Table 1. Lakes with 18 or more years of standard gillnet data. Lake name, county, gear type, sampling range in years, and the number of years sampled (N) are shown. Asterisks indicate lakes with both gillnet and trapnet data.

Lake name	County	Sampling range (years)	N (years)
Pepin	Goodhue	1965-2007	43
Vermilion*	St. Louis	1941-2007	34
Mille Lacs	Mille Lacs	1972-2007	33
Namakan	St. Louis	1962-2007	33
Lake of the Woods	Lake of the Woods	1968-2007	30
Sand Point	St. Louis	1970-2007	29
Kabetogama	St. Louis	1980-2007	26
Rainy	St. Louis	1980-2007	26
Cass	Beltrami	1983-2007	25
Leech	Cass	1983-2007	25
Red	Beltrami	1984-2007	24
Winnibigoshish	Cass	1983-2007	24
Fox*	Martin	1981-2007	22
Green*	Kandiyohi	1956-2007	22
Lac Qui Parle	Lac Qui Parle	1956-2007	22
Traverse*	Traverse	1971-2007	21
Big Stone*	Big Stone	1971-2005	20
Cut Foot Sioux	Itasca	1975-2007	18
James	St. Louis	1973-2007	18
Pine*	Cook	1960-2004	18

Table 2. Lakes with 15 or more years of standard trapnet data. Lake name, county, gear type, sampling range in years, and the number of years sampled (N) are shown. Asterisks indicate lakes with both gillnet and trapnet data.

Lake name	County	Sampling range (years)	N (years)
Vermilion*	St. Louis	1953-2007	23
Fox*	Martin	1981-2007	22
Green*	Kandiyohi	1956-2007	22
Rebecca	Hennepin	1954-2005	19
Big Stone*	Big Stone	1971-2005	18
Round	Hennepin	1976-2006	18
Clear	Waseca	1982-2005	17
Lura	Blue Earth	1972-2004	17
Olson	Washington	1960-2005	17
Traverse*	Traverse	1971-2005	17
Winona	Winona	1953-2006	17
Ash	St. Louis	1957-2002	16
Pine*	Cook	1960-2004	16
Crooked	Anoka	1951-2004	15
DeMontreville	Washington	1961-2005	15
Elephant	St. Louis	1962-2006	15
Jane	Washington	1950-2007	15
Owasso	Ramsey	1948-2006	15
Rebecca	Dakota	1961-2006	15
Snelling	Hennepin	1960-2003	15

Table 3. Percentage of lakes that each species occurred in lake surveys for the given time period. N is the number of surveys (both gillnet and trapnet data) per year for the given time period.

Species	1940-1970	1971-1980	1981-1990	1991-2000	2001-2008
	N = 19	N = 26	N = 34	N = 34	N = 34
Centrarchidae					
Bluegill	57.9%	65.4%	70.6%	82.4%	85.3%
Largemouth Bass	31.6%	30.8%	61.8%	70.6%	58.8%
Smallmouth Bass	36.8%	26.9%	32.4%	35.3%	38.2%
Ictaluridae					
Black Bullhead	57.9%	57.7%	79.4%	85.3%	64.7%
Yellow Bullhead	31.6%	30.8%	52.9%	61.8%	55.9%
Salmonidae					
Tullibee	26.3%	30.8%	35.3%	35.3%	35.3%
Lake Whitefish	10.5%	11.5%	23.5%	26.5%	26.5%

Table 4. Counts (N) of significant slopes (*P*<0.1) from regressions of catch-per-unit-effort versus temperature variables for all lakes. Counts include both trapnet and gillnet regressions. The temperature variable used in each regression, species name, and number of significant positive and negative slopes are shown along with the total number of lakes each species occurred in (N lakes).

Temperature variable	Species	N positive slopes	N negative slopes	N. lakes
Maximum 7-day max				
	Largemouth Bass	6	2	24
	Smallmouth Bass	2	0	14
	Bluegill	4	1	29
	Black Bullhead	3	0	30
	Yellow Bullhead	1	1	22
	Tullibee (Cisco)	0	1	12
	Lake Whitefish	0	1	10
Average annual				
	Largemouth Bass	1	2	24
	Smallmouth Bass	5	0	14
	Bluegill	6	2	29
	Black Bullhead	2	5	30
	Yellow Bullhead	2	2	22
	Tullibee (Cisco)	1	2	12
	Lake Whitefish	2	1	10

Table 4 (continued).

Average summer				
	Largemouth Bass	6	2	24
	Smallmouth Bass	3	1	14
	Bluegill	3	2	29
	Black Bullhead	1	1	30
	Yellow Bullhead	0	1	22
	Tullibee (Cisco)	0	3	12
	Lake Whitefish	1	0	10
Average winter				
	Largemouth Bass	1	4	24
	Smallmouth Bass	1	1	14
	Bluegill	3	1	29
	Black Bullhead	2	2	30
	Yellow Bullhead	1	0	22
	Tullibee (Cisco)	0	0	12
	Lake Whitefish	0	1	10
Degree days above 5 C				
	Largemouth Bass	3	1	24
	Smallmouth Bass	4	0	14
	Bluegill	4	1	29
	Black Bullhead	3	3	30
	Yellow Bullhead	0	1	22
	Tullibee (Cisco)	0	1	12
	Lake Whitefish	1	1	10

Table 5. Best fit (lowest AIC) significant models established from stepwise regressions of the temporal abundance slope versus lake characteristics. Gear type is given if models differed between gillnet (GN) and trapnet (TN) data. The response variable "y" is the slope from regressions of CPUE versus year. XUTM and YUTM are longitude and latitude coordinates respectively in kilometers. MAXD is the maximum depth, and surface area is given as a log-transformed variable "Log(Area)". R^2 and p-values (*P*) are shown for models.

Model	R^2	*P*
Smallmouth Bass		
y = 0.53 - 0.008Log(Area) - (2.00e-07)XUTM - (6.55e-08)YUTM	0.80	0.007
Bluegill		
y = 4.32 – 0.453Log(Area)	0.15	0.091
Black Bullhead GN		
y = -0.16 + (3.13e-06)YUTM	0.30	0.018
Black Bullhead TN		
y = -0.01 – 0.429log(Area) + (2.30e-05)YUTM	0.46	0.018

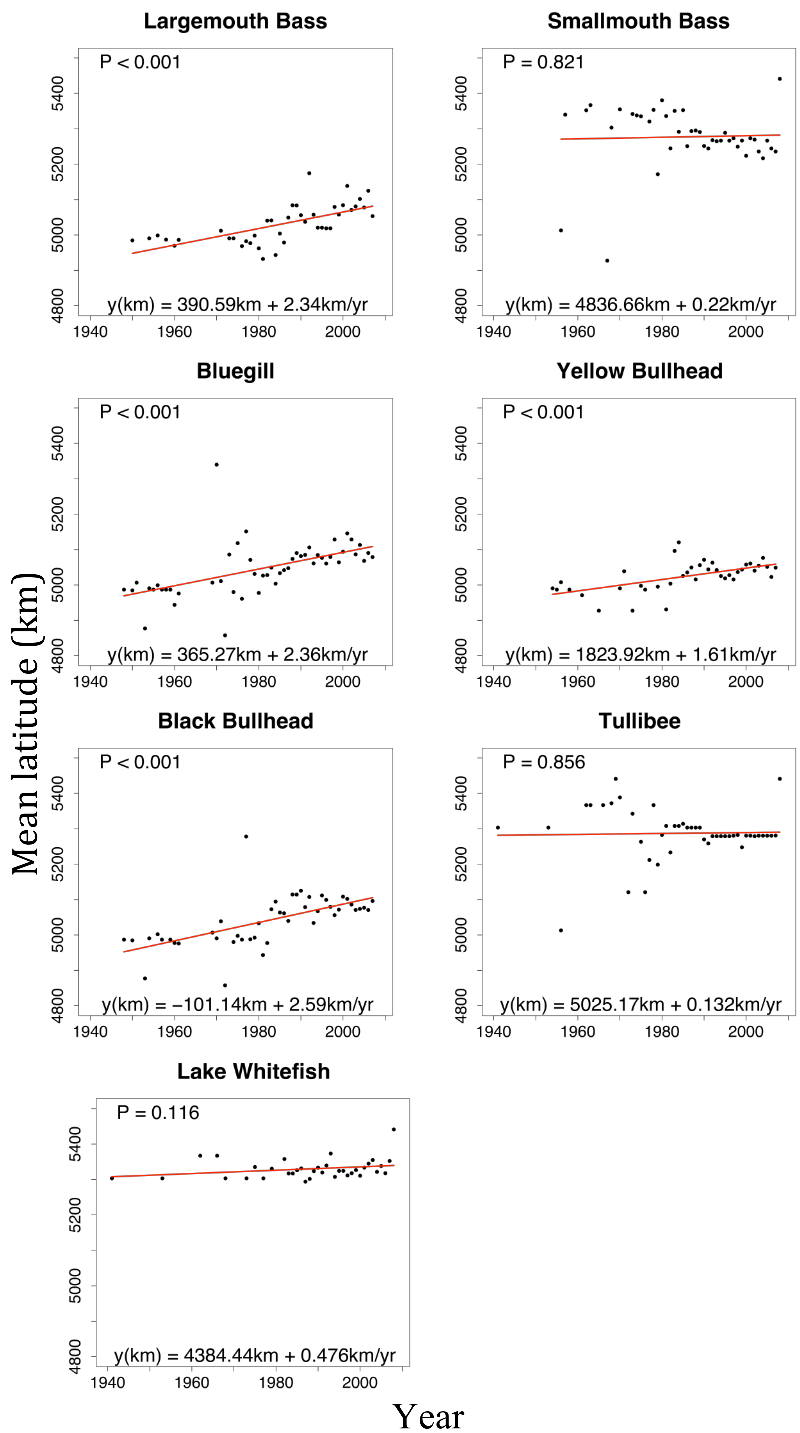

Figure 1. Regressions of mean latitude (km) versus year for 7 species. The red line is the regression line. *P*-values and slopes (km) are shown on plots.

CHAPTER 4

EPILOGUE

As climate change continues to be a topic of growing interest, and changes in species phenology and distributions are observed following predictions from climate change scenarios (Parmesan 2006), concerns arise about the effects of climate change on biological communities. Climate change can affect biological systems directly and indirectly by affecting processes such as migration (Bohlin et al. 1993; Reading 1998), reproduction (Blaustein et al. 2001), and recruitment (Shuter et al. 2002), and by shifting species distributions (Jackson and Mandrak 2002; Perry et al. 2005; Sundby and Nakken 2008). In Minnesota, evidence of climate change such as advanced ice-out dates (Magnuson et al. 2000; Jensen et al. 2007) and increased stream flows (Novotny and Stefan 2007) furthered curiosity about its effects on fish communities. In this thesis I determined if there is evidence of climate change in Minnesota's aquatic communities. I examined walleye spawning records collected by the Minnesota DNR to determine if there have been changes in the timing of spawning runs that are associated with climate change (Chapter 2). I also examined Minnesota ice-out data for changes in ice-out dates and to determine if there is a relationship between the timing of spawning and ice-out (Chapter 2) because there is extensive evidence that the timing of ice-out is sensitive to climate change (Magnuson et al. 1997; Magnuson et al. 2000; Jensen et al. 2007). In Chapter 3, I examined 7 fish species for evidence of changing abundances and shifting distributions associated with climate change. Mean latitude and CPUE were regressed against year to determine if species distributions and abundances were changing respectively, and lake physical and chemical characteristics were examined to determine if variability in trends could be explained by lake surface area, depth, location, or Schupp's (1992) lake classes.

In Chapter 2, I showed that first egg-take was significantly related to the timing of ice-out, and the start of spawning runs and ice-out has advanced at some locations but not all. There was a significant positive relationship between first egg-take and ice-out date at all locations, and even after a Bonferroni correction, 10 of 13 regressions were significant. Walleye spawning runs started 0.5 to 1 day earlier for every day ice-out occurred earlier. Regressions of peak egg-take showed similar results. Walleye spawning is typically reported to occur soon after ice-out (see Scott and Crossman 1973; Wolfert et al. 1975; Becker 1983), but our results indicate that in some cases walleye spawning may begin before ice-out. This may be a result of using first egg-take as an indicator of the start of spawning runs (i.e. individual versus populations response); first egg-take and the first capture of ripe walleye females occurred 20 days before to 27 days after ice-out (average of 3.3. days after ice-out). However, peak egg-take and peak capture of ripe females occurred 0 to 25 days after first egg-take and first capture of ripe females. Photoperiod and prior thermal history are both important determinants of the timing of spawning that likely affected these trends over time (Hokanson 1977; Malison et al. 1994; Malison and Held 1996), but there was still a strong relationship between first egg-take and ice-out dates at all but 3 locations.

Biological constraints that determine the duration of spawning could also affect relationships between the timing of walleye spawning runs and ice-out. With later ice-outs most fish may have mature gametes and be ready to spawn, but with earlier ice-outs we might expect to observe extended spawning runs. However, there was no indication that run duration was generally increasing in Minnesota. Hokanson (1977) suggested that environmental conditions have only a limited effect on the duration of stages of gonad maturity in adult percids, and therefore, instead of changes in spawning duration in response to temperature changes, there would be a shift in spawning temperatures and a change in the timing of spawning. Similarly, in a study of walleye from upper Midwestern lakes and rivers, Malison et al. (1994) suggested that it may be possible to induce earlier spawning in walleye via environmental manipulations because gonadal maturation was more or less completed several months before spawning (about mid-winter). Although, the timing of walleye spawning runs was affected by changes in temperature, spawning duration essentially remain unchanged.

Regressions of walleye spawning and ice-out dates over time showed mostly negative trends. Regressions of start of walleye spawning versus year indicated that walleye spawning is getting significantly earlier at some locations in Minnesota, but not all. If we applied a Bonferroni correction, only 1 (Lake Koronis) of 16 regressions would be significant. However, the probability of getting 14 negative slopes out of 16 regressions was very low (0.0018). For the timing of ice-out versus year, 25 of 26 regressions were negative, and although a Bonferroni correction would result in no significant regressions, the probability of getting 25 negative slopes out of 26 regressions was very low (<0.0001). The results for ice-out are consistent with previous studies that documented earlier ice-out over time (Schindler et al. 1990; Robertson et al. 1992; Magnuson et al. 2000; Johnson and Stefan 2006), and in general, results suggest that the timing of ice-out and walleye spawning runs were getting earlier. The lack of significance at each location could indicate either that there is, in fact, no relationship or that the power to detect a significant relationship is low for any particular location (discussed in more detail later). Moreover, statewide distribution of trends may be more relevant than local site trends when studying regional effects of climate change (see Urquhart et al. 1998).

Changes in the timing of walleye spawning runs are of interest because earlier (or later) spawning may have negative impacts on walleye populations. Earlier spawning could cause a temporal mismatch in the timing of peak zooplankton blooms and peak larval walleye abundance that would negatively affect growth and survival of walleye if prey populations do not respond to climate change by hatching earlier. Studies have documented negative impacts on species such as Atlantic cod (Gadus morhua) and Daphnia resulting from a temporal mismatch of this kind (Gotceitas et al. 1996, Winder and Schindler 2004). Additionally, because there is strong evidence that discharge events affect larval walleye survival (Becker 1983; Mion et al. 1998; Jones et al. 2006), walleye recruitment may suffer if there is a temporal mismatch in the timing of peak larval emergence and optimal discharge events.

Because ice-out date is sensitive to climate change (e.g. Magnuson et al. 1997; Magnuson et al. 2000) and because of the significant relationship between egg-take and ice-out dates, I suggested that the timing of walleye spawning would be a useful biological indicator of climate change. My work suggests that at least a strategic set of walleye egg-take sites should continue to be monitored. Aside from a biological indicator, it would also provide insight about effects of climate change on walleye populations that could have important implications for management and fisheries policies.

In Chapter 3, I examined Minnesota historical lake survey data for changes in abundances and distributions of 7 fish species that appeared to be indicators (largemouth bass, smallmouth bass, bluegill, yellow and black bullhead, tullibee (cisco), and lake whitefish). Centrarchid abundance was increasing in lakes, black bullhead abundance was decreasing, and other species were increasing in some lakes and decreasing in others. All species' ranges were significantly advancing northward except smallmouth bass and whitefish. Changes in species abundances and distributions were associated with local climate variables, and lake characteristics may have influenced these responses.

My results indicate that centrarchids and possibly bullhead may be good indicators of climate change. My recommendation for centrarchids as indicators is further supported by previous work that studied climate-driven changes in centrarchid populations (Meisner et al. 1987; Chu et al. 2005) and the effects of centrarchid invasions on native populations (Findlay et al. 2000; Jackson 2002; Jackson and Mandrak 2002). However, research on bullhead populations has focused mostly on temperature preferences and effects of temperature on the biology of these species instead of the use of bullheads as indicators of climate change (e.g. Black 1953; Cvancara et al. 1977; Kayes 1977; Reynolds and Casterlin 1978; Carveth et al. 2006). Yellow bullhead typically responded negatively to warmer temperatures, and black bullhead responses were variable, however, both species, which are known to prefer warm temperatures (Cvancara et al. 1977; Kayes 1977; Reynolds and Casterlin 1978; Carveth et al. 2006), were advancing northward in Minnesota. Further research on the response of bullheads to climate change is warranted. Analyses of whitefish populations mostly lacked trends, but temperature analyses showed that tullibee and whitefish typically responded negatively to warmer temperatures.

Observations of significant relationships between CPUE and air temperature are important because of growing concerns about climate change, but I acknowledge that temperature alone does not drive changes in biological communities; i.e. photoperiod, land use, eutrophication, etc., may be important. It would have been difficult to determine all sources of variation in fish community responses to climate, so we instead chose to analyze only a few lake physical and chemical characteristics that were readily available for all lakes. My results indicated that lake characteristics and lake class (or groups) explained variability in trends for some species. For future research and management plans, I recommend the use of sampling designs that help eliminate variability due to lake physical and chemical characteristics or analyses that incorporate lake characteristics into predictive models.

It's important to understand and identify changes in fish abundances and distributions associated with climate change because of potential implications for native fish populations, anglers, and aquatic resource management agencies. Most notable may be the expansion of ranges and increases in abundance of centrarchid populations. These changes could alter trophic interactions and community structure in lakes; numerous studies have shown that introduced centrarchids, such as smallmouth bass and bluegill, negatively impact fish communities by decreasing species richness and by decreasing abundance of fishes such as cyprinids (Jackson and Harvey 1989; Marchetti 1999; Findlay et al. 2000; Jackson and Mandrak 2002). Jackson (2002) showed that lakes with bass had significantly fewer species than lakes without bass. As centrarchids invade, fish communities may shift so that managers need to manage for bass and sunfish instead of walleye, and sport fisheries may become dominated by bass. Management agencies and biologists can use my results to make predictions that aid in future management plans for Minnesota's aquatic resources. Therefore, I recommend the continuation of lake surveys and further investigation of lake characteristics' influence on fish community responses to climate change.

From results for both chapters 2 and 3, it may be too obvious to say that significant trend detection and sampling design/methods are important aspects of this project that need further consideration. Small sample sizes and relatively short time spans likely limited the power to detect significant trends in individual lakes and for certain species. From Russ Lenth's power analysis (2006-09) I computed that the power to detect significant trends in egg-take data was only 48% (detectable beta = 02; Median sample size = 35, Error SD = 0.6), and the power to detect significant trends in ice-out data was only about 30% (detectable beta = 0.2; Median sample size = 38; Error SD = 0.9 and 0.8). Larson et al. (2001) showed that the probability of detecting a 2% per year trend with no interannual variation could be about 90% after 10 years with 100 sites, but if components of variability are influencing trends, it could take 15 to 25 years of data to reach a power of 80% with 100 sites. Similarily, Stockwell and Peterson (2002) reported that for linear regression to achieve 65% accuracy, about 50 data points were needed reaching maximum accuracy at 100 data points. My datasets for each lake or river were typically much smaller; walleye spawning and ice-out data ranged from 8 to 89 years, and lake survey data ranged from 15 to 43 years. Because my work suggests the timing of walleye spawning and some fish (centrarchids and ictalurids) distributions and abundances may be good indicators of climate change, I recommend that egg-take sites and lake surveys, or at least of subset of these, should continue to be monitored over time to increase samples sizes, timespans, and the power to detect significant trends.

Variability due to sampling designs also likely affected my ability to detect significant trends. Walleye spawning records collected by the Minnesota DNR contained information on egg-take and individual fish counts obtained from twelve walleye egg collection operations conducted by various Minnesota hatcheries from 1938 to 2007. From 1987 to 2007, the data recorded included number of walleye captured by sex and reproductive state of females (green, ripe, or spent), along with egg-take on each date. Prior to 1987, data on individual walleyes were generally not recorded and only data on egg-take were available. Sampling protocols have also varied over time for lake surveys in Minnesota. Lake survey data from the Minnesota DNR was collected for 4,145 lakes with data ranging from 1940 to 2007. Surveys were used to collect information about fish communities (i.e. species present, number of individuals…etc.) and general lake characteristics such as water temperature and secchi depth. Data were collected from several types of surveys: initial, re-survey, populations assessments, and special assessments. Special assessments were all surveys not considered to be standard, so these were excluded in our analyses. There were 61 different types of sampling stations that used gear such as standard gillnets, standard trapnets, ice fishing, seining, and trotlines. We narrowed the dataset down to 21 lakes with 18 or more years of gillnet data and 21 lakes with 15 or more years of trapnet data. There were 35 individual lakes within this subset because some lakes had both gillnet and trapnet data. All years were not sampled, and sampling effort varied within and across lakes over time. I chose to work with a subset of the data to eliminate locations with the shortest timespans and because of time constraints on this project. The broader dataset is available and could be used for further investigations.

Some components of variation that likely affected my ability to detect significant trends were (see Urquhart et al. 1998; Larson et al. 2001): index variance such as crew variance, measurement variance, gear variance, etc.; interaction variance from year-to-year changes in each lake unrelated to changes in other lakes; and site-to-site differences occurring within (i.e. variance due to sampling at different locations within a lake or river each year) and across locations. Year-to-year variation was not a concern for egg-take versus ice-out regressions because there was no evidence of autocorrelation, nor was it a concern for time series data because when investigating climate signals or climate-driven changes over time, you are essentially looking for annual variation that is explained by climate variables. Because sampling design has an effect on the ability to detect trends, I recommend that agencies develop sampling designs that consider components of variation such as those discussed by Urquhart et al. (1998). Discontinuity in variables measured, failure to record dates, or procedural changes such as variability in gear type or sampling effort are counterproductive for trend detection. Although technology allows for new methods of sampling such as electrofishing that are more efficient and effective than previous methods, my work suggests that these should be incorporated with older methods (gillnets and trapnets) instead of replacing them to avoid losing the ability to assess trends. Finally, for future research and management studies, I suggest analyzing regional trends in data instead of local trends to help reduce variability and to increase the ability to detect significant trends.

In summary, I've presented evidence that the timing of walleye spawning runs, fish abundances, and fish distributions in Minnesota are changing, and these changes, consistent with predicted effects (e.g. Magnuson et al. 1990; Meisner 1990; Magnuson et al. 1997; Stefan et al. 2001; Chu et al. 2005; Jensen et al. 2007), may be associated with climate change. Information from this and other studies about climate-driven changes in fish phenology and distributions will benefit state and local agencies as they develop future management plans for Minnesota's aquatic resources. I recommend continued monitoring of the timing of walleye spawning runs in Minnesota because it may be a good biological indicator that can also be used to document climate-driven changes in walleye populations. While there is nothing comparable to ice-out in warmer regions, fish species responses may be similar across regions and thus, may be a more universal indicator than ice-out. Spawning records for other populations or species may be good indicators in other regions. Furthermore, I recommend continued monitoring of centrarchids and perhaps bullhead in lake surveys as these species may also be good indicators of climate change. Finally, it's important for management agencies and biologists to consider the influence of lake characteristics on fish responses to climate change; my work suggests that location, lake size, and lake class may be important covariates to consider. The ability to define these relationships will become even more important if we continue to observe trends of warming temperatures.

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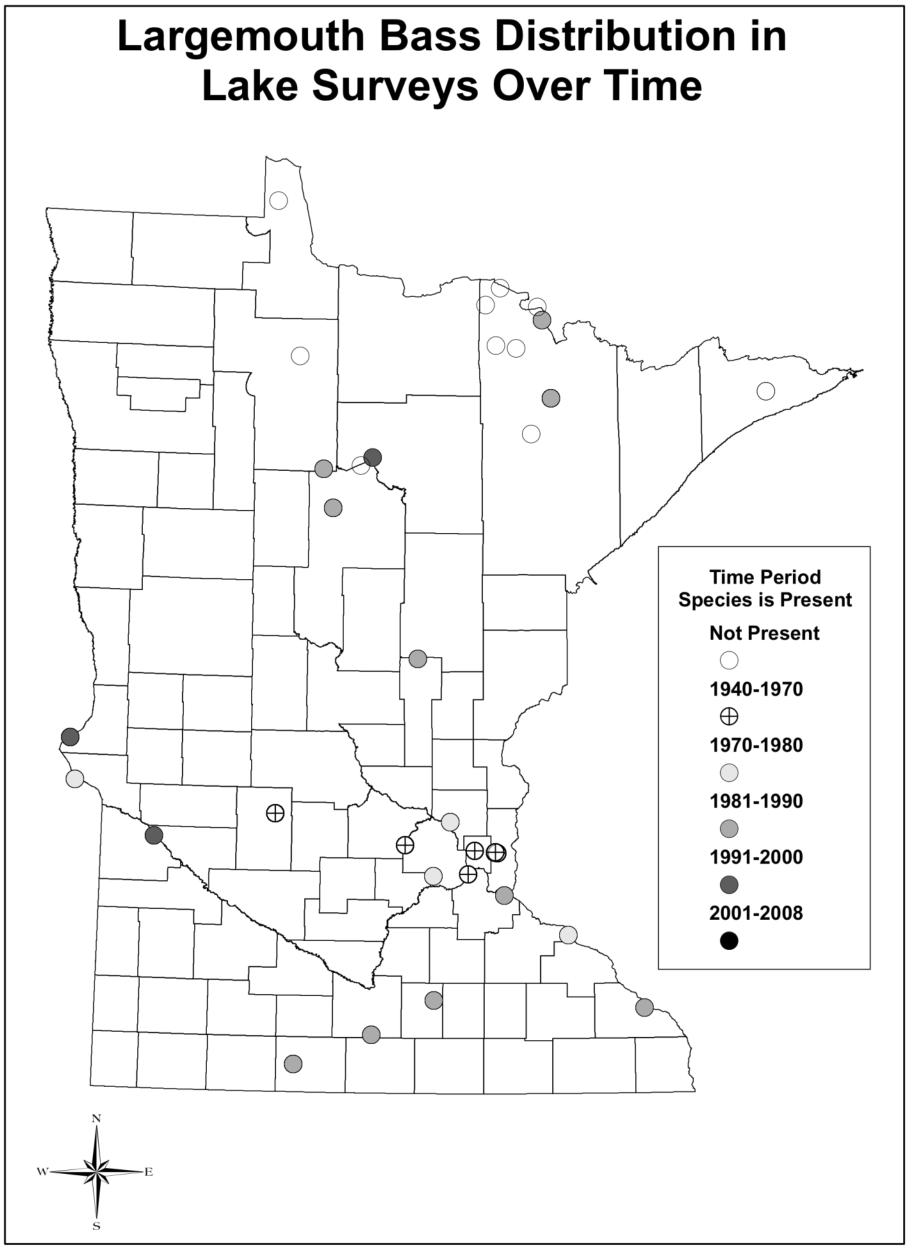
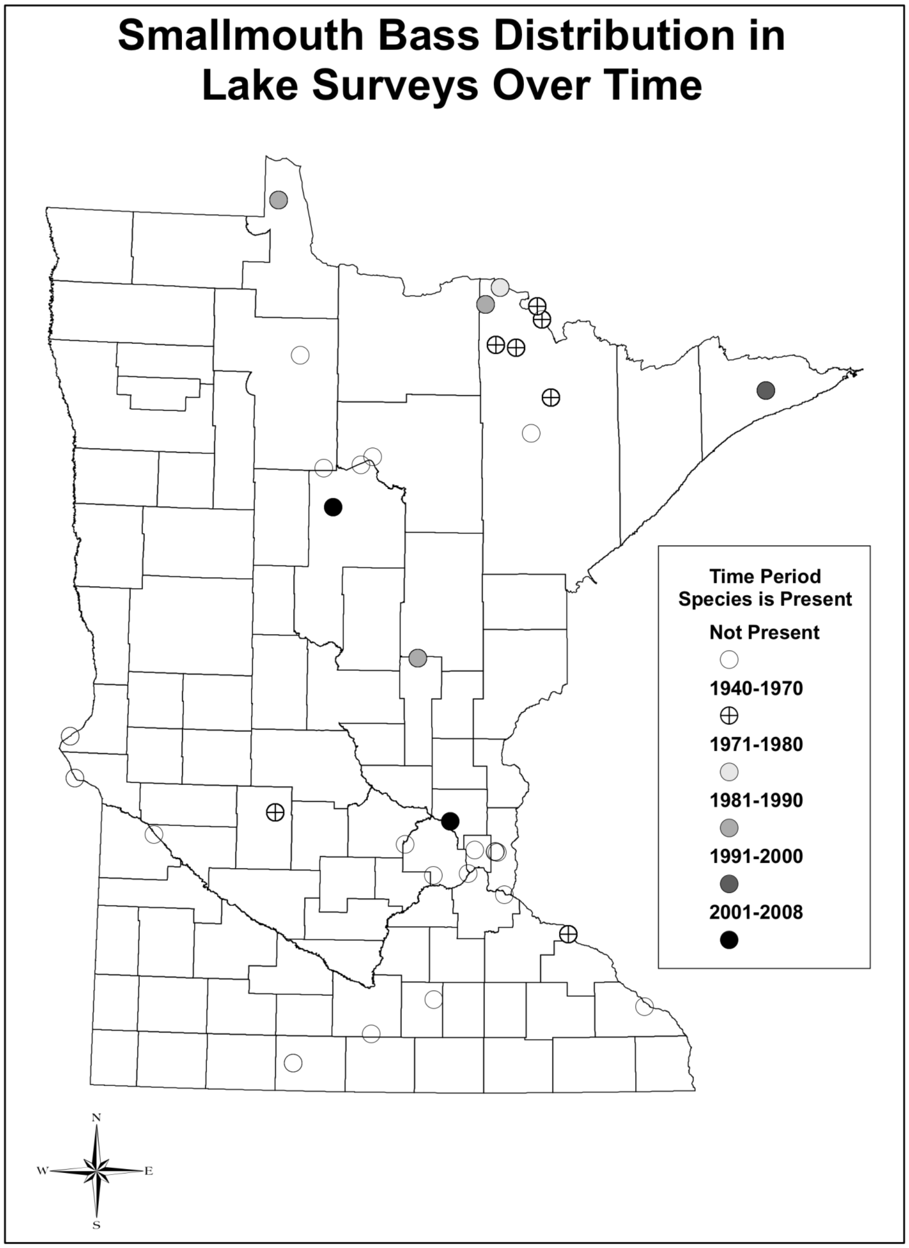
Appendix A: Maps of species distributions over time in Minnesota lake surveys.

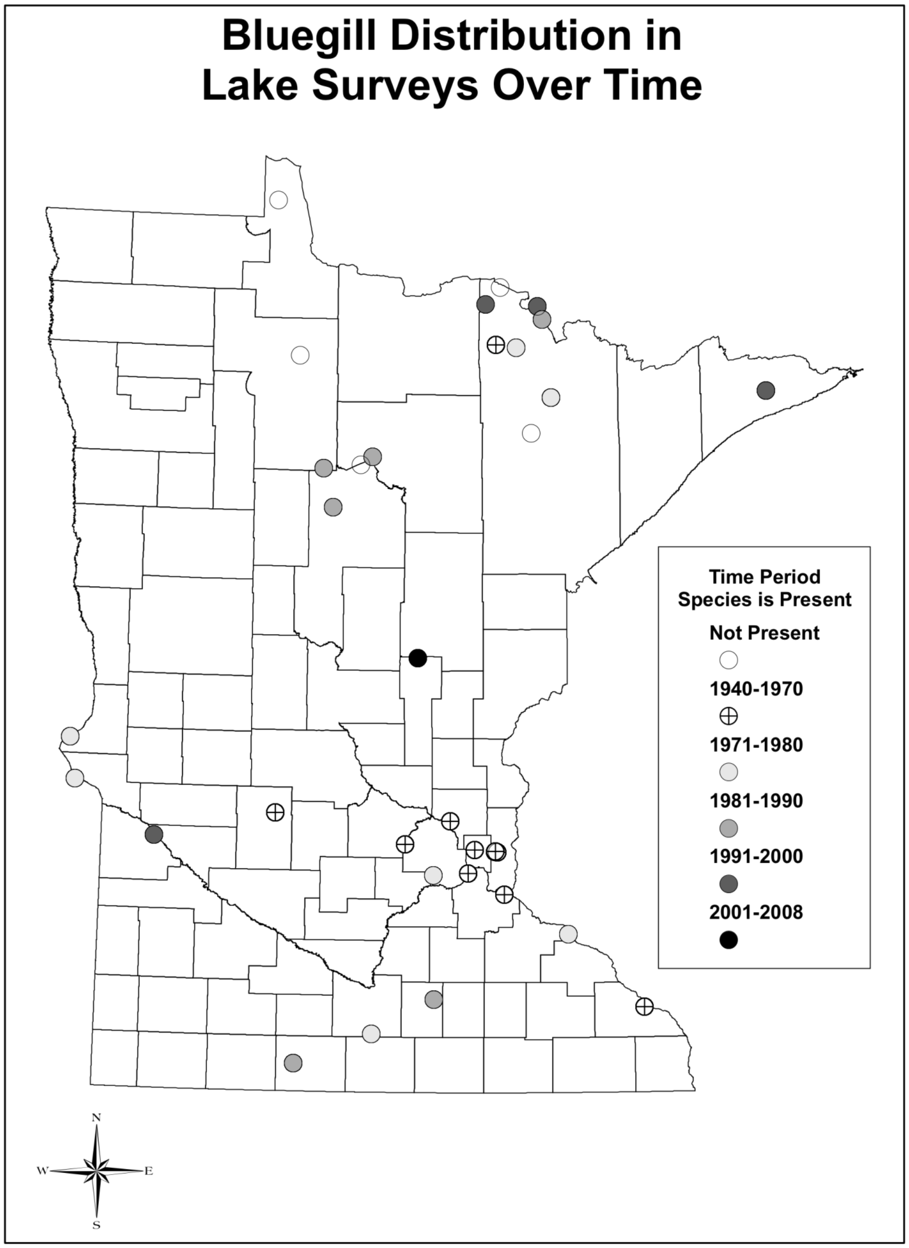
Appendix A1: Map of largemouth bass distributions



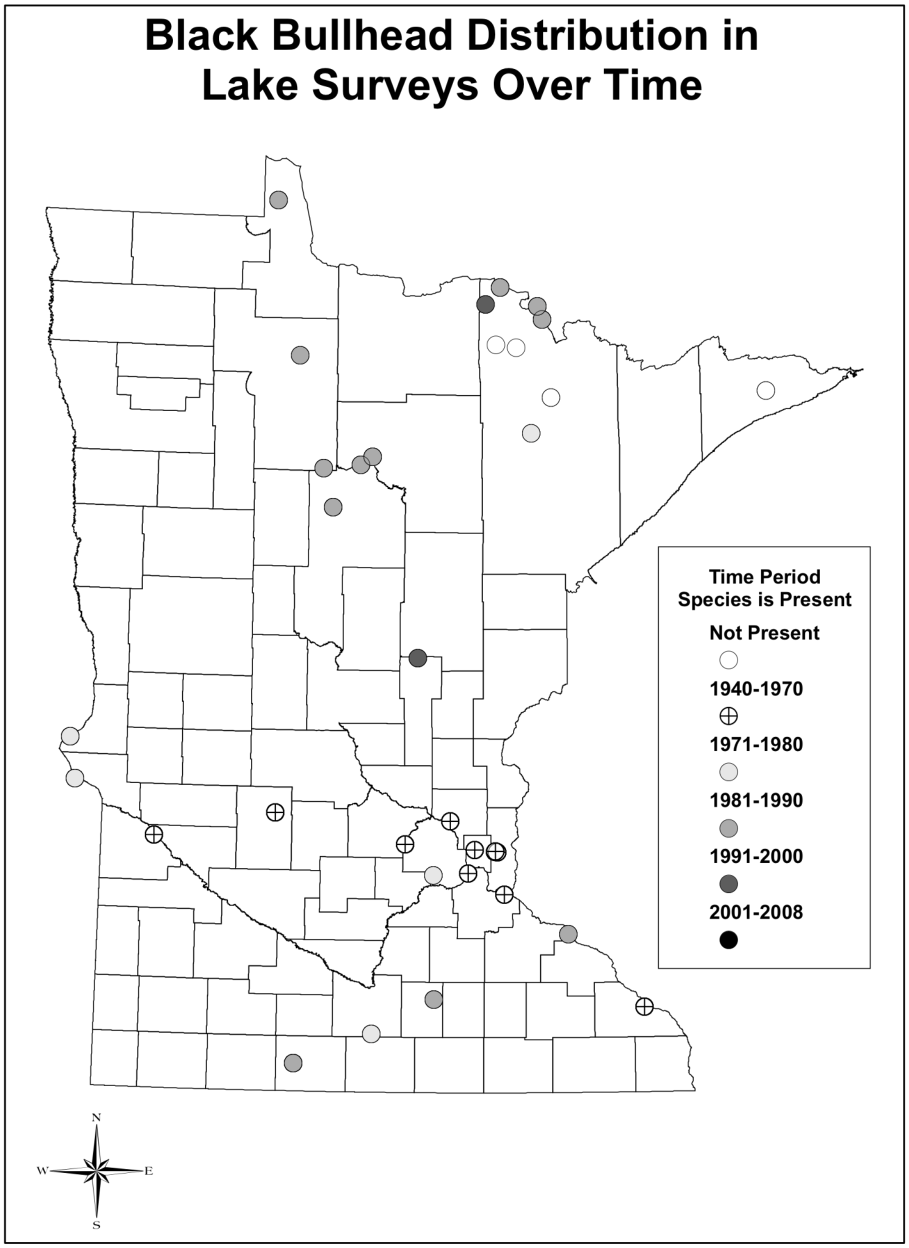
Appendix A2: Map of smallmouth bass distributions



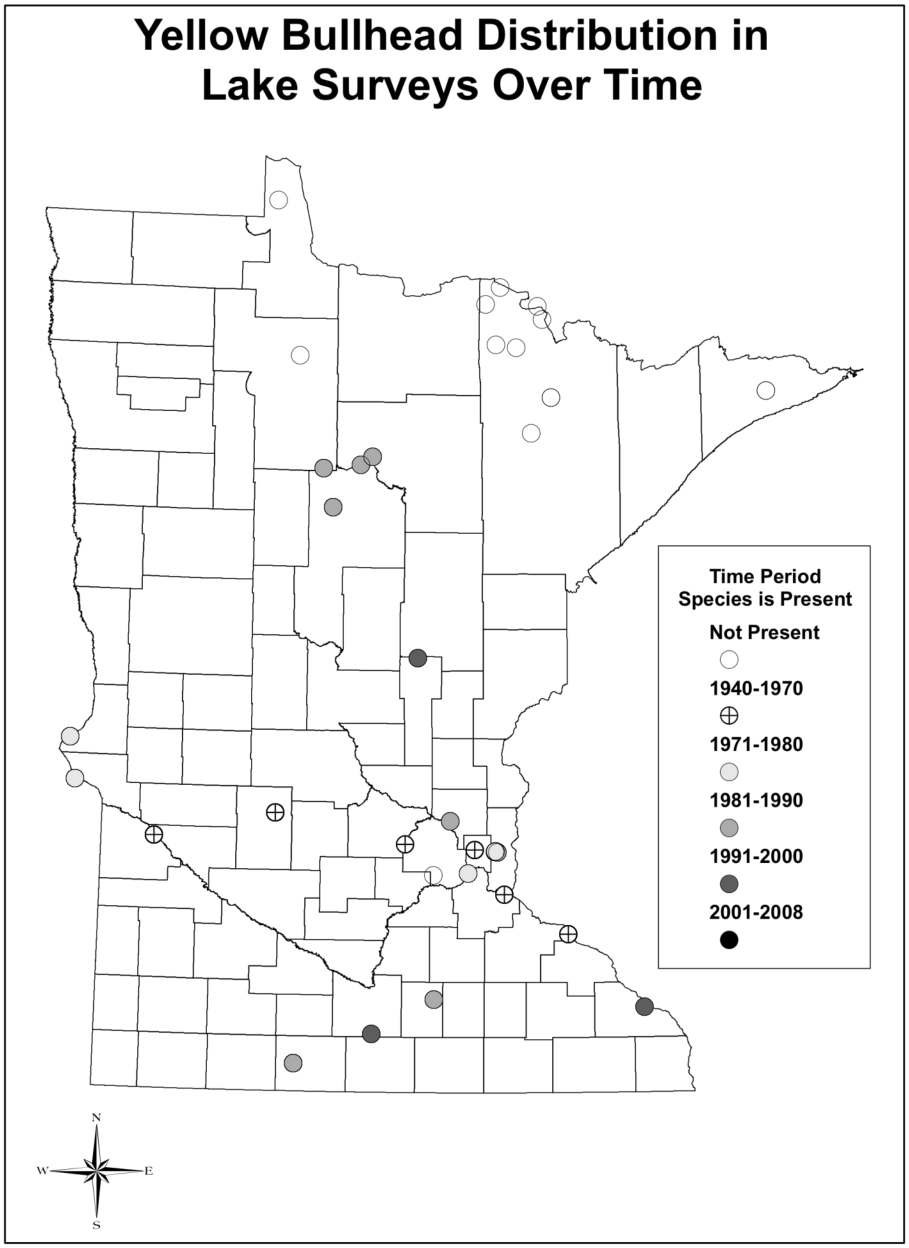
Appendix A3: Map of bluegill distributions



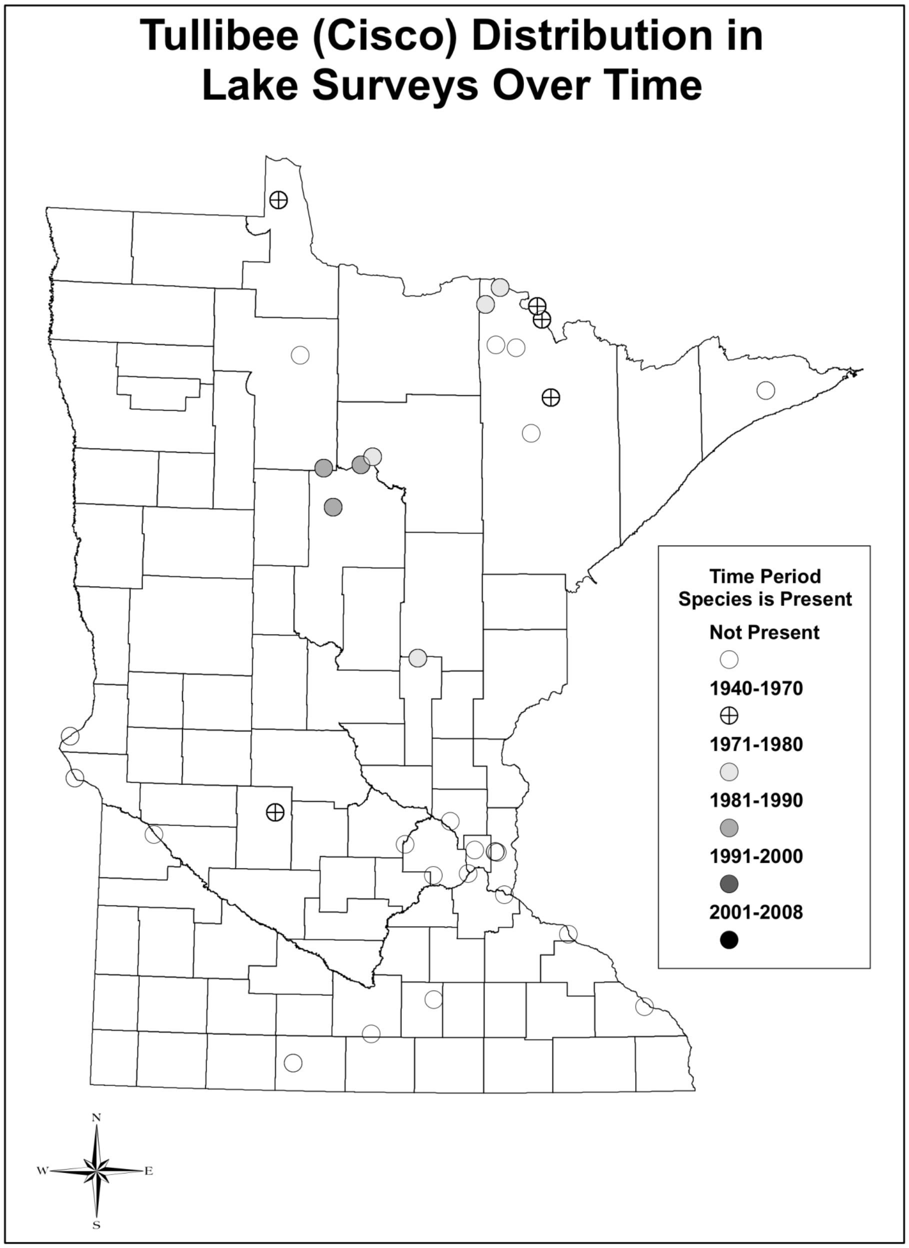
Appendix A4: Map of black bullhead distributions



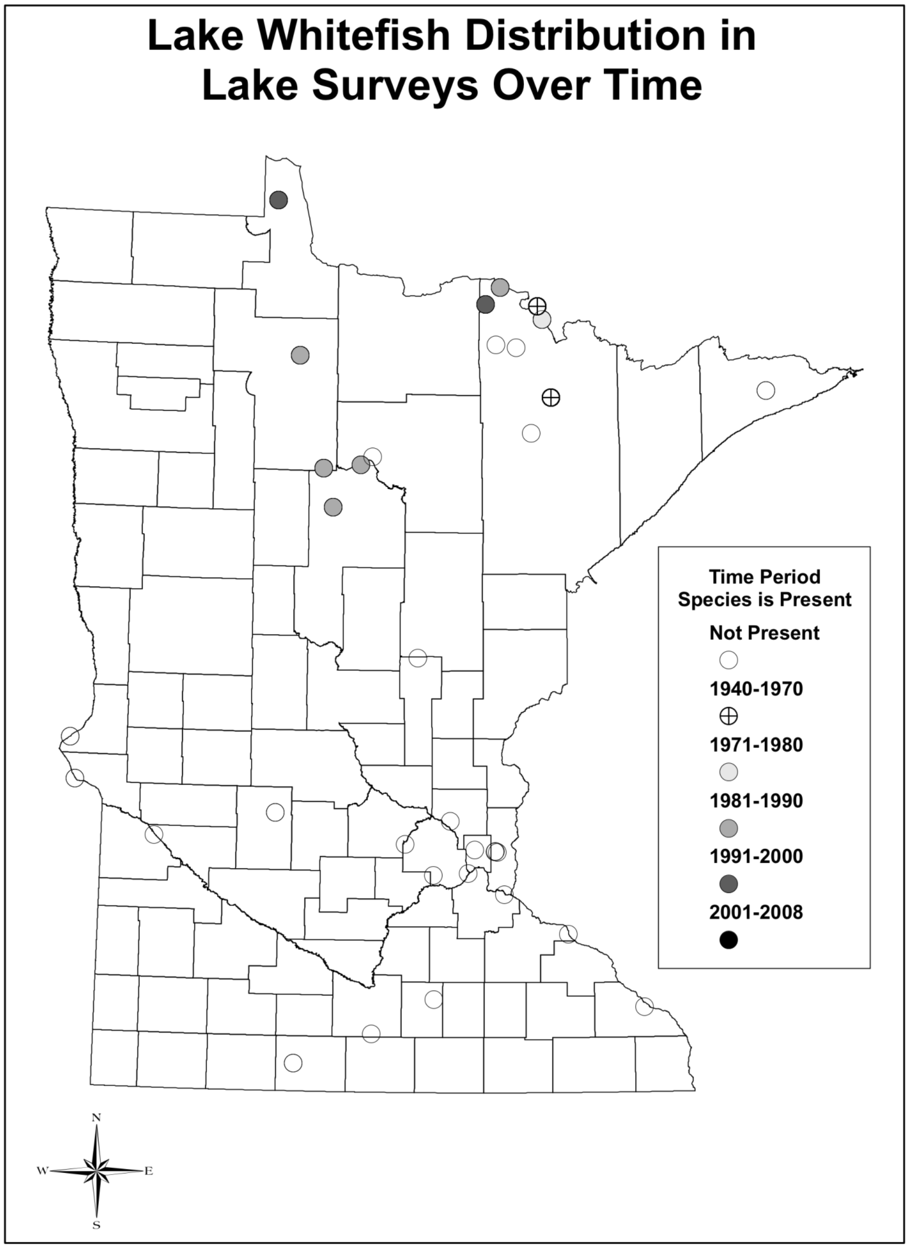
Appendix A5: Map of yellow bullhead distributions



Appendix A6: Map of tullibee distributions

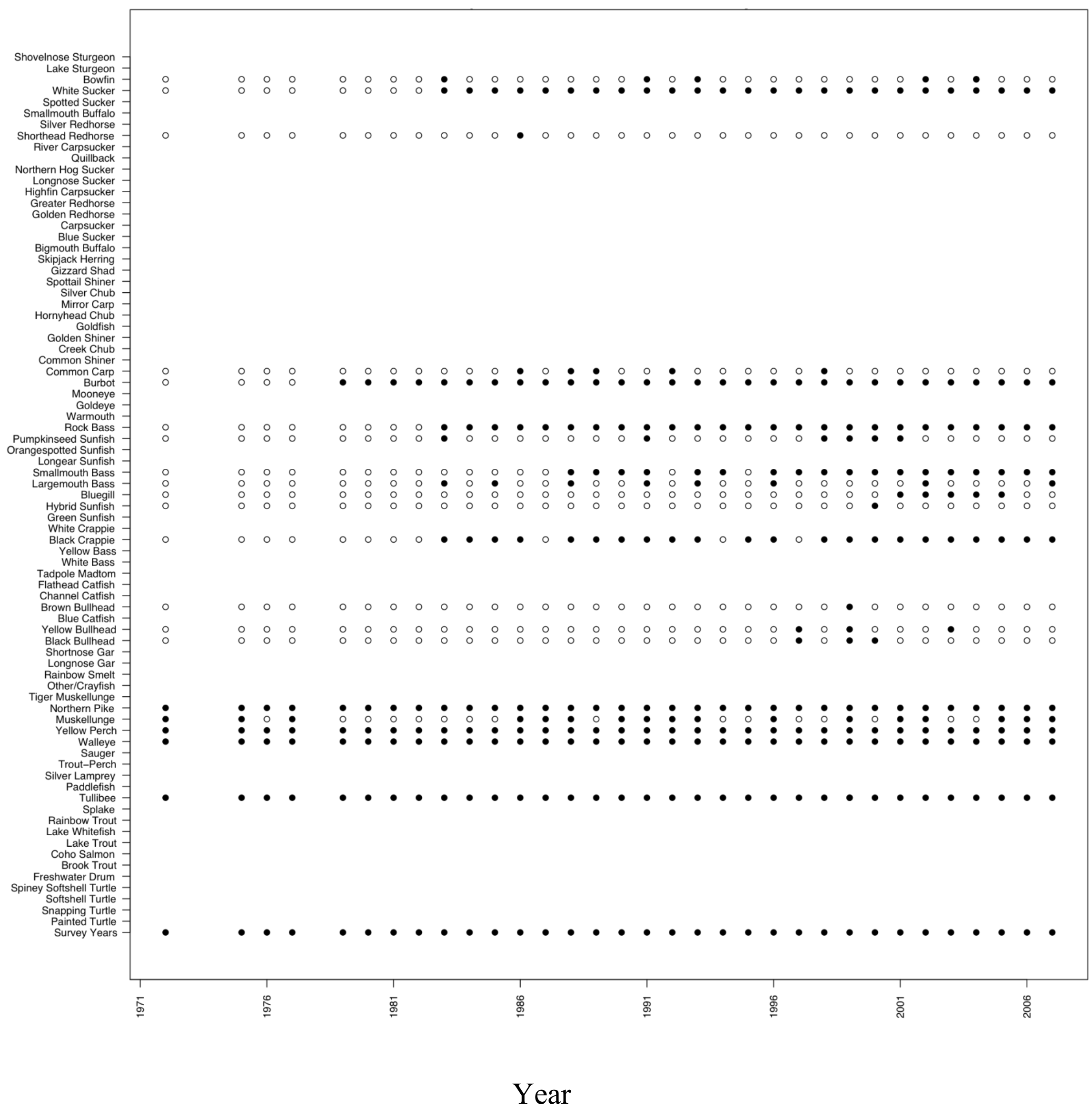


Appendix A7: Map of lake whitefish distributions

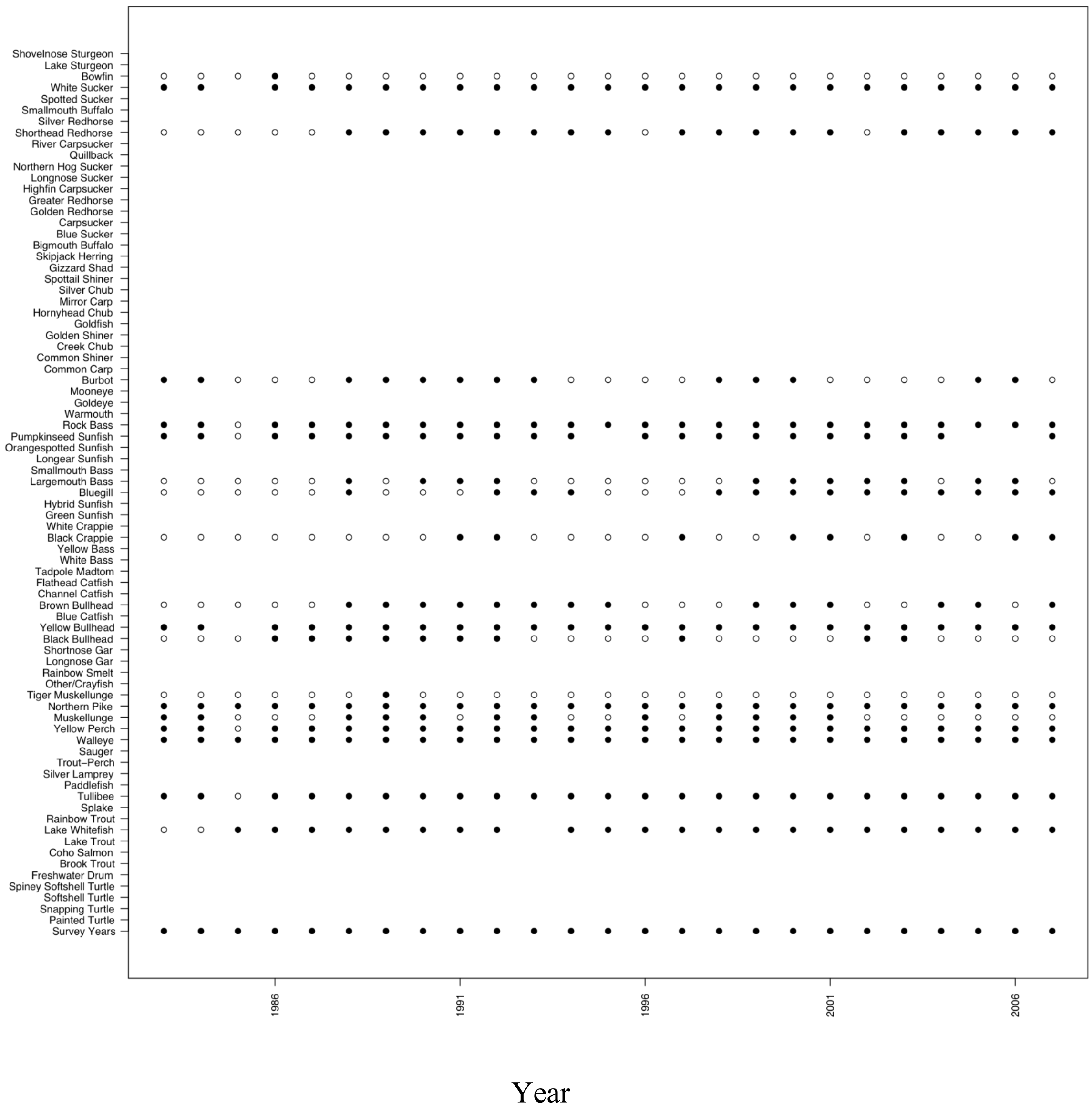


Appendix B: Example plots of species occurrence over time in Minnesota lake surveys for gillnets and for trapnets. Common names of species are listed on the y-axis. Circles represent years sampled, and solid circles indicate species presence.

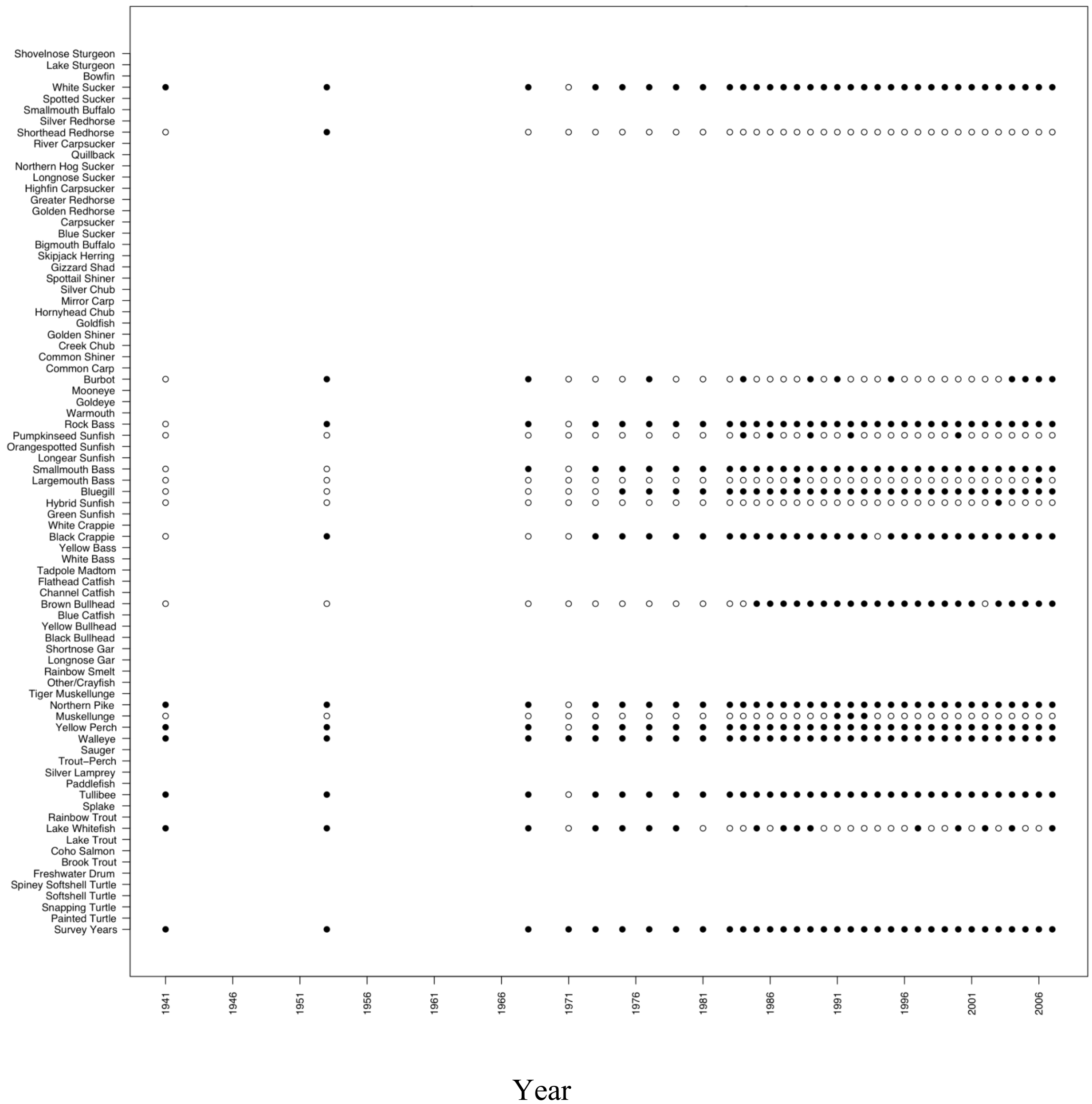
Appendix B1: Species occurrence in Mille Lacs gillnets



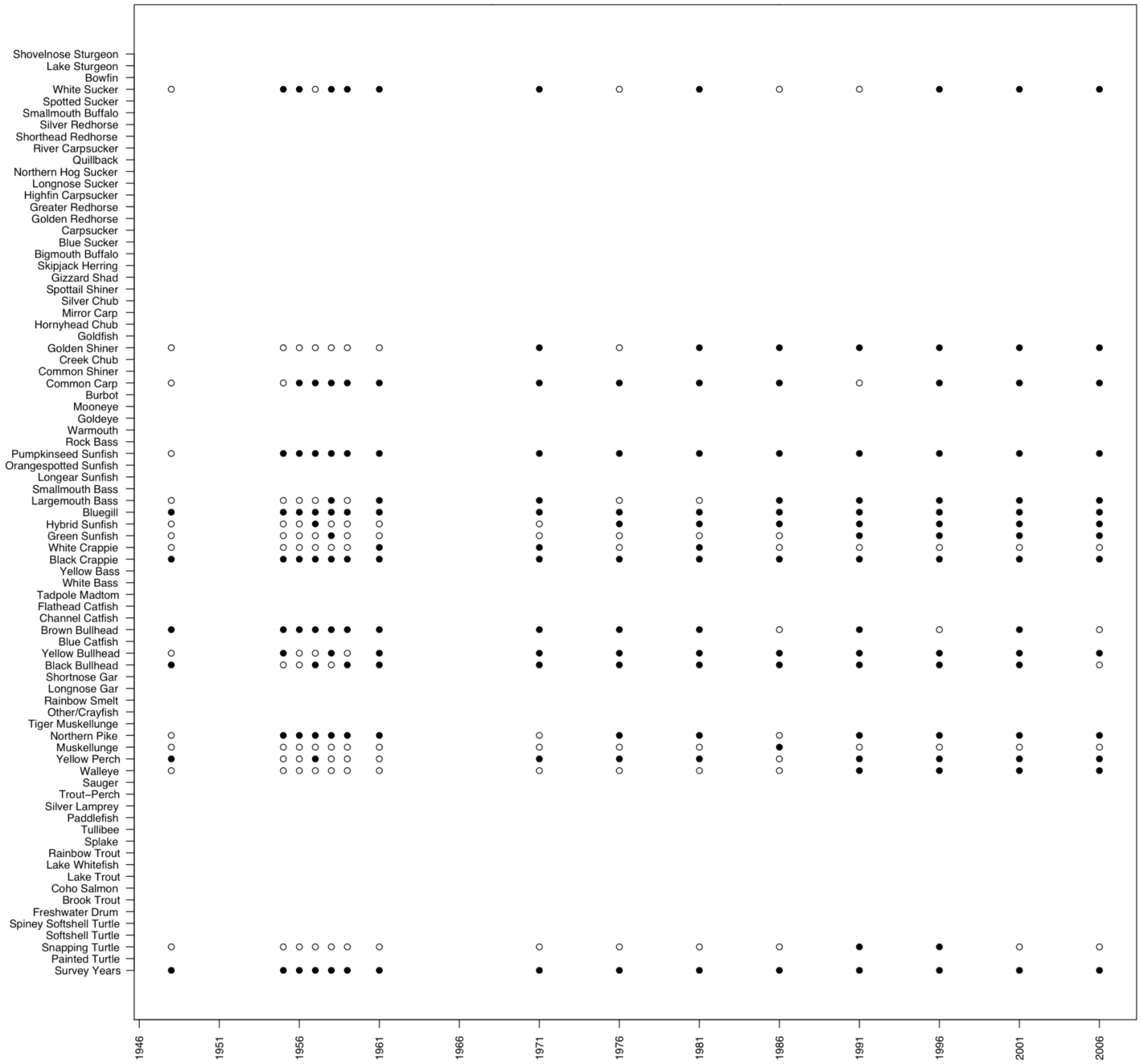
Appendix B2: Species occurrence in Cass gillnets



Appendix B3: Species occurrence in Vermilion gillnets

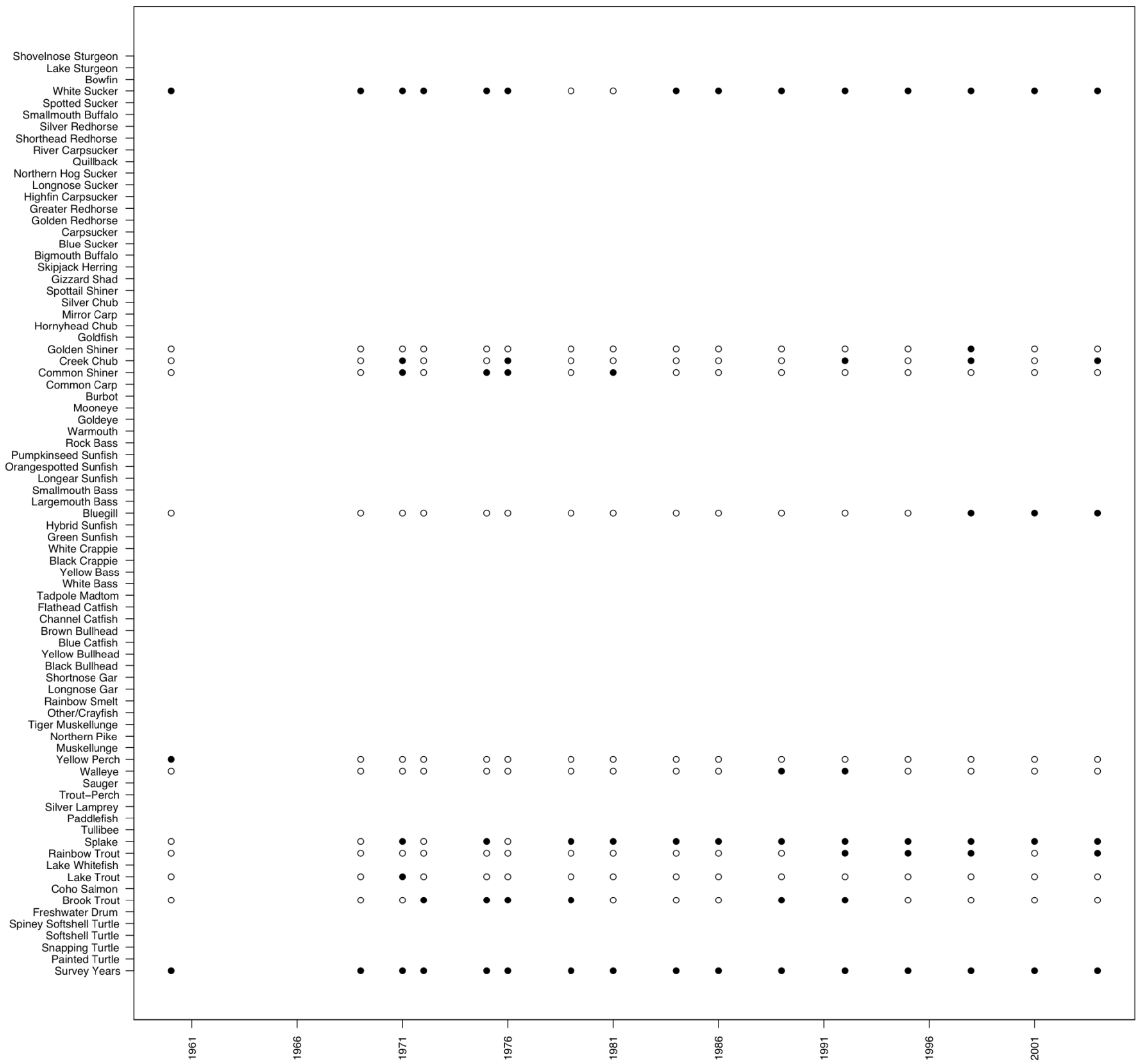


Appendix B4: Species occurrence in Owasso trapnets

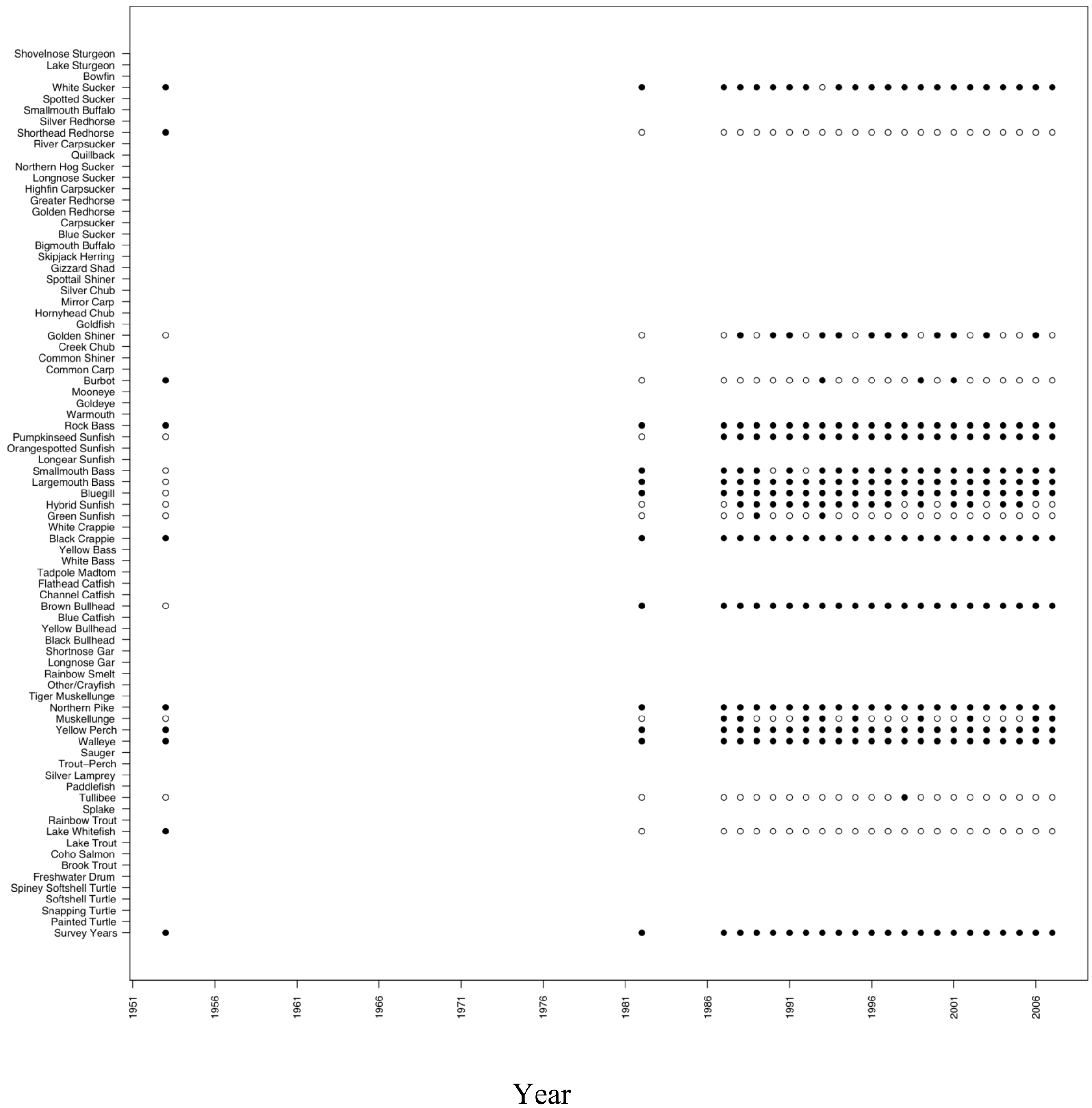


Year

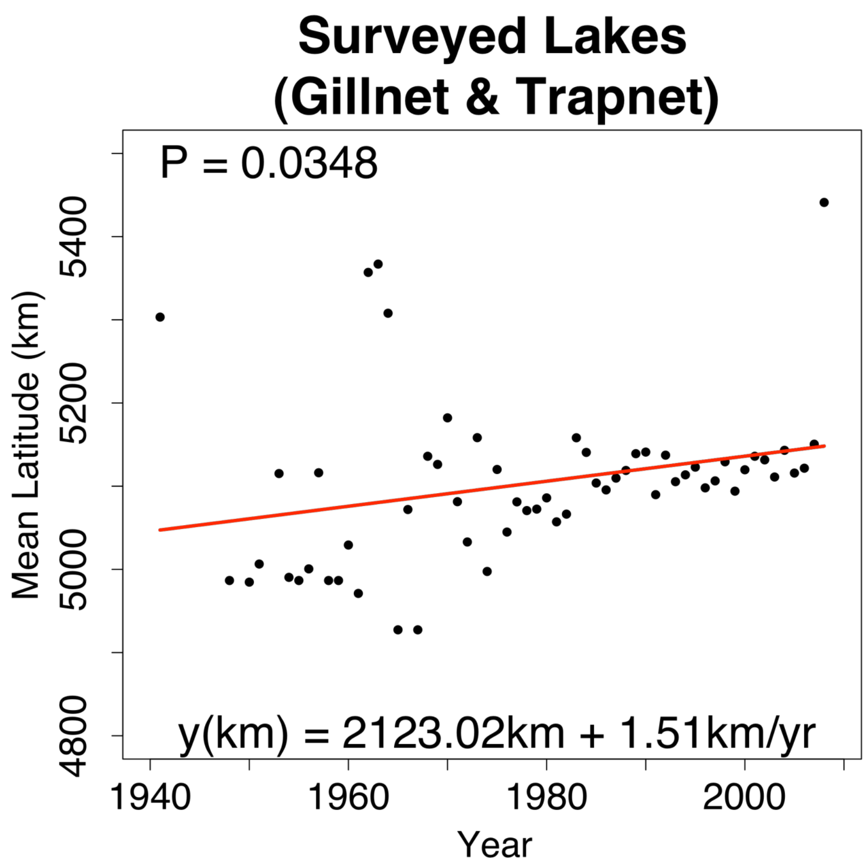
Appendix B5: Species occurrence in Pine River trapnets



Appendix B6: Species occurrence in Vermilion trapnets.



Appendix C: Regression of mean latitude (km) of lakes surveyed (gillnet and trapnet) versus year. The solid line is the regression line. Each point represents one year.



Trend analyses for species of concern: Analysis of CPUE data for walleye, cisco, and smallmouth bass 1970-2008

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[2]Center for Water and the Environment Natural Resources Research Institute, University of Minnesota Duluth

Gill net catch per unit effort (CPUE) data on walleye (2203 lakes), smallmouth bass (465), and cisco (701) from Minnesota lakes were examined for trends during the period 1970-2008. To account for repeated measures of lakes over time and correlated annual variation in CPUE among lakes, we used a linear mixed model (Venables & Ripley,2002) to estimate the temporal trend in ice out date using the *lmer* function from the lme4 package in version 2.8.1 of the R statistical program (R Development Core Team, 2008).

Methods: A mixed model has two components, a fixed effects portion and a random effects portion. In this case, the fixed effect portion was an ordinary linear regression of $\log_e$ CPUE+1 versus time:

$$CPUE_j = \beta_0 + \beta_1 * j + \varepsilon_j,$$

for j = (-19,…, 19) representing the years 1970-2008 centered by subtracting 1989, and for residual error $\varepsilon_j \sim N(0, \sigma)$. The β_1 parameter represents the intrinsic growth rate of the population (assuming CPUE is proportional to abundance); if the β_1 parameter is greater than zero, abundance is exponentially increasing, and conversely, if the β_1 parameter is less than zero, the abundance is declining over time. Because the year data were centered, the β_0 parameter represents the average $\log_e$ CPUE value over the group of lakes in 1989 (excluding year effects we discuss below).

The above regression would be a satisfactory model for a time series from a single population; however, our interest is not just in CPUE trends for a single lake, we also wanted to estimate the large scale, statewide trend in CPUE for each species. To analyze the data at that level, we use time series from many lakes (e.g., over 2200 lakes for walleye); however, the joint analysis of multiple time series introduces correlations among the observations that could potentially bias the trend estimate. We accounted for these correlations with random effects for year and lake-specific trends, giving the mixed effects model for the CPUE value in year j at lake i:

$$CPUE_{ij} = (\beta_0 + b_{0i}) + (\beta_1 + b_{1i}) * j + \psi_j + \varepsilon_{ij},$$

where b_{oi} and b_{1i} are random adjustments to the intercept and slope terms for lake i, and were assumed to be distributed as $N(0, \sigma_{L0})$ and $N(0, \sigma_{L1})$ respectively. The ψ_j term accounts for correlations in CPUE measurements within year j, and was assumed to be distributed as $N(0, \sigma_Y)$. Note that using the random effects adds 3 variance parameters to the model; an equivalent fixed effects-only model would use thousands of parameters for to account for individual lake and year effects. Though b_{0i}, b_{1i}, and ψ_j are not estimated parameters in the model, we can derive unique predictors of the individual lake regression coefficients and year effects. These predictors are denoted as BLUPs for 'best unbiased linear predictors', and can be used to determine annual deviations from the linear trend and to estimate CPUE trends in the individual lakes. For example, the terms ($\beta_0 + b_{0i}$) give the mean CPUE value for lake *i* in 1989 (excluding the random year effect), and the ($\beta_1 + b_{1i}$) terms give the trend in CPUE for lake *i*. We also used the lake BLUPs to evaluate differences in mean CPUE or trend over latitudinal, longitudinal, maximum lake depth, and lake geomorphic gradients.

Walleye (*Sander vitreus)* **results:** The overall trend estimate for walleye was slightly positive (0.0007), but was not statistically different from zero (t = 0.52; p = 0.61 on 37 df). The variation in mean $\log_e$(CPUE+1) among lakes had a standard deviation σ_{L0} = 0.65, and the standard deviation of individual lake trends was σ_{L0} = 0.019; BLUPs of individual lake trends varied from a 5% per year decline to a 5% per year increase. Of the 2203 lakes with walleye gillnet captures 10.1% (223 lakes) had per year declines greater than 1%, while only 12.9% (283 lakes) had per year increased greater than 1%; the remainder of the lakes (77%) had changes less than 1%, which could not be distinguished from no or flat trend. The annual variation about the fixed trend (i.e., random year effects) had a standard deviation σ_Y = 0.074 (see figure below for plot of fixed trend along with random year effects).

Random effects:			
Groups Name	Variance	Std.Dev.	Corr
DOWLKNUM (Intercept)	0.4248226	0.651784	
YR	0.00036685	0.019153	-0.013
YR (Intercept)	0.00546446	0.073922	
Residual	0.25718614	0.507135	
Number of obs: 9611, groups: DOWLKNUM, 2203; Yr, 39			

Fixed effects:			
	Estimate	Std. Error	t value
(Intercept)	1.380288	0.019778	69.79
YR	0.000708	0.001372	0.52

Figure XX. Average CPUE trend and annual deviations for walleye CPUE in 2203 MN lakes.

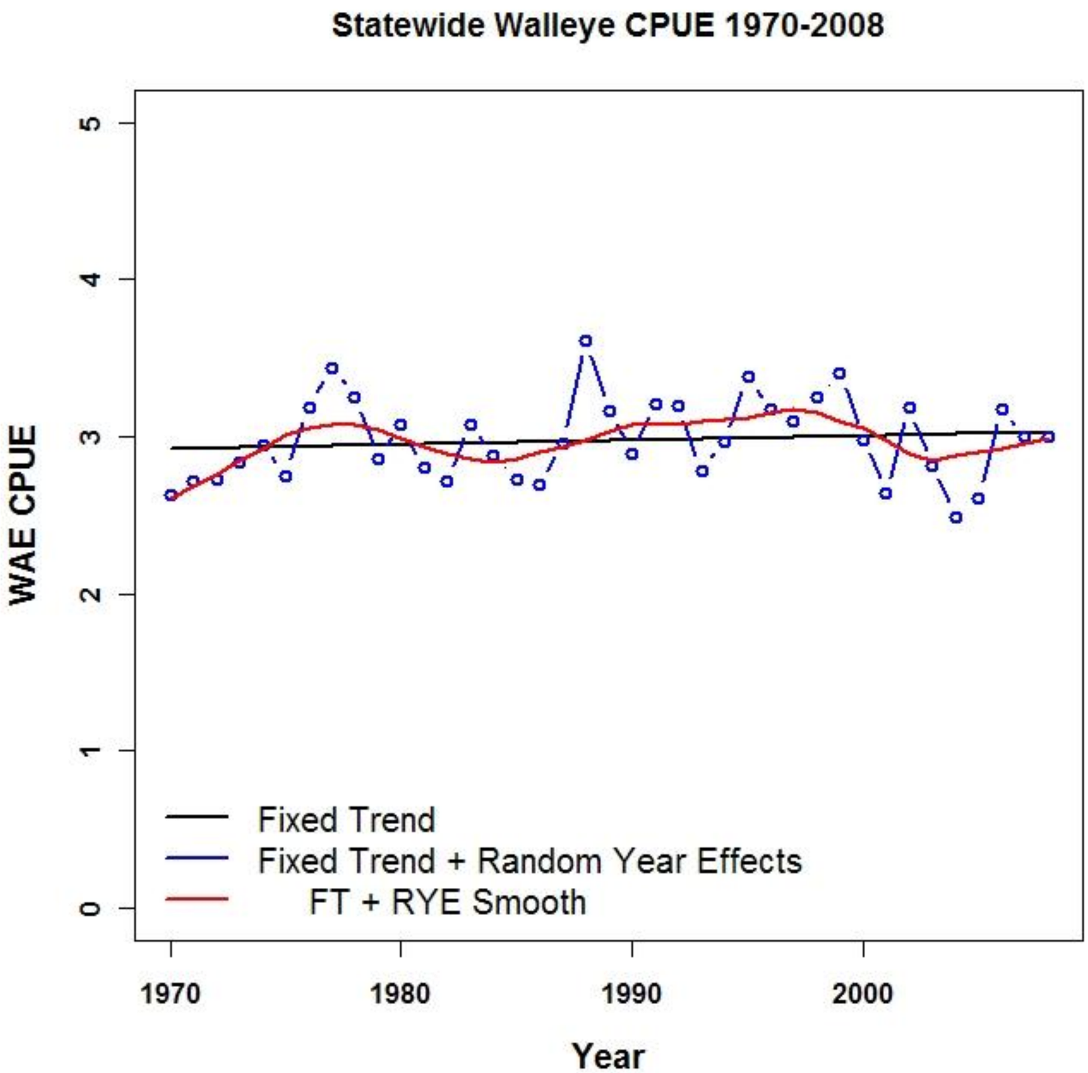
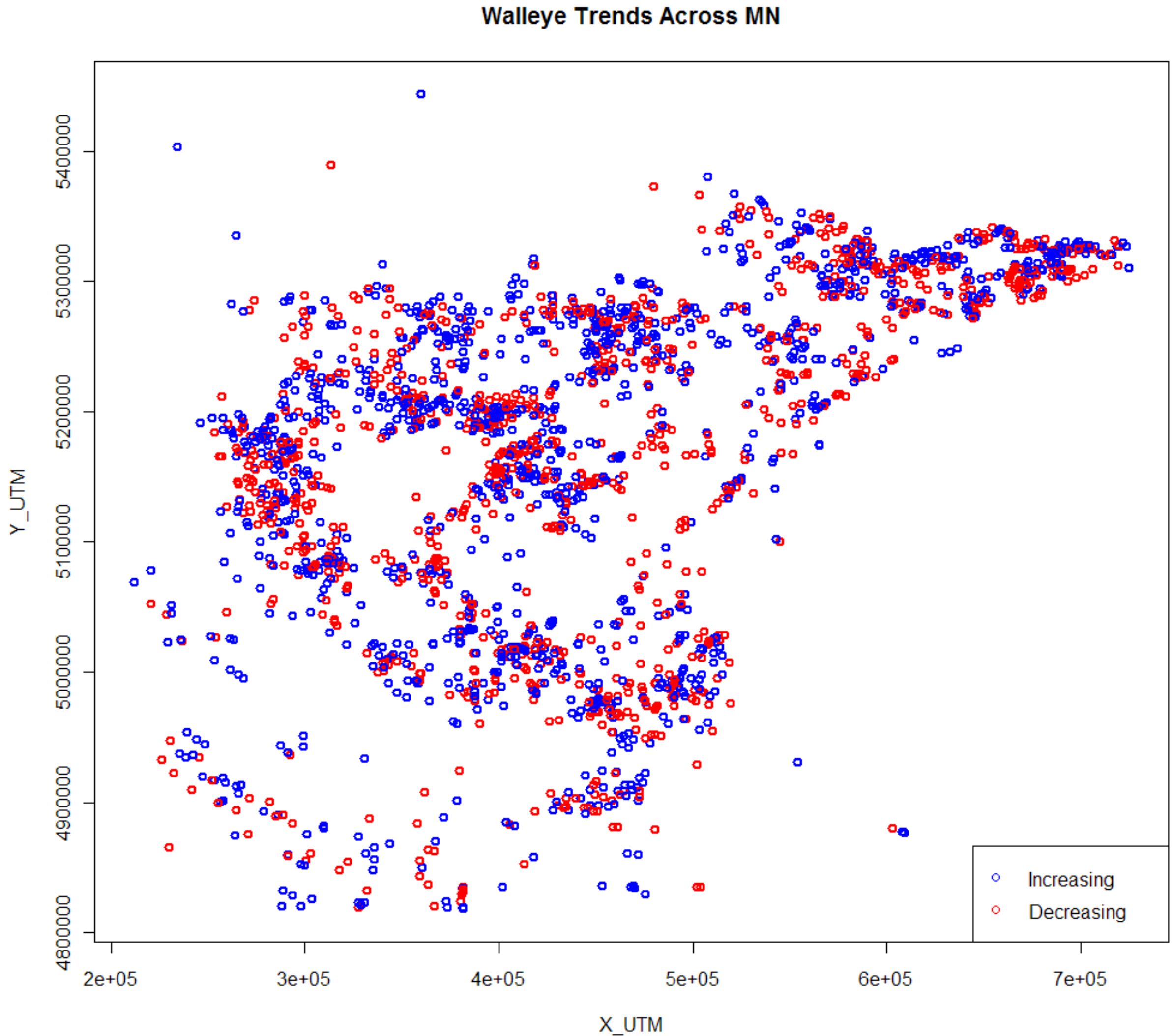


Figure XX. Spatial distribution of increasing and decreasing walleye lakes.



We did not detect a strong spatial pattern for increasing versus decreasing lakes.

Figure XXX. Lake specific BLUPs of intercept and slope versus UTM coordinates. These reflect individual lake differences in CPUE trends. Blue dashed lines are fixed intercept and trend values, red line is a non-parametric lowess smooth of the BLUP values. Intercept BLUPs reflect spatial differences in mean CPUE values. The slope BLUPs suggest that trends in walleye CPUE are similar across the state.

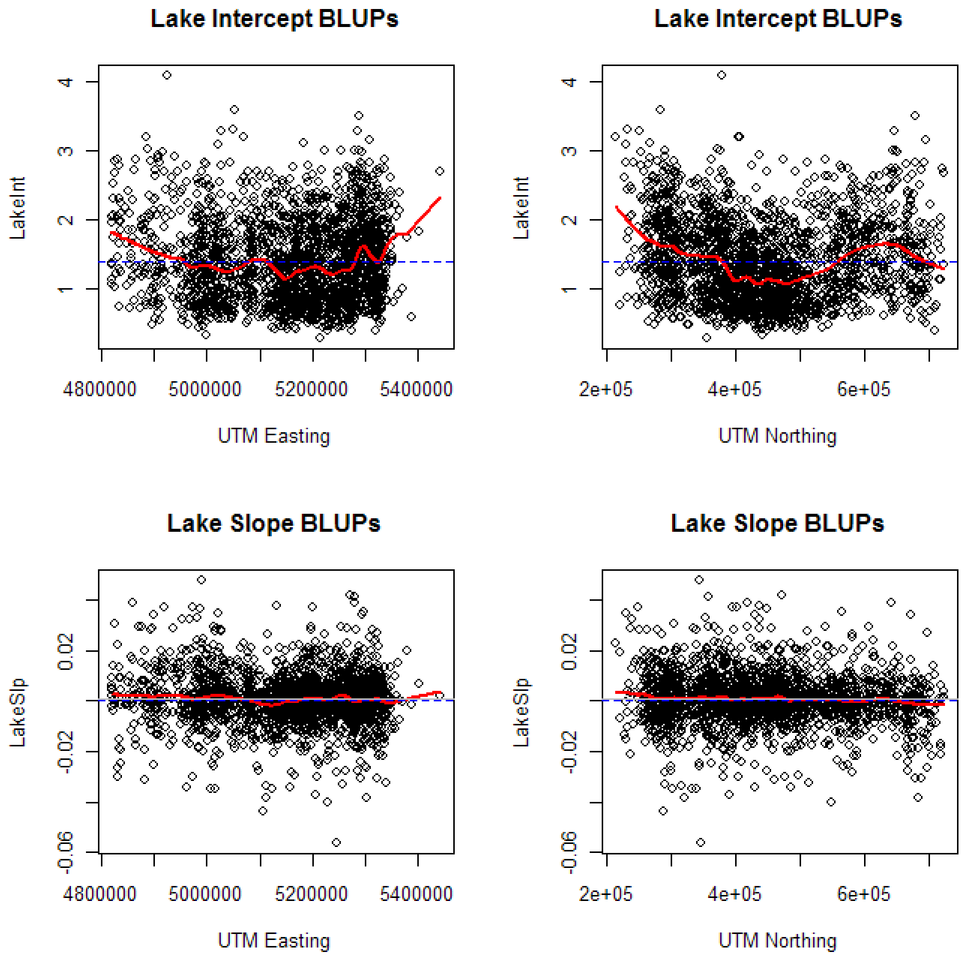
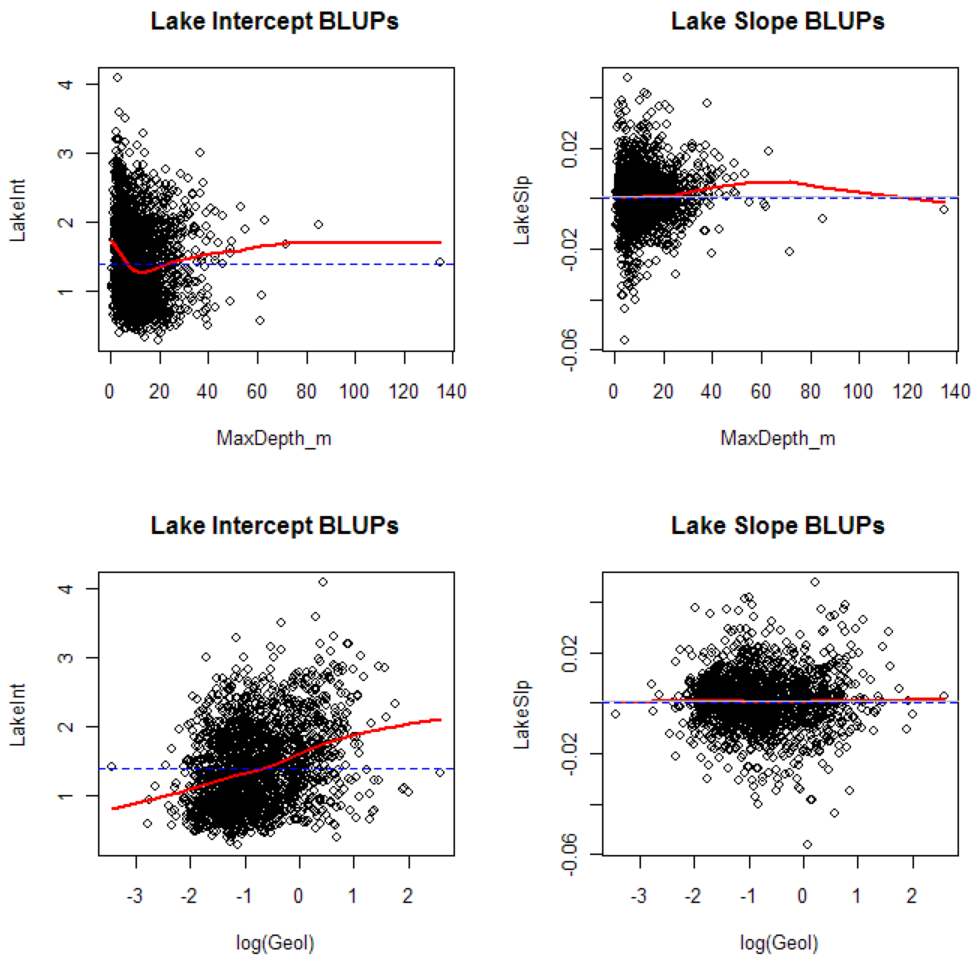


Figure XXX. Lake intercept and slope BLUPs versus geomorphic measurements. Walleye CPUE tended to be higher in shallower lakes and those with larger geomorphic index values (GeoI = area$^{.25}$/maximum depth). Temporal trends in walleye CPUE are relatively similar.



Cisco (*Corregonus species*) results: The overall trend estimate for cisco was significantly negative (-0.014, t = -5.28, p < .0001 on 37 df), indicating about a 1.5% per year decline since 1970. The variation in mean $\log_e$(CPUE+1) among lakes had a standard deviation σ_{L0} = 0.73, and the standard deviation of individual lake trends was σ_{L0} = 0.025; BLUPs of individual lake trends varied from a 5% per year decline to a 5% per year increase. Of the 701 lakes with cisco gillnet captures 63.9% (448 lakes) had per year declines greater than 1%, while only 4.4% (31 lakes) had per year increased greater than 1%. The annual variation about the fixed trend (i.e., random year effects) had a standard deviation σ_Y = 0.13 (see figure below for plot of fixed trend along with random year effects).

Random effects:			
Groups Name	Variance	Std.Dev.	Corr
DOWLKNUM (Intercept)	0.533142	0.73017	
YR	0.00063806	0.02526	-0.108
YR (Intercept)	0.01736128	0.13176	
Residual	0.37600301	0.61319	
Number of obs: 3119, groups: DOWLKNUM, 70; Yr, 39			

Fixed effects:		
Estimate	Std. Error	t value
(Intercept) 1.358317	0.038191	35.57
YR -0.013938	0.002641	-5.28

Figure XX. Average CPUE trend and annual deviations for cisco CPUE in 701 MN lakes.

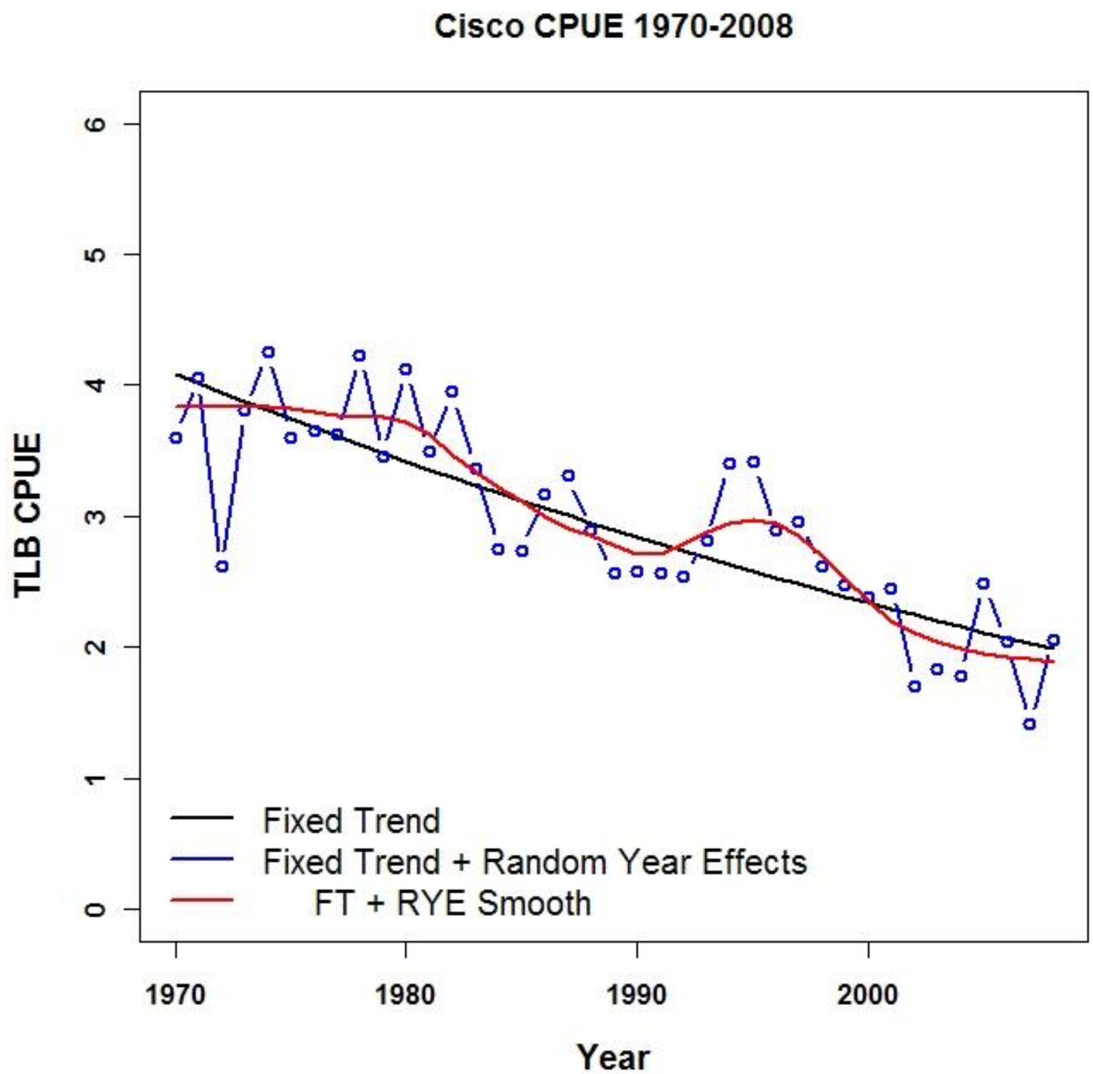
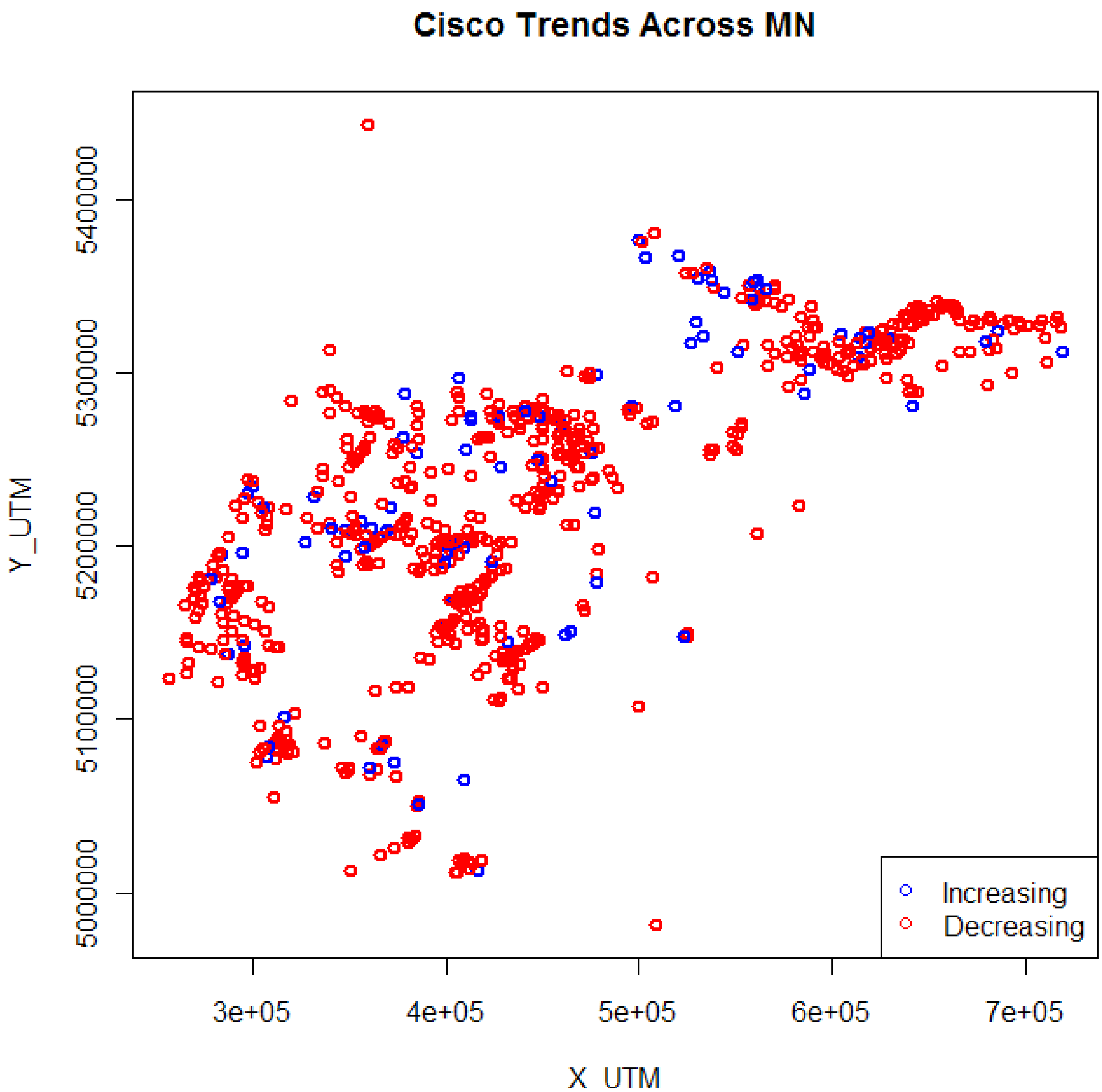


Figure XX. Spatial distribution of increasing and decreasing cisco lakes.



We did not detect a strong spatial pattern for increasing versus decreasing lakes. Nor did we detect any geomorphic relationship to increasing versus decreasing lakes or strength of decreasing trends.

Figure XXX. Lake specific BLUPs of intercept and slope versus UTM coordinates. These reflect individual lake differences in CPUE trends. Blue dashed lines are fixed intercept and trend values, red line is a non-parametric lowess smooth of the BLUP values. Intercept BLUPs reflect spatial differences in mean CPUE values (e.g., cisco CPUE tends to be higher in northeastern lakes). The slope BLUPs suggest that trends in cisco CPUE are similar across the state.

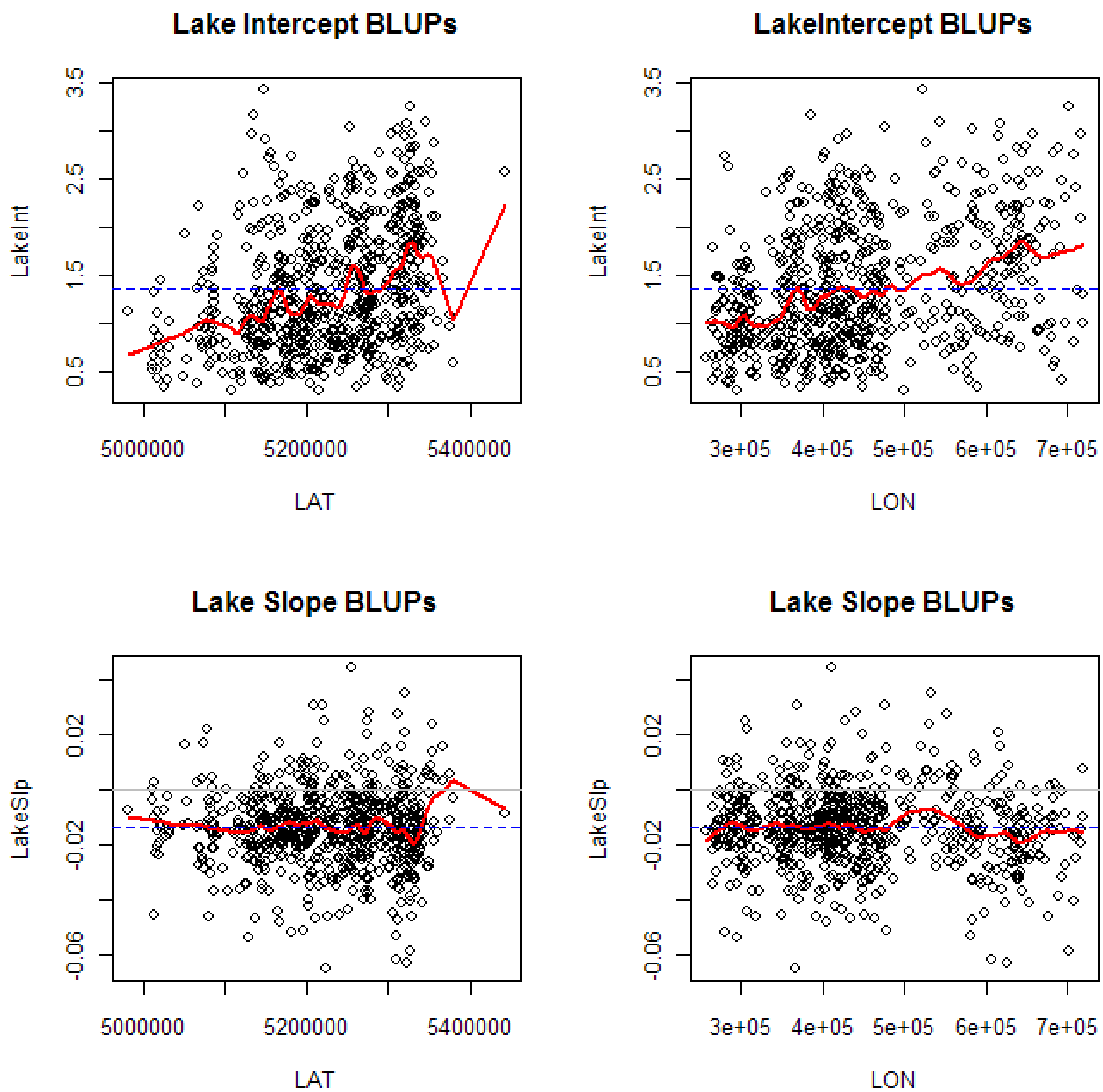
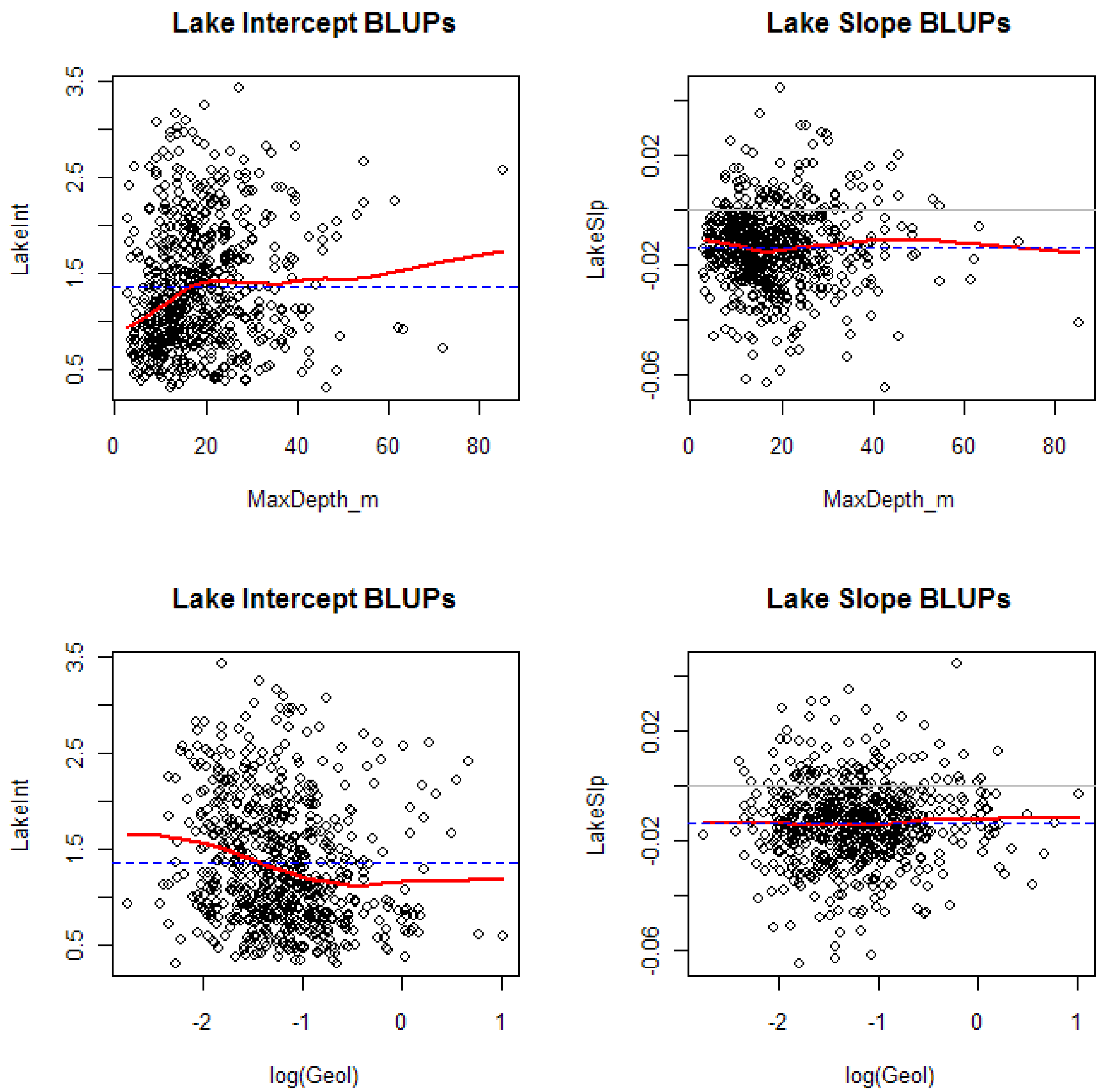


Figure XXX. Lake intercept and slope BLUPs versus geomorphic measurements. Cisco CPUE tended to be higher in deeper lakes and those with lower geomorphic index values (GeoI = area$^{.25}$/maximum depth). Temporal trends in cisco CPUE are relatively similar over the geomorphic gradients.



Smallmouth Bass (*Micropterus dolomieu*) results: The overall trend estimate for smallmouth bass was slightly positive (0.0006), but was not statistically different from zero (*t* = 0.35; *p* = 0.73 on 37 df). The variation in mean $\log_e$(CPUE+1) among lakes had a standard deviation σ_{L0} = 0.40, and the standard deviation of individual lake trends was σ_{L0} = 0.016; BLUPs of individual lake trends varied from a 4% per year decline to a 3.5% per year increase. Of the 465 lakes with smallmouth bass gillnet captures 6.7% (31 lakes) had per year declines greater than 1%, while 9.3% (43 lakes) had per year increased greater than 1%; the remainder of the lakes (84%) had changes less than 1%, which could not be distinguished from no or flat trend. The annual variation about the fixed trend (i.e., random year effects) had a standard deviation σ_Y = 0.067 (see figure below for plot of fixed trend along with random year effects).

Random effects:			
Groups Name	Variance	Std.Dev.	Corr
DOWLKNUM (Intercept)	0.158681	0.398348	
YR	0.000251	0.015834	-0.095
YR (Intercept)	0.004548	0.067437	
Residual	0.092956	0.304887	
Number of obs: 1727, groups: DOWLKNUM, 65; YR, 39			

Fixed effects:			
	Estimate	Std. Error	t value
(Intercept)	0.580761	0.024526	23.679
YR	0.000596	0.001699	0.351

Figure XX. Average CPUE trend and annual deviations for smallmouth CPUE in 465 MN lakes.

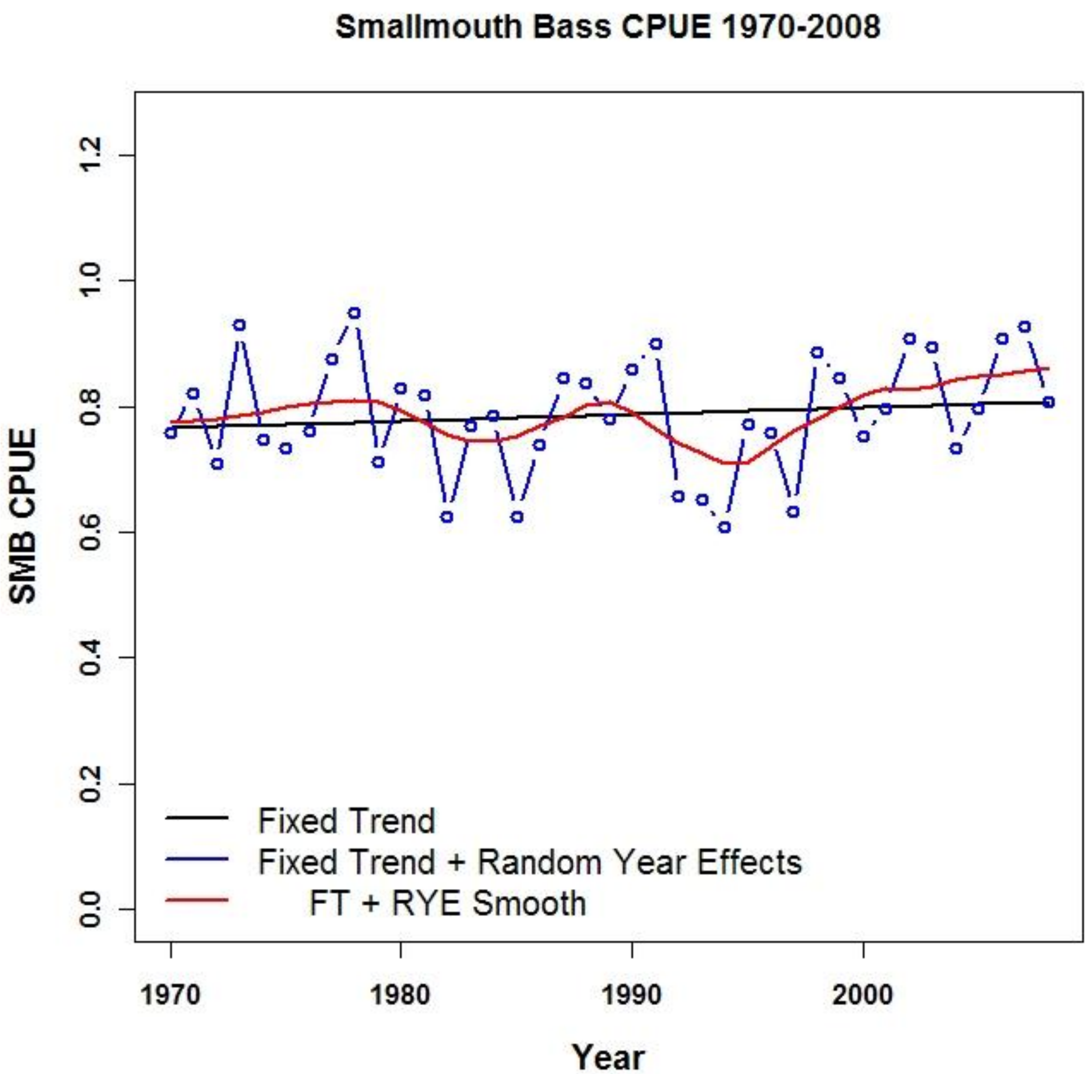


Figure XX. Spatial distribution of lakes with increasing and decreasing smallmouth bass CPUE.

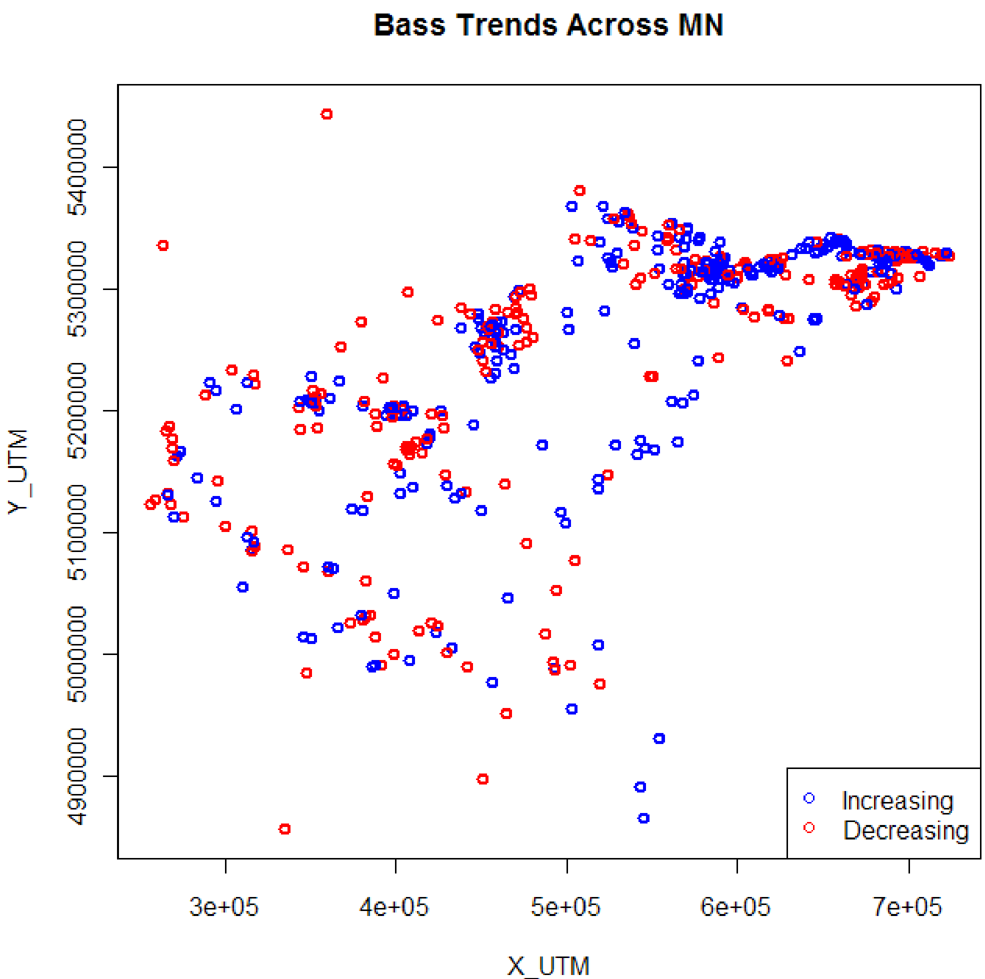


Figure XXX. Lake specific BLUPs of intercept and slope versus UTM coordinates. These reflect individual lake differences in smallmouth CPUE trends. Blue dashed lines are fixed intercept and trend values, red line is a non-parametric lowess smooth of the BLUP values. Intercept BLUPs reflect spatial differences in mean CPUE value. The slope BLUPs suggest that trends in smallmouth CPUE are similar across the state.

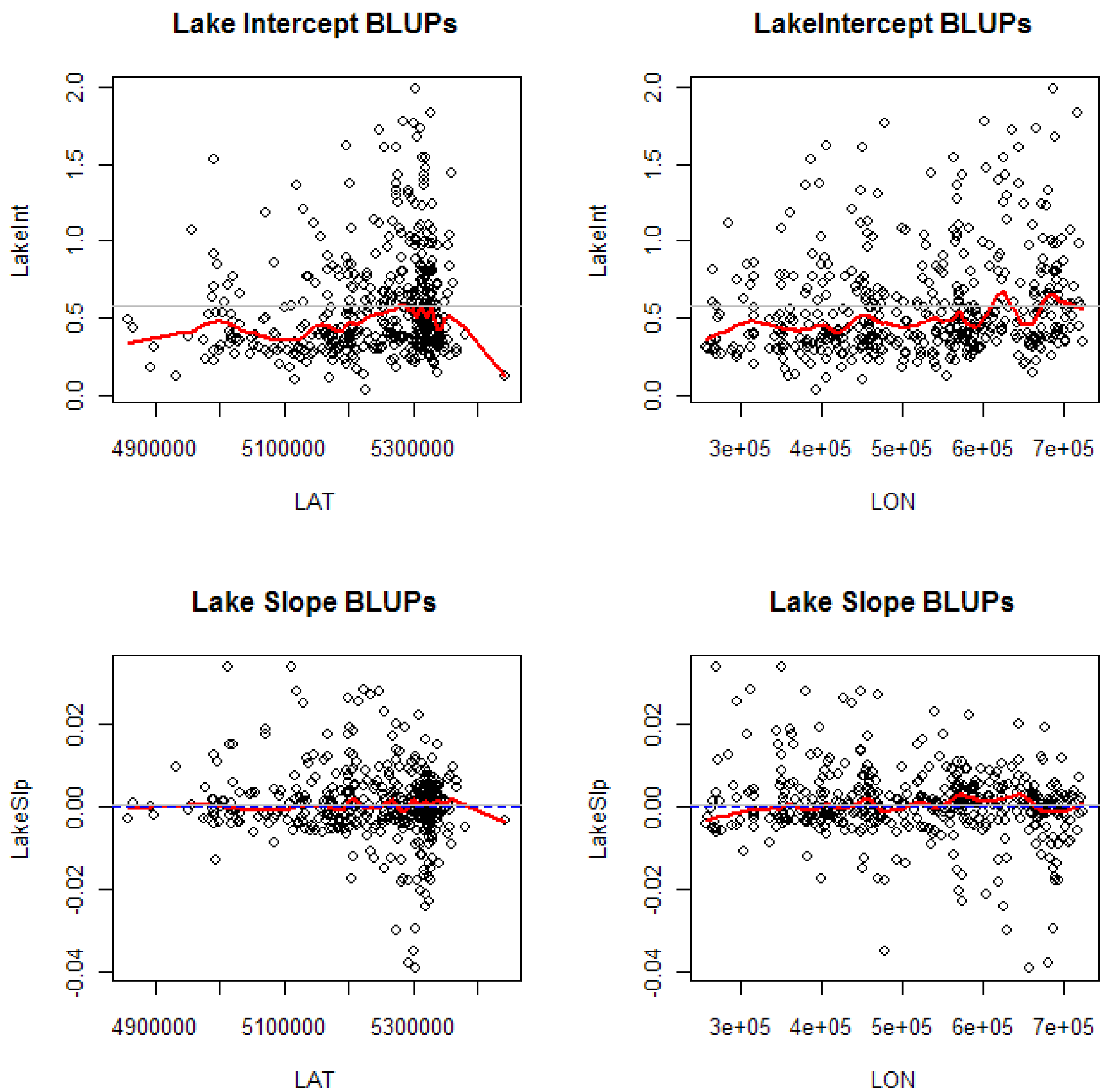
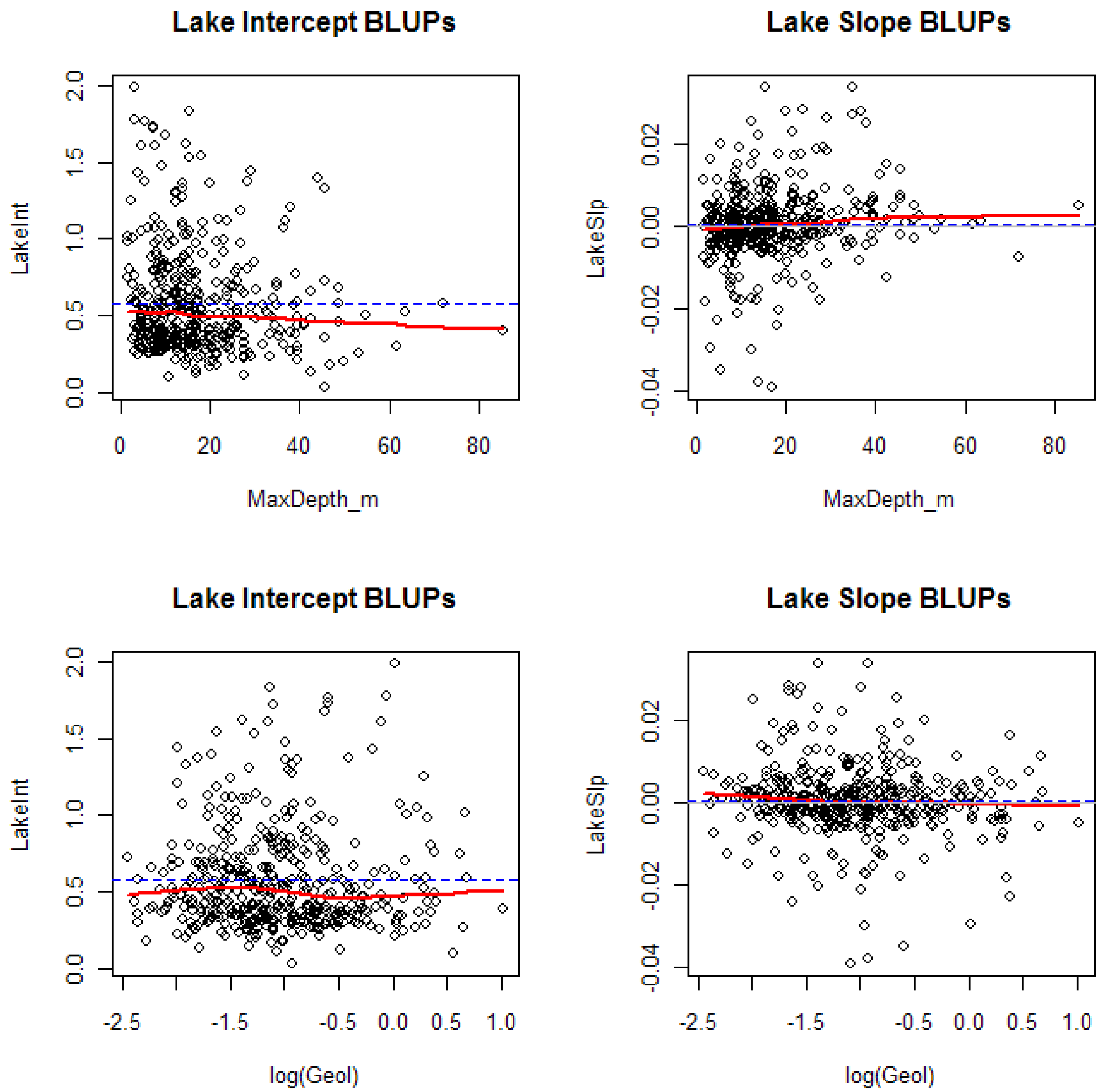


Figure XXX. Lake intercept and slope BLUPs versus geomorphic measurements. Smallmouth CPUE and its trend tended to be similar over the geomorphic gradients.



Water quality responses during historical climate regimes (*scenarios*)
To detect the effects of extreme seasonal weather on water quality we used the water quality data and climate regimes developed as part of Result 2 of this project (summarized in Appendix D and reported in the LCCMR2005 project: Impacts on Minnesota's aquatic resources from climate change Phase I - W-12).

Methods: We used the following water quality indicators to test for responses in years with temperatures and precipitation outside of the 'normal' range: secchi depth, surface temperature, specific electrical conductivity (EC25), thermocline depth, trophic state index (TSI: the mean of TSI-secchi, TSI-chlorophyll *a,* and TSI-phosphorus), surface levels of chlorophyll-*a*, and surface levels of total phosphorus (TP). Surface measurements which included measurements from zero to two meters deep were averaged across these depths, or were collected from a two meter tube sampler.

Each variable was tested independently over 3 different *extreme* weather scenarios developed in Result 2 of this project: warm and dry, warm and wet, or cold and wet. A region was considered 'warm' for a particular year if the temperature of that region for that year, or the portion of year used in the analysis (i.e. Jun-Sep) was greater than 1.5 standard deviations above the mean temperature for that region over all years. Similarly a year was considered to be 'cold' for a region when the temperature for that year or portion of year was 1.5 standard deviations below the mean temperature. 'Wet' and 'dry' were identified with the same process using precipitation for the year or portion of year and 1.5 standard deviations above or below the mean precipitation levels, respectively. Only years that were extreme in both temperature and precipitation were included in these analyses: warm and dry, warm and wet, or cold and wet. During the 100 year weather data set, simultaneous 'wet and warm' and also 'cold and dry' scenarios were uncommon, especially during the ice-free growing season and summer when the vast majority of lake data is collected. Cold-dry was not used in these analyses due to the lack of years with water quality data that would be classified as 'cold and dry.' A lake's value for a particular water quality parameter for an extreme climate was the average of the lake's values for that variable over all years that were considered within that combination of extreme climate for which there were data.

The effect that extreme climate potentially had on water quality was tested using two methods. Lakes that had water quality data for any two types of extreme climate were compared using a Mann-Wilcox paired test (McLeod 2009). This paired comparison analysis was completed for all lakes statewide as well as for lakes considered shallow across the state using a combination of lakes identified by MN DNR Wildlife (Shallow Lakes Program, http://www.dnr.state.mn.us/wildlife/shallowlakes/index.html) and Minnesota Pollution Control Agency.

Shallow lakes were further examined on a regional basis, using Minnesota's nine climate divisions (www.esrl.noaa.gov/psd/data/usclimdivs/data/map.html#Minnesota) to group lakes geographically. This allowed lakes to be pooled by assuming that the sample set included lakes fairly homogeneous in water quality because they were likely to be located in the same Ecoregion (as per MPCA 2004) and depth (i.e. all shallow). This analysis tested the effect extreme weather has on water quality within a region by performing a Mann-U test (also known as the Wilcoxon rank-sum test) on all lakes within that region over all three possible extreme weather contrasts (McLeod 2009). Non-parametric tests were used for both sets of analyses because of the non-normality of the data.

MPCA. 2004a. Minnesota's Water Quality Monitoring Strategy 2004-2014. Minnesota Pollution Control Agency, St. Paul, MN 55155. http://www.pca.state.mn.us/publications/reports/p-gen1-10.pdf

McLeod, A.I. 2009. Package 'Kendall' Version 2.1. Kendall rank correlation and Mann-Kendall trend test in Project "R" http://cran.r-project.org/web/packages/Kendall/Kendall.pdf.

Table 1. Summary of statistically significant water quality responses comparing years that were warm and dry, warm and wet, or cold and wet (based on at least 1.5 standard deviations from the mean temperature and precipitation) for all lakes across Minnesota, and for shallow lakes by climate division as well as statewide (see METHODS for classification details). n=sample size; Δ = difference between compared climate regimes; NS=none significant (p>0.05)

	Type of Analysis		
Water Quality Parameter	**All Lakes: Statewide[a]** (pairwise comparisons)	**Shallow Lakes: Statewide[b]** (pairwise comparisons)	**Shallow Lakes: by climate division[c]**
Secchi depth (m)	cold-wet< warm wet (n=235; p<0.0001; Δ 0.18 m) warm-wet> warm-dry (n=72; p<0.0001; Δ 0.38 m)	cold-wet> warm-wet (n=42; p<0.05; Δ 0.17 m)	South Central: cold-wet> warm-wet (n=19,37; p<0.02; Δ 0.17 m)
Trophic State Index (mean TSI)	cold-wet< warm-dry (n=90; p<0.05; Δ 1.3) warm-wet< warm-dry (n=72; p<0.01; Δ 2.2)	cold-wet< warm-dry (n=41; p<0.01; Δ 3.6) cold-wet< warm-wet (n=43; p<0.001; Δ 3.4) warm-dry to warm-wet NS, n=252	South Central: cold-wet< warm-wet (n=21,37; p<0.05; Δ 3.4) West Central: warm-wet< warm-dry (n=76,61; p= 0.08; Δ 4.0)
Specific electrical conductivity (EC25, µS /cm)	cold-wet< warm-wet (n=23; p<0.001; Δ 140 µS /cm)	warm-wet< warm-dry (n=42; p<0.001; Δ 31 µS/cm)	NS
Surface water temperature (°C)	cold-wet< warm-dry (n=11; p<0.05; Δ 2.6°C) cold-wet< warm-wet (n=44; p<0.001; Δ 4.0°C)	cold-wet< warm-dry (n=6; p<0.05; Δ 3.4°C) cold-wet< warm-wet (n=7; p<0.05; Δ 3.2°C)	South Central: cold-wet< warm-dry (n=6,10; p<0.05, Δ 2.0°C) cold-wet< warm-wet (n=6,10; p<0.05, Δ 1.3°C) West Central: cold-wet< warm-dry (n=8,16; p<0.05; Δ 2.1°C) cold-wet< warm-wet (n=8,17; p<0.01; Δ

		warm-dry< warm-wet (n=80; p<0.01; Δ 0.4°C)	2.5°C) <u>East Central</u>: warm-dry< warm-wet (n=86,227; p<0.001; Δ 0.9°C)
Thermocline depth (m)	NS	NS	NS
Chlorophyll-*<u>a</u>* *<u>(ug/L)</u>*	NS	NS	NS
Total phosphorus (ug/L)	NS	NS	NS

[a] May-Oct Climate data, June-Sept WQ data
[b] May-Oct Climate data, June-Sept WQ data, (same results with water year Climate data)
[c] May-Oct Climate data, May-Oct WQ data

Summary:

The statistical analyses described above represent an important first step in combining 100 years of intensive weather records for the nine climate regions of Minnesota and the much more limited sets of “longer-term” water quality data from Minnesota’s lakes in order to better understand how changes in climate might affect the lakes. The approach taken here was to identify years in which weather was abnormally cold, warm, wet, or dry and to then examine the water quality available for lakes to determine if statistically valid associations could be identified. The lake data set, while seemingly enormous, is limited by the fact that there are relatively few lakes (~ 600) with water quality data spanning 15 different years, and within this set of lakes there is often only a single parameter, secchi depth (water clarity), to examine. Further, the lakes with longer term data are not randomly distributed across the state or across a gradient in water quality. The current set of heavily biased towards the Minneapolis-St-Paul metropolitan area and lake regions with long history of intensive shoreline development. More work is needed to examine individual lake records to see if these general trends are consistent for well monitored lakes.

Despite the limitations noted above, a number of patterns were observed that were statistically defensible. Across all lakes and analyses, warmer air temperature scenarios resulted in warmer surface water temperatures. This pattern occurred for both warm-wet years and warm-dry relative to cold-wet years for all lakes state-wide, for shallow lakes state-wide, and for shallow lakes in the south-central and west-central climate divisions of the state (Table 1).

Additionally, warm years, tended to be associated with greater productivity, as indicated by TSI-mean, than cold years, with higher TSI values in warm-dry years in shallow lakes across the state, as well as when all lakes were analyzed. As might be expected since much of the TSI data was based upon secchi depth measurements, warmer scenarios whether wet or dry tended to be associated lower secchi depths. There were also strong associations between warm-wet years and higher TSI and lower secchi depths for shallow lakes in the South

Central climate division of Minnesota. We hypothesized that the most productive summer growing seasons would occur for wet-warm scenarios due to increased watershed runoff of nutrients and more wind mixing associated with storms, coupled with warmer temperatures. In fact, we found the opposite: warm-wet years had significantly clearer water (greater secchi depth) than either cold-wet or warm-dry years for all lakes statewide and warm-dry years were more productive (higher TSI) than either warm-wet or cold-wet years for the entire set of shallow lakes across the whole State. We caution that these apparently conflicting results are preliminary and that there are inherent assumptions, which may not be valid, that all lakes and all shallow lakes across the state are limnologically similar except for climate variables, and that all shallow lakes in a climate division are similarly “created equal.” These assumptions have yet to be tested and were beyond the scope of the current project.

Specific electrical conductivity (EC25), a measure of the total amount of dissolved ions and dissolved salts in the water, was found to be higher in warm-wet years relative to cold-wet in the statewide analysis for all lakes, and higher than warm-dry years for shallow lakes statewide. Unfortunately, there was insufficient data to compare warm-wet to cold-wet years for the shallow lake set. This suggests a warm versus cold effect, which could be due to enhanced evaporation in summer when the water quality data was collected, The wet versus dry effect for the shallow lakes is also consistent with both increased runoff of salts from the watershed and with increased roadsalt in wetter (i.e. icier and snowier) winters. Again, these interpretations are speculative at this time but suggest further exploratory analyses that might be conducted.

Similar exploratory analyses were performed on the total phosphorus (TP), chlorophyll-*a,* thermocline depth, bottom water temperature, and bottom water dissolved oxygen but none were statistically significant.

2008 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Pharmaceutical and Microbiological Pollution
PROJECT MANAGER: Timothy M. LaPara
AFFILIATION: University of Minnesota
MAILING ADDRESS: 500 Pillsbury Drive SE
CITY/STATE/ZIP: Minneapolis, MN 55455
PHONE: 612-624-6028
E-MAIL: lapar001@umn.edu
WEBSITE: n/a
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 5L.

APPROPRIATION AMOUNT: $302,000

Overall Project Outcome and Results

The goal of this project was to develop technologies that eliminate antibiotic-resistant bacteria, hormones, and other pharmaceutical compounds from Minnesota's surface waters. Laboratory-scale digesters were established in which wastewater solids were treated under both aerobic and anaerobic conditions at temperatures of 72°F, 98°F, 115°F, and 130°F. Our results demonstrated that aerobic digestion had no significant effect on the destruction of these genes; in contrast, the anaerobic digesters operated at 115°F and 130°F showed a very significant ability to reduce the quantities of these genes (with 130°F performing better than 115°F). This research demonstrates that anaerobic digesters treating wastewater solids (or agricultural manure) should be operated at the highest feasible temperature to help eliminate antibiotic resistance genes, which should help slow the proliferation of these organisms. In terms of antibiotic removal, the aerobic and anaerobic digesters were effective in the removal sulfamethoxazole, trimethoprim, and tylosin, with removal generally being greater at higher temperatures. Digestion did not lead to removal of the antibacterial triclosan or the estrogens tested. Laboratory and pilot-scale photolysis experiments revealed the compounds subject to direct photolysis (triclosan, tetracycline, tylosin) are likely to be amenable to degradation in wastewater treatment stabilization ponds or treatment wetlands. Cover materials either had minimal or inhibitory effects on photolysis rates. Two compounds (sulfamethoxazole and trimethoprim) were photodegraded more rapidly in wastewater effluent than in surface water or purified water, indicating that photodegradation is more likely to occur (and perhaps should be encouraged by design) in sunlit wastewater treatment process steps than in the environment. While solar photolysis shows some promise for treatment of pharmaceuticals, no evidence for removal of antibiotic resistance genes was in the photoreactor.

Project Results Use and Dissemination

This project has been used in numerous ways. First, we have communicated the results back to the State Legislature via informal (i.e., with individual State Senators and Representatives) and formal (i.e., hearings). Second, we have communicated these results to our various partners who operate municipal wastewater treatment facilities as well as other municipalities who operate municipal wastewater treatment facilities. Finally, we have disseminated our research results as broadly as possible, including via presentations at national and regional technical meetings as well as via publication in the peer-reviewed technical literature.

Trust Fund 2007 Work Program Final Report

Date of Report: October 15, 2010
Final Report
Date of Work program Approval: June 5, 2007
Project Completion Date: June 30, 2010

I. PROJECT TITLE: Pharmaceutical and Microbiological Pollution

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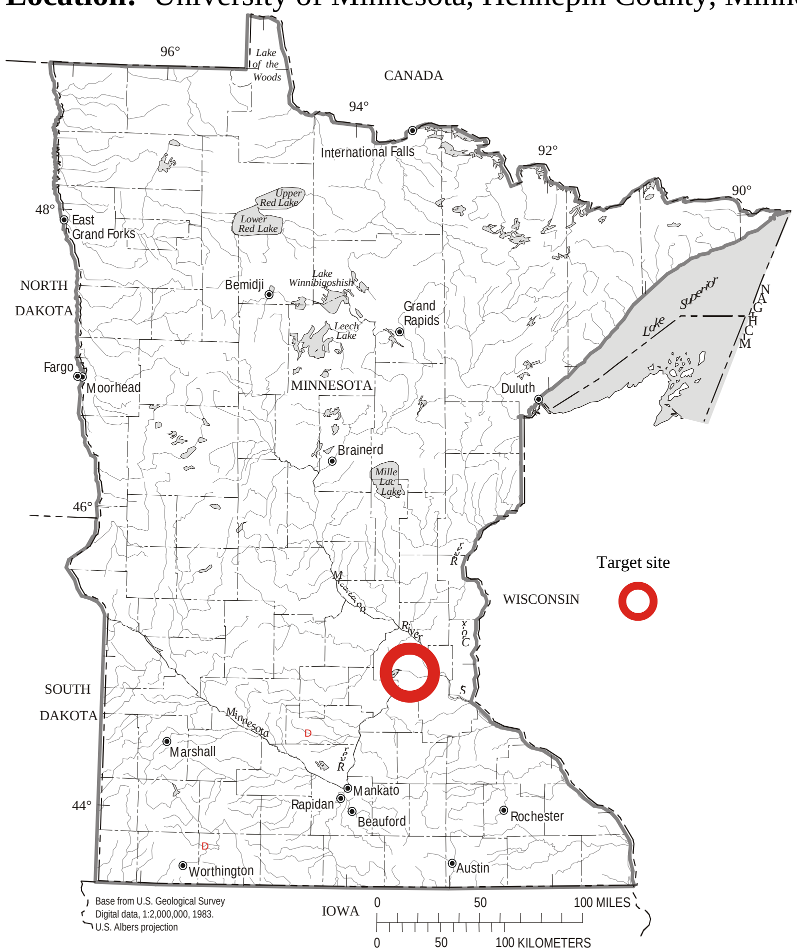

Total Trust Fund Project Budget: Trust Fund Appropriation: $ 302,000
Minus Amount Spent: $ 302,000
Equal Balance: $ 0

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 5L.

Appropriation Language: *Pharmaceutical and Microbiological Pollution Minnesota's surface waters. $302,000 is from the trust fund to the University of Minnesota to develop technologies that eliminate antibiotic-resistant bacteria, hormones, and other pharmaceutical compounds from Minnesota's surface waters.*

II. and III. FINAL PROJECT SUMMARY
Same as document 3, project abstract. Length = 300 words or less

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Thermophilic treatment of municipal and agricultural biosolids

Description: We collected biosolids from a municipal wastewater treatment plant and used these to establish lab-scale (0.5 L) aerobic and anaerobic bioreactors operated at different temperatures (75°F, 98°F, 115°F, and 130°F; 8 total bioreactors). At the end of each batch operation, two-thirds of the reactor volume was removed and replaced with untreated biosolids. These bioreactors were operated in this semi-continuous/semi-batch-mode for at least 10 hydraulic residence times (aerobic residence time: 4 days; anaerobic residence time: 15 days) to ensure that these bioreactors are operating effectively for solids stabilization and gas production (anaerobic only) before initiating the active portion of the experiments. We monitored these digesters using typical assays to measure digester performance (*e.g.*, volatile solids, COD, etc.) as described by *Standard Methods for the Examination of Water and Wastewater.*

Once these anaerobic and aerobic digesters were established, we measured the ability of these bioreactors to inactivate tetracycline-resistant bacteria. Individual samples were collected following the initiation of an individual semi-batch cycle as well as 4-6 samples per each semi-batch cycle. We were unable to enumerate total heterotrophic bacteria as well as tetracycline-resistant bacteria by cultivation (the digester contents were a paste that was very difficult to work with). We also collected biomass samples from which we extracted total genomic DNA for quantitative PCR to characterize the inactivation of tetracycline resistant bacteria in our lab-scale digesors. Prior research has demonstrated that untreated biosolids from municipal wastewater treatment plants contains substantial quantities of tetracycline-resistant bacteria. We anticipated performing at least three replicate kinetic experiments with each digester, although became an excessive and unnecessary work load (replicate anaerobic digesters provided very reproducible results).

We used these lab-scale digesters to track the loss of antibiotics (trimethoprim, tylosin, sulfamethoxazole) and estrogens (bisphenol A, nonylphenol, estradiol) in laboratory-scale experiments We spiked a known, quantifiable concentration of these compounds at the initiation of each run and track its disappearance over time (note: we originally intended to study the antibacterial triclosan degradation in this manner, but the “background” concentration of triclosan was higher than our experimental concentration. Thus, this background concentration was used to evaluate triclosan removal.) These experiments measured the intrinsic ability of the microbial community to degrade these compounds without explicit prior adaptation. We anticipate that the biomass will have substantial biodegradation activity given that these compounds are generally found in municipal wastewater.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$** 151,000
	Amount Spent:	**$** 151,000
	Balance:	**$** 0

Deliverable	**Completion Date**	**Budget**	**Status**
1. Anaerobic Digestion	May 31, 2009	$76,000	Completed
2. Aerobic Digestion	March 15, 2010	$75,000	Completed
3.			

Completion Date: June 1, 2010

Final Report Summary: Substantial differences were observed in the ability of anaerobic and aerobic digesters to reduce the quantity of genes encoding tetracycline resistance and a gene encoding the integrase of Class 1 integrons. In most cases, aerobic digestion had no significant impact on gene quantities, although this could have been due to the relatively short retention time (4 days) of the experiments. In contrast, the anaerobic digesters operated at high temperatures showed significant rates of removal for most of the genes that were quantified (the exception was *tet*(L)) at temperatures of 115°F and 130°F, whereas the digesters operated at temperatures of 72°F and 98°F did cause any significant reductions in gene quantities. Of particular importance, the anaerobic digester operated at 130°C achieved a reduce in *intI1* genes from approximately 10% of the total biomass to less than 0.001% over a period of 5 days; this result is important because integrons have been implicated as a general genetic mechanism that helps the proliferation of antibiotic resistance. This research demonstrates that the operation of anaerobic digesters at high temperatures (> 125°F) offers a substantial benefit for reducing the quantity of antibiotic resistance genes in wastewater solids; with the widespread implementation of this technology, it might be possible to slow the spread of antibiotic resistance. The full details of this research is currently under review for publication in *Environmental Science and Technology*; this research was also used as data in a research proposal to the National Science Foundation that has been funded for almost $400,000 over a 3-year period.

Removal of antibiotics and estrogens from the digesters was variable depending on the compound and operating conditions. In the aerobic digesters, sulfamethoxazole was at or below the analytical detection limits within one day of spiking at all temperatures. This indicates that aerobic digestion is a viable treatment option for this antibiotic. For trimethoprim, removal varied from 40% to >95% (on a mass of compound per mass of solids basis) in the eight day monitoring period, with better removals seen at the temperatures of 115°F and 130°F (80% and >95% respectively). For tylosin, there was no removal in the 72°F digester. At 98°F and 130°F 70% removal was observed over four days. Substantially different results were observed for triclosan. Over the 8 day monitoring period, the concentration of triclosan in the solids *increased* by up to 8-fold. Concentrations are measured on a mass of compound per mass of solids basis. Because the solids are being degraded by the digester, the denominator of this ratio decreases with time. Essentially, this result demonstrates that triclosan is not degraded in the aerobic digesters. For the three estrogens tested, nonylphenol was the only compound the produced consistent data. For all temperatures, the concentrations decreased at the same rate as that would be expected by dilution of digester caused by sampling. Because the solids mass is being reduced over time, this indicates that nonylphenol is degraded at the same rate of solids digestion. The data for bisphenol A suggests similar trends but is not conclusive. It was not possible to detect estradiol suggestion either that it degrades rapidly or that there is analytical interference. We consider the latter to be more likely. Only one temperature produced reliable for the anaerobic digesters (98°F). In this digester, removal of sulfamethoxazole (rapidly below detection limits), tylosin (80%) and trimethoprim (90%) were observed. Triclosan behavior was similar to that in the aerobic digesters, indicating no degradation of this compound.

Result 2: Solar treatment of water for pharmaceutical destruction and disinfection

Description: Laboratory Studies. Initial experiments will be performed in the laboratory. Experiments will be conducted with treated wastewater (collected prior to final chemical disinfection) and runoff collected from agricultural fields that either use treated wastewater for irrigation or manure as fertilizer. This will allow us to simulate operating conditions more closely, as the organic material (which influences light penetration and leads to indirect photolysis processes) and bacterial populations will be those expected in the field. For experiments solely focused on pharmaceutical degradation, the collected waters will be filter-sterilized (to prevent any biological degradation of the compounds), and for those focused on bacterial inactivation, no pharmaceuticals will be added (to prevent any development of resistance during the test). Experments will also be conducted on samples containing both the target pharmaceuticals and active bacteria. Pharmaceuticals will be dosed individually or in mixtures at 1-10 mg/L to facilitate detection. Our prior research suggests that substantial numbers of antibiotic resistant bacteria will be present; but if not, then we will add a known quantity of tetracycline-resistant *E. coli* harboring a *tet*(A) gene on a plasmid. The light source will be sunlight whenever possible, with the solar intensity measured via actinometry and/or using the St. Anthony Falls Laboratory weather station. When weather prevents outdoor experiments, a solar simulator will be used. For the compounds in this study, the quantum yields are known. Thus, the goal is to optimize the conditions to maximize degradation/disinfection.

In the laboratory simulation of passive systems (i.e., holding pond), the goal will be to test the light exposure times necessary to achieve a given level of compound removal and disinfection (as measured by the decrease in heterotrophic plate counts [with and without tetracycline] and quantitative real time PCR) for various depths. Experiments will be conducted in a small, open flask (~0.5-1 L capacity). Another parameter to be tested in the laboratory is important for pumped systems—the material of the cover that is used to trap the heat. Experiments will be similar to those for the passive system, except that a cover will be added to the tank. The cover enables heat to be trapped/temperature to be increased. A disadvantage is the potential alteration of the light spectrum. Microbial inactivation is optimal with UV-A wavelengths of light (320-400nm) while more energetic UV-B light (< 320nm) is often necessary for efficient organic contaminant destruction. Cover materials to be tested include quartz (completely UV transparent), Pyrex glass (blocks UV-B radiation), and acrylics (which are more durable/lighter weight) of varying UV transparency. Temperature will also be a variable in these studies, with the reactors being heated passively (either ambiently or using a reflector to focus/increase light dosage). Control experiments (no light exposure) will be conducted in parallel to all photolysis experiments. In all experiments, aqueous samples (~ 1 mL) will be collected at selected time intervals from the reactors run in duplicate. At least seven time points will be collected.

Pilot Studies. The laboratory experiments will be used to guide the design of a pilot scale system to be set up at the Blue Lake wastewater treatment plant in Shakopee, MN. This treatment plant is particularly well suited for the study, because after undergoing activated sludge treatment, wastewater passes through a holding pond prior to final disinfection and discharge. Using data from the laboratory studies (specifically, the kinetics of bacterial inactivation and pharmaceutical destruction) the performance of the pilot system will be predicted for a given volume/depth (passive) or volume, depth, and flow rate (active system). The cover material to be used in the active system will also be based on the results of the laboratory studies. In both systems, water depth (rather than volume) is expected to be the crucial geometric parameter. The passive system will be a tank with total capacity of approximately 50-100 L. The active system will have a volume of approximately 2 L. It is expected that residence times in the active system will need to be on the order of one hour, so flow rates will vary from 0.5 to 8 L/hr.

We will focus this study on the human antibiotics (sulfamethoxazole and triclosan) and one of the estrogenic compounds (to be determined). Both passive and active systems will be studied. In the passive systems, samples will be removed to monitor pharmaceuticals, heterotrophic plate counts (with and without tetracycline), and antibiotic resistance genes as a function of time. In the active systems, influent and effluent concentrations of these parameters will be measured. The analytical methods are described below. We will also conduct a pilot-scale study of the passive system at an agricultural site using tylosin and tetracycline as the target compounds. The procedures will be the same as those described above. We anticipate that we will have to spike the waters with the target compounds for both the wastewater and the agricultural pilot tests to ensure we can routinely and easily detect the target compounds.

In both the active and passive systems, the performance of the system will be measured as a function of residence time, solar exposure (i.e., season), temperature, and water depth. With the active system, the utility of a light reflection system will also be evaluated. Temperature will be monitored using a thermocouple and a data logger. The ultimate goal is to determine if the laboratory measured parameters accurately represent pilot system performance, and if not, what correction factors are necessary to design the system to achieve the desired performance.

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$** 151,000
	Amount Spent:	**$** 151,000
	Balance:	**$** 0

Deliverable	**Completion Date**	**Budget**	**Status**
1. Laboratory Studies	January 1, 2009	$75,000	Completed
2. Pilot Studies	May 31, 2010	$76,000	Completed

Completion Date: May 1, 2010.

Final Report Summary: As expected based on previous results, all four antibiotics (sulfamethoxazole, trimethoprim, tylosin, and tetracycline) as well as the antibacterial triclosan were susceptible to direct photolysis. It was hypothesized that a cover material (either quartz, borosilicate glass, or acrylic) could be used to focus light and/or elevate temperature and enhance reaction rates. The acrylic prevented transmission of the necessary wavelengths of light and slowed photolysis by a factor of two. UV-transparent acrylic was therefore used as a substitute. None of the cover materials, however, led to enhances photolysis rates. Thus, further laboratory photolysis experiments did not use cover materials and focused on the scenario of a holding pond. Tylosin, tetracycline, and triclosan were most susceptible to photolysis both in purified water and in wastewater effluent (half-lives of 0.5-2 hours). Sulfamethoxazole and trimethoprim reacted much more slowly that the other compounds. One interesting finding of this study, however, was that the rate of photolysis of these two antibiotics was enhanced in wastewater compared to purified water (2-fold for sulfamethoxazole and 10-fold for trimethoprim). This enhanced reactive was traced to dissolved constituents of wastewater (specifically, nitrate and effluent organic matter) that produce reactive intermediates in sunlight (hydroxyl radical and triplet excited organic matter) that then react with these antibiotics. A manuscript describing these findings is currently under review for publication in the journal *Water Research.* For triclosan, tetracycline, and tylosin, this process is unimportant because the reaction caused by the direct absorption of sunlight dominated for these three compounds. Laboratory screening studies on nonylphenol, bisphenol A, and estradiol indicated that these compounds did not undergo photolysis at a sufficient rate to merit study in the pilot reactor.

Because the laboratory studies could be used to predict behavior of passive pilot systems, pilot studies focused on an active flow through system. The aqueous medium was either purified water or wastewater effluent. Field runoff was not used because experiments with river water showed no difference in reactivity to purified water (unlike wastewater effluent). The pilot reactor (3 hour residence time) demonstrated that tetracycline, triclosan, and tylosin are amenable to treatment in a flowing systems (either reactor or holding pond) that is exposed to sunlight. For the water receiving maximum solar exposure (e.g., entering the reactor around 12 noon and exiting at 3pm), up to 90% of the tetracycline, 80% of the triclosan, and 25% of the tylosin was degraded in a three hour exposure period. This was essentially unaffected by the matrix (purified water or wastewater effluent) or the presence of a cover (none or UV-transparent acrylic). Removals were lower for parcels of water receiving less intense sunlight. Photolysis will only occur to the depth to which light penetrates. Thus, large areas, shallow depths, and long retention times will be necessary in solar treatment systems if a substantial fraction of these compounds is to be removed consistently. Treatment wetlands offer such a possibility. Despite their higher photoreactivity in wastewater effluents, sulfamethoxazole and trimethoprim were not degraded in the pilot reactor. To test whether removal of triclosan occurred in a wastewater treatment holding pond, samples from the influent and effluent of the wastewater stabilization pond at the end of the treatment train at the Blue Lake Wastewater Treatment plant in Shakopee, MN was collected and analyzed. Effluent samples had triclosan levels 30-50% lower than influent samples, and biodegradation controls showed no losses, suggesting that photolysis (or another abiotic process) was responsible for the decrease.

The pilot reactor was also used to test the possibility of using sunlight for disinfection/removal of antibiotic resistance genes. Based on fecal coliform counts, disinfection efficiency was 60-95% in the 3-hour exposure period. There was no observable difference in the number of tetracycline resistant genes between the influent and effluent of the reactor. This indicates that even if the bacteria are inactivated by sunlight, the genes are not destroyed.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $222,000
Equipment: $50,000
Development: $ 0
Restoration: $ 0
Acquisition, including easements: $ 0
Other: $ 30,000. Laboratory supplies and services (e.g., analytical chemistry, microbial analyses) and travel funds to test sites and for expenses to disseminate our results to Minnesotans and to other interested individuals at local, regional, and national workshops/conferences.

TOTAL TRUST FUND PROJECT BUDGET: $302,000

Explanation of Capital Expenditures Greater Than $3,500:

A sum of $40,000 is budgeted for the purchase of a high pressure liquid chromatograph. This essential piece of equipment is required to monitor the concentrations of the target antibiotics and estrogens in the laboratory experiments as well as in the pilot-scale tests. (Trace level analysis will be performed on mass spectrometry equipment). The investigators do currently have access to an HPLC. The instrument, however, is beyond its expected lifetime, and spare parts are no longer available. If the instrument fails, the project will be unable to proceed. Thus, a new instrument is necessary to ensure the project goals are met. Given the number of samples expected to generated by the project, it is more economical to purchase an instrument rather than pay per sample fees on an instrument in another laboratory.

A sum of $10,000 is budgeted for the purchase of a real time PCR machine to quantify genes encoding resistance to tetracycline. The benefit of purchasing this instrument is that we would be able to process more samples with higher quality results (with fewer users, the instrument will be maintained better) in a shorter period of time. Additional funds will be leveraged to purchase this equipment (the LCCMR financial contribution will be $10,000 of the total instrument cost of $26,100; the remaining $16,100 will come from other research projects).

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

William A. Arnold

University of Minnesota
Department of Civil Engineering
500 Pillsbury Drive SE
Minneapolis, MN 55455

B. Other Funds Proposed to be Spent during the Project Period: $5000
An additional $5,000 towards the purchase of the HPLC will be leveraged from an unrelated grant of Dr. Arnold. Dr. Arnold is also leading a National Science Foundation sponsored project ($266,000) studying the fate of triclosan in the environment. A portion of this effort is focused on the transformation of triclosan when it is exposed to sunlight, and we will be able to leverage the results for this project.

We will also partner with the Metropolitan Council Environmental Services, Western Lake Superior Sanitary District, and anonymous farmers. Drs. LaPara and Arnold have teamed with these groups in past research efforts, and thus a good working relationship between the lead invesigators and partners already exists. The partners will provide in-kind contributions (i.e., site access, sampling assistance, staff time) at no direct cost to the proposed project.

C. Past Spending: $0

D. Time: The peer-review panel recommended a time frame of three years to complete the proposed project.

VII. DISSEMINATION ACTIVITIES

Drs. LaPara and Arnold testified at a hearing of a combined state senate/house committee on wastewater treatment on January 7, 2008. One manuscript is currently being considered for publication by *Environmental Science and Technology* and other manuscripts are currently in preparation.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than January 2008, July 2008, January 2009, and November 2009. A final work program report and associated products will be submitted between June 30 and August 1, 2010 as requested by the LCCMR

IX. RESEARCH PROJECTS:

Research Addendum for Peer Review

Project Manager Name: Dr. Timothy LaPara

Project ID and Title: (SN-56) Pharmaceutical and Microbiological Pollution

I. Abstract

Human and veterinary antibiotics, hormones, and antibiotic resistant bacteria enter Minnesota waters via wastewater discharges, biosolids (manure), and runoff. Almost no research into approaches and technologies to control the release of pharmaceuticals and antibiotic resistant bacteria in municipal wastewater and in agricultural runoff has been performed. Practical, low cost technologies are necessary to manage the large volumes of wastewater, agricultural runoff, and biosolids generated in Minnesota. There are two treatment techniques that have potential to both destroy pharmaceuticals and to kill antibiotic resistant bacteria: thermophilic (aerobic or anaerobic) treatment of biosolids and solar treatment of water. Our goal is to determine the capabilities of both "low tech" (solar treatment) and "high tech" (thermophilic treatment) approaches with respect to the destruction of pharmaceuticals and antibiotic resistant bacteria. Although a simple technique, solar treatment is expected to be both effective and low cost and applicable to small-scale applications, such as the stereotypical family farm or a small wastewater treatment facility. Although more expensive to initially construct, thermophilic treatment should be more effective and cost-efficient for large-scale facilities, such as municipal wastewater plants and larger agricultural operations. This research will establish innovative approaches that will substantially benefit Minnesota by reducing the antibiotics, hormones, and antibiotic resistant bacteria released into our surface and ground waters.

II. Background and Hypotheses

Pharmaceuticals as contaminants

Pharmaceutical and personal care product (PPCP) contamination of surface waters was first reported in Europe, with studies conducted in Britain (Richardson and Bowron, 1985), Germany (Ternes, 1998; Hirsch et al., 1999), and other countries (Halling-Sorensen et al., 1998; Kumpel et al., 2001). More recently, American researchers have begun to take stock of the pharmaceutical contamination in US surface waters. Most prominent is the nationwide reconnaissance of organic wastewater contaminants by the US Geological Survey, in which over 95 different organic wastewater compounds were detected in US streams and rivers (Kolpin et al., 2002). The main conclusions of the European and American studies were the same: pharmaceuticals are found in the environment and can be attributed to both human and animal applications. The contamination of human origin is largely the result of incomplete removal in the wastewater treatment process. The animal-use derived contamination is more direct, coming from food animal production runoff. Recent calculations (Anderson et al., 2004) have predicted that 2 to 98 percent of specific human pharmaceuticals will pass through wastewater treatment systems and enter the environment via wastewater discharge. The percentage resistant to treatment depends on the specific compound, and the total mass of the compound released depends on usage/prescription rates. Based on the usage and removal rates provided by Anderson et al., it is predicted that 60,000 kg/year of the antimicrobial triclosan and 36 kg/year of ethyinyl estradiol are released in to surface waters in the US. The latter number appears small, but estrogenic compounds are extremely potent, and small releases on a mass basis are of concern.

Even the fraction of the PPCPs removed via wastewater treatment can still enter the environment. A major removal pathway is association/removal with the sludge (*e.g.*,Heidler et al. 2006; Anderson et al., 2004). If this material is then processed and spread on fields as fertilizer, the pharmaceuticals may be released. This has proven to be the case, for recent work has also shown that re-use of treated wastewater and application of treated sludge as fertilizer in agricultural applications leads to pharmaceutical release into the environment (Cordy et al., 2004; Pedersen et al., 2005).

Although many PPCPs reach the environment, of specific concern is the release of antibiotic and estrogenic compounds. Both classes of compounds are known to and/or designed to have specific physiological effects, and thus these two groups of compounds have the potential to adversely affect surface waters, aquatic ecosystems, and humans. Estrogenic compounds have a demonstrated ability to interfere with the development of aquatic organisms (Stuer-Lauridsen et al., 2000; Ternes, 2001), while there is concern that the presence of antibiotics in natural waters will lead to an increase of antibiotic resistant bacteria (Hirsch et al., 1999; Kumpel et al., 2001).

Antibiotic resistant bacteria as pollutants
Although scientists have long-known that disease-causing bacteria are becoming increasingly resistant to antibiotics (Fig. 1), relatively little has been done to avoid this pending catastrophe until the last decade or so. The public health sector is now focused on limiting inappropriate antibiotic use – specifically by limiting inappropriate prescriptions (*e.g.*, for viral infections) and by educating patients to closely follow their prescription guidelines. While these changes will limit the development of newly-resistant strains, they are likely insufficient to stem the proliferation of antibiotic resistance. Also controversial is the substantial fraction of antibiotics that are used in agriculture (50-70% of total antibiotic use in the United States) for prophylaxis and growth-promotion.

A major hypothesis currently driving research in the LaPara group is that the majority of antibiotic resistant bacteria are generated in the gastrointestinal tracks of human beings and animals taking antibiotics. These resistant bacteria are then expelled from the body via defecation, suggesting that better collection and treatment of fecal material (both of human and of agricultural origin) could substantially help slow the proliferation of antibiotic resistance. Prior research by us (Firl et al., 2006; LaPara et al., 2006) and others (Auerbach et al., 2007) has demonstrated that human sewage contains substantial quantities of antibiotic resistant bacteria. Likewise,

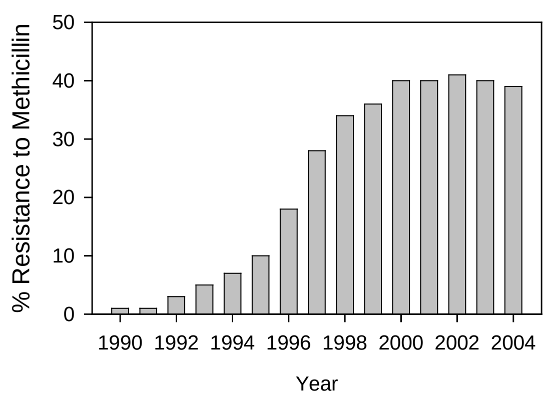

Fig. 1. Resistance to methicillin among *Staphylococcus aureus* isolated from blood cultures in England and Wales (Johnson et al., 2005).

agriculturally-generated manure is a substantial source of antibiotic resistant bacteria (Alonso et al., 2001; Onan and LaPara, 2003; Rooklidge, 2004; Ghosh and LaPara, 2006). As such, researchers now consider antibiotic resistant bacteria – as well as their genes that encode for resistance – as emerging pollutants of environmental concern (Pei et al., 2006; Pruden et al., 2006).

Goal and Hypotheses

Because of the potential adverse effects of antibiotics, estrogens, and antibiotic resistant bacteria on humans and on the environment, it is desirable to prevent the release of these pollutants. To eliminate the discharge of these contaminants, both biosolids and waters will have to be treated. The goal of this project is to evalute the utility of two technologies to achieve this goal: thermophilic digestion of biosolids and solar treatment of water.

In thermophilic digestion, microbial activity results in either the direct release of heat (aerobic) or the production of methane gas (anaerobic) that can be burned to heat the bioreactor. High reactor temperatures (> 130°F) then pasteurize the waste, which should include the destruction of the majority of resistant bacteria. The fate of antibiotics and hormones in thermophilic bioreactors is unknown. Solar treatment is simply the exposure of water to sunlight. The light destroys chemicals (pharmaceuticals, DNA) and also heats the water, which enhances these effects. The minimum requirement for this technique is passive exposure to sunlight. In an active (pumped) system, it is possible to use a solar collector to enhance the heat collected.

Based on the information presented above, we propose to test the following hypotheses in the experiments described below:

1. The elevated temperatures generated in thermophilic sludge digesters will lead to the inactivation of antibiotic resistant bacteria and the degradation of pharmaceutical compounds. This technology will be effective for large-scale facilities that can accommodate the required capital investment.

2. With sufficient dosage, storage time, and appropriate design, the combination of solar light and elevated temperature will lead to destruction of antibiotic and estrogenic compounds as well as the inactivation of antibiotic resistant bacteria in treated wastewater and agricultural runoff. The technology will be feasible for small-scale operations.

Although each is an established technology, the application of the thermophilic digestion or solar treatment targeted to the simultaneous removal of pharmaceuticals and antibiotic resistant bacteria has not been pursued. A brief background on the two technologies is provided below.

Thermophilic digestion of biosolids

There are numerous approaches to dealing with the solid residues collected at municipal wastewater treatment facilities. The most common approach, and the one that most people believe is environmentally sustainable, is to biologically stabilize the solids (i.e., reduce their organic content; a.k.a. "digestion") and then apply these stabilized solids to farm land as both a fertilizer and a soil conditioner. The conventional technology for solids stabilization is mesophilic anaerobic digestion, which involves incubation of the solids at ~98°F in the absence of oxygen. This technology is quite effective at stabilizing the solids, but the process is relatively ineffective at inactivating pathogens because these digesters are operated at the approximate temperature of the human body.

In an attempt to improve the stabilization process, researchers have developed two high-temperature process alternatives: (1) Thermophilic anaerobic digestion, and (2) Autothermal thermophilic aerobic digestion (ATAD). Thermophilic anaerobic digestion works similar to conventional anaerobic digestion, except that a greater fraction of the methane generated by the process is used to heat the bioreactors to much higher temperatures. ATAD processes work similar to conventional composting in which the heat released by aerobic bacterial metabolism is sufficient to "auto-heat" the reactor to high temperatures. Although both thermophilic anaerobic digestion and ATAD are used in practice, neither has achieved widespread implementation. Simply put, they are more expensive to construct and to operate, while they offer only marginal benefit for solids stabilization.

Thermophilic anaerobic digestion and ATAD processes, however, should be far superior to conventional anaerobic digestion if the inactivation of antibiotic resistant bacteria (and pathogens) becomes an explicit goal of solids digestion (i.e., in addition to stabilization). These processes operate at temperatures well above that of the human body (> 130°F), which is sufficient to inactivate virtually all bacteria that could adversely affect humans. Research is needed, however, to determine the rates at which antibiotic resistant bacteria are inactivated during thermophilic anaerobic digestion and ATAD processes. As stated above, the fate of antibiotics and hormones in the digestion process (particularly at high temperatures) is essentially unknown.

Solar treatment of water: potential for pharmaceutical destruction and disinfection
As reviewed by Boreen et al. (2003), many pharmaceuticals are subject to degradation upon direct exposure to sunlight (direct photolysis). For this reason, it is often advised to store medications in the dark and to avoid sunlight/wear sunscreen when taking specific medications. Much work in the past few years has focused on determining photolysis rates of pharmaceuticals under environmentally relevant conditions (Fasani et al., 1999; Poiger et al., 2001; Sprehe et al., 2001; Araki et al., 2002; Tixier et al., 2002; Andreozzi et al., 2003; Buerge et al., 2003; Doll and Frimmel, 2003; Valero and Costa, 2003; Latch et al., 2003a; Latch et al., 2003b; Packer et al., 2003; Boxall et al., 2004; Boreen et al., 2004; Boreen et al., 2005; Lin and Reinhard, 2005; Latch et al., 2005; Werner et al., 2005a; Werner et al. 2006). This work, including work targeting the antibiotics to be studied in this project conducted by Dr. Arnold's group, has demonstrated that direct photolysis is an important natural degradation process for pharmaceuticals that has the potential to be exploited in engineered systems.

The kinetics of direct photochemical destruction are described by the following equation (Zepp and Cline, 1977; Mill, 1999):

$$\frac{dC}{dt} = -\Phi\sum_{\lambda}\varepsilon_{\lambda}L_{\lambda}[C] = -k_{p}[C]$$

where ε_{λ} is the extinction coefficient at wavelength λ, L_{λ} is the averaged sunlight intensity for shallow water depth, and Φ is the quantum yield or efficiency of the process. It is important to note that a large quantum yield value (near 1) does not guarantee a rapid reaction nor does a small value mean the direct photolysis will be slow. The key parameter is the product of □□ and the spectral overlap integral $\sum_{\lambda}(\varepsilon_{\lambda}L_{\lambda}$; which quantifies the total light absorbance of the compound).

Extinction coefficients for compounds can easily be measured using a UV/visible spectrophotometer. For the compounds of interest in this study (see below), the extinction coefficients (as a function of pH) and quantum yields are known. If the solar exposure is known, the total time of solar exposure necessary to achieve a specific level of removal for a compound is readily calculated.

In addition to direct photolysis, indirect photolysis can also lead to the destruction of pharmaceuticals. For indirect processes, organic matter (which is present in both wastewater and agricultural runoff) absorbs the light and generates a variety of reactive species, including hydroxyl radicals, singlet oxygen, and triplet-state excited organic matter. Work in Dr. Arnold's laboratory has shown that indirect photolysis processes are also important in pharmaceutical degradation (Latch et al. 2003a; Werner et al., 2005a; Boreen et al., 2005).

In water, sunlight is a potent and often unexploited disinfectant. Although chemical disinfectants are effective, they have drawbacks including high operating or capital costs, toxic byproduct formation, safety issues, and the requirement of skilled operators. Recent research has shown that exposure of treated wastewater and river water to sunlight results in 99.9 to 99.99% removal of coliform bacteria (an indicator measurement of total disinfection; McLoughlin et al. 2004; Caslake et al., 2004) with 30-60 minutes of solar exposure in active/covered reactors. In fact, the process is being successfully implemented in third-world countries to reduce outbreaks of gastrointestinal illness. Some bacterial strains, however, require doses up to 5 times greater than coliform-type organisms (Gill and McLoughlin, 2007). Thus, it is important to track the disinfection rates for specific target organisms or organisms that contain a specific characteristic (*e.g.,* virulence, antibiotic resistance), and such detailed work has not yet been performed.

Solar treatment can be active or passive. A passive treatment system is as simple as a shallow holding pond that allows exposure to sunlight for a given period prior to discharge. Advantages of this system are simplicity of operation and low cost. A benefit of an active solar collector in which the water is pumped through an enclosed system (*e.g.,* clear plastic or glass tubes) is that the captured light also heats the water. In general, increasing temperature accelerates reactions and improves disinfection. The effects are relatively modest. For an increase in temperature of 10°C, photolysis rates are accelerated by less than 50% (Schwarzenbach et al., 2002). Disinfection rate has been reported to increase by ~ 3 fold if temperatures of 45°C (110°F) can be obtained (Caslake et al. 2004; Gill and McLoughlin, 2007). These increases in effectiveness need to be balanced with the capital or energy input costs. Nonetheless, such increases in rate are advantageous in that a shorter exposure time and thus reactor volume is necessary if temperature is raised. Additionally, the heat collected in the water could be used for other purposes (*e.g.,* temperature control of an onsite building).

III. Methods

In this project we will focus our efforts on bacteria that are resistant to tetracycline, which is a broad-spectrum antibiotic that serves as an excellent surrogate for the overall problem of "antibiotic resistance" (i.e., there are far too many antibiotics to study resistance to each drug). Dr. LaPara's laboratory has developed numerous cultivation-based and cultivation-independent techniques to enumerate and track the genes encode for tetracycline resistance (unpublished results). The specific antibiotics to be studied include those used in human medicine (trimethoprim, sulfamethoxazole), veterinary medicine (tylosin, tetracycline), and a household antimicrobial (triclosan). Dr. Arnold's research team has previously studied the fundamental photochemical transformation rates and mechanisms of each of these compounds (Table 1). For estrogens, bisphenol A, nonylphenol, and estradiol will be the target compounds. The basic photochemistry of these compounds has also been studied (Table 1). Each of the antibiotics and estrogens selected were detected with high frequency in U.S. surface waters (Kolpin et al., 2002) suggesting that technologies to remove these specific compounds will be particularly useful.

Table 1. Detection frequencies and quantum yields for the pharmaceuticals to be studied.

Target compound	*Surface Water Detection Frequency (Kolpin et al., 2002)*	*Quantum Yield (□)*	*Reference*
Sulfamethoxazole	19%	0.09[1]	Boreen et al., 2004
Trimethoprim	27%	0.006[2]	Werner et al., 2005b
Tylosin	13.5%	0.0014	Werner et al., 2007
Tetracycline	1.2%	0.0019[3]	Werner et al., 2006
Triclosan	58%	0.12	Latch et al., 2003a,2005
Bisphenol A	41%	-[4]	Chin et al., 2004
Nonylphenol	50%	0.003	Neamtu and Frimmel, 2006
Estradiol	10%	0.0048	Lin and Reinhard, 2005

[1] Quantum yields for sulfa drugs are pH dependent. The quantum yield reported is for the dominant protonation state expected at pH 7.

[2] Reactions are accelerated 8-fold in river water, suggesting indirect photolysis processes are also important.

[3] The quantum yields for tetracycline drugs depend upon pH and calcium ion concentration. The value reported is for pH 7.5 with $[Ca^{2+}] = 10^{-3}$ M.

[4] Direct photolysis is slow, but indirect processes in the presence of organic matter give a half-life of ~16 hours.

Thermophilic treatment of municipal and agricultural biosolids

We will collect biosolids from a municipal wastewater treatment plant and use these to establish lab-scale (0.5 L) aerobic and anaerobic bioreactors operated at different temperatures (75°F, 98°F, 115°F, and 130°F; 8 total bioreactors). At the end of each batch operation, two-thirds of the reactor volume will be removed and replaced with untreated biosolids. These bioreactors will be operated in batch-mode for at least 10 hydraulic residence times (aerobic residence time: 4 days; anaerobic residence time: 15 days) to ensure that these bioreactors are operating effectively for solids stabilization and gas production (anaerobic only) before initiating the active portion of the experiments. We will monitor these digesters using typical assays to measure digester performance (*e.g.*, volatile solids, COD, etc.) as described by *Standard Methods* (1995). Dr. LaPara's laboratory has substantial experience in operating both thermophilic and anaerobic bioreactors (LaPara et al., 2000; Kappell et al., 2005).

Once these anaerobic and aerobic digesters are established, we will measure the ability of these bioreactors to inactivate tetracycline-resistant bacteria. Individual samples will be collected following the initiation of an individual batch run as well as 4-6 samples per each batch run. Bacterial enumerations will be used to quantify total heterotrophic bacteria as well as tetracycline-resistant bacteria. We will also collect biomass samples from which we will extract total genomic DNA so that quantitative and qualitative PCR can be used to characterize the inactivation of tetracycline resistant bacteria in our lab-scale digesors. Prior research has demonstrated that untreated biosolids from municipal wastewater treatment plants contains substantial quantities of tetracycline-resistant bacteria (LaPara et al., 2006). We anticipate performing at least three replicate kinetic experiments with each digester.

We will also use these lab-scale digesters to track the loss of antibiotics (trimethoprim, triclosan, tylosin, sulfamethoxazole, tetracycline) and estrogens (bisphenol A, nonylphenol, estradiol) in laboratory-scale experiments. We will spike a known, quantifiable concentration of these compounds at the initiation of each run and track its disappearance over time. Results will be compared to killed controls (i.e., using a portion of the digester biomass + sodium azide) operated at the same temperatures to discern the impact of biological activity on loss rates of the pharamaceutical compounds. These experiments will measure the intrinsic ability of the microbial community to degrade these compounds without explicit prior adaptation. We anticipate that the biomass will have substantial biodegradation activity given that these compounds are generally found in municipal wastewater. Depending on the results of our proposed study, future research could elucidate optimal degradation rates using explicitly acclimated anaerobic or aerobic digesters.

Solar treatment of water for pharmaceutical destruction and disinfection

Laboratory Studies. Initial experiments will be performed in the laboratory. Experiments will be conducted with treated wastewater (collected prior to final chemical disinfection) and runoff collected from agricultural fields that either use treated wastewater for irrigation or manure as fertilizer. This will allow us to simulate operating conditions more closely, as the organic material (which influences light penetration and leads to indirect photolysis processes) and bacterial populations will be those expected in the field. For experiments solely focused on pharmaceutical degradation, the collected waters will be filter-sterilized (to prevent any biological degradation of the compounds), and for those focused on bacterial inactivation, no pharmaceuticals will be added (to prevent any development of resistance during the test). Experments will also be conducted on samples containing both the target pharmaceuticals and active bacteria. Pharmaceuticals will be dosed individually or in mixtures at 1-10 mg/L to facilitate detection. Our prior research (Firl, 2006) suggests that substantial numbers of antibiotic resistant bacteria will be present; but if not, then we will add a known quantity of tetracycline-resistant *E. coli* harboring a *tet*(A) gene on a plasmid. The light source will be sunlight whenever possible, with the solar intensity measured via actinometry and/or using the St. Anthony Falls Laboratory weather station. When weather prevents outdoor experiments, a solar simulator will be used. For the compounds in this study, the quantum yields are known. Thus, the goal is to optimize the conditions to maximize degradation/disinfection.

In the laboratory simulation of passive systems (i.e., holding pond), the goal will be to test the light exposure times necessary to achieve a given level of compound removal and disinfection (as measured by the decrease in heterotrophic plate counts [with and without tetracycline] and quantitative real time PCR) for various depths. Experiments will be conducted in a small, open flask (~0.5-1 L capacity). Another parameter to be tested in the laboratory is important for pumped systems—the material of the cover that is used to trap the heat. Experiments will be similar to those for the passive system, except that a cover will be added to the tank. The cover enables heat to be trapped/temperature to be increased. A disadvantage is the potential alteration of the light spectrum. Microbial inactivation is optimal with UV-A wavelengths of light (320-400nm) while more energetic UV-B light (< 320nm) is often necessary for efficient organic contaminant destruction. Cover materials to be tested include quartz (completely UV transparent), Pyrex glass (blocks UV-B radiation), and acrylics (which are more durable/lighter weight) of varying UV transparency. Temperature will also be a variable in these studies, with the reactors being heated passively (either ambiently or using a reflector to focus/increase light dosage). Control experiments (no light exposure) will be conducted in parallel to all photolysis experiments. In all experiments, aqueous samples (~ 1 mL) will be collected at selected time intervals from the reactors run in duplicate. At least seven time points will be collected.

<u>Pilot Studies.</u> The laboratory experiments will be used to guide the design of a pilot scale system to be set up at the Blue Lake wastewater treatment plant in Shakopee, MN. This treatment plant is particularly well suited for the study, because after undergoing activated sludge treatment, wastewater passes through a holding pond prior to final disinfection and discharge. Using data from the laboratory studies (specifically, the kinetics of bacterial inactivation and pharmaceutical destruction) the performance of the pilot system will be predicted for a given volume/depth (passive) or volume, depth, and flow rate (active system). The cover material to be used in the active system will also be based on the results of the laboratory studies. In both systems, water depth (rather than volume) is expected to be the crucial geometric parameter. The passive system will be a tank with total capacity of approximately 50-100 L. The active system will have a volume of approximately 2 L. It is expected that residence times in the active system will need to be on the order of one hour, so flow rates will vary from 0.5 to 8 L/hr. Funds for the materials and labor for the construction of the tanks (~$2,000) and a pump (~$1,000) are included in the supply budget.

We will focus this study on the human antibiotics (sulfamethoxazole and triclosan) and one of the estrogenic compounds (to be determined). Both passive and active systems will be studied. In the passive systems, samples will be removed to monitor pharmaceuticals, heterotrophic plate counts (with and without tetracycline), and antibiotic resistance genes as a function of time. In the active systems, influent and effluent concentrations of these parameters will be measured. The analytical methods are described below. We will also conduct a pilot-scale study of the passive system at an agricultural site using tylosin and tetracycline as the target compounds. The procedures will be the same as those described above. We anticipate that we will have to spike the waters with the target compounds for both the wastewater and the agricultural pilot tests to ensure we can routinely and easily detect the target compounds.

In both the active and passive systems, the performance of the system will be measured as a function of residence time, solar exposure (i.e., season), temperature, and water depth. With the active system, the utility of a light reflection system will also be evaluated. Temperature will be monitored using a thermocouple and a data logger. The ultimate goal is to determine if the laboratory measured parameters accurately represent pilot system performance, and if not, what correction factors are necessary to design the system to achieve the desired performance.

Analytical methods and data analysis

Total heterotrophic and tetracycline-resistant heterotrophic bacteria will be enumerated by standard spread-plating techniques. LB-agar plates will be made by mixing 10 g tryptone, 5 g yeast extract, 5 g NaCl, and 15 g washed agar per liter of deionized water. This media will be sterilized by autoclaving (20 min; 121°C; 15 psig). To enumerate tetracycline-resistant bacteria, tetracycline will be added (20 mg/L final concentration) following sterilization, after allowing the media to cool to ~ 60°C. Aqueous samples will undergo a 10-fold serial dilution in phosphate-buffer saline (10 mM; pH 7) and be applied to agar plates using aseptic techniques. Bacteria will be enumerated in digester solids by adding 0.5 g of material to 9 mL of phosphate-buffer saline (10 mM; pH 7) prior to dilution. LB agar plates will be incubated at 37°C for 1 day. All assays will be performed in triplicate.

Because a substantial fraction of tetracycline-resistant bacteria might not grow on LB plates, we will also enumerate tetracycline resistant bacteria by real time quantitative PCR. Five replicate samples will be collected at each time point so that the variability of quantitative PCR can be assessed (Dionisi et al., 2003; Mumy and Finlay, 2004). Aqueous samples (about 10 mL of sample is anticipated) will be filtered through 25-mm diameter poretics filters (pore size = 0.2 μm) to concentrate the biomass. These filters will then be suspended in lysis buffer and subjected to three consecutive freeze-thaw cycles, followed by a 90 min incubation at 70°C to help lyse cells. For sludge samples, the cells will be concentrated by centrifugation and re-suspended in lysis buffer and lysed using a bead-beater approach (FastPrep FP120; Qbiogene).

Total genomic DNA will be purified from these samples using the FastDNA Spin Kit. Extracted DNA will be quantified by staining with Hoescht dye 33258 and correlating results to a standard curve calibrated with calf thymus DNA. Four different genes encoding for tetracycline resistance will be quantified by real time PCR (*tet*(A), *tet*(L), *tet*(O), and *tet*(W)) (unpublished results from the LaPara lab; Smith et al., 2004) and normalized to 16S rRNA genes, also quantified by real time PCR (as described by Pei et al., 2006). Our facilities utilize 96-well microtiter plates, and thus this technique can be very high-throughput.

We will complement these enumerations of tetracycline resistance by targeted analysis of the bacterial isolates and genes encoding tetracycline resistance. Bacterial isolates will be characterized by 16S rRNA gene sequence (i.e., for identification), multiplex PCR for 14 different genes encoding for tetracycline resistance (Ng et al., 2001), and resistance to multiple antibiotics (ciprofloxacin, ampicillin, sulfamethoxozole/trimethoprim, and erythromycin). We will also perform limited PCR-clone libraries of *tet*(A), *tet*(L), *tet*(O), and *tet*(W) to confirm our results. More detailed descriptions of these methods can be found in Firl (2006).

Pharmaceutical compound concentrations will be monitored by a variety of methods. In water samples that are dosed with higher levels of the compounds (1-10 mg/L), direct analysis of the samples with high pressure liquid chromatography with UV detection will be used. For experiments/pilot trials using lower levels, solid phase extraction will be used to concentrate the samples and analysis will be performed via either gas or liquid chromatography coupled with mass spectrometry. For biosolids samples, the material will be dried and Soxhlet extracted. The extract will then be concentrated and analyzed as described above. These methods are currently being used in Dr. Arnold's laboratory for related projects.

When a detailed temperature record is necessary, a thermocouple will be used to measure temperature and the data recorded by a personal computer (laboratory) or data logger (field). Additional water quality parameters to be measured via standard/routine methods included pH, dissolved oxygen, turbidity, total organic carbon, alkalinity, hardness (i.e., Mg^{2+} and Ca^{2+} concentrations), nitrate/ammonia concentration, and UV/visible light absorption for water samples (*Standard Methods*, 1995).

Chromatography systems will be calibrated using, at a minimum, five-point calibration curves. Precision and accuracy will be evaluated via replicate experiments and analyses. Additionally, errors (95% confidence intervals) associated with instrument calibration and detection limits will be quantified. All measured concentrations will be reported with appropriate propagated errors. Blanks, spiked samples, and replicate analyses will be used as quality assurance/quality control measures.

All data fitting and statistical analyses will be performed using commercially available software packages (*e.g.*, *Scientist* for Windows, Microsoft *Excel*). Kinetic rate constants for pharmaceutical and baceterial removal in both laboratory and pilot studies will be regressed using averaged data from replicate experiments and 95% confidence intervals determined. Comparisions between different treatments/conditions (i.e., cover materials and temperatures in the laboratory experiments and residence time, solar exposure, temperature, and water depth in the pilot studies) will be made at the 95% confidence interval to determine if the removal rates are statistically different from each other and from zero.

IV. Results and Products

It is expected that both thermophilic treatment of biosolids and solar treatment of water will effectively remove both the target pharmaceuticals and antibiotic resistant bacteria. Specifically, both types of thermophilic digestion will be excellent at inactivating antibiotic resistant bacteria, but that there will be substantial differences between anaerobic and aerobic thermophilic digestion to biodegrade antibiotics and pharmaceutical compounds (*e.g.,* some compounds will be rapidly biodegraded under aerobic conditions but not under anaerobic conditions). The deliverable product is evaluation of which thermophilic treatment method (aerobic or anaerobic) provides the best removal efficiencies. This research will extend the suitable applications of these established technologies, fulfilling a technology need that will benefit Minnesota. This research will also demonstrate the further importance of thermophilic digestion, which is currently employed within Minnesota at the Western Lake

Superior Sanitary District. The implementation of thermophilic digestion is also under consideration at least one other Minnesota municipality (Knoff, 2007).

For the solar treatment of water, we expect the active/covered systems to be more effective for disinfection. For the removal of pharmaceuticals, the active/covered system will have positive and negative effects. The increased temperature and the possibility to focus the light (using a reflective surface) will enhance removal, but the covering materials will partially attenuate the UV-B radiation that generally leads to pharmaceutical destruction. Thus, we expect an open system with shallow depth will give most effective removal of the pharmaceuticals. The outcomes of this result are (1) determination of the feasibiltiy of solar treatment to simultaneously destroy pharmaceuticals and bacteria and (2) quantification of necessary light doses/exposure times as a function of season, and (3) required capacity and reactor depth to treat a given volume (passive) or flow rate (active) of water.

V. Timetable

The research tasks outlined above will be accomplished according to the following schedule. Shaded regions are continuous efforts and X's mark discreet events.

	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Result 1: Thermophilic treatment of biosolids												
Biosolid collection	X				X							
Establish reactors												
-anaerobic	■	■										
-aerobic					■	■						
Reactor operation												
-anaerobic			■	■	■	■						
-aerobic							■	■	■	■		
Data analysis			■	■	■	■	■	■				
Product delivery							X					X
Result 2: Solar treatment of water												
Laboratory studies												
-Water collection	X	X	X									
-Optimize depth, time, and temperature	■	■	■	■								
-Evaluate cover materials			■	■	■	■						
Pilot-scale reactor operation						■	■	■	■	■	■	
Data analysis		■	■	■	■	■	■	■	■	■	■	■
Product delivery							X					X

VI. Deliverable products correlated to the timetable

We estimate that after eighteen months, we will be able to report on the performance of the anaerobic digesters. At this point, we will also have determined the necessary times to destroy the individual pharmaceuticals and will have determined the best cover material for active solar treatment systems.

VII. Budget requirements

The requested funds from LCCMR total $302,000. The total cost breakdown is as follows.

Staff or Contract Services. Over the three year project, Drs. LaPara and Arnold will devote 8% (1 month per year) of time to the project (total salary and fringe benefits of $81,052). The responsibilities of the principal investigators includes experimental design, product coordination, data analysis, student guidance, and report/product preparation. Two graduate student researchers pursuing M.S. or Ph.D. degrees will conduct the day-to-day experiments described above. A 50% appointment is considered full time for students (and includes tuition payment and health insurance), and funds for two 40% appointments is budgeted ($146,530). The remaining 10% appointment will be supplied by teaching assistantships (TAs) or funding from other research grants. Support for the environmental engineering laboratory manager/technician is also requested (5%; $9,932). Responsibilities of the technician include aiding the students in sample preparation/analysis, equipment maintenance, and enforcing laboratory safety protocols.

Equipment. A sum of $40,000 is budgeted for the purchase of a high pressure liquid chromatograph. This essential piece of equipment is required to monitor the concentrations of the target antibiotics and estrogens in the laboratory experiments as well as in the pilot-scale tests. (Trace level analysis will be performed on mass spectrometry equipment, see below). The investigators do currently have access to an HPLC. The instrument, however, is beyond its expected lifetime, and spare parts are no longer available. If the instrument fails, the project will be unable to proceed. Thus, a new instrument is necessary to ensure the project goals are met. Given the number of samples expected to generated by the project, it is more economical to purchase an instrument rather than pay per sample fees on an instrument in another laboratory.

Other. Additional funds totaling $24,486 dollars are requested for travel (mileage charges for trips to partner wastewater facilities/farms; $1,000), laboratory supplies (glassware, chemicals, analytical reagents/consumables, gloves, data storage media, materials for reactor construction); $12,486), analytical services (microbial analyses, gene sequencing, instrument time on liquid chromatograph-mass spectrometers for trace chemical analysis; $10,000), and publication/dissemination costs ($1,000).

Leveraged funds. An additional $5,000 towards the purchase of the HPLC will be leveraged from an unrelated grant of Dr. Arnold. Dr. Arnold is also leading a National Science Foundation sponsored project ($266,000) studying the fate of triclosan in the environment. A portion of this effort is focused on the transformation of triclosan when it is exposed to sunlight, and we will be able to leverage the results for this project.

We will also partner with the Metropolitan Council Environmental Services, Western Lake Superior Sanitary District, and anonymous farmers. Drs. LaPara and Arnold have teamed with these groups in past research efforts, and thus a good working relationship between the lead invesigators and partners already exists. The partners will provide in-kind contributions (i.e., site access, sampling assistance, staff time) at no direct cost to the proposed project.

The proposed project is a result of past research and collaborations of Drs. Arnold and LaPara. Previous funds totaling $340,000 have been spent on studies on the proliferation on antibiotic resistant bacteria in agricultural soils, the fate of pharmaceutical and personal care products in surface waters, and the release of antibiotic resistant bacteria from the Metropolitan Wastewater Treatment plant (St. Paul). The knowledge and techniques from these past projects will be used in the proposed LCCMR project.

VIII. Investigators' qualifications

Drs. LaPara and Arnold are nationally-known researchers with expertise on antibiotic resistance/thermophilic digestion and the environmental chemistry of pharmaceutical compounds, respectively. Dr. LaPara will be responsible for studying the inactivation/disinfection of antibiotic resistant bacteria in the targeted treatment systems and design/operation of the thermophilic digestion experiments. Dr. Arnold will focus on the degradation of the pharamceuticals and have responsibility for the design/operation of the solar treatment studies.

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PROFESSIONAL EXPERIENCE

2006- **Associate Professor**, Department of Civil Engineering, University of Minnesota, Minneapolis, MN and member of the graduate faculty in Water Resources Sciences

2000-2006 **Assistant Professor**, Department of Civil Engineering, University of Minnesota, Minneapolis, MN and member of the graduate faculty in Water Resources Sciences

EDUCATION

1999 **Ph.D.** Purdue University, West Lafayette, IN, School of Civil Engineering, Geography and Environmental Engineering.

1995 **B.S.C.E.** University of Notre Dame, Notre Dame, IN, Civil Engineering

RESEARCH INTERESTS

Biological wastewater treatment, wastewater microbiology, environmental microbiology, structure-function relationships in mixed microbial communities, antibiotic resistant bacteria, microbial ecology, and microbial evolution

RELEVENT CURRENT AND PAST RESEARCH FUNDING

"Antibiotics in the Environment: Linking Environmental Fate to the Proliferation of Antibiotic Resistant Bacteria", PI, US Department of Agriculture, $240,000, 9/1/03-8/31/07.

"The current role of municipal wastewater treatment facilities in the proliferation of antibiotic resistant bacteria", PI, Center for Urban and Regional Affairs, $45,054, July 1, 2004 – December 31, 2005

SELECTED HONORS AND AWARDS

2005 *Bonestroo, Rosene, Anderlink & Assoc. Undergraduate Teaching Award*, Univ. of Minnesota

1999 *Donald E. Bloodgood Memorial Award*, Purdue University

1995 *Walter L. Shilts Award***,** University of Notre Dame

PROFESSIONAL AFFILIATIONS

American Society for Microbiology, Water Environment Federation, International Water Association, International Society for Microbial Ecology, Association of Environmental Engineering and Science Professors

RELEVANT PEER REVIEWED PUBLICATIONS

1. Wammer KH, **TM LaPara**, K McNeill, WA Arnold, and DL Swackhamer. 2006. Changes in antibacterial activity of triclosan and sulfa drugs due to photochemical transformations. *Environmental Toxicology and Chemistry* **25**(6):1480-1486.
2. Kappell AS, MJ Semmens, PJ Novak and **TM LaPara**. 2005. A novel application of oxygen-transferring membranes to improve anaerobic wastewater treatment. *Biotechnology and Bioengineering* **89**(4):373-380.
3. Onan LJ and **TM LaPara**. 2003. Tylosin-resistant bacteria cultivated from agricultural soil. *FEMS Microbiology Letters* **220**(1):15-20.
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5. **LaPara TM**, A Konopka, CH Nakatsu and JE Alleman. 2001. Thermophilic aerobic biological wastewater treatment of a synthetic wastewater in a membrane-coupled bioreactor. *Journal of Industrial Microbiology and Biotechnology* **26**(4):203-209.
6. **LaPara TM**, CH Nakatsu, LM Pantea and JE Alleman. 2000. Phylogenetic analysis of bacterial communities in mesophilic and thermophilic bioreactors treating pharmaceutical wastewater. *Applied and Environmental Microbiology* **66**(9):3951-3959.
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PROFESSIONAL EXPERIENCE

2006-2007 **Visiting Researcher,** Eawag, The Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland

2005- **Associate Professor**, Department of Civil Engineering, University of Minnesota, Minneapolis, MN and member of the graduate faculty in Water Resources Sciences and in Stream Restoration Science and Engineering

1999-2005 **Assistant Professor**, Department of Civil Engineering, University of Minnesota, Minneapolis, MN and member of the graduate faculty in Water Resources Sciences

EDUCATION

1999 **Ph.D.** The Johns Hopkins University, Baltimore, MD, Department of Geography and Environmental Engineering.

1995 **M.S.** Yale University, New Haven, CT, Department of Chemical Engineering.

1994 **S.B.** Massachusetts Institute of Technology, Cambridge, MA, Chemical Engineering, Minor in Chemistry.

RESEARCH INTERESTS

Fate and abiotic transformations of anthropogenic chemicals in natural and engineered aquatic systems, including

- Redox reactions at metal and mineral surfaces
- Photochemistry in surface waters and for water treatment
- Disinfection by-product degradation and formation
- Reactive membrane systems

RELEVENT CURRENT AND PAST RESEARCH FUNDING

"Collaborative Research: Formation of Polyhalogenated Dioxins and Furans from Triclosan and PBDEs in Rivers", PI, National Science Foundation, $266,000, 6/1/06-5/31/08.

"Photochemistry of Antibiotics and Estrogens in Surface Waters: Persistence and Potency", co- PI, National Institutes for Water Resources, $134,070, 9/1/02-2/28/06.

"Antibiotics in the Environment: Linking Environmental Fate to the Proliferation of Antibiotic Resistant Bacteria", co-PI, US Department of Agriculture, $240,000, 9/1/03-8/31/07.

"Environmental Estrogens and Antibacterials in Aquatic Systems: Occurrence, Persistence, and Fate", co-PI, Dreyfus Foundation, $96,000, 8/1/03-7/31/05.

"Photodegradation of Pharmaceutical Compounds Discharged and Detected in Natural Waters", PI, National Institutes for Water Resources, $102,656, 9/1/01-8/31/03.

SELECTED HONORS AND AWARDS

2005 Excellence in review award from *Environmental Science and Technology*

2003 1st Place Montgomery-Watson-Harza Consulting Engineers/AEESP Master's Thesis Award for Jennifer L. Packer's Thesis

2003 Bonestroo, Rosene, Anderlik and Associates Undergraduate Faculty Award (for excellence in teaching, advising, and mentoring of students)
2003 MFES Minnesota Young Engineer/Science & Technology Professional of the Year
2003 ASCE Minnesota Section Young Engineer of the Year

PROFESSIONAL AFFILIATIONS

American Chemical Society (Environmental Chemistry Division), American Geophysical Union (Hydrology Section)**,** American Society of Civil Engineers, Association of Environmental Engineering and Science Professors, Licensed Professional Engineer (Minnesota)

RELEVANT PEER-REVIEWED PUBLICATIONS

1. Werner, J.J.; **Arnold, W.A.**; McNeill, K., 2006. Water hardness as a photochemical parameter: tetracycline photolysis as a function of calcium concentration, magnesium concentration, and pH, *Environmental Science and Technology,* v. 40, 7236-7241.
2. Edhlund, B.L.; **Arnold**, **W. A.;** McNeill, K. 2006. Aquatic photochemistry of nitrofuran antibiotics, *Environmental Science and Technology*, v. 40, 5422-5427.
3. Wammer, K. H.; LaPara, T. M.; McNeill, K.; **Arnold**, **W. A.;** Swackhamer, D. L. 2006. Changes in antibacterial activity of triclosan and sulfa drugs due to photochemical transformations, *Environmental Toxicology and Chemistry*, v. 25, 1480-1486.
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7. Boreen, A.L.; **Arnold, W.A.**; McNeill, K., 2004. Photochemical Fate of Sulfa Drugs in the Aquatic Environment: Sulfa Drugs Containing Five-Membered Heterocyclic Groups. *Environmental Science and Technology*, v. 38, 3933-3940.
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Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: *Pharmaceutical and Microbiological Pollution Minnesota's surface waters; 5(L)*

Project Manager Name: *Timothy M. LaPara*

Trust Fund Appropriation: $302,000

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Result 1 Revised Budget:**	**Amount Spent 6/30/10**	**Balance 6/30/10**	**Result 2 Budget:**	**Amount Spent 6/30/10**	**Balance 6/30/10**	**TOTAL BUDGET**
	Thermophilic treatment of municipal and agricultural biosolids	*Thermophilic treatment of municipal and agricultural biosolids*			*Solar treatment of water for pharmaceutical destruction and disinfection*			
BUDGET ITEM								
PERSONNEL: wages and benefits	~~118,684~~	103,684	102,284	16,400	118,684	112,563	2,613	~~237,368~~
Other direct operating costs *(laboratory supplies, travel for pilot studies and wastewater collection, publication costs, and analytical services such as DNA sequencing and real-time PCR)*	~~11,316~~	16,316	18,038	-6,722	11,316	18,383	-2,559	~~22,632~~
Equipment / Tools *(High Pressure Liquid Chromatograph; cost = $40,000; real time thermal cycler, trust fund cost = $10,000 out of $26,100 total -- additional funds will come from other research grants)*	~~20,000~~	30,000	30,000	-10,000	20,000	20,000	0	~~40,000~~
Printing	0	0	0	0	500			500
Travel expenses in Minnesota	0	0	0	0	500			500
Other *(ST Rents & Leases)*	1,000	1,000	678	322	0	54	-54	1,000
COLUMN TOTAL	**$151,000**	**$151,000**	**$151,000**	**$0**	**$151,000**	**$151,000**	**$0**	**$302,000**

2007 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Threat of Emerging Contaminants to Upper Mississippi Walleye
PROJECT MANAGER: Dr. Heiko L. Schoenfuss
AFFILIATION: St. Cloud State University
MAILING ADDRESS: 720 Fourth Avenue South, WSB-273
CITY/STATE/ZIP: St. Cloud, MN 56301
PHONE: (320) 308-3130
E-MAIL: hschoenfuss@stcloudstate.edu
WEBSITE: web.stcloudstate.edu/aquatictox
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION:

M.L. 2009, Chapter 143, Section 2, Subd. 16. Carryforward
The availability of the appropriations for the following projects is extended to June 30, 2010:
5) Laws 2007, chapter 30, section 2, subdivision 5, paragraph (m), threat of emerging contaminants to Upper Mississippi walleye.

APPROPRIATION AMOUNT: $97,000

Overall Project Outcome and Results

In this combined field and laboratory study we assessed whether populations of native walleye in the Upper Mississippi River experienced altered genetic diversity correlated with the exposure to estrogenic endocrine active compounds. We collected fin-clips for genetic analysis from almost 600 walleye (13 sites) and sub-sampled over 360 of these fish (6 sites) for blood and reproductive organs. We further enhanced our sample size by adding genetic data from over 900 walleye analyzed for previous studies. Finally, we caged male fathead minnows at three of the sample sites to confirm the presence of estrogenic endocrine active compounds. Our findings indicate that male walleye in four river segments produce measurable concentrations of plasma vitellogenin (an egg-yolk protein and, when expressed in male fish, a biomarker of acute estrogenic exposure), a finding consistent with the presence of estrogenic endocrine active compounds and consistent with published historical data for at least three of these study sites (Grand Rapids, Pool 2, Lake Pepin). Patterns of vitellogenin induction were consistent for native walleye and caged fathead minnows. No widespread occurrence of histopathological changes such as intersex was found. To assess the genetic diversity of the walleye populations at the study sites, we DNA fingerprinted individual fish using molecular genetic markers. Genetic differences were observed between populations, however, these differences were consistent with geographic distance between populations (greater geographic distance=greater genetic difference) with the largest observed difference in genetic diversity found between fish upstream and downstream of St. Anthony Falls (and/or Lock and Dam 1 of the Mississippi River), a historical barrier to fish movement. In summary, while the persistent occurrence of endocrine disruption in wild fish populations is troubling, this insult has not resulted in the degradation of reproductive organs in individual walleye or alteration in genetic diversity of walleye populations.

Project Results Use and Dissemination

Project results have been provided to the LCCMR on a semi-annual basis and in this final report. A related report on some of the genetic findings is also being prepared for the MN Department of Natural Resources.

We plan to present the results of this study to the scientific community in form of a peer-reviewed manuscript in the near future.

Furthermore, we will present our results to the regional scientific community and stakeholders at upcoming fisheries (i.e., Annual Meeting of the American Fisheries Society, Minnesota Chapter) and toxicological (i.e., Annual Meeting of the Society for Environmental Toxicology & Chemistry, Midwest Chapter) meetings.

We have also provided limited project information on the website of the Aquatic Toxicology Laboratory at St. Cloud State University (web.stcloudstate.edu/aquatictox) and will provide a more extensive review of the study after approval of the final report by the LCCMR.

Trust Fund 2007 Work Program Final Report

Date of Report: August 16, 2010
Final Report
Date of Work program Approval:
Project Completion Date: June 30, 2010

The completion data of the project has been extended by one year to June 30, 2010 per M.L. 2009, Chapter 143, Section 2, Subd. 16. Carryforward.

I. PROJECT TITLE: Threat of Emerging Contaminants to Upper Mississippi Walleye

Project Manager: Dr. Heiko L. Schoenfuss
Affiliation: St. Cloud State University
Mailing Address: 720 Fourth Avenue South, WSB-273
City / State / Zip : St. Cloud / MN / 56301
Telephone Number: (320) 308-3130
E-mail Address: hschoenfuss@stcloudstate.edu
FAX Number: (320) 308-4166
Web Page address: web.stcloudstate.edu/aquatictox

Location: Upper Mississippi Watershed

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$** 97,000
	Minus Amount Spent:	**$** 97,000
	Equal Balance:	**$0**

Legal Citation:

M.L. 2009, Chapter 143, Section 2, Subd. 16. Carryforward
The availability of the appropriations for the following projects is extended to June 30, 2010:
5) Laws 2007, chapter 30, section 2, subdivision 5, paragraph (m), threat of emerging contaminants to Upper Mississippi walleye.

ML 2007, [Chap. 30], Sec.[2], Subd. 5m.

Appropriation Language:
$97,000 is from the trust fund to St. Cloud State University to assess whether the genetic diversity of walleye in the Upper Mississippi is negatively impacted by emerging contaminants at pollution hotspots where feminized male fish have been identified.

II. and III. FINAL PROJECT SUMMARY

In this combined field and laboratory study we assessed whether populations of native walleye in the Upper Mississippi River experienced altered genetic diversity correlated with the exposure to estrogenic endocrine active compounds. We collected fin-clips for genetic analysis from almost 600 walleye (13 sites) and sub-sampled over 360 of these fish (6 sites) for blood and reproductive organs. We further enhanced our sample size by adding genetic data from over 900 walleye analyzed for previous studies. Finally, we caged male fathead minnows at three of the sample sites to confirm the presence of estrogenic endocrine active compounds. Our findings indicate that male walleye in four river segments produce measurable concentrations of plasma vitellogenin (an egg-yolk protein and, when expressed in male fish, a biomarker of acute estrogenic exposure), a finding consistent with the presence of estrogenic endocrine active compounds and consistent with published historical data for at least three of these study sites (Grand Rapids, Pool 2, Lake Pepin). Patterns of vitellogenin induction were consistent for native walleye and caged fathead minnows. No widespread occurrence of histopathological changes such as intersex was found. To assess the genetic diversity of the walleye populations at the study sites, we DNA fingerprinted individual fish using molecular genetic markers. Genetic differences were observed between populations, however, these differences were consistent with geographic distance between populations (greater geographic distance=greater genetic difference) with the largest observed difference in genetic diversity found between fish upstream and downstream of St. Anthony Falls (and/or Lock and Dam 1 of the Mississippi River), a historical barrier to fish movement. In summary, while the persistent occurrence of endocrine disruption in wild fish populations is troubling, this insult has not resulted in the degradation of reproductive organs in individual walleye or alteration in genetic diversity of walleye populations.

IV. OUTLINE OF PROJECT RESULTS*:*

Rationale. In 2006 St. Cloud State University in collaboration with the US Geological Survey conducted a study of fish health in the Upper Mississippi River from Lake Itasca to the Iowa border. Our study sampled 43 sites and included fish samples from four species, including walleye and smallmouth bass, as well as water and sediment samples from each location. This survey of fish health in the context of emerging contaminants, especially endocrine disruptors and pharmaceuticals, represents the largest such effort in North America to date.

Our results indicate that there are several “hotspots” where fish health in the Mississippi River is impaired in a fashion that is consistent with the effects of emerging contaminants (see map). These effects include the feminization of male fish, which has been linked to intersex (hemaphrodism) and reduced reproductive ability in male fish. The long-term health of Minnesota fish populations may be at risk due to the impacts of these emerging contaminants on fish health. This is especially true since recent genetic research has demonstrated that long-term fish exposure to treated wastewater effluents can alter the genetic structure of fish populations and potentially result in genetic bottlenecks that can cripple a population. Fish populations that may appear healthy could in fact be approaching a critical deficit in genetic diversity to overcome subsequent environmental challenges. This is a crisis that is not obvious to the naked eye until it is too late.

We propose a combined field and laboratory approach that would for the first time, link the occurrence of emerging contaminants in the Mississippi River to feminization in male fish and explore the possibility of reduced genetic diversity in populations of walleye. The study is designed to make use of existing data and the broad expertise of our collaborative group, including an aquatic toxicologist (HLS), a fish geneticist (LMM), and aquatic ecologist (MLJ). Results of this study would allow resource managers and agencies to focus resources on particularly vulnerable populations of walleye and could be extrapolated to fish populations in all Minnesota waters.

Result 1: Field Collection of Feminized Fish

Description: We will confirm the feminizining effects of Mississippi River waters on walleye and fathead minnows at four contamination "hotspots" identified in our extensive existing data set. We will also identify two reference sites where fish and water samples showed no indication of the presence of emerging contaminants. All six sites will be re-sampled for walleye (up to 60 fish) and fathead minnows to generate a larger fish sample than was possible in our previous study (we will be able to add archived samples from the previous study). In addition we will cage male fathead minnows at each sites for seven days, an US EPA recommended length of time. The caging of fathead minnows will serve two purposes, first, it will confirm the presence of emerging contaminants at the identified hotspot sites before the commencement of the costly genetic analysis, and second, it will allow us to link our field studies to an existing large body of laboratory research on the effects of emerging contaminants on fish. All walleye collected will be assessed for their reproductive health (Result 2) and genetic diversity (Result 3).

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$** 19,000
	Amount Spent:	**$ 19,000**
	Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. *Collecting Walleye I*	*Sept. 30, 2007*	*$5,000*	*$0*
2. *Cage Fatheads*	*Dec. 31, 2007*	*$9,000*	*$0*
3. *Collect Walleye II*	*Sept. 30, 2008*	*$5,000*	*$0*

Completion Date: December 31, 2009

Final Report Summary:
During three field season (2007-2009) we collected 377 adult walleye from six field sites in the Mississippi River between Lake Winnibigoshish and Lake Pepin, including several previously identified "hotspot" sites (Grand Rapids, Clearwater,

Pool 2, Lake Pepin) and two control sites (Downstream of Lake Winnibigoshish, Sartell) (Table 1, below). Fish were collected by various means with a sizeable portion being donated by anglers on the Mississippi River on walleye openers in 2007 and 2008. Additional collections were made by the St. Cloud State University Aquatic Toxicology Laboratory and the MN Department of Natural Resources. Although our collections targeted male fish, we were able to assess parameters related to endocrine disruption in 66 female fish (18% of the total catch). We also proceeded with the deployment of caged fathead minnows on the Mississippi River (Table 2), however drought conditions in 2007, the flooding in 2008 and concerns about *viral hemorrhagic septicemia* limited the success of this effort to three sites.

Table 1. Summary of walleye collected in this study for assessment of endocrine disruption and genetic diversity.

Sampling location	river mile[1]	2007		2008		2009		Sum	
		Morphology & physiology	genetics[2]	Morphology & physiology	genetics[2]	Morphology & physiology	genetics[2]	Morphology & physiology	genetics[2]
Lake Bemidji	1282		30[3]						**30**
Upstream of Grand Rapids	1,202	79	81	25	20	30	24	**134**	**125**
Grand Rapids	1,183	40	39	67	59	37	33	**144**	**131**
Aitkin	1,060		25						**25**
Brainerd–above dam	1008		28						**28**
Brainerd-below dam	1005		34						**34**
Little Falls	965		19						**19**
Sartell	929	27	30					**27**	**30**
Clearwater	923	9	3					**9**	**3**
Monticello	898				18				**18**
Pool 2	836	22	47					**22**	**47**
Red Wing	792						47		**47**
Lake Pepin	771	15	15	26	32			**41**	**47**

[1] River mile as measured above Cairo, IL
[2] Genetic sample size differs from morphology/physiology sample due to extra fin clips added to the study from other sources and occasional DNA amplification failure.
[3] Sampled in 2006 by MN DNR

Figure 1. Map of the Upper Mississippi River in Minnesota with sites from which walleye were collected.

Our attempts to collect walleye for his study provided some important insights for future studies of this important species in Minnesota waters: (i) collecting large numbers of walleye nearly concurrently at multiple sites in large river system is extremely challenging as weather and water conditions (i.e., ice coverage) will vary across the State, as fish move into deeper water shortly after spawning in early spring, and as these fish seldom occur in large densities. (ii) Out of necessity and in correspondence with the MN Department of Natural Resources, we resorted to collecting fish tissues from walleye captured by anglers on walleye opener. This technique was very successful, engaged the local fishing community and provided a temporally very concise sample. We recommend the involvement of local fishing organizations for future studies with similar parameters.

Summary of field methods applied: Three to 5 milliliters (mL) of blood was drawn from the caudal vasculature and transferred into a hematocrit tube that was stored on wet ice. The fish was then sacrificed, and measurements were recorded for the fish's weight, total and standard lengths. Body Condition Indices (BCIs) were calculated as [(total weight/standard length^3)*1000000]. The BCI is considered a measure to examine whether fish are of similar nutritional condition across field sites.

Several testis samples were collected for histological analysis, and placed into histological cassettes. In male fish, both testes were removed and a representative sample was collected and placed into a histological cassette. If gravid ovaries were present in the abdominal cavity, the sex was noted on the data sheets as female, but no attempt was made to weigh or collect these tissues for later histological analysis. The rationale for the exclusion of female reproductive tissue was that a gravid female ovary was too fragile to be removed intact and that histological analysis would not yield any further information. All histological cassettes were then placed into a site-specific container with 4 percent formalin. During the collection, an effort was made to return collected fish samples (blood and testis) to the laboratory within 15 hours but not more than 36 hours, from collection time. All specimens were maintained on ice until they could be processed according to analysis needs in the laboratory.

Result 2: Laboratory Assessment of Fish Health

Description: We will (1) confirm the presence of emerging contaminants at the field site and (2) link the findings in the wild caught walleye to more defined laboratory endpoints in the fathead minnow. The SCSU Aquatic Toxicology Laboratory is well equipped to analyze the reproductive health of all captured and caged fish. We have extensive expertise in documenting the likely effects of fish exposure to emerging contaminants in a timely and cost efficient manner. All fish captured and caged will undergo a histopathological analysis of the reproductive organs to test for the occurrence of hemaphrodism, a blood plasma analysis for the female egg yolk protein in male fish (a bioindicator of acute exposure to emerging contaminants), and will be measured for morphometric endpoints. The inclusion of caged fathead minnows will provide a linkage between relevant field and laboratory data. This unique study design would greatly increase the interpretive power by establishing a cause and effect relationship between emerging contaminants and fish samples instead of merely allowing for correlations to be made.

Summary Budget Information for Result 2: **Trust Fund Budget:** **$** 29,000
Amount Spent: **$ 29,000**
Balance: **$ 0**

Deliverable	Completion Date	Budget	Status
1. *Walleye VTG I*	*Dec. 31, 2007*	*$4,000*	*$0*
2. *Walleye Histology I*	*March 31, 2008*	*$6,000*	*$0*
3. *Fathead Minnow VTG/Histology*	*Dec. 31, 2008*	*$9,000*	*$0*
4. *Walleye VTG II*	*March 31, 2009*	*$4,000*	*$0*
5. *Walleye Histology II*	*June 30, 2009*	*$6,000*	*$0*

Completion Date: June 30, 2010

Final Report Summary:
We collected mature walleye from six sites on the Upper Mississippi River and assessed the potential for physiological or morphological responses consistent with the exposure to endocrine active compounds (Figure 2). In addition, we assessed similar parameters in male fathead minnows that were caged at three of the six field sites (Table 2).

Figure 2. (A), (B) Physiological (vitellogenin induction [µg/mL]), and (C), (D) morphological (Body Condition Index) characteristics of walleye collected in the Mississippi River 2007-09.

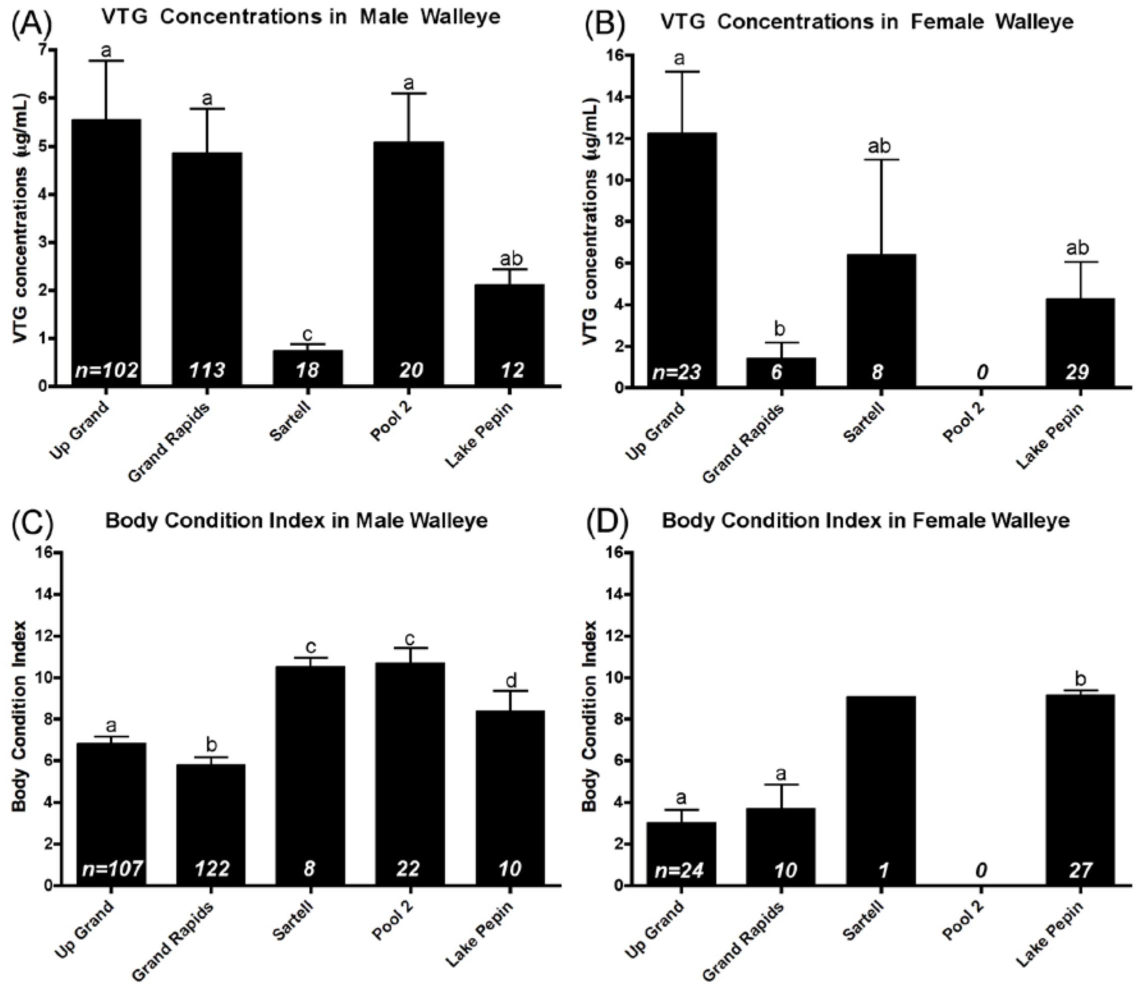


Table 2. Physiological and morphological assessment of male fathead minnows caged at three sites in the Upper Mississippi River.

Caging Location	n	Plasma vitellogenin mean ± standard error	Body Condition Factor mean ± standard error
Upstream Grand Rapids	0	cages lost in 2008 flooding	
Grand Rapids	0	cages lost in 2008 flooding	
Sartell	7	2.2 ± 0.54	11 ± 0.43
Clearwater	20	24 ± 8.8	11± 0.25
Pool 2	19	152 ± 120	11 ± 0.23
Lake Pepin	0	no fish caged due to concerns over *viral hemorrhagic septicemia*	

Our analysis of the collected walleye and caged fathead minnows revealed that fish in several sections of the Upper Mississippi River in Minnesota are exposed to estrogenic endocrine active compounds that are persistent enough to result in physiological responses (vitellogenin induction), but not severe enough to cause morphological (body condition index, histopathology) changes to the exposed fish. We observed the induction of plasma vitellogenin in four of the six river segments from which we collected fish: Upstream of Grand Rapids, Grand Rapids, Pool 2 in St. Paul, MN, and in Lake Pepin. No induction was seen in Clearwater, downstream of St. Cloud, where plasma vitellogenin concentrations were near the detection limit for wild caught walleye as well as caged male fathead minnows. Vitellogenin induction in male fish was consistent for walleye and caged fathead minnows in Pool 2. Interestingly, three of the four sites that were found to contain wild male walleye with measurable concentrations of vitellogenin have been reported to be estrogenic in past studies (Grand Rapids, Pool 2 and Lake Pepin) (Hinck et al. 2009, Aquatic Tox; Barber et al. Aquatic Tox 2007, 82:36-46; Lee et al. 2000, USGS Report 00-4202; Folmar et al. 2001 Arch Environ Contam Toxicol 40:392-398). At none of these sites was induction of vitellogenin correlated with histopathological changes to reproductive organs. In fact, only sporadic histopathological changes were observed across all walleye collected in this study.

The fourth site to exhibit estrogenic activity as assessed by vitellogenin induction in male walleye was just upstream of Grand Rapids (below the outfall of Lake Winnibigoshish). No clear source of estrogenicity is apparent upstream of this collection site. However, other studies have suggested non-point sources such as septic systems, agricultural runoff, and phytoestrogens released from decomposing leave litter may contribute to estrogenicity at specific sites.

Differences in vitellogenin induction and in body condition indices in female walleye across the study sites are likely related to differences in reproductive state of these fish. As most fish were collected on the same day during each of the three field seasons (Walleye Opener), fish in the southern most sites (Lake Pepin, Pool 2) were further past spawning then fish at the northern most sites (Upstream of-, and in Grand Rapids).

Summary of laboratory methods applied: Vitellogenin concentrations were determined in fish plasma using enzyme-linked immunosorbent assay (ELISA) techniques. Whole blood samples were centrifuged in hematocrit tubes (Phoenix Research Products, Hayward, California) for 5 minutes at 5,800 x g, and two aliquots of more than 1 mL plasma were retained for analyses. Triplicate aliquots from each sample were stored in two separate -80 ºC freezers before analyses. An ELISA antibody for striped bass was used to analyze vitellogenin concentrations in walleye plasma (Biosense Laboratories, Bergen, Norway). Standard curves were calculated based on five to seven dilution points (after removing the highest and lowest dilution points). Each ELISA plate included two blanks and a series of purified vitellogenin standards at 250, 125, 62.5, 31.25, 15.62, 7.81, 3.90, 1.95, 0.97, 0.18, and 0.024 micrograms per milliliter (µg/mL). The r-square values for the standard curves were greater than 0.99.

Testis of all male (or perceived male) fish were removed and processed for histological analysis. Histological cassettes were processed in a Jung TP1050 automated tissue processor (Leica, Wetzlar, Germany) according to an established histological protocol of dehydration and embedding in paraffin wax (Gabe, Histological Techniques, 1976). Once embedded, histological sections (three sections per histological cassette) were produced and stained with hematoxylin and eosin stains (two sections). The slides were examined for reproductive condition (immature, gravid, spawned out) and occurrence of intersex or other histopathological findings (i.e., parasitic cysts). Fish were designated as intersex if microscopic evaluation determined the simultaneous occurrence of ovarian and testicular tissue.

Result 3: Emerging Contaminant Population-Level Genetic Effects

Description: Using DNA-based genetic markers, we will assess patterns of genetic diversity within and between walleye populations collected at the contaminated "hotspot" sites and the uncontaminated reference sites. Evaluation of multiple sites along the length of the river will determine if consistent patterns emerge in relation to pollution levels. These assessments will determine if the documented biological effects on individual fish are also translating to genetic and ecological effects at the population level, possibly threatening the genetic integrity and persistence of fish populations. The AquaGen Laboratory at the University of Minnesota is a well-established molecular genetic laboratory focusing specifically on fish population genetics and has a long history of analyzing population level genetic diversity in game fish.

Summary Budget Information for Result 3:	**Trust Fund Budget:**	**$** 49,000
	Amount Spent:	**$ 49,000**
	Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. Walleye DNA Year 1	Dec. 31, 2007	$15,000	$0
2. Data analysis Year 1	June 30, 2008	$5,000	$0
3. Walleye DNA Year 2	Dec. 31, 2008	$22,000	$0
4. Data analysis Year 2	June 30, 2009	$7,000	$0

Completion Date: June 30, 2010

Final Report Summary:

Summary of laboratory methods and data analysis applied:

We genotyped walleye from 12 sites in the Mississippi River (Table 1, above) and added additional reference sites from prior studies (Table 3, below) to determine if patterns in genetic diversity were related to levels of endocrine disruptor effects. The most plausible genetic effect of exposure to endocrine active compounds is a reduction in genetic diversity due to a bottleneck, which can be caused by reductions in population size and altered mating success among individuals. We found genetic differences among walleye along the length of the river but no patterns correlated with effects consistent with exposure to endocrine active compounds. Most of the population differentiation was attributed to a split between samples collected above and below the Twin Cities. This split may be due to historical barriers to fish movement, and thus genetic exchange, at St. Anthony Falls in Minneapolis. Populations above the Twin Cities, both hot spot and reference site samples, had lower genetic diversity than those below, with a trend toward increasing diversity going downstream. Nearby reference and hot spot samples had no significant differences in genetic diversity. While endocrine active compounds may alter the reproductive physiology of individual walleye as determined in Result 2, they are not causing population bottlenecks severe enough to detectably alter genetic diversity throughout the Mississippi River.

Table 3. Location, sample size (N), and major drainage for samples of walleye with data from previous research by L. Miller. These samples had data for only 8 of 10 microsatellite DNA markers used in the current project.

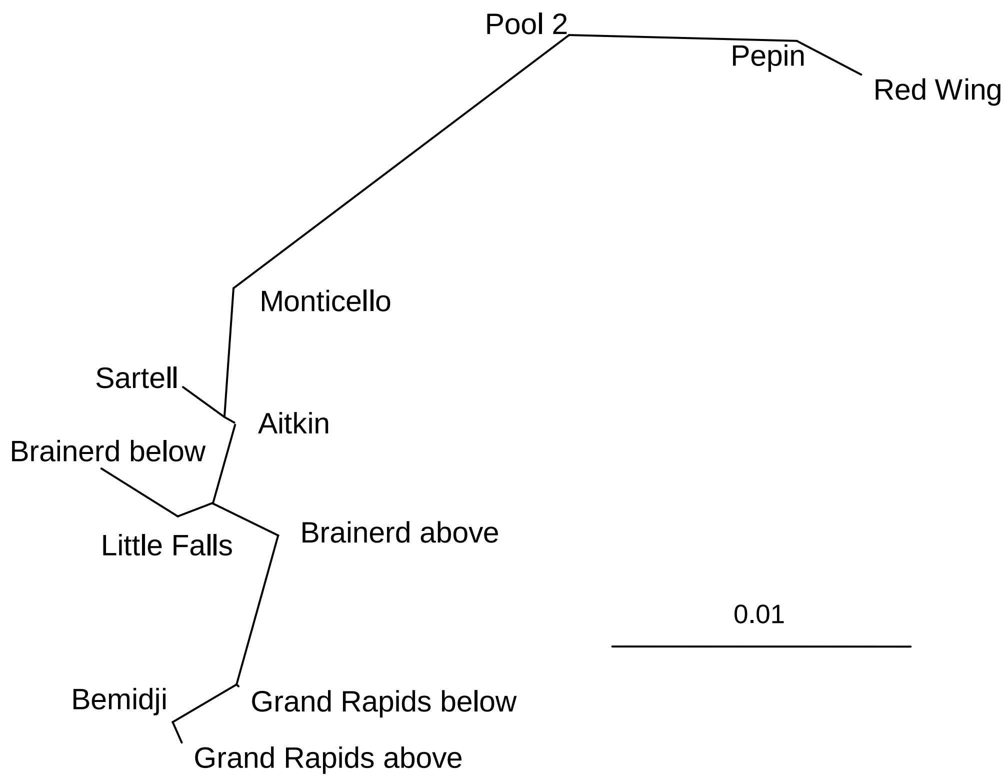
Sample location	N	Drainage
Cutfoot/Lake Winnibigoshish	182	Mississippi
Leech Lake	82	Mississippi
Little Boy River	71	Mississippi
Pine River	91	Mississippi
St. Louis River	171	Great Lakes
Pike River	178	Rainy/Hudson
Red Lake	169	Hudson

Result details

We genotyped each walleye using 10 genetic markers of types known as microsatellite DNA loci. Microsatellite markers typically reveal high genetic variation among individuals and populations, and have been used to study relationships between toxins and genetic diversity (e.g., Whitehead et al. 2003; Bourret et al. 2008). Each locus, which represents a small region of DNA on the pairs of chromosomes of the fish, was amplified by the polymerase chain reaction (PCR) to make millions of copies that could be visualized. The PCR fragments were scored based on their lengths. Fragments with different lengths, called alleles, indicate differences in DNA sequences. The allele scores across all 10 genetic markers make up the DNA fingerprint of the individual. The genetic diversity of individuals and populations can be measured by the number of different alleles (allelic richness) or the number of loci with different alleles on each of the pair of chromosomes (heterozygosity). Population genetic structure (i.e., genetic diversity among populations) can be measured in various ways generally based on allele frequency differences among populations.

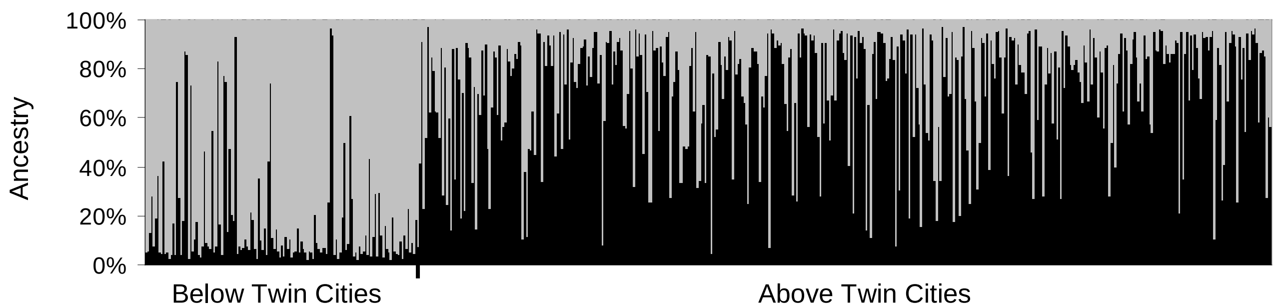
Several approaches to analyzing genetic population structure indicated that there are genetic differences among walleye along the length of the river but that most of the differentiation is attributed to a split between samples collected above and below the Twin Cities. The measure F_{st}, which is a sensitive measure of differences in allele frequencies among populations, was small and sometimes statistically non-significant in comparisons among populations above (F_{st} range 0-0.021) or below (F_{st} range 0-0.008) the Twin Cities. In contrast, F_{st} was larger and significant for all comparisons between above and below Twin Cities populations (Fst range 0.012-0.046), except for the Monticello and Pool 2 samples. It is not surprising that some populations above the Twin Cities had slight genetic differences as they came from over 320 river miles with numerous dams between some of them. A tree diagram depicting genetic relationships among populations revealed a similar picture: large branching between populations above and below the Twin Cities and slightly separated clusters of upper Mississippi (Grand Rapids and Bemidji) samples and middle Mississippi (Aitkin to Monticello) samples (Figure 3).

Figure 3. Tree diagram of genetic relationships among Mississippi River walleye populations based on the genetic distance F_{st}. Longer branch lengths indicate greater genetic differences.



The approach to identifying genetic clusters with the program STRUCTURE identified only two main groupings. The two clusters were not perfectly distinguishable (as indicated by the presence of both colors in each sample in Figure 4), but populations below the Twin Cities averaged 74-90% assignment to one cluster while those above averaged 58-79% to the second cluster, indicating that the strongest genetic structuring of Mississippi River walleye occurs between populations above and below the Twin Cities. The lack of distinguishing power for samples above the Twin Cities was likely a result of only slight differences among samples and an isolation-by-distance pattern of genetic structure.

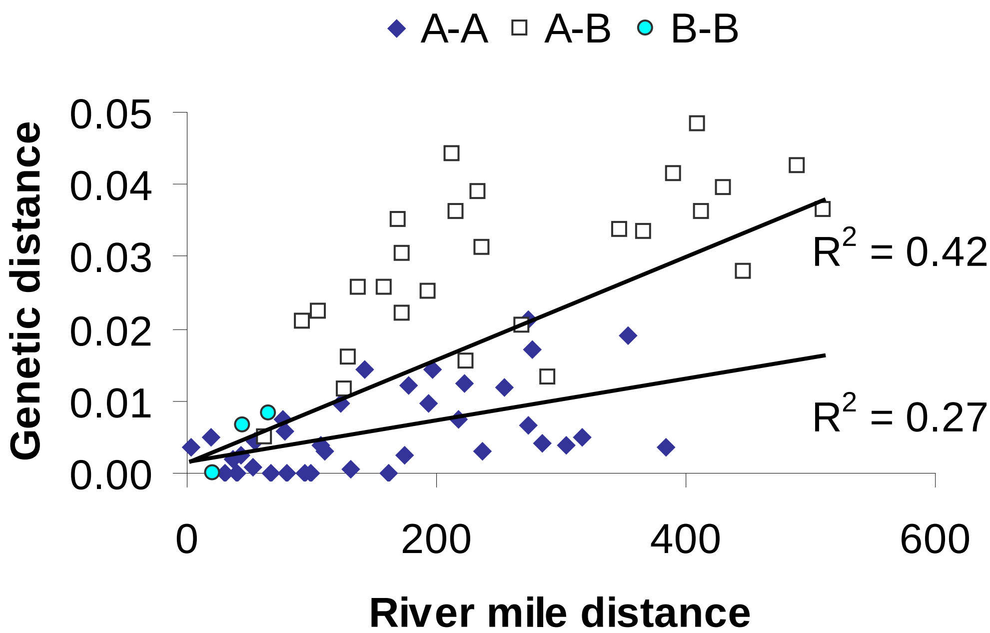
Figure 4. Assignment of ancestry based on STRUCTURE analysis for 12 samples of Mississippi River walleye. Each vertical bar represents a single fish with the proportion of ancestry assigned to each of two genetically distinct clusters indicated by color.



The F_{st} and STRUCTURE approaches to assessing genetic structure among populations do not work well when populations have subtle differences along a geographic gradient, as can occur along a river. This phenomenon is known as isolation-by-distance (IBD). When IBD occurs, a sample does not represent an isolated genetic unit. Instead, some movement and gene exchange tends to occur at shorter distances but less so with increasing distance. Distant locations along the river may develop genetic differentiation but in fact may have genetic exchange over many generations as descendents move up or down the river.

Statistical tests provided strong evidence for patterns of isolation-by-distance in Mississippi River walleye (Figure 5). For all sample pairs, river distance between them was significantly correlated with genetic distance ($p = 0.0012$, R^2 0.42), but this was driven in part by the higher genetic differentiation between samples above and below the Twin Cities. When the tests were repeated with only the samples from above the Twin Cities, the relationship was still significant but not as strong ($p = 0.012$, R^2 0.24). Although numerous dams now block upstream movements of fish, and stocking has occurred in systems that connect with the river, walleye still show genetic patterns consistent with historical population connectivity throughout the upper Mississippi River above St. Anthony Falls.

Figure 5 Genetic distance (Fst/[1-Fst]) versus river mile distance between sample sites. The symbols indicate comparison within and between sites above (A) and below (B) the Twin Cities. The top line is the linear regression (i.e. statistical relationship between genetic and geographic distances) for all pairs of sites while the bottom line is for comparisons of above Twin Cities sites only (A-A).



We found no detectable relationship between genetic diversity and levels of endocrine disruptor effects in Mississippi River walleye. In one test known as analysis of molecular variance, samples were grouped to determine if they shared common patterns of genetic variation. An analysis run with samples grouped by EDC levels (hot spots versus reference sites) showed that this factor explained little of the genetic structure of populations but geography (above and below the Twin Cities) had significant effects (Table 4). Because geography had a strong effect, we repeated the analysis with only populations above the Twin Cities but still found no patterns of genetic variation that differentiated EDC hot spots from references sites.

Table 4. Analysis of molecular variation (percentage of the genetic variation explained by the grouping factor) for samples of Mississippi River walleye grouped according to EDC level (hot spot v. reference) or geography (above or below Twin Cities).

Samples included	Grouping factor	% variation	Statistically significant?
All sites	Hot spot v. reference	0.15	No
Above Twin Cities only	Hot spot v. reference	0.65	No
All sites	Above v. below Twin Cities	2.78	Yes

A second test directly compared measures of genetic diversity between EDC hot spots and references sites. Allelic richness and heterozygosity would both be expected to decline if EDCs were affecting reproduction but allelic richness is a more sensitive indicator because it is expected to decline more quickly following a population bottleneck (Allendorf 1986). Neither measure of diversity showed reductions at EDC hot spot locations. Instead, there was a trend of increased diversity from upstream to downstream, especially for heterozygosity, with a significant increase in samples below the Twin Cities (Figure 6). Above the Twin Cities, the three hot spots did not differ significantly from any reference site for allelic richness or from Rice L. or Aitkin for heterozygosity. Below the Twin Cities, the two hot spots did not differ from the reference site. We also compared the diversity of Mississippi River populations to that in other lakes and rivers to determine if there were any broad river-wide patterns (Figure 7). Sample sites below the Twin Cities have the highest levels of genetic diversity of all Minnesota walleye populations studied while sites above the Twin Cities are similar to other locations within and outside the Mississippi River basin. Our results show the importance of sampling many sites when evaluating possible population-level genetic effects of pollutants to account for other patterns of genetic diversity. In our case, the decreased genetic diversity above the Twin Cities may be a natural pattern related to the isolation of walleye populations as St. Anthony Falls was formed.

Figure 6. Measures of genetic diversity, average allelic richness (above) and average expected heterozygosity (below), for 10 microsatellite DNA markers in walleye samples from 12 sites in the Mississippi River. Sites are in order going downstream from Bemidji to Lake Pepin.

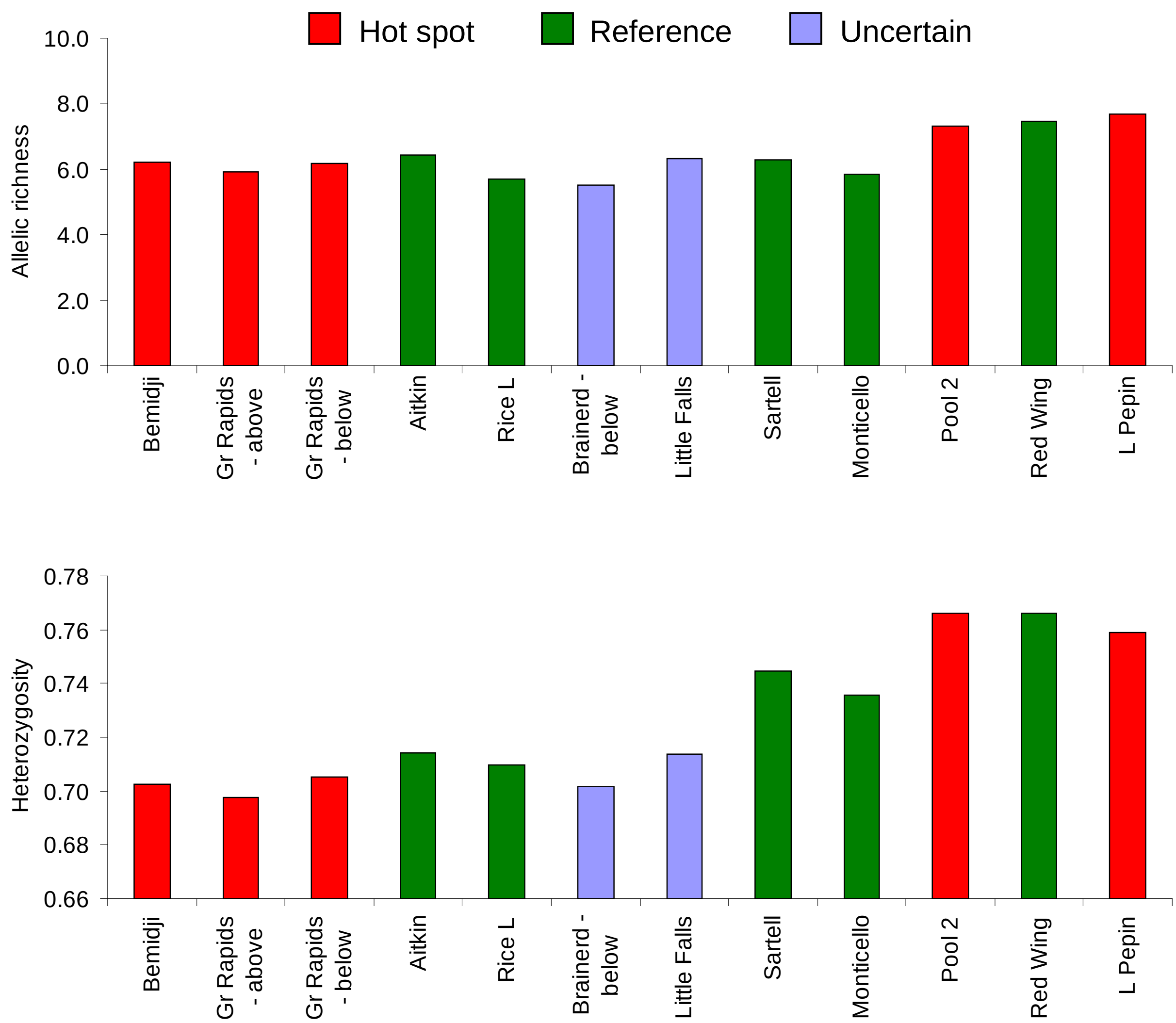
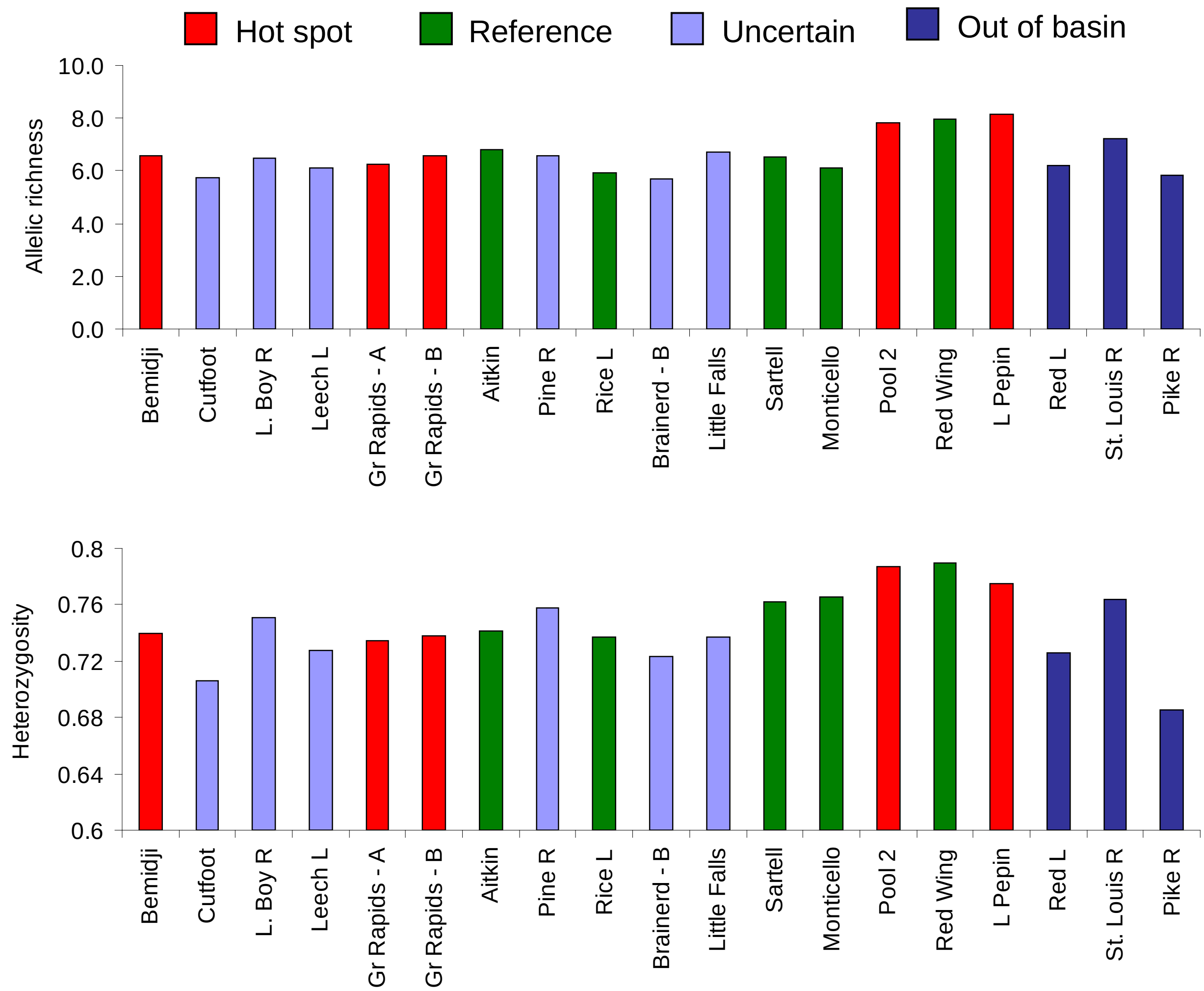


Figure 7. Measures of genetic diversity, average allelic richness (above) and average expected heterozygosity (below), for 8 microsatellite DNA markers in walleye samples from 19 sites. Samples from previous studies were added, including Pine River, Little Boy River, Leech Lake and Cutfoot Sioux Lake (Winnibigoshish) in the Mississippi River basin and three sites on the right from other basins. Mississippi River basin sites are in order going downstream from Bemidji to Lake Pepin.



<u>Summary of laboratory methods and data analysis applied</u>:

Genotyping

Genotypes were determined for 10 published walleye microsatellite DNA loci (*Svi2, Svi4, Svi6, Svi16, Svi18, Svi20, Svi26, Svi33, SviL2 and SviL6*; Borer et al. 1999; Wirth et al. 1999; Eldridge et al. 2002). DNA was extracted from tissue samples by boiling a scale or sliver of tissue in a 250 µL 5% Chelex (Sigma Chemical, St. Louis, MO) solution. Polymerase chain reaction (PCR) amplification was performed in 15 µL reactions containing 1x polymerase buffer (10 mM Tris-HCl, 50 mM KCl, 0.1% Triton X-100), 1.5 mM MgCl2, 0.2 mM each dNTP, 0.5 mM of each primer with the forward primer fluorescently-labeled, and 0.5 U *Taq* DNA polymerase (Promega, Madison, WI). Each run included a water blank as a negative control to detect possible contamination of PCR solutions.

Amplifications were conducted in a Hybaid Omn-E thermocycler (Thermo-Hybaid U.S., Franklin, MA) using 35 cycles and a 50°C annealing temperature. Products of PCR amplifications were submitted to a genetics core facility (Biomedical Genomic Center, University of Minnesota, St. Paul) for electrophoresis on an ABI Prism 3130xl Genetic Analyzer (Applied Biosystems, Foster City, CA). Allele scores were determined relative to an internal size standard in each lane using Genemapper v.4.1 (Applied Biosystems).

Data analysis

We assessed genetic structure, or patterns in the distribution of genetic variation, using several approaches. First, we estimated the measure of genetic differentiation F_{st} (the analog theta from Weir and Cockerham 1984) between all population pairs using Fstat (Goudet 1995) and 1,000 permutations to test significance. A neighbor-joining tree depicting genetic relationships between populations based on F_{st} distances was constructed in TreeFit (Kalinowski 2009) and visualized using TreeView. The program STRUCTURE (vers. 2.2.3; Pritchard et al. 2000; also refer to http://pritch.bsd.uchicago.edu) was used to estimate the number of genetically distinct populations contributing to our samples. STRUCTURE uses Bayesian clustering algorithms to divide individuals, based on their genotypes alone and not location information, into groups that maximize genetic equilibrium. Three replicates were run to test the likelihood of 1-5 distinct genetic clusters in the Mississippi River data. The burn-in period was 50,000 replications, which was followed by 150,000 Markov chain Monte Carlo (MCMC) simulations run under a model that assumed possible admixture and correlated allele frequencies. Finally, to examine the possibility of an isolation-by-distance pattern of genetic differentiation, we conducted Mantel tests to determine if genetic distances between pairs of populations ($F_{st}/[1-F_{st}]$) were correlated with geographic distances (river miles).

We estimated common measures of genetic diversity in each sample. Observed and expected heterozygosities were calculated, and conformance with Hardy-Weinberg expectations was confirmed, for each locus in each sample using exact test procedures of Guo and Thompson (1992), as implemented by GENEPOP v4 (Raymond and Rousseau 1995). Allelic richness was estimated for each sample by the software HP-Rare (Kalinowski 2005), using rarefaction techniques to standardize to an equal sample size of 30 genes.

We assessed the relationships of genetic diversity and structure with EDCs in two ways. We first used analysis of molecular variance (AMOVA) in the software Arlequin (Excoffier et al. 2005) to partition genetic variation into differences among individuals within population, differences among populations, and differences among groups of populations. Statistical significance was tested with 16,000 permutations of the data. Differences in genetic diversity measures were compared between pairs of populations using Wilcoxon signed-rank tests and one-sided p-values to test the hypothesis that EDC hotspots had lower diversity than reference sites.

New marker development attempt

As part of this project, we attempted to identify additional genetic markers to increase our power to assess differences in genetic diversity. We used a technique known as AFLP (Vos et al 1995), which does not require cloning and DNA sequencing to develop new markers. AFLP has been used successfully with numerous species, including fish, but no literature could be found showing it has been attempted on walleye. We had moderate success producing markers (bands) but few were polymorphic so they were not useful for assaying genetic diversity. Continued pursuit of AFLP markers for future studies would require a reinvestment in time and costs associated with DNA purification and screening with additional primer combinations.

Table 5. Total number of bands and number of polymorphic bands for 10 AFLP primer combinations in 24 Mississippi River walleye.

Primer combination	Number of bands	Number polymorphic
EcoC – Mse1	33	17
EcoC – Mse2	34	2
EcoC – Mse3	64	5
EcoC – Mse4	30	2
EcoC – Mse5	16	3
EcoG – Mse1	19	4
EcoG – Mse2	16	1
EcoG – Mse3	33	5
EcoG – Mse4	15	3
EcoG – Mse5	5	1

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V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services:

Schoenfuss, Project Leader – 1 Month/year 100% time (incl. fringe) to supervise field study and lab analysis. ($15,635 +37% fringe) **$** 21,420

Graduate Students, St. Cloud State University – 9 months/year 50% time to conduct laboratory assessment of fish health and assist in field study **$** 19,000

Loren M. Miller, Population Geneticist – University of Minnesota – 3 months/year to conduct genetic analysis. ($21,789 +33% fringe) **$** 28,980

Undergraduate Assistant, U of MN (10 weeks/year 50% time) **$** 3,600

Equipment: Field supplies $1,800; expendable SCSU lab supplies $ 4,980; field site travel $ 800; expendable AquaGen Lab supplies $ 15,920; field site travel $ 500.
Development: $ 0
Restoration: $ 0
Acquisition, including easements: $ 0
TOTAL TRUST FUND PROJECT BUDGET: $ 97,000

Explanation of Capital Expenditures Greater Than $3,500: *n/a*

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

Loren M. Miller – Population Geneticist, AquaGen, University of Minnesota $49,000
Matthew L. Julius – Aquatic Ecologist, St. Cloud State University

B. Other Funds Proposed to be Spent during the Project Period: $0

C. Past Spending: $120,000 for longitudinal study of Mississippi River at 43 sites from Lake Itasca to Iowa border.

D. Time: Our recently completed longitudinal study of the Mississippi River provides the most exhaustive data set to date on the health of fish in the Mississippi River in correlation with the presence of emerging contaminants in the water and sediment. The transient nature of this information in the context of future studies requires any approach that uses this data set to occur in the very near future, i.e., the next two years. Beyond such time, a complete re-sampling of water and sediment would have to be conducted, more then doubling the overall cost of the project.

VII. DISSEMINATION:

Dissemination of the results of this study will be made available to the funding agency and interested parties in quick and efficient fashion through the use of multiple dissemination tools:

(1) periodic progress reports to LCCMR
(2) final report to LCCMR

(3) reports to the MN Department of Natural Resources (related projects)
(4) presentations at regional, national, and international research conferences.
(5) press releases of significant findings through the St. Cloud State University Public Relations office.
(6) submission of manuscripts on the studies results to peer reviewed scientific journals.
(7) updates on the aquatic toxicology web site at St. Cloud State University (web.stcloudstate.edu/aquatictox)

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than Dec 31, 3007; June 30, 2008; Dec. 31, 2008; June 30, 2009; December 31, 2009. A final work program report and associated products will be submitted between June 30 and August 1, 2010 as requested by the LCCMR

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects - **Summary and a Budget page for each partner (if applicable)**

Project Title: Threat of Emerging Contaminants to Upper Mississippi Walleye

Project Manager Name: ***Project Partner - Miller***

Trust Fund Appropriation: $ *97,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 2 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 3 Budget:**	**Amount Spent** *(7/23/2010)*	**Balance** *(7/31/2010)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Field Collection of Feminized Fish.			*Laboratory Assessment of Fish Health*			*Emerging Contaminant Population-Level Genetic Effects*				
BUDGET ITEM			0			0			0	0	0
PERSONNEL: wages and benefits	0		0			0	32,580	33,687	-1,107	32,580	-1,107
Other direct operating costs *(expendable laboratory supplies for DNA analysis)*			0			0	15,920	15,017	903	15,920	903
Travel expenses in Minnesota			0			0	500	296	204	500	204
COLUMN TOTAL	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$49,000**	**$49,000**	**$0**	**$49,000**	**$0**

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: Threat of Emerging Contaminants to Upper Mississippi Walleye

Project Manager Name: ***Dr. Heiko L. Schoenfuss***

Trust Fund Appropriation: $ *97,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet
2) Remove any budget item lines not applicable

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent (7/23/2010)	Balance (7/31/2010)	Result 2 Budget:	Amount Spent (7/23/2010)	Balance (7/31/2010)	Result 3 Budget:	Amount Spent (date)	Balance (date)	TOTAL BUDGET	TOTAL BALANCE
	Field Collection of Feminized Fish.			*Laboratory Assessment of Fish Health*			*Emerging Contaminant Population-Level Genetic Effects*				
BUDGET ITEM			0			0			0	0	0
PERSONNEL: wages and benefits	16,400	16,400	0	24,020	24,020	0	0		0	40,420	0
Other direct operating costs *(expendable laboratory supplies for DNA analysis)*	1,800	1,800	0	4,980	4,980	0	0		0	6,780	0
Travel expenses in Minnesota	800	800	0	0		0	0		0	800	0
COLUMN TOTAL	**$19,000**	**$19,000**	**$0**	**$29,000**	**$29,000**	**$0**	**$0**	**$0**	**$0**	**$48,000**	**$0**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Cedar Creek Groundwater Project Using Prairie Biofuel Buffers
PROJECT MANAGER: Dr. Clarence Lehman
AFFILIATION: University of Minnesota
MAILING ADDRESS: 100 Ecology Building, 1987 Upper Buford Circle
CITY/STATE/ZIP: St. Paul, MN 55108
PHONE: 612-625-5734
E-MAIL: lehman@umn.edu
WEBSITE: http://www.cbs.umn.edu/eeb/faculty/LehmanClarence/
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, [Chap. 30], Sec.[2], Subd. 5(n).

APPROPRIATION AMOUNT: $659,000

Overall Project Outcome and Results

Two great environmental challenges ahead—for Minnesota and the world—concern water and energy. This project has gathered new information on how the production of bioenergy can simultaneously improve water quality in the state. It is one of an integrated suite of existing and proposed projects to understand the potential for bioenergy to help improve wildlife habitat, water quality, natural landscape management, electrical generation efficiency, climate, and the general ecological integrity of the landscape.

The project has established an “underground observatory" to monitor water and what it carries from the surface to our groundwater and aquifers below. The project examined water filtered by the soil and roots beneath three different potential bioenergy sources: prairie, hay, and corn.

As expected, the deep roots of restored native prairies were best at filtering nitrogen contaminants from water. In addition, a number of less expected discoveries of the project will help in future planning and development:

1. Water retention in the soils was poorest in corn and bare ground, intermediate in hay, and greatest in prairie.
2. Prairies did not significantly decrease the total quantity of water re-supplied to groundwater but improved its quality.
3. Nitrogen removed by prairie plants significantly increased the quantity of biofuel they produced while not reducing biodiversity.
4. Effects on levels of pharmaceutical contaminants is still under analysis.
5. Significant carbon sequestration occurred in prairie soils but not those of hay, corn, or bare ground.
6. The downward flow of dissolved substances through even sandy soils is much slower than expected.

The underground observatory is a valuable ongoing resource, with much remaining to learn. The project organizers will seek continued funding from various sources to enable further understanding of how we can sustainably inhabit our planet.

Project Results Use and Dissemination

We have a project website available through the Cedar Creek Natural History Area website (www.cedarcreek.umn.edu). Many public and private tours are conducted at Cedar Creek annually and the plots in the present study were featured among them during relevant tours. Visitors receive verbal and written descriptions of the research and its implications, including handouts and review of installed signage. Presentations (oral or poster) to special interest groups, research groups, and other interested parties were given by project collaborators throughout the duration of the project. Publication of the results in a peer-reviewed scientific journal will be completed after field data has all been collected, summarized, and analyzed.

Trust Fund 2007 Work Program Final Report

Date of Report: 8/19/2010
Trust Fund 2007 Work Program Final Report
Date of Work program Approval:
Project Completion Date: June 30, 2010

I. PROJECT TITLE: Cedar Creek Groundwater Project Using Prairie Biofuel Buffers

Project Manager: Dr. Clarence Lehman
Affiliation: University of Minnesota
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FAX Number: 612-624-6777
Web Page address: http://www.cbs.umn.edu/eeb/faculty/LehmanClarence/

Location: The work will take place at Cedar Creek Ecosystem Science Reserve (CCESR), formerly known as Cedar Creek Natural History Area, which straddles the border of Anoka and Isanti Counties just north of the Twin Cities. The main lab building address at CCNHA is 2660 Fawn Lake Drive, Bethel, MN 55005. See map for further details.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	**659,000**
	Minus Amount Spent:	**$**	**659,000**
	Equal Balance:	**$**	**0**

Legal Citation: ML 2007, [Chap. 30], Sec.[2], Subd. 5(n).

Appropriation Language:
Cedar Creek Groundwater Project using Prairie Biofuel Buffers

$659,000 is from the trust fund to the University of Minnesota, Cedar Creek Natural History Area, to provide quantitative data on the ability of diverse prairie buffers to capture runoff pollutants, to produce biofuel with minimal water requirements, and to provide high carbon sequestration. This appropriation is available until June 30, 2010, at which time the project must be completed and final products delivered unless an earlier date is specified in the work program.

II. AND III. FINAL PROJECT SUMMARY

Two great environmental challenges ahead—for Minnesota and the world—concern water and energy. This project has gathered new information on how the production of bioenergy can simultaneously improve water quality in the state. It is one of an integrated suite of existing and proposed projects to understand the potential for bioenergy to help improve wildlife habitat, water quality, natural landscape management, electrical generation efficiency, climate, and the general ecological integrity of the landscape.

The project has established an “underground observatory" to monitor water and what it carries from the surface to our groundwater and aquifers below. The project examined water filtered by the soil and roots beneath three different potential bioenergy sources: prairie, hay, and corn.

As expected, the deep roots of restored native prairies were best at filtering nitrogen contaminants from water. In addition, a number of less expected discoveries of the project will help in future planning and development: (1) Water retention in the soils was poorest in corn and bare ground, intermediate in hay, and greatest in prairie. (2) Prairies did not significantly decrease the total quantity of water re-supplied to groundwater but improved its quality. (3) Nitrogen removed by prairie plants significantly increased the quantity of biofuel they produced while not reducing biodiversity. (4) Effects on levels of pharmaceutical contaminants is still under analysis. (5) Significant carbon sequestration occurred in prairie soils but not those of hay, corn, or bare ground. (6) The downward flow of dissolved substances through even sandy soils is much slower than expected.

The underground observatory is a valuable ongoing resource, with much remaining to learn. The project organizers will seek continuing funding from various sources to exploit the established infrastructure for further understanding of how we can sustainably inhabit our planet.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Establishment of Vegetation and Experimental Design

Description: Included in this result are the set up and initial characterization of the field site so that we can compare diverse restored native prairie with non-native grassland and agricultural row crops for (1) leaching of chemical pollutants to groundwater, (2) production of renewable biofuel energy, and (3) other relevant criteria such as carbon sequestration. This establishment phase includes several deliverables:

1. *Plot establishment and site characterization.* The goal of this deliverable is to finalize details of the experiment, establish the plots, and assess the initial conditions present in the plots (i.e. plant community composition, root biomass, soil properties, and ground-water parameters). The budget for this includes funds for field supplies, treatment application, chemical analyses of the soils and groundwater, and personnel time including the

project management team (for planning and managing), undergraduate interns (for planting and maintaining plots), and a USGS technician (for sampling soil and groundwater).

2. *Plot Instrumentation.* The goal of this deliverable is to purchase and install the hydrologic equipment necessary for monitoring soil and ground-water quality. The budget for this includes funds for hydrologic monitoring equipment and personnel time including the project management team (for planning and managing), undergraduate interns (for installation of equipment), and a USGS technician (for quality control of equipment installation).
3. *Educational media.* The goal of this deliverable is to provide media to help explain the project, the societal need, the underlying science, and sources of funding to visitors from the general public as well as from professional groups. Media will include interpretative signage at the site, brochures, and a project web site. The budget for this includes funds for the project management team (for writing and management) and undergraduate interns (for installation and technical assistance), plus funds for supplies.

Amendment Approved [3/18/2010]: 3/10/2010 Result 1 Amendment details: The total budget for each of Deliverable 1 and Deliverable 2 remains unchanged, however funds are being moved between line items within each budget. Within Deliverable 1, we request that the excess funds from UMN lab analytical and supply/equipment line items be moved into UMN personnel to cover labor costs necessary to establish and characterize the plots. Some analytical work originally planned in this deliverable was paid for with other non-LCCMR Cedar Creek funds, thus freeing up funds for the increased labor expense. Within Deliverable 2, we request that the excess funds budgeted for UMN supplies and equipment be used to cover UMN labor costs necessary for instrument installation and troubleshooting. We further request that excess UMN supply and equipment funds be used to cover UMN travel expense which includes mileage reimbursement for travel to and from and around the field site. The total cost of Deliverable 3 was lower than anticipated because of labor cost reductions. Labor for installing signage was paid for by non-LCCMR Cedar Creek funds. We request that the remaining dollars ($1197) be shifted to cover labor costs in Result 2, deliverable 5, Final Reports.

Amendment Approved [3/18/2010]: USGS subcontract work: The USGS personnel time required to characterize the groundwater of the site (Deliverable 1) and instrument the plots (Deliverable 2) was greater than anticipated. Additionally, the USGS worked on the project web page (Deliverable 3). USGS site visits consumed more fuel than originally planned for Deliverable 1 and 2. USGS supply and equipment costs were greater than anticipated for completing Deliverables 1 and 2. Travel expenses from attending a USGS training meeting on unsaturated zone processes and instrumentation were underestimated originally. Given that the USGS matching funds paid for most of the analytical analyses for Deliverable 1, we request that funds be transferred from the lab analytical line item to cover the expenses listed above. Additional supplies required above and beyond the original budget that are part of the plot instrumentation include: tensiometer construction materials (PVC pipe, glue, rubber stoppers, wire, pressure sensors), grounding rods, data collection shelters and mounting equipment, solar panels, and voltage controllers. Other supplies required for the experimental establishment include tracers (KBr and Rhodamine WT), PPE for application, and related items. Items purchased for plot instrumentation (hydrologic monitoring) by the USGS will remain at Cedar Creek after the LCCMR funded portion of the project is completed. Since the USGS matching funds covered most of the lab analytical for Result 1, we request that LCCMR funds originally budgeted for lab analytical under Result 1 be used to cover the additional personnel, supply, and vehicle costs listed above.

Amendment Approved [3/18/2010]:

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$113,803**
	Amount Spent:	**$113,803**
	Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. Plot establishment and site characterization	11/2007	$59,280	Complete
2. Plot Instrumentation	11/2007	$46,820	Complete
3. Educational media	11/2007	$ 7,703	Complete

Completion Date: 7/31/2010

Final Report Summary:

Deliverables 1 and 2: The site specific data collected for this project will be accessible to future CCESR researchers through the Cedar Creek web page at www.cedarcreek.umn.edu. The plot instrumentation will remain in place and will be used for future investigations as funds are available.

For the period of January 1, 2008 through June 30, 2010, over 900 people toured this experiment and others at CCESR. This project is the sole investigation into groundwater quality currently in process at CCESR and complements the broader topics of biodiversity and biofuel production, which are investigated extensively at CCESR. Many K-12 students, college students, and high school teachers visited the site. Notable international visitors also toured this research project, including the Prime Minister of Norway, Jens Stoltenberg and former Vice President Walter Mondale. This project was also highlighted during a national site review by a panel of scientists in the Long Term Ecological Research (LTER) program. This particular project was viewed favorably since it added a new dimension to the existing CCESR research into the ecosystem services provided by biodiversity.

In addition to the site tours given, the project has been highlighted in numerous national and international presentations by principal investigators, Clarence Lehman, David Tilman, and others, and several formal presentations were dedicated specifically to this project:

- St. Thomas University Hydrogeology Course guest speaker, April 2009?. Jared Trost gave a presentation titled, "Prairies: biofuels for clean water."
- Cedar Creek Ecosystem Science Reserve Research Symposium. June 22, 2009. Jared Trost gave a presentation titled, "Prairies: biofuels for clean water."
- Minnesota Water Resources Conference, October 26-27, 2009. Jared Trost gave a presentation titled, "Can perennial biofuel crops be used to remove pharmaceuticals (and nutrients) from the environment?"
- University of Minnesota, May 4, 2010. Jared Trost presented his thesis titled, "Effects of perennial and annual vegetation on a soil water balance and groundwater recharge."

Additionally, four undergraduate research projects were advised by the management team of this project. These projects both provided insight into the broader questions being asked and educated the students in the process of scientific investigation.

- "Leaching of N and pharmaceuticals through lab microcosms." Done by Joy Deglinnocenti, Fall 2007
- "A biofuel economy: improving yields and saving on costs in the production of biofuels" Done by Jason Williams. Summer 2008.
- "Determination of antibiotics in aqueous and plant samples via ELISA method." Done by A. Bertsch, K. Thapa, and M. Persenaire. Summer 2008
- "Measuring the distribution of bromide in vertical soil profiles." Done by M. Sullivan, A. Brandstetter, and B. Brown. Summer 2010.

The project website will remain accessible indefinitely through the USGS at: http://mn.water.usgs.gov/projects/cedarcreek/index.html.

Result 2: Measurement, analysis, and reporting

Description: Included in this result are field data collections, chemical analyses, data management and interpretation, and final reporting. Samples of water, soil, and plant tissue will be collected and analyzed throughout the project. Water balance analyses will be conducted for each plot. Final reports will cover (1) a summary of direct measurements; (2) interpretation and analysis of data collected; (3) estimates of effects the present study is not large enough nor long enough to directly measure, such as wildlife enhancements and carbon sequestration; (4) recommendations about future related studies, such as extensions to a multiplicity of soil types, slopes, and landscapes. This measurement and reporting phase includes several deliverables:

1. *Bioenergy production assessment.* The goal of this deliverable is to determine the bioenergy available in diverse prairie used as a water filter and in non-native grass communities used for the same purpose. The budget includes funds for the project management team (for planning and

managing), undergraduate interns (for mowing, drying, sorting, weighing, and evaluating plant material), and laboratory costs (for analysis of plant tissue).

2. *Soil hydrology assessment.* The goal of this deliverable is to document the water movement through the unsaturated zone and its potential for reaching groundwater. The budget includes funds for the project management team (for planning and managing) and USGS hydrological technicians (for sampling), plus laboratory costs (for analysis of tracers) and field supplies for sample collection purposes. Some USGS matching funds apply to this deliverable.

3. *Contaminant transport assessment.* The goal of this deliverable is to determine the level of filtration accomplished by the plant communities under study. The budget includes funds for the project management team (for planning and management), USGS technicians (for sampling and analysis), chemical assay equipment, and laboratory costs for analysis of the samples. The bulk of the USGS matching funds are allocated to this deliverable.

4. *Carbon sequestration estimates*. The goal of this deliverable is to estimate the level of carbon captured in the roots and soils of the plant communities under study, both to understand effects on atmospheric greenhouse gases and to parameterize potential for restoration of degraded soils. The budget includes funds for the project management team (for planning and management), undergraduate interns (for sampling and data recording), and laboratory costs (for analysis of soil samples).

5. *Final reports.* The goal of this deliverable is to collect and archive the project and its results, to suggest extensions of the project to other parts of the region and the world, and to offer ideas for future refinements based on lessons learned during the project. The final reports will be prepared in hard copy form and will also be distributed through the project website. The budget includes funds for the project management team (for writing), USGS technician (for writing), and printing costs.

Amendment Approved [3/18/2010]: **Deliverables 1 and 4.** The total budget for Deliverables 1 and 4 remain unchanged, however we request that excess funds in the UMN supply/equipment, UMN lab analytical, and UMN travel line items be transferred into UMN labor to cover the true labor required to complete these deliverables. The UMN lab analytical budget decreased because some analytical work originally planned in this budget is being paid for with other non-LCCMR Cedar Creek funds and the analyses are cheaper per sample than originally estimated.

Amendment Approved [3/18/2010]: **Deliverable 3**. The total budget for Deliverable 3 remains unchanged, however an amendment to the allocation of funds within the USGS subcontract portion of this deliverable is requested. We request that funds be shifted from the lab analytical line item into USGS personnel, UMN personnel, and USGS equipment/supplies for two reasons: (1) to provide funding for analyzing the samples locally using trained UMN students rather than a contract lab in Kansas and (2) to provide adequate funding for labor and non-capital equipment expenses necessary for generating quality reportable data.

LAB: By analyzing samples locally, it will decrease the cost/sample and increase the total number of samples analyzed for contaminants. This will (1) provide greater assurance that we capture the plume front as it moves through the unsaturated zone (2) better utilize the replicated experimental design of this project by increasing the strength of statistical comparisons through time; and (3) allow us to develop and test methods necessary to detect compounds in plant material. The total equipment and supply budget for the lab work is estimated to be $62,000, of that an estimated $57,800 will be spent on consumable supplies. The ELISA kits used for contaminant analysis are the largest individual expense in the supply budget at a total of $51,000. No single item will cost more than $1,000. The lab labor budget is estimated to be $89,000. Equipment and supplies purchased to accomplish this deliverable include: clean and quality assured sample bottles, Teflon tubing, C-flex tubing, pipettors (200 ul, 1000 ul, 10ml), glass fiber filters, syringe filters, solvents (citric acid, methanol, organic free water, inorganic free water), analytical standards, ELISA kits, UHP nitrogen gas, labels, sample storage freezers, a vortex shaker, rotators, and related items. In summary, we request the lab analytical line item be reduced by $151,000 to cover the supplies and labor as described above for analyzing samples locally.

SAMPLING: The collection of field samples, quality control, equipment maintenance, and data management and archiving necessary to produce a defendable final report to USGS standards requires more labor than originally budgeted. The non-capital equipment and supplies associated with USGS methods of field sample collection, processing, and storage cost more than anticipated. Additional items (above the original budget) necessary to complete Deliverable 3 include: batteries, teflon tubing, silicone tubing, field calibration standards, sample storage bottles, filters, vacuum pumps, repairs of broken equipment, clean soil sampling equipment, and related items. Additionally, the USGS subcontract will be reduced by $10,000 from the lab analytical line item to pay for UMN personnel who completed water quality sampling originally planned to be done by the USGS. In summary, we request that the lab analytical line item be reduced by $120,310 to cover the supplies and labor for field data collection and management ($7,346 to USGS supplies, $10,000 to UMN for labor, and $102,964 to USGS labor).

Amendment Approved [3/18/2010]: **Deliverable 5.** Given the broad scope of research objectives set forth in this project and the variety of methods employed that require documentation, the final reporting will take longer than originally expected. Therefore we request that the extra UMN funds from Result 1, Deliverable 3 ($1,197) be added to this deliverable to cover UMN labor expenses.

Amendment Approved [3/18/2010]:

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$545,197**
	Amount Spent:	**$545,197**
	Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. Biofuel production assessment	12/2009	$ 19,850	in process
2. Soil hydrology assessment	12/2009	$ 63,652	in process
3. Contaminant transport assessment	12/2009	$417,244	in process
4. Carbon sequestration	12/2009	$ 16,550	in process
5. Final reports	07/2010	$ 27,901	in process

Completion Date: 7/31/2010

Final Report Summary:

Deliverable 1: As introduced in our 2006 Science paper (Tilman etal 2006), native prairie flora can be a superior low-input source of bioenergy. This project extended our understanding by testing the auxiliary benefit of water purification by prairie biofuel plantations. Details will be forthcoming in peer-reviewed scientific publications. In summary, prairie biofuel plantations significantly improved water quality compared with the alternative treatments without reducing its quantity. Even in the short three-year term of the project, carbon sequestration in the soils was evident in the prairie plots but not in the other treatments. Preliminary results indicate that pharmaceuticals can be removed from waters by the roots in the prairie plots, but these results are still being analyzed. In a completely unexpected finding, when nitrogen and water were added to prairie biofuel plots, simulating intentional irrigation and fertilization from agricultural runoff, it did not decrease their biodiversity when they were harvested each year (Figure 1b), though it did increase their yields (Figure 1a). The increase in yield is directly related to water purification, since it derives from nitrogen removed from rooting zone (Figure 1c).

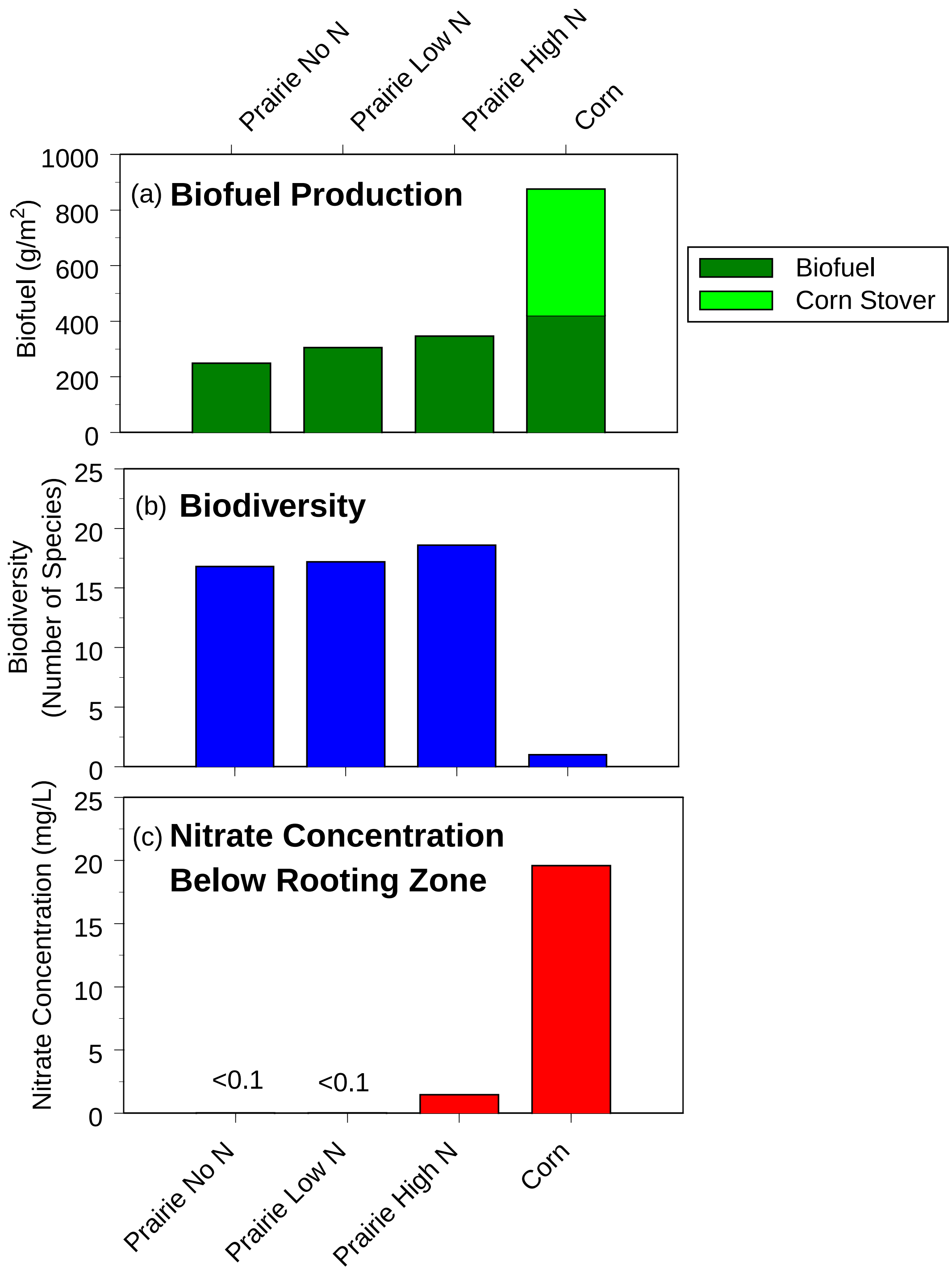


Figure 1. Mean (a) biofuel production, (b) biodiversity, and (c) nitrate concentration below rooting zone of prairies receiving different rates of nitrogen fertilization and corn fertilized at an average rate of 146 lb N/acre/yr. For the prairie treatments, No N = no fertilizer added, Low N = 62.5 lb N/acre/year , High N = 125 lb N/acre/yr. Only corn kernels were considered corn biofuel (dark green), whereas all prairie aboveground biomass was considered biofuel. The corn stover is included in (a) to show the total above ground biomass production.

Deliverable 2: This deliverable is explained in detail in the attached document, Trost, J.; “Effects of perennial and annual vegetation on a soil water balance and groundwater recharge.” M.S. Thesis, University of Minnesota, 2010.

Summary from this document: The movement of land applied fertilizers, pesticides, and other agricultural chemicals from land surface to groundwater is a major environmental concern, especially in regions of coarse textured soils with shallow unconfined aquifers. A replicated field experiment was conducted on the Anoka Sand Plain, Minnesota, to examine the effects of perennial and annual vegetative cover on the movement of water through the unsaturated zone to groundwater. A Darcian analysis of soil water flow, water table hydrograph analysis, and chemical analysis of a bromide tracer in pore water in the unsaturated and saturated zones were utilized to estimate recharge rates and amounts to a shallow unconfined aquifer beneath four land cover types: corn (*Zea mays*), well-established prairie, newly-established hay, and bare ground. Soil water storage and precipitation were measured directly. Evapotranspiration (ET) estimates were determined by difference in the other water balance terms. The following results were found:

1. ***Perennial prairie and hay place a higher demand on soil water earlier in the growing season as compared with annual corn.*** Prairie soils to 125 cm were maximally drier than corn soils by mid-July each season due to greater early season ET demands by prairie than corn, with the maximum difference in soil water storage being -6.3 cm.
2. ***Perennial prairie and hay cause slight reductions in drainage (groundwater recharge) through greater ET losses than annual corn.*** Hay, prairie, corn, and bare ground recharge (drainage) estimates from 6/3/2008 through 12/31/2009 were 31.6 +/- 4.5 cm, 37.9 +/- 3.3 cm, 40.2 +/- 3.4 cm, and 43.7 +/- 6.8 cm representing 28 %, 33%, 35%, and 39% of precipitation, respectively. ET losses during this time were 71.6 cm, 73.9 cm, 69.1 cm, and 59.8 cm for hay, prairie, corn, and bare ground, respectively.
3. ***Residence time and pore velocity in the unsaturated zone are affected both by crop type and by local soil properties.*** Piston flow model estimates of residence time in the upper 225 cm of the soil profile were 312, 410, 352, and 318 days for hay, prairie, corn, and bare ground respectively. Hay and bare ground had significantly different recharge (31.6 cm versus 43.7 cm); however the residence time and pore velocities were nearly identical due to a greater physical soil water storage capacity in the bare ground relative to hay.
4. ***Well established perennial prairies reduce solute leaching to groundwater.*** Bromide mass loss as determined for soil pore water 160 cm below land surface in one continuously monitored plot of each treatment resulted in 0.7%, 34%, 34%, and 100% of applied bromide leaching in prairie, hay, corn, and bare ground plots respectively. Peak bromide concentrations in prairie soil water were marginally significantly lower than all other treatments, primarily due to the lack of early high

concentration peaks. Bromide was detected in the groundwater of all five replicate plots for hay, bare ground, and corn treatments, but only detected in two of five prairie replicate plots.

Implications for water quality. Results indicate annually harvested perennial crops show potential for reducing the risk of groundwater contamination from land applied chemicals through two mechanisms. First, annually harvested perennial crops reduce groundwater recharge slightly as compared to annual corn. Since advective flow is the primary mechanism by which solutes are transported through the unsaturated zone to ground water (Green et al., 2008) any reduction in this property will slow the migration of contaminants to groundwater. Second, well established perennial prairies reduce leaching losses and peak concentrations of a conservative tracer below the rooting zone. While the exact mechanism explaining this observation was not determined, it is an important characteristic that holds enormous potential for well-established perennial prairies reducing inputs of land-applied contaminants to groundwater.

Deliverable 3: Selected antibiotics and estrogens, both common environmental contaminants, were applied to the treatments. All samples have been collected and analyzed in our local lab, however analyses have not been completed in the USGS Organic Research Geochemistry Lab. In our local lab, over 1,000 plant, soil, and water samples have been analyzed for 17 beta estradiol, sulfamethazine, and sulfamethoxazole. Interpretive results will be reported when the data return from the USGS lab and the chemistry database is fully quality assured. No further LCCMR funds will be spent in this process.

Deliverable 4: Significant carbon sequestration was measurable in the prairie plots but not in the other treatments even during the relatively short three-year term on the project. Total soil carbon percent (C) in the upper 30 cm of the profile was determined by dry combustion-GC analysis on a Costech ECS4010 using the following equation:

$$C = m_{carbon}/(m_{soil}+m_{carbon}) \quad (1)$$

where m_{carbon} = mass of carbon in grams
m_{soil} = mass of dry soil in grams.

The total percent soil carbon is an estimation of the total soil carbon pool including all forms of carbon, inorganic and organic with the exception of intact plant roots, as they are removed prior to soil sample analysis. It was assumed that any change observed in the total percent soil carbon reflected carbon additions or losses from the recalcitrant, long term storage pools rather than labile pools. The percent soil carbon (C) data is presented in Table 1 did not differ significantly (ANOVA F statistic = 0.52, p = 0.67) between plots assigned to each of the experimental treatments prior to crop establishment.

When the two sample points in each plot were considered a matched pair, only the prairie treatment showed a significant positive change in total soil carbon (Figure 2). A significant positive change is defined as zero not included in the 95% confidence interval of the mean. The mean change for corn was greater than zero,

though not statistically different from zero. This change in corn soils, in contrast to prairie, is partly due to the addition of pel-lime to the plots rather than vegetation-driven carbon storage. The prairie plots (n=10) had an average percent total carbon increase of 0.065 over the period from August 2007 through April 2010.
According to the equation:

$$C_{mass} = 0.367*(C_{mean}/100)*V_{soil}*B$$

Where C_{mass} = mass of carbon (short tons/acre)
C_{mean} = mean change in soil carbon percent = 0.065
V_{soil} = volume of soil (cm^3) = 300,000 cm^3 for the upper 30 cm of a 1 m^2 area.
B = soil bulk density (g/cm^3) = 1.5 g/cm^3 for the experimental field.

The average carbon accumulation in the upper 30 cm of the prairie soils was 1.07 short tons of carbon per acre, corresponding to an average soil carbon accumulation rate of 0.39 short tons/acre/year.

Table 1. Percent total soil carbon and change in percent total soil carbon from 2007 through 2010 in each of the crop treatments. Standard errors of the means are given in parentheses.

Crop Treatment	Number of replicates	2007 Mean Percent Total Soil Carbon	2010 Mean Percent Total Soil Carbon	Mean Carbon Change
Bare ground	10	0.56 (0.04)	0.53 (0.03)	-0.03 (0.03)
Corn	5	0.54 (0.03)	0.65 (0.04)	0.10 (0.05)
Hay	10	0.52 (0.04)	0.53 (0.04)	0.01 (0.03)
Prairie	10	0.58 (0.03)	0.64 (0.03)	0.07 (0.01)

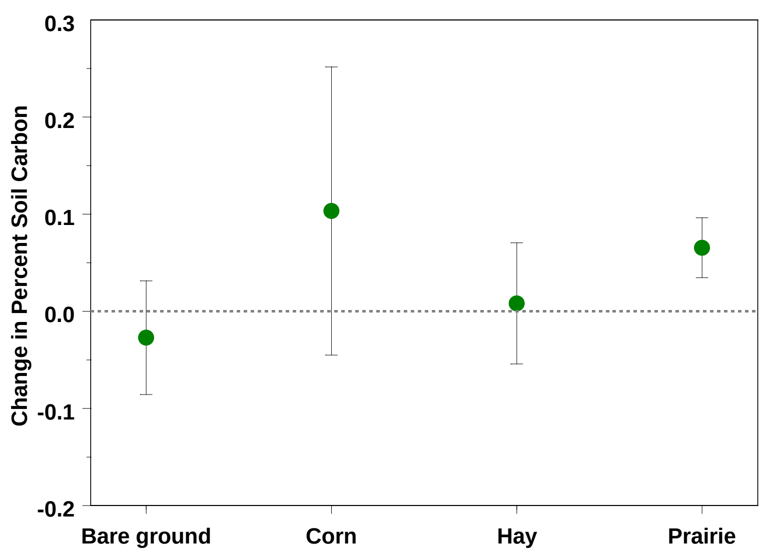


Figure 2. Mean change in soil carbon and 95% confidence interval, including all plots in the experiment (n=5 for corn plots, n=10 for bare ground, hay, and prairie plots).

Higher soil carbon accrual is known to result from higher root biomass (Fornara and Tilman, 2008). No statistically significant difference in root biomass existed between treatments in 2007 (note that no data was available for the corn plots) prior to the establishment of the crop treatments. After the establishment of treatments, the prairies had significantly more root biomass than all other treatments in both 2008 and 2009, a likely explanation for the soil carbon sequestration observed over the project period. In both 2008 and 2009, prairie root biomass was significantly greater than all other treatments. In 2008, mean prairie root biomass to a depth of 30 cm was 76%, 82%, and 430% greater than hay, bare ground, and corn root biomass, respectively. In 2009, mean prairie root biomass to a depth of 30 cm was 37%, 186%, and 215% greater than hay, bare ground, and corn root biomass, respectively. Corn showed no potential for soil carbon storage as its root biomass was not statistically different from bare ground in any year. Stover was completely harvested and removed each year, leaving only corn roots to input carbon below ground.

The root biomass that existed in the bare ground plots remained from pre-existing vegetation and from annual weeds that grew up prior to herbicide application. The corn root biomass was so low relative to bare ground in 2008 due to the tilling of only the corn plots. Tilling broke up the root mass from pre-treatment vegetation, resulting in lower recovery during the 2008 root sampling efforts.

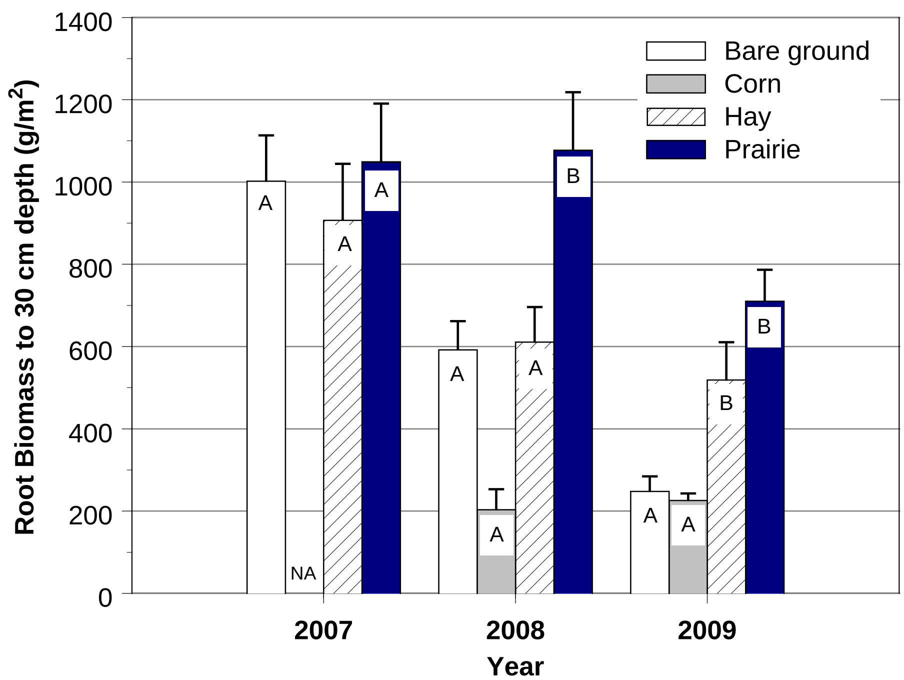


Figure 3. Yearly mean root biomass in g/m^2 and standard error for each crop type to a depth of 30 cm. Treatments marked by different letters within a year were significantly different from one another as indicated by a Tukey pair-wise comparison. No significant difference in root biomass existed between treatment and control plots within each vegetation treatment, therefore, the means in this graph include all experimental replicate plots, n=5 for corn and n=10 for bare ground, hay, and prairie.

V. TOTAL TRUST FUND PROJECT BUDGET: SEE ATTACHMENT A.

Staff or Contract Services: Amendment Approved [3/18/2010]:

UMN Wages and Benefits: Includes salary+ benefits, benefits rate ranges from 9.4% to 32.7% depending on appointment

- $54,608- Academic salary and benefits for Clarence Lehman (6 months) for project management, data analysis, reporting, and related tasks.
- $93,142- Salary and benefits for research assistants and research managers for sampling, data collection, project coordination, and related tasks.

USGS Subcontract Wages and Benefits: Includes salary+ benefits, benefits rate ranges from 7% to 42%, depending on appointment

- $30,279 - Hydrologist salary and benefits for project planning, design, data analysis, reporting, and related tasks.

- $296,096 – Hydrologic technician and student salary and benefits for sample collection, sample processing and analysis, data management and analysis, field activity coordination, and related tasks.

Equipment: Amendment Approved [3/18/2010]:

UMN Non-Capital Equipment and Supplies: $7,341

- seeds, biomass harvest equipment, nutrient application equipment, sample collection equipment, shipping costs, repair costs, and other necessary supplies

USGS Subcontract Equipment and Supplies: $110,444

- **$12,964 Capital Equipment**** dataloggers, soil-moisture probes, multiplexers, pressure transducers, thermocouples, a tipping bucket rain gauge, solar panels, voltage controllers, cable, grounding rods, shelters, tensiometers, and mounting hardware. (***although each individual part (sensors, wires, etc.) of this system was purchased separately at a cost well below the $3,500 cutoff, the combined system as a whole cost more than $3,500 and will remain at Cedar Creek after the LCCMR project completion)*
- **$97,480 Non-capital Equipment and Supplies**: tracers (KBr and Rhodamine WT), various hardware and tools, PPE for application, suction lysimeters and well construction materials, batteries, teflon tubing, silicone tubing, field calibration standards, clean and quality assured sample collection and storage bottles, capsule filters, vacuum pumps, repairs of broken equipment, pipettors (200 ul, 1000 ul, 10ml), glass fiber filters, syringe filters, solvents (citric acid, methanol, organic free water, inorganic free water), analytical standards, ELISA kits, UHP nitrogen gas, labels, sample storage freezers, and other necessary items.

Development: $0
Restoration: $0
Acquisition, including easements: $0

TOTAL TRUST FUND PROJECT BUDGET: $659,000

Explanation of Capital Expenditures Greater Than $3,500:

USGS Equipment / Tools: The equipment purchased here is for monitoring the hydrology and contaminant movement in the project. Specific purchases will include dataloggers, soil-moisture probes, multiplexers, pressure transducers, thermocouples, and a rain gauge.

USGS Suction lysimeters and well construction materials ($21,000): These are for collecting soil- and ground-water samples for chemical analysis.

UMN Lab and Field Supplies ($8,000): The equipment purchased here is for the installation of our project, maintenance of our project, and sample collection. Specific purchases will include: seeds, fertilizers, equipment for nutrient application, emerging contaminants (ie. growth hormones and antibiotics), vials and bags for sample storage, equipment for preparation of tissue and soil samples for analysis.

All capital equipment will be useful in ongoing aspects of the experiment and its extensions.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

1. United States Geological Survey (USGS): $502,000

   James Stark

   Geoffrey Delin

   Kathy Lee

   Richard Kiesling

2. University of Minnesota: $147,000

   Clarence Lehman

   David Tilman

   John Nieber

   Jared Trost

   Troy Mielke

B. Other Funds Proposed to be Spent during the Project Period:

The USGS will provide an additional $410,000 of federal matching funds towards this project during the funding period

C. Past Spending: This specific project is new, but it will use an existing experimental area at Cedar Creek established with over $1 million of National Science Foundation support during the past 12 years.

D. Time: We have requested a one-year extension, with the final report due in 2010. This will allow us to collect data through two complete field seasons; given the variability in natural systems, two complete years of data will increase confidence and reliability of the findings. The 2007 field season will be used for establishment of plots. 2008 and 2009 will be used for field data collection. The final report will be complete in July of 2010.

VII. DISSEMINATION: We will have a project website available through the Cedar Creek Natural History Area website (www.cedarcreek.umn.edu). Many public and private tours are conducted at Cedar Creek annually and the plots in the present study will be featured among them as during relevant tours. Visitors will receive verbal and written descriptions of the research and its implications, including handouts and review of installed signage. Presentations (oral or poster) to special interest groups, research groups, and other interested parties will be given by any number of the project collaborators throughout the duration of the project. Publication of the results in a peer-reviewed scientific journal will be completed after field data has all been collected, summarized, and analyzed.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than November 1, 2007, May 1, 2008, November 30, 2008, May 31, 2009, November 30, 2009, May 31, 2010, August 1, 2010. A final work program report and associated products will be submitted between June 30 and August 1, 2010 as requested by the LCCMR**.**

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects - **Summary and a Budget page for each partner (if applicable)**

Project Title: *Cedar Creek Groundwater Project using Prairie Biofuel Buffers (proposal #5n)*

Project Manager Name: *Clarence Lehman*

Trust Fund Appropriation: *$659,000 (with an additional $410,000 in Federal matching funds)*

2007 Trust Fund Budget	Result 1 Budget 08/17/2010	Amount Spent (08/17/2010)	Revised Balance 08/17/2010	Result 2 Budget 08/17/2010	Amount Spent (08/17/2010)	Revised Balance 08/17/2010	TOTAL BUDGET 08/17/2010	TOTAL BALANCE 08/17/2010
Cedar Creek Groundwater Project using Prairie Biofuel Buffers	Establishment of vegetation and initial characterization			Measurement, analysis, and reporting				
BUDGET ITEM								
UMN PERSONNEL: (includes salary+ benefits, benefits rate ranges from 9% to 33%). Academic salary for Clarence Lehman (6 months), Additional salary for Junior Scientists and summer interns.	44,484	44,484	0	103,266	103,199	67	147,750	67
UMN SUPPLIES AND MATERIALS: seeds, biomass harvest equipment, nutrient application equipment, sample collection equipment, shipping costs, repair costs, and other necessary supplies	4,714	4,714	0	2,626	2,626	0	7,341	0
UMN LABORATORY ANALYTICAL SERVICES: (includes soil C and N, plant C and N)	600	600	0	1,245	1,312	-67	1,845	-67
UMN TRAVEL	5	5	0	60	60	0	65	0
UMN TOTAL	**49,803**	**49,803**	**0**	**107,197**	**107,197**	**0**	157,000	**0**
								0
USGS SUBCONTRACT PERSONNEL: includes salary + benefits for hydrologist, lab technician, student hydrologists, and IT support	30,085	30,085	0	296,290	310,706	-14,416	326,375	-14,416
USGS SUBCONTRACT EQUIPMENT ($12,964): dataloggers, soil-moisture probes, multiplexers, pressure transducers, thermocouples, a tipping bucket rain gauge, solar panels, voltage controllers, cable, grounding rods, shelters, and mounting hardware. **USGS SUBCONTRACT SUPPLIES ($97,480):** suction lysimeters and well construction materials, batteries, teflon tubing, silicone tubing, field calibration standards, clean and quality assured sample collection and storage bottles, capsule filters, vacuum pumps, repairs of broken equipment, pipettors (200 ul, 1000 ul, 10ml), glass fiber filters, syringe filters, solvents (citric acid, methanol, organic free water, inorganic free water), analytical standards, ELISA kits, UHP nitrogen gas, labels, freezers, and other necessary items.	31,098	31,098	0	79,346	63,195	16,151	110,444	16,151
USGS SUBCONTRACT VEHICLE	231	231	0	500	337	163	731	163
USGS SUBCONTRACT PRINTING	0	0	0	500	0	500	500	500
USGS SUBCONTRACT TRAVEL	1,342	1,342	0	1,364	1,735	-371	2,706	-371
USGS SUBCONTRACT LAB ANALYTICAL	1,244	1,244	0	60,000	62,026	-2,026	61,244	-2,026
USGS TOTAL:	**64,000**	**64,000**	**0**	**438,000**	**438,000**	**0**	**502,000**	**0**
							0	0
OVERALL TOTAL:	**113,803**	**113,803**	**0**	**545,197**	**545,197**	**0**	**659,000**	**0**

Comparison of the Soil-Water Balance and Groundwater Recharge Among Annually-Harvested Perennial and Annual Biofuel Crops

Jared Trost[1], **John Nieber**[2], and **Clarence Lehman**[2], [1]United States Geological Survey, [2]University of Minnesota

Summary

Annually-harvested well-established diverse perennial prairies grown on coarse sandy soils reduced the movement of water and solutes to groundwater as compared with annually-planted corn (*Zea mays*). Perennial prairies grown on marginal soils offer a strategy to both produce biofuel and buffer shallow groundwater from land-applied fertilizers.

Introduction

Annually-harvested diverse perennial prairies grown on coarse-textured soils can provide a source of biofuel comparable to corn grain ethanol. The net energy production (energy output minus energy input) from unfertilized, annually-harvested diverse perennial prairies (18.1 GJ/ha) grown on sandy soils is similar to the net energy produced from corn grain ethanol grown on productive soils(18.9 GJ/ha) (Tilman and others, 2006). The replacement of perennial vegetative cover with annual row crops on productive soils in the Midwest, USA has resulted in increased groundwater recharge, which, in turn increases potential for transport of surface-applied fertilizers to groundwater (Brye and others, 2000; Schilling and Libra, 2003). Re-establishing perennial cover may offer a mechanism to both produce biofuel and buffer groundwater from surface-applied fertilizers. Prior to this project, little research had been done to compare the soil water balance and solute transport occurring beneath annually-harvested perennial and annual crops grown on coarse-textured soils, a prime landscape for perennial biofuel production.

Objectives

To compare among well-established perennial diverse prairie, newly-established perennial hay, annual corn, and bare soil the following hydrologic processes:

1. **The soil water balance including soil water storage (S), evapotranspiration (ET), and groundwater recharge (R).**
2. **The fate and transport of a surface-applied conservative tracer, bromide, through the unsaturated zone to groundwater.**

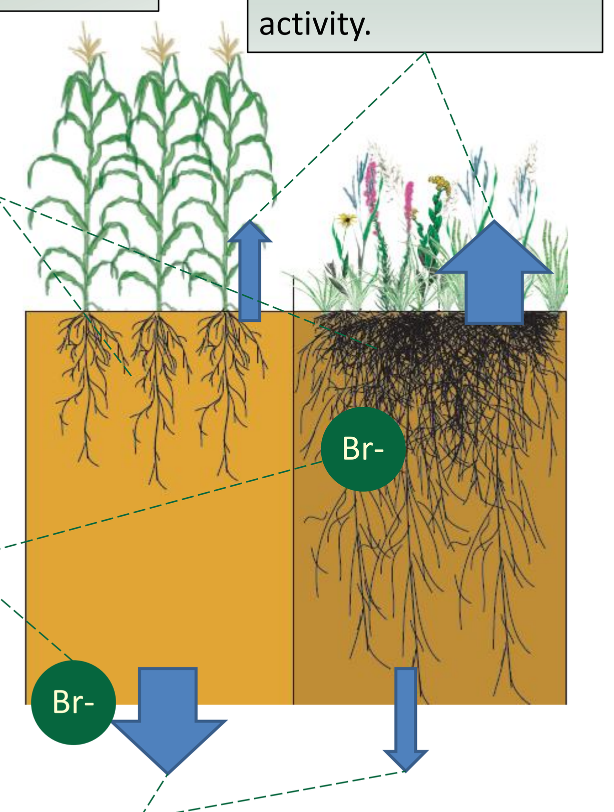
Conceptual Model

Big Idea: Well established perennial crops will utilize more water out of the soil profile than annual crops, thus reducing the flow of water and solutes to groundwater.

Greater annual ET in perennial crops compared to annual crops due to early and late season plant activity.

Lower soil water storage underlying perennial crops compared to annual crops during the growing season.

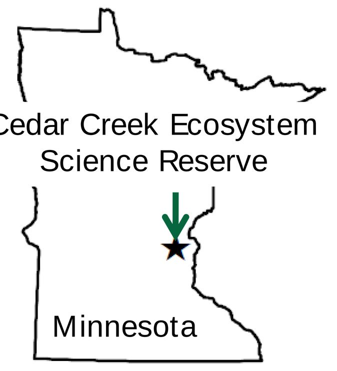
A conservative tracer, bromide, will be transported more slowly through the soil profile of perennial crops than annual crops due to reduced percolation through the rooting zone.



Reduced annual percolation below the rooting zone in perennial crops compared to annual crops. Percolation below the rooting zone is considered equivalent to groundwater recharge.

Experimental and Sampling Design

This study was established in the fall of 2007 and monitored from May 2008 through December 2009. The experiment consisted of thirty-five 11 x 11 m plots: 10 prairie, 10 hay, 10 bare soil, and 5 corn plots. All plots were prairie prior to the establishment of the vegetation treatments. Existing prairie vegetation remained intact for the prairie treatment but was eliminated for establishment of the hay, corn, and bare soil treatments.



Study Location

Soil-Water Balance: ET = P - R - ΔS

ET = evapotranspiration, estimated by difference in the water balance equation for ONE plot per treatment using continuous data from April through November.

P = precipitation, measured continuously with a tipping bucket rain gage.

R = groundwater recharge, calculated for ONE plot per treatment by converting late July in the upper 125 cm... the 2 m moisture content to a recharge rate using a plot-specific relationship.

ΔS = change in soil water storage, $S(t) = \sum \theta_i(t) * \Delta z_i$ where θ_i = volumetric water content % at depth i and Δz_i = vertical depth increment.

- *Continuous*: measured in ONE plot per treatment with Campbell CS616 TDR probes.
- *Discrete*: measured in ALL thirty-five plots with Trime TDR probe from May through October each year.

Tracer Study

Application

- Bromide applied at a rate of 10 g/m² in May 2008 on 5 plots per treatment.

Sample Collection

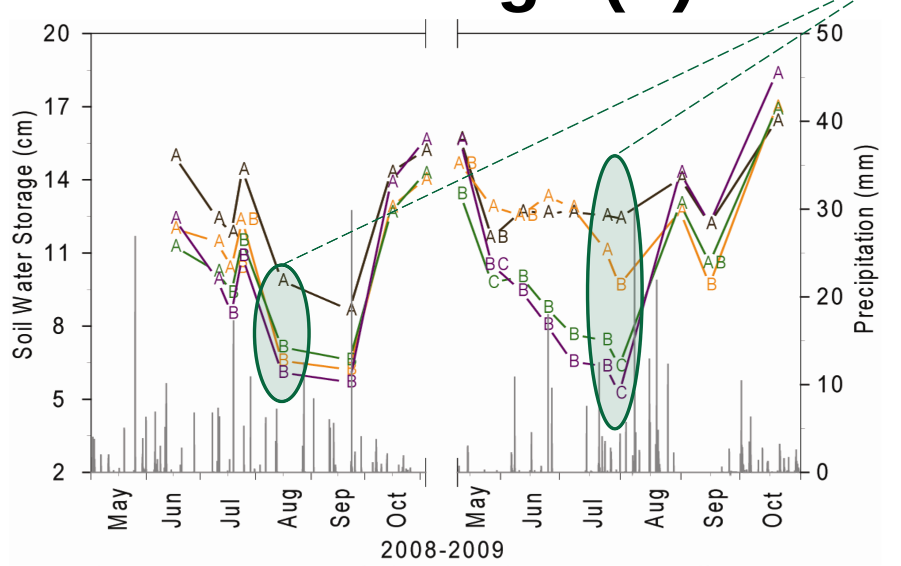
- Soil water sampled periodically with suction lysimeters (one per plot) at 1.6 m below land surface.
- Upper 5-10 cm of aquifer sampled periodically through water table monitoring wells (one per plot).
- Vertical soil profile sampled in 15 cm increments in ONE plot per treatment in November 2009.

Lab

- Extracted bromide from soil samples with deionized water at > 70% recovery.
- Analyzed samples with an ion chromatograph or an ion selective electrode.

Soil Water Balance

Soil Water Storage (S)



Perennial prairie and hay significantly reduced soil water storage compared to corn by late July in the upper 125 cm of the soil profile following a dry spring (2009) but not a wet spring (2008). Bare soil consistently had the most soil water storage.

The perennial "soil water storage effect" is transient and disappears by October.

Figure 1. Discrete measures of the growing season soil water storage (S) of the upper 125 cm of the soil profile and precipitation in millimeters. Different letters on a given sample date indicate significant differences among treatments (Tukey pairwise comparison, p< 0.05).

Evapotranspiration (ET)

Prairie had earlier peak daily rates of ET than corn.

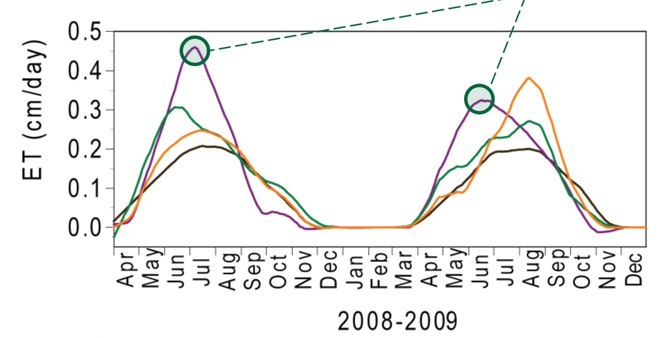


Figure 2. ET rates in cm/day. The smoothed lines are from applying Friedman's Super Smoothing function to three day average ET values.

Prairie and hay had slightly greater cumulative ET and reduced recharge compared to corn.

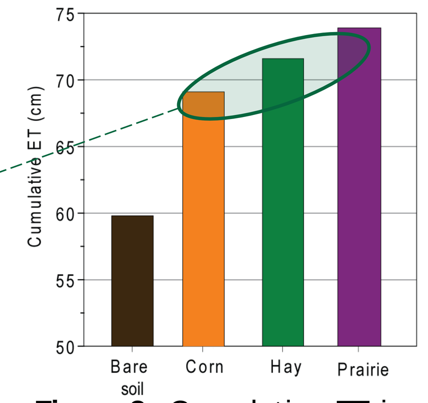


Figure 3. Cumulative ET in cm of water from May 2008 through December 2009.

Groundwater Recharge (R)

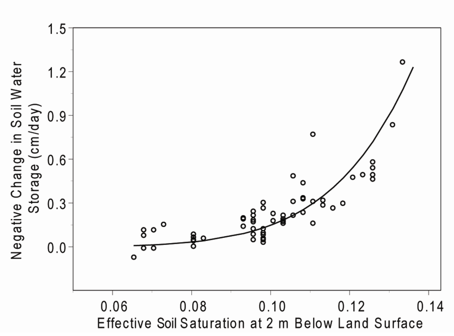


Figure 4. Example non-linear regression between the 2 m moisture content and the daily change in soil water storage.

In early spring and late fall on days with no precipitation, the daily water balance simplifies to -ΔS = R. Cumulative recharge in cm was calculated as follows: $\sum R(\theta_i)$ where $R(\theta_i) = a*(10*S_e)^b * \Delta t$

S_e = effective soil saturation at 2 m below land surface; Δt = time in days; a, b = empirical constants from derived from a regression as in Figure 4.

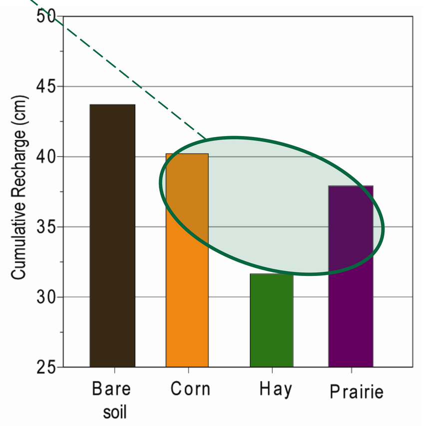
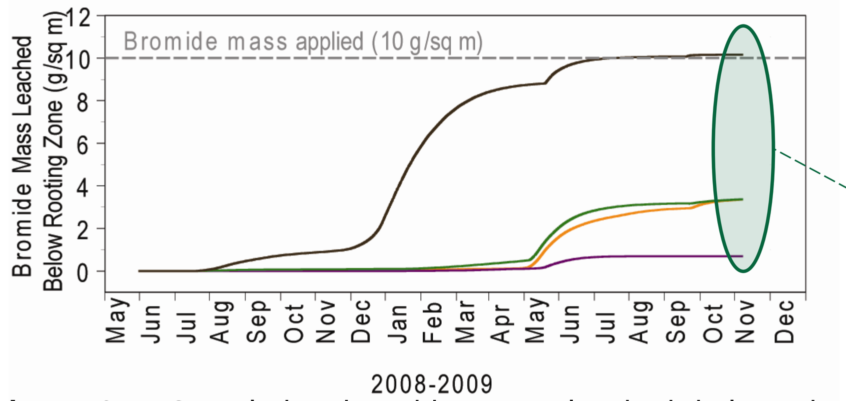


Figure 5. Cumulative recharge in cm of water from May 2008 through December 2009.

Tracer Transport to Groundwater

Bromide Leaching Below Rooting Zone



Prairie most effectively minimized leaching below the rooting zone . A mere 0.7% of applied bromide leached below the rooting zone in prairie, whereas corn and hay leached 34% and bare soil leached 100%.

Figure 6. Cumulative bromide mass leached below the rooting zone (1.6 m below land surface).

Bromide retained in soil profile

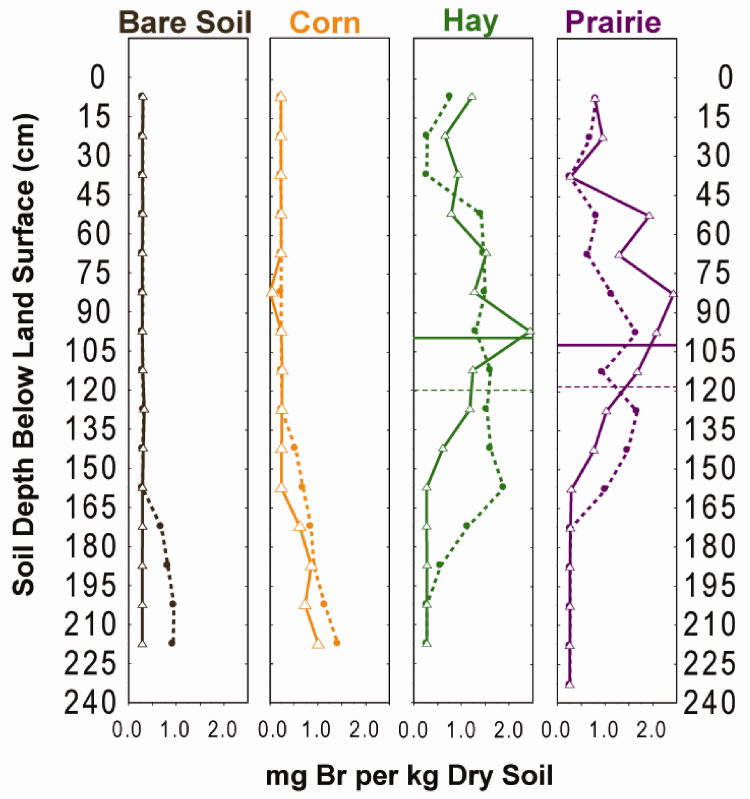


Figure 7. Bromide retained in the soil profile in November 2009 for 2 replicate profiles from 1 plot in each treatment. Horizontal lines indicate the center of mass. The center of mass calculation could not be completed for corn and bare soil as it had migrated below the sampling depth.

Bromide Mass Balance

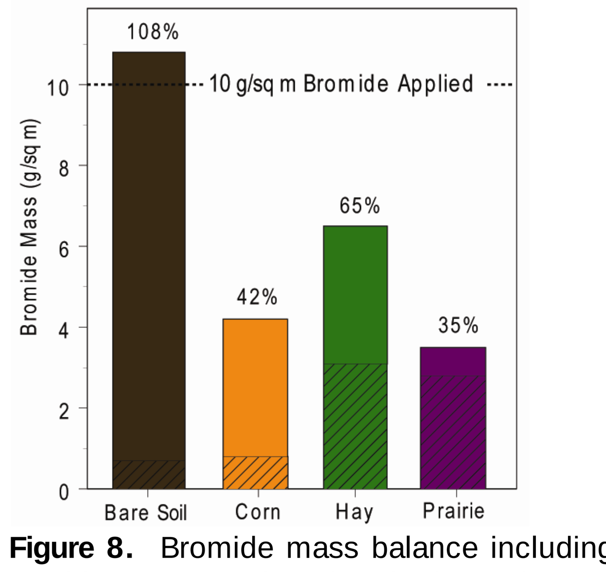


Figure 8. Bromide mass balance including leaching losses (non-hatched portion of bar) and soil retention (hatched portion of bar) to 1.6 m below land surface. Plant uptake was not measured to date. Percents indicate the percent of applied bromide recovered.

Prairie and hay retained more bromide in the soil profile. The center of mass of bromide in the soil underlying corn and bare soil had migrated well beyond the rooting zone (see Figures 7 and 8).

The mass recovered in vegetated plots was well below 100%, an indication of plant uptake.

Conclusions

Annually-harvested well-established diverse perennial prairies and newly-established perennial hay grown on coarse soils slightly reduced groundwater recharge and slightly increased evapotranspiration compared to annual corn.

Well-established diverse perennial prairies reduced leaching losses and increased retention of a conservative tracer in the soil profile compared to annual corn.

Application of these results:
While unfertilized perennial prairies demonstrate a similar efficiency to corn grain ethanol in terms of net energy output, the gross energy produced per area by prairie is only 25% of the gross energy production of corn grain ethanol (Tilman and others, 2006). Fertilization of prairie crops for biofuel production will increase the gross energy output per area. Prairies, if fertilized, will likely reduce impacts on groundwater quality compared to the fertilization of corn biofuel crops. Therefore, well-established diverse perennial prairies grown on marginal soils offer a strategy to both produce biofuel and buffer shallow groundwater from land applied fertilizers.

Acknowledgments

Funding for this project was provided by the USGS Cooperative Water Program and the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

Literature Cited

Brye K. R., J. M. Norman, L. G. Bundy, and S. T. Gower. 2000. Water-budget evaluation of prairie and maize ecosystems. Soil Science Society of America Journal **64**:715-724.

Schilling K. E., R. D. Libra. 2003. Increased baseflow in Iowa over the second half of the 20th century. Journal of the American Water Resources Association **39**:851-860.

Tilman D., J. Hill, and C. Lehman. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science **314**:1598-1600

2008 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Pyrolysis Pilot Project

Project Manager: Roger Ruan
Affiliation: University of Minnesota – Department of Bioproducts/ Biosystems Engineering and Center for Biorefining
Mailing Address: Room 206, BAE Bldg., 1390 Eckles Ave.
City / State / Zip: St. Paul, MN 55108
Telephone Number: 612-625-1710
E-mail Address: ruanx001@umn.edu
FAX Number: 612-624-3005
Web Page address: biorefining.cfans.umn.edu
FUNDING SOURCE: Environment and Natural Resources Trust Fund")
Legal Citation: ML 2007, [Chap.____], Sec.[__2__], Subd.__5___.

Appropriation Amount: $500,000.

Overall Project Outcome and Results

Diversified perennial plants throughout watersheds in rural areas of Minnesota are a source of biomass feedstock which can be converted biofuels while also producing ecosystem and water quality benefits. The nature of sporadic production of this biomass in lands away from power and convenient water supply requires conversion technologies to be mobile, portable, self energy sufficient, and water free. The goal of our project was to develop, build, and demonstrate a mobile microwave assisted pyrolysis system which can be operated on biomass production sites. The two specific aims of the project were: (1) developing water free microwave assisted pyrolysis (MAP) system for conversion of cellulosic feedstocks to biofuels, and (2) demonstrating the technology through outreach and communication. We first optimized the processes which we developed from our previous research. Based on the optimized processes, we designed and constructed our first generation pilot system. We then conducted a series of pilot scale experiments and identified technical and engineering problems. Finally we designed and built the mobile demo system. Our pilot scale system has been demonstrated to more than 300 people including university researchers, government officials, private interests, biomass feedstock producers, bioenergy producers, students, and investors. The mobile system has been tested on the manufacture site and further testing will occur in Minnesota at the University of Minnesota's UMore Park. The technology developed was presented to a broader audience through more than 15 outreach events. Nine (9) peer-reviewed papers have been published and over 30 presentations and reports were made to the public. Our co-PI's company Rural Advantages also developed and offered numerous educational outreach and demonstration events totaling over 78 events with 285 speakers and reaching at least 5,410 attendees.

Project Results Use and Dissemination

Information obtained from the project was disseminated through demonstration of the static pilot scale system, outreach and educational events, and peer-reviewed publications. The results have successfully reached a wide range of audience including university researchers, government officials, private investigators, biomass feedstock producers, bioenergy producers, students, and investors. A number of publications have aroused strong interests from investors. The project also led to efforts to seek additional funding to support work which will employ the new technology and system developed through this project.

2007 LCCMR Work Program Final Report

I. PROJECT TITLE: Pyrolysis Pilot Project

Project Manager:	Roger Ruan
Affiliation:	University of Minnesota – Department of Bioproducts/ Biosystems Engineering and Center for Biorefining
Mailing Address:	Room 206, BBE South Bldg., 1390 Eckles Ave.
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Telephone Number:	612-625-1710
E-mail Address:	ruanx001@umn.edu
FAX Number:	612-624-3005
Web Page address:	biorefining.cfans.umn.edu

Location: St. Paul, Minnesota

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$500,000**
	Minus Amount Spent:	**$500,000**
	Equal Balance:	**$0**

Legal Citation: ML 2007, [Chap.____], Sec.[__2__], Subd.__5___.

Appropriation Language: $500,000 is from the trust fund to the University of Minnesota in cooperation with Rural Advantage to demonstrate a water-free pyrolysis technology for converting biomass feedstock to biofuels. This appropriation is available until June 30, 2010, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II and III. FINAL PROJECT SUMMARY:

Diversified perennial watershed and other coverage plants in Minnesota rural areas are a source of biomass feedstock which can be converted biofuels while also producing ecosystem and water quality benefits. The nature of sporadic production of this biomass in lands away from power and convenient water supply requires conversion technologies to be mobile, portable, self energy sufficient, and water free. The goal of our project was to develop, build, and demonstrate a mobile microwave assisted pyrolysis system which can be operated on biomass production sites. The two specific aims of the project were: (1) developing water free microwave assisted pyrolysis (MAP) system for conversion of cellulosic feedstocks to biofuels, and (2) demonstrating the technology through outreach and communication. We first optimized the processes which we developed from our previous research; based on the optimized processes, we designed and constructed our first generation pilot system; we conducted a series of pilot scale experiments and identified technical and engineering problems; and finally we designed and built the mobile demo system. Our pilot scale system has been demonstrated to more than 300 people who were university researchers, government officials, private investigators, biomass feedstock producers, bioenergy producers, students, and investors. The mobile system is being tested

on the manufacture site. The technology developed was presented to a broader audience through more than 15 outreach events. Nine (9) peer-reviewed papers have been published and over 30 presentations and reports were made to the public. Our co-PI's company Rural Advantages also developed and offered numerous educational outreach and demonstration events totaling over 78 events with 285 speakers and reaching at least 5,410 attendees. The project successfully moved the lab-developed processes to the next level on the way towards transfer of the technology to the commercial sectors. The project also led to efforts to seek additional funding to support work which will employ the new technology and system developed through this project.

IV. OUTLINE OF PROJECT RESULTS*:*

Objectives: We will demonstrate and evaluate pyrolysis of diversified perennials to produce high-value, bio-based products and renewable energy while also producing ecosystem and water quality benefits. This project will support rural socio-economic development as proposed for the Madelia Energy Shed Initiative. Conversion and production of biomass, for a variety of products, will need to meet increasingly stringent environmental and water use standards while remaining profitable for farmers. A key component of this work will be the demonstration of a portable pyrolysis unit which uses a water free process to convert diverse biomass feedstocks to liquid fuels. This project will provide a practical demonstration of the integration of the production and processing of perennial crops for liquid fuel. The project will: 1) implement and demonstrate a portable pyrolysis unit that will convert cellulosic feedstocks to liquid fuels using a water free process; and 2) support educational outreach, promote established third crop plantings, and develop and implement a statewide **communication strategy** that will advance third crop adoption.

Result 1: Water free technology for conversion of cellulosic feedstocks to biofuels.

Description:

To demonstrate an innovative water-free **microwave assisted pyrolysis** technology that addresses the water energy nexus. This technology can convert feedstock produced from the field scale plantings to bio-oil, syngas and char. We will: 1) Develop an energy self-sufficient portable demonstration system that is capable of handling multiple harvested crops. The pyrolytic syngas is used to generate electricity for the operation of the system. The bio-oil produced can be used as home heating oil or blend into diesel fuel. The char residues mainly consisted of carbon and minerals can be used as fertilizer. The system, which does not require water or produce water contaminants, will be mounted on a trailer, and could be towed to different crop production sites. Depending on needs, the system can also be optimized to produce more bio-oil or syngas. 2) Conduct on-site and field testing and demonstration and report results. And 3) Evaluate product properties and energy and material balance for different feedstock applications and report results.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$**446,000
	Amount Spent:	**$446,000**
	Balance:	**$0**

	Deliverable	Completion Date	Budget	Status
1.	Initial prototype pyrolysis system	June 30, 2008	212,000	complete

2. Improved mobile pyrolysis system	June 30, 2009	132,000	complete
3. On-site and field test, demonstration	June 30, 2010	102,000	complete & on-going
4. Product evaluation	June 30, 2010		complete
5. Report	June 30, 2010		complete

Completion Date: *June 30, 2010*

Final Report Summary:

Preparatory R&D Work to Optimize the Processes

We conducted systematic experiments using batch microwave reactors to test catalysts and optimize processes to ensure the processes are energy efficient and the products meet the technical expectations. This part of work involved (1) catalytic pyrolysis to improve bio-oil yield and quality, and (2) catalytic upgrading of the bio-oil produced.

Fourteen catalysts either to assist heating rate or change chemical degradation have been selected, and are being tested. Some of the catalysts increased the liquid yield by 15-20%. It was also observed visually that the appearance of the resultant bio-oils varied with some catalysts, suggesting that these catalysts changed the chemical degradation pathways under pyrolytic conditions. Instrumental analysis of the bio-oils including GC-MS is planned. The analytical results are used as feedback to optimize the processes.

Figure 1 shows that pretreatment of biomass feedstock prior to microwave assisted pyrolysis changed the chemical profiles of pyrolytic oils. Alkaline pretreatments (A and B) seem to increase the phenolics slightly while the acid pretreatments greatly increased the furan compounds, resulting in a jump in product selectivity, compared with the control sample (C). This is a very important finding because this indicates that bio-oils with simple composition are possible with simple pretreatments. However we do not understand how this works. We would like to know whether the increased product selectivity is due to change in the physiochemical properties of the feedstock prior to the pyrolysis or because the acids present in the feedstock indeed function as catalysts during the pyrolysis. We would also like to know if it is possible to control the product variety by using different pretreatments.

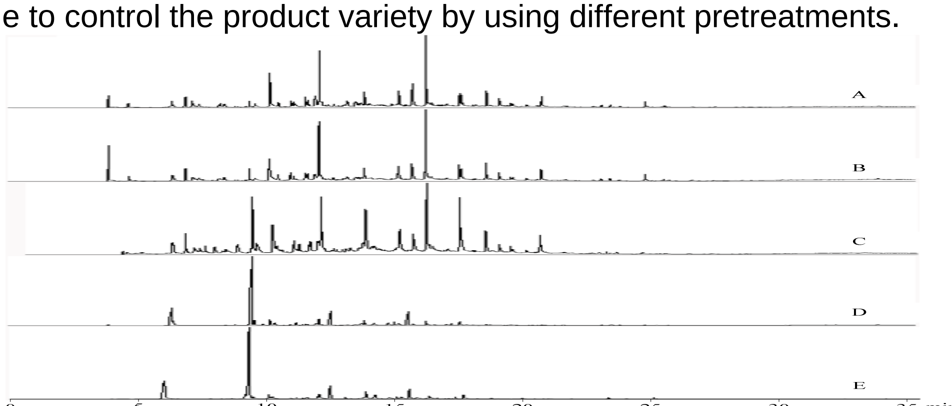

Figure 1. Effect of types of inorganic on bio-oil composition from pyrolysis of aspen: (A) 2%Na_2CO_3, (B) 2%NaOH, (C) Control, (D) 2%H_3PO_4, and (E) 2%H_2SO_4.

Figure 2 shows that catalysts ($MgCl_2 \cdot 6H_2O$, $ZnCl_2 \cdot 2H_2O$, and $Mg(ClO_4)_2$.) mixed with corn stover produced GC spectra of bio-oils with a large dominant peak. This result points to a great potential of simplifying bio-oil chemical profiles using appropriate catalysts. Bio-oils with simplified chemical profiles may require less or no post-conversion processing (upgrading) before they are used as liquid fuels, or the dominant chemical compounds may be separated as a high value product or as chemical stock for synthesis of other chemicals. Research is needed to understand how these and other catalysts work. We need to understand what happens on the biomass surface, particularly the interfaces between biomass and catalysts in molecular scale. Do the catalysts participate in the thermal degrading of the cellular constituents or do they catalyze the reforming of evolved organic volatiles generated after the thermal degradation of cellular constituents? We need to gain insight into the dynamics of the catalytic activities as a function of processing conditions. We also need to screen a range of catalysts for product selectivity data so that we can control the conversion products.

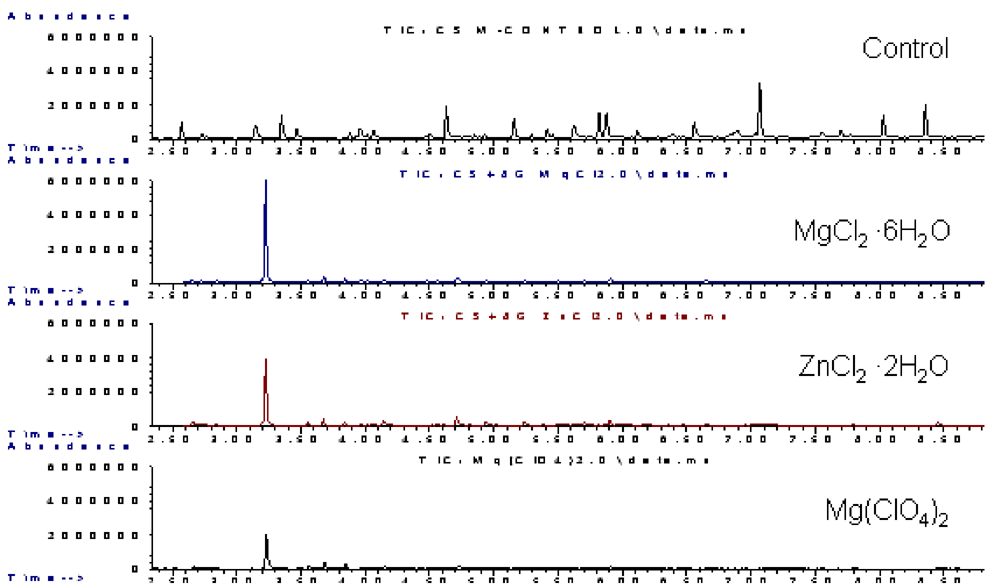

Figure 2. GC spectra of bio-oils from microwave assisted pyrolysis of corn stover: (1) control, (2) $MgCl_2 \cdot 6H_2O$, (3) $ZnCl_2 \cdot 2H_2O$, and (4) $Mg(ClO_4)_2$.

More biomass feedstocks were evaluated. Metal oxides, salts, and acids including $K_2Cr_2O_7$, Al_2O_3, KAc, H_3BO_3, Na_2HPO_4, $MgCl_2$, $AlCl_3$, $CoCl_2$, and $ZnCl_2$ were pre-mixed with corn stover or aspen wood pellets prior to pyrolysis using microwave heating. The thermal process produced three product fractions, namely bio-oil, gas, and charcoal. The best results were obtained from $MgCl_2$ treatment. At 8g $MgCl_2$ per 100 biomass level, the GC-MS total ion chromatograms of the bio-oils from the treated corn stover or aspen show only one major furfural peak accounting for about 80% of the area under the spectrum. We conclude that some catalysts improve bio-oil yields, and chloride salts in particular simplify the chemical compositions of the resultant bio-oils and therefore improve the product selectivity of the pyrolysis process.

<u>Product characterization and improvement</u>

In an effort to explore the uses of the bio-oils, fractionation of different bio-oils were carried out. Light oil and heavy oil phases were obtained. The physical and chemical properties of the two phases were determined. The light oil phase can readily be used as combustion fuel while the heavy oil can be used as heating oil with further refining and cleaning. We also tested the use of the bio-oils for making polyurethane foams.

Figure 3. Large pilot microwave assisted pyrolysis system installed at the Center for Biorefining, University of Minnesota.

<u>Development of a Continuous Pilot System (first generation)</u>

Microwave assisted pyrolysis (MAP) is a rather new technology and no commercial systems are available to date. In order to obtain first hand knowledge of a continuous MAP system, we developed a pilot system to be run in the laboratory conditions. Figure 3 shows the first generation pilot system installed in the Center for Biorefining.

The system has two microwave heating sections. The first one is for microwave assisted pyrolysis of fresh biomass feedstock and the second is for microwave assisted gasification of chars with potential of running water shift reactions to produce syngas. However, our experiments showed that the gasification stage doesn't work well in its original design. We decided to leave this out in our next mobile system.

Biomass feedstock enters the system from the feeder on top of the first microwave heating chamber. Inside the microwave heating chambers, feedstock is moved forward by an auger. The volatiles generated move through the pipes to a water scraper where ash particles are removed from the volatiles. The washed volatiles are cooled with tubular condensers (Figure 4) and the condensable volatiles flow to a bio-oil container while the non-condensable volatiles go into a gas turbine to generate electricity or are flared off.

Figure 4. Condenser of the stationary pilot scale microwave pyrolysis system

After a few test runs, we conducted experiments using the conditions we developed with batch MAP systems with and without catalysts. We were able to validate and improve the processes. During the course of pilot system operation, we met with many reaction and engineering problems. We studied these problems and developed solutions.

This has proven to be very beneficial to the design of our next generation system – the mobile demo system.

Development of Mobile Demo System

Based on the understanding of the MAP processes and experience and knowledge gained during the testing of our first generation pilot system, we designed the mobile demo system. The system, with a processing capacity of 100 kg/hr, is mounted on a 5 ft x 15 ft trailer. The feeding and conveying devices have been much improved. A new cooling approach which involves a two-stage quench is incorporated into the system. The new cooling device enables rapid cooling of volatiles from the reactors and hence improves the yield and quality of bio-oils. A gas turbine is built in the mobile system to provide the needed electricity from the syngas produced from the pyrolysis process. Figure 5 shows the mobile demon system.

Figure 5. Mobile microwave pyrolysis demo system.

Result 2: Demonstration, Outreach, and Communication

Description:

We will do demonstration and educational outreach by a variety of methods to support the pyrolysis technology developed in Result 1 and third crops across the state. We will secure perennial feedstocks for testing and demonstrating the pyrolysis technology. A communication strategy for the advancement of third crops will be developed and implemented across the state.

Summary Budget Information for Result 2: Trust Fund Budget: $54,000.00
Rural Advantage Amount Spent: $39,079.91
UMN Amount Spent: $14,920.09
Balance: $0

	Deliverable	Completion Date	Budget	Status
1.	Communication Strategy Development And Implementation	June 30, 2010	$20,000	complete
2.	3^{rd} Crop Outreach and Demonstration	June 30, 2010	$29,000	complete & on-going
3.	Feedstock Procurement for Pyrolysis Demonstrations	June 30, 2010	$ 5,000	complete

Completion Date: *June 30, 2010*
Final Report Summary

Communication Strategy Development

We developed a communication strategy to disseminate 3rd crop stories to a statewide audience by developing stories about a variety of 3rd crop farmers in Minnesota with geographic diversity. We utilized our existing contacts plus information from our partners to identify successful farmers who would portray a positive story. We contracted with a local writer to contact the farmer[s] and write the story at a rate of about one per month. This resulted in 23 stories being written and published. We developed a dissemination system of all of the newspapers in Minnesota, several regional publications such as The Land and the Agri-News papers and Farm Journal type magazines. Each story was formatted as a press release the same way each time they were sent out. We received positive feedback from the publishers who used our news releases. Many contacted us to do a more in-depth story, especially when it was someone in their area. We found this to be an effective method to elevate the awareness of 3rd crops and increase adoption. The following is a list of the stories.

Title	Date	Person
Land Stewardship: Straub Style	7/9/2008	Straub
Livestock Grazing: For Love and Money	8/11/2008	Hall
Answer to High Gas Prices Might Come From Trees	9/16/2008	Gibson
Growing Your Own: Sustaining Farm, Family & Environment	10/27/2008	Morlock
A Green Island Paradise	11/18/2008	Scheer
Grass Powers Growth	12/8/2008	Kreidermacher
Hazelnuts Work for Environment and Income	12/17/2008	Cerling
Making Deposits in a Different Kind of Bank	2/17/2009	Raney
Experiments in Alternative Energy	3/18/2009	Erickson
Not Your Typical Online Auction	4/13/2009	Domeier
Sowing Seeds of Biomass	4/28/2009	Vogt
Small Crop Gets Big Celebration	6/22/2009	Ford
A Berry Good Idea	9/14/2009	Altrichter
Powering up on Canola	10/20/2009	Dahl
Poultry Only Part of Free-Range Model	11/23/2009	Haslet-Marroquin
Out of a Jam	12/7/2009	Kuhlers
Bees: Honey of a Crop Alternative	1/5/2010	Harris Tinklenberg
Sustainable Ag: Balance Brings Benefits	1/25/2010	Jim Van der Pol
Decorative Woody Florals: Beautiful and Sustainable	2/23/2010	Chad Kingstrom
Strawberries: A Sweet Crop in more ways than One	3/25/2010	Tony Carter
Seeing a Market for the Trees	4/21/2010	Curt Kreklau
Sweetness Flows for Farmer	5/18/2010	Janna Goerdt
Are Hazelnuts the New Soybean?	6/3/2010	Norman Penner

3rd Crop Outreach and Demonstration

Throughout the project we were able to develop and offer numerous educational outreach and demonstration events totaling over 78 events with 285 speakers and reaching at least 5,410 attendees. The core of these events is our annual 3rd Crop Winter Series meetings and our summer Walk N Talks. In addition, we were able to collaborate for the annual corn and soybean meeting in Martin County and assisted with the development and delivery of eight biomass "Biobaler" harvest demonstrations across the state in the fall of 2009 and 4 prairie grass harvest demonstrations across the western edge of MN. We were also able to collaborate with our partners on additional learning activities around perennial feedstocks for bioenergy and 3rd crops.

System demonstration

UMN demonstrated the pilot system to more than 300 people from different sectors such as universities, research labs, biofuel companies, biomass producers, students, and investors.

Rural Advantage also collected and delivered a variety of feedstocks for utilization in test runs of the pyrolysis unit at the university. In addition, we have identified several cooperators, feedstock supply and sites for demonstrating the pyrolysis unit once it arrives. Examples of feedstock materials we have supplied or available include switchgrass, Indian grass, mixed prairie grass, hybrid poplar, short rotation willow, potato vines, miscanthus, corn stover, wheat straw, and big blue stem.

We tested the mobile demo system on the manufacture site. Additional minor improvements have just been made. The mobile demo system is expected to arrive in late August depending on shipping arrangement and customs clearance. The delay is mainly due to the continued inclusion of the additional process improvements. Nevertheless, we are glad that the "Pyrolysis Pilot Project" is a very successful program, thanks to LCCMR's support. We have leveraged a number of supports from DOE/USDA, DOT, and IREE, among others. With these supports, we conducted extensive research on microwave assisted pyrolysis process, catalytic reforming process, and pyrolytic product development and applications. We have been making significant progress in those areas, and built and tested two generations of pilot scale systems. We could have made the final mobile system earlier but we believe it would be a waste if we did not incorporate the new improvements into the final mobile system. We feel this is a more efficient way to use the tax payers' money.

Since we do have other related ongoing projects, we will continue to work with Rural Advantages to conduct field demonstration of the mobile system. In fact, we have done substantial outreach work on this project. We have published quite a few peer-review research journal articles (See publication list), and we have given many tours and interviews including the most recent article on the mobile microwave pyrolysis system in the *Popular Science* magazine (June, 2010), which generated tremendous interested in this technology and system. A patent has been filed to protect our invention of microwave assisted catalytic pyrolysis (See publication list).

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $300,000

Staff: Pyrolysis: Research asst. (50% time/3 years) 96,000

& Post-Doctor (100% time/3 Yr) 150,000
Contract Services: Rural Advantage: 54,000
[Educational Outreach, Biomass Feedstocks, Travel, Signage, Comm. Strategy]

Laboratory Supplies: $50,000
Laboratory supplies, minor components, testing materials

Equipment: $ 150,000
Major system components 130,000
Other components and supplies 20,000

Development: $ (improvement to land or building)
Restoration: $ (how many acres)
Acquisition, including easements: $ (how many acres, also who will hold the title to the land)

TOTAL TRUST FUND PROJECT BUDGET: $500,000

Explanation of Capital Expenditures Greater Than $3,500:

The $200,000 budget will be used to develop, construct, and operate a mobile pyrolysis system that consists of a main reactor, gas turbine generator, condenser/distillation column, and other components. The system can be used for the demonstration of the technology and for evaluation of additional biomass feedstocks after the completion of this three years project.

Explanation of Actual Spending Variations:
We spent slightly more on personnel and less on equipment than originally budgeted because we obtained additional supports from other sources for equipment development, and therefore we put more LCCMR source on process improvement and optimization, the outcomes of which were incorporated into the final mobile system.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

Center for Integrated Natural Resources and Agricultural Management (UMN)	300,190
Department of Agronomy and Plant Genetics (UMN)	150,000
Dept of Bioproducts and Biosystems Engineering and Center for Biorefining (UMN)	446,000
Rural Advantage	120,250
Martin County SWCD	9,000

B. Other Funds Spent during the Project Period:

Office of Naval Research (ONR) & Luna Innovations - Biofuels production from non-edible biooils.
Phase I. 8/1/09 – 7/31/10. $37,000
USDA/DOE - Development of Scalable Biorefining Processes for Distributed Biomass Conversion.
01/01/2007 - 06/30/2012 $1,224,055

USDA FAS - 2008. Lartin American Biofuel Training Grant. 2008	$25,000
US DOT and Sun Grant Initiative - Develop sustainable renewable energy systems for practical utilization of bulky biomass. 9/1/07 – 8/31/11	$1,186,084
University of Minnesota IREE - Catalytic reforming of liquids and gases from thermochemical and biological conversion of biomass. 7/1/09 – 6/30/11	$250,000
EPA-MPCA - Assessing Potential of Watershed and Stream Channel Modifications on Suspended Sediment, Turbidity and Nutrients in the Blue Earth River Basin [UMN]	295,516
Bush Fnd. – Third Crop Init./ Conservation Agronomist [Rural Advantage]	254,000
Xcel Energy – Feasibility of Growing Miscanthus [Rural Advantage]	318,500
McKnight Foundation – Third Crop Initiative [Rural Advantage]	180,673
Clean Water Legacy– Conservation Agronomist [Rural Advantage via GBERBA]	80,000

C. Past Spending:

USDA-CSREES - Improving Water Quality and Enhancing Hydrologic Stability of the MN River through Agroforestry and Other Perennial Cropping Systems [UMN]	556,500
LCMR - 3rd Crops and Native Perennials for Water Quality [BERBI]	622,000
LCMR – 2005 3rd Crops For Water Quality Phase II [Rural Advantage]	500,000
EPA 319 – Innovative Easements, Cost Share, Coordination [BERBI]	671,250

D. Time:

VII. DISSEMINATION:

1. Wang, W, J Wu, F Yu, P Chen, and R Ruan. 2007. *Preparation of polyurethane foam from microwave pyrolytic bio-oils*, in *The 234th ACS National Meeting*. 2007: Boston, MA.
2. Wu, J, Y Wang, F Yu, Y Liu, P Chen, and R Ruan, *Preparation of Bio-polyesters and adhesives from Microwave Pyrolytic Oils*, in *ASABE Annual International Meeting*. 2007: Minneapolis MN.
3. Yu, F, S Deng, P Chen, Y Liu, Y Wan, A Olson, D Kittelson, and R Ruan. 2007. *Physical and chemical properties of bio-oils from microwave pyrolysis of corn stover.* Applied Biochemistry & Biotechnology, 2007. 137-140(1-12): p. 957-70.
4. Yu, F, K Hennessy, S Deng, P Chen, and R Ruan. 2007. *Biofuel production from corn residues by thermochemical conversion*, in *The 234th ACS National Meeting*. 2007: Boston, MA.
5. Yu, F, R Ruan, P Chen, and S Deng. 2007. *Characterization of char from the microwave pyrolysis of corn stover*, in *ASABE Annual International Meeting*. 2007: Minneapolis, MN.
6. Yu, F, R Ruan, S Deng, and P Chen, *Kinetics of thermal decomposition of corn stover studied by two-step consecutive reaction model*, in *ASABE Annual International Meeting*. 2007: Minneapolis, MN.
7. Moen, J, C Yang, B Zhang, K Hennessy, P Chen, and R Ruan, 2008. *Catalytic Microwave-Assisted Pyrolysis of High-diversity Grassland Perennials*, in *The 30th Biotech for chemicals and energy symposium*. 2008: New Orleans, LA.
8. Ruan, R and P Chen, *Bioenergy Industry Status and Prospects*, in *Industrial Crops and Uses*, B. Singh, Editor. 2008, CABI Oxfordshire, UK.
9. Yang, C, J Moen, B Zhang, K Hennessy, P Chen, and R Ruan. 2008. *Fractionation and characterization of bio-oil from biomass pyrolysis*, in *The 30th Biotech for chemicals and energy symposium*. 2008: New Orleans, LA.

10. Yu, F, Z Le, P Chen, Y Liu, X Lin, and R Ruan. 2008 *Atmospheric pressure liquefaction of dried distillers grains (DDG) and making polyurethane foams from liquefied DDG.* Applied Biochemistry & Biotechnology, 2008, 148(1-3): p. 235-43.
11. Wan, Y., P Chen, B. Zhang, C. Yang, Y. Liu, X. Lin, and **R. Ruan.** 2009. Microwave assisted pyrolysis of corn stover pellets with catalysts for bio-oil production. *Journal of Analytical and Applied Pyrolysis* 86(1):161-167.
12. Y Wan, Y Liu, X Lin, C Yang, B Zhang, P Chen, H Lei, R Ruan. 2009. *Microwave assisted pyrolysis of corn stover pellets with catalysts for bio-oil production and its component*. Transactions of the Chinese Society of Agricultural Engineering, 2009. 25(4):190-195.
13. B Zhang, C Yang, M Johannes, Z Le, K Hennessy, Y Wan, Y Liu, H Lei, P Chen, R Ruan. 2009. *Catalytic Conversion of Microwave-Assisted Pyrolysis Vapors*. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, In press.
14. Moen, J., C. Yang, B. Zhang, H. Lei, K. Hennessy, Y. Wan, Z. Le, Y. Liu, P. Chen, **R. Ruan**. 2010. Catalytic microwave assisted pyrolysis of aspen. *International Journal of Agricultural and Biological Engineering* 2(4):70-75.
15. Wan, Y., J. Wu, Y. Qan, H. Lei, F. Yu, P. Chen, X. Lin, Y. Liu, **R. Ruan**. 2009. Liquefaction of corn stover using industrial biodiesel glycerol. *International Journal of Agricultural and Biological Engineering* 2(2): 32-40.
16. Roger Ruan, Yiqin Wan, Changyang Yang, Bo Zhang, Xiangyang Lin, Xiaoquan Wang, Zhiping Le, and Paul Chen. 2009. IMPROVED PROCESS FOR PREPARING BIO-OILS FROM BIOMASS, US Patent Application, PCT/US2009/057009

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted every six months. A final work program report and associated products will be submitted between June 30 and August 1, 2010 as requested by the LCCMR.

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects - **Summary and a Budget page for each partner (if applicable)**

Project Title: *Pyrolysis Pilot Project*

Project Manager Name: *Roger Ruan.*

Trust Fund Appropriation: $500,000

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent (date)	Balance (date)	Result 2 Budget:	Amount Spent (date)	Balance (date)	Result 3 Budget:	Amount Spent (date)	Balance (date)	TOTAL BUDGET	TOTAL BALANCE
	Water free technology for conversion of cellulosic feedstocks to biofuels			*Fill in your result title here.*			*Fill in your result title here.*				
BUDGET ITEM			0			0			0	0	0
PERSONNEL: wages and benefits	273,545	289,108	-15,563			0			0	273,545	-15,563
Contracts			0			0			0	0	0
Rural Advantage - Outreach, Demonstration, Feedstock Supply, Communication Strategy			0	54,000	45,079.91	8,920			0	54,000	8,920
Other contracts *(with whom?, for what?) list out: personnel, equipment, etc.*			0			0			0	0	0
Other direct operating costs *(for what? – be specific)*			0			0			0	0	0
Equipment / Tools *(mobile pyrolysis reactor and components)*	113,800	96,130	17,671			0			0	113,800	17,671
Office equipment & computers - NOT ALLOWED unless unique to the project			0			0			0	0	0
Other Capital equipment *(list specific items)*			0			0			0	0	0
Land acquisition			0			0			0	0	0
Land rights acquisition *(less than fee)*			0			0			0	0	0
Professional Services for Acq.			0			0			0	0	0
Printing			0			0			0	0	0
Other Supplies *(list specific categories)*	58,655	69,683	-11,028			0			0	58,655	-11,028
Travel expenses in Minnesota			0			0			0	0	0
Travel outside Minnesota *(where?)*			0			0			0	0	0
Construction *(for what?)*			0			0			0	0	0
Other land improvement *(for what?)*			0			0			0	0	0
Other *(Describe the activity and cost) be specific*			0			0			0	0	0
COLUMN TOTAL	**$446,000**	**$454,920**	**-$8,920**	**$54,000**	**$45,080**	**$8,920**	**$0**	**$0**	**$0**	**$500,000**	**$0**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Minnesota County Biological Survey
PROJECT MANAGER: Carmen Converse
AFFILIATION: Department of Natural Resources (DNR)
MAILING ADDRESS: Box 25, 500 Lafayette Road
CITY/STATE/ZIP: St. Paul, Minnesota 55155
PHONE: (651) 259-5083
FAX: (651) 259-1811
E-MAIL: carmen.converse@dnr.state.mn.us
WEBSITE: http://www.dnr.state.mn.us/eco/mcbs/index.html
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, Chap. 30, Sec. 2, Subd. 6a.

APPROPRIATION AMOUNT: $1, 500,000

Overall Project Outcome and Results

This appropriation continued and accelerated the ongoing Minnesota County Biological Survey (MCBS), which identifies significant natural areas and systematically collects and interprets data on the distribution and ecology of native plant communities, rare plants, and rare animals. The information gathered by MCBS serves as a foundation for the conservation of critical components of Minnesota's biological diversity through ecological monitoring, environmental review, planning, and critical habitat protection.

In this phase of the MCBS, surveys were completed in Hubbard, Wadena, Itasca, Lincoln, Murray, Cottonwood, Jackson, Watonwan, and Martin counties. Surveys were accelerated in the Border Lakes and Nashwauk ecological subsections. Since 1987, MCBS has added 17,054 new rare feature records to DNR's Rare Features Database. Over 47,000 polygons of native plant communities and over 7,000 MCBS site polygons are available to external customers on DNR's "Data Deli", including MCBS sites of biodiversity significance. Aquatic plant data have been collected from 1,528 lakes.

New locations of animal species documented during this period included Prairie Vole, Chestnut-collared Longspur, Black-throated Blue Warbler, and Four-toed Salamander. Plants documented included *Najas guadalupensis var. olivacea*, a Great Lakes endemic aquatic plant and *Carex supina*, a cliff-dwelling sedge last observed in Minnesota in the 1930's. Sioux quartzite rock outcrop surveys yielded nearly 100 new records of rare plants. Since 1987, Twenty-one species and one hybrid not previously documented in Minnesota were recorded, with a 2008 addition of the aquatic plant *Potamogeton confervoides.*

Project Results Use and Dissemination

Data delivery and technical assistance were provided as related to:

- Forest certification
- DNR and US Forest Service forest planning
- Peatland management planning
- State land exchanges
- Woody and grasslands biomass guidelines
- Off Highway Vehicle guidelines
- State Wildlife Action plan implementation
- Quality lake identification
- Forest legacy projects

- Landscape collaborative planning
- Lake and native prairie monitoring
- Native prairie bank
- Updates to the state lists of rare species and calcareous fens.

Locally, aquatic plant data were delivered to lake associations, staff led field trips for county residents, and training sessions in plant community and plant identification. The publication, *Native plant communities and rare species of the Minnesota River Counties* was well-received by communities bordering the river corridor.

MCBS provided ecological evaluations for Franconia Bluffs, Seminary Fen, Butternut Valley Prairie, and Langhei Prairie that have since become Scientific and Natural Areas.

A statewide web map of the current extent of native prairie as compared to 100 years ago informs prairie ecosystem conservation planning. Another product is an easily downloaded booklet of the Ecological Systems in the Laurentian Mixed Forest Province.

Several MCBS related articles have been published in the *Minnesota Conservation Volunteer*; examples include *Elusive orchids* and *Rock pools on the prairie.*

Trust Fund 2007 Work Program Final Report

Date of Report: August 31, 2009
Date of Work Program Approval: June 5, 2007
Project Completion Date: This workprogram outlines activities and products to be completed during the two-year duration of this funding (ending June 30, 2009). This is a continuation project so data generated from activities of the Minnesota County Biological Survey (MCBS) in previous biennia will be applied to the proposed outcomes, and data and procedures derived from work this biennium will be applied to future surveys and products.

I. PROJECT TITLE: Minnesota County Biological Survey

Program Manager: Carmen Converse
Affiliation: Department of Natural Resources
Mailing Address: Box 25, 500 Lafayette Road
City/State/ Zip: St. Paul, Minnesota 55155
Telephone Number: (651) 259-5083
E-mail Address: carmen.converse@dnr.state.mn.us
FAX Number: (651) 259-1811

Web Page address: http://www.dnr.state.mn.us/eco/mcbs/index.html **(see also map):** Surveys will be completed in Hubbard, Wadena, Itasca, Lincoln, Murray, Cottonwood, and Jackson counties. Surveys will begin and be completed in Watonwan and Martin counties. Surveys will be expanded in St Louis, Lake and Cook counties.

Total Trust Fund Project: $1,500,000

Trust Fund Appropriation:	**$1,500,000**
Minus Amount Spent:	**$1,499,192**
Equal Balance:	**$ 808**

Legal Citation: ML 2007, Chap. 30, Sec. 2, Subd. 6a.

Appropriation Language: Minnesota County Biological Survey
$1,500,000 is from the trust fund to the commissioner of natural resources to accelerate the biological survey that identifies significant natural areas and systematically collects and interprets data on the distribution and ecology of native plant communities, rare plants, and rare animals.

II. and III. FINAL PROJECT SUMMARY

This appropriation continued and accelerated the ongoing Minnesota County Biological Survey (MCBS), which identifies significant natural areas and systematically collects and interprets data on the distribution and ecology of native plant communities, rare plants, and rare animals. The information gathered by MCBS serves as a foundation for the conservation of critical components of Minnesota's biological diversity through ecological monitoring, environmental review, planning, and critical habitat protection.

In this phase of the MCBS, surveys were completed in Hubbard, Wadena, Itasca, Lincoln, Murray, Cottonwood, Jackson, Watonwan, and Martin counties. Surveys were accelerated in the Border Lakes and Nashwauk ecological subsections. Since 1987, MCBS has added 17,054 new rare feature records to DNR's Rare Features Database. Over 47,000 polygons of native plant communities and over 7,000 MCBS site polygons are available to external customers on DNR's "Data Deli", including MCBS sites of biodiversity significance. Aquatic plant data have been collected from 1,528 lakes.

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IV. OUTLINE OF PROJECT RESULTS:

Result 1: Field Surveys (see attached map).

Description: The status and distribution of rare resources will be identified providing a basis for the maintenance of Minnesota's biological diversity through ecological management, planning, research, monitoring, and critical habitat acquisition.

Procedure: A multi-level survey process is followed.
Review and site identification: Plant ecologists, botanists and zoologists review existing relevant natural resource data and record information into electronic databases, using Geographic Information Systems and the DNR's Natural Heritage Information System to consolidate and organize data. Examples of these data include forest inventories, wetlands inventories, wildlife habitat inventories, park surveys, soil surveys, land use data, historical public land surveys, biophysical surveys, academic research, and records from museum collections. Using these data, supplemented by the interpretation of aerial photography or other imagery, staff identify MCBS sites and species habitats for targeted surveys.

Coordination: Staff notify and coordinate surveys when possible with other divisions within the DNR, universities, counties, municipalities, tribal governments, watershed districts, federal natural resource agencies, conservation organizations, corporations, and individual landowners. This is critical to the success of data consolidation and field surveys.

Field Surveys: Ground surveys to assess natural area and native plant community quality and condition also include the collection of vegetation samples using relevés in coordination with other sampling (soils, water chemistry etc.) when possible. Aerial surveys sometimes supplement ground surveys. Additional specialized techniques are used during field seasons to survey selected rare species or groups of species (e.g., plants, birds, mammals, reptiles, amphibians, insects, fish).

Summary Budget Information for Result 1: **Trust Fund Budget:** **$ 550,000**
Amount Spent: **$ 577,349**
Balance: **$ (27,349)**

Deliverable	Completion Date	Budget	Status (see below)
Review and site identification	August 2007 south/March 2008 north	120,000	
Coordination	July 2007-June 2009	100,000	
Field surveys	July-Oct 2007; April-Oct 2008; April-June 2009	330,000	

Final Report Summary June 30, 2009

Review and site identification

The Border Lakes ecological subsection (bordering Canada) was one focal area of potential survey site delineation during this project period. This included the development of a scoring procedure to determine survey priority areas. In preparation for the 2008 field surveys, the Vegetable Lakes Till Plain and Trout Lake Bedrock Complex Land Type Associations (LTAs) were selected for review. In the Trout Lake LTA, 28 preliminary sites encompassing 400,000 were prioritized for field survey. Additional aerial photography was acquired, and logistical plans were completed that included canoe-access trips to a subset of these sites.

Following the 2008 field season, biologists and ecologists again examined the available resources for the entire Border Lakes subsection to select additional potential rare species, native plant community and site targets for the 2009 field season. They reviewed GIS layers of topography, geology, soils, hydrology, past fires, digital elevation data, aerial photography, blowdown maps and rare species range distributions, including Canadian data. The 2009 field season focused on the Cook County portion of the subsection in order to simplify logistics. Survey included the Rove LTA, a large intact landscape with high quality fire-dependent forests, unusual cliffs, undeveloped lakes and potential habitat for numerous rare plant species.

For aquatic plants, a list of the lakes in the Trout Lake and Vegetable Lake LTAs that most closely matched (in water chemistry) each of the targeted rare aquatic plants was added to the evaluation process prior to the 2008 field season. The very rare Algae-like pondweed *(Potamogeton confervoides)*, located during the 2008 field season prompted additional review of known habitat and water chemistry relationships in order to generate a list of lakes in the Border Lakes subsection potentially harboring additional populations of this aquatic plant.

Preliminary boundaries of sites were also identified for survey in the Nashwauk Uplands subsection (located mostly in St Louis County). Delineated sites were posted in spring 2009 on a DNR web site for review by other Divisions.

In Itasca County, the large lake-dominated landscape of the Itasca Moraine Land Type Association (commonly known as the Woman Lake Area) was identified as a targeted area for 2008 aquatic plant surveys.

In southwestern Minnesota, a review of air photos assisted in planning for final field work in the region.

Coordination

Northern Minnesota examples

Border Lakes subsection surveys were productive in part due to early, coordinated planning with staff from the Superior National Forest (SNF). A meeting was held in early 2008 to discuss priorities and logistics that included USFS and DNR ecologists and biologists, monitoring coordinators, and the SNF wilderness area coordinator.

A proposed emergency communication plan was prepared for MCBS staff conducting field surveys in the Border Lakes in coordination with the SNF. An application to conduct research in the Boundary Waters Canoe Area Wilderness (BWCAW) was prepared and approved by the SNF, along with procedures for obtaining BWCAW regular or administrative permits.

A workshop at Wolf Ridge Environmental Learning Center was held for botanists/plant ecologists from the SNF and MCBS to review a new guide to the bryophytes (mosses and liverworts) of the region (led by bryologist contractor J. Janssens).

Botanists conferred with *Botrychium* expert, Don Farrar and SNF biologist Jack Greenlee regarding their current and ongoing survey and monitoring interests in this group of fern species in northeastern Minnesota to help direct MCBS survey work in the Border Lakes. Many of these species are difficult to identify, complicating the knowledge of the distribution and status of species in the group. Botanical observations in the region are also being exchanged with Tony Reznicek (Michigan) and Mike Oldham (Ontario Conservation Data Center).

Rare aquatic plant surveys were conducted in some lakes lacking Division of Waters (DOW) lake numbers. A list of these was sent to DOW staff for lake number assignment so that all data collected on these lakes can be referenced throughout the DNR.

Ecologists met with Potlatch representatives to provide an update on survey outcomes conducted on some of their lands as part of a permit agreement with the company.

In the Nashwauk Uplands subsection, plant ecologists requested permission to survey lands owned by multiple private landowners (including some mining companies).

Native plant community mapping of McCarthy Beach State Park was completed in coordination with DNR Parks and Trails.

Southern Minnesota examples
Ecologists and biologists met with DNR wildlife and parks staff to relate results of survey work and discuss significant prairie and wetland sites.

Animal survey staff used facilities at Talcott Lake WMA as their field location for survey work in the area in 2008.

A cooperative agreement between the North Heron Lake Game Producers Association and animal survey staff helped to provide access to much of the lake through their lands as well as providing lodging for field staff.

At the request of U.S. Fish and Wildlife Service staff, plant ecologist Fred Harris surveyed rare plants at Big Stone National Wildlife Refuge. One rock outcrop supports large populations of several rare plants including seedlings of mud plantain *(Heteranthera limosa)*, one of very few locations of this species in the state.

Other coordination
MCBS staff received training in Wilderness First Aid. “First Responders” and medical staff from Itasca County and Cook County were instructors in the training, providing excellent local perspectives.

In preparation for the proposed statewide Breeding Bird Atlas project, ornithologist Steve Stucker summarized the extensive information collected by MCBS since 1987 related to records of both common and rare species of birds. This is part of a larger effort to summarize data on common animals throughout the Division of Ecological Resources as part of the State Wildlife Action Plan implementation.

Plant ecologists from Minnesota, Wisconsin, Michigan, and NatureServe participated in discussions on the evaluation of forest types in a meeting held at Marine on St. Croix in April 2008. (NatureServe is a national consortium of programs that include biological surveys similar to MCBS).

The Clean Water Legacy Act has focused considerable attention on impaired waters. Another portion of the Act includes the identification and protection of surface waters and shorelines representative of the highest quality locations in the state (i.e. “Legacy Waters”). MCBS participated in a work team to develop a preliminary series of proposed statewide legacy lakes. Staff also participated in the discussions related to the development of a new acquisition plan for Aquatic Management Areas.

Field Surveys

Southern Minnesota
Surveys were completed in Lincoln, Murray, Cottonwood, Jackson, Watonwan and Martin counties.

Highlights
Mammal surveys resulted in the location of three listed species and seven species of greatest conservation need as identified in the State Wildlife Action Plan. These included: American Badger *(Taxidea taxus),* Prairie Vole *(Microtus ochrogaster),* Northern Grasshopper Mouse *(Onychomys leucogaster),* Western Harvest Mouse *(Reithrodontomys megalotis),* and Richardson's Ground Squirrel *(Spermophilus richardsonii).* Bats recorded using the ANABAT tool included: Northern Myotis *(Myotis septentrionalis)* and Eastern Pipistrelle *(Pipistrellus subflavus).*

Surveys for rare jumping spiders documented new records for six species, including the Ant-mimic *(Tutelina hartii),* which had previously been located only two times in Minnesota.

The upper Redwood and upper Cottonwood rivers, Plum Creek, and Great Bend vicinity were some of the focal areas of native plant community surveys.

Twenty-two new calcareous fen locations were documented, often found in association with the Des Moines lobe outwash deposits along major drainages (Rock River and Chanarambie Creek) southwest of the Bemis Moraine. New populations of the calcareous fen plants were located in each of the new fen locations, including hair-like beak-rush (*Rhynchospora capillacea*), marsh arrowgrass *(Triglochin palustris)* and few-flowered spike-rush *(Eleocharis quinquifolius).*

Populations of two federally- protected species were confirmed including western prairie fringed orchid (*Platanthera praeclara*) and a new location of prairie bush clover (*Lespedeza leptostachya*).

Sioux quartzite rock outcrop communities were a focus of botanical surveys. Nearly 100 new locations of rare plants related to rock outcrop communities were an impressive outcome of botanical surveys due largely to excellent timing by survey botanists. By carefully tracking the phenology of this group of often-ephemeral plants, botanists were able to conduct field surveys at the prime time of plant visibility. One example was the documentation of a large population of pigmyweed (*Crassula aquatica*), a small plant inhabiting rock outcrop pools. It was recorded at Blue Mounds State Park and represents only the third known location for this species in southwestern Minnesota.

Northern Minnesota
Surveys of native plant communities and MCBS sites were completed in Hubbard, Itasca, and Wadena counties. Surveys of rare plants and native plant communities were conducted in the Border Lakes and Nashwauk Uplands ecological subsections of Lake, Cook and St Louis counties.

Highlights Hubbard, Wadena and Itasca counties
Ram's-head orchid (*Cypripedium arietinum*) was observed at two new locations in Hubbard County. A population of 135 plants was observed in Wolf Lake Wildlife Management Area (WMA) and 11 plants were found in a sloping black spruce swamp on Hubbard County land. A poor fen in Wolf Lake WMA also supports a large population of another orchid, dragon's mouth (*Arethusa bulbosa*).

Oakes' pondweed *(Potamogeton oakesianus)* occurring at Finn Lake in Wadena County is one of the few very rare plant species located in Wadena County.

In western Itasca County numerous small hardwood forests were surveyed with many showing degradation due to European earthworms. The tree canopy in some of the forests is dominated by bur oak (*Quercus macrocarpa)* and basswood (*Tilia americana)*.

The common down liverwort *(Trichocolea tomentella)* was located in Itasca County, representing the fourth observation of this species in the state. Other plant species of interest observed in the county include triangle moonwort *(Botrychium lanceolatum)*, pale moonwort *(Botrychium pallidum)*, and least moonwort *(Botrychium simplex)*.

A Northern Bog Lemming (*Synaptomys borealis*) was documented in Itasca County, confirming a previous 1993 observation at the site made by University of Minnesota Duluth students and a professor that seemed very reliable, but lacked an enduring physical collection for documentation. (The 2008 collection was deposited in the Bell Museum). The site is a small, isolated black spruce swamp far removed from any large peatland complexes, representing a substantial southern expansion of the known Minnesota range of the species.

Fish surveys in Itasca County resulted in 37 records of rare fish, including Least Darter (*Etheostoma microperca*), Pugnose Shiner (*Notropis anogenus),* Longear Sunfish (*Lepomis megalotis*), Greater Redhorse (*Moxostoma valenciennesi,)* and Northern Brook Lamprey (*Ichthyomyzon fossor)*.

Five bat recording stations were established in Itasca County with the first seasonal record of a Big Brown Bat (*Eptesicus fuscus*) occurring in early April 2008.

Four-toed Salamanders *(Hemidactylium scutatum)* were recorded in 13 locations on state, federal, county, and private lands. A location of Blanding's Turtle *(Emydoidea blandingii)* was recorded just west of the Mississippi River immediately north of the Aitkin/Itasca county line, the first Blanding's Turtle documented in Itasca County.

Bird survey staff completed 163 point counts in Itasca County and produced 241 species lists. A total of 167 potential breeding bird species were found, representing the third highest species total for a county documented by MCBS. Rare species noted included Trumpeter Swan (5), American Bittern (12), Bald Eagle, Red-shouldered Hawk (2), Yellow Rail (6), Sandhill Crane (5), Black-throated Blue Warbler (2), and Nelson's Sharp-tailed Sparrow (1).

Other species of interest recorded included Northern Goshawk (1 nest), Merlin (2), Great Gray Owl (3), American Three-toed Woodpecker (1), Olive-sided Flycatcher (16), Black-billed Magpie (8), Boreal Chickadee (5), Ruby-crowned Kinglet (22), Golden-winged Warbler (15), Red Crossbill (2), and White-winged Crossbill (37).

Boreal forest birds were particularly well-represented—more Ruby-crowned Kinglets were found in one year than in all previous years combined. White-winged Crossbills were extremely common, with the 37+ records far surpassing the 19 records from all previous years combined.

Highlights Border Lakes
The Border Lakes surveys of the Cook County portion of the subsection were accelerated in the spring of 2009. Survey plant ecologists documented high quality, target native plant communities including Red Pine-White Pine Woodland (Canadian Shield), Red Pine-White Pine Woodland (Northeastern Bedrock) and Black Spruce-Jack Pine Woodland. Records include notes on vegetation response to disturbance (fire and wind events, past management), locations of legacy patches (serving as source areas), cold drainages and wetland complexes (serving as refugia). These notes, along with vegetation samples (relevés) and plant species lists (for habitats such as cliff faces, lakes, small seepages and wetlands) assist with application of site ranking criteria.

New locations of the following rare plants have been documented in the Border Lakes: maidenhair spleenwort (*Asplenium trichomanes*), pale moonwort (*Botrychium pallidum*), black hawthorn (*Crataegus douglasii*), small-flowered woodrush (*Luzula parviflora*), Rocky Mountain woodsia (*Woodsia scopulina*), Alpine woodsia (*W. alpina*), moonwort (*Botrychium lunaria*), Mead's sedge (*Carex media*), large-leaved sandwort (*Moerhingia macrophylla*), White Mountain saxifrage (*Saxifraga paniculata*), Arabian whitlow grass (*Draba arabisans*), American shore plantain (*Littorella uniflora*), slender water milfoil (*Myriophyllum tenellum*), blunt-fruited sweet cicely (*Osmorhiza depauperata*), purple reedgrass (*Calamagrostis purpurascens*). Weak Arctic sedge *(Carex supina)*, a cliff-dwelling sedge not found in the state since the 1930's was located in a cliff of the Rove formation.

Fish surveys resulted in collection of several species identified as "species of greatest conservation need" in Minnesota's State Wildlife Action Plan. These include Lake Chub and several species of Ciscos that have been sent to experts to verify identification (likely either Nipigon Cisco and/or Shortjaw Cisco). Two species reaching the southern edge of their ranges were documented: Ninespine Stickleback and Longnose Sucker.

Bird survey staff completed 150 point counts and compiled 247 species in the Border Lakes in 2009. A total of 123 potential breeding bird species were recorded. This included 135 records of rare species: Trumpeter Swan (3), American Bittern (8), Northern Goshawk (1 sighting), Sandhill Crane (3), and Black-throated Blue Warbler (120).

Other species of interest included Boreal Chickadee (13), Ruby-crowned Kinglet (81), Tennessee Warbler (63), Pine Warbler (20), Wilson's Warbler (20), Red Crossbill (2), and White-winged Crossbill (9).

Several boreal forest birds were found in greater numbers than in any other county previously surveyed. Ruby-crowned Kinglets were found at more than 80 locations in 2009, representing a nearly 200% increase in records over all previous years combined. More than 60 singing male Tennessee Warblers were found in 2009. Previously, MCBS had found this species at only two locations elsewhere in northern Minnesota. Black-throated Blue Warblers were relatively common, occurring in relatively mature closed-canopy forests, typically on steep slopes with a dense shrub layer usually dominated by mountain maple *(Acer spicatum).*

Amphibian and reptile surveys did not result in new records of rare species in the Border Lakes. Bat survey call records were obtained and will be analyzed in the winter 2009-10.

Highlights aquatic plant surveys
Border Lakes surveys revealed new locations of Robbins' spikerush (*Eleocharis robbinsii*) and a rather surprising find of lance-leaved violet (*Viola lanceolata*) north of Burntside Lake. A collection of the aquatic species Algae-like pondweed *(Potamogeton confervoides),* a very fine-leaved pondweed, was reported from a small bog pond in the Border Lakes and represents the first record in the state of the species.

Vasey's pondweed *(Potamogeton vaseyi)* and the leafless water milfoil (*Myriophyllum tenellum)* were documented from Ozawindib Lake in Itasca State Park and spiny coontail (*Ceratophyllum echinatum)* was documented at Deer Park in Clearwater County. The slender water naiad *(Najas gracillima)* was found in small lakes in Becker, Hubbard and Clearwater counties. Humped bladderwort (*Utricularia gibba)* was documented in small lakes in Clearwater, Becker, Hubbard and Wadena counties.

Olivaceous Guadalupe Island naiad (*Najas guadalupensis var. olivacea),* a Great Lakes endemic, was found in Beden and Schroeder Lakes in Hubbard County, Hazel Lake in Wadena County and Sand Lake in Cass County.

Rare aquatic plant searches were completed in 81 lakes in Cass County and 10 lakes in the Trout Lake LTA in the Border Lakes subsection. Some highlights are beautiful pondweed (*Potamogeton pulcher*) in Egg Lake in Cass County, and American shore plantain (*Littorella uniflora*) in Nels Lake in the Border Lakes.

By the end of the 2008 field season, a total of 1,528 lakes in 44 counties have been surveyed for rare aquatic plants.

Result 2: Information System Expansion

Description: The Natural Heritage Information System will be expanded by additions to the component databases, including entry of information into a Geographic Information

System. This will result in the distribution of information to individuals, organizations, and agencies having diverse natural resources goals.

Procedure: Natural Heritage Information System: All data collected by MCBS are entered into the related map, manual and computerized files that make up the Natural Heritage Information System. Some of the databases include: rare features (geographic), relevé (vegetation plot samples), county checklists of plants and animal, MCBS sites, native plant community polygons (GIS), and animal aggregations. Locations of native plant communities are mapped at the scale of U.S.Geological Survey 1:24,000 topographic maps using ARC/GIS, and shape files are made available on the DNR's Data Deli accessible through the website. Rare species locations are entered into BIOTICS, an information system developed internationally for storing and distributing rare features data such as that collected by MCBS. Photographic vouchers, color slides, digital images, and other digital media are stored at the DNR, St. Paul. Field data sheets are filed electronically or manually.

Information System Development: The collection and management of data continues to improve through the use of networks, GIS, data portals, relational databases, global positioning systems, and field data recorders. MCBS participates in DNR's efforts to develop shared databases and data standards, and improvements in information delivery using new digital media and the web. MCBS also coordinates with other statewide and national information systems developments. Continued development of information systems is essential to achieve MCBS goals, and requires ongoing investment to satisfy the increasingly complex and diverse demands of users and the related needs for data standards, data security, metadata and other documentation. In order to effectively contribute to data synthesis, analysis, interpretation, and future natural resource monitoring needs, considerable effort is required to maintain data integrity as new technology in Information Systems continuously evolves.

Preparation of Collections: All plant and animal specimens are identified; collections are prepared for permanent storage and deposited in appropriate repositories at the J.F. Bell Museum of Natural History at the University of Minnesota and the Science Museum of Minnesota.

Summary Budget Information for Result 2: **Trust Fund Budget: $ 500,000**
Amount Spent: $ 600,272
Balance: $ (100,272)

Deliverable	**Completion Date**	**Budget**	**Status (see below)**
Data available in Natural Heritage Information System	January 2008 # records added October 2008 #records added March 2009 #records added June 2009 #records added	425,000	
Information	Updates with each status report	25,000	

System Development			
Preparation of Collections	March 2008 #collections deposited June 2009 #collections deposited	50,000	

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Data available in Natural Heritage Information System
Since July 2007, new records of 951 rare features were added to the Rare Features Database. Since MCBS began in 1987, 17,054 new records have been added by MCBS. Since July 2007, 83 vegetation samples (relevés) were added to the statewide Relevé Database, for a total MCBS contribution of 3,880 of the 8,841 total database records. Since July 2007, polygons of about 3,000 MCBS sites of Biodiversity Significance and 11,884 polygons of native plant communities were added to the dataset that resides on DNR's "Data Deli." Statewide, MCBS has added a total of 7,105 MCBS site polygons and 47,398 native plant community polygons since 1987.

Information System Development
Development of a data entry tool using GIS has resulted in more rapid report and map generation related to MCBS sites of biodiversity significance.

Ecological Evaluations describe and interpret the ecological features of some of the most ecologically significant sites evaluated by MCBS. These now have standard templates for presentation and are stored along with historical evaluations in a centralized file. Some of these are also presented on the DNR website.

Native plant community shape files are available to the public on DNR's Data Deli. During this work period, the "year of survey" was added to attribute files associated with the shape files (mapped polygons) that can be obtained by GIS users. This will ensure that the client is aware of the currency of the native plant community polygon data they are retrieving, some of which are now over 20 years old.

Two Corrective Action Requests related to the state's Forest Certification required data summaries created using GIS resources. As one part of this process, names of native plant communities stored in version 1.5 of the DNR's native plant community classification were cross-walked to the version 2.0 classification.

Animal survey staff have analyzed and identified approximately 60,400 bat calls recorded during the 2007 field season in southwestern Minnesota, as well as nearly 11,000 calls recorded in Clearwater County at Itasca State Park in 2005. The analysis of the 2009 Itasca county bat call files continues (30,000 records).

As part of a plan to update the book, *Amphibians and Reptiles of Minnesota,* Carol Hall and her staff sorted, copied, and filed all herp images from all MCBS years based upon year, number, and species.

Plant Name Database: A standard list of plant names and synonymy is critical for effective long-term data collection and analyses proposed for monitoring activities, including issues ranging from climate change to assessment of success of restoration and management activities. Collaboration with national organizations such as NatureServe and federal agencies, along with state museums, universities, colleges and specialists (such as bryologists) is underway as part of this project. Plant ecologist Stacey Olszewski hired during this period has provided substantial assistance to database development.

Field Data Recorders: MCBS, along with others in the Division of Ecological Resources met to explore potential collaboration on programming costs for field hand held data recorders. They determined that the cost was too excessive and that adequate programming assistance was not available. Continued exploration of these tools is probable. Bat recordings continue to be the most successful computerized field data collection tool.

Training of staff in the use of a new version of the computer-mapping tool, ARCGIS caused some delays in mapping, but most ecologists and biologists successfully transferred to the new version.

Specific funding provided through LCCMR for GIS staff, an information officer (web applications) and a plant ecologist with computer skills has been critical to most of the progress related above. However, due to changes in the organization and operation of information system management in the Division and in the Department, assistance especially with programming, has been inadequate to meet the demands.

Preparation of Collections

The Bell Museum herbarium acknowledged the donation of 597 plant collections in fiscal year 2008 and 787 collections in fiscal year 2009. MCBS continues to support the preparation of these collections through staff assistance at the herbarium at least one day per week.

The Bell Museum herbarium worked with MCBS on an agreement to satisfy a new national requirement for labeling plant collections with permit numbers when required for collecting plants in a managed area (such as a National Wildlife Refuge). A DNR permit reference number is being recorded on labels submitted to the herbarium with plant collections that began with field collections made in 2008.

Major progress was made during this project period, working with museums on the proper curation of the fluid-preserved animal specimens.

Result 3: Data Distribution and Interpretation

Description: Private and public protection and ecological management of sites of biodiversity significance identified by MCBS will be promoted through the interpretation of data and distribution of information through maps, electronic formats, publications, presentations and technical assistance.

Summary Budget Information for Result 3: **Trust Fund Budget: $ 450,000**
Amount Spent: $ 321,571
Balance: $ 128,429

Deliverable	Completion Date	Budget	Status (see below)
MCBS data on sites and native plant communities on DNR Data Deli	Two counties: Oct 2007; Two counties: March 2008; Four counties: June 2009	75,000	
Technical assistance, data interpretation	July 2007-June 2009	200,000	
Publications, web products.	July 2007-June 2009	175,000	

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MCBS data on sites and native plant communities were added to the DNR Data Deli for a total of eleven counties.

Technical Assistance and Data Interpretation

General
Staff provided data and technical interpretation as related to the DNR's Conservation Agenda, Climate Change, Forest Certification, State Forest management planning, Forest Legacy project, implementation of the State Wildlife Action Plan, woody and grasslands biomass guidelines, Lakes and Clean Water Legacy, the watershed assessment tool, native prairie monitoring and restoration, and the Lessard-Sams Outdoor Heritage funding proposals.

Plant ecologists worked with other DNR ecologists and DNR park managers and resource staff to plan and lead field training classes for local managers within and outside of the agency in the use of the new native plant community field guides: *Field Guide to the Native Plant Communities of Minnesota: the Prairie Parkland and Tallgrass Aspen Parklands Provinces* and *Field Guide to the Native Plant Communities of Minnesota: the Eastern Broadleaf Forest Province.* Training session locations included Glacial Lake State Park, Kilen Woods State Park and Nerstrand Big Woods State Park.

As related to the state dual Forest Certification, MCBS plant ecologists have provided major assistance, providing data to satisfy a corrective action request related to high conservation value forests. They provided descriptions and reviewed lists of proposed outstanding and high MCBS sites proposed for consideration as HCVF in two ecological sections. Plant ecologist Mike Lee was a member of DNR's Internal Audit Team for Forest Certification that focused on OHV issues.

All staff contributed to the most recent review of the state list of endangered, threatened and special concern species in response to a 1 July 2009 deadline presented to the Division coincidently with 2009 field season preparation in the spring. Staff with botanical expertise worked well with Sarah Wren (Ecological Resources staff assigned to the vascular plant list) to provide their technical input prior to major field season obligations. She then worked with botanist Welby Smith between his field work assignments to draft "Statements of Need and Reasonableness" required for the official update of the list.

Plant ecologist, Nancy Sather coordinated with botanists from the Chicago Botanical Garden on a project to investigate the hybridization of the federally threatened prairie bush clover *(Lespedeza leptostachya)* and the common round-headed bush clover *(L. capitata)*, on some of the MCBS survey sites in Jackson and Cottonwood counties.

The DNR maintains a state list of known locations of calcareous fens. In January 2008 MCBS ecologists provided information on new locations of fens in order to update this list. Under the Minnesota Wetlands Conservation Act (WCA), impacts to calcareous seepage fens are regulated by the DNR. They may not be filled, drained, or otherwise degraded, wholly or partially, by any activity, unless the commissioner of natural resources, under an approved management plan, decides some alteration is necessary (Minn. Statutes 103G.223). In addition to the protection afforded by the WCA, destruction of any state-threatened plants occurring on a calcareous fen may be regulated under Minnesota's endangered species law (Minn. Statutes 84.0895).

Amphibian and reptile surveys documented some unusually dark tiger salamanders *(Ambystomid)* morphs in western Minnesota in 2006 and 2007. Amphibian and Reptile Specialist, Carol Hall is working with researchers at the Bell Museum of Natural History to provide taxonomic clarification of this *Ambystomid* group in western Minnesota. Staff participated in and assisted with the University of Minnesota's Climate Change meetings held in early June 2008.

Prairie Conservation planning and protection
MCBS compiled a statewide map displaying the current known extent of Minnesota's native prairie as compared to prairie recorded about 100 years ago during the public land surveys. Of the 18 million acres that once covered about a third of the state, less than 200,000 acres remains based on MCBS data. This map is available on the web and was widely referenced as part of recent accelerated discussions of issues related to prairie ecosystem conservation including: climate change/monitoring; carbon sequestration; game and non-game wildlife habitat; migratory waterfowl; biofuel production; watershed management (erosion, sedimentation, ditching, drainage etc); exotic species expansion; roadside wildlife habitat; private landowner grassland protection incentive programs; maintenance of adaptability, resilience and genetic diversity of native species, prairie plant communities and processes; and opportunities for growth of nurseries and restoration enterprises.

Data are being used by The Nature Conservancy as part of the Minnesota proposal for a larger Prairie Coteau conservation project (that includes South Dakota).

MCBS worked closely with others in the Division including the Scientific and Natural Area program and the associated prairie private lands programs to assess the current status of protection of prairie habitats based on the near-completion of MCBS surveys in the prairie part of the state. In the fall of 2008, meetings were held in collaboration with Ecological Resources regional staff to review the status and opportunities for additional protection of prairies in the NW, Southern and Central DNR regions. An analysis primarily of MCBS sites of Outstanding and High biodiversity significance resulted in detailed prioritization of opportunities for private or public prairie protection focused on the highest quality prairies.

Langhei Prairie in Pope County and Butternut Valley Prairie in Blue Earth County are two prairie sites surveyed by MCBS that are becoming Scientific and Natural Areas (SNAs).

Native Prairie Bank agreements were completed in Houston, Lac Qui Parle, Murray, Swift, and Pipestone counties.

Plant ecologist Fred Harris prepared an ecological evaluation and presented a landscape area located in western Yellow Medicine County for consideration as a future SNA for approval by the Commissioner's Advisory Committee.

An easement on a prairie site in Lac Qui Parle County was approved as part of a Doris Duke grant for conservation. The site is located adjacent to Plover Prairie and Lac Qui Parle WMA in western MN. A video of the area was made by DNR's Division of Information and Education and will be released on DNR's website.

Ecological Resources is using MCBS data in discussions with the DNR Wildlife Division regarding prioritization of conservation action related to the Working Lands projects.

The results of the MCBS survey were presented to the Pipestone County Board. The meeting was also attended by Pipestone County planning/GIS staff and members of the Friends of Pipestone National Monument. The county staff were interested in how to use the GIS polygons on their website.

Southern Minnesota
Progress continues on the conservation and management of the Franconia Bluffs Scientific and Natural Area and adjacent lands along the St Croix River that include many sites of biodiversity significance identified by MCBS.

A special event celebrating the new Seminary Fen SNA marked the conservation as a natural area of another site surveyed by MCBS.

Plant ecologist Fred Harris made a presentation to the Native Plant Society (NPS) entitled "Rare plants in temporary pools on bedrock Outcrops: Recent discoveries on some of southwest Minnesota's most scenic and threatened habitats." Over 80 people attended and the presentation was summarized in an article published in the NPS Spring 2008 newsletter.

In June, plant ecologist Fred Harris led a tour that included Blue Mounds State Park and a prairie bank site. He led another for staff of the USFWS, Rock County, and members of the public from Luverne to view rare plants in rock pools at Touch the Sky National Wildlife Refuge. Ecologist Nancy Sather conducted a wildflower hike in Lyon County's Garvin Park, made a presentation about environmental history at Southwest Minnesota State University, and led field trips to fens in Murray and Cottonwood counties.

Wright County is using MCBS sites of biodiversity significance as one of the resources to develop a proposed resource land protection policy for the county as part of its land-use planning and land owner assistance process.

Northern Minnesota

Manitou Collaborative: MCBS's northern coordinator, Lawson Gerdes, served as the Ecological Resources representative on the DNR's NE Adaptive Forest Management Team associated with the Collaborative.

Sand Lake Seven Beavers Collaborative: The northern coordinator, Lawson Gerdes led the development of a guiding document (goals, objectives, strategies) for the collaborative and presented a draft to full collaborative. She helped to develop a fire protection and prescribed fire strategy, assisted with the identification of areas for white pine diversity plantings, finalization of the Big Lake patch management project, and reviewed a proposal for adding DNR harvest units to a fragmented area called East River patch.

Plant ecologists cross-walked the Ontario Classification Types to Minnesota native plant communities and provided other professional advice on the native plant communities relevant to the considerations of the Old Growth Lowland Conifer Task Force.

Northern plant ecologists participated in joint site visits with foresters in Outstanding and High-ranked Sites of biodiversity as related to implementation of the state forest management plans. One example of a discussion about action was related to a jack pine-black spruce-balsam fir stand on the Cloquet River due to the rarity of this type.

Plant ecologists provided comments on the 10-year stand exam list for the DNR's State Forest Plan being developed for the Chippewa Plains-Pine Moraines subsections**.**

Information on MCBS data and procedures was provided to the Superior National Forest (SNF) Monitoring Program coordinator to assist in developing a Forest-wide Inventory and Mapping protocol, as part of a USFS Region 9 Resource Inventory pilot project.

Plant ecologist Chel Anderson participated in the review and commentary of the SNF project areas *Glacier* and *Clara* where management actions are implemented as outlined in the Forest Plan.

Botanist Lynden Gerdes provided a one-day *Huperzia* (fir-mosses) field identification workshop to biologists from the SNF. The group observed species morphological characteristics and discussed how to confidently identify the various species.

Northern staff led a field trip of SNF biologists to assess the survival potential of a population of the state endangered orchid, auricled twayblade (*Listera auriculata),* that was heavily covered by debris from the recent blow down.

Northern staff assisted decisions regarding DNR land asset management and land exchanges. For example one ecologist reviewed a list of parcels of state land proposed for sale or exchange with the county and commented that an 80-acre parcel on the list contained designated old-growth pine.

Staff assisted with interpretation of the Red Lake Peatlands by helping to write a descriptive document and leading part of a field tour by LCCMR members on the boardwalk at Red Lake.

There is a current effort to develop management plans for the Scientific and Natural Areas found in the peatland region. As requested by the NW Ecological Resources staff, plant ecologist Norm Aaseng made a presentation regarding the history of the survey of the patterned peatlands and protection at a meeting of knowledgeable individuals interested in the peatland region. Gerda Nordquist and Steve Stucker have also provided information on birds and mammals as related to the management planning process.

Norm Aaseng provided comments on Beaches WMA Ditching Restoration in the Palmville Project.

Plant ecologists met with the Itasca County Land Department to exchange ideas about potential High Conservation Value Forests as related to their forest certification.

Information about survey results in Itasca County was provided as part of planning for the recent easements that are part of the Forest Legacy project.

Staff met with St. Louis County land department staff to deliver and interpret data on native plant communities in SLC, for their county NPC mapping project.

The northern coordinator, Lawson Gerdes, met with Brian Kernohan with Forest Capital Partners (FCP) to discuss information collected by the Survey that might assist their planning as they implement SFI forest certification standards. FCP is an investment firm that acquires and manages large-scale investment-grade forest in North America.

Staff met with the Potlatch biologist to relate 2007 survey results on Potlatch lands, including the location of a new population of bog adder's-mouth (*Malaxis paludosa*) and high quality locations of the rare native plant community, jack pine woodlands. The northern coordinator later met with Potlatch regarding jack pine woodland issues and the potential for alternative management ideas for this fire-dependent system

Staff provided feedback to the Encampment Forest Association (North Shore Highlands) on their ongoing planning process regarding conservation of lands surrounding the Encampment Forest Association property.

Information related to MCBS sites between Duluth and Two Harbors was provided by plant ecologist Ethan Perry to help plan the route of the Superior Hiking Trail.

Plant ecologist Rebecca Anderson reviewed the McCarthy Beach State Park management plan and provided information on the landscape context of the park in the region. She had previously mapped the native plant communities in the park.

Aquatic plants

MCBS continues to conduct rare aquatic plant and nongame fish surveys in lakes in many parts of the state. Based on this information staff developed a draft list of "quality lakes" for each Ecological Classification System (ECS) Subsection. Primary consideration for this draft list included the presence of high quality aquatic plant communities, presence of rare aquatic plant species, intact shoreline/degree of alteration of the lakeshed. Other factors considered were the diversity of aquatic plant species, presence of unique aquatic communities, presence of a suite of rare aquatic plant species at one lake, absence of exotic and disturbance species, amount of lakeshore development, alteration of the lake, and general assessment of the lake.

The aquatic botanist, Karen Myhre, delivered reports that include plant species lists for 1,528 lakes surveyed by MCBS to date to the DNR central office for inclusion in the statewide lake files bank maintained by Fisheries. DNR Fisheries Area offices directly received data for aquatic plant species observed by MCBS for the lakes in their areas. For example, files were provided for the 90 lakes surveyed in the Finland Fisheries Area. That area office also received assistance in the identification of the rare plant, small white waterlily (*Nymphaea leibergii*). Area fisheries managers responded that the data will assist with both their identification skills related to the uncommon aquatic plants and with considerations related to aquatic plant management, including chemical treatments of lakes and rare species locations.

Karen assisted with Eco Resources aquatic plant training workshops in June 2009. She provided mounted specimens of rare aquatic plant species and presented an update on "Minnesota's Rare Aquatic and Shoreline Vascular Plant Species 2009" and collecting guidelines: "Rare Aquatic Plant Collection Guidance" and "Guidance on Documenting and Collecting Rare Plants".

MCBS also provided information to DNR Fisheries about northeastern aquatic plant species to inform the Sentinel Lake project (that includes point-intercept vegetation surveys). This also included the identification of several rare species: broadleaf-water milfoil *(Myriophyllum heterophyllum)* and discussion of potential monitoring of the rare species, sheathed pondweed *(Stuckenia vaginata),* that has a population at one of the Sentinel Lakes.

Final reports for Cross and Pokegema Lake were sent to the Pokegama Lake Association Lake Improvement Committee along with information about the rare aquatic plant species, Walter's barnyard grass (*Echinochloa walteri*), and suggestions for a management plan.

The Aitkin Water Planning Task Force received MCBS aquatic plant data for their use as they update their water plan (also for use by several other lake and watershed groups).

Final lake reports for the north and south basins of Sand Lake, Cass County were provided to the president of the Sand Lake Association.

Publications and web products

Welby Smith, author of the 2008 DNR book, *Trees and Shrubs of Minnesota* made multiple presentations on the book to groups such as the Native Plant Society, Landscape Associations, and bookstores. His years of technical research and data compilation included data from other MCBS botanists. The excellent photos, text and graphics resulted in a highly successful publication.

Plant ecologist, Fred Harris was instrumental in completing and distributing the MCBS 2007 report *Native plant communities and rare species of the Minnesota River Counties* and a companion compact disk to agencies, organizations and interested individuals of the region. This interpretive report is being used in colleges in the Minnesota River area for instruction in biology and ecology classes and by others to help determine conservation priority areas along the river.

Chel Anderson, MCBS plant ecologist, is a co-author of the research article *A six-step approach for identifying and prioritizing potential research natural areas, Superior National Forest* found in the October 2007 issue of the Natural Areas Journal (Vol. 27, No.4).

MCBS ecologist Norm Aaseng was an author of a native plant community classification paper published in Applied Vegetation Science, *Vegetation classification, mapping, and monitoring at Voyageurs National Park, Minnesota: An application of the U.S. National Vegetation Classification* (Faber-Langendoen, Don; Aaseng, Norm; Hop, Kevin; Lew-Smith, Michael, & Drake, J. Applied Vegetation Science 10: 361-374, 2007).

Now available on the DNR website: *A handbook for collecting relevé data in Minnesota* describes the current practices of DNR plant ecologists for collection of vegetation plot data using the relevé method. The handbook is formatted such that the user can easily print a booklet version from a PDF. Also on the web are portions of the three volumes of Minnesota's native plant community field guides.

Rare Species Guide (DNR web): Many MCBS staff wrote or reviewed text related to the individual rare species accounts presented on the DNR web site. For example Welby Smith wrote drafts for 54 rare plants with assistance from Karen Myhre for rare aquatic plants, and Gerda Nordquist reviewed and edited text for Eastern Pipistrelle *(Pipistrellus subflavus*) and Gray Wolf *(Canis lupus).*

Lynden Gerdes and Lawson Gerdes co-authored an article on the first occurrence of Algae-like pondweed (*Potamogetan confervoides*) in the state for presentation on the MCBS web page. They both also reviewed a paper entitled "Occurrences of the Liverwort *Frullania selwyniana* on the Superior National Forest" authored by J. Janssens and J. Greenlee.

The national organization, NatureServe, has collaborated with National Geographic on a project called *Landscope* that has a web/GIS interface. As a preliminary step in developing a larger product, MCBS staff wrote *Minnesota's Landscape and Ecosystems* for presentation on the site that will hopefully be followed by additional content.

Staff provided feedback to DNR Forestry's Ecological Land Classification Program (ECS) on drafts of the silvicultural interpretations of several forested native plant community classes. They also provided photography of native plants to the ECS program and reviewed a field guide to plant identification for species frequently found in the forested native plant communities of the DNR's native plant community field guides.

Tom Klein worked with bryologist Jan Janssens on developing field guide booklets related to the identification of mosses and liverworts that were used at the field workshop in spring 2009.

Staff wrote the following articles that appeared in DNR's *Minnesota Conservation Volunteer:*
-Bog adder's-mouth (*Malaxis paludosa)* was featured in an article, *Elusive orchids*, in the July-August 2007 issue written by MCBS plant ecologist/botanist Erika Rowe.

-The *Walks in the old woods* article in the November-December 2007 issue of the featured field tours and interpretation by MCBS plant ecologist Chel Anderson.

-Steve Stucker, MCBS ornithologist, authored a Minnesota profile on Upland Sandpiper *(Bartramia longicauda)* for the March-April 2008 issue.

-Welby Smith, author of the DNR book, *Trees and shrubs of Minnesota*, co-authored a related article *Wildly adaptable trees* (along with Jan Wolff) that appeared in the September-October 2008 issue.

-Appearing in the November-December 2008 issue: *Mapping home ground* by botanist-plant ecologist Nancy Sather.

-*Rock pools on the prairie* by botanist-plant ecologist Fred Harris and the Minnesota profile on the Golden-winged Warbler by ornithologist Steve Stucker appeared in the March-April 2009 issue. Steve also was interviewed in the article related to the forthcoming Breeding Bird Atlas project.

Plant ecologist Fred Harris provided extensive information on rare resources to Linda Cody for her article *Blowin in the wind* that featured the results of MCBS in the discussion of wind power in the Prairie Coteau published in *__SCAPE*, journal of the Minnesota Chapter of American Society of Landscape Architects Fall 2007. http://www.masla.org/scape/documents/SCAPE-fall07-nature.pdf

All staff contribute to written Ecological Evaluations completed for the highest priority sites for conservation identified in their work areas. These included Dinner Creek in Becker County, Cloquet River in St. Louis County, and the Nopeming Unconformity site outside Duluth. The Sisseebakwet Lake Ecological Evaluation (Itasca County) was presented at the Commissioner's Advisory Committee (CAC), which recommended that the SNA Program work on acceptance of a donation of some private land that was part of the area in the evaluation. Another example is an evaluation prepared by Erika Rowe for a site near Lester Lake in Hubbard County that was presented to the CAC.

In the Northeast an ecological evaluation was prepared for the Upper Swamp River in response to a potential Forest Certification process suggesting that the site might be an example of a proposed High Conservation Value Forest. Chel Anderson also wrote evaluations for Horshoe Bay, Pike Mountain, and Andy Swamp Hardwoods, all in northeastern MN.

Staff coordinated with the Native Plant Society and the Bell Museum to and several were main presenters for two symposia, one featuring the North Shore Highlands and another the Tallgrass Aspen Parklands held at the museum in April 2008 and 2009. Popular follow-up field trips to natural areas in both regions were led by MCBS staff in the summer.

A poster was presented at the annual meeting of the American Society of Mammalogists in Brookings, SD, entitled *Activity patterns of migratory bats in Minnesota* and prepared by MCBS staff Gerda E. Nordquist, Kelly L. Pharis, and Christi A. Spak.

A poster featuring Minnesota Division of Ecological Resources prairie activities was presented at the North American Prairie Conference held in August 2008 at Winona State University.

The "Making a Great Lake Superior" conference held in Duluth in October, 2007 was interdisciplinary and cross-cultural; bringing scientists, managers, economists, educators, citizens and policy-makers together to address the issues and challenges of preserving and managing Lake Superior and the Lake Superior Basin. MCBS presented the results of the Survey in the Lake Superior Basin in an exhibit that displayed MCBS sites, native plant communities and associated species, and provided materials on Survey methods, the native plant community classification, and the high quality lakes assessment.

Dan Wovcha finalized agreements for the proposed publication of a new book on the natural history of Northwestern MN.

Public Television (Channel 17) featured a story produced in collaboration with St John's University and the College of St Benedict entitled "If A Road Runs Through It" that relates the story of the challenges that rapid change and development have brought to the Avon Hills area of Stearns County. The Avon Hills Forest Scientific and Natural Area (SNA) dedication in May 2008 was a highlight of the program, with the Schellinger family, former landowners of the SNA, as major participants in the presentation. MCBS surveyed this site and recommended it as an SNA, with plant ecologist, Mike Lee providing ongoing assistance during the SNA acquisition process.

Plant ecologist Ethan Perry took part in a radio interview with John Latimer of KAXE in Grand Rapids where he talked about the MCBS process and what products are made available to the public.

V. TOTAL TRUST FUND PROJECT BUDGET:
Staff-fulltime: $1,400,000 6 ecologists, 2 botanists, 2 data managers, 1 information officer
Travel $100,000

TOTAL TRUST FUND PROJECT BUDGET: $1,500,000

Explanation of Capital Expenditures Greater Than $3,500
All LCMR expenditures are for Personnel and travel

VI. OTHER FUNDS & PARTNERS:

A. Project Partners: The University of Minnesota-Bell Museum of Natural History and the Science Museum of Minnesota provide resources for the curation of specimens collected by MCBS. This funding request does not include funding for these partners.

	General Fund	RIM General	Heritage Enhancement	SWG*	LCMR
B. Other funds 08-09	373,000	181,400	1,125,000	400,000	
C. Past spending 06-07	373,000	181,400	1,125,000	439,000	1,000,000

*State Wildlife Grants (Federal Funding that requires matching funds).

D. Time: MCBS is proposed for completion in 2021. Future requests for funding from the Minnesota Legislature and other cooperators are anticipated.

VII. DISSEMINATION:

The Natural Heritage Information System is the major repository of data collected by MCBS. Descriptions of the major component databases of this information system are available through the DNR website listed on page one. MCBS procedures, updates, recent maps and links to related data are also presented on the DNR website. Many GIS datasets are delivered through the web and though agreements with the requesting agency and the DNR's Natural Heritage and Nongame Research Program. For data on locations or rare features, a data request form is also available via the web: http://www.dnr.state.mn.us/eco/nhnrp/nhis.html

MCBS invests considerable time in publishing and distributing results of the Survey in a variety of formats for various audiences. The DNR and Legislative libraries and other local information repositories (such as libraries within counties) are sent published products, including maps, reports, field guides and digital media. Increasingly products are available on the DNR web, including GIS shape files of native plant communities and MCBS sites, native plant community field guides, guides to sampling techniques such as the vegetation plot data collection using the relevé method. The MCBS web site is updated with new information and has links to associated resources. http://www.dnr.state.mn.us/eco/mcbs/index.html

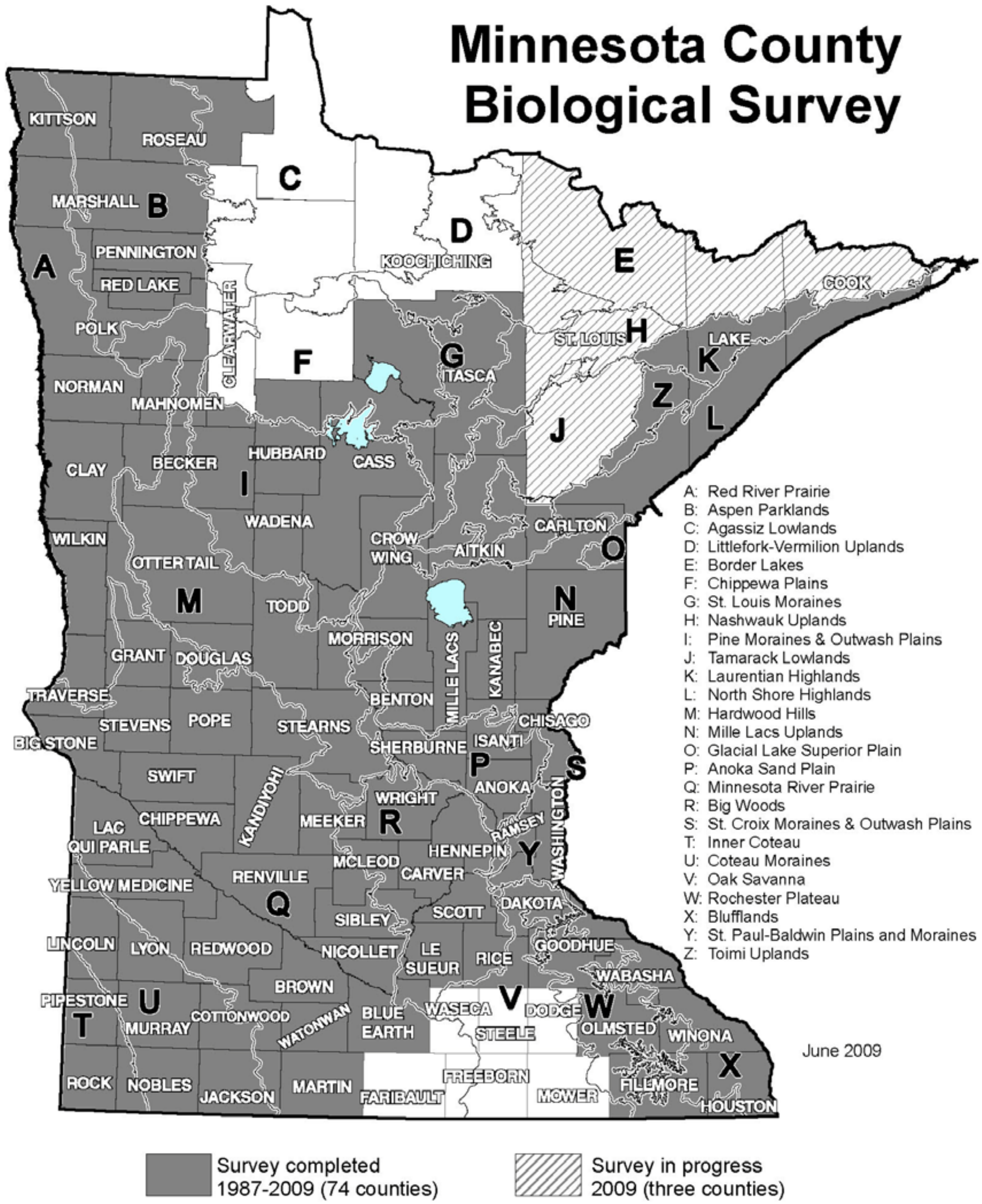
Staff make presentations that describe the Survey goals, methodologies and results to a wide range of audiences that include county boards, local planning groups, citizen advisory groups, other biologists, land managers and students. MCBS staff provide local planners with ecological interpretations related to important sites of biodiversity identified during the Survey to assist with management plans. Staff led or participate in technical workshops and field trips to exchange ideas on survey methodology and provide training in the application and interpretation of the data.

Physical collections are deposited at Minnesota repositories, primarily at the University of Minnesota's J.F. Bell Museum of Natural History and the Science Museum of Minnesota, St. Paul, MN. As part of a larger network of museums and herbaria, these cooperators are essential to the documentation and sharing of MCBS results. MCBS and museum staff meet periodically to address curatorial, data management, and interpretive needs.

MCBS delivers data as part of NatureServe and also shares data with cooperators at colleges and universities and with others in a particular ecological region where surveys are ongoing or completed.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than January 2008, October 2008, and March 2009. A final workprogram report and associated products will be submitted between June 30 and August 1, 2009 as requested by LCCMR.

IX. RESEARCH PROPOSALS: N/A


Minnesota County
Biological Survey
KITTSON
ROSEAU
MARSHALL
PENNINGTON
RED LAKE
POLK
NORMAN
MAHNOMEN
CLEARWATER
KOOCHICHING
ST. LOUIS
LAKE
COOK
ITASCA
HUBBARD
CASS
BECKER
CLAY
WADENA
WILKIN
OTTER TAIL
CROW WING
AITKIN
CARLTON
TODD
PINE
MORRISON
MILLE LACS
KANABEC
GRANT
DOUGLAS
TRAVERSE
BENTON
STEVENS
POPE
STEARNS
CHISAGO
BIG STONE
SHERBURNE
ISANTI
SWIFT
ANOKA
KANDIYOHI
WRIGHT
WASHINGTON
LAC QUI PARLE
CHIPPEWA
MEEKER
RAMSEY
HENNEPIN
YELLOW MEDICINE
RENVILLE
MCLEOD
CARVER
SIBLEY
SCOTT
DAKOTA
LINCOLN
LYON
REDWOOD
NICOLLET
LE SUEUR
RICE
GOODHUE
WABASHA
BROWN
PIPESTONE
COTTONWOOD
WATONWAN
BLUE EARTH
WASECA
STEELE
DODGE
OLMSTED
WINONA
MURRAY
ROCK
NOBLES
JACKSON
MARTIN
FARIBAULT
FREEBORN
MOWER
FILLMORE
HOUSTON
A: Red River Prairie
B: Aspen Parklands
C: Agassiz Lowlands
D: Littlefork-Vermilion Uplands
E: Border Lakes
F: Chippewa Plains
G: St. Louis Moraines
H: Nashwauk Uplands
I: Pine Moraines & Outwash Plains
J: Tamarack Lowlands
K: Laurentian Highlands
L: North Shore Highlands
M: Hardwood Hills
N: Mille Lacs Uplands
O: Glacial Lake Superior Plain
P: Anoka Sand Plain
Q: Minnesota River Prairie
R: Big Woods
S: St. Croix Moraines & Outwash Plains
T: Inner Coteau
U: Coteau Moraines
V: Oak Savanna
W: Rochester Plateau
X: Blufflands
Y: St. Paul-Baldwin Plains and Moraines
Z: Toimi Uplands
June 2009
Survey completed 1987-2009 (74 counties)
Survey in progress 2009 (three counties)

Attachment A: Budget Detail for 2007 Projects
Final report June 30, 2009
Proposal Title: *Minnesota County Biological Survey*

Project Manager Name: Carmen Converse

Trust Fund Appropriation: $ *1,500,000*

2007 Trust Fund Budget	**Result 1 Budget:$550,000**	**Amount Spent**	**Balance**	**Result 2 Budget: $500,000**	**Amount Spent**	**Balance**	**Result 3 Budget: $450,000**	**Amount Spent**	**Balance**	
	Field Surveys			*Information System Expansion*			*Data Distribution and Interpretation*			
BUDGET ITEM										**TOTAL FOR BUDGET**
PERSONNEL: Wages and benefits										
botanist	**61,000**	**56,704**	**4,296**	**40,000**	**55,214**	**-15,214**	**30,000**	**21,314**	**8,686**	**133,232**
botanist	**60,000**	**32,257**	**27,743**	**40,000**	**64,252**	**-24,252**	**30,000**	**33,923**	**-3,923**	**130,432**
Info Officer							**130,000**	**132,699**	**-2,699**	**132,699**
data manager				**120,000**	**131,214**	**-11,214**				**131,214**
data manager				**130,000**	**64,965**	**65,035**				**64,965**
Plant ecologist	**56,000**	**52,750**	**3,250**	**30,000**	**45,011**	**-15,011**	**60,000**	**31,445**	**28,555**	**129,206**
Plant ecologist	**61,000**	**62,665**	**-1,665**	**30,000**	**40234**	**-10,234**	**60,000**	**50,945**	**9,055**	**153,844**
Plant ecologist	**60,000**	**51,476**	**8,524**	**40,000**	**51,843**	**-11,843**	**50,000**	**17,051**	**32,949**	**120,370**
Plant ecologist	**40,000**	**40,059**	**-59**	**20,000**	**38,088**	**-18,088**	**25,000**	**5,712**	**19,288**	**83,859**
Plant ecologist	**40,000**	**43,060**	**-3,060**	**20,000**	**41,042**	**-21,042**	**30,000**	**10471**	**19,529**	**94,573**
Plant ecologist	**72,000**	**41,433**	**30,567**	**30,000**	**68,409**	**-38,409**	**35,000**	**18,011**	**16,989**	**127,853**
SALARIES	**450,000**	**380,404**	**69,596**	**500,000**	**600,272**	**-100,272**	**450,000**	**321,571**	**128,429**	**1,302,247**
Travel expenses in Minnesota	**100,000**	**196,945**	**-96,945**							**196,945**
COLUMN TOTAL	**550,000**	**577,349**	**-27,349**	**500,000**	**600,272**	**-100,272**	**450,000**	**321,571**	**128,429**	**1,499,192**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Soil Survey
PROJECT MANAGER: Greg Larson
AFFILIATION: Board of Water and Soil Resources
MAILING ADDRESS: 520 Lafayette Road North
CITY/STATE/ZIP: Saint Paul, MN 55155
PHONE: (651) 297-7029
FAX: (651) 297-5615
E-MAIL: greg.a.larson@state.mn.us
WEBSITE: www.bwsr.state.mn.us
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, [Chapter 30], [Sec.2], Subd.6 (b).

APPROPRIATION AMOUNT: $ 400,000

Overall Project Outcome and Results

In the ongoing multi-year process to map, classify, interpret and Web-publish an inventory of the soils of Minnesota, this two-year phase of the project focused on accelerating the completion of soil mapping, developing new soil interpretations and developing linkages of soils data with other related natural resources data. Specifically:

- 165,000 acres were addressed in Crow Wing County resulting in a digital soil survey for a portion of Crow Wing County, the Glacial Lake Brainerd area, to be released in the fall of 2009;
- 80,000 acres were addressed by NRCS soil scientists in Koochiching and Saint Louis Counties, resulting in soil mapping for Koochiching County being completed one year ahead of schedule;
- Soil productivity indices for cropland and forests were developed for 84 and 19 counties, respectively, in order to replace the outmoded Crop Equivalent Ratings (CER);
- Web-based decision support system was developed that integrates soils data with other natural resources data;
- Support was provided for the University of Minnesota Land Economics website to better complement USDA Web Soil Survey interpretations;
- Six counties (Cass, Carlton, St. Louis-Duluth subset, Lincoln, Scott and Benton) were digitized and posted on the Web Soil Survey bringing the total to 81 survey areas.

Two key lessons were learned during this 2007 phase that were incorporated into the on-going 2008 and 2009 project. The use of current NRCS employees brought to Minnesota on a work assignment ("detailees") is an efficient way to increase the completion of soil surveys after the initial investigative phase has been completed and a mapping legend has been developed. Additionally, we have determined that the USDA Web Soil Survey system is effective and sufficient for Web-publishing of Minnesota' soil survey data, so an independent system does not need to be developed by the state.

Project Results Use and Dissemination

Digital data through the WEB Soil Survey http://websoilsurvey.nrcs.usda.gov are available for 83 project areas (Two additional survey areas have been completed with 2008 funds). Soil interpretations such as soil erosion and forest productivity indices are available at the University of Minnesota Land Economics Website http://www.landeconomics.umn.edu Soils data for areas not yet mapped and digitized are available to the public on a request basis.

Trust Fund 2007 Work Program Final Report

Date of Report: August 14, 2009
"Trust Fund 2007 Work Program Final Report"
Date of Work Program Approval: June 5, 2007
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Soil Survey

Project Manager: Greg Larson **Affiliation:** Board of Water and Soil Resources
Mailing Address: 520 Lafayette Road North
Saint Paul, MN 55155
Telephone Number: (651) 297-7029
E-mail Address greg.a.larson@state.mn.us
Fax Number: (651) 297-5615
Web Page Address: www.bwsr.state.mn.us

Location: Crow Wing and four or more additional Counties. Web-based delivery has statewide applicability.

Total Biennial LCMR Project Budget:	**LCMR Appropriation:**	**$400,000**
	Minus Amount Spent:	**$400,000**
	Equals Balance:	**$ 0**

Legal Citation: ML 2007, [Chap. 30], [Sec. 2], Subd.6 (b).

Appropriation Language: $400,000 is from the trust fund to the Board of Water and Soil Resources to accelerate the completion of soil survey mapping and Web-based delivery in five or more counties. The new soil surveys must be done on a cost-share basis with local and federal funds.

II. and III. FINAL PROJECT SUMMARY:

In the ongoing multi-year process to map, classify, interpret and Web-publish an inventory of the soils of Minnesota, this two-year phase of the project focused on accelerating the completion of soil mapping, developing new soil interpretations and developing linkages of soils data with other related natural resources data. Specifically:

- 165,000 acres were addressed in Crow Wing County resulting in a digital soil survey for a portion of Crow Wing County, the Glacial Lake Brainerd area, to be released in the fall of 2009;
- 80,000 acres were addressed by NRCS soil scientists in Koochiching and Saint Louis Counties, resulting in soil mapping for Koochiching County being completed one year ahead of schedule;
- Soil productivity indices for cropland and forests were developed for 84 and 19 counties, respectively, in order to replace the outmoded Crop Equivalent Ratings (CER);

- Web-based decision support system was developed that integrates soils data with other natural resources data;
- Support was provided for the University of Minnesota Land Economics website to better complement USDA Web Soil Survey interpretations;
- Six counties (Cass, Carlton, St. Louis-Duluth subset, Lincoln, Scott and Benton) were digitized and posted on the Web Soil Survey bringing the total to 81 survey areas.

Two key lessons were learned during this 2007 phase that were incorporated into the on-going 2008 and 2009 project. The use of current NRCS employees brought to Minnesota on a work assignment ("detailees") is an efficient way to increase the completion of soil surveys after the initial investigative phase has been completed and a mapping legend has been developed. Additionally, we have determined that the USDA Web Soil Survey system is effective and sufficient for Web-publishing of Minnesota' soil survey data, so an independent system does not need to be developed by the state.

IV. OUTLINE OF PROJECT RESULTS:

Soil surveys contain information essential to the management of natural resources.Farmers, foresters and other land managers must consider soil properties in the planning and application of their management systems. Many of the technical specifications for the protection and restoration of soil, water, wetlands and habitats require the consideration of soils data. For many years, the State of Minnesota has supported the efforts of the USDA Natural Resources Conservation Service to map the soils of this state. Soils data is now readily available through the Internet. Progress was made with this project to accelerate the expansion of WEB-based soils data. This project supported the acceleration of soil survey data by making timely use of former and current NRCS soil scientists. Funds were also used to develop and promote the use of soil mapping technology, and explore ways to make the WEB Soil Survey more "GIS-friendly".

Result 1: Maintain current level of support to the Crow Wing County Soil Survey. Crow Wing County comprises about 740,000 acres. The NRCS estimates completion to take about 8 years. State support of this survey generated about $45,000 of local cash support and additional in-kind contributions in the form of office space and soil survey related equipment.

Summary Budget Information for Result 1: Trust Fund Budget: $75,000

Amount Spent: $75,000

Balance: $ 0

Final Report Summary: The NRCS addressed about 165,000 acres**.** Significant to this project is the anticipated WEB publication and fall 2009 release of soils data for the Glacial Lake Brainerd area. Rather than wait until an entire county has been completed as has been past practice, early availability of products will aid land users in this lake-rich area of Crow Wing County.

Result 2: Increase soil mapping and interpretation in Crow Wing and four additional counties. Soil mapping and interpretation was accelerated by augmenting existing NRCS staff with experienced soil scientists familiar with NRCS mapping procedures and the soil landscape and by providing technical and other support to on-going soil surveys. An additional 100,000 acres were anticipated to be mapped by using recently retired NRCS soil scientists, current NRCS soil scientists brought to Minnesota on work assignments and by providing support to field data collection, interpretation of data, and subsurface investigations.

Summary Budget Information for Result 2: Trust Fund Budget: $175,000

Amount Spent: $175,000

Balance: $ 0

Final Report Summary: Five NRCS soil scientists detailed to Minnesota addressed about 80,000 acres in Koochiching and Saint Louis Counties. Detailees demonstrated their ability to meet production goals ensuring their continued use in the accelerated completion of soil surveys. The success of using detailees for production resulted in the completion of soil mapping in Koochiching County about 12 months ahead of schedule. Funding was provided to soil and water conservation districts for backhoe services to aid project soil scientists in developing soil interpretations. This effort was particularly useful in Crow Wing County and contributed to the success reported in Result 1. The University of Minnesota assisted in providing soil survey interpretations and WEB support to the crop and soil productivity indices addressed in Result 3.

Result 3: Accelerate existing NRCS field activities, training, digitizing, data entry and correlation. Additional personnel and funding was provided to the NRCS and an additional 30,000 acres were addressed in the counties mentioned in result 2. Other counties deemed a priority by the NRCS for improving the soil data base, and training of personnel, were accelerated and Benton County was completed one year ahead of schedule. As a condition to NRCS participation in the completion of Lake and Cook counties, county funding was required. Lake and Cook Counties did not provide local funding so activities did not commence.

Summary Budget Information for Result 3: Trust Fund Budget: $75,000

Amount Spent: $75,000

Balance: $ 0

Final Report Summary: Funding for this result was spent by August 2008. Since then, refinement of the crop and forest productivity indices has been ongoing, and in concert with Results 2 and 4, enhancements were made to the Minnesota Land Economics Website incorporating soil productivity indices and soil erosion potential ratings. Agricultural soil productivity indices were completed for 84 soil survey areas (all or part of 81 counties) and forestry productivity indices were completed for 19 northern counties. Based on the number of hits on the WEB Soil Survey Website, these data are popular. Interest in driven in part by the increase in row crop production and the demise of the popular CER (Crop Equivalent Ratings), an assessment and soil management guide developed by the University of Minnesota in the 1970's. Crop and soil productivity indices have officially replaced Crop Equivalent Ratings.

Result 4: Increased technology and utility of data. Soil mapping technology became more readily available, including methods that use high resolution landscape mapping. The University of Minnesota and the Board of Water and Soil Resources developed enhancements to the WEB Soil Survey to make it more "GIS-friendly", and, consequently, make soils data easier to use as a "layer" in GIS applications.

Summary Budget Information for Result 4: Trust Fund Budget: $75,000

Amount Spent: $75,000

Balance: $0

Final Report Summary: A WEB-based soil driven decision support system for natural resources called NRDS (Natural Resource Decision Support System) is fully functional and applications of it are in planning for use in BWSR natural resource grant applications submitted by local units of government. At the time of its completion, NRDS functionality far exceeded the WEB Soil Survey. Since, then, however, the WEB Soil Survey has been updated negating many of the advantages of NRDS.

V. Total Trust Fund Project Budget:

Staff or Contract Services: $400,000

Of this amount, two $75,000 contracts were written, one to Crow Wing County [Result 1] and the other to the University of Minnesota [Result 4]. $250,000 was allocated in Results 2 and 3 as follows: Retired NRCS employees hired through the University of Minnesota ($120,000); Contracts with SWCDs for backhoe services ($30,000) and a contract with NRCS for detailees ($100,000). One retired NRCS employee served as lead employee and oversaw Results 2 and 3.

Equipment: $ 0

Development: $0

Restoration: $0

Acquisition, including easements: $0

Total Trust Fund Project Budget: $400,000 (see Attachment A)

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

The project team included Joe McCloskey, State Soil Scientist, USDA NRCS; Greg Larson, State Soil Specialist, BWSR and Professor Ed Nater, UM Department of Soil, Water and Climate.

B. Other Funds Proposed to be Spent during the Project Period:

Of the $2.5 Million annual commitment of the Minnesota Office of the NRCS to their soils program, about $1.3 Million was spent on completing soil mapping and digitizing activities in the remaining 14 counties. Crow Wing County contributed about $45,000 cash and additional in-kind contributions. The Board of Water and Soil Resources contributed in-kind contributions of about $20,000.

C. Past Spending:

Soil mapping and digitizing received $400,000 of LCMR funding for the biennium ending June 30, 2007. During this period, Crow Wing County contributed about $30,000 cash and in-kind contributions of $15,000.

D. Time:

Results 1 through 3 are part of a multi-county on-going effort to complete soil mapping and digitizing. This phase of the ongoing project was completed on schedule and transitioned into the 2008 project. Result 4, a free standing effort, was also completed by June 30, 2009.

VII. DISSEMINATION: As the projects described herein were developed and approved they were marked "advanced copy" and were distributed by the NRCS and project partners without restriction. The final products were digital and WEB-based.

VIII. REPORTING REQUIREMENTS: Periodic work program progress reports were submitted January 11, 2008; November 25, 2008 and February 25, 2009. A final work program report and associated products was submitted August 14, 2009.

IX. RESEARCH PROJECTS: Not applicable.

Attachment A: Final Budget Detail for 2007 Projects 14-Aug-09

Project Title: Soil Survey

Project Manager Name: Greg Larson

Trust Fund Appropriation: $ *400,000*

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent**	**Balance** *(06/30/09)*	**Result 2 Budget**	**Amount Spent**	**Balance** *(06/30/09)*	**Result 3 Budget**	**Amount Spent**	**Balance** *(06/30/09)*	**Result 4 Budget**	**Amount Spent**	**Balance** (06/30/09)	**TOTAL BUDGET**	**BALANCE**
	Maintain current level of support to the Crow Wing County Soil Survey.			*Increase soil mapping and interpretation in Crow Wing and four additional counties*			*Accelerate existing NRCS field activities, training, digitizing, data entry and correlation*			*Increased technology and utility of data*				
BUDGET ITEM														
Contracts														
NRCS soil scientists detailees				100,000	100,000	0							100,000	0
Crow Wing County	75,000	75,000	0										75,000	0
University of Minnesota				45,000	45,000	0	75,000	75,000	0	75,000	75,000	0	195,000	0
													0	0
													0	0
Soil&Water Conservation Districts				30,000	30,000	0							30,000	0
													0	0
COLUMN TOTAL	**$75,000**	**$75,000**	**$0**	**$175,000**	**$175,000**	**$0**	**$75,000**	**$75,000**	**$0**	**$75,000**	**$75,000**	**$0**	**$400,000**	**$0**

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Field Guide to Minnesota Wetland and Buffer Plant Seedlings
PROJECT MANAGER: Paul Bockenstedt
AFFILIATION: Bonestroo, Inc.
MAILING ADDRESS: 2335 West Highway 36
CITY/STATE/ZIP: St. Paul, MN 55113
PHONE: 651.604.4812
FAX: 651.636.1311
E-MAIL: paul.bockenstedt@bonestroo.com
WEBSITE: www.bonestroo.com
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: *(c) Field Guide for Evaluating Vegetation of Restored Wetlands*
$53,000 is from the trust fund to the Board of Water and Soil Resources for an agreement with Bonestroo, Rosene, Anderlik, & Associates to develop a printed and Web-based field guide to assist the evaluation of the quality of wetland restorations in Minnesota. This wetland guide must be available for downloading free of charge on the Internet.

APPROPRIATION AMOUNT: $ 53,000

Overall Project Outcome and Results
Wetland mitigations in Minnesota are expected to be required to meet minimum native vegetation requirements for approval in the near future. The *Minnesota Field Guide to Wetland & Buffer Plant Seedlings* was developed as an easy-to-use guide to assist in evaluation of the quality of vegetation in wetland restorations in Minnesota.

Bonestroo staff gathered necessary graphic resources for the guide and met with BWSR and MPCA staff to discuss and refine the project layout and contents. Bonestroo graphic designers developed a layout template for the guide. Plant drawings and art were purchased from artist Mark Muller, and additional photos/graphics for native plant seeds and seedlings gathered by Bonestroo staff. Michael Bourdaghs of MPCA assisted with preparation of an abbreviated description of the Floristic Quality Assessment Index (FQAI) process for inclusion as the field methodology for evaluating wetlands.

A total of 2,450 guides were printed (original proposed 2,000) by Modern Press of St. Paul following a competitive bid process. These were distributed to a variety of state and county agencies, as well as federal agencies with Minnesota offices, professional organizations, and educational groups/institutions. A small number of printed guides and the final print-ready version of the guide were provided to Dan Shaw of BWSR. This project created the first guide of its kind for identifying wetland plants, their seeds and seedlings, as well as information on the wetland vegetation evaluation methodology being developed by MPCA. Printed guides were distributed to wetland professionals through a broad network of groups, professional organizations, and local, state and federal agencies. The *Minnesota Field Guide to Wetland and Buffer Plant Seedlings* is also available as a free of charge downloadable PDF on Bonestroo's website at www.bonestroo.com. It is also available to State agencies for posting to their websites, should they choose to do so in the future.

Project Results Use and Dissemination
The *Minnesota Field Guide to Wetland and Buffer Plant Seedlings* is being used as both a printed and online resource by wetland professionals. The guide has been distributed at wetland delineators training sessions, as well as by other wetland and natural resource professional groups. The guide is intended to be a supporting reference for plant identification for the wetland evaluation methodology (FQAI) being developed by the Minnesota Pollution Control Agency. This MPCA-developed methodology is anticipated for completion in 2010. The Guide to Minnesota Wetland and Buffer Plant Seedlings is being promoted both through word of mouth, as well as announcements at meetings, workshops, and conferences, by Bonestroo, agency, and nonprofit staff. A distribution list for printed guides was provided to LCCMR staff along with the final project report in July/August 2009.

Trust Fund 2007 Work Program Final Report

Date of Report: 29 July 2009
Trust Fund 2007 Work Program Final Report
Date of Next Status Report: N/A
Date of Work program Approval: 5 June 2007
Project Completion Date: September 2009

I. PROJECT TITLE: *Field Guide for Evaluating Vegetation of Restored Wetlands*

Project Manager: Paul Bockenstedt
Affiliation: Bonestroo
Mailing Address: 2335 West Highway 36
City / State / Zip: St. Paul, MN 55113
Telephone Number: 651.604.4812 Mobile 651.775.5331
E-mail Address: paul.bockenstedt@bonestroo.com
FAX Number: 651.636.1311
Web Page address: www.bonestroo.com

Location: *Statewide*

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$53,000**
	Minus Amount Spent:	**$53,000**
	Equal Balance:	**$ 0**

Legal Citation: 1. M.L. 2007, Chp. 30, Sec. 2, Subd. 6(c) titled "Field Guide for Evaluating Vegetation of Restored Wetlands".

Appropriation Language:

(c) Field Guide for Evaluating Vegetation of Restored Wetlands
$53,000 is from the trust fund to the Board of Water and Soil Resources for an agreement with Bonestroo, Rosene, Anderlik, & Associates to develop a printed and Web-based field guide to assist the evaluation of the quality of wetland restorations in Minnesota. This wetland guide must be available for downloading free of charge on the Internet.

II. and III. FINAL PROJECT SUMMARY:

Wetland mitigations in Minnesota are expected to be required to meet minimum native vegetation requirements for approval in the near future. The *Minnesota Guide to Wetland & Buffer Plant Seedlings* was developed as an easy-to-use guide to assist in evaluation of the quality of vegetation in wetland restorations in Minnesota.

Bonestroo staff gathered necessary graphic resources for the guide and met with BWSR and MPCA staff to discuss and refine the project layout and contents. Bonestroo graphic designers developed a layout template for the guide. Plant drawings and art were purchased from artist Mark Muller, and additional photos/graphics for native plant seeds and seedlings gathered by Bonestroo staff. Michael

Bourdaghs of MPCA assisted with preparation of an abbreviated description of FQAI process for inclusion as the field methodology for evaluating wetlands.

A total of 2,450 guides were printed (original proposed 2,000) by Modern Press of St. Paul following a competitive bid process. These were distributed to a variety of state and county agencies, as well as federal agencies with Minnesota offices; professional organizations, and educational groups/institutions. A small number of printed guides and the final print-ready version of the guide were to Dan Shaw of BWSR.

This project created the first guide of its kind for identifying wetland plants, their seeds and seedlings, as well as information on the wetland vegetation evaluation methodology being developed by MPCA. Printed guides were distributed to wetland professionals through a broad network of groups, professional organizations, and local, state and federal agencies. The *Minnesota Guide to Wetland and Buffer Plant Seedlings* is also available as a free of charge downloadable PDF on Bonestroo's website at www.bonestroo.com. It is also available to State agencies for posting to their websites, should they choose to do so in the future.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: "Develop *Field Guide for Evaluating Vegetation of Restored Wetlands*"
Description:
Bonestroo ecologist and graphic designer completed a draft version of the guide in mid-April 2009. The draft guide was distributed to select state agency staff for review, including Dan Shaw of BWSR and Michael Bourdaghs of MPCA. Comments were received from reviewers in early May.

The original proposal was for the guide to be 125-150 pages in length (actual 130 pages). The final guide included full-color photos and drawings of native plant seed seedlings, and seedling specific descriptions. The proposed number of native plants proposed for the guide was 50-60 (actual 75). The guide was proposed to include a minimum of 20 problem weeds common to restored wetlands in Minnesota and the Upper Midwest (actual 27).

The guide included a summary-level section on the practical field review of native plant restoration describing the Floristic Quality Assessment Index (FQAI) method that is in the process of being developed by MPCA and other Wetland Conservation Act stakeholders. Bonestroo anticipates having a downloadable pdf version of the guide available on their internet site by mid-August 2009. State agencies may also make this publication available through their internet sites, but no word was available as to the status of such an effort at the time of this report.

The original proposal was to include a wetland vegetation assessment procedure in the guide. The wetland vegetation procedure that was proposed for inclusion in the guide had not been completed by MPCA staff at the time the guide went to the printer. Therefore, this section included a basic description of the anticipated methodology. The wetland plant guide for this project may be updated in the future to include a more complete treatment of the FQAI method, when it is completed by MPCA.

Budget: $*42,250*

Summary Budget Information for Result 1: **Trust Fund Budget: $42,250**
Amount Spent: $42,250
Balance: $ 0

Deliverable	**Completion Date**	**Budget**	**Status**
1. *Development and layout of guide*	*March 2008*	*$35,500*	
2. Draft printing/review	*April 2008*	*$ 4,500*	
3. *Incorporate Edits and Final Draft*	*June 2008*	*$ 2,250*	

Result 2: "*Printing and guide distribution*"
Description:
Competitive bids were accepted for printing of the final guide and the final draft sent to Modern Press of St. Paul in mid-May 2009. A total of 2,450 guides were printed. A draft distribution plan was submitted to Dan Shaw of BWSR and Michael Bourdaghs of MPCA, as well as other select professionals active in the wetland regulation and restoration community in April 2009. A final distribution plan was arrived at in May 2009. After the guides were returned from the printer, distribution was accomplished (final distribution list provided to LCCMR as an MS Excel spreadsheet). A small number of surplus guides (approximately 200) are being stored by Dan Shaw of BWSR and will be distributed based on requests, and additional distribution at conferences and wetland professionals meetings.

Budget: $10,750

Summary Budget Information for Result 2: **Trust Fund Budget: $10,750**
Amount Spent: $10,750
Balance: $ 0

Deliverable	**Completion Date**	**Budget**	**Status**
1. *Printing of Guide*	*June 2009*	*$10,000*	
2. *Provide Guides to Agencies for distribution*	*June 2009*	*$ 550*	
3. *Make guide available on internet as pdf (free, downloadable) downloadable from www.bonestroo.com , and perhaps State agencies*	*June '09*	*$ 200*	

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $53,000 (Bonestroo, & a printing company to be determined based on best value/bid)
Equipment: *Not applicable for this project*
Development: $ *Not applicable for this project*
Restoration: $ *Not applicable for this project*
Acquisition, including easements: *Not applicable for this project*

TOTAL TRUST FUND PROJECT BUDGET: $53,000

Explanation of Capital Expenditures Greater Than $3,500: *None*

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

BWSR, Dan Shaw – photos, guide content advisor/reviewer
MPCA, Michael Bourdaghs, Wetland Biologist, - guide content advisor/reviewer. FQAI method development project manager
St. Croix Watershed Research Station, Science Museum of MN, Dr. Shawn Schottler, – photos of native plant seeds
Iowa DNR, Bill Johnson - photos of native plants and seedlings
Mark Müller, Independent Graphic Artist – artwork of native and nonnative plants for guide.
Ramsey County Corrections Greenhouse (Sean Uslabar) – growing of seedlings to photograph
Minnesota Department of Natural Resources – Doug Norris time for review/distribution
Wetland Professionals Association – guide content advisor/reviewer, distribute guides
Prairie Moon Nursery – supplied seed for photos of some seed
USDA NRCS PLANTS Database – photos of plants/seeds for use in guide
MN Department of Agriculture – photos of weeds, weed seedlings and weed seed
Ion Exchange – Making seedlings available for photos at their native plant greenhouses
MN Waterfowl Association – Guide distribution
Ducks Unlimited – Guide distribution
U.S. Corp of Engineers – Guide distribution
Modern Press of St. Paul, printing of guide, following a competitive bid process.
The Ohio State University – photos for select weed seedlings

B. Other Funds Proposed to be Spent during the Project Period:
Not applicable

C. Past Spending:

Not applicable

D. Time:

- July 2007 – January 2009 – development and layout of guide
- May 2009 – Completion of Draft Guide and peer review
- June 2009 – Final Guide printing and distribution to partnering agencies
- July 2009 – Guide available on Bonestroo website www.bonestroo.com as a free, downloadable PDF document

VII. DISSEMINATION:
A total of 2,450 guides were printed and distributed. The guide is available for free downloading from the Bonestroo website as a pdf file. It may also be hosted on the internet in the future by one or several state agencies such as BWSR and/or MPCA.

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports were submitted:

- March 2008
- March 2009

A final work program report and associated products were submitted between June 30 and August 1, 2009, as requested by the LCCMR

IX. RESEARCH PROJECTS: *Not applicable for this project*

Attachment A: Budget Detail for 2007 Projects

Project Title: *Field Guide for Evaluating Vegetation of Restored Wetlands*

Project Manager Name: *Paul Bockenstedt; Bonestroo, 2335 West Highway 36, St. Paul, MN 55113 ; 651.604.4812*

Trust Fund Appropriation: $ *53,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

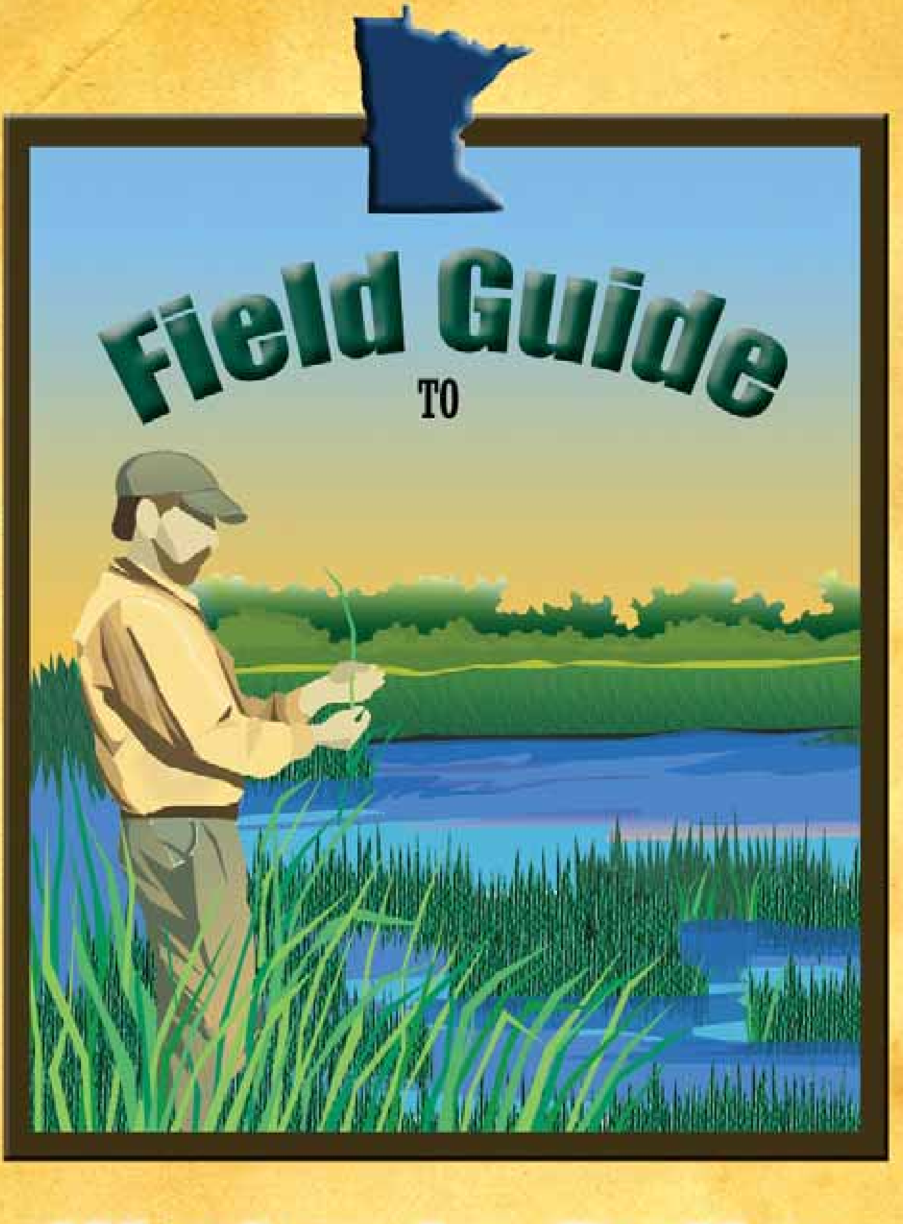
2) Remove any budget item lines not applicable

2007 Trust Fund Budget	Result 1 Budget:	Amount Spent (date)	Balance (date)	Result 2 Budget:	Amount Spent (date)	Balance (date)	Result 3 Budget:	Amount Spent (date)	Balance (date)	TOTAL BUDGET	TOTAL BALANCE
	Develop Field Guide			*Printing and guide distribution*			*Not Applicable for this project*				
BUDGET ITEM			0			0			0	0	0
PERSONNEL: wages and benefits	41,500	41,636	-136	750	750	0			0	42,250	-136
Printing	200	186	14	10,000	10,640	-640	0	0	0	10,200	-626
Travel expenses in Minnesota	550	338	212	550	0	550	0	0	0	1,100	762
COLUMN TOTAL	**$42,250**	**$42,160**	**$90**	**$11,300**	**$11,390**	**-$90**	**$0**	**$0**	**$0**	**$53,550**	**$0**

Wetland Guide FINAL Distribution List				
Agency/Group	**Contact Name**	**# of copies?**	**Phone**	**email**
BWSR	Dan Shaw, Vegetation Specialist/Landscape Ecologist	500	651.296.0644	Dan.Shaw@state.mn.us
MPCA (MN Native Plant Society)	Michael Bourdaghs	100	651.757-2239	Michael.Bourdaghs@state.mn.us
MnDOT	Ken Graeve, Botanist	250	651.366.3613	Kenneth.Graeve@dot.state.mn.us
USACE	Tom Mings, Senior Ecologis - Banking	75	651.290.5365	Thomas.S.Mings@usace.army.mil
MN Wetland Professionals Ass'n	Rich Davis, President	150	507.380.6859	wetlandman34@yahoo.com
MN Association of SWCDs	LeAnn Buck, Executive Director	300	651.690.9028	leann.buck@maswcd.org
MN DNR	Doug Norris	150	651.259.5125	doug.norris@dnr.state.mn.us
NRCS	Paul Flynn, Wetland	200	651-602-7870	paul.flynn@mn.usda.gov
Ducks Unlimited	Jon Schneider, Bob Usgaard, or Ryan Heineger	100	320.762.9916	jschneider@ducks.org
MN Association of Watershed Districts	Ray Bohn	75	651.905.4948	raybohnmga@aol.com
MN Waterfowl Association	Brad Nylin, Executive Director	100	952.767.0320	brad.nylin@mnwaterfowl.com
Pheasants Forever	Matt Holland, Biologist	100	320.354.4377	mholland@pheasantsforever.org
Minnehaha Creek WD	Julie Westerlund	75		
LCCMR	Distributed at field day 16 June, 2009	35		
WCA Rule Training 7-23-09	General Distribution	78		
	Bonestroo	62		
	TOTAL	2350		
*anticipated 2,000 copies for printing and distribution in June 2009				
Institution	**Name**	**Number**	**AddressLine1**	**AddressLine2**
Legislative Reference Library	Jess Hopeman	5		100 Rev. Dr. Martin Luther King Jr. Blvd.
University of Minnesota Twin Cities	Aquisitions	5	McGrath Library	1984 Buford Ave
University of Minnesota Duluth	Bill Sozansky	5	Library	10 University Dr
University of Minnesota Crookston	Owen Williams	5	Library	2900 University Ave.
University of Minnesota	Erin Fider	5	Itasca Biological Station & Laboratories	28131 University Circle
Bemidji State University	Aquisitions Librarian	5	A.C. Clark Library	1500 Birchmont Dr. NE
St. Cloud State University	Aquisitions Librarian	5	Library	720 Fourth Avenue South
Southwest Minnesota State University	Aquisitions Librarian	5	Library	1501 State St.
Minnesota State University, Mankato	Aquisitions Librarian	5	Memorial Library	PO Box 8419-ML 3097
Winona State University	Aquisitions Librarian	5	Darrell W. Krueger Library	PO 5838, 175 West Mark St
Natural Resources Research Institute	Susan Hendrickson	5		5013 Miller Trunk Highway
US Army Corps of Engineers	Tom Mings	5	Sibley Square at Mears Park	190 5th St. E., Suite 401
US Army Corps of Engineers	Tim Smith	5	Sibley Square at Mears Park	190 5th St. E., Suite 401
Iowa DNR	Vince Evelsizer	2		109 Trowbridge Hall
Wisconsin DNR	Tom Bernthal	3		101 S. Webster
Fond du Lac Environmental Dept.	Ric Gitar	5		1720 Big Lake Rd
Hennepin County	David Thill	5	Environmental Services Dept.	417 N. 5th St., Suite 200
Minnesota State University Mankato	Brad Cook	5		242 Trafton Science Center South (Office-T
Ramsey Washington Metro Watershed	Bill Bartodziej	5		2665 Noel Drive
University of Minnesota Crookston	Rhett Johnson	5	Natural Resources Dept.	2900 University Ave.
University of Minnesota Twin Cities	Susan Galatowitsch	5	260 Alderman Hall	1970 Folwell Ave.
		100		
	TOTAL	**2450**		

Field Guide

TO



Wetland & Buffer Plant Seedlings

Development of this guide was funded by The Minnesota Environmental Trust Fund as recommended by the Legislative-Citizens Commission on Minnesota Resources

Acknowledgments

This guide is the result of the hard work and collaboration of numerous individuals. We are very grateful for their contribution of time, talent, and resources to the guide.

- Dan Shaw – MN Board of Water & Soil Resources
- Michael Bourdaghs – MN Pollution Control Agency
- Dr. Shawn Schottler - Science Museum of Minnesota, St. Croix Watershed Research Station
- Bill Johnson and M.J. Hatfield - Iowa Department of Natural Resources
- Prairie Moon Nursery
- Mark Muller - accomplished artist
- Howard and Donna Bright - Ion Exchange, Inc.
- Anthony Cortilet - Minnesota Department of Agriculture
- Sean Uslabar – Ramsey County, MN

Dedicated to Bob Jacobson – his thirst for knowledge and ability to challenge each of us to learn and grow

Bonestroo Project Team Members
Paul Bockenstedt – Plant/Restoration Ecologist
Beau Thunshelle - Biologist
Susanne Short – Graphic Design
Jeff Peterson – Graphic Design
Amy Strasheim – Editing

Bonestroo

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Grasses, Sedges, & Rushes

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Appendix

Introduction

Historically, wetlands have been maligned and their function on the landscape misunderstood. Wide-scale drainage of wetlands occurred throughout much of the 19th and 20th centuries, the pace of which accelerated as new technologies developed. In southern Minnesota, more than 80% of wetlands on the landscape prior to Euroamerican settlement have been drained.

Today, we better understand the vital and multiple roles wetlands play on the landscape and in contributing to quality of life in Minnesota. Among the most biologically productive natural systems on earth, wetlands provide benefits to water quality, groundwater, wildlife, and recreation.

While wetland losses still occur, the rate of loss has been substantially stemmed through passage of the Clean Water Act. In recent years, the Minnesota Wetland Conservation Act provided an added and important safety net at the state level for isolated, depressional wetlands. For many reasons, Minnesota is recognized as a leader in wetland conservation as well as restoration.

Wetland mitigation banking related to regulatory efforts, and other programs such as the Wetland Reserve Program, have become important tools for minimizing wetland loss and attempting to restore wetland functions and values.

Although efforts to replicate prairie through restoration began in the 1930s and have steadily improved through substantial research and practical experience, wetland research has lagged in determining similar best practices for establishing quality native vegetation in wetland restorations.

Historically, wetland restorations often focused on restoring water levels (hydrology), with the hope that appropriate wetland vegetation types would re-colonize a particular site. We now know restoring water levels in drained wetlands and planting seed, tubers, and plugs of desirable plants greatly increases the chance desirable native vegetation will develop.

Restoring native wetland vegetation is not always an easy task. Because wetlands tend to be dynamic systems, conditions are not consistently favorable for establishing plantings. As a result, it is important to identify native and weed seedlings early in the process to proactively identify problems and help guide appropriate maintenance activities to improve the success of wetland restoration efforts.

This guide is intended to help natural resource professionals, students, and average persons identify plants, their seeds, and seedlings common to restored wetlands and adjacent upland buffers in Minnesota. It includes drawings, photographs, and written descriptions specific to seedlings. Comparisons are also provided for seedlings of plants that might be easily confused with one another.

Although efforts were made to include images and descriptions that help with field identification, some species and groups of plants pose special challenges in identification at the seedling stage, and sometimes even as adult plants. This is particularly true of wetland grasses, sedges and rushes, which are often difficult to differentiate by species and sometimes by plant family.

Identifying young wetland plants takes practice, especially for easily confused species. However, it is an attainable goal. Practice makes permanent in this case.

The majority of this guide is comprised of pages on native grasses, sedges, and rushes and flowers. Also included is a section with nonnative weeds common to both buffer and wetland plantings.

On the following page, you'll also find a brief summary of the Floristic Quality Assessment (Rapid FQAI). This method will become an important tool for wetland professionals in Minnesota, and will have some bearing on evaluating restored wetland sites and mitigation efforts. Likewise, the Board of Water & Soil Resources *Minnesota Wetland Restoration Guide* is a valuable reference. This document can be viewed and downloaded at: http://www.bwsr.state.mn.us/restoration guide.html

This easy-to-read and understand guide was developed to be carried in the field in a pocket or vehicle glove compartment. We hope you find this guide to be useful in your natural resource endeavors.

Monitoring vegetation of restored wetlands

Monitoring the vegetation component of a wetland restoration provides important feedback about whether things are progressing appropriately, if additional work is required, and how quickly intervention should occur. It is also an important regulatory component for wetland mitigation and wetland banking sites.

For most plantings, taking the time to learn field identification of 20-30 plants and their seedlings will go a long way toward making you an expert. Identifying plant seedlings does take some time, but need not be intimidating.

Monitoring can vary in the amount of effort and field plant identification required. Intense field data gathering yields detailed information, but can take substantial time. These types of studies are most often undertaken by researchers.

A basic seeding evaluation can be carried out with a few simple tools, some basic plant identification skills, and a bit of patience. The steps for a less intense method of evaluating seedings that still yields some good information to base management on is included in the *Prairie Seedling & Seeding Evaluation Guide*. This guide is available as a free pdf download from the internet at: http://www.bonestroo.com

Minnesota wetland regulatory agencies are placing increasing emphasis on monitoring wetland restoration sites to determine if performance standards are being met. The US Army Corps of Engineers recently adopted an official St. Paul District Policy for Wetland Compensatory Mitigation in Minnesota (http://www.mvp.usace.army.mil), and the Board of Water & Soil Resources is revising the state wetland rule (http://www.bwsr.state.mn.us) as of spring 2009. Both outline monitoring requirements for wetland mitigation and banking plans. Additionally, the Minnesota Wetland Restoration Guide, produced by the Board of Water & Soil Resources, describes how to develop and execute plans to meet monitoring requirements, and includes a vegetation monitoring and assessment component.

Floristic Quality Assessment Index (FQAI)

As methods become established and refined, scientifically based wetland assessment techniques are increasingly being used to evaluate the success of wetland restoration efforts, particularly as part of specified performance standards. One such technique for assessing vegetation condition is the Floristic Quality Assessment (FQA).

FQA is a method for assessing a natural community's condition based on the plant species occurring there and their individual affinity with unaltered habitats. This affinity of a particular species is called the Coefficient of Conservatism (C), and is expressed as a numerical rating from 0-10. Species with a high or exclusive affinity to unaltered habitats are assigned a high C-value. Conversely, species with low or no affinity to unaltered habitats are assigned a low C-value.

FQA consists of numerical scores (metrics) derived from the C-values (such as Mean C or the Floristic Quality Index, which is the Mean C multiplied by the square root of the number of native species) for the species occurring at a site. With FQA, higher metric values for a site typically indicate the vegetation is in good condition.

First developed in the late 1970s and refined in the 1990s, FQA has been an effective tool for understanding wetland vegetation condition. With a demonstrated track record of performance, FQA has been increasingly used to measure wetland restoration success.

In 2007, the Minnesota Pollution Control Agency (MPCA) published Floristic Quality Assessment for Minnesota Wetlands (http://www.pca.state.mn.us/publications/wetlandassessment-guide.html), which includes the C-values for the state's wetland flora. The C-values for the featured species in this guide have been included to facilitate using FQA for vegetation monitoring in restored wetlands. For readers who would like to learn more, please refer to the FQA publication for a more comprehensive background and instruction of the method.

As of spring 2009, the MPCA is leading a multi-agency effort to establish standard sampling procedures and scientifically based assessment criteria for using FQA in Minnesota. This project will provide an important tool and improved ability to assess vegetation condition in restoration sites, and lead toward greater use of FQA as a scientifically based performance standard in mitigation and banking plans.

What's on each plant page?

The pages in this guide include information with both the wetland professional and amateur native plant enthusiast in mind. As a result, each plant description page includes information to help each of these user groups. Each page includes photos of seed and seedling(s) as well as a line drawing of a mature plant. Below is a brief summary of the written information included with each page.

Common name - a generally accepted non-scientific name for a particular plant. Some plants may have several common names, depending on the region and the background of the person describing the plant.

Scientific name – also referred to as the Latin name of a plant. There may be several scientific name synonyms for a particular plant. We have included frequently applied scientific names for each plant and included a list of synonyms in the back of the guide to try and help with sorting out the many name changes that have taken place the last few decades.

Habitat: Wetland, Edge, and/or Upland – based on the general habitat affinity of a particular plant species.

R3 Indicator Status: A code assigned to plant species to indicate the likelihood (% probability) that a particular plant will occur in a wetland. Region 3 (R3) includes seven states in the upper Midwest. The list was developed by the U.S. Fish & Wildlife Service and National and Regional Interagency Review Panels.

MN C Value: Also referred to as Coefficient of Conservatism, this number reflects the relative affinity for a particular plant species to high quality/unique habitats scored on a 0-10 basis, where 10 indicates an affinity of a particular plant species to a high quality/unique habitat and 0 indicates no affinity (think weedy plant).

Flowers: Typical month(s) for blooming

Seedling Description:

With a focus on describing features common to seedlings for a particular species that can be observed in the field. This section may also include information describing features of more mature plants of a species.

Look Alikes

This section is primarily focused on giving some basic clues on how to differentiate between plants common to wetland restorations that have similar characteristics.

Grasses, Sedges, & Rushes

American Slough Grass

Beckmannia syzigachne

Science Museum of Minnesota

Seed

Seedling

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 4

Flowers: July-September

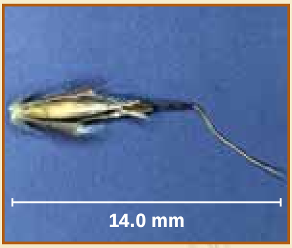
Seedling Description: Slough grass is an annual and therefore has seedlings that develop quickly. Seedlings have flat leaves that are rough to the touch with large ligules where the leaf blade meets the stem. As seedlings grow, leaf sheaths can more readily be seen to overlap along the length of the stem. Plants may develop several stems from a single base, with elongated compound panicles of short, crowded spikes that overlap.

Look Alikes: Because slough grass is an annual and grows quickly, it may be confused with some of the weedier grasses such as foxtail, barnyard grass (both of which have wide, often red, stem bases), or the tame hay grass, timothy. Nonnative, weedy grasses tend to form thick canopies, whereas slough grass tends to be more upright, and less likely to form a thick canopy.

Adult Plant

Andropogion gerardii

Big Bluestem



Seed

Seedling

Habitat: Edge/Upland

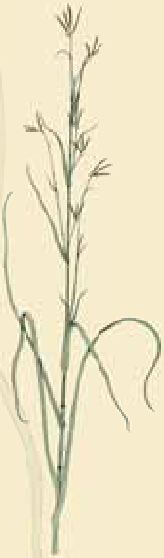
R3 Indicator Status: FAC

MN C-Value: 4

Flowers: June-August

Seedling Description: Seedlings are upright and rigid. Leaves are long, narrow (2-4 mm on plants under one foot tall), and often form a graceful arch from the main stem. Ligule is thin and short, with fine hairs. Seedlings can range from hairy to smooth, and may or may not have a waxy bloom. Leaf and stem base color can also vary substantially and are therefore not the most reliable field indicators.

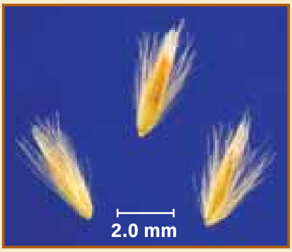
Look Alikes: Big bluestem is perhaps most easily confused with switchgrass and sideoats grama. Big bluestem has an obvious ligule, and seedlings typically have hairs extending well up the leaf blade while switchgrass often only has a patch of hairs at the base of each leaf. Sideoats has stiff hairs that protrude distinctively outward from leaf margins, while big bluestem is often more densely hairy, with hairs in areas other than the leaf margin. Indian grass seedling leaves taper to a narrow base and develop a stout, keeled midrib on each leaf that is easily recognized by touch.



Adult Plant

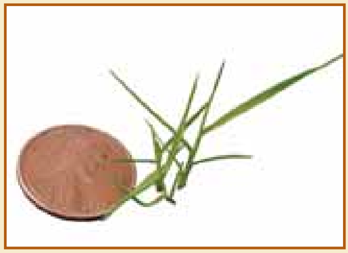
Bluejoint

Calamagrostis canadensis



Steve Hurst- USDA-NRCS

Seed



Iowa DNR

Seedlings

Habitat: Wetland/Edge

R3 Indicator Status: OBL

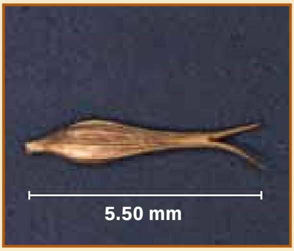
MN C-Value: 4

Flowers: June

Seedling Description: Seedlings tend to have fine, narrow leaves that are smooth. Seedlings often have a blue-green cast. As seedlings become more developed, this color becomes easier to notice that the leaf sheaths. Leaves eventually become 4-8 millimeters wide and rough on the top and bottom surfaces, while the stem is smooth. Seedlings tend to develop relatively slow.

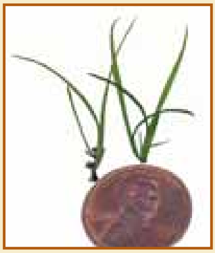
Look Alikes: Perhaps most similar in appearance to prairie cordgrass when seedlings are small. Prairie cordgrass tends to be more stiff and wiry. As plants grow, bluejoint remains more “fine-featured” than cordgrass, which develops much longer leaves with sharp teeth on the margins (capable of cutting persons that run their skin across the edge from leaf tip to base).

Adult Plant



Science Museum of Minnesota

Seed



Seedlings

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 4

Flowers: June

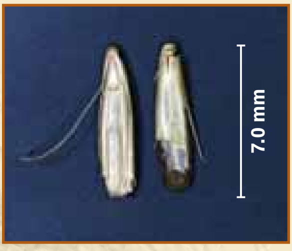
Seedling Description: Seedlings of bottlebrush sedge become easier to identify after reaching approximately four or more inches in height. The relatively wide leaf of bottlebrush sedge and its m-shaped cross section are characteristic. Leaves form a bushy-looking basal rosette in immature plants.

Look Alikes: Other sedges common to restoration plantings that are similar in growth characteristics include porcupine sedge *C. hystericina* and common hop sedge *C. lupulina*. Most other sedges tend to stand more upright even as young plants, and typically have narrower leaves (e.g., tussock sedge and lakebank sedge). Bottlebrush sedge may also be confused with dark green bulrush, which also forms something resembling a basal rosette.

Adult Plant

Canada Wildrye

Elymus canadensis



Science Museum of Minnesota

Seed

Iowa DNR

Seedling

Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 3

Flowers: June-July

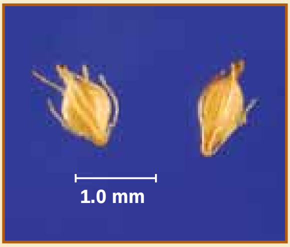
Seedling Description: Canada wildrye seedlings have thin, smooth, dark green leaves that often feel waxy. The auricles at the leaf base usually wrap around the stem and will occasionally overlap. Leaf widths range from 3-12 mm. The first leaves emerging after germination are often twisted on axis from bottom to top. The ligule is a thin membrane.

Look Alikes: Canada wildrye seedlings are perhaps more commonly confused with seedlings of cover crops, weedy grasses, or pasture grasses such as orchard grass and timothy than with other native grasses typically included in prairie plantings. Canada wildrye seedlings appear more erect with leaves held higher on the stems than the pasture grasses mentioned above. The leaves of Canada wildrye are wider than most other native grasses. Other wildrye, and brome seedlings can be confused with Canada wildrye as they also exhibit twisting of the leaf blade. June grass also has this trait, but is smaller, with much narrower leaves.

Inflorescense

Dark Green Bulrush

Scirpus atrovirens



Seed

Steve Hurst- USDA-NRCS

Seedlings

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 4

Flowers: June-July

Seedling Description: Dark green bulrush seedlings form a basal rosette. Leaves quickly develop an m-shaped cross-section and are a bright green color. As seedlings mature, successive leaves become wider and eventually reach as great as 3/4 inch in width. The sheaths of leaves are brownish or green (not red).

Look Alikes: Because the m-shaped leaves are similar to several species of sedges common to wetland restorations, dark green bulrush may be confused with bottlebrush sedge, hop sedge, or similarly wide-leaved wetland sedges. As dark green bulrush matures and flowers, it may reach 4-5 feet and overtop similar-looking sedge species, which generally do not exceed two feet in height. Wool grass has leaves that are v-shaped in cross section.

Adult Plant

Fowl Bluegrass

Poa palustris

Seed

Steve Hurst- USDA-NRCS

Seedling

Habitat: Edge

R3 Indicator Status: FACW

MN C-Value: 5

Flowers: June

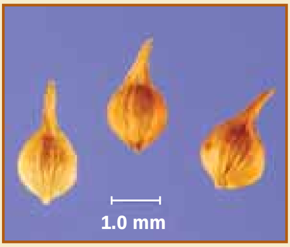
Seedling Description: Germinating in less than one week in many situations, fowl bluegrass is quick to establish but can be difficult to identify as a small seedling. However, the characteristic boat-shaped leaf tip becomes evident fairly early in development. Holding the leaf blade with the tip pointing out as well as up and a little to the side reveals this characteristic. Leaf bases are typically purplish, and stems have a tendency to recline toward the ground.

Look Alikes: Fowl bluegrass germinates quickly (7-10 days under good conditions), and often more uniformly than many of the other native sedges, grasses, and rushes common to wetland restoration seed mixes, which can be helpful in identification. Some species of rushes can be confused (such as wool grass) with fowl bluegrass when very small, but tend to germinate more slowly and often less uniformly.

Adult Plant

Carex vulpinoidea

Fox Sedge



Seed

Steve Hurst- USDA-NRCS

Seedlings

Seedlings

Habitat: Wetland/Edge

R3 Indicator Status: OBL

MN C-Value: 3

Flowers: June

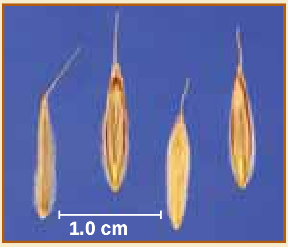
Seedling Description: Fox sedge forms somewhat loose, fountain-like clumps. Leaves are flat or nearly so, and 2-5 mm wide. The leaf sheath on the side of the stem opposite the leaf blade is sparsely red-dotted. The inflorescence of this plant typically becomes yellow-green as it matures. Fox sedge is generally fast-developing compared to most other sedge species. It may flower in the first, or more likely the second year after seeding.

Look Alikes: Several sedge species common to restoration plantings have similar growth form, including awl-fruited sedge *C. stipata*, crowfoot fox sedge *C. crus-corvi*, and lance-fruited oval sedge *C. scoparia*. These are most easily differentiated when the plants flower/produce fruit.

Adult Plant

Fringed Brome

Bromus ciliatus



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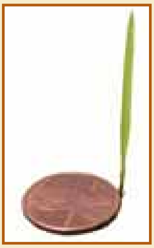


Seed

Seedling

Habitat: Wetland/Edge

R3 Indicator Status: FACW

MN C-Value: 6

Flowers: June-July

Seedling Description: Seedlings of fringed brome tends to have leaves that twist in a helical fashion. As seedlings develop, characteristic pubescence at the nodes becomes more noticeable, as do the short, ragged ligules where the leaf meets the stem. As plants continue to develop, an m-shaped wrinkle develops across the leaf blade, usually about two thirds of distance from the stem.

Look Alikes: In wetland restorations, fringed brome is perhaps most easily confused with Virginia wildrye which has rough upper and lower leaf surfaces. May also be confused with woodland brome (B. purgans), prairie brome (B. kalmii), or the nonnative smooth brome (B. inermis), although none of these three are typically found in wet habitats.

Adult Plant

Jose Hernandez- USDA-NRCS

Seed

Seedlings

Habitat: Wetland

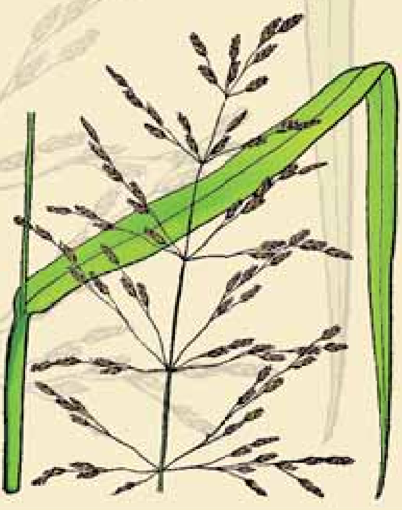
R3 Indicator Status: OBL

MN C-Value: 6

Flowers: June-July

Seedling Description: Giant manna grass tends to develop stout, upright stems with shiny, yellow-green foliage. New leaves emerge folded from an oval-shaped stem. Leaf sheaths are frequently closed. When mature, manna grass stems are stout, often several to a plant, and at five feet in height, overtops most other wetland grasses.

Look Alikes: May be confused with species of cutgrass (Leersia spp.), which also have light green foliage, but are much more "grabby" due to abundant spinules. Rice cutgrass has flat leaves compared to the leaves of giant manna grass that are slightly folded along the midvein.



Adult Plant

Indian Grass

Sorghastrum nutans

Seed

Steve Hurst – USDA-NRCS

Seedling

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 5

Flowers: July-August

Seedling Description: Ligule is a thin membrane with fine hairs often present. The “rifle sight” ligule characteristic of mature plants is indistinct or absent in seedlings. Leaf base narrows near the stem with leaves of young plants ranging from 2-5mm (5-10 mm for mature plants). Leaf develops strong, keeled midrib. Base of main stem may or may not be hairy.

Look Alikes: Indian grass is easily confused with big bluestem. However, Indian grass develops a more pronounced, keeled midrib on each leaf and a leaf that tapers at the base. Both can vary widely in color, hairiness, and amount of waxy bloom. Switchgrass does not have an obvious ligule and only has a triangular patch of hairs at the base of each leaf. Sideoats has stiff hairs that protrude distinctively outward from leaf margins.

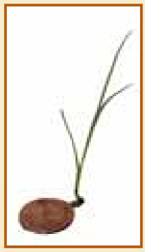
Adult Plant

Lakebank Sedge

Carex lacustris

Seed

Science Museum of Minnesota



Seedling

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 5

Flowers: June

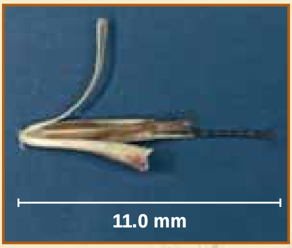
Seedling Description: Once seedlings start getting over about four inches tall, the characteristic m-shaped cross section becomes more evident in leaves, as do prominent teeth on the leaf margins. The red bases and feather-like (pinnate) pattern of fibers along the lower stem are not evident in small plants. Stems tend to be rigid and upright, sometimes developing a bluish-green cast as plants mature.

Look Alikes: Leaves of lakebank sedge are wider than those of most other bunch-forming sedges used in wetland restoration (8-15 mm in larger, mature plants). Sedges pose special challenges for identification, sometimes even when in fruit. Utilizing an original seeding list in a process of elimination may be helpful.

Inflorescence

Little Bluestem

Schizachyrium scoparium



Seed

Science Museum of Minnesota

Seedling

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 5

Flowers: July-September

Seedling Description: Seedlings are upright with fine leaves ranging in width from about 1.5-3 mm (3-7 mm on mature plants). Ligule is a short membrane (<1mm) with hairs on the outside edges. Plants can range from hairy to smooth, blue-green to green, and may have a heavy waxy coating (particularly genotypes from sandy soils/arid regions). Stem is semi-flattened with a bulbous base that is often reddish. Little bluestem begins forming multiple-stem bunches earlier than many other native grasses.

Look Alikes: The flattened stem and narrow leaves set little bluestem apart from other native grasses. It may be mistaken for barnyard grass and some species of foxtail, both of which are common weeds with flattened stems. However, these weedy species often exceed several feet in height within six weeks of germination, as compared to a height measured in inches for little bluestem over a similar time period.

Inflorescence

Spartina pectinata

Science Museum of Minnesota

Seed

Seedlings

Habitat: Edge/Upland

R3 Indicator Status: FACW

MN C-Value: 5

Flowers: July-August

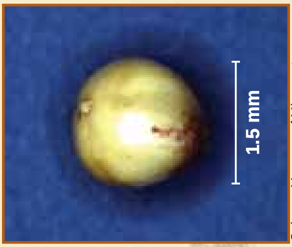
Seedling Description: Leaves are just over 1 mm wide when plants are approximately 10 cm tall. Seedling leaves are stiff and pointed upward, about 30-45 degrees from the main stem. Leaves are smooth, with the exception of the leaf margin, which is detectably rough when rubbed from tip to base. As plants develop, leaves become long, arching and gradually taper to a narrow point.

Look Alikes: Porcupine grass and prairie dropseed both have long, arching leaves that narrow to a sharp point. Prairie cordgrass leaves have a strong midrib, are over 5 mm wide, and have sharply serrated edges. Porcupine grass has leaves 2-5 mm wide. Prairie dropseed leaves are even narrower with edges rolled inward on the upper surface.

Inflorescence

Prairie Dropseed

Sporobolus heterolepis



Seed

Seedlings

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 9

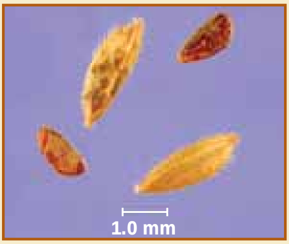
Flowers: July-August

Seedling Description: Seedlings lack hairs and develop slowly. Leaves are very fine (0.5-2 mm wide). On young plants, the leaves are flat and held stiffly outward on a wiry, upright stem. Leaves are concentrated at the base of the stem forming graceful arches, with leaf edges rolled inward toward the top-center of the leaf. Fine hairs on the main stem of seedlings are visible with a magnifying hand lens.

Look Alikes: Prairie dropseed seedlings are short, fine, and difficult to spot in the field. The stiff, upright posture of seedlings with just a few rigid leaves held outward are characteristic. Prairie dropseed might be confused with porcupine grass, which has wider leaves and is more robust. Prairie cordgrass is also more robust, with a strong leaf midrib and very sharp, serrated leaf margin. Its leaves exceed 5 mm in width.

Inflorescence

Leersia oryzoides



Steve Hurst – USDA-NRCS

Seed


Patrick J. Alexander – USDA-NRCS

Spinules

Seedling

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 3

Flowers: June

Seedling Description: Seedlings are stout, with broad, yellow-green leaves. New leaves emerge rolled. Although relatively smooth as small seedlings, rice cutgrass develops clear spinules (miniature spines) on the leaf margins. These make the leaves feel rough and "grabby" when rubbed by hand or walked through. These spinules are visible in larger plants with minimal magnification. Similar to the leaf margins, the leaf sheaths are also rough. As plants develop, stems tend to sprawl across the ground and have the ability to root from the stem nodes.

Look Alikes: The wide and flat leaves, together with the roughness of leaf margins and leaf sheaths of rice cutgrass, make it relatively easy to distinguish from other wetland grasses.

Adult Plant

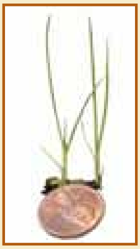
River Bulrush

Schoenoplectus fluviatilis

Seed

Carole Ritchie – USDA-NRCS

Seedling



Seedlings

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 4

Flowers: June-July

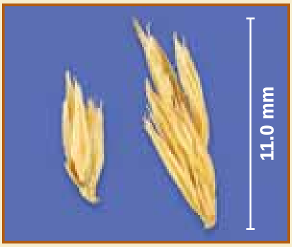
Seedling Description: Plants are relatively slow-developing, as seedlings may take three years to reach flowering. Leaves of seedlings are held stiffly upward at about 45 to 60 degree angles. The m-shaped leaf cross section and sharply triangular stem become evident as the seedlings mature.

Look Alikes: Several sedge species and dark green bulrush have leaves with m-shaped cross sections and may be confused with river bulrush. However, river bulrush is typically taller and more tolerant of growing in standing water, forming many-stemmed mats. Dark green bulrush leaves are up to 8 mm wide, while river bulrush leaves may reach 16 mm in width.

Inflorescence

Sideoats Grama

Bouteloua curtipendula



Steve Hurst – USDA-NRCS

Seed


Iowa DNR

Seedling

Habitat: Upland

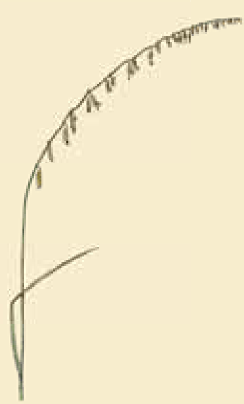
R3 Indicator Status: UPL

MN C-Value: None Assigned

Flowers: June-July

Seedling Description: Sideoats has fine, light green leaves as small as 2 mm wide in young plants, but up to 7 mm wide in plants reaching reproductive maturity. Leaves have stiff hairs 5-8 mm long that protrude distinctively outward from leaf margins, each having a very small bulbous structure at the base that is visible through a hand lens. Leaves are long, form graceful arches from the stem, and gradually taper to a very fine tip. Ligule is short (usually less than 0.5mm), with a fringe of hairs. New leaves are rolled as they emerge from the stem.

Look Alikes: Sideoats has stiff hairs that protrude distinctively outward from leaf margins, making it one of the easier native grasses to identify as a seedling. Indian grass and big bluestem seedlings can be confused with sideoats, although individual hairs on these plants tend to be thinner and the plants more hairy overall. Big bluestem, Indian grass and switchgrass all have stronger midribs on the leaves, and are perhaps most easily confused with sideoats.



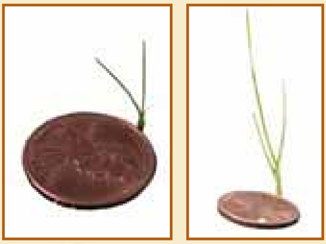
Inflorescence

Softstem Bulrush

Schoenoplectus tabernaemontani

Science Museum of Minnesota

Seed



Seedling

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 4

Flowers: June-July

Seedling Description: Small seedlings are similar to other rushes. As softstem bulrush seedlings mature, successive leaves originate from the base of the plant and are round in cross-section. The chambered stems are easily crushed between thumb and forefinger.

Look Alikes: Small seedlings are similar in appearance to and difficult to distinguish from other rushes. Hardstem bulrush has a stem that is more difficult to crush between thumb and forefinger than softstem bulrush. River and three-square bulrush have triangular stems. Woolgrass and dark green bulrush develop a large number of basal leaves. Other rushes such as Torrey’s and Canada rush are shorter in stature, seldom exceeding two feet.

Adult Plant

Panicum virgatum

Switch Grass

Seed

Steve Hurst – USDA-NRCS

Seedlings

Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 2

Flowers: June-July

Seedling Description: Switchgrass seedlings are stiffly upright. Seedling leaf widths generally range from 3-5 mm, with mature plants having leaves 5-15 mm wide. As seedlings grow, they develop a triangular patch of hairs at the base of each leaf, and a densely hairy ligule.

Look Alikes: Switchgrass is perhaps most easily confused with big bluestem, Indian grass, and sideoats. Unlike switchgrass, big bluestem and Indian grass have an obvious ligule. Big bluestem seedlings typically have hairs extending well up the leaf blade, while switchgrass has a triangular patch of hairs at the base of each leaf. Sideoats has stiff hairs that protrude distinctively outward from leaf margins. Indian grass seedlings are sometimes difficult to discern from big bluestem, but develop a stouter, keeled midrib on each leaf. The round stem of switch-grass contrasts with the flattened stem of little bluestem.

Inflorescence

Tussock Sedge

Carex stricta

Seed

Steve Hurst – USDA-NRCS


Seedling

Habitat: Wetland

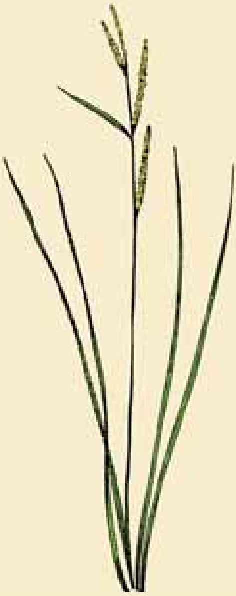
R3 Indicator Status: OBL

MN C-Value: 5

Flowers: June

Seedling Description: The characteristic m-shaped cross section becomes more evident in leaves as the plant matures, as do the teeth on the leaf margins. As seedlings become more developed, stem bases develop ladder-like (fibrillose) fibers caused by splitting of the leafy sheaths. Leaf width increases along with plant size, eventually reaching 3-8 mm. Stems tend to be stiff and upright, and sometimes develop a bluish-green color as plants mature.

Look Alikes: Other sedges common to restoration plantings tend to have wider leaves and/or less upright stems. Lakebank sedge also has stiff, upright growth character and is bunch forming, but has wider leaves and feather-like fibers at leaf bases rather than ladder-like fibers.


Adult Plant

Virginia Wildrye

Steve Hurst – USDA-NRCS

Seed

Seedling

Habitat: Edge

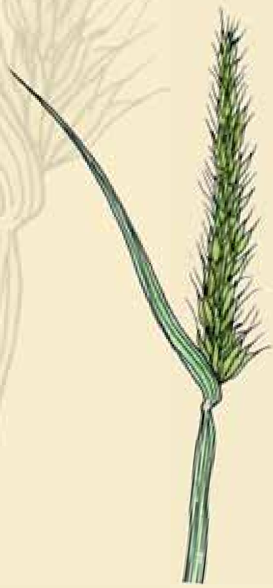
R3 Indicator Status: FACW

MN C-Value: 4

Flowers: June-July

Seedling Description: Leaves of young plants are about 4 mm wide, reaching 10 mm as the plant matures. Both the upper and lower leaf surfaces are somewhat rough to the touch. This species shows substantial variation in physical characteristics across its geographic range. Stems have reddish color at base.

Look Alikes: Canada wildrye is similar, however, its leaves are not rough on both sides. Canada wildrye may only have one, or no rough leaf surfaces. The auricles of Canada wildrye are generally larger than those of Virginia wildrye, and may clasp the stem.



Inflorescence

Woolgrass

Scirpus cyperinus

Seed


Science Museum of Minnesota

Seedlings


Seedlings

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 3

Flowers: June-July

Seedling Description: Woolgrass seedlings are difficult to identify when small. As seedlings develop, they form basal rosettes of leaves that are v-shaped in cross section. Woolgrass tends to germinate well, but develops slowly and may take three years to reach flowering. Leaf sheaths are brownish or green.

Look Alikes: Dark green bulrush forms similar-looking basal rosettes, but its leaves have an m-shaped cross section compared to the v-shaped cross section of woolgrass leaves.


Adult Plant

Forbs

American Vetch

Vicia americana

Seed

Seedling

Habitat: Edge/Upland

R3 Indicator Status: NI

MN C-Value: None Assigned

Flowers: May-July

Seedling Description: First true leaf of seedlings is typically a single leaflet, the next few leaves that form have two leaflets. Leaves continue to gain an increasing number of leaflets per leaf on a smooth, zigzag stem until reaching 8-16 leaflets per leaf as the plant matures. The rachis of leaves on mature plants terminates with tendrils that grab adjacent features and plants for support. Leaf stipules are sharply serrate.

Look Alikes: American vetch has a relatively unique leaf shape compared to other commonly planted native flowers. It is perhaps most easily confused with nonnative vetches sometimes included in conservation and roadside plantings, especially hairy vetch *V. villosa*.

Adult Plant

Black-Eyed Susan

Rudbeckia hirta

Seed

Science Museum of Minnesota

Seedling

Seedlings

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 3

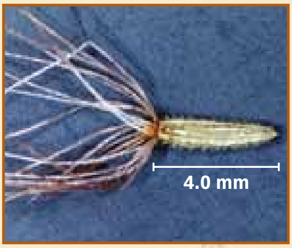
Flowers: June-July

Seedling Description: The first true leaves are about 2 cm long and have a rounded elliptical shape. Leaves have readily visible white hairs concentrated on the outer third of the leaf blade, along the outer leaf margin, and on the stem of the youngest leaves. These hairs cover the entire surface of later leaves. Leaves form a basal rosette and lack teeth. A prominent mid-vein develops, as well as two other obvious veins that follow the leaf margin and recurve toward the rounded or sharp leaf tip.

Look Alikes: Because it grows so rapidly, black-eyed susan is usually quite conspicuous within a few months of planting. Pale purple coneflower has stiff, sandpapery leaves that are held upright compared to the low, soft, spreading leaves of black-eyed susan. Wild quinine forms a basal rosette of more rigid leaves and matures much more slowly than black-eyed susan.

Adult Plant

Liatris pycnostachya



Science Museum of Minnesota

Seed

Iowa DNR

Seedling

Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 7

Flowers: June-August

Seedling Description: Seed leaves and the first true leaf have the appearance of a sword. Leaves are narrow and long, and often appear slightly bent along the flat axis of the leaf. Leaves may have a slightly wavy edge. The distinctive central vein often has a pale appearance. Successive leaves emerge from ground level or below and develop into a basal rosette of flat, thinly fleshy leaves. The first few true leaves of young prairie blazingstar *L. pycnostachya* are about 1.5-2 mm wide, while leaves of rough blazingstar *L. aspera* and meadow blazingstar *L. ligulistylis* seedlings are wider (3-5 mm). Leaves of seedling marsh blazingstar *L. spicata* often exceed 5 mm in width.

Look Alikes: Blueflag iris is much more robust, with new leaves that emerge in the fold of previous leaves. Perhaps the greatest problem in identifying blazingstar seedlings is spotting them at all, as they tend to be very inconspicuous.

Adult Plant

Blueflag Iris

Steve Hurst – USDA-NRCS

Seed


Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: OBL

MN C-Value: 5/4

Flowers: May-June

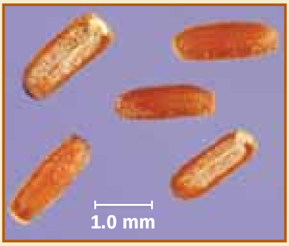
Seedling Description: Sword-like leaves develop from a flattened stem base, with each new leaf becoming successively longer. In cross-section, each leaf is somewhat swollen at the center and folded at the midrib, forming a slot from which later leaves emerge. The leaf margin appears somewhat translucent. Seed hull remains attached to the seedling through development of at least the first few true leaves and may be visible above ground.

Look Alikes: Blueflag iris is most readily confused with wet meadow/ wetland species such as cattail Typha spp., which has a round stem base; and sweetflag Acorus calamus which has a similar leaf, but is not folded over at the midrib. Sweetflag also has a prominent, citrus-like aroma. Blazingstar species have a similar leaf shape, but seedlings are smaller and new leaves do not emerge from the fold of previous leaves.

Adult Plant

Blue Vervain

Verbena hastata



Seed

Steve Hurst – USDA-NRCS

Seedlings

Seedling

Habitat: Edge

R3 Indicator Status: FACW

MN C-Value: 6

Flowers: July-August

Seedling Description: Seedlings have hairy, narrowly oblong leaves held opposite each other. Even small seedlings have sharp, forward-pointing teeth. As the plant continues to develop, the square stem becomes more evident.

Look Alikes: May be confused with spotted joe-pye weed when young. As seedlings mature, joe-pye weed develops whorls of 4-5 leaves on a round stem, while blue vervain has leaves opposite each other on a square stem. Blue vervain seedlings could also be confused with the nonnative weed, stinging nettle, which has stiff, long hairs and a much more angular square stem. Stinging nettle also has the undesirable quality of causing itching, thanks to a liquid injected into the skin through plant hairs if brushed up against too hard.

Adult Plant

Boneset

Eupatorium perfoliatum

Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Seedlings

Habitat: Wetland/Edge

R3 Indicator Status: FACW

MN C-Value: 4

Flowers: July-October

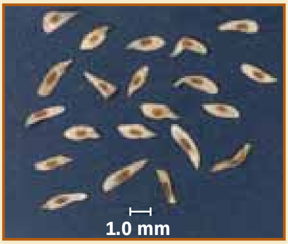
Seedling Description: Seedling leaves are round in shape with stems as long as the leaves. The first true leaves develop with a few rounded teeth. Successive leaves have an increasing number of teeth and become coarsely hairy. As the plant matures, leaves form opposite and grow together (perfoliate) around the hairy stem.

Look Alikes: Boneset seedlings may be confused with spotted joe-pye weed, which is less hairy and develops whorls of 4-5 leaves around the stem rather than two leaves opposite on the stem fusing together. Blue vervain has opposite, somewhat hairy leaves with stems (rather than clasping each other and the stem).

Adult Plant

Bottle Gentian

Gentiana andrewsii



Science Museum of Minnesota

Seed **Seedling**

Habitat: Edge

R3 Indicator Status: FACW

MN C-Value: 6

Flowers: August-October

Seedling Description: Bottle gentian seedlings develop slowly and tend to be susceptible to damping off, a condition where seedling stems are attacked near the soil surface by one of several pathogens. Seedlings form basal rosettes of fleshy green and shiny leaves. Leaves of the youngest plants are nearly round and crowd each other in a tight rosette. As the plant matures, leaves become more elongate with a sharper point and a stronger mid-vein. Leaves have a slight upward fold. Seeing the small and slowly developing seedlings is often the greater challenge in identification.

Look Alikes: The waxy, thinly fleshy feel and shiny appearance of the leaves of bottle gentian make it fairly easy to distinguish from other plants. Cream gentian may be confused with bottle gentian, but generally occupies upland prairie, savanna, and woodland habitats in our region. Cardinal flower and great blue lobelia also have waxy, fleshy leaves that form basal rosettes, but have teeth and tend to develop faster than bottle gentian.

Adult Plant

Sparganium eurycarpum

Steve Hurst – USDA-NRCS

Seed

Seedling

Seedling

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 5

Flowers: June-July

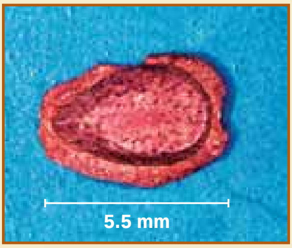
Seedling Description: Seedlings develop quickly after germination in most circumstances. Plants are fleshy, with a main stem and arching leaves when small. As the seedlings mature, they develop linear, bright-green leaves that are strongly keeled. Leaves of the mature plant are triangular with flat edges in cross-section.

Look Alikes: Seedlings of bur reed may be confused with other emergent plants when small. Identification becomes easier when the leaves take on their characteristic triangular cross-section shape. More mature plants may be confused with sweet flag, although in cross-section, bur-reed leaves are flattened triangular, while those of sweet flag are flattened diamond-shaped. Sweet flag foliage is also highly aromatic.

Adult Plant

Butterfly Milkweed

Asclepias tuberosa



Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: None assigned

Flowers: June-August

Seedling Description: Butterfly milkweed has oblong seed leaves with long stems. True leaves are bluntly rounded at the tip, about 4-5 times as long as they are wide, and opposite one another on the seedling stem with leaf pairs perpendicularly offset. Plants develop coarse hairs on the stem and leaves, as well as longer leaves with a triangular to somewhat heart-shaped base that clasps the stem as the plant matures.

Look Alikes: Butterfly milkweed has distinctive seedling leaves, with long leaf stems and oblong leaf shape. Other upland milkweed species such as common and Sullivant's milkweed have narrower, longer leaves as seedlings that are sharply pointed and sometimes 8-10 times as long as they are wide. Unlike other milkweed species, butterfly milkweed does not develop a milky, latex sap.

Adult Plant

Anemone canadensis

Science Museum of Minnesota

Seed


Alexis Knispel- University of Manitoba

Seedling

Habitat: Wetland/Edge/Upland

R3 Indicator Status: FACW

MN C-Value: 3

Flowers: May-July

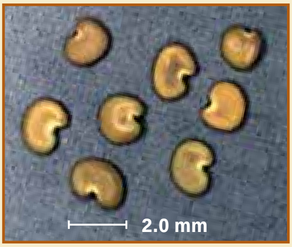
Seedling Description: Seedling leaves are oval to elliptic in shape and held close to the ground. The first true leaves have rounded bases with a general shape similar to a red maple or grape leaf. Leaf veins (3 – 5) radiate out from a central point near the base of the leaf. As the plant grows, successive leaves develop 3-5 prominent lobes with coarse teeth. Although difficult to see without magnification, leaves have fine hairs on both top and bottom surfaces. As seedlings mature, Canada anemone begins spreading by rhizomes. Depending on the amount of available root space and competitiveness of surrounding plants, Canada anemone may form a compact mat or with stems more widely spaced.

Look Alikes: Canada anemone seedlings look much like those of its upland cousins, tall anemone *A. virginiana* and long-headed thimbleweed *A. cylindrica*. Neither tall anemone nor thimbleweed is tolerant of standing water or saturated soils.

Adult Plant

Canada Milkvetch

Astragalus canadensis



Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: FAC

MN C-Value: 5

Flowers: June-July

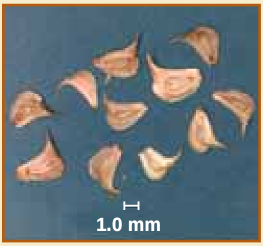
Seedling Description: Canada milkvetch seedlings are smooth and develop a fleshy and striated stem. The first few true leaves usually only have one leaflet; then develop three, five, and eventually 15-35 leaflet pairs per leaf. The first leaflets are nearly round, while later leaves become more narrow and oblong, with stipules at the base of each leaf stem. Leaflets are folded upward along the midrib. Leaflet margins seen through a hand lens reveal long, cream-colored hairs that lie flat and point toward the leaflet tip.

Look Alikes: Illinois bundleflower has very small (1.5-3 mm), narrow leaflets that occur on a twice pinnately compound stem, giving it a fern-like appearance. Partridge pea has more leaflets, develops more quickly, and is somewhat reactive to touch (folds up). The invasive nonnative crown vetch is easily confused with Canada milkvetch when young. Canada milkvetch may form multiple but upright stems, while crown vetch quickly begins to develop recumbent stems that form a clonal patch.

Adult Plant

Common Arrowhead

Sagittaria latifolia



Science Museum of Minnesota

Seed

Seedling

Seedling

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 3

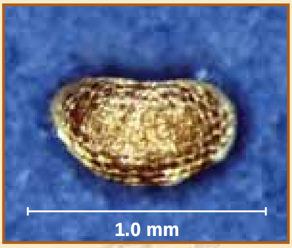
Flowers: June-August

Seedling Description: Seedlings generally germinate and begin development in saturated soil conditions to a few inches of water. The first leaves of arrowhead seedlings are narrow with nearly parallel sides, tapering to a blunt point. After the first three or four true leaves, the plant begin forming what looks like a rosette of splayed out triangular-shaped leaves, seedlings become increasingly easier to identify. Typical arrowhead leaf shape develops later.

Look Alikes: The basal whorl of triangular-shaped leaves is relatively characteristic for seedlings. As plants develop further, the arrowhead leaf shape makes positive identification easy. Water plantain develops very narrow, linear leaves. Pickerel plant leaves are triangular, with a pointed (rather than blunt) tip.

Adult Plant

Veronicastrum virginicum



Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 6

Flowers: June-July

Seedling Description: Plants develop slowly, sometimes taking several years to reach the point where they can flower. Young plants have narrowly elliptic, finely to sharply toothed leaves that are opposite one another on an often dark-colored, hairy stem. As plants continue to develop, new leaf sets are in whorls of 3 at first, and eventually 5-6. Leaves are hairy or smooth underneath.

Look Alikes: Culver's root is perhaps most easily confused with hoary vervain as a seedling, the latter being more coarsely toothed (and not toothed all the way to the leaf base).
Butterfly milkweed has a similarly hairy stem, but lacks teeth on the leaves. After Culver's root plants begin forming whorls of leaves, they are easier to distinguish from other prairie seedlings.

Adult Plant

Silphium perfoliatum

Steve Hurst – USDA-NRCS

Seed

Iowa DNR

Seedling

Habitat: Edge

R3 Indicator Status: FACW

MN C-Value: 4

Flowers: June-August

Seedling Description: Coarse leaves have stiff, short hairs and a relatively short, winged leaf stem. Early leaves are somewhat round in a basal rosette. Later leaves develop a more prominent point, are opposite on the stem, and eventually clasp each other across the stem (forming the distinctive cup).

Look Alikes: Cup plant seedlings are perhaps most easily confused with those of wild goldenglow *Rudbeckia laciniata*, which develops deep lobes after getting a few (smooth or fuzzy) true leaves. Cup plant has thicker, more rigid and coarse leaves.

Adult Plant

False Aster

Boltonia asteroides

Science Museum of Minnesota

Seed

Seedling

Habitat: Upland

R3 Indicator Status: FACW

MN C-Value: 4

Flowers: July-October

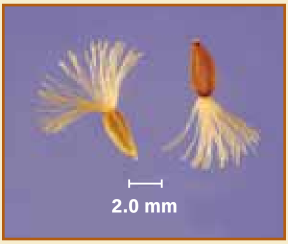
Seedling Description: Seedling leaves are oval to rounded, with the first true leaves forming a fountain-like basal rosette of diamond-shaped leaves with rounded edges. As the plant matures, leaves become more lance-shaped and narrow, appearing stalkless to slightly clasping on the stem. The leaf margins are rough to the touch. Stems are smooth and stout. As the plant develops and flowers, it has a shrubby, crowded appearance with a remarkable number of blooms.

Look Alikes: Several aster species common to wetland edges are similar as seedlings, and difficult to distinguish from false aster. Look for the smooth stems and characteristic leaf shape of false aster as seedlings develop.

Adult Plant

Flat-topped Aster

Doellingeria umbellatus



Tracey Slotta – USDA-NRCS

Seed | Seedling | Seedlings

Habitat: Wetland/Edge

R3 Indicator Status: FACW

MN C-Value: 5

Flowers: July-September

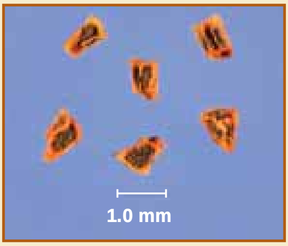
Seedling Description: Even as small seedlings, flat-topped aster leaves have the open, net-like vein pattern on leaves also found in more mature plants. Seedlings have stems and leaves with short, but dense hairs (mostly at the outer edges). Lance-shaped leaves develop alternately along the stem.

Look Alikes: Spotted joe-pye weed, boneset, and blue vervain have opposite leaf arrangement on the stem. Red-stemmed aster develops clasping leaves. The hairy stem and outer leaf edges combined with the alternate leaf arrangement help distinguish flat-topped aster from other wetland asters

Adult Plant

Foxglove Beardtongue

Penstemon digitalis



Steve Hurst – USDA-NRCS

Seed

Seedling

Habitat: Upland

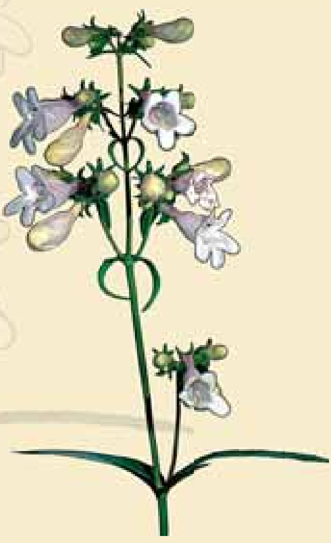
R3 Indicator Status: FAC

MN C-Value: None assigned

Flowers: May-July

Seedling Description: The first leaves are born in clusters (6-8 leaves in young seedlings) that form a basal rosette. Seedlings have oval- to elliptic-shaped leaves about 2 cm wide and 4 cm long. Leaves taper to a narrow point where the leaf attaches to the leaf stalk. Leaves are opposite on the stem. Seedlings are very smooth and waxy to the touch, with leaf margins that lack teeth. A depressed, whitish-colored midvein is often visible. Leaves typically turn a burgundy to rich red-brown color in fall.

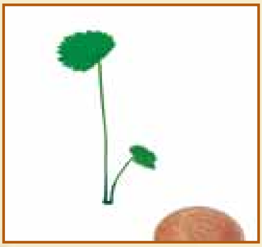
Look Alikes: Smooth blue aster and large-flowered beardtongue have fleshy light green leaves with a waxy cast. Smooth blue aster leaves are alternate on the stem. Large-flowered beardtongue leaves are shorter and more rounded.



Infloresence

Seed

Science Museum of Minnesota



Seedling

Iowa DNR

Seedling

Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 6

Flowers: May-June

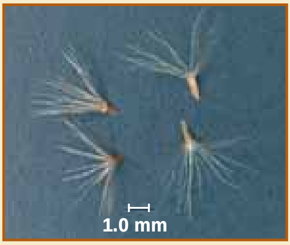
Seedling Description: Seed leaves are short and ribbon-like with sharp points. The first true leaves are round with sharp to somewhat rounded, shallow teeth along a slightly irregular leaf edge. Subsequent leaves progress to having deeper lobes until 3 deep lobes appear on each leaf. Juvenile and adult plants eventually have leaflet stems and 1-3 sets of 3 leaflets per leaf. Leaves are smooth.

Look Alikes: Leaves of alumroot seedlings have a similar appearance, but are finely hairy and deeply toothed. Prairie cinquefoil seedlings have coarse and sharp teeth. Both alumroot and cinquefoil have veins that radiate from one spot at the base of the leaf when plants are young. However, cinquefoil seedlings lose this characteristic after a few true leaves are formed, and develop readily visible brownish hairs on the stem. This species can also be confused with heartleaf alexander *Zizia aptera*.

Adult Plant

Grass-Leaved Goldenrod

Euthamia graminifolia



Science Museum of Minnesota

Seed

Seedlings

Habitat: Edge/Upland

R3 Indicator Status: FACW

MN C-Value: 4

Flowers: June-September

Seedling Description: Leaves of seedlings have a grainy and rubber-like appearance and lack hairs. As seedlings continue to develop, leaves become more linear and grass-like with three veins visible without magnification. As plants mature, they spread by rhizomes. A single plant can occupy a large area with many stems.

Look Alikes: Lanceleaf aster and Riddell's goldenrod have smooth, nearly linear leaves, but widen near the end. Some upland asters also have linear leaves, but typically do not occur in the same habitat as grass-leaved goldenrod.

Adult Plant

Lobelia siphilitica

Seed

Seedling

Habitat: Wetland/Edge

R3 Indicator Status: FACW

MN C-Value: 5

Flowers: June-August

Seedling Description: Leaves form a basal rosette of thinly fleshy, green to purple-red leaves that are easily crushed. Leaf margins are wavy-toothed. The short, wide, leaf stem tapers from the base of the leaf. Because there are two varieties of this species in the Upper Midwest, leaves may have fine hairs or be smooth.

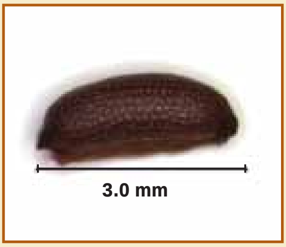
Look Alikes: Great blue lobelia may be confused with ragworts *Senecio spp.*, which have flat leaf bases and narrow, unwinged leaf stems. Culver's root leaves can look similar, but have sharply toothed margins on the outer half of the leaf and do not form basal rosettes. Alumroot is palmately veined, with leaf veins radiating out from one spot at the leaf base. Cardinal flower has a similar leaf shape when young. Cardinal flower leaves tend to be thicker and waxier.

Adult Plant

Great Blue Lobelia

Great St. Johnswort

Hypericum ascyron



Seed

Science Museum of Minnesota

Seedling

Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 6

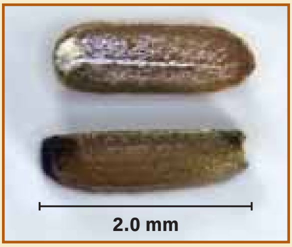
Flowers: June-September

Seedling Description: Leaves of seedlings are oppositely arranged and are elliptic in shape. As seedlings mature, leaves reach about 4 cm in length. Leaves lack teeth and are attached directly to the stem. Lacking a leaf stalk, leaves sometimes clasp the stem. Stems are yellow-green and smooth. Leaves are darker yellow-green than leaf midveins, lateral veins, and stem. Leaves tend to turn yellow- to orange-brown color in fall.

Look Alikes: Riddell's goldenrod and panicled aster have more linear leaves, held opposite on stems. Monkeyflower and obedient plant leaves have teeth.

Adult Plant

Hoary Vervain



Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: None asssigned

Flowers: June-July

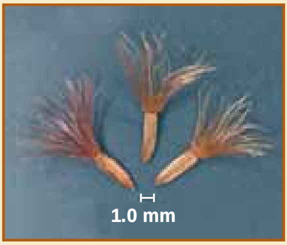
Seedling Description:
Seedlings develop leaves on opposite sides of the stem. The leaf shape is variable and rounded to elliptic with sharp, crowded teeth of various sizes on the outer two thirds of the leaf. Plants are hairy, with the leaf bottoms being more densely hairy than the upper surface.

Look Alikes: Culver’s root is similar, but has finer, more evenly sized small teeth to the leaf base, narrower leaves, and eventually develops whorled sets of 3-6 leaves.

Adult Plant

Ironweed

Vernonia fasciculata



Science Museum of Minnesota

Seed

Seedling

Habitat: Wetland/Edge

R3 Indicator Status: FACW

MN C-Value: 5

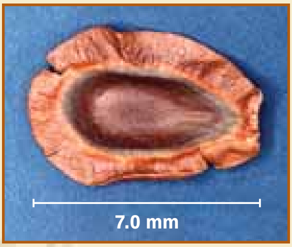
Flowers: July-August

Seedling Description: Seedling leaves are spatula-shaped. The first true leaves are elliptic in shape with a prominent light green to whitish mid-vein and several lateral veins extending periodically outward. Leaves have slightly in-rolled leaf margins and shallow, forward-pointing teeth that are at times difficult to notice. As seedlings mature, leaves become increasingly longer than wide with coarsely saw-toothed leaves. The midvein on the underside of the leaf also becomes more prominent as the plant matures.

Look Alikes: Seedlings of ironweed are fairly easy to confuse with other members of the composite family, including goldenrods and asters. Positive identification becomes easier as seedlings mature and the characteristics mentioned above become more prominent.

Adult Plant

Asclepias incarnata



Seed

Seedling

Habitat: Wetland/Edge

R3 Indicator Status: OBL

MN C-Value: 4

Flowers: July-September

Seedling Description: Seed leaves are oblong with long stems. Often appearing crowded on the plant, true leaves are lanceolate in shape with short leaf stems Leaves on seedlings vary from softly fuzzy to smooth. Seedlings develop a milky sap just a few weeks after germination, about the time they are approximately 10 cm tall.

Look Alikes: Common milkweed has a somewhat similar leaf shape and can be distinguished from marsh milkweed by the more oblong rather than lanceolate leaf of marsh milkweed, which is wider at the base and narrows to a sharper point.

Adult Plant

Monkey Flower

Mimulus ringens

Seed

Science Museum of Minnesota

Seedlings

Seedlings

Habitat: Wetland/Edge

R3 Indicator Status: OBL

MN C-Value: 5

Flowers: June-September

Seedling Description: Seedlings are slow to develop and may take three years to flower from seed. Seedlings are also very small, making them difficult to spot. Smooth leaves become lance-shaped to somewhat linear with sharp, forward-pointing teeth. Leave bases clasp the square stem, which is sometimes winged.

Look Alikes: May be confused with turtlehead, and skullcaps *Scutellaria spp*., some species of which have similar leaves. Spotted joe-pye weed and blue vervain have hairy leaves. Obedient plant has smooth leaves with teeth, but its leaves are longer and narrower than those of monkey flower.

Adult Plant

Symphyotrichum novae-angliae

Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Habitat: Edge/Upland

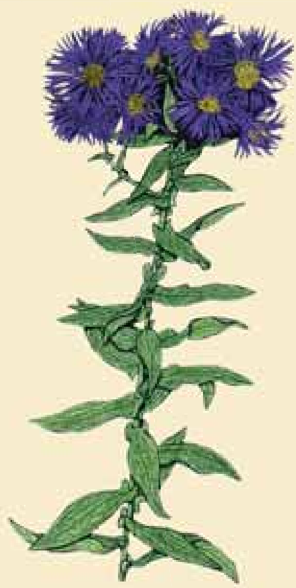
R3 Indicator Status: FACW

MN C-Value: 3

Flowers: September-November

Seedling Description: Seedlings of New England aster develop characteristics of adult plants early. They lose seedling leaves rather quickly. True leaves and stems on seedlings are similar to those of adults, having stiff hairs on leaf undersides and margins. Toothless lanceolate to spoon-shaped leaves vary somewhat in shape with blunt leaf tips and wide leaf bases that clasp the stem as the plant develops.

Look Alikes: Heath aster looks similar as a seedling, but develops linear leaves compared to the clasping leaves of New England aster. New England aster can also be easily confused with red-stemmed aster, *A. puniceus*, a wet meadow species with similar characteristics. It is relatively common in wetland plantings. It develops pointed leaves that often have shallow, distantly spaced teeth.



Adult Plant

Obedient Plant

Physostegia virginiana

Seed

Science Museum of Minnesota

Seedling

Juvenile

Habitat: Edge

R3 Indicator Status: FACW

MN C-Value: 6

Flowers: June-September

Seedling Description: Seedling leaves are oblong in shape. True leaves develop in a basal rosette with successive leaves increasing in size. Basal leaves eventually reach a proportion of having leaf blades about 4-5 times as long as wide, with leaf stems nearly equal to the blade length. Leaves have a spongy appearance when viewed up close, and are even more so when viewed with a hand lens. Leaf midveins may be light green to reddish. Seedling leaf margins may be smooth or with fine, shallow teeth.

Look Alikes: The fleshy leaves have a spongy appearance, red-tinged mid-veins, and habit of forming a basal rosette causing Obedient plant to have an appearance similar to the nonnative weed curly dock. Curly dock generally grows in upland settings (performing poorly in wet, saturated soils), and the leaves lack teeth.

Adult Plant

Oxeye False Sunflower

Heliopsis helianthoides

Science Museum of Minnesota

Seed

Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: None assigned

Flowers: June-August

Seedling Description: This plant shows substantial variation in leaf shape across its geographic range. Small plants have ovate to rounded diamond-shaped leaves that may be sharply or bluntly toothed, tapering to a slightly winged stem at the leaf base. Leaves are opposite one another on the stem, have impressed veins, and may be smooth to slightly rough to the touch. New leaves tend to have a somewhat puckered appearance, similar to seersucker fabric.

Look Alikes: Can be confused with bergamot when small, however bergamot has a deeper blue-green color and a minty smell when rubbed. Maximillian sunflower has leaves that are narrower, longer, somewhat folded along the mid-vein, have shorter leaf stalks, and are more reliably sharply, but shallowly toothed.

Adult Plant

Panicled Aster

Symphyotrichum lanceolatum

Science Museum of Minnesota

Seed

Seedling

Habitat: Edge

R3 Indicator Status: FACW

MN C-Value: 5

Flowers: July-November

Seedling Description: Seedlings have oval-shaped leaves with sharp teeth on the outer edge. As seedlings continue to grow, leaves become more elongate in a basal rosette, with sharp teeth concentrated at the outer edge. Leaves are smooth, with exception of tiny hairs along the midvein. As plants mature, branching occurs from points where leaves meet the stem. Leaves do not typically clasp the stem.

Look Alikes: Red-stemmed aster looks similar as a seedling, but has stiff, readily visible hairs concentrated along the leaf stalks and leaves that clasp the stem in mature plants. Panicled aster is perhaps most easily confused with calico aster which is similar in appearance, and more variable in hairiness.

Adult Plant

Chamaecrista fasciculata

Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: FACU-

MN C-Value: 2

Flowers: June-July

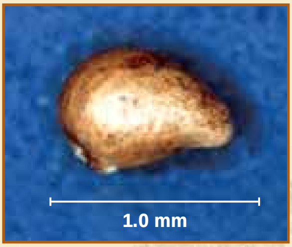
Seedling Description: The seedling leaves of partridge pea are bluntly pyramidal. The first few sets of true leaves have 5 pairs of leaflets, progressing to as many as 18 pairs of leaflets in mature plants. Leaves have no terminal leaflet. As plants grow, they develop a small gland (nectary) on the leaf stem, which appears as a small, green, globular structure about the same width as the leaf stem. Plants have dark green leaves with light green veins, leaf(let) stems, and plant stems. Leaflets fold together each night.

Look Alikes: The lack of a terminal leaflet and presence of a gland on the leaf stem can cause this plant to be confused with senna species Senna marilandica and S. herbecarpa, as well as Illinois bundleflower Desmanthus illinoiensis when young. Senna has fewer but much larger leaflets, and plants are much larger (up to 6 feet tall). Illinois bundleflower has 8-24 leaflets that are generally smaller than those of partridge pea. Leadplant and milkvetch species have terminal leaflets.

Adult Plant

Prairie Cinquefoil

Potentilla arguta



Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 8

Flowers: June-July

Seedling Description: Leaves of seedlings form a basal rosette. Initially, with a few deep, sharp teeth at the end of each leaf, but subsequent leaves have deep teeth that eventually extend around the entire margin of the leaf. Leaf stems have brownish hairs. As the plant matures, the number of leaflets increases to 3 not-so-deeply toothed leaves; and then eventually to 7-11 elliptic, shallowly toothed leaflets. Leaf undersides often appear red-brown in young plants.

Look Alikes: Leaves of alumroot seedlings have a similar appearance, but are not as deeply toothed. Both have veins that radiate from one spot at the base of the leaf when young. However, cinquefoil seedlings lose this characteristic after a few true leaves are formed. Golden alexanders have shallowly toothed and smooth leaves. There are a number of other cinquefoil species (as well as wild strawberry) that look similar to immature prairie cinquefoil, but lack the light brown hairs.

Adult Plant

Science Museum of Minnesota

Seed

Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: None assigned

Flowers: June-August

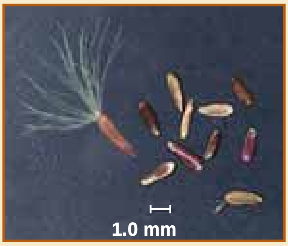
Seedling Description: Seedlings quickly develop leaves with 3 leaflets that look very similar to those of mature plants. As the plant matures, the number of leaflets increase and range from 3 to 7, with 5 leaflets being most common. Young plants often have wispy stems and may have leaflets about half the size of adult plants (5-10 mm). Plants may be smooth or appear very finely hairy when viewed through a hand lens.

Look Alikes: White prairie clover is similar, but quickly develops broader leaves with pointed tips. White prairie clover also has more leaflets per leaf after the third or fourth set of true leaves develop. White prairie clover leaflets range from 5-9, with 7 being the most common.

Adult Plant

Red-Stemmed Aster

Symphyotrichum puniceum



Science Museum of Minnesota

Seed — Seedlings — Seedling

Habitat: Wetland/Edge

R3 Indicator Status: OBL

MN C-Value: 6

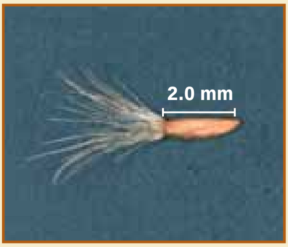
Flowers: July-September

Seedling Description: Seedlings have leaves with coarse, stiff, whitish hairs, especially toward the outer edges of leaves and on the stems – a characteristic carried through to adult plants. Seedlings may have reddish leaf margins. Leaf stems are wide and become lobed at the base (clasping the stem) as the plants mature.

Look Alikes: Leaves of red-stemmed aster are similar to New England aster, which has a more crowded appearance to leaves and typically green stems. Red-stemmed aster is tolerant of wetter soils than New England aster.

Adult Plant

Oligoneuron riddellii



Science Museum of Minnesota

Seed

Seedling

Habitat: Wetland/Edge

R3 Indicator Status: OBL

MN C-Value: 8

Flowers: July-September

Seedling Description: Seedlings have leaves that are at first elliptic in shape. As the plants mature, the smooth and waxy-feeling leaves become increasingly linear with a pointed tip, and folded along the midrib. When viewed from the side, leaves appear sickle-shaped. New leaves emerge rolled. Leaves have a prominent mid-vein that is light green in color with a secondary set of smaller veins that appear almost net-like. These net-like veins become less evident as the plant matures. Foliage tends to turn burgundy to bright red in the fall. Upper leaves are stalkless and clasp the stem. Riddell's goldenrod has a flat-topped flowering head with a pubescent inflorescence.

Look Alikes: Several species of aster (flat-topped) and false aster are similar to Riddell's goldenrod. The smooth, linear leaves of Riddell's goldenrod help distinguish it from similar species, particularly as seedlings become more developed. Panicled aster is perhaps the easiest to confuse, but is not commonly used in wetland restoration seed mixes.

Adult Plant

Round-headed Bushclover

Lespedeza capitata

Science Museum of Minnesota

Seed

Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: FACU

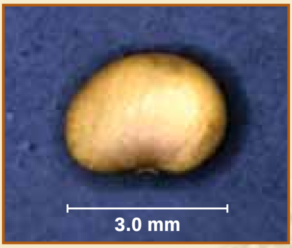
MN C-Value: 3

Flowers: June-August

Seedling Description: The first true leaf that develops has a single leaflet and is round in shape. Subsequent sets of leaves have 3 leaflets that are usually elliptic in shape, but can be variable. Leaves and stems have fine hairs that lie down on the plant, giving it a silvery-whitish cast, especially on the main stem and along leaf margins.

Look Alikes: White prairie clover and leadplant seedlings have a similar appearance when young. As they grow, white prairie clover and leadplant become more easily distinguished as they have more leaflets (5-9 or more for leadplant). White prairie clover also has smooth stems and leaves.

Adult Plant



Seed

Science Museum of Minnesota

Seedling

Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: FAC

MN C-Value: 4

Flowers: June-August

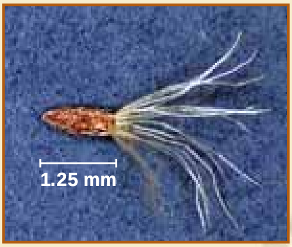
Seedling Description: The seed leaves are robust and persist on the stem past development of the third or fourth true leaf. Seedling stems vary from green to straw colored, are wiry, and often zigzag. The first true leaves have a single leaflet, vary from round to bluntly pointed on the end, and have a rough feeling. Later leaves become more elliptic in shape and are characteristic of the 3-parted leaf of showy tick trefoil.

Look Alikes: Other species of this genus have a similar appearance when they are seedlings. Velvetleaf weed seedlings can also have a similar appearance. However, they have toothed leaf margins, thick stems, develop very quickly, and have a thicker, softer feel to the leaves.

Adult Plant

Sky Blue Aster

Symphyotrichum oolentangiense



Science Museum of Minnesota

Seed

Seedling

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: None assigned

Flowers: July-September

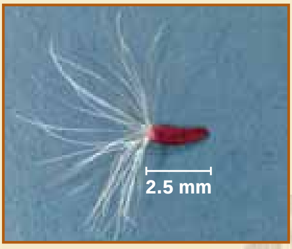
Seedling Description: Seedlings form a basal rosette of heart-shaped leaves. Leaf margins may be smooth or have sharp teeth. Stiff hairs are prominent on the leaf margins and stem. The leaves of young plants have a thin, rough feel. Rosette leaves of young sky blue aster seedlings are approximately 2 cm wide by 3 cm long.

Look Alikes: Seedlings that could be commonly confused with those of sky blue aster include smooth blue aster, which feels fleshy, has few hairs, and lacks a heart-shaped leaf base. Several woodland asters have seedlings with a similar appearance, including heartleaf *A. cordifolius*, short's *A. shortii*, and other similar woodland species.

Adult Plant

Smooth Blue Aster

Symphyotrichum laevis



Seed

Science Museum of Minnesota

Seedling

Habitat: Edge/Upland

R3 Indicator Status: UPL

MN C-Value: None assigned

Flowers: June-October

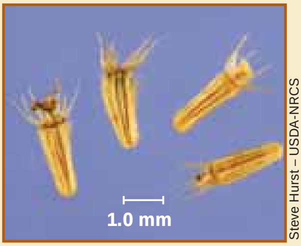
Seedling Description: Leaves of seedlings are crowded in a basal rosette and can vary substantially in shape. They have a waxy blue-green coating and a net-like vein pattern that becomes more prominent as the plant matures. Leaves are toothed, sometimes have a reddish to purple cast along the veins, and usually have a wide leaf base. They also have fine hairs that are visible with a hand lens.

Look Alikes: Sky blue aster seedlings are similar, but typically have a more obvious leaf stem as well as a rough feel and a heart-shaped leaf base. The leaf shape and bluish-green waxy coating of smooth blue aster leaves make it relatively easy to identify, even as a seedling.

Adult Plant

Sneezeweed

Helenium autumnale



Seed

Seedlings

Juvenile

Habitat: Edge

R3 Indicator Status: FACW

MN C-Value: 4

Flowers: August-October

Seedling Description: Seedlings form basal rosettes of fleshy, smooth (to finely fuzzy) leaves that have a prominent yellow-green central vein and shallow, rounded teeth. As successive leaves form in the rosette, leaves become more linear with teeth concentrated toward the outer third.

As the plant grows, the main stem is winged with leaves held alternate of each other.

Look Alikes: Great blue lobelia, cardinal flower, and bottle gentian also form basal rosettes. Bottle gentian leaves are reliably smooth, while those of cardinal flower and great blue lobelia may be finely hairy, similar to sneezeweed.

Adult Plant

Tradescantia ohiensis

Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 6

Flowers: June-July

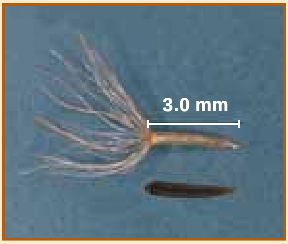
Seedling Description: The fleshy, bluish-green leaves may lack hairs or have fine hairs most concentrated at the base. Stems are often silvery to reddish-purple in color, particularly along the veins. Leaves of young plants are concentrated at the base, moderately folded in a v-shape, and clasp the stem with a long sheath. Of the three most common species in our area, Ohio spiderwort *T. ohiensis* is the tallest and most robust, reaching 1 meter in height. Western spiderwort *T. occidentalis* and bracted spiderwort *T. bracteata* are generally under one half meter (about 1.5 feet) in height.

Look Alikes: Spiderwort plants are distinctive with linear leaves that feel similar to rubber bands. Seedlings are hard to spot in restorations when small, but easy to distinguish once they reach the subadult stage. Ohio spiderwort, *T. ohiensis* shown.

Adult Plant

Spotted Joe-pye Weed

Eupatoriadelphus maculatus



Science Museum of Minnesota

Seed

Seedling

Habitat: Wetland/Edge

R3 Indicator Status: OBL

MN C-Value: 4

Flowers: July-September

Seedling Description: Seedling leaves are narrowly elliptic with the successive true leaves forming opposite of each other. The first true leaves have only a few teeth, rounded bases, and leaf stalks about one-fourth as long as the leaf itself. Leaves of young plants have one prominent mid-vein, and two relatively distinct veins on either side. The leaves have coarse, but sharp teeth that point toward the tip. Hairs are visible on leaf margins and leaf surface, and are especially prominent on new leaves as they emerge and expand. As the plant matures, purple spots become more evident on the stem and leaves develop in whorls of four or five.

Look Alikes: Boneset and blue vervain also have opposite leaves that are hairy. As spotted joe-pye weed matures, leaves develop in whorls of 4-5.

Adult Plant

Oligoneuron rigidum

Science Museum of Minnesota

Seed

Seedling

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 4

Flowers: June-August

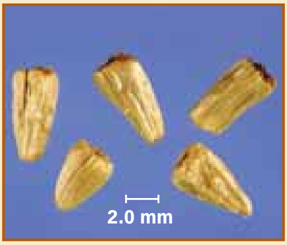
Seedling Description: The first leaves are rounded to pointed oblong-lanceolate with a wide base, forming a small basal rosette. Subsequent leaves have longer leaf stems and leaf blades with an elliptic shape. Leaf margins may have sharp or rounded, shallow teeth, or may lack teeth. New leaves emerge somewhat inrolled along the leaf margins and long axis of the leaf. Because there are two varieties in the Upper Midwest, leaves may vary from stiffly rigid to softly hairy, or nearly smooth.

Look Alikes: Stiff goldenrod basal leaves can be confused with those of compass plant, which are reliably stiff and sand papery. Stiff goldenrod leaves can vary from rigid and coarse, to fuzzy, to nearly smooth. Compass plant leaves have a sharper point at the end than stiff goldenrod leaves. Showy goldenrod has a similar leaf, but has a wider leaf stem and teeth only on the outermost half of the leaf blade, not the entire leaf blade margin. This species is difficult to distinguish from other goldenrods and asters when very small.

Adult Plant

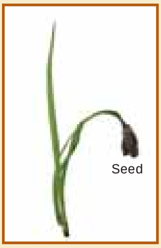
Sweetflag

Acorus americanus



Steve Hurst – USDA-NRCS

Seed



Seedling

1.0 mm

Seedlings

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 7

Flowers: June-July

Seedling Description: Even as seedlings, crushed leaves give off a characteristic citrusy, aromatic odor that smells much like citronella. Also known as calamus, sweet flag has sword-like, light green leaves that are narrowly diamond-shaped in cross section. As the plant matures, it develops successive leaves in an expanding bunch. Mid-veins and secondary veins are prominent throughout the length of leaves. Seed hulls are often borne on the tip of the first leaf, giving an opportunity to identify very small seedlings by looking closely at the seed.

Look Alikes: This plant is similar in appearance to blueflag iris. However, blueflag iris tends to have darker green leaves and does not have the citrus-like odor when its leaves are crushed. Iris leaves also have a sharp fold that new leaves emerge from inside of.

Adult Plant

Thalictrum dasycarpum

Tall Meadow Rue

Science Museum of Minnesota

Seed


Iowa DNR

Seedling

Habitat: Wetland/Edge

R3 Indicator Status: FACW

MN C-Value: 4

Flowers: May-June

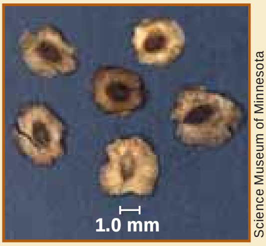
Seedling Description: Leaves of young plants are initially round-shaped. Subsequent leaves have lobes that resemble the distinctly 3-lobed leaves of adult plants. Leaves are smooth on top and sometimes finely hairy underneath with a thinly fleshy feel. The stems of small plants are wiry and often purple-blue in color. Plants often develop a waxy coating on the green to purplish stems, giving them a whitish cast.

Look Alikes: Tall meadow rue is perhaps most easily confused with seedlings of prairie larkspur, a dry prairie species not commonly included in prairie plantings. Prairie larkspur seedlings also have a 3-lobed leaf. However the lobes are deeper, and leaf tips more sharply pointed in prairie larkspur.

Adult Plant

Turtlehead

Chelone glabra



Seed

Seedlings

Seedlings

Habitat: Wetland/Edge

R3 Indicator Status: OBL

MN C-Value: 7

Flowers: July-September

Seedling Description: Seedlings have somewhat rounded leaves that become linear to lance-ovate in shape as seedlings mature. Leaves have very short stems, or lack them altogether. Smooth leaves are opposite on stem, with sharp teeth that point toward the leaf tip. Leaf veins are typically prominent, including a central vein and several lateral veins. Stems are four-angled and may have a waxy, whitish cast (glaucous bloom).

Look Alikes: May be confused with skullcaps (Scutellaria spp.), which have similar leaves to turtlehead seedlings. As turtlehead matures, leaves become longer and narrower than those of skullcap. Skullcap is seldom planted in restorations as seed due to availability/cost. Spotted joe-pye weed and blue vervain have hairy leaves. Swamp milkweed has milky sap. Monkeyflower has similar leaves, but more crowded teeth and a more net-like vein pattern on leaves.

Adult Plant

Pycnanthemum virginianum

Virginia Mountain Mint

Science Museum of Minnesota

Seed

Iowa DNR

Seedlings

Seedlings

Habitat: Edge/Upland

R3 Indicator Status: FACW

MN C-Value: 6

Flowers: June-August

Seedling Description: Seedlings usually have deep green foliage, and are often reddish-purple tinged. Leaves are lanceolate to narrow and opposite each other on a square stem. Leaf margins are smooth and leaves appear crowded on seedlings. Spearmint-like smell of foliage is evident when rubbed between fingers. Because this plant develops slowly, it tends to be one of the harder seedlings to spot in prairie plantings.

Look Alikes: Even as a seedling, the minty smell of foliage distinguishes this plant from others that have a similar appearance. Bergamot, which has a more pungent minty smell reminiscent of Earl Grey tea, is larger, and matures from seed well ahead of mountain mint in most settings.

Adult Plant

Cicuta maculata

Steve Hurst – USDA-NRCS

Seed


Iowa DNR

Seedling

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 5

Flowers: June-August

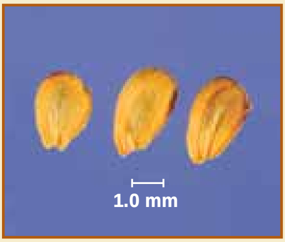
Seedling Description: Seedling leaves are needle-shaped and, when bruised, give off a distinct mouse-like odor. First true leaves are compound with 3-toothed leaflets. As the plants mature, leaves become progressively larger and more finely dissected. Mature poison hemlock plants have distinctly purple-spotted, hollow stems that lack hairs.

Look Alikes: May be confused with poison hemlock, which is leafier and tends to grow in tall, dense stands. Poison hemlock stems have purple spots and streaks. Water hemlock tends to grow as scattered stems in wetter soils. Both of these attractive plants are highly poisonous.

DANGER: Roots and stem are extremely poisonous to humans and livestock. They contain cicutoxin, which causes paralysis of the nervous system in as little as 15 minutes. One ingested root is sufficient to kill a cow or horse.

Adult Plant

Alisma subcordatum & A. trivale



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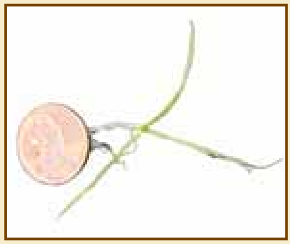


Seed

Seedling

Habitat: Wetland

R3 Indicator Status: OBL

MN C-Value: 4

Flowers: June-July

Seedling Description: Seeds may germinate in shallow water or open mud flats. Seedlings have small, fine, linear leaves. As seedlings continue to grow they develop upright, elliptic leaves, eventually becoming broad, flat blades that may be rounded or tapered at the base. Seedlings develop relatively quickly in favorable settings.

Look Alikes: Similar emergent and wetland edge species include arrowhead and pickerel plant. Arrowhead seedlings have short, broad, and thick, strap-like leaves with rounded tips. Pickerel plant develops leaves as a seedling that are similar to those of arrowhead, but with a much sharper leaf tip. Water plantain leaves are much narrower than those of either arrowhead or pickerel plant as a seedling.

Adult Plant

White Prairie Clover

Dalea candida

Science Museum of Minnesota

Seed


Agrecol Corporation

Seedling

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: None assigned

Flowers: June-August

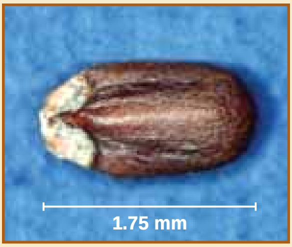
Seedling Description: Seedlings first develop leaves with 3 wide, rounded leaflets, increasing to 5 leaflets per leaf. There are 5-9 leaflets on mature plants, with 7 leaflets most common. Leaves of juvenile plants are typically 5-8 times long as they are wide, and look similar to those of mature plants. Leaves are smooth and flat to somewhat folded along the midrib. Young plants have wiry stems that range in color from light green to straw or light brown. Seedlings have leaflets about half the size of those found on adult plants.

Look Alikes: The first few true leaves of white prairie clover seedlings have an appearance similar to those of Canada milkvetch. However, after about the third set of true leaves, the leaflets of white prairie clover become characteristically narrow. Both leadplant and Canada milkvetch develop more leaflets per leaf than the 5-9 characteristic of white prairie clover. Purple prairie clover has smaller, narrower leaflets and plants may be very finely hairy.

Adult Plant

Monarda fistulosa

Wild Bergamot



Science Museum of Minnesota

Seed

Iowa DNR

Seedlings

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 3

Flowers: June-July

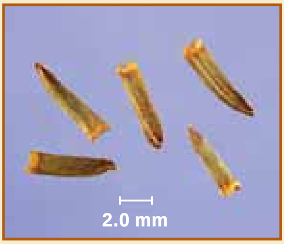
Seedling Description: Even as a seedling, all plant parts have a pleasant, minty aroma similar to that of Earl Grey tea. The aroma is easily detected by gently rubbing foliage. Stems, leaf stems, and leaf bases often have a pinkish- to purplish-green color, and are generally about one-fourth to one-third the length of the leaf blade. Paired opposite each other on a square stem, leaves are light to dark green, and are slightly rounded-triangular to heart-shaped. Leaves often have sharp to rounded teeth, but are sometimes without. Plants can vary from smooth to finely hairy.

Look Alikes: Bergamot seedlings might be confused in general appearance with oxeye false sunflower or common evening primrose. Neither of these species has a minty aroma.

Adult Plant

Wild Goldenglow

Rudbeckia laciniata



Steve Hurst – USDA-NRCS

Seed

Seedling

Habitat: Edge

R3 Indicator Status: FACW

MN C-Value: 4

Flowers: June-August

Seedling Description: The first true leaves of wild goldenglow seedlings are nearly round, with stalks almost as long as the leaf blades, and a few coarse teeth toward the outermost edges. As seedlings mature, leaves become increasingly dissected and the veins of the leaves often have a light green to whitish color. Leaves are borne alternately on a stem that is often slightly ribbed. There are two varieties of wild goldenglow in our region, one of which has smooth and somewhat waxy foliage (giving it a whitish cast), while the other is typically softly pubescent.

Look Alikes: Wild goldenglow seedlings could be confused with those of cup plant. However, cup plant leaves are thicker, more firm, and coarser to the touch than wild goldenglow seedlings. Also, goldenglow leaves become increasingly dissected as the plant matures, whereas cup plant leaves remain entire, become stalkless, and eventually clasp the square stem.

Adult Plant

Ratibida pinnata

Seed

Science Museum of Minnesota

Seedlings

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: None assigned

Flowers: June-August

Seedling Description: Seedlings vary from softly to somewhat coarsely hairy (seedling leaves are usually fairly soft to touch, as opposed to stiff and rigid). The first true leaves are oval to elliptic in shape, lack teeth, have leaf stems about as long as the leaf blade, and are often slightly folded along the mid-vein. Subsequent leaves gain an increasing number of sharp teeth, then develop 3-5 deep lobes characteristic of adult plants.

Look Alikes: Can be confused with seedlings of a number of other species, including purple coneflower which quickly develops larger, coarser leaves; thin-leaved coneflower *Rudbeckia triloba* has thinner leaves, wide leaf stems and longer, coarser hairs; wild goldenglow, *Rudbeckia laciniata* eventually develops deep lobes with coarser teeth; sweet coneflower, *Rudbeckia subtomentosa* has fuzzier leaves, and eventually has up to 3 lobes.

Adult Plant

Weeds

Barnyard Grass

Echinochloa crusgalli

MN Dept. of Agriculture

Seed

MN Dept. of Agriculture

Seedling

Habitat: Edge/Upland

R3 Indicator Status: FACW

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics:

Barnyard grass seedlings and adult plants have a pronounced flattened stem and hairless leaf blades and sheaths. The base of the stem is usually red and sometimes bulbous in appearance. When the leaf blade is bent over parallel to the stem, no ligule is visible. Barnyard grass has no claw-like appendages encompassing the stem (auricles) at the base of the leaf blade.

Adult Plant

Seed

Seedling

Habitat: Edge/Upland

R3 Indicator Status: UPL

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Cupgrass seed is cream colored, flattened, and large compared to most other grass seeds. The first true leaves are wide at the base. Leaves are covered with short, fine, dense hair, making the leaves appear and feel fuzzy. Leaf blades are hairy on the entire leaf surface, and have a distinguishing crinkle or wave on one margin. No hairs are present on sheath margins.


Inflorescence

Giant Foxtail

Setaria faberi


MN Dept. of Agriculture

Seed


MN Dept. of Agriculture

Seedling

Habitat: Edge/Upland

R3 Indicator Status: FACU

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Although similar in appearance to green foxtail, giant foxtail is a much larger and robust plant that can reach 7 feet in height. Leaf blades are rough to the touch and tend to be flattened. The upper leaf surface has long, bulbous-based soft hairs. The lower leaf surface lacks hairs.

Adult Plant

Setaria viridis


MN Dept. of Agriculture

Seed


MN Dept. of Agriculture

Seedling

Habitat: Edge/Upland

R3 Indicator Status: UPL

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: The stem of green foxtail is not flattened. The upper leaf surface is rough, while the lower leaf surface is less so, or smooth. The leaf sheath margins are hairy with the sheaths being sometimes hairy. The leaf blade has little or no hair. Hairs are visible on the ligule when the leaf blade is bent over parallel to the stem.

Adult Plant

Quackgrass

Elytrigia repens

The Ohio State University

Seed

The Ohio State University

Seedling

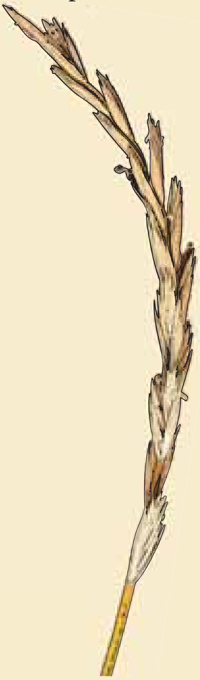
Habitat: Edge/Upland

R3 Indicator Status: FACU

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Very prominent hairless auricles encircling the stem are present at the base of the leaf. The sheath is hairy on seedlings but is not hairy on mature plants. Leaves are finely ribbed on the upper and lower surfaces. The upper blade surface and margins are typically rough or slightly hairy, and the lower surface is smooth. Smooth brome may be confused with quackgrass, but it lacks the prominent claw-like appendages (auricles) that clasp the stem at the top of the sheath in quackgrass.



Inflorescence

Reed Canary Grass

Phalaris arundinacea

MN Dept. of Agriculture

Seed

The Ohio State University

Seedling

Habitat: Wetland/Edge

R3 Indicator Status: FACW

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics:

Ligule is prominent and membranous, and the stem is hollow. Small clasping auricles are present at the base of the leaf. The leaves are flat, hairless and smooth, with the exception of somewhat rough edges. Leaf blades of mature plants are approximately 4 - 14 inches long and ¼ - ¾ of an inch wide. The wide leaf blade narrows abruptly at its base.

Adult Plant

Smooth Brome

Bromus inermis


A. Blaschka – USDA-NRCS

Seed


The Ohio State University

Seedling

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Ligule is membranous and short with the leaf blade and sheath hairless or sparsely hairy. Leaf blades are narrow, long and erect. Auricles are inconspicuous to absent and the sheath is united.

As plants mature, a “W” mark develops across the width of each leaf blade, about half to two-thirds of the way up the leaf. Smooth brome can be confused with quackgrass Elytrigia repens. However, quackgrass has prominent claw-like appendages (auricles) that clasp the stem at the top of the sheath and smooth brome does not.

Adult Plant

Setaria glauca

Seed

MN Dept. of Agriculture

Seedling

Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: The sheath is hairless and the stem is flattened. Long hairs are present only at the base of the leaf blade. The base of the leaf sheath for this species is often reddish/purple.

Adult Plant

Absinthe Sage

Artemisia absinthium

USDA-NRCS Plants Database

Seed

Seedling

Juvenile

Habitat: Edge/Upland

R3 Indicator Status: UPL

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: The first leaves of absinthe sage following germination are about 3-4 mm in length and 1-2 mm in width, with a spatulate shape. Subsequent leaves gain increasingly deeper lobes with sharp points. Even the leaves of young plants have a bright green to silvery cast to them. Seed is very fine, spread readily by hay, wind water and animals, and is viable for 3-4 years.

Perhaps most conspicuous is the pungent odor similar to that of black walnut husks. This is in contrast to the native prairie sage, which gives off a more pleasant odor similar to the sage used in traditional Thanksgiving Day dressings.

Adult Plant

Beach Clotbur

Xanthium strumarium

MN Dept. of Agriculture

Seed

MN Dept. of Agriculture

Seedling

Juvenile

Habitat: Edge

R3 Indicator Status: FAC

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are large, thick, and waxy; and are lanceolate in appearance. True leaves have three prominent lobes. Seedlings consist of a slender, straight, whitish-green stem 1 to 3 inches tall. Two strap-shaped green leaves cap this stem, each about 1¼ inches long and ¼ inch wide. Mature plants can be distinguished from spiny clotbur by broader cockleburs, more ovoid leaves on long leaf stalks (petioles), and lack of spines.

This is a native species that may be prominent during the “weedy” early stages of prairie restoration.

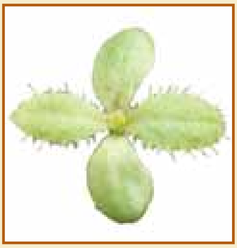
Adult Plant

Bull Thistle

Cirsium vulgare

MN Dept. of Agriculture

Seed



MN Dept. of Agriculture

Seedling

MN Dept. of Agriculture

Juvenile

Habitat: Edge/Upland

R3 Indicator Status: FACU

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are round to spatulate in shape, are smooth and fleshy, and have short stalks. The first true leaves are oval to spatulate with spines, have a rough bumpy surface, and can have a downy appearance on the upper surfaces. Seedlings form rosettes, while adult leaves become more deeply lobed.

The upper leaf surface is dark green and covered with sharp hairs, making it prickly to the touch. The lower surface is light green and covered with soft, wooly hairs. At the tip of each leaf lobe is a long spine. Smaller spines are irregularly distributed along other parts of the leaf edge.

Inflorescence

Arctium minus

Seed

MN Dept. of Agriculture

Seedling

MN Dept. of Agriculture

Basal Leaves

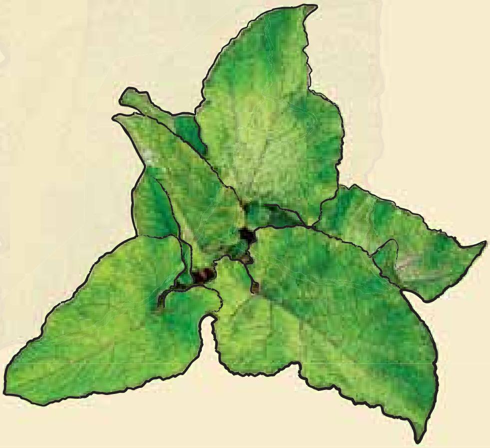
Habitat: Edge/Upland

R3 Indicator Status: UPL

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are spoon-shaped and have a waxy surface. First true leaves are egg-shaped, flocked with short hairs, puckered between the veins, and have a widened base. Plant forms a rosette with leaves becoming broadly heart-shaped, 6-18 inches long and 4-14 inches wide, with hollow petioles and wavy, toothed margins. The undersides of these leaves are loosely hairy and light green. Leaves borne along the main stem of maturing plants are much smaller than other leaves, alternate, and egg-shaped. For the adventurous, chewing the leaves reveals a bitter taste.



Basal Leaves

Canada Thistle

Cirsium arvense

Seed

MN Dept. of Agriculture

Seedling

Province of British Columbia

Juvenile

Habitat: Edge/Upland

R3 Indicator Status: FACU

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics:
Seed leaves (cotyledons) are oblong to broadly oval in shape, dull green, and thick. Joined at the base, the seed leaves form a small cup. True leaves are at first egg-shaped with bristly hairs on the upper and lower surfaces. Seedlings form small rosettes with the first true leaves paired at right angles to seed leaves. Later leaves are wavy-edged, somewhat hairy underneath, and irregularly lobed with spiny edges. Plants appear compressed to the ground early, with clasping leaves more widely spaced along the main stem as plants mature.

Inflorescence

Ambrosia artemisiifolia

Common Ragweed

Seed

MN Dept. of Agriculture

Seedling

Catherine Herms OSU

Juvenile

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are small and oval to spatulate in shape with purple spots on undersides. First true leaves are opposite to seed leaves, five-lobed, and have a lacy appearance.

This is a native species that may be prominent during the “weedy” early stages of prairie restoration. There is also a native perennial ragweed species, *Ambrosia psilostachya*, that occurs in similar habitats. It is considered to be part of the normal flora of dry prairies.

Adult Plant

Rumex crispus

MN Dept. of Agriculture

Seed

Seedling

MN Dept. of Agriculture

Juvenile

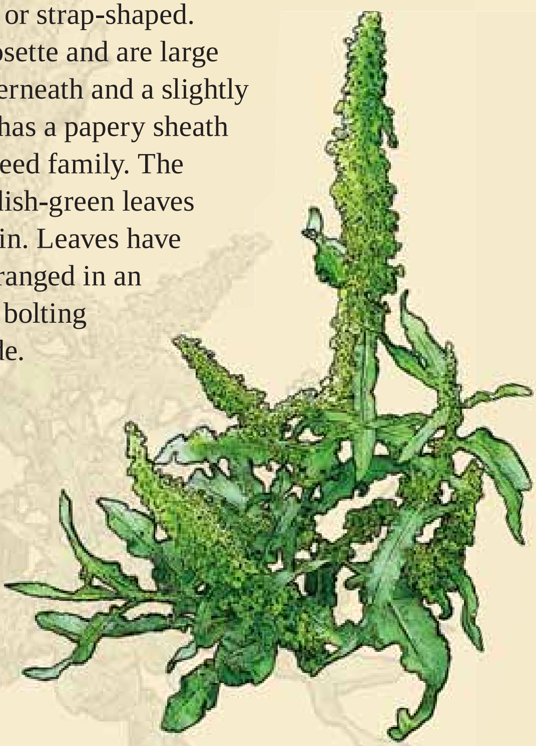
Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are opposite and diamond- or strap-shaped. True leaves form a basal rosette and are large with a prominent vein underneath and a slightly pointed tip. The leaf base has a papery sheath characteristic of the knotweed family. The fleshy, bluish-green to reddish-green leaves have a curly or wavy margin. Leaves have short leaf stems and are arranged in an alternate fashion along the bolting stem, with one leaf per node.



Adult Plant

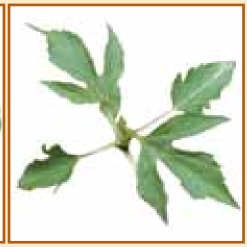
Giant Ragweed

Ambrosia trifida

Seed

MN Dept. of Agriculture

Seedling



Juvenile

MN Dept. of Agriculture

Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are large, round to oblong, and thick. The stem below the seed leaves is often purple. First true leaves are not lobed. They are lanceolate in shape, with toothed margins. Subsequent leaves are increasingly large and deeply 3-lobed (less commonly 5-lobed), opposite each other on the stem, and have a rough surface.

This is a native species that may be prominent during the “weedy” early stages of prairie restoration.

Adult Plant

Chenopodium album

MN Dept. of Agriculture

Seed

MN Dept. of Agriculture

Seedling

MN Dept. of Agriculture

Juvenile

Habitat: Edge/Upland

R3 Indicator Status: FAC-

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics:

Seed leaves appear small and linear in shape, and have nearly parallel sides. First true leaves are opposite and ovate in shape with smooth edges. Seed leaves and early true leaves are dull blue-green above and often purple below. True leaves will begin to appear whitened above with a red-violet appearance on the underside as plants mature.

Adult Stem

Leafy Spurge

MN Dept. of Agriculture

Seed

MN Dept. of Agriculture

Seedling

MN Dept. of Agriculture

Stem and Leaves

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are elliptical in shape and hairless. True leaves are also elliptical, hairless, and are arranged in spirals alternate of each other around the stem. A white milky latex that can cause skin irritation seeps from the plant when it is cut or torn. Leafy spurge can be confused with the native flowering spurge Euphorbia corollata, which is common to dry prairies and only rarely included in prairie restoration seed mixes.

Adult Plant

Nodding Thistle

Cardruus nutans


MN Dept. of Agriculture

Seed


MN Dept. of Agriculture

Seedling


MN Dept. of Agriculture

Rosette

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics:
Seed leaves are rectangular to oblong in appearance, and approximately three times as long as they are wide. Seed leaves have little or no stalk and have distinctive white veins on their upper surface. Young leaves are essentially without hairs and immediately form a dense rosette. Seedlings have waxy, pale green-colored leaves with shallowly lobed margins containing irregular prickles.

Inflorescence

Amaranthus retroflexus

Pigweed, Redroot


MN Dept. of Agriculture

Seed


MN Dept. of Agriculture

Seedling


MN Dept. of Agriculture

Stem and Leaves

Habitat: Edge/Upland

R3 Indicator Status: FACU

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are linear in appearance and hairless. First true leaves are alternate, strongly egg-shaped (ovate), and have a deep notch or indentation at the tip. The leafstalks or petioles of the true leaves are purple. As the seedlings mature, the stem becomes very rough and hairy. Other pigweed species have a generally similar appearance to seedlings.

Adult Plant

Perennial Sow-thistle

Sonchus arvensis


MN Dept. of Agriculture

Seed


The Ohio State University

Seedling


MN Dept. of Agriculture

Juvenile

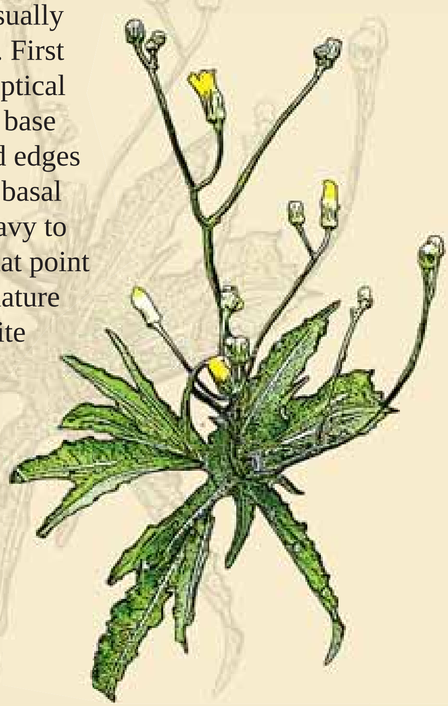
Habitat: Edge/Upland

R3 Indicator Status: FAC

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: All leaves, including seedling leaves, have a milky sap. Seed leaves (cotyledons) are round to oval in shape with slight indentations at the tips. Although they tend to wither, the seed leaves usually remain until true leaves develop. First few true leaves are alternate, elliptical to oval in shape, narrower at the base than at the tips, and have toothed edges with soft prickles. Plants form a basal rosette. Leaf margins become wavy to lobed, and contain spiny teeth that point backwards. Lower surfaces of mature leaves often have a powdery white to purplish film.



Adult Plant

Poison Hemlock

Conium maculatum

Steve Hurst – USDA-NRCS

Seed


The Ohio State University

Seedling


The Ohio State University

Basal Leaves

Habitat: Wetland/Edge

R3 Indicator Status: FACW

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves are narrow, lanceolate, and have long leaf stalks (petioles). First true leaves have two or more leaflet divisions (pinnately compound), hairless, and often purple at the base. Plants form basal rosettes of finely divided, fern-like leaves during the first year. Mature plants have distinctly purple-spotted stems without hairs.

WARNING: although rarely eaten, plant is poisonous to cattle, hogs, poultry, horses, goats, and sheep that consume it.

Adult Plant

Purple Loosestrife

Lythrum salicaria


MN Dept. of Agriculture

Seed


Oregon State University-
Larry Burrell & Jed Colquhoun

Seedling

Habitat: Wetland/Edge

R3 Indicator Status: OBL

MN C-Value: None assigned

Flowers: July - September

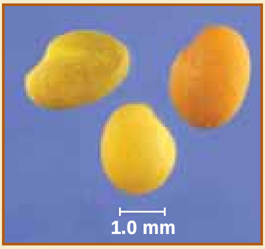
Distinguishing Characteristics: Purple loosestrife is an aggressive nonnative plant brought to the U.S. from Europe in the early 1800's. It has the potential to readily colonize a wide variety of wetland and wetland edge settings.

Look for downy, triangular leaves, with smooth edges that are wider at the base, where they meet a square stem. Leaves are opposite each other in pairs which alternate down the stalk at 90 degree angles, and rarely in groups of three. Purple loosestrife is taller and more robust than the native winged loosestrife *Lythrum alatum* that is also found in wetlands in Minnesota and has a purple flower. Winged loosestrife generally does not exceed two feet in height and as the common name implies, has a winged stem.

Adult Plant

Sweet Clover (Yellow & White)

Melilotus officinalis and *M. alba*



Seed

Steve Hurst – USDA-NRCS

Seedling

Leaf Structure

Habitat: Upland

R3 Indicator Status: FACU

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are very small, twice as long as they are wide, and pale green in color. First true leaf is heart-shaped and wavy around the edges. The second and subsequent leaves become compound, are alternate, and have three leaflets per leaf (trifoliate). Sweet clover seedlings lack hair on the lower leaflet surfaces and have an acrid, bitter taste.

Yellow Sweet Clover Inflorescence

Teasel

MN Dept. of Agriculture

Dipsacus laciniata and *D. sylvestris*

Seed

MN Dept. of Agriculture

Seedling

MN Dept. of Agriculture

P. laciniata Leaf

Habitat: Edge/Upland

R3 Indicator Status: NI

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics:
Seed leaves (cotyledons) are oval to round in shape and occur on short leaf stalks (petioles). First true leaves are also round to oval in shape, and have rounded or scalloped teeth. The plant forms a basal rosette with leaves ranging from somewhat ovoid in young plants, to large and oblong leaves that are quite hairy in older rosettes. Leaves have a puckered surface, reminiscent of seersucker fabric, and persist overwinter from the first to second year of the plant's lifecycle.

Adult Plant

Velvetleaf

Abutilon theophrasti

MN Dept. of Agriculture

Seed

MN Dept. of Agriculture

Seedling

MN Dept. of Agriculture

Heart-shaped Leaf

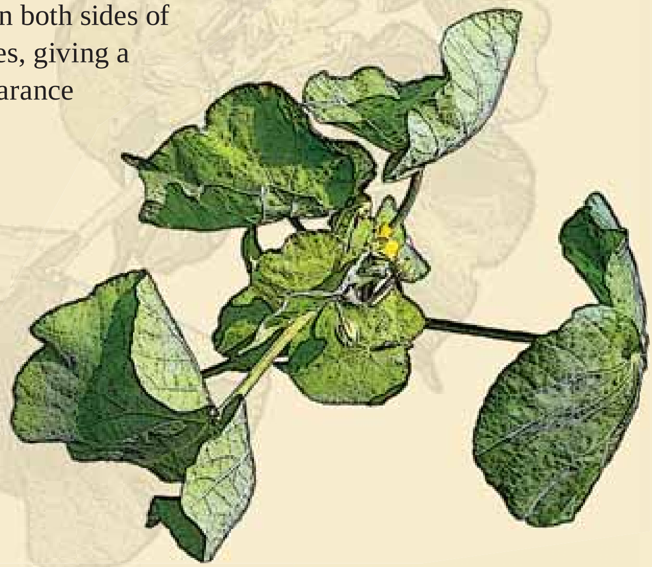
Habitat: Edge/Upland

R3 Indicator Status: FACU

MN C-Value: 0

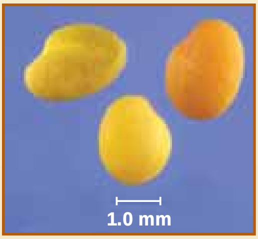
Flowers: June-August

Distinguishing Characteristics: Seed leaves have one rounded and one heart-shaped seed leaf (cotyledons). These seed leaves are about as long as they are wide and have a velvety appearance. The stem below the cotyledons is densely covered with soft hairs. The first true-leaves are alternate, heart-shaped, and have serrated margins. Short hairs are present on both sides of the true leaves, giving a velvety appearance to the leaves.



Adult Plant

Pastinaca sativa



Steve Hurst – USDA-NRCS

Seed


The Ohio State University

Seedling


The Ohio State University

Basal Leaves

Habitat: Upland

R3 Indicator Status: UPL

MN C-Value: 0

Flowers: June-August

Distinguishing Characteristics: Seed leaves (cotyledons) are linear in shape. True leaves are small, ovate, and attached to the stem by long leaf stalks (petioles). A basal floret containing compound true leaves is formed during the first year of growth. Although biennial, this plant is reported to be monocarpic, meaning it has the ability to live until seed is produced if successful reproduction is delayed by mowing or other similar disturbances. This plant is sometimes confused with the native species Alexanders, which has fleshy, waxier feeling leaves.

Adult Plant

Appendix

Appendix

List of Synonyms for Common and Scientific Names

Having trouble finding a plant you're looking for? Below is a list of some of the more frequently used synonyms for plants known by more than one common and/or scientific name.

Common name (synonym)	*Scientific name (synonym)*
Butterfly milkweed (pleurisy root)	***Asclepias tuberosa***
Common arrowhead (duck potato)	***Sagittaria latifolia***
Flat-topped aster	***Aster umbellatus (Doellingeria umbellatus)***
Giant manna gras (reed manna grass)	***Glyceria striata (Glyceria maxima)***
Grass-leaved goldenrod	***Euthamia graminifolia (Solidago graminifolia)***
Great St. Johnswort	***Hypericum ascyron (Hypericum pyrimidatum)***
Little bluestem	***Schizachyrium scoparium (Andropogon scoparius)***
Marsh milkweed (swamp milkweed)	***Asclepias incarnata***
New England aster	***Aster novae-angliae (Symphyotrichum novae-angliae)***
Partridge pea	***Chamaecrista fasciculat (Cassia fasciculata)***
Panicled aster	***Aster simplex (Symphyotrichum lanceolatum) (Aster lanceolatus)***

Common name (synonym)	***Scientific name (synonym)***
Purple prairie clover	***Dalea purpurea (Petalostemon purpureum)***
Quackgrass	***Elytrigia repens (Agropyron repens)***
Red-stemmed aster (purple-stemmed aster)	***Aster puniceus (Symphyotrichum puniceum)***
Riddell's goldenrod	***Solidago riddelli (Oligoneuron riddellii)***
River bulrush	***Scirpus fluviatilis (Schoenoplectus fluviatilis)***
Sky blue aster	***Aster oolentangiensis (Symphyotrichum oolentangiense) (Aster azureus)***
Smooth blue aster	***Aster laevis (Symphyotrichum laevis)***
Softstem bulrush	***Scirpus validus (Schoenoplectus tabernaemontani)***
Spotted Joe-pye weed	***Eupatorium maculatum (Eupatoriadelphus maculatus)***
Stiff goldenrod	***Solidago rigida (Oligoneuron rigidum)***
Yellow coneflower (gray-headed coneflower)	***Ratibida pinnata***

Glossary of Technical Terms

We have made an effort to avoid using technical botanical terms in this guide. Despite our good intentions, some botanical terms were included.

Acute – Sharp-pointed.

Annual – A plant that completes its life cycle in one year or less.

Aromatic – With fragrant smell; sometimes only if broken or crushed.

Axil – The area or angle formed between the base of an organ and the structure from which it originated, such as between the leaf base and the stem.

Basal – Pertaining to the base of the plant or some organ of the plant.

Biennial – A plant that requires two years to complete a life cycle; the first year typically forming a basal rosette, the second year forming an inflorescence.

Bipinnate – Twice pinnately compound.

Bract – A reduced leaf or scale, typically below a flower stalk or group of flowers. It also can refer to small leaves on a stem.

Bristly – With stiff hairs.

Clasping – Tending to encircle or invest, as in the base of a leaf that forms partly around the stem to which it is attached.

Coarse – Rough.

Compound – Leaves that are divided into distinct leaflets.

Cordate – Heart-shaped.

Cotyledon – A seed leaf; the first leaf (or leaves) to appear during the development of a seedling.

Cultivar – A cultivated variety of a particular species of plant, usually selected or manipulated for specific traits.

Elliptic – A circular shape widest about the middle.

Entire – Leaf margins without teeth; even though the margin may have hairs.

Fruit – Structure that bears the seeds.

Glabrous – Smooth, in the sense of not possessing hairs.

Glaucous – Covered by a white or pale, often waxy, bloom.

Hirsute – With stiff, usually straight, hairs.

Inflorescence – The flowering part of a plant or arrangement of flowers on a stalk.

Lanceolate – Lance-shaped, broadest below the middle, long-tapering above the middle, several times longer than wide.

Leaflet – One of the discriminate segments of the compound leaf of a dicotyledonous plant. Leaflets may resemble leaves, but differ principally in that buds are not found in the axils of leaflets, and that leaflets all lie in the same plane.

Ligule – For plants in the grass family this is an extension, often membranous, of the summit of the leaf sheath.

Linear – Very long and narrow, with nearly or quite parallel margins.

Lobe – Any segment or division, particularly if blunt.

Midnerve, Midrib, Midvein – The central or principal vein of a leaf, bract, sepal or petal.

Nerve – Same as a vein.

Node – The point along a stem which gives rise to leaves, branches, or inflorescences.

Oblong – Several times longer than wide with nearly, or parallel sides.

Oval – Broadly elliptical.

Ovate – Egg-shaped.

Palmate – Radiately lobed or divided, with individual segments originating at a common point or nearly so.

Parallel-veined – A feature where veins are parallel to each other and the midrib, or nearly so.

Pedicel – The stalk of a single flower in a cluster.

Pendulous – Drooping.

Perennial – A plant that lives for more than two years.

Perfoliate – Condition where the stem appears to pass through the leaf.

Petiole – A leafstalk.

Pinnate – Leaf structure that is compound or deeply divided, the principal divisions arranged along each side of a common axis.

Pubescent – Hairy.

Pungent – Very sharp; acrid taste or smell.

Recurved – Directed backward or downward.

Reflexed – Abruptly turned or bent downward.

Rhizomatous – Bearing rhizomes.

Rhizome – An underground stem, typically horizontal.

Serrate – With sharp, typically forward-pointing teeth.

Sessile – Without a stalk.

Stipule – An appendage or bract situated at either side of a leaf axil.

Tomentose – Dense, matted hairs.

Translucent – Between opaque and transparent; allows some light to pass through.

Vegetative – Plants or plant parts not involved in flowering or seed/fruit production.

Vein – A wire-like bundle of tissue in a leaf or other plant part. Same as nerve.

Weed – A plant growing in an undesired location. Relevant to prairie restorations, this typically refers to nonnative, invasive species that can potentially crowd out native plants/seedlings.

Plant Species Index

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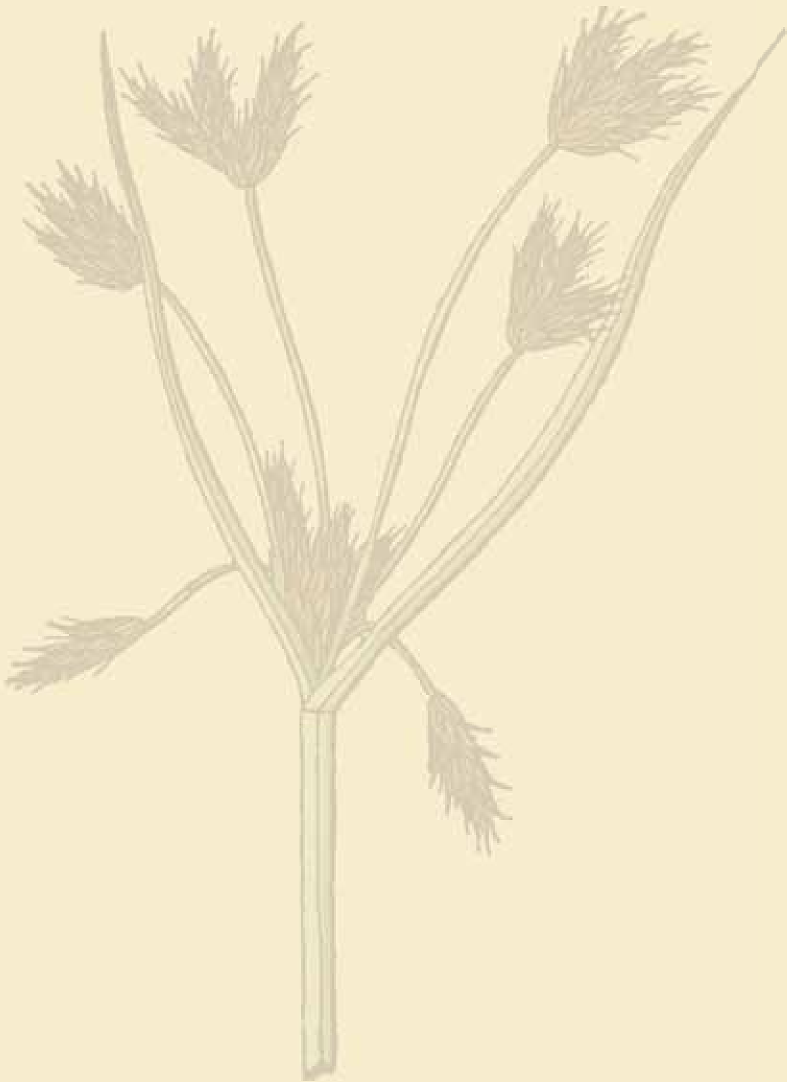

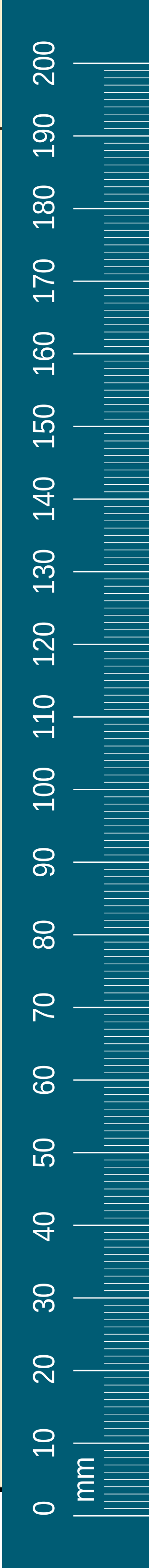

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The process of restoring wetlands is becoming increasingly important for restoring water quality, reducing flooding, improving wildlife habitat and to meet regulatory requirements. Understanding how the vegetation is establishing within restored wetlands and adjacent upland buffers is vitally important during the early phases of a restoration effort.

The ***Wetland & Buffer Plant Seedlings Guide*** is intended to be an easy to use resource for wetland professionals and native plant enthusiasts alike. It includes images and descriptions for over 50 native wetland and buffer plants of Minnesota, including pictures of seed and seedlings. It also includes information for over two dozen common weeds.

We hope you find this guide useful during your natural resource endeavors and that the pages of your copy become well-worn.

2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: DataWorkshop: Democratizing access to Minnesota's data assets – a user friendly data integration and visualization tool
PROJECT MANAGER: Terry Brown
AFFILIATION: Natural Resources Research Institute, University of MN
MAILING ADDRESS: 5013 Miller Trunk HWY
CITY/STATE/ZIP: Duluth, MN, 55811
PHONE: 218-720-4345
FAX: 218-720-4328
E-MAIL: tbrown@nrri.umn.edu
WEBSITE:
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2007, Chp. 30, Sec. 2, Subd. 6(d) and M.L. 2007, Chp. 30, Sec. 2, Subd. 7

APPROPRIATION AMOUNT: $61,000

Overall Project Outcome and Results

Originally developed to facilitate the work behind the Statewide Conservation and Preservation Plan, the DataWorkshop is a tool that allows users to combine and cross reference existing GIS datasets to synthesize new information. The DataWorkshop is now available for use by other users such as the public, municipalities, non-profits, and state and county agencies The ability to integrate existing datasets through a web browser without the need for additional software and with only a basic computer background makes the tool unique. Users previously lacking any such capability are enfranchised and users with GIS resources may find DataWorkshop simpler and more efficient for some analysis tasks.

For example, a user may wish to produce a map of all the lakes larger than 100 acres in the western prairie habitat zone. The user would use this system to select the DNR's lake and habitat zone datasets, select from the lake dataset those lakes with an area greater than 100 acres, and from that subset, only those lakes which overlap the prairie habitat zone.

The project has used free (open source) software technologies to minimize the cost associated with hosting this service on the web. These include UMN-Mapserver, Postgis, and Python. NRRI will temporarily host a demonstration site to allow interested parties to evaluate the system and until a permanent location is determined on a Minnesota state agency website. The project will also be promoted at the upcoming MN GIS/LIS Consortium conference. Although projects of this kind can only be truly evaluated by their long term adoption and use, we are hopeful that this work has been a valuable step towards democratizing access to Minnesota's data assets.

Project Results Use and Dissemination

At the time of writing we are in the final stages of releasing the project, which we will promote through our contacts with agencies, potential users, and the MN GIS/LIS Consortium conference in Duluth in October.

NRRI will host a demonstration version of the website at http://gisdata.nrri.umn.edu/DataWorkshopDemo – this site should be available starting Jan. 1 2010 when a necessary server upgrade is complete.

Trust Fund 2007 Work Program Final Report

Date of Report: August 04, 2009
Trust Fund 2007 Work Program Final Report
Date of Next Status Report:
Date of Work program Approval:
Project Completion Date: June 30, 2009

I. PROJECT TITLE: DataWorkshop: Democratizing access to Minnesota's data assets – a user friendly data integration and visualization tool

Project Manager: Terry Brown
Affiliation: Natural Resources Research Institute, University of MN
Mailing Address: 5013 Miller Trunk HWY
City / State / Zip : Duluth, MN, 55811
Telephone Number: 218-720-4345
E-mail Address: tbrown@nrri.umn.edu
FAX Number: 218-720-4328
Web Page address: System development site: http://gisdata.nrri.umn.edu/Tracker/DataWorkshop/
Public / distribution site: TBA

Location: Statewide

Total Trust Fund Project Budget: **Trust Fund Appropriation:** **$**61,
000

Minus Amount Spent: **$**61,000

Equal Balance: **$**0

Legal Citation: M.L. 2007, Chp. 30, Sec. 2, Subd. 6(d) and M.L. 2007, Chp. 30, Sec. 2, Subd. 7

M.L. 2007, Sec. 2., Subd. 6. (d) Natural Resource Data Collection and Mapping $49,000 is from the trust fund to the Legislative-Citizen Commission on Minnesota Resources for analysis and implementation of critical state natural resource data collection and mapping.

and $12,000 from the Emerging Issues Account

M.L. 2007, Sec. 2, Subd. 7.Emerging Issues Account $160,000 is from the trust fund to an emerging issues account as authorized in Minnesota Statutes, section 116P.08, subdivision 4, paragraph (d).

II. and III. FINAL PROJECT SUMMARY:

Overall Project Outcome and Results

Originally developed to facilitate the work behind the Statewide Conservation and Preservation Plan, the DataWorkshop is a tool that allows users to combine and cross reference existing GIS datasets to synthesize new information. The DataWorkshop is now available for use by other users such as the public, municipalities, non-profits, and state and county agencies The ability to integrate existing datasets through a web browser without the need for additional software and with only a basic computer background makes the tool unique. Users previously lacking any such capability are enfranchised and users with GIS resources may find DataWorkshop simpler and more efficient for some analysis tasks.

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IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Development of the DataWorkshop data integration and visualization capabilities for Statewide Plan analyses.

Description: In this phase we developed, tested, and implemented a working version of the DataWorkshop with datasets specific to the LCCMR Statewide Plan for Conservation and Preservation.

Summary Budget Information for Result 1: **Trust Fund Budget:** **$**12,000
Amount Spent: **$**12,000
Balance: **$** 0

	Deliverable	Due	Budget	Status
1	Develop basic architecture	1-Feb-08	1200	Completed
2	Concept demo with Statewide plan data (tabular format)	15-Mar-08	4200	Completed (see text)
3	Beta testing of basic functions with Statewide team members	30-Apr-08	3800	Completed (see text)
4	Application with Stateside Plan data	30-Apr-08	2000	Completed (see text)
5	Prototype documentation complete	15-Jun08	800	Completed (see text)

Completion Date: 30-Jun-08

Notes: The intent of this phase was to develop and test a working version of the DataWorkshop with team members from Statewide Plan to provide data for plan completion. Since the funding came in the final stages of the statewide plan, the testing was conducted NRRI and the work required to supply GIS data for the plan was used to guide development of the tool.

Result 2: DataWorkshop Online

Description: In this phase we developed the GIS mapping capabilities and Internet access capabilities of DataWorkshop.

Summary Budget Information for Result 2: **Trust Fund Budget:** **$**49,000
Amount Spent: **$**49,000
Balance: **$**0

	Deliverable	Due	Budget	Status
1	Develop spatial data architecture model	01-Mar-08	8100	Complete
2	Concept demo with Statewide plan data (GIS format)	30-Mar-08	9500	Complete, modified, see text.
3	Beta testing of basic functions (spatial)	30-Aug-08	4200	Complete

4	Internet interface development and implementation	30-Sep-08	11900	Complete
5	All output formats functional	31-Dec-08	8300	Final review
6	Final documentation release	15-Apr-09	4000	Final review
7	Final documentation and model delivery	30-Jun-09	3000	Final review

Completion Date: 30-Jun-09

Final Report Summary:

We have successfully implemented a web-only application for simple GIS analyses. This application creates a new level of access to data sets not previously available, making Minnesota's natural resource data accessible to a wider audience. We will be finalizing deployment of a demonstration site for the project in the next 2-3 months.

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: Terry Brown, system development, 70%, to June 08
George Host, 8%, to June 08
Terry Brown, 20%, July 08 to June 09
George Host, 6%, July 08 to June 09
Total Salary & Fringe: $58,233

Equipment: none
Development: N/A
Restoration: N/A
Acquisition, including easements: N/A
Other: Travel $1,180; Supplies $480; NRRI GIS lab fees $1,107

TOTAL TRUST FUND PROJECT BUDGET: $61,000

Explanation of Capital Expenditures Greater Than $3,500: *none*

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

B. Other Funds Proposed to be spent during the Project Period:

C. Past Spending:

D. Time:

VII. DISSEMINATION:

At the time of writing we are in the final stages of releasing the project, which we will promote through our contacts with agencies, potential users, and the MN GIS/LIS Consortium conference in Duluth in October.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than June 2008, December 2008, June 2009**. A final work program report and associated products will be submitted between June 30 and August 1, 2009 as requested by the LCCMR** .

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2008 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: *Democratizing access to Minnesota's data assets – a user friendly data integration and visualization tool*

Project Manager Name: *Terry Brown*

Trust Fund Appropriation: $ *61,000*

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2008 Trust Fund Budget	Result 1 Budget:	Amount Spent (6/30/09)	Balance (6/30/09)	Result 2 Budget:	Amount Spent (6/30/09)	Balance (6/30/09)	TOTAL BUDGET	TOTAL BALANCE
	Development of the DataWorkshop			DataWorkshop Online				
PERSONNEL: wages and benefits	10,430	11,125	-695	47,803	48,093	-290	58,233	-985
Other direct operating costs: *GIS lab. user fees*	500	500	0	607	607	0	1,107	0
Printing	0	0	0	0	100	-100	0	-100
Other Supplies: *backup media*	480	175	305	0	0	0	480	305
Travel expenses in Minnesota	590	200	390	590	200	390	1,180	780
COLUMN TOTAL	**$12,000**	**$12,000**	**$0**	**$49,000**	**$49,000**	**$0**	**$61,000**	**$0**

Invoice detail for LCCMR funded project *"DataWorkshop: Democratizing access to Minnesota's data assets – a user friendly data integration and visualization tool"* (described as *"Deliverable A5: User-Friendly Data Portal – GIS Data"* on the invoice).

This project produced a web-based application for performing simple GIS data processing and turning GIS data sets into simple maps. The application increases access to the large quantity of GIS data that is available on-line but could not previously be used without specialist training and / or software.

Spending was consistent with the proposal, primarily salary expenditure to cover application development: **$59218** (George Host, management, $6967, Terry Brown, development, $52,251).

- software system evaluation and selection
- software development
- software testing
- software deployment system development
- documentation preparation
- project management and administration

Additional expenditure covered:

- GIS lab. fees: **$1107**
  - access to source data sets
  - server space
- Supplies (backup media, poster preparation): **$275**