2010 Project Abstract
For the Period Ending June 30, 2015

PROJECT TITLE: Agricultural and Urban Runoff Water Quality Treatment Analysis
PROJECT MANAGER: Craig Austinson
AFFILIATION: Blue Earth County
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2010, Chp. 362, Sec. 2, Subd. 5d
M.L. 2014, Chapter 226, Section 2, Subdivision 19

APPROPRIATION AMOUNT: $485,000

Overall Project Outcomes and Results

This project provided proof to landowners and agencies that conditions for agricultural production were enhanced and water quality was improved by implementing a combination of Best Management Practices on Blue Earth County Ditch No. 57 (CD57) in the Mapleton area of south central Minnesota. These results surpassed expectations and overwhelmingly proved that water quality was improved by reducing sediment and nutrient loading throughout the system. Water storage and drainage capacity were increased, which reduced flooding and improved field conditions for crop yields.

A combination of BMPs included two water storage basins, buffer strips, two-stage ditch, and a rate control weir. The two storage basins significantly increased storage capacity, with the Klein Pond providing 26.3 acre-feet of storage and the City Pond providing 23 acre-feet. Peak flow rates were reduced with reductions ranging from 10% to 50% at Klein Pond and the rate control weir averaging 6% in reduction for monitored rain events.

Water quality results show dramatic improvements for Total Suspended Solids, Total Phosphorus and Nitrates. Reductions for each pollutant ranged between 15% and 50% for the Klein Pond, averaging nearly 25%. The two-stage ditch and rate control weir had reductions between 2% and 10%, averaging nearly 5%. The Klein Pond was most effective at removing trapped sediments: 230,000 pounds of sediment, 415 pounds of phosphorus, and 23,000 pounds of nitrogen. Of the three BMPs monitored, results showed they removed a total of 251,000 pounds of sediment, equivalent to nearly 75 dump truck loads. Unexpected baseflow water quality improvements include reductions in TSS by more than 33% and TP concentrations reduced by more than 16%. Baseflow water quality also improved and increased habitat for wildlife. This project had a significant improvement in water quality and makes the CD 57 system a thriving place for a variety of species to live.

Project Results Use and Dissemination

Communication and Outreach

The information from this project has been shared and disseminated in a variety of ways, including the following:

1. Event and Tour: Agricultural Drainage & the Future of Water Quality Workshop 2012
2. Event and Tour: Agricultural Drainage & the Future of Water Quality Workshop 2014 (165 in attendance)
3. Event: Agricultural Drainage & the Future of Water Quality Workshop 2015 (175 in attendance)
4. Multiple Site Visits: Blue Earth County, Minnesota Department of Agriculture, ISG and interested parties
5. Website: http://www.is-grp.com/ag
6. Presentations: By Chuck Brandel and/or Craig Austinson
    a. Minnesota State University Mankato, Department of Civil Engineering (2010)
    b. American Society of Civil Engineers (2011)
    c. Faribault County Drainage Authority (2013)
    d. Minnesota Water Resources Conference (2015)
    e. Iowa Water Conference (2014)
    f. Blue Earth County Soil and Water Conservation District (2014)
    g. Sibley County Drainage Authority (2015)
7. Article: Conservation Drainage article, DIRT Magazine (Gislason and Hunter Law Firm publication)
8. CD 57 Fun Facts Brochure: Distributed at various events and activities
9. Final Report: Summarizes the entire CD 57 project
10. Water Quality Report: Quantitative data and methods used in the water quality analysis and all results

Environment and Natural Resources Trust Fund (ENRTF)
2010 Work Plan Final Report

Date of Report: August 14, 2015
Date of Next Progress Report: Final Report
Date of Work Program Approval:
Project Completion Date: December 2014

I. PROJECT TITLE: Agricultural and Urban Runoff Water Quality Treatment Analysis

Project Manager: Craig Austinson
Affiliation: Blue Earth County
Mailing Address: Blue Earth County Drainage Authority, Blue Earth County Courthouse, 204 South Fifth St.
City /State / Zip: Mankato / MN / 56001
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Web Site Address: www.co.blue-earth.mn.us

Location: This project will occur within Mapleton and Beauford Townships in Blue Earth County. Specifically, water quality improvements are proposed for County Ditch No. 57 at a point approximately 0.5 miles to the southwest of the City of Mapleton through to its terminus at the Big Cobb River, approximately five miles to the northeast of the City of Mapleton. An exhibit is enclosed that identifies the project location within Blue Earth County.

Total ENRTF Project Budget:	ENRTF Appropriation:	$	485,000.00
	Minus Amount Spent:	$	482,042.15
	Equal Balance:	$	2957.85

Legal Citation: M.L. 2010, Chp. 362, Sec. 2, Subd. 5d
M.L. 2014, Chapter 226, Section 2, Subdivision 19

Appropriation Language:
$485,000 is from the trust fund to the Board of Water and Soil Resources for an agreement with the Blue Earth County Drainage Authority to reduce soil erosion, peak water flows, and nutrient loading through a demonstration model evaluating storage and treatment options in drainage systems in order to improve water quality. This appropriation is available until June 30, 2014, by which time the project must be completed and final products delivered.
Carry forward: The availability of the appropriations for the following projects are extended to June 30, 2015: (10) Laws 2010, chapter 362, section 2, subdivision 5, paragraph (d), Agricultural and Urban Runoff Water Quality Treatment Analysis.

II. PROJECT SUMMARY AND RESULTS

This project is a model for future drainage projects across the state and represents a fundamental shift in the way rural drainage systems interact with the landscape. This is a community-based water quality and treatment demonstration project in which landowners, local government, and state agencies have developed a watershed approach to improving water quality and replacing outdated drainage systems. The project will improve water quality, improve wildlife habitat, and develop a process for future projects by constructing water quality features within the 6,000 acre watershed. The project focuses on Blue Earth County Ditch 57, part of the Le Sueur River Minor Watershed of the Minnesota River Basin. This watershed includes runoff from agricultural as well as urban sources.

ENRTF funding will provide assistance to construct two surge basins, in-channel treatment, native grass buffer strips, and a rate control weir at the outlet of the ditch. Nine monitoring stations are also proposed that will record flow and water quality data for three years. In addition, this project will provide documentation on how successful water quality treatments can be incorporated into Drainage Law. Once monitoring is completed, public education via site visits, presentations, and information posted to web sites will be provided to describe the effect of project features on water quality and how these features can be incorporated into other drainage projects.

III. PROGRESS SUMMARIES

Progress Summary as of January 15, 2011

The construction portion of the project stated in September one surge basin and in-channel and is approximately 15% complete. Work ceased in November due to the depth of the snow fall. Construction should be completed this summer with the planting of the native grass buffers starting after the earth work has been completed. The monitoring stations have not yet been constructed but we pulled grab samples before construction began.

Progress Summary as of July 15, 2011

Construction was delayed due to the wet spring and some difficulty in obtaining a permit from MnDOT. Construction on the 2nd surge basin is 85% complete and will be completed shortly. Construction on the first surge basin will resume as soon as we obtain the MnDOT permit. We will continue to pull grab samples until the monitoring stations are constructed.

Progress Summary as of January 15, 2012

The construction of the project is completed except for final stabilization and grass strips. Construction was difficult due to the large amount of snow and rain in the Winter of 2010/2011 and Spring/Summer 2011. This caused added expenses to dewater and regrade portions of the project that were previously constructed in November 2010. The dry fall of 2011 did help to get the project completed but change orders have added to the construction budget. Monitoring structures will be ordered in March 2012 for installation for the monitoring during the 2012 growing season. Minnesota State University Civil Engineering Students will be utilized to assist in monitoring and gathering data throughout the project.

Progress Summary as of July 15, 2013

The native grass seeding is progressing, with a mowing occurring anytime. Monitoring continuing, numerous rain events in 2013 have given significant amounts of data but also caused issues due to the prolonged high water levels. Some monitoring equipment has been damaged and needs to be replaced. MSU students are continuing to assist with monitoring and water quality sampling.

Progress Summary as of January 15, 2014

Monitoring is completed for 2013. Analysis for previous two years of monitoring is currently being completed. MSU students are continuing to assist with monitoring and water quality sampling.

Progress Summary as of July 15, 2014

The native grass is better than was in 2014 but needed to be replanted is some areas. A side inlet blew out during the spring rain events. The cause appears to be a redirection of the surface flow by a landowner. Monitoring is continuing. A workshop outlining 2013 results was presented to 180+ people on June 26, 2014.

Progress Summary as of January 15, 2015

The project construction and monitoring is complete. The final data from monitoring was completed in December 2014 and the final report is currently being reviewed for completion. The results of the project are very promising with significant reductions in peak flow, TSS, phosphorus and nitrogen reported for the BMPs.

Progress Summary as of July 1, 2015
The final data from monitoring has been completed and a full water quality analysis has also been completed on the collected data. The analysis includes data collected from the 3 years of post BMP installation (2012-2014) and 3 years of pre BMP installation (2009-2011). A final report has been completed summarizing the entire CD 57 project while a water quality report is complete which specifically addresses methods used in the water quality analysis. These reports are complete and are being formatted with graphics to make each report easier to read. The reports will be submitted to the LCCMR on July 15, 2015. The project was a success in that the monitoring has shown that the BMP's reduced peak flows, flooding, total suspended solids and phosphorus while providing drainage capacity for the adjacent farmland to increase productivity.

Final Summary
<u>Overall Project Outcomes and Results</u>
This project provided proof to landowners and agencies that conditions for agricultural production were enhanced and water quality was improved by implementing a combination of Best Management Practices on Blue Earth County Ditch No. 57 (CD57) in the Mapleton area of south central Minnesota. These results surpassed expectations and overwhelmingly proved that water quality was improved by reducing sediment and nutrient loading throughout the system. Water storage and drainage capacity were increased, which reduced flooding and improved field conditions for crop yields.

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IV. OUTLINE OF PROJECT RESULTS

Result 1: Provide storage and treatment for agricultural and urban runoff to improve water quality and improve habitat diversity.

Description: To provide storage for runoff from agricultural and urban sources, two surge basins will be designed and constructed that will have a combined capacity for storage of 40 acre-feet of runoff. These basins will be constructed adjacent to the existing and proposed ditch improvements. Trust fund dollars will be used to purchase permanent easements on 1 acre for one of the basins and the landowners will purchase the remaining land for that basin. The other basin will incorporate land already owned by the City of Mapleton. Trust fund dollars will also be utilized for the design, excavation and seeding for the basins including the expansion of an existing City Pond to provide additional storage in the system. To improve water quality, a two-stage ditch and sediment trap will be constructed that will provide in-channel treatment. This will be accomplished by widening and over excavating existing and proposed new portions of ditch that will be constructed with landowner funding. Trust Fund dollars will be used to purchase an easement on 4 acres of land to widen the ditch. Also trust fund dollars will be used for the additional excavation to widen the ditch and the additional native seeding required on the ditch benches.

Water quality will also be improved through the planting of native grass buffer strips along 4.1 miles of the ditch. The landowners will purchase the required 16.5 foot easements required by statute to complete this work, with a total of 17 acres being purchased for easement by the landowners. Trust funding will assist in funding planting of native grasses and purchasing easements for wider buffer areas up to 50 feet where necessary due to large amounts of flow and potential for erosion. The trust fund funding will also be utilized to provide maintenance of the native plantings during growth to provide an enhanced buffer for collection of the sediment that is entrained in overland flow before runoff reaches the ditch. The native plantings also represent an improvement in habitat diversity as compared to the monoculture typical of agricultural settings and the typically grasses planted in required buffers.

Finally, a weir will be placed at the outlet of the ditch near the confluence with the Big Cobb River. The purpose of the weir will be twofold. The weir will be designed to reduce peak flow along the ditch and also provide a means to divert runoff to US Fish and Wildlife (USFWS) property. The USFWS property is located to the north of the conjunction of the ditch with the Big Cobb River and will potentially utilize the diverted runoff to support a 40-acre wetland on USFWS property.

All of the water quality improvements that the trust fund is funding are not required by statute but are water quality features proposed by the landowners. The construction of these water quality improvements will occur on land under easements that will either be obtained by individual landowners or are already under the control of the Drainage Authority. All easements purchased will be permanent and the Blue Earth County Drainage Authority will be maintaining the easement and will monitor the condition of each of the water quality improvements. Any repairs to the proposed improvements will be paid for by the landowners in the system through the ditch repair fund which is controlled by the Blue Earth County Drainage Authority. The Drainage Authority has over 100 years of experience obtaining and maintaining permanent easements on drainage infrastructure. Some of these easements have included surge basins, in-channel easements, dams for lakes and other water quality structures. All easements are utilizing $5,000 per acre for estimate purchase. This number is based on recent land purchases in the area and the amount estimated for land purchase for RIM/WRP projects in this area for 2009.

A budget for each item as well as a timeline is presented in the table below.

Summary Budget Information for Result 1: ENRTF BUDGET: $270,463
Amount Spent: $ 270,463
Balance: $268,505.15

Deliverable	Completion Date	Budget
Project Management, Hydrologic/Hydraulic Design, Construction Plans, and Onsite Project Management completed by I&S Group, Inc.	November 30, 2010	$80,562
Construct In Channel treatment in a new drainage ditch by widening 1610 feet of proposed new open ditch. Construction includes grading and seeding of benches with native seed.	November 30, 2010	$24,439
Easement Acquisition of 4 acres at $5000 per acre for widening of proposed and existing open ditch for construction of In-Channel Treatment by use of sediment basin and two stage ditch. Includes $1,000 for legal and appraisal services.	August 15, 2010	0
Construct two surge basins for storage and treatment of agricultural and urban runoff, including grading construction, outlet construction and seeding. Completed by grading contractor.	November 30, 2010	$156,000
Easement Acquisition of 1 acre at $5,000 per acre for Surge Basin Construction. Includes $1,000 for legal and appraisal services.	August 15, 2010	$0
Construct and Maintain Native Grass Buffer Strips on 4.1 Miles of Existing Open Ditch. 16.5 foot buffers will be purchased by landowners as required by statute. Seeding and wider buffers up to 50 feet in selected areas will be completed with trust funds. Also 3 years of maintenance will be performed to ensure establishment of buffers.	November 30, 2013	$9,462

Result Completion Date: November 30, 2013

Result Status as of January 15, 2011
Amendment Request: Due to a landowner backing out and declining the use land for one of the surge basins it is necessary to make some amendments to the project costs. We are able to relocate the basin to land owned by the City of Mapleton. The new location is less than 600 feet south east of the original location and is will treat water from the same sub-watershed so our deliverables will remain unchanged. We will need to shift some of the costs. Since easements on city owned land is unnecessary will be able to save the costs of purchasing easements which will offset most of the cost of re-engineering the basin. The bids for seeding of both basins are well under our estimate which is reflected in the lower seeding costs. Construction of the relocated basin will start in the spring of 2011.
Amendment approved:

100% of Hydraulic/Hydrologic Design Completed for Surge basins and In-Channel treatment, including preliminary and final reports, drainage authority hearings per statute, construction plans, construction specifications, and bidding. Project construction underway. 95% of In-channel Treatment completed. 20% of Surge Basin Construction Completed before winter freeze up. 50% of other work on system completed that is not part of LCCMR funding project
Amendment Approved: 5/9/14

Result Status as of July 15, 2011
Work on the 2nd surge basin is 85% completed. The MnDOT permit problem has delayed the outlet for the first surge basin so no additional work has been done other than mulching the site to prevent erosion.

Result Status as of January 15, 2012
Amendment Request: Due to large snow fall during the winter of 2010-2011 and rain during the spring/summer of 2011, and permit issues, the project was delayed and portions of the project needed to be re-graded, reworked, and dewatered multiple times. Also buried concrete debris was found below portions of the surge basin and needed to be removed and disposed of. These items caused the construction costs to exceed planned contingencies. All construction is completed except for final stabilization and seeding of grass buffers.

Amendment Approved: 5/9/14

Result Status as of July 15, 2013
All construction is completed except for maintenance of the seeding. A mowing is due at this time and will be completed shortly.

Result Status as of January 15, 2014
All construction is completed except for maintenance of the seeding. A mowing was completed in 2013 with one more in 2014. Amendment Request – seeding and maintenance lower than expected. Request funding shift to more monitoring in 2014.
Amendment Approved: 5/9/14

Result Status as of July 15, 2014
The native grass is better than was in 2014 but needed to be replanted is some areas. A side inlet blew out during the spring rain events. The cause appears to be a redirection of the surface flow by a landowner.

Progress Summary as of January 15, 2015
The project is complete. The final data from monitoring was completed in December 2014 and the final report is currently being reviewed for completion. The results of the project are very promising with significant reductions in peak flow, TSS, phosphorus and nitrogen reported for the BMPs. The system is working well and the native grasses need very little maintenance.

Progress Summary as of July 1, 2015 – Final Report Summary
The final data from monitoring has been completed and a full water quality analysis has also been completed on the collected data. The analysis includes data collected from the 3 years of post BMP installation (2012-2014) and 3 years of pre BMP installation (2009-2011). A final report has been completed summarizing the entire CD 57 project while a water quality report is complete which specifically addresses methods used in the water quality analysis. These reports are complete and are being formatted with graphics to make each report easier to read. The reports will be submitted to the LCCMR on July 15, 2015.

Result 2: Monitor and Analyze how the proposed strategies improve water quality and reduce peak flows

Description: This item includes the construction and installation of control and monitoring structures including the time to gather the data from each structure. The control structures will meter flow throughout the system. Control structures will be constructed at the end of the system, at the downstream end of the in-channel treatment area, at the inlet to the in-channel treatment area, and at the outlet of each surge basin. Monitoring structures will be also be located along with the control structures where feasible and along strategically placed locations in the watershed. These areas include a portion of the system that have no water quality treatment and is primarily agricultural flow, a portion of the system that has primarily urban flow and the outlet for the potential wetland restoration area.

Monitoring structures will monitor flow and allow for composite and grab samples to monitor Total Suspended Solids, Phosphorus, Nitrogen and other pollutants. Monitoring structures will be placed throughout the watershed to determine the effectiveness of each of the proposed water quality improvements. The flow will be monitored for a total of three years. After which, a monitoring report will be prepared to summarize the results and provide recommendations for future water quality improvements.

A budget for each item as well as a timeline is presented in the table below.

Summary Budget Information for Result 2: ENRTF BUDGET:$ 182,726
Amount Spent: $ 182,726
Balance: $ 0

Deliverable	Completion Date	Budget
Construction of Rate Control Structures including structures at inlet and outlet of in-channel treatment area, the outlet for both surge basins, the outlet of the southern improvement and the including Rate Reduction Weir at End of System	November 30, 2010	$50,750
Construct 9 monitoring structures including samplers and data loggers. All structures will monitor flow and 6 structures will also have samplers	November 30, 2010	$11,500
Project Management, Hydrologic/Hydraulic Analysis, Develop Base Flow Report, Complete assessment of multiple treatment options and how they benefit a diverse watershed and improve water quality. Complete Monitoring Report.	Request Extension to December 2014	$100,495
Testing Results of Samples estimated at $80 per sample with 125 samples taken over monitoring period	Request Extension to December 2014	$19,981

Result Completion Date: ~~June 30, 2014~~ – Request Extension to December 2014

Result Status as of January 15, 2011

Amendment Request: The bids for the control structures came in over our estimate so we will need to increase that cost in our budget. We are now going to partner with MSU Mankato for analysis and reporting so we are able to reduce this portion of the budget and allowing us to switch the costs to the additional costs of moving of the surge basin in result 1.
Amendment approved:

Pre-Construction Sampling in summer and fall 2010 completed to provide base line for watershed before construction of water quality improvements. Samples during rain events and rain gage data collected during this time. Samples analyzed by independent lab

Amendment Approved: 5/9/14

Result Status as of July 15, 2011
Samples continue to be collected during construction.

Result Status as of January 15, 2012
Amendment Request: More cost effective flow rate monitoring equipment which is currently being used by MSU Mankato has been found to allow more monitoring sites (12) at a much lower cost. This allows us to get more flow rate data and do more water quality testing. The result will be more data with less cost. This helps to make up for some of the overruns during construction. Also a contract with MSU Mankato will be utilized to assist with monitoring and utilizing some of the MSU Mankato equipment. This all results in a lower cost for the same monitoring result.

Monitoring continued during portions of construction. Monitoring equipment will be ordered for the newly constructed structures and installed in March 2012.

Result Status as of July 15, 2013
Amendment Request: The seeding cost has been reduced due to a portion of land previously seeded by landowners into CRP and a low bid price per acre. The amendment is requested due to the large amount of rain and the damage to equipment that more time is needed for monitoring. MSU has added their biology department to assist in water quality sampling and I&S has spent more time monitoring structures due to the large amount of flow and rain. Structures have been reset to higher ground and some equipment repurchased.

Result Status as of January 15, 2014
Amendment request: The seeding cost has been reduced including maintenance. Monitoring continued and was completed for 2013. Analysis of data is currently being completed. This amendment is to continue monitoring through the 2014 growing season utilizing MSU Engineering and Biology Departments and I&S for final analysis in December 2014.
Amendment Approved: 5/9/14

Result Status as of July 15, 2014
Monitoring is continuing for completion in 2014. Analysis for previous two years of monitoring is currently being completed. MSU students are continuing to assist with monitoring and water quality sampling. A workshop outlining 2013 results was presented to 180+ people on June 26, 2014. The different surge ponds, two stage ditch and the weir are working as expected in reducing the surge during rain events. We are also seeing significate reductions in TSS, Phosphorus and Nitrogen. A more detailed report of the 2013 results are attached. A complete report will be completed after we finish with the 2014 monitoring.

Progress Summary as of January 15, 2015
The project is complete. The final data from monitoring was completed in December 2014 and the final report is currently being reviewed for completion. The results of the project are very promising with significant reductions in peak flow, TSS, phosphorus and nitrogen reported for the BMPs. There is much interest in continuing the monitoring. Additional grants are being perused and the equipment for this project is being proposed to be utilized to continue monitoring in 2015 and beyond.

Progress Summary as of July 1, 2015 – Final Report Summary
The final data from monitoring has been completed and a full water quality analysis has also been completed on the collected data. The analysis includes data collected from the 3 years of post BMP installation (2012-2014) and 3 years of pre BMP installation (2009-2011). A final report has been completed summarizing the entire CD 57 project while a water quality report is complete which specifically addresses methods used in the water quality analysis.

The water quality monitoring and analysis for the CD 57 system showed several water quality benefits. Average peak flow reductions for the rate control weir and Klein Pond were 6 and 28 percent respectively. The rate control weir, Klein Pond, and two-stage ditch showed reductions between 5 and 25 percent for total suspended solids (TSS), phosphorus, and nitrogen. The Klein Pond removed 725 cubic yards of sediment over the 3 years of monitoring. Baseflow concentrations of TSS and TP were reduced on average of 30 percent compared to the pre BMP installation data. Overall, the BMPs installed in the CD 57 system showed significant water quality improvements for the three years of post BMP installation monitoring.

Result 3: Provide documentation on how the drainage/treatment system could be incorporated into Drainage Law

Description: A drainage law expert will be hired to assist with incorporating the drainage/treatment system into drainage law. The findings will also be presented in a report to the state legislature. It is anticipated that this will be completed by June 30, 2014.

Summary Budget Information for Result 3:	ENRTF BUDGET:	$13,811
	Amount Spent:	$12,811
	Balance:	$1,000

Deliverable	Completion Date	Budget
Provide Report to Legislature on how treatment/storage options could be incorporated into new Drainage Law completed by Drainage Authority, Engineer and drainage law expert.	June 30, 2014	$13,811

Result Completion Date: June 30, 2014

Result Status as of January 15, 2011
We are still in the construction phase of this project and have yet not started working on this result.

Result Status as of July 15, 2011
A draft of the preliminary data collected so far is almost complete and is being reviewed.

Result Status as of January 15, 2012
Preliminary data collected will be reviewed as part of the final report.

Result Status as of July 15, 2013
The data is still being collected. Minor analysis has been performed.

Result Status as of January 15, 2014
Amendment Request: Data is being collected. A June 2014 workshop is being planned to discuss some results. Extension to December 2014 requested to include 2014 growing season data. Additional analysis due to more data in 2014.

Result Status as of July 15, 2014
Monitoring is continuing for completion in 2014. Analysis for previous two years of monitoring is currently being completed. MSU students are continuing to assist with monitoring and water quality sampling. A workshop outlining 2013 results was presented to 180+ people on June 26, 2014.

Result Status as of January 15, 2015

The final report is almost completed and will be reviewed by project partners. Since others have reviewed drainage law, this report concentrates on how the individual practices fit into current drainage law. Also potential changes are suggested that would make implementation of the practices used here easier for landowners and drainage authorities to implement.

Progress Summary as of July 1, 2015 – Final Report Summary
The final data from monitoring has been completed and a full water quality analysis has also been completed on the collected data. The analysis includes data collected from the 3 years of post BMP installation (2012-2014) and 3 years of pre BMP installation (2009-2011). A final report has been completed summarizing the entire CD 57 project while a water quality report is complete which specifically addresses methods used in the water quality analysis. The final report addresses how BMPs can be incorporated into Minnesota drainage law and what parties should be involved. As of 2014, drainage projects need to acknowledge drainage and water quality when working on county ditch systems. While many BMPs have been suggested for these projects, as done similarly in CD 57, implementation has not been 100 percent for the suggested practices.

Result 4: Provide Outreach, Education, Field Days, and Website Development

Description: A final technical memorandum will be prepared to summarize the results of the monitoring. Field site presentations will be conducted to identify pertinent project features to interested parties including Drainage Authorities, Watershed Groups, Landowners, and State Agencies. In addition, presentations to organizations such as the annual Water Resources Conference are anticipated in order to demonstrate model effectiveness in other systems. Results, design, and other final products will then be posted to county, agency and firm websites. A budget for each item as well as a timeline is presented in the table below.

Summary Budget Information for Result 4: ENRTF BUDGET: $18,000
Amount Spent: $18,000
Balance: $0

Deliverable	Completion Date	Budget
Completion of Final Technical Memorandum by I&S and Blue Earth County Drainage Authority.	June 30, 2014	$7,000
Provide four field days at site during and after construction inviting county drainage authorities and landowners, items included are copies, onsite signage, facility rentals, and personnel time by I&S.	June 30, 2014	$4,000
Provide multiple presentations to County Drainage Authorities, Watershed Organizations, and other organizations to demonstrate how model can be duplicated on other drainage systems. Items included are copies, facility rentals and personnel time by I&S.	June 30, 2014	$5,000
Post Results, Design Model, and provide Technical Memorandum on Partner Websites including updates during monitoring timeframe.	June 30, 2014	$2,000

Result Completion Date: June 30, 2014

Result Status as of January 15, 2011
We are still in the construction phase of this project and have yet not started working on this result.

Result Status as of July 15, 2011
We are still in the construction phase of this project and have yet not started working on this result.

Result Status as of January 15, 2012
Amendment Request: I&S and MN Department of Agriculture will be sponsoring the first of 5 field days in June of 2012 with no assistance of the LCCMR funds. This will reduce the cost of future field days as the invite list and some of the marketing materials can be reused. Also since the field day will be on-site no facility rental will be needed.

Result Status as of July 15, 2013
A drainage workshop was completed in June of 2012 to display progress on the system. No LCCMR funds were used for this workshop.

Result Status as of January 15, 2014
Data is being collected. A June 2014 workshop is being planned to discuss some results. Extension to December 2014 requested to include 2014 growing season data.

Result Status as of July 15, 2014
A workshop outlining 2013 results was presented to 180+ people on June 26, 2014. This project is continuing to be used as an example for other projects. There have several groups meeting at the site to discuss alternatives to traditional drainage, including soybean and corn growers and watershed groups such as the Le Sueur watershed.

Result Status as of January 15, 2015
This project is continuing to be used as an example for other projects. The final results are proposed to be presented to multiple drainage authorities, workshops and conferences. There have been hundreds of people that have toured the BMP's and marketing of the project has been done in 2 workshops, at the Minnesota Water Resources Conference, and in trade magazines. There have several groups meeting at the site to discuss alternatives to traditional drainage, including soybean and corn growers and watershed groups such as the Le Sueur River Watershed. Continued monitoring and presentations are proposed including a presentation at the Iowa Water Conference in 2015

Progress Summary as of July 1, 2015– Final Report Summary
This project has continued its reputation for being a model for current and future drainage projects in Minnesota. Along with the three previous drainage workshops held relating to this project, a fourth workshop is scheduled for the fall of 2015. This workshop will be similar to the previous three and will discuss how BMPs can and should be incorporated into drainage systems.

Along with the 4 workshops, several other educational outreaches have been done for CD 57 including a publication in DIRT Magazine and several presentations to audiences such as other drainage authorities, watershed groups, water resources conferences, and local SWCD groups.

<u>Overall Project Outcomes and Results</u>
Agencies and landowners needed proof that conditions for agricultural production could be enhanced and water quality could be improved by implementing a combination of Best Management Practices on Blue Earth County Ditch No. 57 (CD 57) in the Mapleton area of south central Minnesota.

This project provided evidence that these goals can be accomplished using landowner contributions and the help of grant funding to support Minnesota Drainage Statute 103E. Water storage and drainage capacity were improved resulting in reduced flooding to improve field conditions for crop yields. Water quality was also improved by reducing sediment and nutrient loading throughout the system.

The CD 57 system is part of a river system that includes the Big Cobb River, Le Sueur River, Blue Earth River, Minnesota River, and eventually drains into Lake Pepin and then the Gulf of Mexico. The CD 57 Watershed encompasses 6,000 acres including the entire City of Mapleton. The Minnesota River and its tributaries are impaired water for turbidity, aquatic life, fecal coliform, aquatic recreation, and aquatic consumption. This project provided a reduction of total suspended solids, nitrogen and phosphorus runoff from this area. It improved water quality by providing water storage and treatment of urban and agricultural runoff while enhancing conditions for improved crop yields and reducing flooding in portions of the watershed.

A *Final Report* and a *Water Quality Report* include the project process, methods and results. It serves as a model that can, and should be incorporated into new Drainage Law and utilized on deteriorating drainage systems as they need to be updated. Other watersheds can now utilize similar treatment options on agricultural and urban systems. This project showcases how water quality improvements can and should be implemented along with improvement and repair projects for agricultural drainage systems using grant funding along with landowner contributions.

V. TOTAL ENRTF PROJECT BUDGET

Personnel: All personnel time by Blue Earth County is in Kind to the project – see Attachment B

Contracts: $477,200 Total:

$187,519 to I&S Group Inc. acting as Engineer for Blue Earth County Drainage Authority to assist Blue Earth County in the project management and completion of the hydrologic and hydraulic design for the water quality improvements, the construction plans and specifications, onsite project administration, environmental consultation and technical memorandums. I&S will also perform monitoring, including downloading of data and collection of grab and composite samples and analysis. As results are documented I&S will coordinate presentations and website development to promote the water quality improvements and how they can be incorporated into future projects.

$5,000 for a to be determined drainage law expert to assist in completing report to Legislature on how treatment/storage options could be incorporated into new Drainage Law.

$231,189 to a Grading Contractor to be determined by publically bidding the project. The selected contractor will complete the grading of the surge basins, the grading of in-channel treatment, installation of the rate reduction weir, and all control structures associated with the water quality improvements.

$9,505 to a Seeding Contractor to be determined by publically bidding the project. The selected contractor will complete the seeding of the native grass buffers along 4.1 miles of open ditch. The contractor will also perform routine maintenance of the plantings for 3 years to ensure establishment. This will include 20 acres of seeding with the seed, weed control, re-seeding, and maintenance estimated at $3,000 per acre.

$ (11,500) to a Monitoring Equipment Supplier to purchase ~~and install 9~~ 12 monitoring stations with equipment appropriate to each location. This equipment will include water samplers, flow monitoring and data loggers.

$19,981 to a Testing Lab to test the Grab and Composite Samples throughout the monitoring period. Testing of Samples with an estimated~~125~~ 294 samples taken over monitoring period.

Equipment/Tools/Supplies: $1,000 for project website development and postings to Blue Earth County, Minnesota Department of Agriculture, and other agency websites.

Acquisition (Fee Title or Permanent Easements): $ 0
Using LCCMR funds for the acquisition of easements is no longer necessary due to the switch the 2nd treatment basin to property owned by the City of Mapleton. We will be using the funds from the landowners to purchase the easement for the 1st basin.

Additional Budget Items:
$2,500 for 10 Facility Rentals at $300 each for presentations and field days. Based on current Blue Earth County Library Rates.

$3,000 for completion of mailings, notices, handouts for Field Days and for Presentations. This is estimated at $250 per field day or presentation.

$500 completion of onsite project signs for field days and public viewing

VI. PROJECT STRATEGY

A. Project Partners

Partner	Duties/Function	Appropriation Funding Amount
Blue Earth County Drainage Authority	• Project Management • Project Administration • Review and Approval of Project • Distribute ENRTF Funding for Drainage Improvements	$297,481[1]
Minnesota Department of Agriculture	• Co-Sponsor • Assist with Design, Monitoring, Technical Memorandum, and Presentations	$0 (All Time is in-kind)
Minnesota Department of Natural Resources (DNR)	• Provide Review of the Proposed System	$0 (all time is in-kind and required by Drainage Law)
Land Owners in Blue Earth County Ditch No. 57	• Funding source for majority of project costs • Recipients of project improvements	$0
I&S Group, Inc.[1]	• Provide Design • Assist with Project Administration, Monitoring, and Technical Memorandum • Presentations of Results	$187,519[1]
Blue Earth Soil and Water Conservation District	• Provide Review and Funding for 7 acre surge basin	$0
Greater Blue Earth River Basin Alliance (GBERBA)	• Provide Review and Funding for 7 acre surge basin	$0
Natural Resources Conservation Service (NRCS)	• Funding source for Wetland Restoration Project	$0

[1]I&S Group will be acting as engineer for the Blue Earth County Drainage Authority. Blue Earth County Drainage Authority will distribute $182,519 of funds to I&S Group for Design, Monitoring, Reports and Presentations. I&S will also complete project signs and printing, mailings and handouts for field days and presentations.

B. Project Impact and Long Term Strategy

The Blue Earth County Ditch No. 57 (BECD57) system drains into the Big Cobb River, which drains into the Le Sueur River, which drains into the Blue Earth River just before the Blue Earth River converges with the Minnesota River, which eventually drains into Lake Pepin and then the Gulf of Mexico. The BECD57 Watershed also encompasses 6,000 acres including the entire City of Mapleton (population 1,662). The Minnesota River and its tributaries are impaired water for turbidity, aquatic life, fecal coliform, aquatic recreation, aquatic consumption, etc. The project seeks to impact the area by improving water quality in the Minnesota River Basin by providing storage and treatment of both agricultural and urban runoff in the Big Cobb River Watershed while increasing yield and reducing flooding in portions of the watershed. The project will also develop a model that could be incorporated into new Drainage Law and utilized on deteriorating drainage systems as they need to be updated. A reduction of total suspended solids, nitrogen and phosphorus runoff from this area is expected. If results are positive this model utilizing a multiple treatment options could be utilized on other agricultural systems and could be incorporated into new ditch legislature.

In addition, after project completion, the monitoring of the system could continue indefinitely. This could be funded by others or taken up by another public entity or university program to determine the longer term effects of the system. If successful, this system could also be duplicated in other portions of the Minnesota River Basin and additional projects could be added in this watershed could be added.

C. Other Funds Proposed to be Spent during the Project Period

Land Owners will pay $30,000 to acquire permanent easement on 5 acres of land for one surge basin and temporary construction easements for excess material and land disturbance during construction. Land Owners will construct $726,105 of drainage improvements replacing 100 year old portions of the drainage system. These improvements include construction of 1610 feet of new open ditch, construction of1640 feet of 54-inch tile, construction of field crossings sized to control peak flow, 3.1 acres of permanent easement acquisition for open ditch construction, 16 acres of temporary easement acquisition for land disturbance and spoil placement, seeding of the open ditch, directional boring of tile under in place county roads, construction of 2290 feet of 24-inch tile, construction of 1250 feet of 18-inch tile, tile connections to the new tiles, drop intakes, design of the system, hiring viewers to view the ditch per statue, legal fees, and administration costs. Owners will acquire 17 acres of land for 16.5 foot wide buffer strips estimated at $85,000. Cobb River Watershed will contribute $26,700 (Pending) for additional excavation costs for the construction of one of the surge basins. NRCS will purchase easement and construct 40-acre wetland for $300,000 (Pending). I&S Group has donated approximately $15,000 for preliminary design, grant research, grant writing and other project work to obtain funds through the LCCMR and other sources.

Total estimated other funding is $1,182,805.

D. Spending History

Land Owners have spent approximately $800,000 on the preparation of surveys, preliminary designs, preliminary engineering reports, grants, ditch viewing, land owner meetings, and construction. Most of the construction is completed.

VII. DISSEMINATION

Blue Earth County, I&S Group and speakers from other agencies, potentially including Minnesota Department of Agriculture, Minnesota Department of Natural Resources, and others, will conduct as many as five field visits to the site to identify project features to interested parties. In addition, Blue Earth County and I&S Group will provide multiple presentations how the model can be replicated on other drainage systems. The results and design model will then be posted on partner and firm websites along with a technical memorandum. Websites include Blue Earth County (www.co.blue-earth.mn.us), Minnesota Department of Agriculture (www.mda.state.mn.us), and I&S Group (www.is-grp.com).

Final Report Summary

The information from this project has been shared and disseminated in a variety of ways including:

1. Event and Tour: Agricultural Drainage & the Future of Water Quality Workshop 2012
2. Event and Tour: Agricultural Drainage & the Future of Water Quality Workshop 2014 (165 in attendance)
3. Event: Agricultural Drainage & the Future of Water Quality Workshop 2015 (175 in attendance)
4. Multiple Site Visits: Blue Earth County, Minnesota Department of Agriculture, ISG and interested parties
5. Website: http://www.is-grp.com/ag
6. Presentations: By Chuck Brandel and/or Craig Austinson
    a. Minnesota State University Mankato, Department of Civil Engineering (2010)
    b. American Society of Civil Engineers (2011)
    c. Faribault County Drainage Authority (2013)

d. Minnesota Water Resources Conference (2015)
e. Iowa Water Conference (2014)
f. Blue Earth County Soil and Water Conservation District (2014)
g. Sibley County Drainage Authority (2015)

7. Article: Conservation Drainage article, DIRT Magazine (Gislason and Hunter Law Firm publication)
8. CD 57 Fun Facts Brochure: Distributed at various events and activities
9. Final Report: Summarizes the entire CD 57 project
10. Water Quality Report: Quantitative data and methods used in the water quality analysis and all results

VIII. REPORTING REQUIREMENTS

January 2015

Periodic work program progress reports will be submitted in January and July of each year between 2010 and 2014. A final Work Program report and associated products will be submitted by July 15, 2015 as requested by the LCCMR.

Final Attachment A: Budget Detail for 2010 Projects - Summary and a Budget page
Submital Date: December 27, 2010
Project Title: Mapleton Area Agricultural/Urban Runoff Water Quality Treatment Analysis

Project Manager Name: Craig Austinson, Blue Earth County

Trust Fund Appropriation: $ **485,000**

2010 Trust Fund Budget	Result 1 - Provide storage and treatment for agricultural and urban runoff to improve water quality	Result 1 Budget:	Revised Result 1 Budget (1/15/15)	Amount Spent (6/30/15)	Balance (6/30/15)	Result 2 - Monitor and Analyze how the proposed strategies improve water quality and reduce peak flows	Result 2 Budget:	Revised Result 2 Budget (1/15/14)	Amount Spent (6/30/15)	Balance (6/30/15)
BUDGET ITEM	Design and Construction of Two Surge Basins, In-Channel Treatment, Control Structure on Outlet, and Seeding of Grass Strip with Native Buffers					Construct and Install Control Structures, and Monitoring Structures, Monitor Flow for 3 years, Complete Monitoring Report and Technical Memorandum				
PERSONNEL: wages and benefits (ALL PERSONNEL TIME IS IN-KIND)										
Contracts										
Professional/technical	I&S Group, Inc - Project Management, Design, Specifications, Hydrology/Hydraulics, and Environmental Consultation	~~30,000~~	54,099	54,099	0	I&S Group, Inc - Project Management, Technical Writing, Hydrology/Hydraulics, Monitoring, Grab Samples, and Analysis	~~75,000~~	100,495	100,495	0
	I&S Group, Inc - Project Management, Onsite Project Administration **		18,463	18,463	0					
	I&S Group, Inc - Project Construction Staking		8,000	8,000	0					
Other contracts	Grading Contractor to build In-Channel Treatment Basins and Surge Basins	~~164,000~~	180,439	180,439	0	Grading Contractor to Furnish and Install Control Structures	~~50,000~~	50,750	50,750	0
	Seeding Contractor for Seeding and Maintainence of Vegative Strips along 4.1 Miles of Open Ditch with Native Buffers	~~60,000~~	9,462.00	7,504.15	1,957.85	Supplier for Monitoring Equipment to Furnish and Install Samplers and Data Loggers	~~36,000~~	11,500	11,500	0
		0		0		Testing Lab to Test Grab Samples estimated at $80 per sample with 125 samples taken over monitoring period	~~10,000~~	19,981	19,981	0
Non-capital Equipment / Tools										
Land acquisition										
Easement acquisition*	**0.64~~(4)~~ Acres for In-Channel Treatment**	~~20,000~~	0	0	0					
	1 Acres for Surge Pond	~~5,000~~	0	0	0					
Professional Services for Acq.*	**Realator/Apraiser to be Determined**	~~2,000~~	0	0	0					
Facility Rental for Field Days and Presentations										
Copying/Printing/Mailings										
Onsite Signage										
Travel expenses in Minnesota	**Blue Earth County Travel all In Kind**	0		0	0					
COLUMN TOTAL		**~~$281,000~~**	**$270,463.00**	**$268,505.15**	**$1,957.85**		**~~$171,000~~**	**$182,726**	**$182,726**	**$0**

2010 Trust Fund Budget	Result 3 - Provide documentation on how the drainage/treatment system could be incorporated into Drainage Law	Result 3 Budget:	Revised Result 3 Budget (1/15/14):	Amount Spent (6/30/15)	Balance (6/30/15)	Result 4 - Provide Outreach, Education, Field Days, and Website Development	Result 4 Budget:	Revised Result 4 Budget (2/8/12)	Amount Spent (6/30/15)	Balance (6/30/15)	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	Completion of Report on Drainage Law					Provide five field days at site, Provide multiple presentations how model can be duplicated on other drainage systems, Post Results, Design Model, and provide Technical Memorandum on Partner Websites including updates during monitoring timeframe						
PERSONNEL: wages and benefits (ALL PERSONNEL TIME IS IN-KIND)												
Contracts												
Professional/technical	I&S Group, Inc - Project Management, Technical Writing, Hydrology/Hydraulics Analysis	~~4,000~~	7,811	7,811	0	I&S Group, Inc - Project Management, Technical Input, Coordination of Presentations and Completion of Technical Memorandum	~~16,000~~	11,000	11,000	0	173,405	0
											18,463	0
	Hire a Drainage Law Expert to Review and Provide Documentation for report and to present report to Legilature**	5,000	5,000	4,000	1,000		0	0	0	0	13,000	1,000
Other contracts											231,189	0
											20,962	1,957.85
				0					0		19,981	0
Non-capital Equipment / Tools						Website Development and Postings to Blue Earth County, Minnesota Department of Agriculture and other agency websites	1,000	1,000	1,000	0	1,000	0
Land acquisition											0	0
Easement acquisition*											0	0
											0	0
Professional Services for Acq.*											0	0
Facility Rental for Field Days and Presentations						10 Facility Rentals at $300 each (Based on Blue Earth County Library Rates) for Field Days and Presentations	3,000	3,000	3,000	0	3,000	0
Copying/Printing/Mailings	Mailings and Report Presentation Handouts	1,000	1,000	1,000	0	Mailings, Notices, Handouts for Field Days and for Presentations Estimated at $250 per field day or presentation	2,500	2,500	2,500	0	3,500	0
Onsite Signage						Provide Onsite Project Signage for Field Days	500	500	500	0	500	0
Travel expenses in Minnesota												
COLUMN TOTAL		**~~$10,000~~**	**$13,811**	**$12,811**	**$1,000**		**~~$23,000~~**	**$18,000**	**$18,000**	**$0**	**$485,000.00**	**$2,957.85**

* All Easement Acquisition Paid for by Landowners with $30,000 contribution to Water Quality. City of Mapleton donated easement for use of surge pond wihich accounted for more storage. Professional Fees and Consturction Fees then moved from Landowner $30,000 contribution to LCCMR.

I+S GROUP

FINAL REPORT PREPARED FOR:
MINNESOTA LEGISLATIVE-CITIZENS COMMISSION ON MINNESOTA RESOURCES

MAPLETON AREA AGRICULTURAL + URBAN RUNOFF ANALYSIS

SOUTHERN MINNESOTA - BLUE EARTH COUNTY DITCH NO. 57 (CD 57)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

BLUE EARTH COUNTY

ISG

AUGUST 14, 2015

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MAPLETON AREA AGRICULTURAL + URBAN RUNOFF ANALYSIS

SOUTHERN MINNESOTA - BLUE EARTH COUNTY DITCH NO. 57 (CD 57)

PREPARED ON BEHALF OF:
THE BLUE EARTH COUNTY DRAINAGE AUTHORITY

PREPARED BY:
ISG

AUGUST 14, 2015

ACKNOWLEDGMENTS

Thanks to the following agencies and individuals for their support and involvement in the Blue Earth County Ditch 57 project:

Blue Earth County Board and Staff

Craig Austinson - Blue Earth County Ditch Manager
Kip Bruender - Blue Earth County Commissioner
Will Purvis - Blue Earth County Commissioner

ISG

Chuck Brandel, PE - Senior Civil Engineer
Civil, Environmental and Surveying Groups

Minnesota Department of Natural Resources

Leo Getsfried - Former Area Hydrologist

Minnesota Department of Agriculture

Mark Dittrich - Senior Planner, Conservation Drainage

Minnesota Board of Water and Soil Resources

Al Kean and Staff - Chief Engineer Manager - Assistance with State Funding and Support

Blue Earth County Ditch 57 Landowners

Pat and Kris Duncanson - Project Petitioner and Supporter
Dick Nienow - Project Petitioner and Supporter
Dave Keller - Project Petitioner and Supporter

Blue Earth County Soil and Water Conservation District

Jerad Bach, District Manager - Provided feedback and review, Supporter

Minnesota State University, Mankato

Dr. Steven J. Druschel - Department of Civil and Mechanical Engineering - Data Collection and Monitoring Assistance
Dr. Bryce W. Hoppie - Department of Chemistry and Geology - Data Collection and Monitoring Assistance, Water Quality Analysis Review

City of Mapleton, MN

Patty Woodruff, City Administrator

TABLE OF CONTENTS

*Glossary terms are bolded throughout the report and are defined in the Glossary section at the end of the report

EXECUTIVE SUMMARY

Water quality is being improved through an innovative approach to agricultural drainage. Incorporating conservation methods enhances conditions for crop production while protecting natural resources. Blue Earth County Ditch No. 57 (CD 57) is an extremely successful project, providing increased production and yields in the watershed while decreasing peak flows, sediment and nutrients downstream. Reductions for pollutants were as high as 50% with averages near 25%. Over 70 dump truck loads of sediment were kept out of public waters. If more projects like this were implemented, nutrient reduction goals could be met while keeping our agricultural based economy strong, feeding the world.

This innovative project addresses water quality and serves as a model for drainage projects now and into the future. This project report includes the drainage improvement process, incorporation of Minnesota Environment and Natural Resources Trust Fund (ENTRF) grant funding for water quality **Best Management Practices** (BMPs)*, and results from monitoring the system to quantify the BMP's effectiveness.

There is significant interest by government agencies, landowners and environmental advocates, in finding BMPs that are efficient at reducing peak flows and removing nutrients, as well as being cost effective. CD 57 serves as a pilot project and a model for constructing, combining and monitoring several BMPs. This process is necessary to determine their effectiveness and overall feasibility when incorporated into an improvement project for installation in other agricultural drainage systems. These improvements include modifications to the existing **open ditch** system, additional **storage** and water quality BMPs, and replacing portions of the existing deteriorating **county tile** system.

This project serves as a model of cooperation and coordination between landowners who were interested in an improved drainage system that protects water quality by incorporating environmentally sound practices. The existing CD 57 system had insufficient capacity in several portions, primarily those in the upper half of the watershed and was in a severely degraded state. Landowners in this area had experienced flooding and crop loss due to the undersized and failing system that was deteriorated to the point of needing replacement.

Through many meetings and workshops, **landowners**, **drainage engineers** and agencies came together to identify a better way to approach agricultural drainage. With a concerted effort at the local level, together they came up with an innovative approach that would provide a means to accomplish the goal of improving water quality while addressing agricultural drainage needs.

INTRODUCTION

HISTORY

Perhaps the most dramatic human modification to Minnesota hydrology was the conversion of prairie to farmland and the straightening of streams into ditches, thereby changing water storage, surface flow and the flow of water through soil. As settlers moved west to the Minnesota region, they found the land to contain fertile topsoil that was prime for agricultural production. However, much of the land was covered with wetlands and **prairie pothole** lakes.

Since these areas were highly suitable for crop growth, they were intensely drained to make farming more practical, productive, and economical during the late 1800s and early 1900's. This practice was encouraged by local agencies to drain water from the landscape as quickly as possible and has made the Prairie Pothole region some of the most productive farm land. This was also encouraged by officials for public health reasons, namely to reduce mosquito populations and the diseases they carried. This agricultural region became the backbone of the rural economy by providing grains and raw food products throughout the United States and later to a global market.

This transformation to the rural community infrastructure and agriculture would not have been possible without **artificial drainage**. Due to increasing awareness of water quality concerns, landowners and producers are beginning to recognize their social responsibility. They realize their impact on Minnesota's natural resources and areas downstream of modifications or repairs to these systems.

DRAINAGE INTRODUCTION

Traditional agricultural drainage consists of deep open ditches and underground county tile systems designed to rapidly drain the water from the landscape. Although the method is effective and results in a drained landscape, it also results in increased peak flows, higher nutrient loading in the water, and a restructured habitat regime. Today, there is a more efficient, economical, and environmentally friendly practice available. This report outlines an alternative conservation drainage method that can be applied to a broad area throughout the Midwest.

The efficiency of today's agricultural cropland is due in part to its drainage. The ability to control the water on the landscape improves yields and makes planting and harvesting more predictable. Most drainage systems were installed over 100 years ago and they are deteriorating quickly. This condition of disrepair is relatively common, making the planning process a timely event for drainage improvement and environmental protection.

Today, many of these systems are being replaced due to a number of reasons. First, they have exceeded their usable lifespan. Second, in some years, low crop prices deterred improvements as they were not considered cost effective due to low landowner profits. Third, the increase in private tiling and **system tiling** has maximized the capacity of the systems and increased their rate of deterioration; as a result, their efficiency decreases. The photographs in *Figures 1 and 2* show examples of issues found today with aging drainage systems. *Figure 1* shows a damaged county tile main that is failing. A section of the tile

Figure 1 - Existing Damaged Tile Main

Figure 2 - Open Ditch Slough

collapsed and the flow of water pulled soil into the line and caused erosion. *Figure 2* shows a portion of the open ditch that has eroded away causing sediment accumulation in the ditch.

CD 57 OVERVIEW

The Mapleton Area Agricultural Urban Runoff Analysis focuses on a County Ditch watershed in Southern Minnesota – Blue Earth County Ditch No. 57 (CD 57).

The CD 57 drainage system is a 6,041 acre watershed located in southern Minnesota and is comprised of agricultural farmland and urban runoff from the City of Mapleton. Located in southern Blue Earth County, CD 57 was in a state of disrepair, common to many systems in the area. As a public system since 1921 with portions of the system installed privately by landowners prior to 1900, the first and only improvement was completed in the mid-1970s. By 2007, portions of the system had deteriorated and failed. Landowners acknowledged this failure and requested that the degraded system be addressed via a **petition** to the **Drainage Authority**. As the petition was being developed, flooding concerns were voiced by downstream landowners.

CONCERNS WITH THE PETITION

Through landowner meetings and personal communication between county staff and landowners, concerns were addressed in the petition process with a statement of intent that indicated water storage would be included to protect downstream landowners from flooding. Through this interactive process, a set of conservation drainage practices were evaluated. The initial designs were crafted and presented to landowners for the petition process and feedback. The CD 57 improvement provided an opportunity to include and assess the effectiveness of BMPs on water quality.

FUNDING SOURCES

Funding to monitor BMP effectiveness was provided through a grant from the Legislative-Citizen Commission on Minnesota Resources (LCCMR) Environmental and Natural Resources Trust Fund. This grant provided funding for the construction of BMPs and three years of water quality monitoring to determine their effectiveness. This report outlines the following:

- The history and background of CD 57
- Multi-purpose drainage management and Minnesota Drainage Law
- The BMPs installed in the CD 57 System
- The timeframe and partners involved in the project
- Water quality outcomes
- Challenges to the project and recommendations on moving forward with BMPs in drainage systems throughout the region

The *CD 57 Water Quality Report* specifically analyzes the water quality monitoring results and is a separate document from this report.

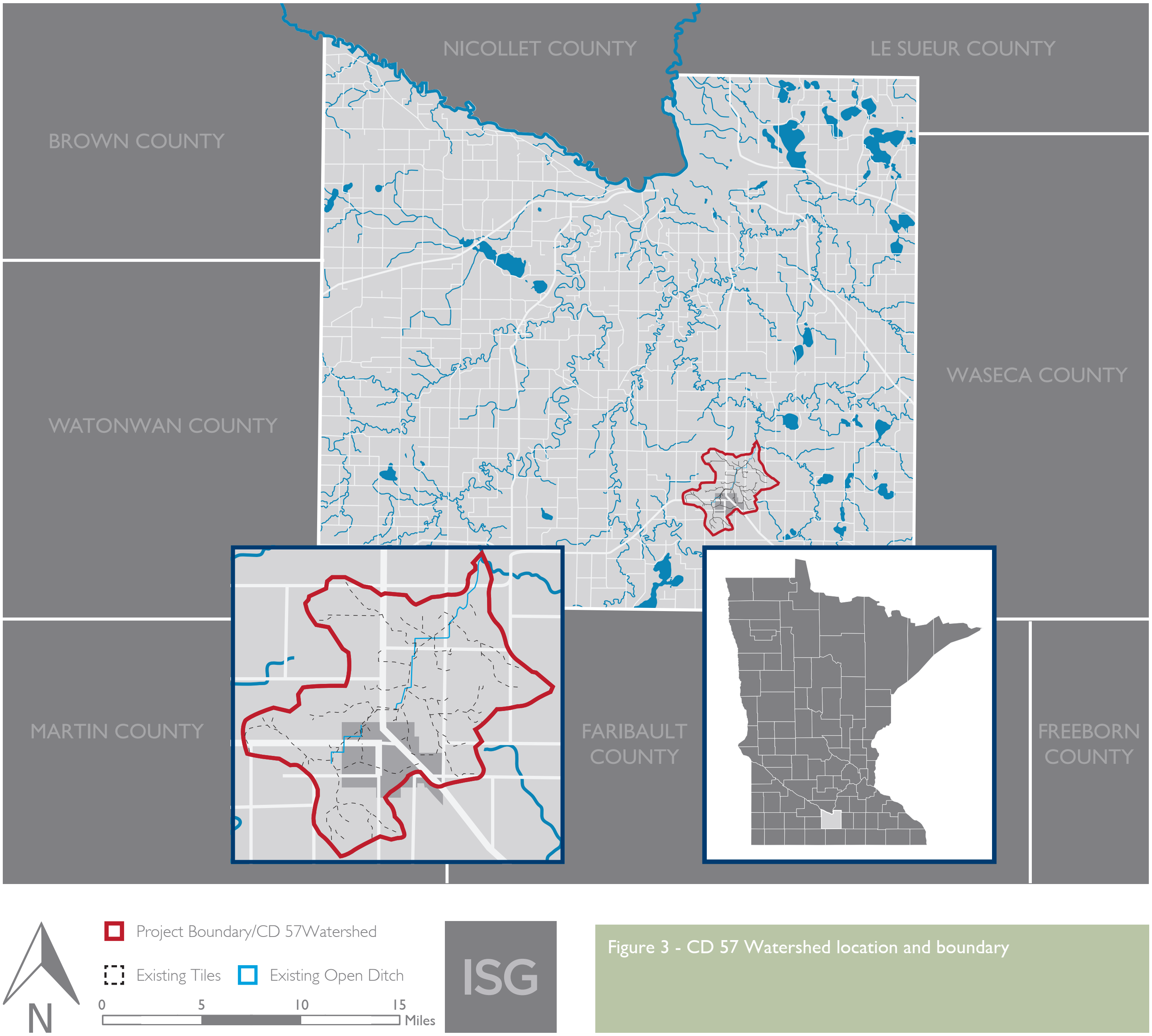


Figure 3 - CD 57 Watershed location and boundary

CD 57 BACKGROUND

WATERSHED

CD 57 is part of the Le Sueur River Minor Watershed of the Minnesota River and discharges into the Big Cobb River in Section 22 of Beauford Township. The watershed consists primarily of agricultural land use (approximately 87%), and of that crop land, approximately 93% is in two year corn-soybean rotation (Minnesota Pollution Control Agency, 2012). The remaining portions of the watershed include the City of Mapleton (400 acres, 7% of watershed), farmsteads and roads. The population of Mapleton in 2010 was 1,162. *Figure 3* shows the CD 57 watershed boundary and its location. Elevations within the watershed range from approximately 970 to 1,040 feet above Mean Sea Level (MSL).

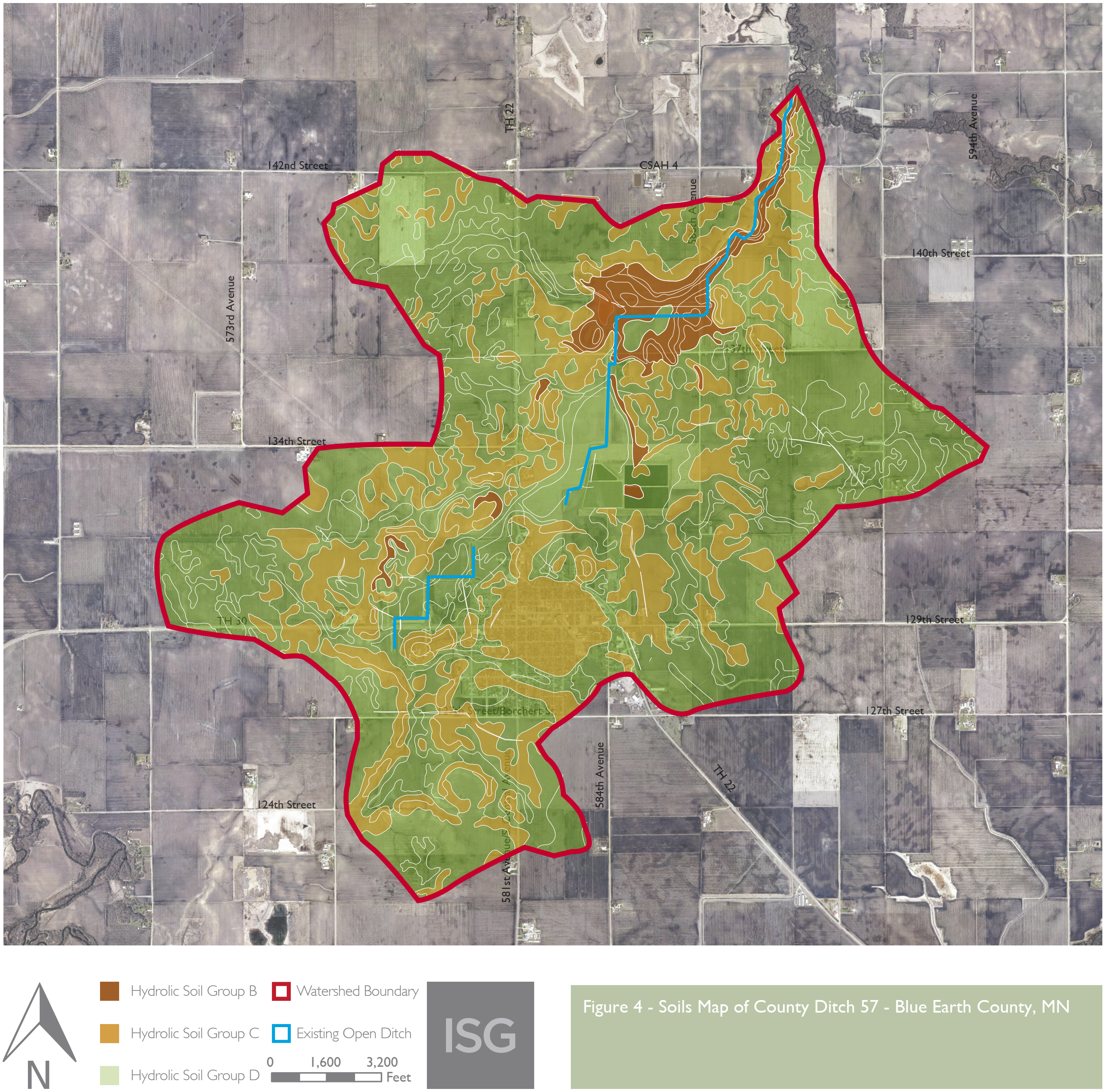
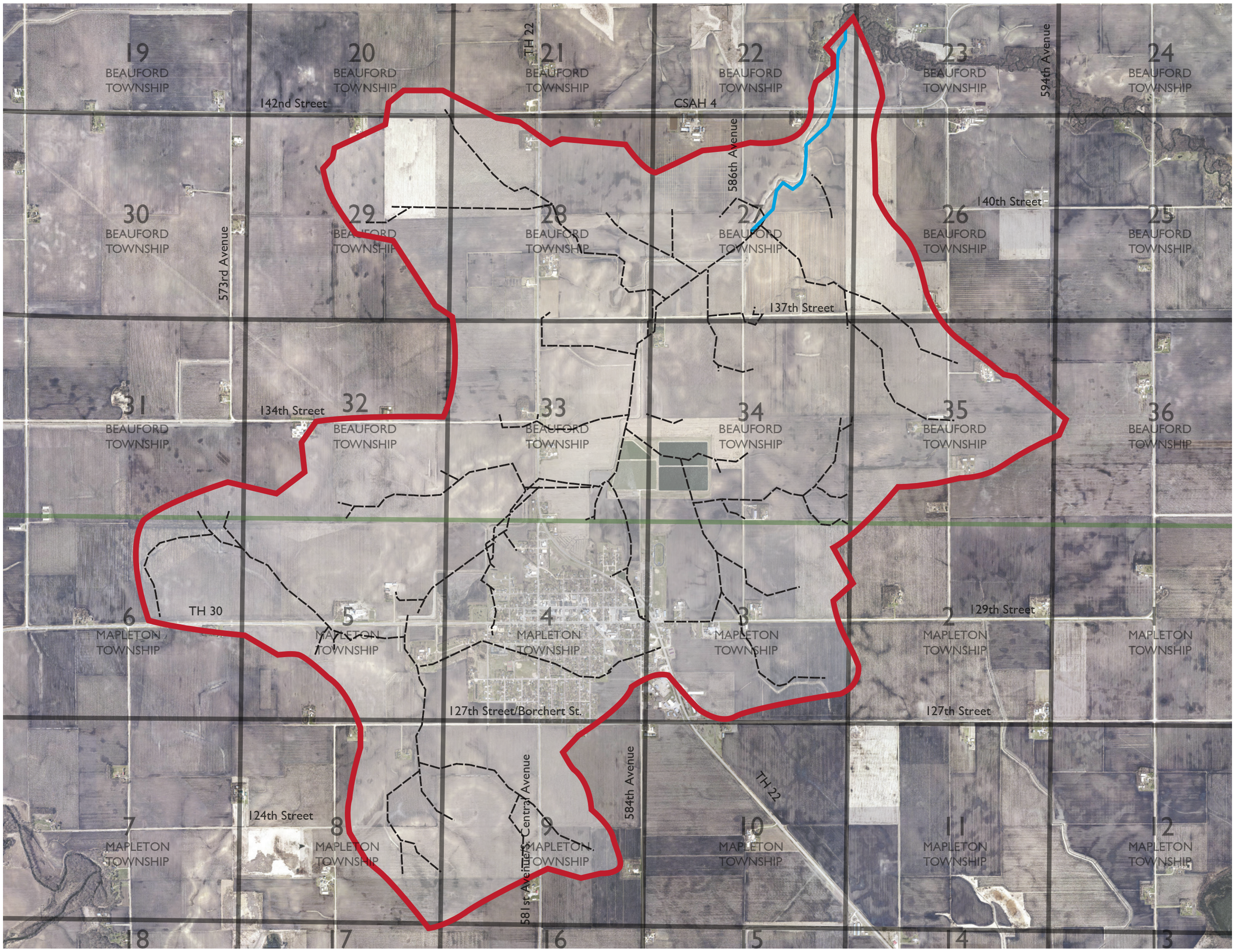


Figure 4 - Soils Map of County Ditch 57 - Blue Earth County, MN

SOILS

The Natural Resources Conservation Service (NRCS) classifies four hydrologic soil groups (A-D); Group A consists primarily of sandy soil with low runoff potential, Group B consists of sandy-silt loams with moderately low runoff potential, Group C consists of silty-clay loams with moderately high runoff potential, and Group D consists of clay loams with high runoff potential. The soil groups identified in the CD 57 watershed (*Figure 4*) predominantly include type B to type D soils, all of which are considered prime farmland if adequately drained. Soil textures include silt loam, silty clay loam, clay loam, silty clay, and clay.



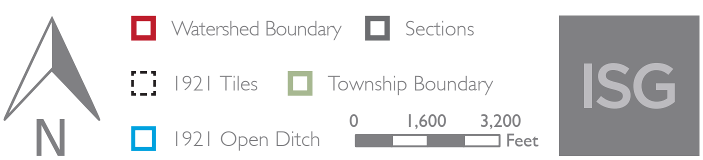


Figure 5 - 1921 Original Tiled System

HISTORY

The CD 57 system was originally constructed in 1921 as a primarily tiled system incorporating previously private tile with an open ditch outlet. The open ditch extended southwesterly from the Big Cobb River to 586th Avenue in the center of Section 27, Beauford Township (*Figure 5*).

The improvement constructed in the mid 1970's, extended the open ditch from 586th Avenue southwesterly to a point in the southern portion of the southeast 1/4 of Section 33, Beauford Township. An open ditch was also constructed from a point in the northern portion of the northwest 1/4 of Section 4, Mapleton Township, southwesterly, across Minnesota Trunk Highway (TH) 30, to a point in the northern portion of the southeast 1/4 of Section 5, Mapleton Township. Both ditch segments generally followed the alignment of the original mainline tile. These open ditches replaced failing tiles that were constructed under the original 1921 improvements. The two ditches were connected by the two tile lines including the existing mainline concrete tile and a supplemental corrugated metal tile.

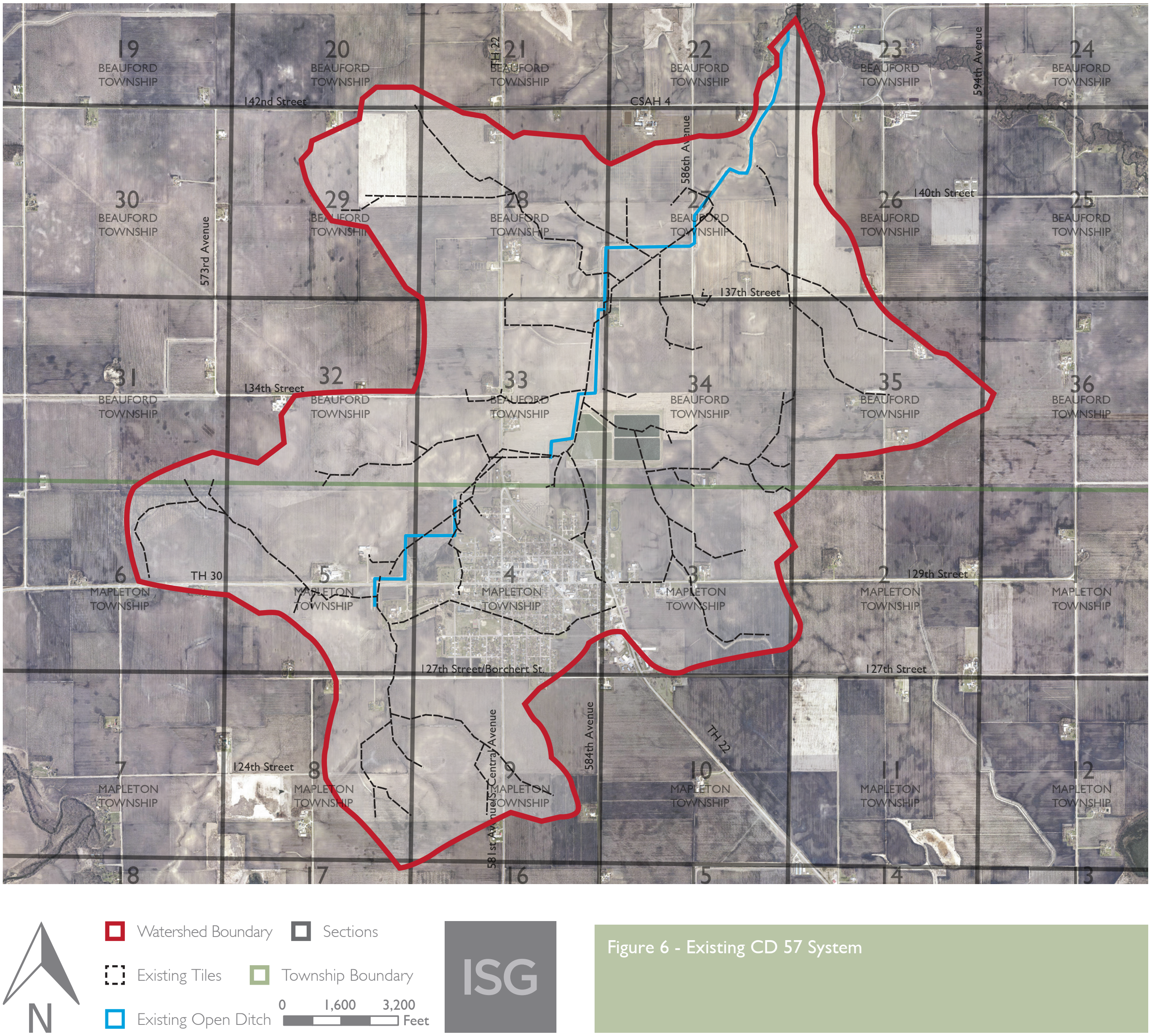


Figure 6 - Existing CD 57 System

As development progressed within the City of Mapleton, portions of the CD 57 system within the City were abandoned or integrated into the municipal storm sewer system. The majority of the City of Mapleton discharges to the CD 57 system in three locations. Flows from the southern portion of the City were routed around a stormwater pond that stored water when the system backed up and were discharged to the open ditch segment south of TH 30 via a county tile branch. A stormwater pond serving a small residential development in the northwest portion of the City discharges to the open ditch segment in the northwest 1/4 of Section 4, Mapleton Township. As part of a routine maintenance, the City of Mapleton discharges treated wastewater from the treatment lagoons to the open ditch twice a year in the eastern portion of the southeast 1/4 of Section 33, Beauford Township. *Figure 6* shows the existing layout of the CD 57 system.

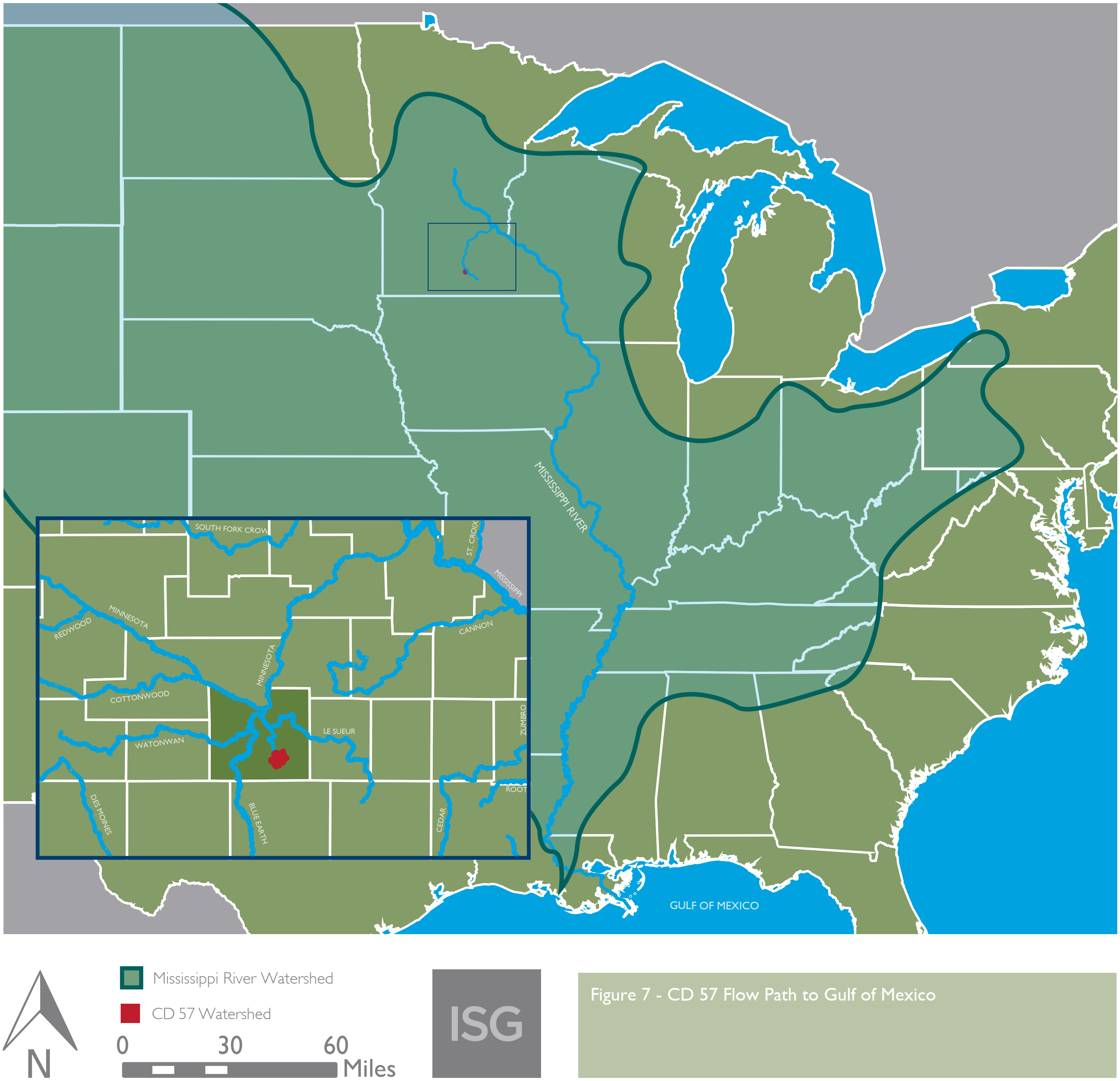


Figure 7 - CD 57 Flow Path to Gulf of Mexico

EXISTING CONDITIONS

CD 57 has an important influence on the water quality of other downstream watersheds. It drains northeast into the Big Cobb River, then flows west into the Le Sueur River and eventually into the Blue Earth River. The Blue Earth River converges with the Minnesota River and drains into the Mississippi River and terminates at the Gulf of Mexico. This area of the Gulf contains extremely low dissolved oxygen levels that cannot support aquatic life, a condition referred to as **hypoxia**. This condition is impacted by the level of water quality that flows from other rivers into the Mississippi River. *Figure 7* shows the flow path of CD 57 to the Gulf of Mexico.

CATEGORIES OF AGRICULTURAL BMPs

PREVENTATIVE	CONTROL	TREATMENT
Residue Management	Rate Control Weir	Buffer Strip
Nutrient Management	Alternative Intake	Wetland Restoration
Crop Rotation	Culverts	Surge Basin
Cover Crops	Two-Stage Ditch	Woodchip Bioreactor
	Grassed Waterways	
	Riparian Vegetation	
	Controlled Subsurface Drainage	
	Toe-wood Sod Mats	

Figure 8 - Preventative Measure - Cover Crop

MULTI-PURPOSE DRAINAGE MANAGEMENT

Laws and regulations put in place to protect the health of **public waters** are an important consideration for agricultural producers. Recently, there has been an increase in the awareness of social responsibility to protecting water quality. The improvement process requires environmental considerations for the health of public waters. However, implementation is not well defined in the process.

Farmers are incorporating more conservation drainage methods to protect the environment and to make drainage financially and environmentally sustainable. While every farm and every field may have different conservation needs, the primary pollutants found in agricultural settings include sediment and nutrients, primarily phosphorus and nitrogen. Although some nutrient discharge may be necessary for agricultural production, there are various agricultural practices to mitigate adverse effects. These beneficial practices are called Agricultural Best Management Practices (BMPs) as defined in *The Agricultural BMP Handbook for Minnesota*, published by the Minnesota Department of Agriculture (2012), and address specific water quality impairments such as sediment, nitrogen or phosphorus.

AGRICULTURAL BMPS

Agricultural BMPs can be divided into three major categories: *preventative measures, control measures*, and *treatment measures*.

Preventative measures are practices that can be applied to the existing landscape without dramatically changing its current land use. These practices can be used by any landowner through educated decisions based on guidance from Soil and Water Conservation Districts (**SWCD**), in regards to the crops and the land area in which they are planted. These measures will contribute towards increased water quality through erosion control, soil stability, and nutrient management. Examples of preventative measures include **residue management**, **nutrient management**, **crop rotation**, and **cover crops**. *Figure 8* shows a cover crop used as a preventative measure for winter erosion.

Control measures are practices that either convey water, control flow direction and rate, or maintain a desired water level. These practices are typically installed in existing drainage ditches, ponds, or wetlands and require agreements by several landowners or ditch systems. These BMPs are expected to reduce peak flow rates, sediment, and nutrient loading. Examples of control measures include rate control weirs, **alternative intakes**, **culverts**, **two-stage ditches**, **grassed waterways**, **riparian vegetation**, **controlled subsurface drainage**, and **toe-wood sod mats**. *Figure 9* shows a rate control weir used to reduce peak flow rates from an open ditch system.

Treatment measures are practices designed to improve the water quality of either surface runoff or water being carried through drainage systems. They are primarily aimed at treating sediment or nutrient loaded water. Examples of treatment measures include filter strips—often referred to as **buffer strips**—wetland restorations, **surge basins**, water and sediment control basins (WASCOBs), **woodchip bioreactors**, and **saturated buffers**. *Figure 10* shows a wetland restoration within an agricultural drainage system.

Figure 9 - Control Measure - Rate Control Weir

Figure 10 - Treatment Measure - Wetland restoration

MINNESOTA DRAINAGE LAW

In 1883, the first drainage laws were established and eventually became the framework for **Minnesota Drainage Statute 103E**, which outlines the requirements for establishing, repairing, improving and all other items related to **public drainage systems** in Minnesota. County commissioners were the first government authority group to accept and approve petitions to create public drainage systems. These systems were established to effectively drain the landscape for agricultural production, develop a cost share agreement for benefited owners along the system, and maintain the outlet through repairs and improvements. Today, the process is nearly the same, but primarily focuses on repairing damaged systems and improving undersized systems.

Early drainage systems established between 1880 and 1920 were designed to drain vegetated wetlands, or swamp lands which held water between depths of 1 to 6 feet. These systems primarily drained the low, wet areas for agricultural production. During this time, rainfall routinely caused the landscape to become flooded and therefore wasn't conducive for practical farming without artificial drainage.

From the 1920s through the 1930s, drainage activity slowed as rainfall amounts lessened during the time of the Depression and Dust Bowl. Existing drainage systems were able to handle the rainfall. After 1940, normal rainfall amounts returned and repair and improvement projects became routine due to the fact that the existing systems were becoming damaged and were undersized.

The 1950s and 1970s brought the first political influence from the public to address conservation. The creation of watershed districts helped influence conservation and changed the authority from the county board to applicable watershed districts. Many people from the public including wildlife groups brought up issues dealing with the function of wetlands as they relate to wildlife and waterfowl production. State programs were developed in the late 1970s to establish payment programs to farmers who committed to not drain the wetlands and leave them as wildlife areas. These programs are often referred to as state conservation easements.

Again, in the 1980s and 1990s rainfall amounts decreased and slowed drainage projects. Also during this time, land prices declined and it was difficult for drainage projects to show enough benefits for the desired project. The 1980s also brought the involvement of the Department of Natural Resources to drainage projects. At this time, one-rod buffers (16.5 feet) were required on all public drainage systems that had a **redetermination of benefits**. In 1991, the Minnesota Wetland Conservation Act established that existing wetlands could no longer be artificially drained without mitigating the impacts to a wetland.

During the late 1990s and into the 2000s, drainage projects substantially increased as existing drainage systems were damaged, aging, and in most cases beyond repair. This period also brought higher land prices while newer technologies made the land much more economical to farm. System tiling began to increase dramatically and resulted in more improvements because existing systems could no longer handle the amount of water draining from the landscape.

Historically, the main objective of a drainage project was to drain the land in the most economical way possible. Storage and water quality were not considered for drainage projects. In 2000, a portion of Minnesota Drainage Statute 103E was modified to allow for the use of external sources of funding to assist in the addition of wetland preservation, wetland restoration, water quality improvements, and flood control. This allowed for drainage systems to have the ability to use grants or other funding sources to add storage and water quality practices.

Drainage projects progressed through the 2000s and 2010s with more environmental and political pressure regarding water quality. Agencies began to strongly assess drainage and water quality and the impacts that public drainage systems have on public waters. The DNR began reviewing public drainage projects and providing feedback to the Drainage Authorities. Many requests were made by the DNR to address water quality in improvement projects. At this time, water quality was not the primary focus of drainage improvements throughout most of the State.

Due to inadequacies of the original drainage systems constructed 100 years ago, the costs to bring them up to today's standards is relatively high. In order to improve a drainage system, the benefits realized throughout the watershed must have a greater value than the cost to improve it. This leaves very little room to fund BMPs in accordance with Minnesota Drainage Statute 103E.

In 2014, the Drainage Statue was modified to include water quality multi-purpose drainage management options on projects. This put more emphasis on water quality in drainage projects. It requires the drainage authority to investigate the potential use of external sources of funding and technical assistance (Subd.1a). The following tasks are required to complete a **drainage improvement**:

- Develop a Petition with at least 26% of the affected or crossed over landowners in the system
- Submit the Petition to the Drainage Authority for approval and appointment of an Engineer
- Engineer Prepares Survey of the system and **Preliminary Engineering Report (PER)**
- Multi-purpose drainage management and water quality are reviewed by Engineer, **affected landowners**, and the drainage authority and are addressed in the PER
- PER is reviewed, public comments are received and the Drainage Authority approves or denies report
- **Ditch viewers** are assigned to complete a **redetermination of benefits** for the existing system and the proposed improvement
- A **Final Engineering Report (FER)** is prepared and submitted to the Drainage Authority
- A public meeting is established to Review the FER and **Improvement Determination of Benefits**.
- The project is approved if the benefits outweigh the costs, the outlet is adequate, the system is of public benefit, is feasible and cost effective along with meeting the other requirements of Minnesota Drainage Statute 103E
- After approval, the project is constructed, and then finally accepted by the Drainage Authority

DRAINAGE IMPROVEMENT PROCESS: REPAIR VS. IMPROVEMENT

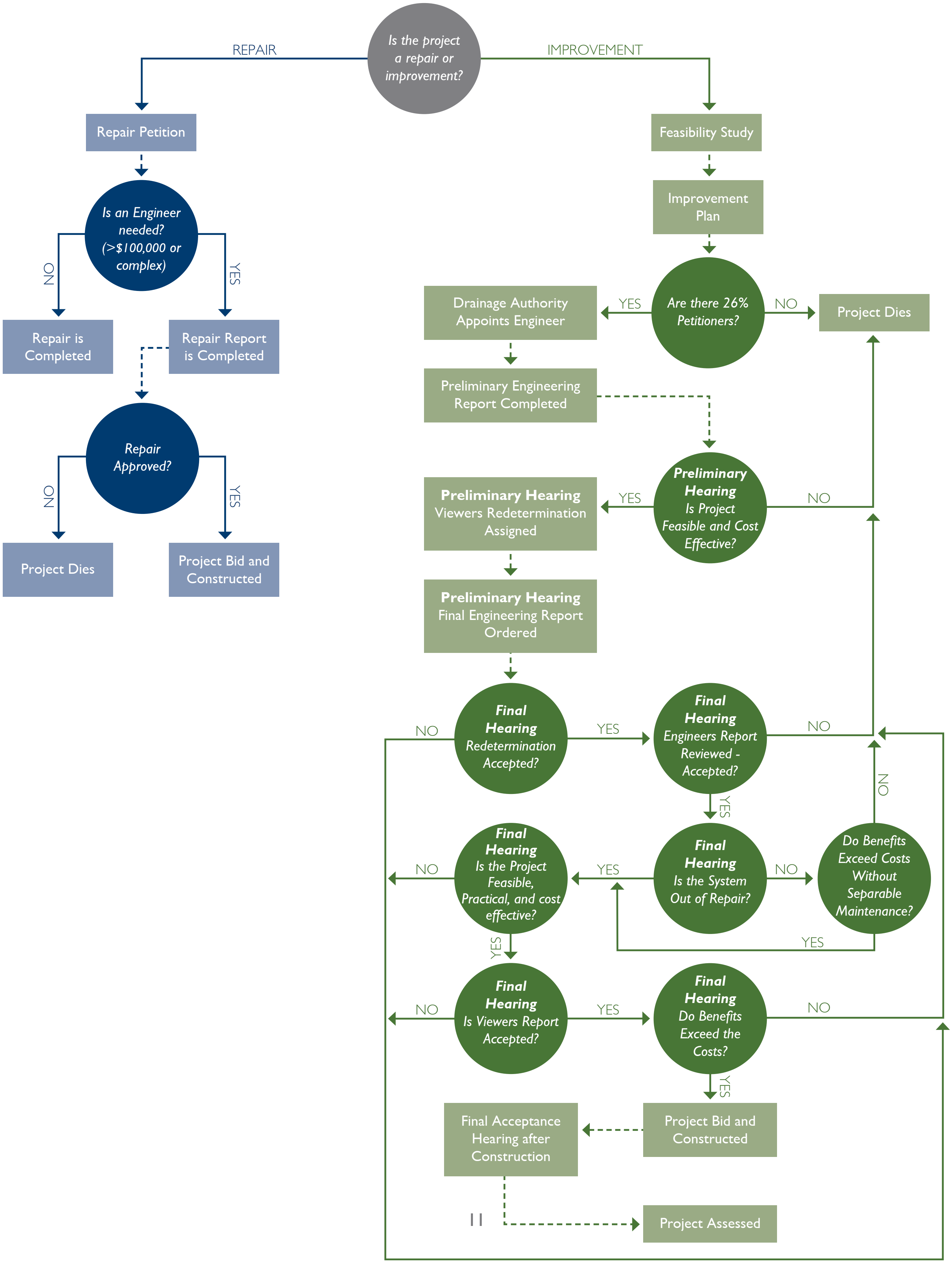


Figure 11 - Collapsed Existing County Tile

Figure 12 - Accumulated Sediment in Ditch

CD 57 IMPROVEMENTS

The CD 57 improvement project was developed because the existing system was damaged, needed repair, and had undersized county tile mains contributing to poor drainage. There were areas in the watershed where the system was at the point of failure. The tile connecting the open ditch segments under TH 22 was failing and causing significant flooding. The system needed increased drainage capacity and storage. Since the proposed goal was to provide an improvement to the drainage system, Minnesota Drainage Statute 103E requires that the landowners must recognize a benefit from the project.

Figures 11 and 12 show the existing deteriorating CD 57 system with collapsing county tile mains (*11*) and accumulated sediment in the open ditch (*12*).

INCREASED CAPACITY

The soil profile can be described as a 'sponge', as it absorbs and stores water between each individual soil particle. Areas where artificial drainage exists lower the **groundwater table** and in turn remove water from the sponge, thus allowing more water to be stored in the soil rather than ponding on the surface. This method of artificial drainage has proven to be very effective as less water is ponded in agricultural fields, thus it allows for farmers to more consistently maneuver equipment through the land and puts less stress on crops during the growing season.

Increased capacity describes the method where artificial drainage is increased through any of the following:

- Larger system tile lines to effectively drain more water below the surface
- Additional tile lines, sometimes placed lower in the ground to create a larger area of soil to absorb water. This is considered the sponge effect.
- Larger public drainage systems (either large ditches or tile main lines) to reduce the amount of backwater on the sponge and the associated system tile lines draining that area
- Any other alternative in which the water table is effectively lowered and drained more quickly

The most common way to describe **drainage capacity** is through the **drainage coefficient**. The drainage coefficient is a method used to measure flow through system tiling and public drainage systems. The units of the drainage coefficient are in inches per day. This describes the depth of water (inches) that can be drained in a 24 hour period (day). Today's standards recommended by the NRCS are a minimum of 0.50 inches/day for system tiles and public tiling systems, and 1.0 inches/day for public open ditch systems. Most original public drainage systems installed had designed drainage coefficients of 0.10 inches per day for public tiling systems and 0.25 for public open ditch systems. The existing CD 57 drainage coefficients ranged from 0.24 to 0.39 inches per day due to the improvements implemented in the 1970's.

To provide increased capacity to the system, the project improved

Figure 13 - Downstream CD 57 Open Ditch with Flooding

CD 57 between the two existing open ditch segments and south of the existing southern open ditch segment. NRCS recommendations indicate that these segments need a minimum capacity of 0.75 inches per day or greater. Landowner negotiations resulted in a petition to the Drainage Authority, which proposed an increase to the capacity of the system to 0.60 inches per day with supplemental storage to account for additional drainage. Also, it was originally recommended to construct an improvement south of Trunk Highway (TH) 30 as a replacement of the original tile. However, since the original tile was still functioning, the decision was made to construct improvements south of TH 30 to supplement the existing tile.

INCREASED STORAGE

It was also important to incorporate storage in the upper half of the watershed to protect the downstream landowners from flooding. Due to the limited capacity of the ditch system downstream, landowners feared that flooding would consistently occur downstream with a ditch improvement. By implementing BMPs in the upper half of the watershed to provide storage, the downstream landowners would be protected from higher peak flow rates and flooding. *Figure 13* shows a portion of the downstream ditch that experienced periodic flooding.

TIMEFRAME AND PARTNERS

Landowners recognized that they would need to provide a portion of funding for storage, however outside funding was needed to provide additional water quality BMPs and monitoring. The results could be useful in promoting ongoing use. The benefit of these costs could not be justified via the existing Statute without outside funding. Interest in water quality and available funding sources to improve water quality provided an opportunity to work with federal, state and local governments to incorporate BMPs into the drainage system improvement. This process provided an opportunity to include different BMPs and demonstrate how they can fit into existing Minnesota drainage law.

Outside funding sources would be used to construct BMPs that would provide more capacity to the system and reduce soil erosion and nutrient loading to downstream water bodies. This was primarily accomplished through creating storage, constructing improved open ditches, and ensuring adequate vegetative buffers were present.

The results from this project provided a unique opportunity to demonstrate the ability to work with multiple collaborators in a concerted effort to provide valuable data on how BMPs affect water quality in a southern Minnesota drainage system.

This project also provided an opportunity to leverage grant funding to demonstrate a number of potential BMPs that would not have been cost effective otherwise. In addition to the qualitative results from this effort, such as BMP constructability and longevity, this project included monitoring of the system for both flow and water quality data. This monitoring provides insight into the effectiveness of each BMP and reflects the potential for use in other systems that may have similar impairments.

The following organizations collaborated to differing degrees on the development and implementation of this project:

- The *Blue Earth County Drainage Authority* reviewed and approved the project, served as the project manager and a conduit to landowners, and provided project administration. They also acted as the funding mechanism for the drainage improvement.

- The *Blue Earth County SWCD* provided support of the project by reviewing the water quality BMPs.

- The *City of Mapleton, MN* provided land for the City Pond and funding towards the project The Greater Blue Earth River Basin Alliance provided a letter of support.

- *ISG*, acting as engineer for the Blue Earth County Drainage Authority, provided design services, assistance with project administration, monitoring, technical memorandum, and presentations.

- *Land Owners* in Blue Earth County Ditch No. 57 outlined the needs of the project through landowner meetings, led the project from the improvement to include the water quality components, and provided the majority of the funding for construction. They also received the drainage benefits of the drainage improvement.

- The *Legislative-Citizen Commission on Minnesota Resources (LCCMR)* provided funding for the implementation of the BMPs and monitoring.

- The *Minnesota Department of Agriculture (MDA)* served as a co-sponsor of the project and assisted with design, monitoring, technical memorandum, and presentations.

- The *Minnesota Department of Natural Resources (DNR)* provided review of the proposed improvements and water quality BMPs.

- *Minnesota State University, Mankato* Departments of Civil and Mechanical Engineering and Chemistry and Geology, provided technical assistance and water quality monitoring.

Together, the collaborators worked to implement the Minnesota Drainage Statute 103E, which outlines the specific requirements for work involving drainage in the State:

- Landowners petition Drainage Authority.

- Drainage Authority appointed Engineer (ISG).

- ISG developed preliminary engineering report meeting 103E requirements.

- Drainage Authority approved preliminary engineering report and ordered ISG to find grant money to do the project.

- ISG consulted with Minnesota Department of Natural Resources (DNR), Minnesota Pollution Control Agency (MPCA), Blue Earth County Soil and Water Conservation District (SWCD), Greater Blue Earth River Basin Alliance (GBERBA), Minnesota Department of Agriculture (MDA), Blue Earth County, and others on grants.

- Funding for the project came primarily from drainage beneficiaries (landowners draining into the system) as described in drainage law, but also applied for funds with ENRTF for BMPs and analysis of water quality on improved system.

- Through this process ISG consulted/collaborated with landowners, agency representatives, the MN Drainage Workgroup and other drainage experts to review the storage and treatment options that were proposed and how to monitor their effectiveness.

- The final engineering report was developed by ISG and the viewers determined the benefits.

- The Blue Earth County Drainage Authority approved the project and ordered bids and construction.

- The project was constructed.

- Monitoring began and was implemented for 3 growing seasons.

- Three agricultural drainage workshops were completed during the project to outline the design, construction and results.

- This final report and results will be presented to the LCCMR

IMPROVEMENT TIMELINE COMPARISON

STANDARD DITCH PROJECT

2007
- Landowners experience flooding and system failures
- Landowners hire ISG feasibility study (BEDA, ISG)
- Informational meeting on improvement; LOA bring lawyers, LOF bring lawyers, BEDA, ISG

2007-2008
- Petition develops; Storage included; $30,000 cap

2008
- BEDA appoint ISG, redetermination, and PER
- Survey, hydroanalysis, and PER developed; Costs determined that more than $30,000 needed for storage

2009
- PER complete and approved

2009-10
- Construction; Record snowfall; Spring 2011 wet - delayed project

2010
- **Construction Complete**

BLUE EARTH COUNTY DITCH 57 PROJECT

2007
- Landowners experience flooding and system failures
- Landowners hire ISG feasibility study (BEDA, ISG)
- Informational meeting on improvement; LOA bring lawyers, LOF bring lawyers, BEDA, ISG
- LOA meet with DNR

2007-2008
- Meetings with LOA and LOF, BEDA, ISG, and lawyers; Compromise achieved; Storage provided

2008
- Petition develops; Storage included; $30,000 cap
- BEDA appoint ISG, order redetermination, and PER
- Survey, hydroanalysis, and PER developed; Costs determined that more than $30,000 needed for storage

2008-2009
- BEDA, ISG, and LOF pursued grant funding - denied; MPCA 3/9 clean water, GERBA, ENRTF

2009
- 1st drainage workshop by ISG and CD 57 discussed
- PER completed and approved; Multiple storage options included

2009-10
- ENRTF again - added BMP's and monitoring; Monitoring began by ISG with no funding

2010
- ENRTF approved!
- Storage options reviewed - #1 is a no go; #2 and #3 are approved
- PER complete and approved

2010-2011
- Construction; Record snowfall; Spring 2011 wet - delayed project

2012
- Newly installed drainage system with BMP's; Began monitoring water quality and stage
- 2nd drainage workshop on CD 57

2012-2014
- Monitored multiple presentations on project

2014
- 3rd drainage workshop on CD 57

2015
- Final report to LCCMR
- 4th drainage workshop

2016-Future
- Future monitoring

COSTS WITHOUT FUNDING	COSTS WITH ENRTF
$1,311,600 - Project Cost	$1,311,600 - Project Cost (ENRTF - $485,000)
$1,148,200 - Project Cost without Monitoring	$826,600 - Project Costs After Grant Removed
$856,600 - Separable Maintenance	$856,600 - Separable Maintenance
$291,600 - Net Cost per 103E (Project cost minus Separable Maintenance)	$0 (-30,000) - Net Cost per 103E (Project cost minus Separable Maintenance)
$240,000 - Net Benefits	$240,000 - Net Benefits
$240,000 (Net Benefits) - $291,600 (Net Cost per 103E) = **-$51,600**	$240,000 (Net Benefits) - $0 (Net Cost per 103E) = **+$240,000**
*Project does not meet Minnesota Drainage Statute 103E as Costs are higher than Benefits	*Project meets Minnesota Drainage Statute 103E

Table 1 - CD 57 Costs

COSTS

Multiple options were considered for improving the system. During the feasibility stage, the landowners within the watershed understood that they were going to have to pay for the project due to the existing Statute, however the downstream landowners didn't believe they would benefit. This made the process very difficult. Many of those landowners now understand how the system was improved and how the storage benefited their properties. The added storage reduced flooding throughout the system.

During the project, it was determined that repairs necessary to the existing system in the project area would cost approximately $856,600. The downstream landowners wanted to limit their costs to this amount. The cost for the improvement without storage was estimated at $800,000. Landowners decided that they would contribute $30,000 for storage. To accomplish the landowner's request for water storage to protect downstream areas from flooding, the $30,000 contribution was not sufficient. The ENRTF grant of $485,000 provided the additional funding to add storage to effectively reduce peak flows downstream and provide a project in which water quality could be improved. After the ditch viewers reviewed the project, the net benefits were calculated at $240,000 for the project. Without the ENRTF, landowners could have contributed up to $245,000 for storage and water quality. This would have constructed some of the storage, but not all of the water quality features would have been incorporated and no monitoring would have been conducted. The additional funds from the ENRTF made the results that were found with this project possible. *Table 1* summarizes the costs for the project with and without the ENTRF grant.

To summarize, without the ENRTF grant, the project as designed and implemented would not have been cost effective and thus not feasible per Minnesota Drainage Statute 103E. Portions of the water quality improvements and storage areas would have been eliminated or reduced in size to provide the required benefits to meet the requirements of the Statute. Monitoring would not have been included in the project and the effectiveness of the BMP's would not have been documented. The contributions from the ENRTF grant allowed for a good project to become a great project as it maximized the water quality BMPs effectiveness, which has a larger effect on water quality in Minnesota.

ENRTF GRANT

INITIAL EFFORTS

A major component of the success of the CD 57 project was the ability to find outside funding to allow for adequate storage and water quality practices to be constructed in the system. Multiple sources were approached for funding. At the time, there were many opportunities, but each time an application was made, it was denied. Some of the comments received stated that the project was a "good project" but was denied because the project was considered an "improvement project". The following funding opportunities were applied for and denied:

- MPCA 319 Grant
- 2009 NRCS Clean Water Legacy Grant
- NRCS RIM/WRP Wetland Restoration Programs
- 2009 ENRTF Grant
- Cobb River Watershed Grant
- DNR Streambank Funding
- MPCA Nature Conservancy Funds
- NRCS Watershed Work Group

After these denials, a review of outside funding for the project was taken upon Blue Earth County Drainage Authority, ISG, and others. It was decided that instead of focusing just on storage, that it was time to address the improvements with a broader approach that included a combination of BMPs in order to obtain a more significant improvement to water quality and a reduction in peak flow. This led to the development of a work plan combining several methods including storage, water quality, reduced peak flows, and monitoring. This combination of goals would later serve as a model project on how to improve water quality on a drainage system.

ENRTF GRANT AWARD

An ENRTF grant was applied for, and denied in 2009. In 2010, a second application for the ENRTF was submitted and the project was selected for an interview. The feedback provided important information for the application to be resubmitted and awarded a ENRTF grant in 2010. The interview with the legislative and citizen panel provided the opportunity to discuss the fact that funding sources other than landowners were unavailable. While landowners were interested in providing an investment in the improvements, they expressed a need for outside funding to implement BMPs that had costs that were in addition to the cost of improving the ditch system. According to the team that submitted the application, there was a great project idea, but no outside sources of funding would support it. The case was made at the legislative hearing that the project was an innovative approach to address drainage and water quality that may result in a potential change for the future of agricultural drainage. During the ENRTF presentation, one of the legislators asked the committee, "This seems like a great project, but aren't there other funding avenues to support this?" The committee responded that many other potential sources of funding were identified, applied for, and denied because funding groups thought the project was merely an improvement for landowners.

PROJECT GOALS

The main goals for the improvement project were to:

- Increase drainage capacity to the CD 57 drainage system;
- Provide storage to protect land downstream;
- Improve water quality by reducing soil erosion and nutrient loading by providing storage, thus increasing system capacity;
- Enhance ecological value and increase critical land and habitat by adding vegetative buffer strips with native grass species;
- Provide an innovative demonstration project following Minnesota drainage law that provides alternative strategies that satisfy the collective needs of public waters and property owners by considering both economic and environmental costs and benefits; and,
- Develop a tool for landowners, land managers, planners, and conservationists as a model for future agricultural drainage projects across the state as many outdated and failing ditch systems require upgrades and repairs.

PROPOSED CONDITIONS

Based on the existing conditions and impairments of the drainage system and the downstream reaches, specific BMPs were selected to be incorporated during the design of the overall project. These BMPs are described below and include the following:

- Surge Basins
- Two-Stage Ditch
- Buffer Strips
- Rate Control Weir
- Over-dug Ditch

Figure 14 on the next page shows each of these water quality BMPs and where they were installed within the CD 57 watershed.

SURGE BASINS

Surge basins, also referred to as sediment or storage ponds, are used as a primary method of runoff retention, rate control, and increased water quality through the temporary storage of runoff. This technique has been used for many years in urban settings with much success. Rate control is achieved through providing storage with a reduced outlet size, thus allowing water to temporarily pond in the basin. The primary process through which sediment and the attached nutrients are removed is through gravity. Therefore, having adequate time for ponding is critical as it allows sediment to drop out of the water and not travel downstream. Primary drawbacks of storage are finding willing landowners, the cost of land, a high likelihood of significant earthwork, and locating the facility as to not back water into the existing system.

Several potential locations were initially identified in the CD 57 watershed based on topography and location with respect to the system. The landowners in the system did not want to force storage upon any landowner and thus the most effective location option was not chosen due to landowner resistance. The identified landowner was hesitant to take land out of production since they were a small farming operation. This landowner felt the impacts of a storage easement would be too significant since the operation was less than 100 acres. Based on

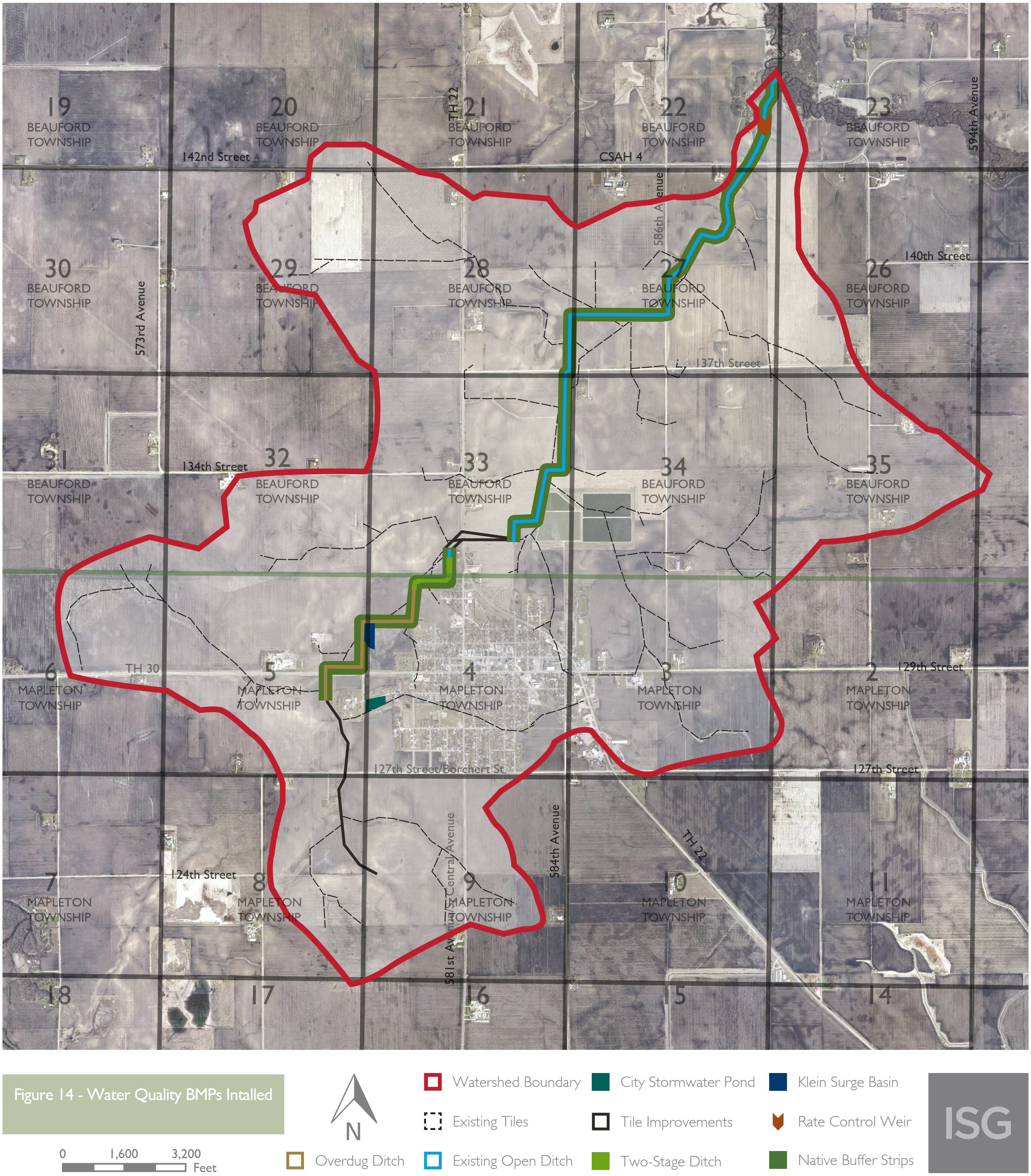


Figure 14 - Water Quality BMPs Intalled

Figure 15 - Inlet structures to Klein Pond

Figure 16 - City Pond

other potential sites, meetings were held with landowners to determine if there was interest in providing land for this basin. Ultimately the Klein Pond site was selected north of TH 30 adjacent to the ditch.

KLEIN POND

This surge basin is referred to as the Klein Pond because the Klein family was the landowner at the time of construction. This landowner was receptive to the project because they were aware of, and supportive of the concept behind social responsibility for water quality. The Klein Pond was constructed by excavating the existing low area to provide for 26.3 acre-feet of storage over a 4 acre area. Flow from the ditch is routed to this basin by a diversion weir and 48 inch culvert placed in the ditch. Once the pond reaches maximum capacity, the water flows over the weir and into the ditch downstream. Flow exits the pond through a 15-inch outlet, which reduces outgoing flow rates. The basin is planted with native vegetation to increase nutrient uptake and decrease the time the basin is saturated. The majority of the pond was designed as a detention basin with a small section that was over-dug to act as a sediment trap. It was over-dug below the 15-inch outlet and has a slight amount of permanent water in it. *Figure 15* shows the inlet structures into the sediment trap (pooled water section in the foreground) and Klein Pond (extra storage area in the background).

CITY POND

A second surge basin was constructed by expanding the existing City of Mapleton regional stormwater pond, thus it is referred to as the City Pond. The City of Mapleton allowed the CD 57 system to expand a pasture area that was previously utilized for flood storage. This basin is located south of the Klein Pond adjacent to Troendle Street SW. The existing pond was expanded to provide additional storage, capacity, and residence time to further remove sediment from the urban runoff. This pond was designed as a retention pond, thus it has a designed maintained water elevation. The City Pond provides storage of 23 acre-feet. The primary outlet of this pond is a 24-inch concrete pipe which eventually drains into the open ditch south of TH 30. Flow to the outlet is first routed through an 18-inch pipe, which is placed at a lower elevation than the 24-inch pipe. This provides a skimming effect within the pond to prevent debris and less dense oils and particles from traveling downstream. Like the Klein Pond, the City Pond was planted with native vegetation to increase nutrient uptake. *Figure 16* shows the expanded City Pond.

TWO-STAGE DITCH

A two-stage ditch is a specially constructed open ditch intended to provide water quality improvements while maintaining good flow characteristics that mimic natural fluvial process. The two-stage ditch is designed with a smaller inner channel that provides low flow and baseflow hydraulic capacity to prevent aggradation and erosion over a significant period of time. This channel controls the meandering capability, resulting in shorter flow lengths, faster velocities, and less sediment buildup in the inner channel making the two-stage ditch a self-sustaining system. The inner channel also keeps the saturated area away from the ditch banks and thus reduces the chance for sloughing and erosion. Benches provide hydraulic capacity for larger flow events, allow

Figure 17 - Two Stage Ditch

Figure 18 - Over-dug Ditch

for sedimentation and nutrient uptake, and also provide critical habitat area and increased vegetation, resulting in greater slope stability. Finally, vegetated buffers with native vegetation provide stormwater filtering and nutrient uptake for surface flow.

The location selected for the two-stage ditch was downstream of the surge pond and upstream of the tiled section across TH 22. The ditch section included a 2-foot wide inner channel, 2:1 side slopes, and 10-foot wide benches. The two-stage ditch spans 1,409 linear feet upstream from the tiled section west of TH 22 behind Casey's General Store in Mapleton. *Figure 17* shows the two-stage ditch behind Casey's General Store.

OVER-DUG DITCH

In-channel sediment storage was constructed on the existing open ditch north and south of TH 30 upstream of the two-stage ditch. This over-dug, in-channel storage consists of lowering the existing ditch bottom to provide approximately three feet of maintained water which allows sediment to settle out of suspension. The water elevation of the over-dug ditch section is maintained by several culvert crossings in the ditch. This allowed the system to gain depth creating more capacity for tile branches entering the system. *Figure 18* shows the over-dug ditch section of CD 57.

BUFFER STRIPS

Buffer strips are an area of vegetation planted between fields and surface waters to minimize organics, nutrients, and sediment in runoff from entering nearby surface waters. Per Minnesota Drainage Statute 103E, areas adjacent to public open ditch systems require 16.5 foot wide (1-rod) buffers along the top of the open ditch. Approximately 75% of the existing open ditch did not have the required buffer prior to the improvement. In lieu of typical buffer grasses, these areas were planted with native grasses and native vegetation to provide additional wildlife habitat and increase erosion protection. Deep rooted vegetation such as Big Bluestem, Canada Wildrye, and Switchgrass were planted to increase soil stability and nutrient uptake in runoff. *Figure 19* shows the native buffers planted throughout the system.

RATE CONTROL WEIR

Exiting peak flow rates are a major issue in every agricultural drainage ditch improvement. Per Minnesota Drainage Statute 103E, each drainage improvement needs to ensure an adequate outlet, thus protecting downstream landowners. One strategy of protecting downstream landowners is to reduce peak flow rates through a rate control weir. With the increase in drainage capacity of the system, peak flow rates are likely to increase without the use of a hydraulic weir.

The rate control weir was placed at the outlet of the ditch system and utilized a concrete section restricting flows to a narrow 18-inch opening for a depth of 5 feet. This weir created temporary ponding in the existing ditch for a lengthy linear section. This in turn reduced existing peak flow rates, allowed for storage, sedimentation, and nutrient removal for the entire system. *Figure 20* shows the rate control weir installed at the outlet of the system.

Figure 19 - Native Buffer Strips

Figure 20 - Rate Control Weir at System Outlet

WILDLIFE DIVERSITY

One parameter that was not formally tested, but rather was observed through field visits and the onsite cameras was the wildlife diversity provided by this project. Numerous different species were observed throughout the watershed. At the rate control weir, several species were observed from the onsite camera which included raccoons, deer, birds, cats, and fish. The weir provided perennial flows for fish to navigate, but also provided an ideal location for predators to feed and hunt. It also provided a more navigable pathway for these animals to cross the waterway.

The native buffers installed throughout the system also provide a significant habitat area that would otherwise have been in agricultural production. Several species of birds and mammals were observed in these areas including:

- Mallard (Anas platyrhynchos)
- Great Egret (Ardea alba)
- Great Blue Heron (Ardea herodias)
- Blue Winged Teal (Anas discors)
- Double Crested Cormorant (Phalacrocorax auritus)
- Wood Duck (Aix sponsa)
- Belted Kingfisher (Ceryle alcyon)
- Canada Goose (Branta canadensis)
- Raccoon (Procyon lotor)
- White-tailed Deer (Odocoileus virginianus)

The surge basins and two-stage ditch provided both an area of maintained water and a perennial flow area for birds and migrating water fowl species. Many different species of birds and waterfowl were observed in these areas. Without the creation of these water storage features, these areas would have been in agricultural production and would not have provided the diversified wildlife habitat. *Figure 21* shows several species of diversified wildlife that were captured on the onsite time-lapse cameras.

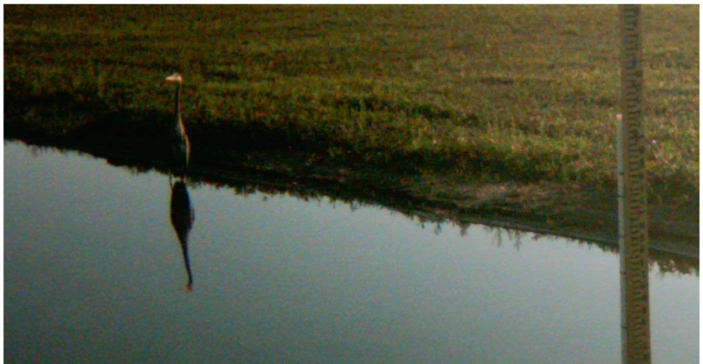


Figure 21.1 - Great Blue Heron (Ardea herodias)

Figure 21.2 - Wood Duck (Aix sponsa)

Figure 21.3 - Great Egret (Ardea alba)

Figure 21.4 - Belted Kingfisher (Megaceryle alcyon)

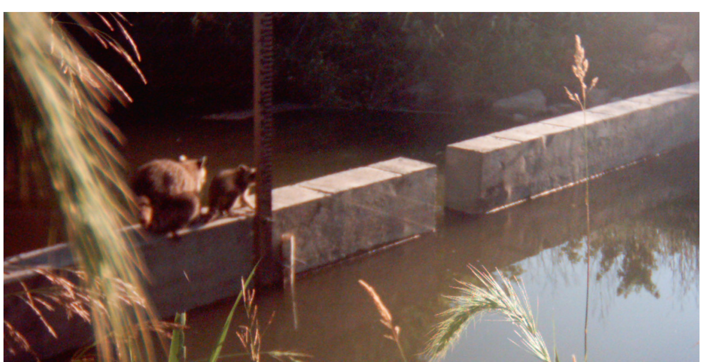


Figure 21.5 - Racoons (Procyon lotor)

Figure 21.6 - White-tailed Deer (Odocoileus virginianus)

Figure 22 - 54-inch RCP under TH 22

Figure 23 - Construction of two-stage ditch in wet conditions

Figure 24 - Final construction of two-stage ditch

Figure 25 - Area of Klein Pond flooded due to wet conditions

CONSTRUCTION

The CD 57 project was bid in two parts in October 2010. One part included the tile and ditch improvements and the other included all of the BMP's and water quality improvements. This was done to separate the ENRTF funding portion of the project from the landowner portion of the project. Holtmeier Construction was the low bidder for each publicly bid project. The project was awarded in early November 2010 and construction began immediately thereafter. It included construction of the two-stage ditch and the over-dug ditch, the grading of the Klein Pond and City Pond, the construction of the rate control weir, construction the supplemental 24-inch mainline in the upper end of the watershed, seeding of the native buffers, and installing the 54-inch reinforced concrete pipe (RCP) under TH 22 connecting the two open ditch segments (*Figure 22*), along with all of the other portions of the project.

Record rain and snowfall during the fall and winter of 2010 created extremely wet and difficult working conditions (*Figure 23*). This slowed and delayed the overall construction of the project. By the end of December, the two-stage ditch construction was complete (*Figure 24*), but the construction of the Klein Pond had halted.

Construction continued in the spring of 2011 with the Klein Pond and over-dug ditch. However, a very wet spring further delayed construction (*Figure 25*). Due to severe flooding in the Klein Pond area, construction of the project moved to the City Pond which was complete by mid-July (*Figure 26*).


Figure 26 - Construction of City Pond


Figure 28 - Rate Control Weir


Figure 27 - Completed Klein Pond

In late August and early September 2011, construction of the over-dug ditch and Klein Pond resumed. The dry conditions allowed the equipment to maneuver throughout the area to complete the Klein Pond. Spoils from the Klein Pond were spread in the adjacent field, raising the entire field by 2 to 3 feet. This minimized the flood damage to the area and created an excellent area for crop production. By mid-October 2011, the Klein Pond was complete and began to store water (*Figure 27*).

The diversion weir and 48-inch diversion culvert for the Klein Pond were completed in November 2011. The construction crew then moved on to the last two portions of the project. This included the rate control weir (*Figure 28*), seeding and mulching of the ponds and ditches. By December 2011, the entire improvement project was complete. Seeding the native grass buffers was completed and monitoring equipment was installed along the newly constructed structures and BMPs throughout the system in spring 2012.

The native grasses were maintained and mowed in 2012 and 2013 to control weed growth.

Figure 29 - Increased Storage Capacity Provided by Klein Pond

WATER QUALITY REPORT AND OUTCOMES

The *Water Quality Report* analyzes the water quality monitoring results that are summarized here.

WATER QUALITY HIGHLIGHTS

There were many benefits to water quality in the CD 57 system based on the six total years of monitoring. The following are the major water quality benefits.

- Increased Storage Capacity: The Klein Pond provided a substantial amount of storage to the upper half of the CD 57 watershed. During rain events, the Klein Pond would store water up to an area 650 feet by 250 feet and nearly 12 feet in depth, equaling 26.3 acre-feet of storage. This is equivalent to 13 Olympic sized swimming pools which is equivalent to 0.20 inches of rainfall across the contributing watershed. With a reduced outlet of a 15-inch pipe, water backed up into the pond, dramatically slowing the water flow. This allowed water downstream to drain out prior to water in the upper watershed from draining, preventing flooding. (*Figure 29*)

- Reduced Peak Flow: With an increase in drainage capacity, protecting downstream landowners and the receiving waters was a major concern in the design of the system. It was essential to the landowners to record the depth of water, thus flow throughout the system to insure that peak flow rates were protected. Peak flows also contribute to the highest pollutant loading. Therefore, reducing peak flow rates also reduced pollutant loading. Peak flow rates in the CD 57 system reached nearly 500 cfs after large rain events and may have been higher prior to the installed BMPs. The peak flow rates were reduced at two points as the flow travels through the watershed, once in the Klein Pond and once at the outlet of the system. Peak flow reductions at the Klein Pond ranged between 10 and 50 percent throughout the three years of monitoring and averaged 28 percent reduction for all monitoring storms. The rate control weir had a top reduction in peak flow of 25 percent and averaged 6 percent in reduction for the monitored rain events. The Klein Pond had more than 4 times the storage than the rate control weir, thus had a higher peak flow reduction. (*Figure 30*)

- BMP Water Quality Improvements: Water quality of the passing water had dramatic improvement in reductions of pollutants. Each BMP installed had a function to reduce the loading of TSS, TP, and TN to improve the overall water quality throughout the ditch system. While a traditional

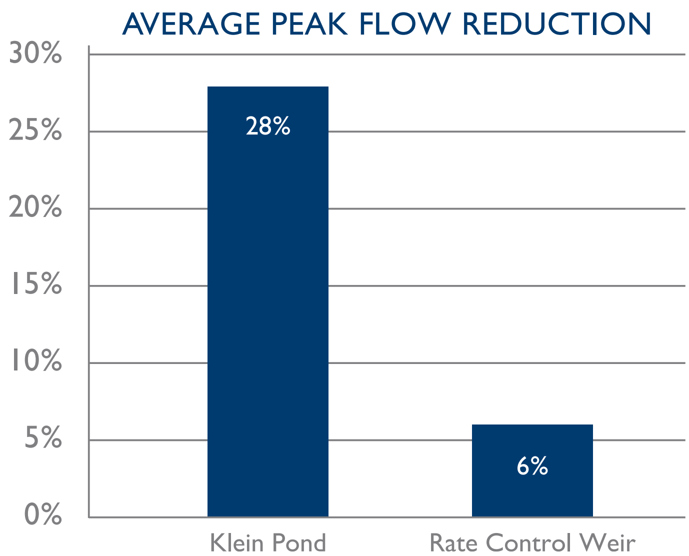


Figure 30 - Reduced Peak Flow

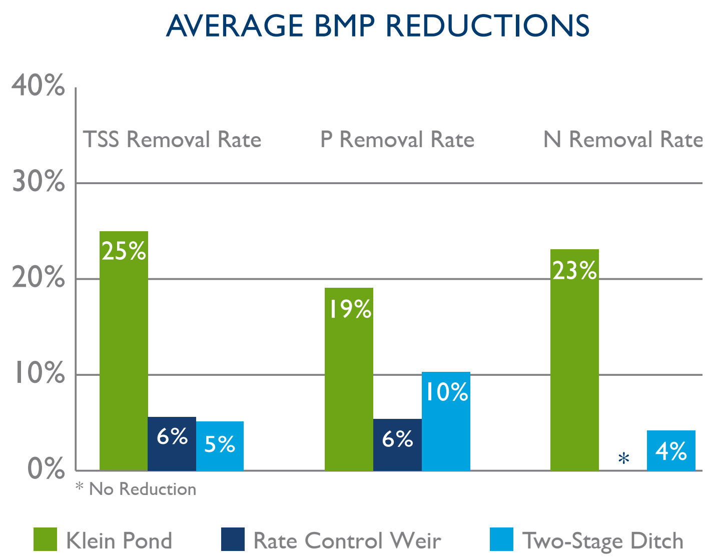


Figure 31 - BMP Water Quality Improvements

ditch increases its loading as it travels downstream, the CD 57 system decreased loading as the water passed through the treatment train of each BMP. The Klein Pond, two-stage ditch, and rate control weir were analyzed to determine how effective they were at reducing the total loading of TSS, TP, and TN. All three BMPs showed reductions, thus improving the overall water quality of the ditch. Reduction of each pollutant ranged between 15 and 50 percent for the Klein Pond, averaging nearly 25 percent for each. The two-stage ditch and rate control weir had reductions between 2 and 10 percent, averaging nearly 5 percent. Pre-BMP installation monitoring showed that the pollutants increased on average 30 percent as the water moved downstream. This is more than a 50 percent difference and substantially improves the water quality of the ditch. The installation of these BMPs are making a difference in the water quality downstream. (*Figure 31*)

- Trapped Sediment: Yearly topographic surveys were performed on the CD 57 system. After the completion of the 3 years of post-BMP installation monitoring, the Klein Pond was surveyed to determine how much sediment had accumulated in the pond. The survey revealed over 725 cubic yards of sediment had accumulated, equivalent to over 70 dump truck loads. The Klein Pond was the most effective at removing pollutants as over 230,000 pounds of sediment, 415 pounds of phosphorus, and 23,000 pounds of nitrogen were removed. Together, all three BMPs removed a total of 251,000 pound of sediment, equivalent to nearly 75 dump truck loads of sediment. (*Figure 32*)

- Baseflow Water Quality Improvements: During baseflow conditions, wildlife utilize waterways for their habitat. However, many waterways have degraded water quality and cannot support aquatic life. Therefore it is very important to provide a healthy environment for wildlife to thrive. Pre- and post- BMP installation monitoring was performed to determine the water quality changes during baseflows as a result to the installed BMPs. On average, the TSS and TP concentrations were reduced by more than 33 and 16 percent from the installed BMPs respectively. This provides a significant change in water quality and makes the CD 57 system a thriving place for a variety of species to live. Without the BMPs, it is likely that the CD 57 system would not support a diverse wildlife habitat for many species. Improving water quality during rain events impacts the natural resources on a national scale, however, improved water quality during baseflow conditions impacts natural resources on a local scale. (*Figure 33*)

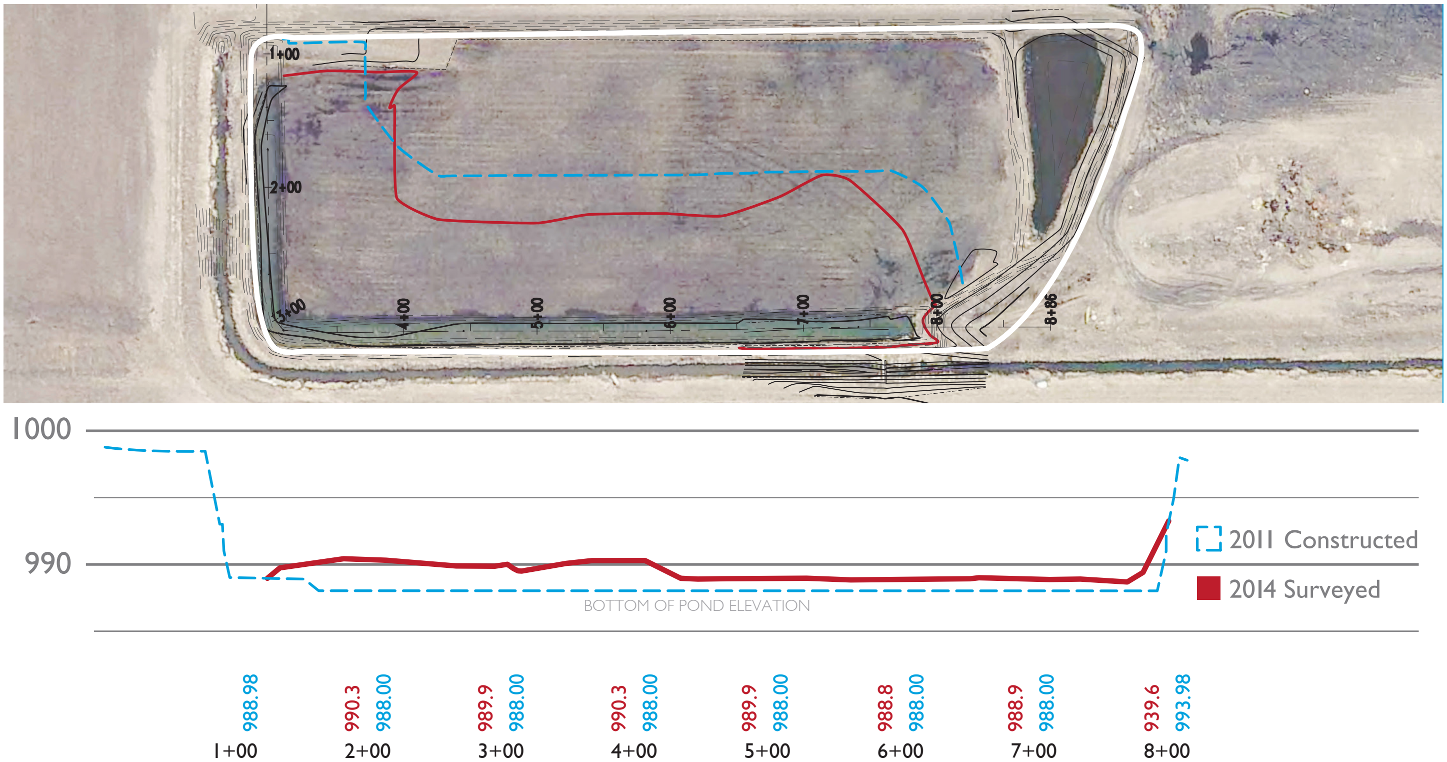


Figure 32 - Trapped Sediment

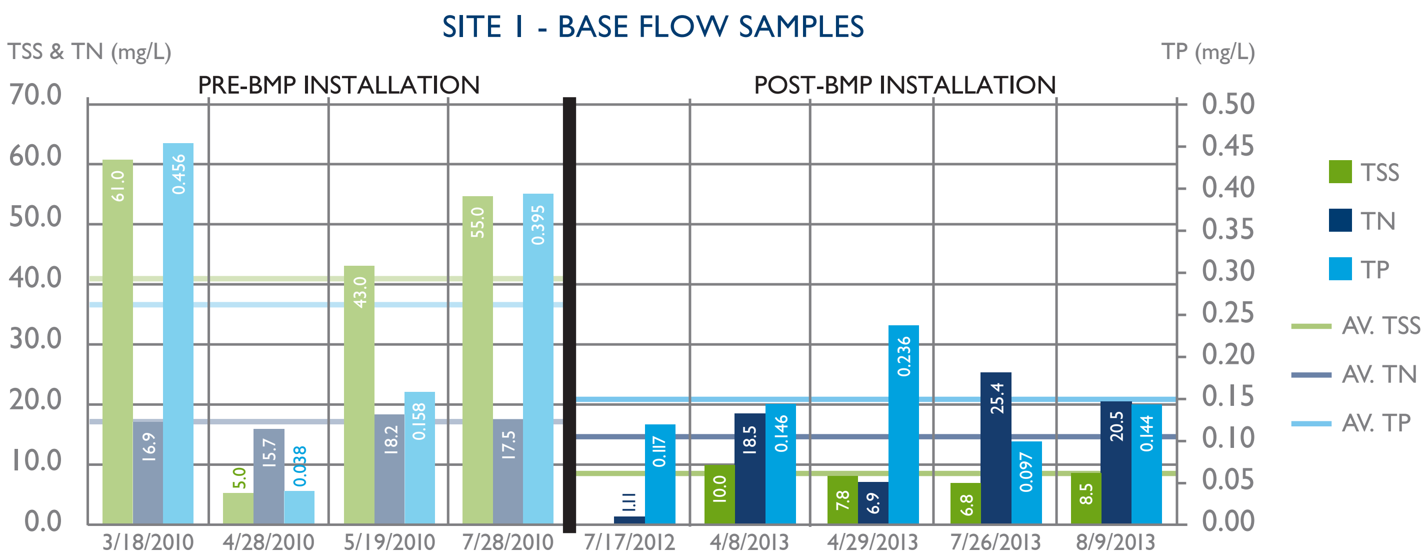


Figure 33 - Base Flow Water Quality Improvements
(Bars indicate date specific measurements; Lines indicate average measurement)

TSS Reduction = 33% TN Reduction = 3% TP Reduction = 12%

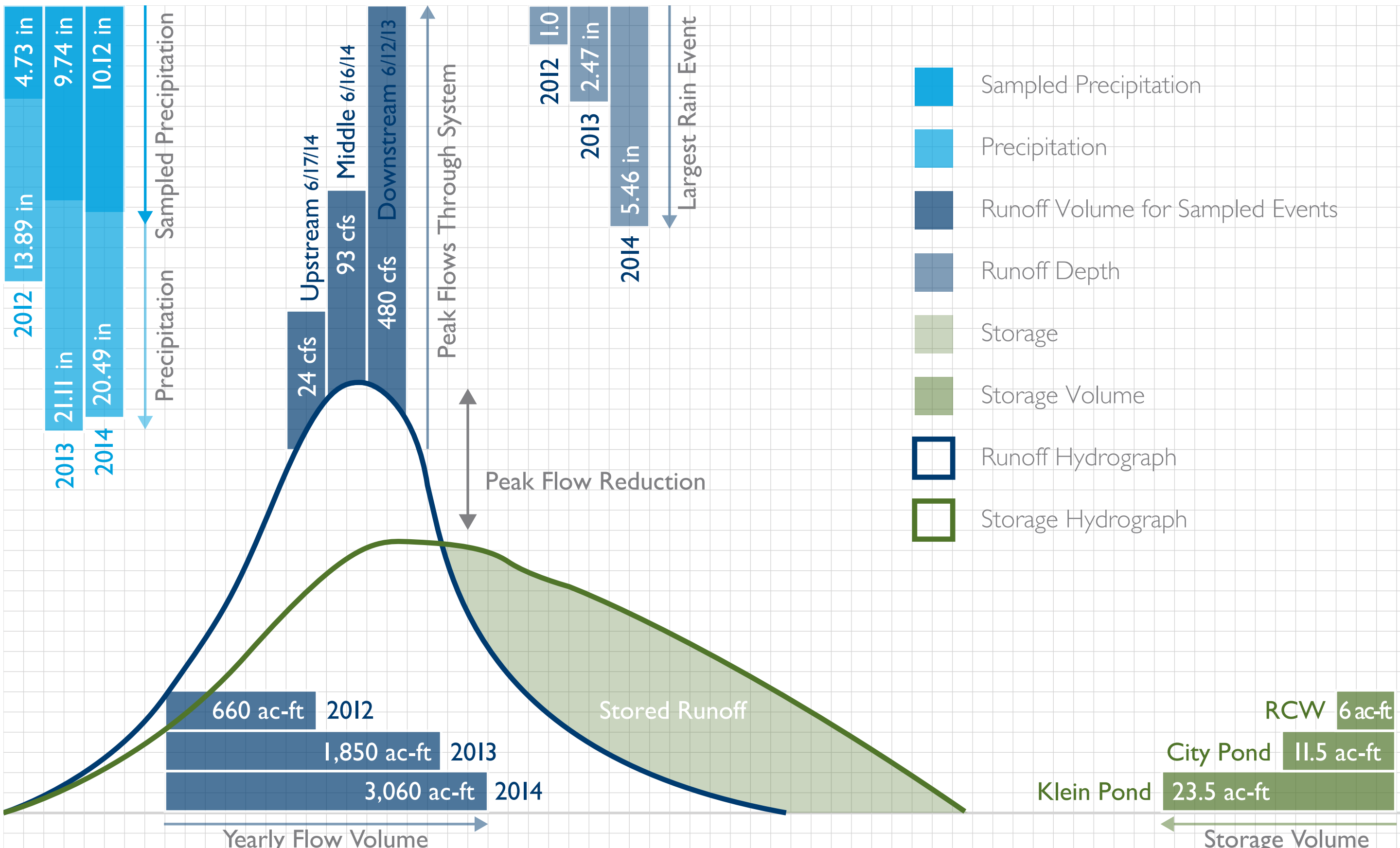


Figure 34 - Hydrograph Summary

FLOW

Flow monitoring for the CD 57 system was interpolated using stage (depth) data collected utilizing data logging devices. There were 19 rain events over 0.5-inches of rainfall that were sampled and analyzed for both flow and water chemistry. The data logging devices used collected rainfall depth, barometric pressure, and stage was used to determine the following: total rainfall and sampled rainfall depths, runoff depth, peak flow rates, and total flow volumes.

Rainfall was measured for every 0.01 inch of rain and was recorded with an onsite rain gauge and data logger. Rainfall was recorded at one location in the middle of the CD 57 watershed.

The total flow volume of a rain event at a given point is defined as the cumulative volume of water that passes through a point for a rain event. It is found by calculating the area under the hydrograph curve.

The runoff depth is calculated from the total flow volume recorded throughout the watershed. Compared to rainfall, runoff depth is less in depth due to infiltration of the soil.

Peak flow rates are the highest recorded flow rate and are the top most point of the hydrograph curve. Peak flow rate are generally linked to the highest pollutant loading that a watershed contributes.

Peak flow rates and total flow volume generally increase moving from upstream to downstream as the watershed size increases. Rainfall depth and runoff depth are generally similar throughout the watershed, but can vary as rainfall intensity varies. (*Figure 34*)

EDUCATION

One of the benefits of this project is the way it is being used as an educational tool. There have been many opportunities where the project was showcased as a model. They include workshops, publications, seminars, presentations and conferences. Audiences have included landowners from various ditch systems, government agencies, land managers, drainage authorities and members of the public.

AGRICULTURAL DRAINAGE WORKSHOPS

Three educational drainage workshops were held on behalf of Blue Earth County Drainage Authority, LCCMR, MNDNR, and MDA, with ISG and others to present this project to a diversified audience. The workshops contained a history, background, and overview of this project and the effort it took to achieve the outcome. It also included guest speakers with different perspectives to create an unbiased atmosphere for those in attendance. A tour of CD 57 was provided at two of the workshops. The 2014 event was attended by nearly 200 people.

PUBLICATION

The CD 57 project was also featured in the 2015 Gislason and Hunter Law Firm's agricultural law newsletter *DIRT Magazine*. The article titled, "Conservation Drainage" described the impacts that BMPs can have on agricultural drainage and water quality.

OTHER PRESENTATIONS

On behalf of Blue Earth County, ISG has presented this project to several other audiences since it began in 2007. Presentations were given to the following audiences:

- Minnesota State University, Mankato Department of Civil Engineering (2010)
- American Society of Civil Engineers (2011)
- Faribault County Drainage Authority (2013)
- Minnesota Water Resources Conference (2014)
- Iowa Water Conference (2014)
- Blue Earth County Soil and Water Conservation District (2014)
- Sibley County Drainage Authority (2015)

It addition to presentations, handouts were distributed to landowners across southern Minnesota. This includes a summary of the CD 57 project and a Fun Facts Brochure which highlights the major outcomes from monitoring this project.

CONCLUSION

Agencies and landowners were seeking proof that agricultural production could be enhanced and water quality could be improved by implementing a combination of BMPs. This project provided proof that these goals can be accomplished simultaneously. Storage and drainage capacity were improved resulting in reduced flooding which resulted in improved field conditions for crop yields. Water quality was also improved by reducing sediment and nutrient loading throughout the system.

It is evident that with proper planning, community and agency collaboration, and incorporation of innovative engineering, increased drainage capacity can be designed while also protecting water quality. This project demonstrated a unique circumstance of a degrading drainage system, protection of downstream landowners, water quality concerns, implementation of BMPs using outside funding, and an overall improved drainage system.

There were many benefits from the CD 57 Project including collaboration between many agencies and landowners, improved drainage and water quality through BMPs, and a unique tool to use in the future when dealing with similar projects.

Overall the project was successful. All parties involved learned how to work together to achieve a common goal for those impacted by the CD 57 Project. With the implementation of BMPs to the system, drainage was improved to the watershed while also enhancing water quality. The water quality benefits to this project are a significant bonus to the project. On a small scale these benefits can be applied in a variety of ways to all drainage systems in southern Minnesota. Together, they can affect a large scale watershed environment. This project provided an exceptional demonstration on how BMPs can be used in conjunction with improvements to agricultural drainage systems.

This project serves as a guide to others located in the area that are experiencing degraded drainage systems and water quality concerns. This project will help the future of agricultural drainage design and will make it easier to incorporate BMPs to improve the water quality in these systems. Hypoxia in the Gulf of Mexico continues to be a concern at a national scale. By implementing these type of projects throughout the agricultural community in the Midwest, sediment and nutrient levels can be reduced and lead to an overall water quality improvement throughout the Mississippi River Watershed.

CHALLENGES

There were several challenges during the 2009-2014 project construction and water quality monitoring of the CD 57 Project. During the pre-construction monitoring, limited data was collected due to lack of funding. Funding for water quality monitoring was not determined until late 2010,

Figure 35 - Damaged Camera due to High Water Levels

which limited the amount of samples that could be obtained. Pre-BMP installation samples only included grab samples during baseflow conditions and were not taken after rain events. The following were the major challenges associated with monitoring the CD 57 system for water quality:

- Costs
- Equipment
- Weather
- Maintenance
- Vandalism
- Agencies
- Funding
- Time

COSTS

Very few ditch systems in Minnesota have been monitored for flow and water quality. The main reason for this is due to the difficulty in monitoring. Major difficulties in ditch monitoring include backwater effects, inconsistent soil conditions, water quality variations with peak flows, and flow variations between open ditches and culvert crossings. To accurately monitor water quality and flow with varying site conditions requires higher quality equipment and additional monitoring sites in specific locations based on conditions. The high cost of this equipment would be more than the cost for constructing the BMPs. Therefore, it was not feasible to purchase the higher cost equipment.

One of the main focuses of the project was determining how the BMPs affected the system and water levels adjacent to the ditch. The theory was to use data loggers to record depth to show the improvements didn't negatively impact the adjacent farmland. Landowners needed assurance that the water levels in the ditches would not exceed the ditch banks.

EQUIPMENT

Post-BMP installation water chemistry sampling and testing was done through the Minnesota State University (MSU), Mankato, Departments of Civil and Mechanical Engineering and Chemistry and Geology and occurred during the peak flow, following 1-inch rain events and baseflow. This provided a unique opportunity for students to learn the methods needed to properly test for multiple water chemistry parameters. This combined effort allowed for a general analysis of the BMPs installed and how effective they were during rain events.

If sufficient funding was available for equipment, several changes would have been made to the monitoring approach. Data loggers would have been replaced by flow-velocity meters to monitor flow (cubic feet per second (cfs)) versus depth. In addition, rather than one grab sample at the peak flow of the storm, a real time portable sampler would be installed at each monitoring site. This sampler would take water quality samples from the ditch at different intervals of a storm, providing more measurements on water quality associated with different flows throughout a storm event. Water chemistry would also be tested through a certified testing lab. This would provide a validated water quality analysis of the tested parameters.

WEATHER

A major difficulty came from the unpredictability of severe weather in the area. The project started in the fall and winter of 2010-2011. Record rainfall and record snow fall during this time delayed some of the construction and added additional costs for pumping water, erosion control and other increased time for completion. Several storm events damaged monitoring equipment including staff gauges, data loggers, cameras, and rain gauges. With high winds and high flows, several of the staff gauges became loose and tipped over in the ditch. Cameras were also susceptible to flood damage since they needed to be placed within 20 feet of the staff gauge for a clear picture. Several cameras were flooded out during high flow periods. High winds also damaged the rain gauge and weather station. The rain gauge was periodically blown off the mount and needed to be remounted. *Figure 35* shows a camera that was damaged due to high water levels.

MAINTENANCE

Regular maintenance is required to make sure the equipment is functioning correctly. This includes trimming vegetation around cameras, removing debris from staff gauges, ensuring data loggers and rain gauges are correctly reading pressure and depth, and routine inspection for damage after rain events. Maintenance costs were not included in the grant amount and future requests for funding would include ongoing maintenance, along with improved monitoring strategies.

VANDALISM

Vandalism and theft periodically occurred to the monitoring equipment. Cameras, staff gauges, and data loggers were consistently tampered with at three monitoring locations. Due to the limited visits, the incidents were not noticed until the next scheduled collection. A multi-functioning weather station valued at $10,000—provided at an in-kind contribution by MSU—was stolen and was never replaced.

AGENCIES

This project could not have happened without agency involvement. Specifically, there were individuals who were instrumental in moving the project forward. Leo Getsfried, Minnesota Department of Natural Resources was able to see how the BMPs could both improve water quality while also enhance crop conditions for landowners. This combination is essential in making agricultural drainage projects with combined BMPs so effective. Mark Dittrich, Minnesota Department of Agriculture, provided consistent, effective feedback and guidance that maximized the water quality improvements. Al Kean, Minnesota Board of Water and Soil Resources and staff ensured the best interests of the State while also helping to move the project forward as efficiently as possible with timely responses and solutions. Other agencies and staff from the DNR, BWSR, NRCS, and SWCD also contributed meaningful input to maximize the water quality benefits.

While input from agencies resulted in a successful project there were several challenges. These challenges sometimes impeded efforts to improve water quality. Below is a list of the challenges of the project.

- Too many agencies: There were several agencies and several groups of agencies that were involved in the drainage improvement process. This made for a confusing process.

- Lack of Communication: The responsibility of communication was not handled among agencies. Rather, the engineer appointed by the Drainage Authority was required to communicate between agencies and different departments in each agency to relay information between landowners, the drainage authority, and agencies. This slowed the process.

- Variety of Goals: Each agency has its own list of priorities and goals related to improving water quality. In many cases, the priorities conflicted with each other.

- Different Requirements: In the event that goals of the project aligned among agencies, the requirements for the goals did not align.

- Delays: Different requirements and policies lead to a delay in the implementation of the project since all agencies had to review the project and had their own timelines for review. This process significantly delayed the overall project from the petition stage to the final construction to 5 years. If there were a more streamlined process for collaborating with multiple agencies, this process could have been completed in two to three years.

- Added Costs: The delay time resulted in unnecessary costs to fulfill the needs and requirements of each agency. The added costs would have been better spent on water quality BMPs.

- Landowner reluctance to deal with agencies: Due to the time, costs, and requirements of agencies, many landowners are reluctant to work with agencies to achieve water quality goals. This requires additional time with landowners to build trust in order to move forward in working with agencies.

- Financial Support: Agencies do not provide enough financial incentives to implement BMPs within their existing budgets. This is due in part to the belief that the BMPs only benefit the landowners rather than benefitting the public waters and the landowners. Without LCCMR funding, water quality projects like CD 57 are difficult to get implemented.

- Lack of Implementation: The challenges listed above contribute to the lack of implementation of more BMP projects throughout Minnesota.

FUNDING

Another difficulty was the limited outside funding sources available for projects dealing with water quality in agricultural drainage systems. Many federal, state, and local governments strive for water quality improvements while supporting the agricultural economy. However, there are limited sources for funding for BMPs. BMPs associated with agricultural drainage can be very costly and in some cases, implementing these would not prove cost effective for the system. This results in many drainage improvement projects that are constructed as less effective, traditional style ditches with limited water quality aspects associated with them.

TIME

Drainage improvement projects happen when there is a failure or near failure of the system. In order to prevent additional system failure, crop loss, erosion and other damage, there is significant pressure on the drainage authority to rush through the process. The engineer must then move quickly to meet all requirements for construction. This puts more focus on completing the project rather than considering water quality improvements.

RECOMMENDATIONS

Although this project was a success in terms collaboration between agencies, increased system capacity, and water quality improvements, there were several lessons learned throughout the process that make for valuable recommendations to future projects.

COST EFFECTIVENESS AND DRAINAGE LAW

In early phases of this project, several locations were targeted for wetland restorations. While wetland restorations add incredible valuable to water quality and wildlife habitat, they were difficult to incorporate into this drainage project due to high associated costs with little benefit to the drainage system (i.e., landowners). This nearly eliminates the potential for wetland restorations throughout southern Minnesota drainage systems without outside funding. While the overall goal of many agencies is to restore as many wetlands as possible, it is difficult to include them as part of drainage projects. In order for wetlands to be incorporated into drainage systems, outside funding is needed to make the project cost effective. The current rules for utilizing this funding when available should be reviewed. They do not allow a drainage system to obtain funding through RIM/WRP and thus this option is eliminated without 100% landowner support.

A similar issue arose when incorporating BMPs into this drainage system. Without funding from the LCCMR, the water quality BMPs installed in this system would not have been cost effective to the system. Even with willing landowners to contribute more money to storage within the watershed, the benefit amount fell short of what the costs were to improve the system. This is also a common mishap in drainage systems throughout southern Minnesota. While many landowners are open and willing to incorporate BMPs into their drainage systems, funding allocations limit the availability and practicality of these practices. Again, outside funding is needed to help implement these practices into southern Minnesota drainage systems.

MONITORING

This project was one of the first drainage systems with BMPs that included monitoring for water quality. Although monitoring for this project provided great results, many strategies were learned throughout the monitoring process that need to be taken into consideration for the next similar project.

More monitoring is needed prior to the construction of agricultural BMPs or an improvement to a ditch system. Monitoring should occur during baseflow conditions and also within 24 hours of a rainfall event, primarily those events greater than 1-inch. This will help provide a comparison of data. In addition to pre-BMP installation monitoring, it would also be beneficial to model sediment transport throughout each BMP and compare results to the post-BMP installation water quality data. This could be used in the future to calibrate sediment transport models.

While data loggers and grab samples were adequate to assess the water quality throughout the CD 57 system, more sophisticated equipment would better gauge and depict the water quality of the system. Real time flow and water quality devices would provide a more accurate depiction of the flow and water quality of the system. This would also reduce the amount of ambiguities within the data collected for monitoring.

Throughout the three years of post BMP-installation monitoring, the CD 57 system experienced snow melts, ice outs, and heavy rainfalls that damaged or destroyed monitoring equipment. Higher quality equipment that can handle extreme conditions would save money through reduced maintenance and replacement costs and would also reduce the risk of losing valuable data.

DESIGN AND INSTALLATION

Water quality results for the two-stage ditch in this system indicated it was much less effective than what was anticipated. However, this was likely due to the nature of this project and the location of the two-stage ditch in relation to the other BMPs. The two-stage ditch was constructed immediately downstream of the surge pond, which effectively reduced the sediment and nutrient loading. Since the two-stage ditch was receiving already treated water, the two-stage ditch appeared to be less effective at reducing the sediment and nutrient loading. Future monitoring would incorporate a system where a two stage ditch can be monitored independently to better gauge the effectiveness of this practice.

OVER-DUG DITCH

The concept behind the over-dug ditch was to create a long linear sediment trap in the existing ditch and also gain depth throughout the system. However, many portions of the over-dug ditch contained silty, unstable soils with steep bank slopes. This caused several areas of the over-dug ditch to slough, and added to the erosion potential of the ditch. It is recommended not to construct over-dug ditches in these situations. *Figure 36* shows a part of the over-dug ditch where erosion occurred.

MAINTENANCE

Monitoring showed that the BMPs analyzed had significant sediment removals. Specifically, the Klein Pond accumulated 725 cubic yards of sediment in the pond. At this rate, maintenance and sediment removal is necessary and should be budgeted for in the future. Consistent with its design intent and the current rate of sediment accumulation, the Klein Pond will need to be cleaned in a period of 10 years per MPCA recommendations. Portions of the over-dug ditch contained highly organic and silty soils. In some areas, erosion and sloughing occurred

Figure 36 - Erosion in Over-dug Ditch

Figure 37 - Removing Sediment from Pond

and periodic maintenance will be required for these areas. The buffer strips have been mowed and maintained over the past three years and ongoing maintenance will need to continue for these areas. Sediment in the City Pond was not monitored for sediment accumulation, however it is anticipated the sediment will need to be removed in 10 years per MPCA recommendations. (*Figure 37*)

LANDOWNER PARTICIPATION

There were instances where, for legitimate reasons, a landowner chose not to participate in a land easement for water quality improvement, even when it was the most ideal site to impact water quality. This was typically due to lost revenue and/or a significant percentage loss of productive land. For example, one property was identified as the most cost effective location for storage; however after multiple attempts involving the drainage authority, engineer, and other landowners, the property owner chose not to take the land out of production. The CD 57 petitioners didn't want to force a taking since this landowner only had 80 acres of tillable farmland. Taking this land out of production was a significant impact on the farmer. In the future, landowners may be more willing to participate in water quality BMPs if they are more adequately compensated for taking land out of production.

AGENCIES

There are many opportunities to improve the process of collaborating with agencies.

- One point of contact/decision making: Assign one agency to serve as the main contact to landowners.
- Improve Communication: Determine a more efficient process for interagency communication. Implement a step-by-step process between agencies rather than a back and forth process.
- Streamline and Prioritize Goals: Identify similar needs of each agency and prioritize BMPs based on these similarities.
- Review Process: Require a faster turn-around time for agencies to provide feedback on projects.
- Reduce Delays: By having fewer points of contact, improved communication, prioritized goals, and a more efficient review process will result in reduced delays.
- Financial Support: Consider the benefits to the receiving waters and those impacted as a result of the water quality improvements when allocating funding.

TIME

In order to include water quality improvements to systems, proper planning, watershed management and prioritizing is needed prior to the point of failure. This requires multi-purpose drainage management plans to be developed for each ditch system.

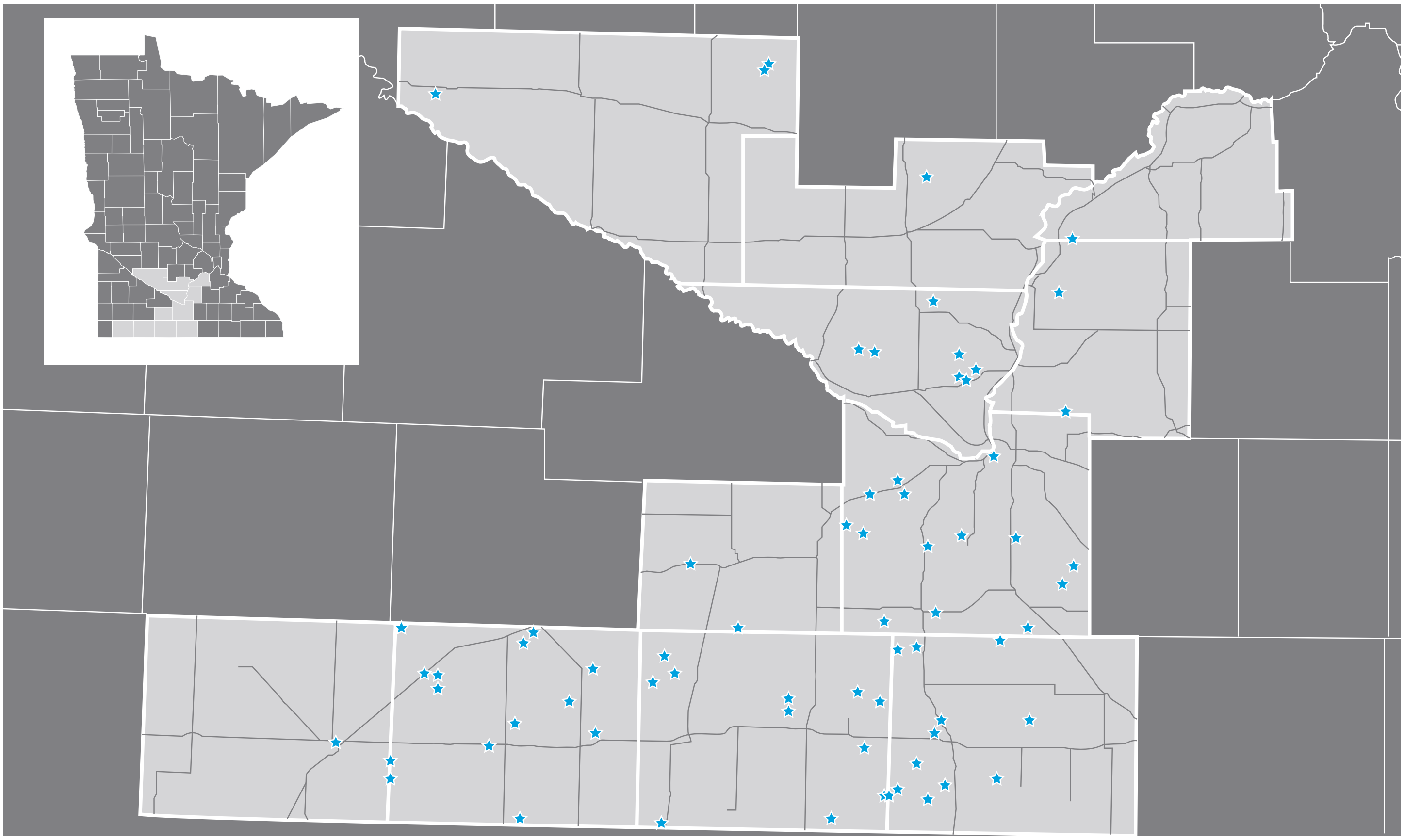


Figure 38 - Map of ISG Projects that have or will encorporate BMPs

ISG

MOVING FORWARD

Most agricultural drainage systems in southern Minnesota do not have an effective plan to address the watershed. Many of these BMPs are not one size fits all projects and need to be evaluated based on several factors including watershed size, watershed slopes, soil types, rainfall frequencies and many other factors within the watershed. Each drainage system needs to have its own Multi-Purpose Drainage Management Plan which identifies areas where BMPs are most effective. This allows each system to develop a strategy at implementing each practice. These plans will be helpful in seeking outside funding sources.

There are also very few systems that have both BMPs and monitoring with them which makes it difficult to design for desired water quality outcomes and to be able to quantify their impacts. More research and monitoring is needed to determine the effectiveness of these practices within their given circumstances. However, without funding for these type of projects, it is difficult for ditch systems to do these projects based on their cost effectiveness.

There are nearly 40 current agricultural drainage projects throughout southern Minnesota currently underway that have an opportunity to implement water quality BMPs to improve water quality (*Figure 38*).

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GLOSSARY

Affected Landowner: A landowner who owns property that is in some way influenced by a public drainage system.

Alternative Intake: Any method of replacing open surface intakes that are flush to the ground with an alternative method that temporarily ponds water, thus preventing sediment from entering. They include a variety of perforated risers, rock inlets, dense pattern tile, or any alternative of these.

Artificial Drainage: Any means of underground tiling or open ditches to effectively lower the groundwater table for adequate crop growth and to allow for proper workability of farm equipment.

Benefit: The financial value allocated to a parcel of land based on its capability to adequately drain water.

Best Management Practices (BMPs): Any method or practice that is used in an agricultural landscape to effectively reduce peak flow rates, sediment loading, erosion, and nutrient loading.

Buffer Strips: An area of perennial vegetation planted between agricultural fields and waterways. They are located adjacent to the top of both sides of any waterway. Buffer strips are required to be a distance of 16.5 feet (one rod) from the top of an open ditch for a Public Drainage System and 50 feet from the top of a public water. Buffer strips are often referred to as buffers or filter strips.

Controlled Subsurface Drainage: A practice used to manipulate the ground water elevation through the use of control structures located on a private tile line. This method allows water to be held higher in the soil profile during the growing season for better crop uptake while draining the water table during the planting and harvesting seasons.

County Tile: A county tile refers to a network of subsurface tiling that conveys water off the landscape and is part of a public drainage system. A county tile is comprised of a network of mainlines, branches, and laterals that are all part of the public drainage system. County tile is often referred to as a tile, tile main, county main, branch, or any variation of these.

Cover Crops: A non-perennial plant that is grown between the main crop in a rotation to enrich the soil through added organic matter, reduced leaching, and reduced soil erosion. They include a variety of small grains including wheat, rye, oats, and barley.

Crop Rotation: Crop rotation is defined as a system for growing several different crops in a planned succession on the same field. It includes the rotation of a small grain such as hay, oats, barely, or alfalfa.

Culvert: A device used to convey water under a roadway or crossing. They include a variety of round, square, or arched pipes made of either concrete, corrugated metal, wood or any other material.

Ditch Viewers: Ditch viewers provide an unbiased approach of determining benefits and damages to affected landowners of a drainage system.

Drainage Authority: Local unit of government that acquires jurisdiction over the land in which public drainage systems pass over. This jurisdiction allows the drainage authority to access the land in which a public drainage system passes for maintenance, repairs, and improvements to that system. It also enables the drainage authority to assess costs through the county treasury for projects related to public drainage systems. A drainage authority is comprised of the county board, joint county board, or watershed district.

Drainage Capacity: Drainage capacity refers to the amount of water than can be stored in the landscape and effectively drained through a public drainage system. It often associates how much water can be drained and how fast that water can be drained from the landscape.

Drainage Coefficient: A method used to measure flow through system tiling and public drainage systems. It is defined as the depth of water (inches) that can be drained in a 24-hour (day) period.

Drainage Engineer: Licensed engineer who is responsible for designing efficient and cost effective drainage systems to adequately convey water from an agricultural landscape. The engineer provides surveys, studies, and reports on the drainage system and the associated findings with designs. The drainage engineer is often referred to as the appointed engineer or engineer.

Drainage Improvement: Improvement of an existing drainage system involves enlarging, extending, deepening, or straightening of the legally established drainage system. The work typically consists of widening, deepening, or enlarging an open ditch or installing a larger tile size in underground tiling systems.

Drainage Repair: Minor or major work on an existing drainage system to maintain the designed drainage capacity. The work typically consists of removing debris, weeds, or sediment deposits from open ditches or replacing portions of damaged tiles.

Final Engineering Report: A document prepared by the drainage engineer that incorporates survey, design, modeling, reviews by the drainage authority, landowners, and ditch viewers for any repairs or improvements to a system. It is the final document of the proposed project including costs, designs, viewers report. It is presented to the drainage authority for approval for construction.

Grassed Waterways: Vegetative channels through agricultural land which provides a means for concentrated flows to drain from the surface while minimizing soil erosion.

Groundwater Table: The depth below the ground surface in which the ground is completely saturated with water. Is this better?

Hypoxia: A condition where a body of water contains extremely low dissolved oxygen levels that cannot support aquatic life.

Hypoxic Water Body: A body of water containing extremely low dissolved oxygen levels that cannot support aquatic life. This condition is also referred to as a hypoxic condition or hypoxia.

Landowner: Any person that owns property connected to the drainage system. This includes farmers, residents, or road authorities that pay an assessment to the drainage system.

Minnesota Drainage Statute 103E: Legal statue in which Minnesota Public Drainage projects must follow the outlined process to work on drainage projects. This process involves the drainage authority, ditch viewers, affected landowners, and the drainage engineer.

New Drainage System: The creation of a public drainage system through use of either underground tile or open ditches to effectively drain the landscape. It also involves establishing legal boundaries of the system and affected landowners.

Nutrient Management: The process of applying and adequate amount of fertilizer to a cropped field taking into consideration soil type, infiltration rate, and application rate.

Open Ditch: In an agricultural setting, an open ditch is referred to as a man-made waterway that was dug to convey water effectively off the surrounding landscape. An open ditch is often referred to as a ditch, dredge, channel, or any variation of these. The majority of open ditches are part of a public drainage system.

Prairie Pothole: Depressional or shallow wetlands that are not connected by stream networks.

Petition: A formal and legal request by landowner(s) to act upon an issue in which the governing agent has authority over. In drainage law, a petition is most commonly a request by landowners to establish, repair, or improve a drainage system.

Preliminary Engineering Report (PER): A document prepared by the drainage engineer that incorporates survey, design and modeling for any repairs or improvements to a system. It is the first draft of the proposed project that is presented to the drainage authority.

Public Drainage System: Public drainage systems, often referred to as drainage systems, ditch systems, or systems, include underground tile and/or open ditches through which water is conveyed off the landscape and crosses over multiple parcels of land. The system is designed to manipulate the water table for agricultural production. The system is owned by the property owners of the land areas affected, but it is governed by the drainage authority, in accordance with Minnesota Statute 103E.

Public Water: Any waterway in which the Minnesota Department of Natural Resources has jurisdiction. These waters consist of lakes, rivers, streams, and wetlands.

Rate Control Weir: A structure that is designed to convey water while control flow rate and direction. Most rate control weirs are constructed with either concrete or steel and are placed in a waterway creating a vertical wall to effectively hold water behind it.

Re-determination of Benefits: The process in which ditch viewers assess the land value involved in a public drainage system. This process is ordered by the drainage authority when a petition for drainage improvements is submitted. The total benefits (increase in land value) that the system receives must exceed the total cost of the project.

Residue Management: A practice in which materials left from harvest including stems, leaves, stalks, and seed ponds are left on the land and are not fully turned over into the ground.

Riparian Vegetation: A mix of grasses, forbs, sedges, and trees that serve as an intermediate zone between upland and aquatic environments. Riparian vegetation is typically planted in the banks of an open ditch or waterway, or on upper portions of buffer strips.

Saturated Buffer: An area in which water from a tile line is released below the surface through an area of perennial vegetation such as a buffer strip or riparian vegetation.

Separable Maintenance: The cost to fully repair the entire drainage system to the currently designed size and grade. In drainage law, separable maintenance can be subtracted from the improvement cost when comparing costs and benefits in the existing system can be proven to be out of repair. A system is out of repair if drainage repairs would not fully fix damages to the system.

Soil and Water Conservation District: SWCDs are political subdivisions of the State established under Minnesota Statute 103C. Each SWCD is governed by a board of elected supervisors to provide land and water conservation services to owners of private lands.

Sponge: The soil is sometimes referred to as a sponge, as it absorbs and stores water in each individual soil particle. The sponge is affected by the soil type and if it contains artificial drainage. Artificial drainages lowers the water table in the soil which allows for a large sponge to absorb more water.

Storage: Designated areas for water to temporarily pond, reducing peak flow rates, flooding and increase capacity to a drainage system.

Surge Basin: An excavated area designed to store large volumes of water during a rain event and slowly release that water through an outlet such as a culvert, tile, or rate control weir.

System Tiling: System or pattern tiling is a method to increase the drainage to private farmland to make the farming more practical, economical, and productive. This typically involves installing private tiling throughout an agricultural field with 4-8 inch perforated tiles which outlet into a public drainage system.

Tile: An underground pipe with holes or perforations that allow groundwater to drain. Tiles are typically installed on private lands by the landowner and range between 3 and 12 inches in diameter.

Toe-wood Sod Mats: A method of river or streambank stabilization and erosion control that utilizes woody debris such as tree branches, logs, or limbs. The wood debris is placed in areas that experience erosion and are covered topsoil, sod, and shrubs.

Two-Stage Ditch: A two-stage ditch is a low flow channel inside a high flow channel. The low flow channel is small and carries the perennial baseflows while the outer channel serves as the floodplain for high flows.

Viewers Report: A document prepared by the ditch viewers that assess the current land value and the re-determined value involved in a public drainage system. It is included in the Final Engineering Report and compares the cost of the proposed project and the benefits to the system.

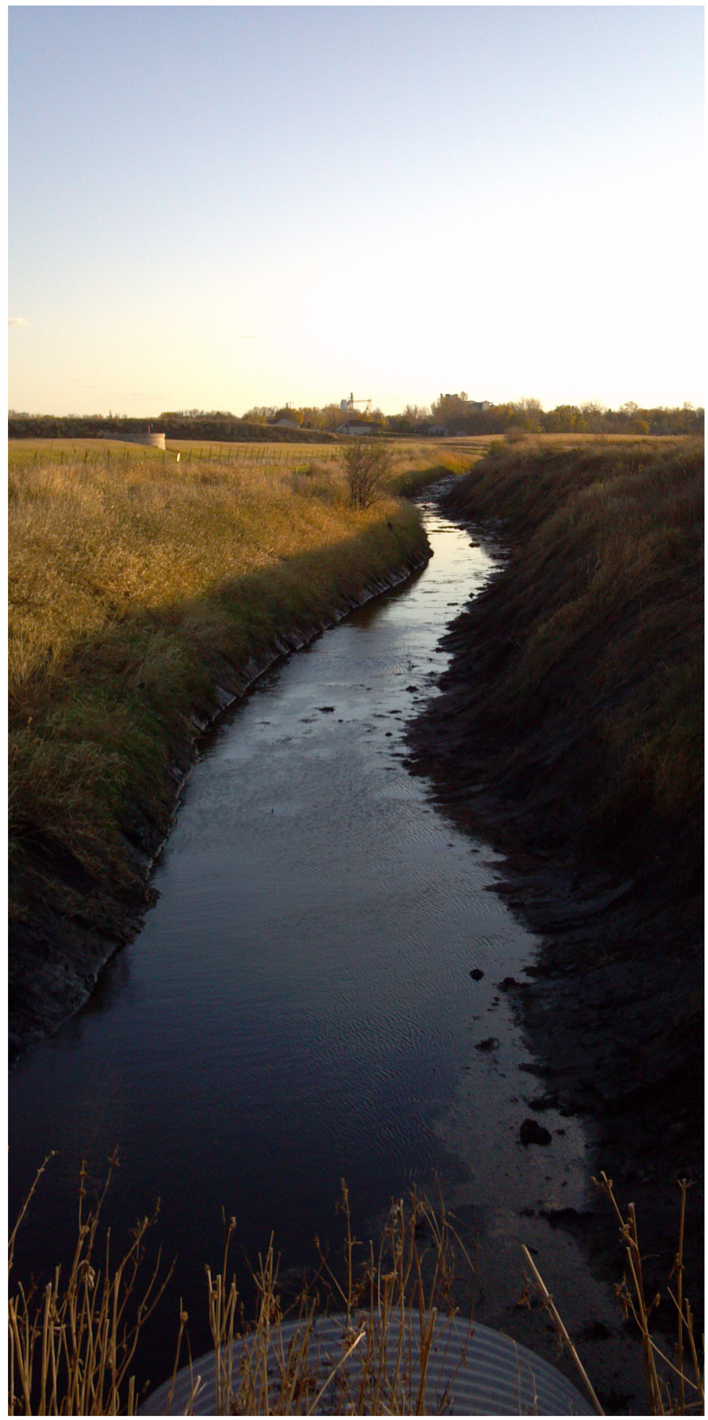
Water and Sediment Control Basin (WASCOB): An earthen embankment installed perpendicular to the surface flow of water on a hillside, creating a linear pond area to temporally store water.

Watershed: A watershed is the area of land where all of the water that is under it or drains off of it goes into the same place.

Waterway: Waterways refer to either an open ditch, stream, river, or other channel that conveys water.

Wetland Restoration: The reestablishment of natural hydrology and/or vegetative to a former wetland basin that has either been drained, farmed, or modified beyond its original state.

Woodchip Bioreactor: An excavated, underground trench filled with woodchips in which water from a tile is directed into the trench for nutrient removal.



I+S GROUP

WATER QUALITY REPORT PREPARED FOR:
MINNESOTA LEGISLATIVE-CITIZENS COMMISSION ON MINNESOTA RESOURCES

MAPLETON AREA AGRICULTURAL + URBAN RUNOFF ANALYSIS

SOUTHERN MINNESOTA - BLUE EARTH COUNTY DITCH NO. 57 (CD 57)

AUGUST 14, 2015

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

BLUE EARTH COUNTY

ISG

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PREPARED ON BEHALF OF:
THE BLUE EARTH COUNTY DRAINAGE AUTHORITY

PREPARED BY:
ISG

AUGUST 14, 2015

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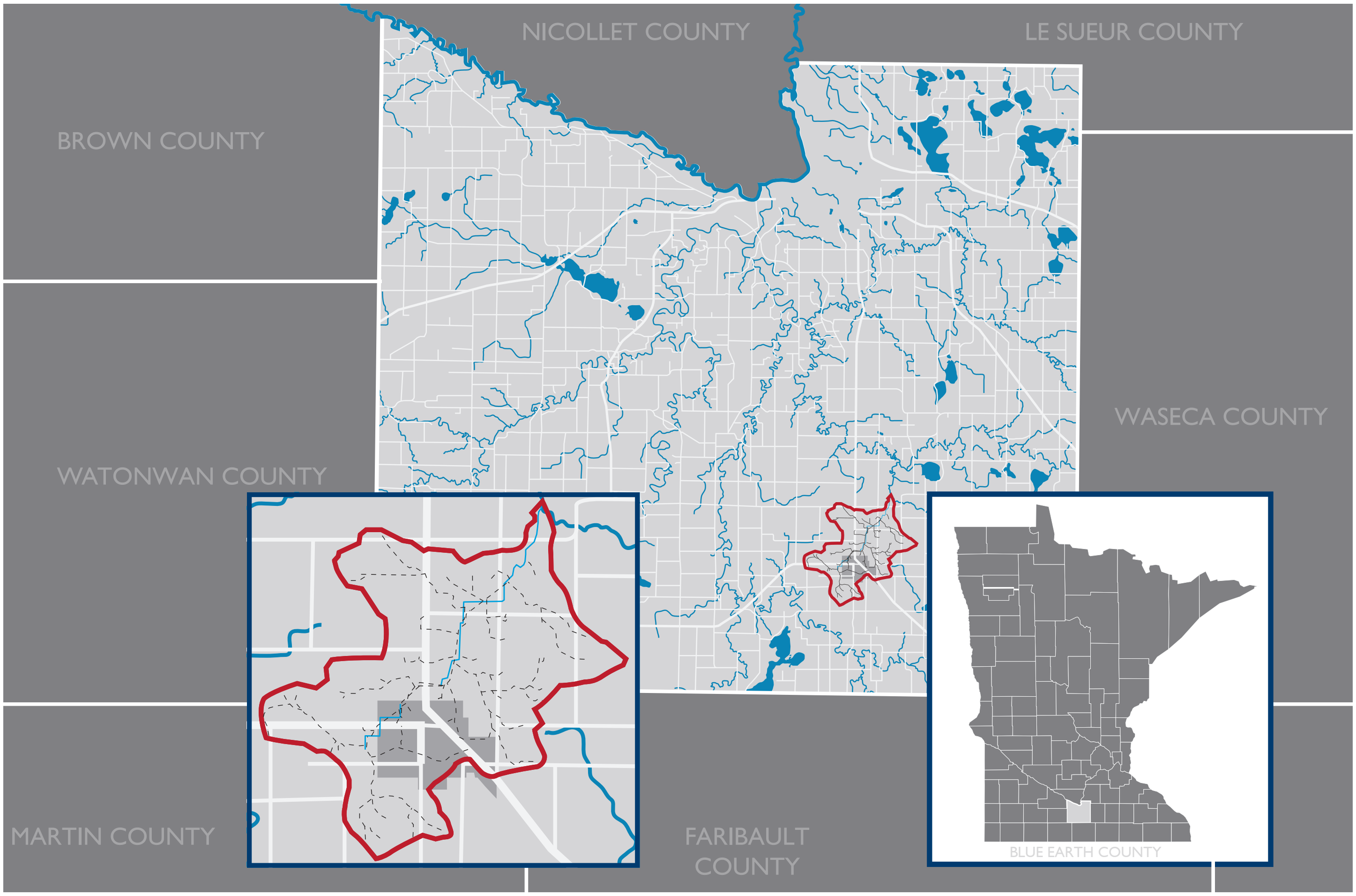

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Blue Earth County and DC 57 Location

OVERVIEW AND BACKGROUND

This Water Quality Report supplements the Final Report: Mapleton Area Agricultural and Urban Runoff Analysis and addresses water quality conditions of Blue Earth County Ditch 57 (CD 57). The report outlines and describes the approach used to monitor and analyze water quality parameters before and after the installation of agricultural Best Management Practices (BMPs) within the CD 57 system. These BMPs include buffer strips, surge basins (City Pond, Klein Pond), a two-stage ditch, sediment trap, and weir structures. These practices were designed to reduce peak flow rates and pollutant loading throughout the CD 57 system and improve water quality. The results documented in this report are vital in the ongoing efforts to evaluate potential effectiveness of combining BMPs in small, upland watersheds of the Western Corn Belt Ecoregion.

Water sampling results and other data were used to: 1) determine the effect of storage and peak flow reductions of flooding, 2) determine the effectiveness of BMP's installed, 3) analyze seasonal variations in water quality; and 4) evaluate compliance with water quality standards. These data are available to all interested parties, particularly landowners, drainage authorities, watershed groups, and state agencies. Results and reports are available through Blue Earth County and were provided to the Legislative-Citizens Commission on Minnesota Resources and the Minnesota Environmental and Natural Resources Trust Fund (LCCMR/ENTRF). Project partners for the CD 57 water quality monitoring project include landowners throughout the CD 57 watershed, Blue Earth County Drainage Authority, ISG, Minnesota State University, Mankato (MSU), and Minnesota Valley Testing Laboratories (MVTL).

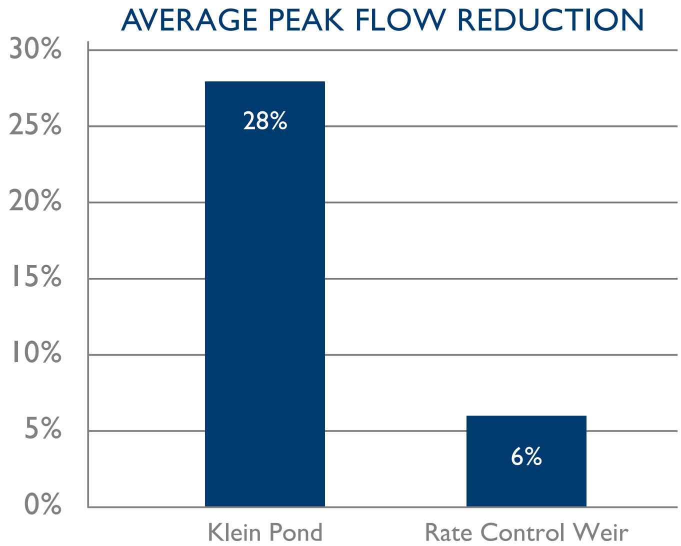


Figure 1 - Average Peak Flow Reductions

Figure 2 - Rate Control Weir Storing Water

PROJECT GOALS

The project's overall goals included improving a nearly century-old drainage system by:

- Increasing drainage capacity while protecting downstream receiving waters
- Improving the water quality of the ditch by reducing soil erosion and nutrient loading by providing storage and treatment practices
- Enhancing ecological value and increasing critical land and habitat
- Providing an innovative demonstration project dealing with Minnesota Drainage Law
- Developing a tool for landowners, land managers planners, and conservationists as a model for future drainage projects

Expected results from the installation of surge basins, native grass buffer strips, a two-stage ditch, sediment trap, and weir structures include: less intense flood events, reduced peak flow rates, and reduced sediment and nutrient loading. Water quality was expected to improve due to less suspended solids in the water column and reduced peak flow rates facilitated by additional storage to the system, a designed self-cleaning system created by the two-stage ditch, and an enhanced habitat for wildlife.

PROJECT RESULTS

This section reviews results of the following data collection: storage and peak flows, average water quality improvements from BMPs, trapped sediment, and perennial baseflows.

STORAGE AND PEAK FLOWS

Storage and peak flow reduction was a major concern for all landowners throughout the CD 57 system. Downstream landowners were fearful of flood damage and crop loss with the upstream improvements to the ditch. Conversely, upstream landowners needed to increase the capacity to prevent their land from routine flooding. This lead to the development of a design that sought to balance storage and peak flow reduction throughout the system through various BMPs.

The City Pond, Klein Pond, and a rate control weir all provided storage and peak flow reduction. The upstream watershed utilized the City and Klein ponds for storage and peak flow reductions while the downstream landowners utilized the rate control weir for storage and peak flow reduction. The average peak flow reductions for the Klein Pond (upstream watershed) and rate control weir (downstream watershed) for the 3 years of monitoring (2012-2014) were compared (*Figure 1*).

The rate control weir provided a total storage of 6 acre-feet. This is equivalent to 3 Olympic sized swimming pools. Peak flow rates were lowered by an average of 6 percent from the upstream ditch section.

The photograph (*Figure 2*) of the rate control weir shows its effectiveness

Figure 3 - Klein Pond Storing Water

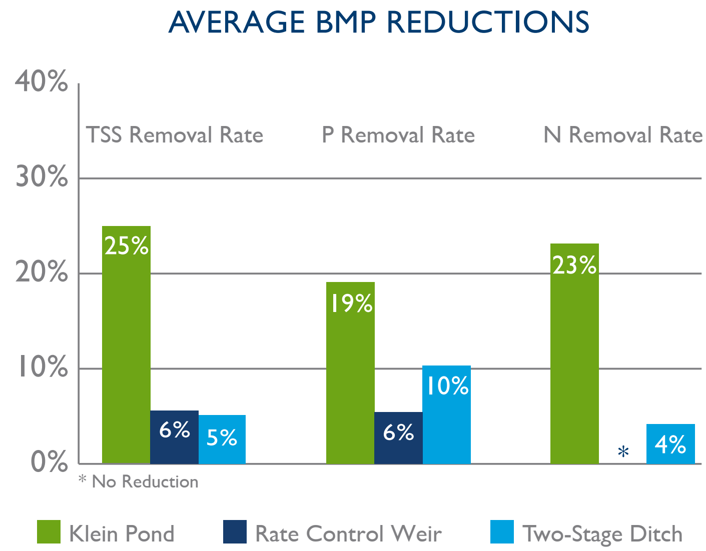


Figure 4 - Average Reductions for TSS, TP and N

at storing water during a rain event.

The Klein Pond provided a total storage of 26.3 acre-feet. This is equivalent to 13 Olympic sized swimming pools. Peak flow rates from the ditch upstream of the pond were reduced by an average of 28 percent. For the watershed area of 1,693 acres at this point, the total storage provided is equivalent to 0.20 inches of rainfall. A photograph (*Figure 3*) shows Klein Pond effectively storing water during a rain event.

AVERAGE BMP REDUCTIONS

Three agricultural BMPs were analyzed through three years of water quality monitoring to determine their overall effectiveness of reducing the loading of total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN). This analysis included calculating the total loading upstream and downstream of each BMP and determined how much of each parameter was removed. The average TSS, TP and TN reductions for the Klein Pond, two-stage ditch, and rate control weir were compared (*Figure 4*).

Of the three BMPs, the Klein Pond was the most effective at reducing TSS, TP, and TN loading. The two-stage ditch also saw reductions in each of the three parameters, however the reductions were lower than the Klein Pond. The rate control weir also caused reductions in TSS and TP, but did not decrease TN loading.

Three other BMPs were installed to improve water quality and include the City Pond, sediment trap, and buffer strips. Due to monitoring and sampling constraints, the loading for these BMPs could not be analyzed as more monitoring points would be needed to properly measure their effectiveness.

ACCUMULATED SEDIMENT

Sediment loading is a major concern in waterways due in part to the adverse impacts on downstream navigation, potable water supply, and aquatic habitat. Sediment deposits in nearby rivers, lakes, and wetlands where flow velocities are slower, cause the water to back up and results in flooding in the surrounding landscape including agricultural land and residential areas. Sediment also carries nutrient bound particles, most notably phosphorous and nitrogen. These nutrients are linked to poor water quality through algal blooms, oxygen depletion, and hypoxic conditions which do not support aquatic life.

While the main goal of the Klein Pond was to provide storage and reduce peak flow rates, it was also intended to provide a large area to accumulate sediment, thus preventing it from traveling downstream and negatively impacting waterways. To quantify how much sediment accumulated over the three years of post-BMP installation monitoring, a topographic survey was performed in November 2014 to compare the original pond floor to the pond floor after three years of sediment accumulation. This topographic survey revealed substantial sediment accumulation in the pond in some cases reaching nearly 2.5 feet in thickness. A total of 725 cubic yards of sediment had accumulated over three years in the pond, equal to approximately 72 standard dump trucks. This benefits water quality by reducing pollutant loading to downstream waters. *Figure 5* shows the profile of the Klein Pond, which compares the original bottom of the pond and the sediment accumulated in the pond.

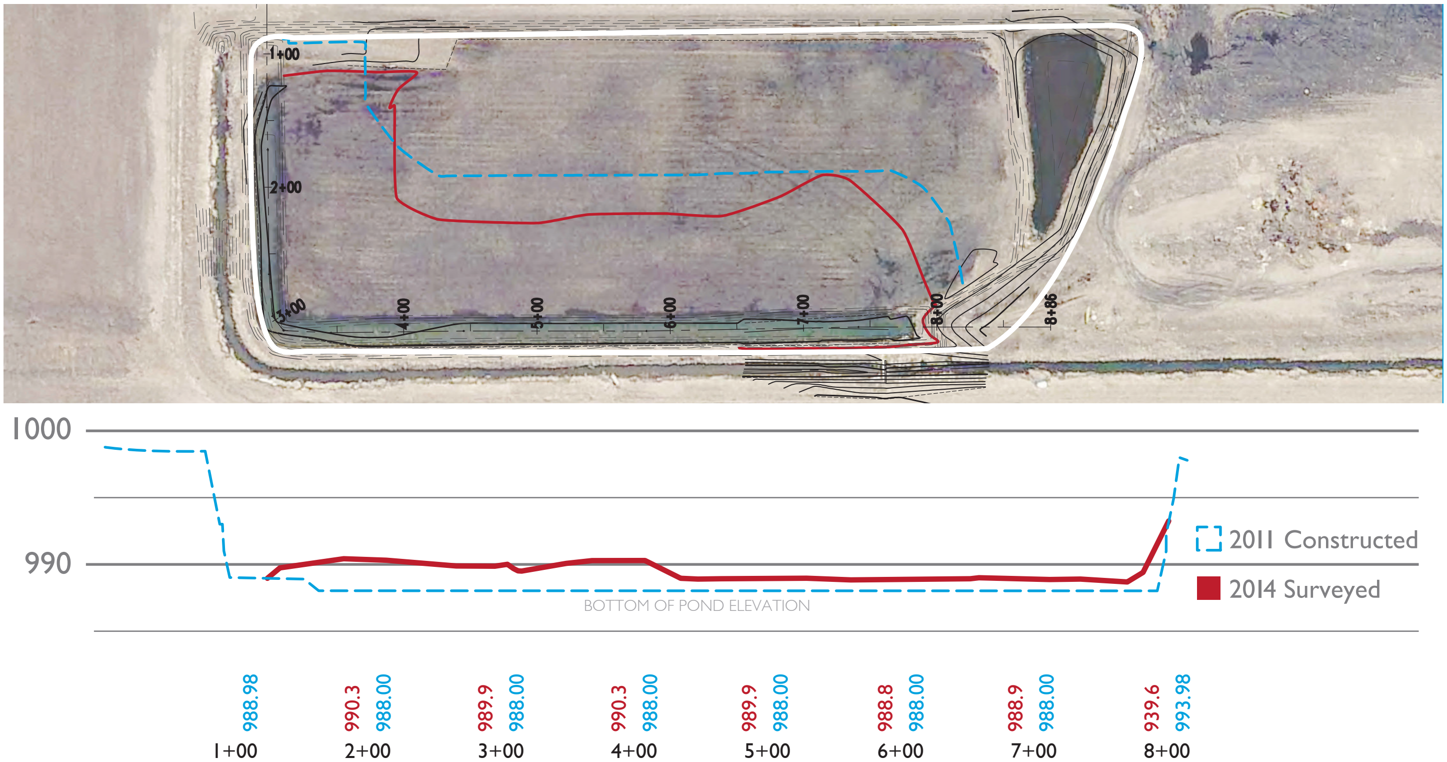


Figure 5 - Accumulated sediment in the Klein Pond

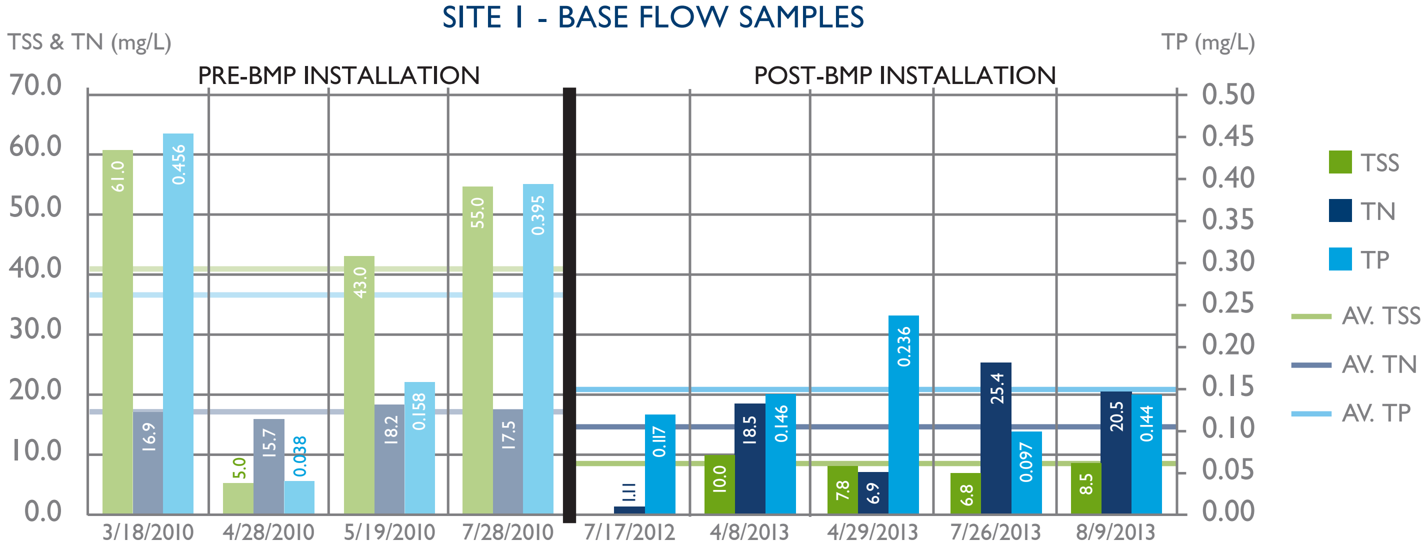


Figure 6 - Pre and Post BMP Installation Low Flow Sample Comparison
(Bars indicate date specific measurements; Lines indicate average measurement)

TSS Reduction = 33%   TN Reduction = 3%   TP Reduction = 12%

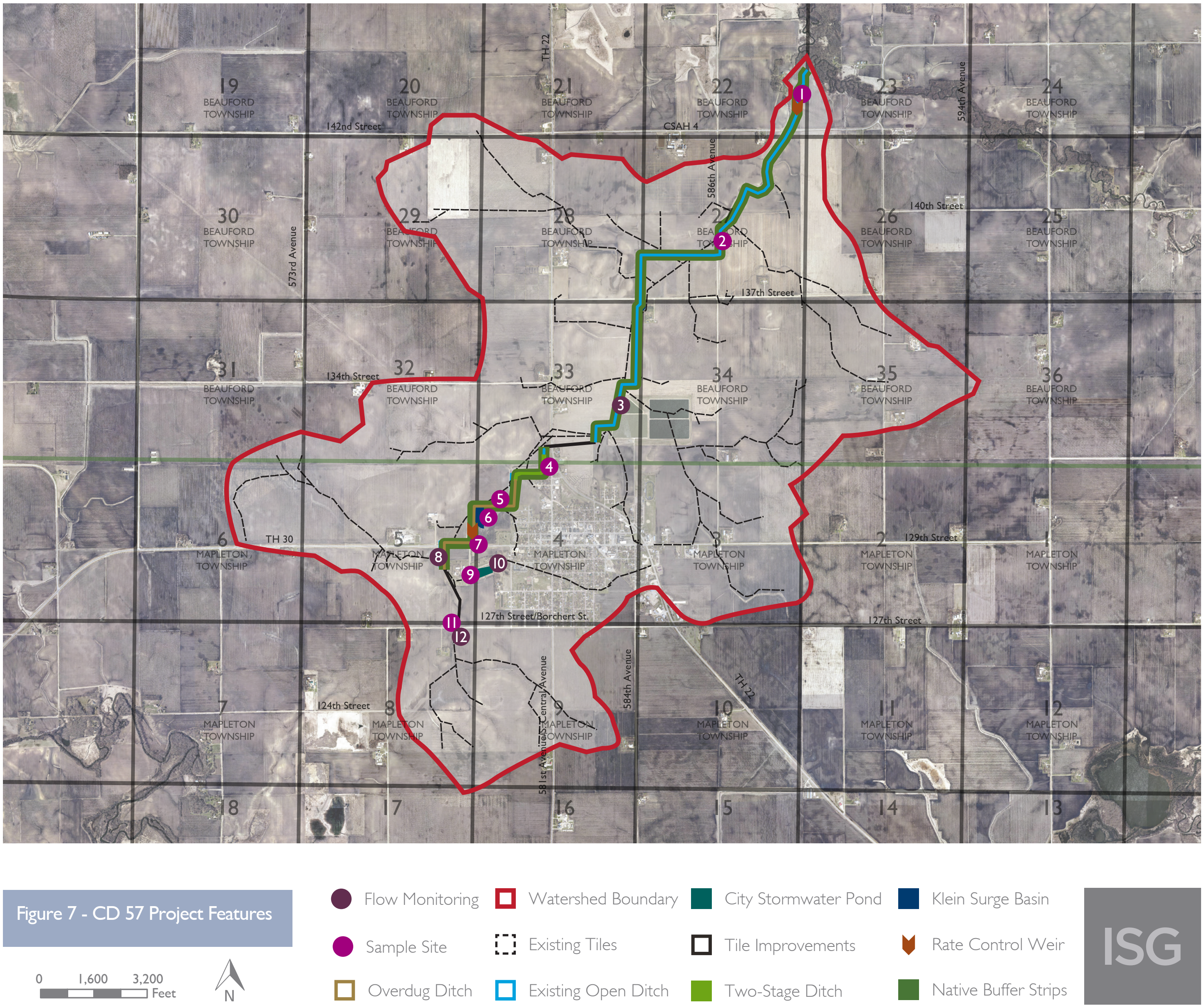


Figure 7 - CD 57 Project Features

PERENNIAL BASEFLOWS

While most of the water quality analyses for CD 57 focused on its function during rain events, it is important to note the condition of the system during low, perennial flows. These flows occur when surface runoff is not present and the flow in the ditch is fed by effluence from subsurface tiling and shallow groundwater. Low flow water quality samples were taken prior to and subsequent to the installation of the BMPs. *Figure 6* compares these samples at the outlet of the CD 57 system (Site 1) for the pre- and post- BMP installation.

The post-BMP installation samples contain lower concentrations of TSS and TP while TN remained nearly the same (*Figure 6*). This can be expected as nitrogen is always present in water despite the passing flow volume. This shows that even during low, perennial baseflows the BMPs prove to be effective at reducing TSS and TP concentrations.

BLUE EARTH COUNTY DITCH 57

This project included six water quality improvement features throughout the 6,041 acre watershed (*Figure 7*). One rod (16.5-foot wide) buffer easements were installed, replacing 17 acres of agricultural land along 4.1 miles of the ditch with native grass buffer strips to improve water quality. A rate control weir was constructed at the outlet of the CD

Figure 8 - Native Grass Buffer Strips Installed

Figure 9 - Klein Pond after 25-Year Rain Event

57 system near the Cobb River, which reduces peak flow rates from the system. The Klein surge basin (Klein Pond) was constructed to store runoff from surrounding farmlands of the upper portion of the watershed. The City of Mapleton's stormwater pond, known in this report as City Pond, was expanded to store runoff from the City and portions of the upper watershed. A two-stage ditch was installed to mimic the conditions that exist within naturally flowing streams that limit in-channel sedimentation. A sediment trap was installed to create in-channel treatment of sediment by over digging portions of the ditch, allowing for sedimentation to occur. Overall, this improvement project provided storage and treatment for agricultural and urban runoff in an effort to improve drainage, water quality, and increase diverse habitat.

BUFFER STRIPS

Buffer strips play an important role along waterways by regulating surface flow, dissipating high water events, and stabilizing stream banks. County ditch systems in southern Minnesota, by design, are usually lacking buffers and therefore, are also lacking the functions that buffer strips provide. One-rod native grass buffer strips (*Figure 8*) were installed adjacent to the ditch along 4.1 miles (17 acres) of CD 57. Areas chosen for the installation of buffer strips include locations where buffer strips were not present, steeper bank slopes occurred, or where a large volume of surface flow occurs, overtopping ditch banks. These native grass buffer strips provide a means to stabilize the sediment and reduce erosion, sediment and nutrient loading, surface flow rates and direction.

KLEIN SURGE BASIN

The Klein surge basin (Klein Pond) covers 4 acres of land and has 26.3 acre-feet of storage. It is located north of Trunk Highway 30 (TH 30), west of the City of Mapleton. This location was chosen to provide adequate storage for the upper half of the watershed (1,700 acres) while protecting the downstream portions of the system from flooding. In general, this pond provides an area where excess water can be stored during high flow periods. The increase in water storage provided by the pond results in decreased peak flow rates and less flooding in CD 57 and downstream rivers (Big Cobb and Le Sueur rivers). With the increased holding capacity, the water has a longer residence time to allow for sedimentation of suspended solids. The pond also removes nutrient bound particles and improves water quality in the system. A photograph (*Figure 9*) shows the Klein Pond after a rain a 25-year rain event in 2013.

CITY POND: CITY OF MAPLETON'S STORMWATER POND EXPANSION

The city stormwater pond existed prior to this project and is owned by the City of Mapleton. The stormwater pond is located south of TH 30, southwest of the City of Mapleton. The city stormwater pond serves as a storage area for the majority of Mapleton's runoff (400 acres) and outlets into a tile in the CD 57 system. The stormwater pond was underutilized for storage during most minor rain events. The CD 57 improvement project expanded the original City stormwater pond into a larger pond by digging the basin deeper and wider, covering an area of 2 acres. The City Pond was designed based on Minnesota Pollution Control Agency's (MPCA) water quality standards which have been well studied for optimum pollutant removals. The outlet was modified to create a retention pond with a maintained water level, provided 11.5 acre-feet of wet storage. This provides additional water treatment and

Figure 10 - Inlet Structures to Klein Pond

Figure 11 - City Pond (Retention Pond) Under Normal Flow Conditions

storage by adding a skimming outlet to prevent suspended solids and debris from entering the CD 57 system. During rain events, the pond has the capacity of 23 acre-feet of storage. The City Pond has a similar purpose to the Klein Pond, but handles primarily municipal stormwater runoff with a small portion of agricultural land. A photograph (*Figure 11*) shows the City Pond under normal flow conditions.

TWO-STAGE DITCH

Two-stage ditches create a low-flow channel within a high-flow channel. Traditional ditches are overly large for low, perennial flows and have no floodplain for large flows (Ward & Mecklenburg 2004). A two-stage ditch allows for a smaller (inner) channel for low perennial flows and a wider (outer) channel (serving as a floodplain) for high flows (Ward & Mecklenburg 2004). The low-flow channel dimensions contain a 2 foot deep, 2 foot wide bottom and 4 foot wide top while the floodplain banks are 10 feet wide. The floodplain banks were planted with native buffers as well as a one-rod buffer strip along the upper banks, allowing for additional filtration and uptake of nutrients and sediment. The inner channel prevents the meandering capability of the ditch, thus attributes higher velocities for baseflows and prevents sediment from depositing in the main channel. This design mimics the conditions that exist within naturally flowing streams that limit in-channel sedimentation.

The two-stage ditch in CD57 includes 1,409 linear feet, treating 2,300 acres of runoff. It is located at the northwest corner of the City of Mapleton, west of Trunk Highway 22 (TH 22). This location was chosen for two reasons. First, new construction of either an open ditch or large tile was required to provide adequate drainage to the system. Since the new tile would be very large, it was more cost effective to construct an open ditch. Second, this location experiences more perennial flows from the City of Mapleton, Klein Pond, City Pond, and several tile branches that enter the ditch just upstream of this location. Therefore, this length of the ditch will more fully support the continuous flow needed to maintain fine sediment throughput and in-channel vegetation. The two-stage ditch is controlled by a 54-inch tile that connects the two-stage ditch to the open ditch on the east side of TH 22. A photograph (*Figure 12*) shows the two-stage ditch looking upstream towards the Klein Pond.

SEDIMENT TRAP

In addition to the two-stage ditch, a sediment trap (in-channel treatment) was constructed. This form of in-channel treatment provides an elongated linear sediment storage basin within the existing ditch channel. This section of ditch was over dug by approximately 3 feet to provide a wet sedimentation basin within the channel. The in-channel treatment includes 5,000 linear feet of ditch beginning south of TH 30 where the City Pond and mainline tile outlets into the open ditch. At this location, 1,600 acres of rural and urban runoff are treating. It then spans northeast through the Klein Pond and ends at the beginning of the two-stage ditch. This location was chosen since the area had historically high sediment transport in the ditch. A photograph (*Figure 13*) shows the overdug ditch downstream of the Klein Pond.

RATE CONTROL WEIR

The rate control weir was constructed near the outlet of CD 57, slightly upstream of the confluence with the Big Cobb River, north of County

Figure 12 - Two-Stage Ditch Looking Upstream

Figure 13 - Overdug Ditch Section

Figure 14 - Rate Control Weir After Rain Event

Highway 4. The purpose of this structure is to reduce the peak flow rates from the CD 57 system prior to discharging into the Big Cobb River. The weir reduces peak flow rates by creating a long linear pond within the open ditch, allowing sediment and nutrients to settle out of suspension. The concrete structure spans entirely across the open ditch with an 18-inch opening in the center of the ditch. The weir is 5 feet in height with the top of the weir at an elevation 1 foot lower than the lowest tile invert of the ditch. A photograph (*Figure 14*) shows the rate control weir storing water after a rain event.

MONITORING

THEORY

While water quality monitoring of Minnesota's rivers and stream networks is widespread and has covered many waterways over many years, water quality monitoring of Minnesota's public ditch systems is limited. Monitoring and analysis of an entire ditch system with multiple sample points throughout has not been completed in this region, therefore it is challenging to establish a monitoring scheme.

Although public ditch systems and river networks are different in terms of size, watershed, flow and many other attributes, they do share many similarities. Both rivers and ditches increase their flow as the contributing watershed increases. They both also have point sources that lead to an increase in flow. Both also have drastic changes in water flow rates and water quality during rain events as peak flow rates increase.

Since ditches and rivers share many similarities, the monitoring methods used in rivers were used as a baseline for monitoring the CD 57 system. Most rivers utilize stream gauging stations in which river stage, or depth is measured. The CD 57 system utilized a similar method at determining stage by utilizing data logging devices, which recorded pressure (depth) throughout the system. River monitoring for water chemistry utilizes grab samples with the majority of the samples collected during high flow periods. Sampling is important during high flows since they carry high sediment and nutrient loads (MPCA 2012). The assessment of water chemistry in CD 57 includes grab samples acquired during the peak flow after rain events and periodic baseflow samples. The results are used to compare the water quality prior to and following the implementation of the BMPs.

Several sites were chosen throughout the CD 57 watershed for monitoring. They include 12 sites where stages were recorded and 7 sites where water quality samples were obtained. While all 12 sites contain valuable information, the 7 sites that contain water quality sampling were locations deemed most useful for analysis. These 7 sites were selected based on their proximity to an installed BMP. The locations are either upstream or downstream of each BMP. This allowed for the best analysis to determine how effective each BMP was at reducing sediment and nutrient loading.

Sampling frequency also played a major role in the water chemistry monitoring. The Minnesota Pollution Control Agency (MPCA) uses one-half inch rainfall as a general guidance of a significant rain event to trigger stream monitoring. It was anticipated that infiltration would account for some of the runoff, thus one-inch rain events were chosen to trigger a sampling event for this project with multiple sampling events between 0.5 and 1 inch.

ISG, in conjunction with Minnesota State University's (MSU) departments of Civil and Mechanical Engineering and Chemistry and Geology collected and analyzed six years of water chemistry and stage data with three of these years occurring after the installation of the water quality BMPs. MSUs role over the course of the monitoring included the collection of both water quality and stage data that were subsequently transferred to ISG for analysis. Stage data were calibrated and adjusted based on the barometric pressure and was recorded monthly throughout the monitoring season. Continuously acquired precipitation and temperature data were also collected for all three years via a rain gauge sampler. The rain gauge data were compared to the estimated precipitation amounts listed on Minnesota Climatology Working Group and The Climate Corporation to validate the rainfall. The water quality, stage, and precipitation data were provided to ISG in raw data and calibrated data for use of analysis. ISG then provided a data analysis of the data for each monitoring season.

METHODOLOGY

Parameters

Parameters that were sampled and monitored in the CD 57 system are listed in *Table 1*.

Parameters were selected based on the information they provide on the water's overall quality. Each parameter is further described here:

PARAMETER	HOLDING TIME [1]	LIMIT [2]
Conductivity	N/A	1,000 µmhos/cm
Flow	N/A	N/A
pH	N/A	6.5 to 8.5
Temperature	N/A	≤90°F daily average or ≤5°F above natural, Class 2C waters
Total Dissolved Solids	N/A	500 mg/L
Dissolved Oxygen	N/A	Minimum of 5 mg/L daily average between April 1 - Nov. 30; Minimum of 4 mg/L at all other times
E. coli	6 hour, <24 hours	126 organisms/100mL geometric mean of not less than 5 samples in any calendar month; No more than 10% of all samples taken in a calendar month exceed 1,260 organisms/100mL
Nitrogen (Nitrate+Nitrate)	48 hours	10 mg/L
Ortho-Phosphate	48 hours	N/A
Total Phosphorus	48 hours	12 µg/L, Class 2A waters 30 µg/L, Class 2B, C
Total Suspended Solids	7 days	65 mn/L
Turbidity	24 hours	10 NTU, Class 2A waters 25 NTU, Class 2B, C, D waters

Table 1 - Water Quality Monitoring Parameters

[1](EPA 1997)
[2](Minnesota Office of the Revisor of Statutes 2012 (a))
N/A indicates the paameter is measured in the field immediately

Conductivity: As described by the EPA (1997), conductivity refers to the ability of water to pass an electrical current. Water with higher amounts of inorganic dissolved solids (chloride, nitrate, phosphate, sodium, calcium, aluminum, and other positive and negative ions) has greater conductivity (EPA 1997). Sewage can raise the conductivity due to the presence of chloride, phosphate, and nitrate (MPCA 2004). Streams that support good mixed fisheries have a range between 150 to 500 µmhos/cm (MPCA 2004). Conductivity outside this range could indicate water is not suitable for certain fish and/or macroinvertebrates (MPCA 2004).

Stage: A measurement of depth of water above the bottom of the ditch. This is measured by Onset Data logging devices that record pressure. Pressure is converted to depth by accounting for the water pressure about the data logging device and the air pressure of the ambient air.

Flow: A measurement used to record the water velocity over the area of water at a given time (Teledyne Isco 2009). This will give insight to water level and flow at the time of the sample. Water level loggers are inserted in stilling wells and continuously record mean water level through measuring the amount of pressure that is around the sensor. The water level can be converted to flow with the aid of survey data and a hydrologic/hydraulic model. CD 57 is extensively modeled due to the water quality features that were constructed. If the amount of water within the open channels, tile lines, or ponds is known, then the flow can be calculated based on pressure and water level. Flow is an important focus point for this project since flow aids in transporting nutrients and sediment downstream.

pH: Measures the relative alkalinity or acidity of the sample (EPA 1986). The pH scale ranges from 1 to 14 with low values considered acidic and higher values considered basic (EPA 1986). Because the pH scale is logarithmic, each one-unit change represents a 10-fold change in the acidity/basicity of the sample. Pollution can affect the pH of a waterbody, which can in turn, affect the solubility and availability of nutrients (MPCA 2004). Pollution, therefore, has an indirect influence on how nutrients can be utilized by aquatic biota (MnDNR 2010). Biota may also become stressed when the pH exceeds their tolerances, which can in turn affect the diversity of surface waters (MnDNR 2010). The state of Minnesota defines the range of pH for most Class 2 waters to be between 6.5 and 8.5 (Minnesota Office of the Revisor of Statutes 2012(a)). However, natural waters can exhibit a very broad range of pH values, such that those exceeding the standard range as a result of natural causes (e.g., bogs) may not necessarily be considered an exceedance (MPCA 2004).

Temperature: Measures how hot or cold the water is. It plays an important role in many physiological and chemical processes. As temperature increases, the oxygen levels within the water become lower (EPA 1986). Temperature also has an impact on the rate of photosynthesis, metabolic rates of organisms, and sensitivity of organisms to toxic wastes, parasites, and diseases (EPA 1986). Each organism has an optimal temperature and when the temperature of the surface water changes due to influences by stormwater, groundwater, or other inflows of water, the ability of organisms to persist in that system may be affected (MPCA 2004). Temperature ranges in this area for water are 90 degrees Fahrenheit or 5 degrees Fahrenheit of the natural temperature for that waterbody (Minnesota Office of the Revisor of Statutes 2012(a)).

Total Dissolved Solids: Measures of the amount of particulate solids that are in solution, passing through a 2-micron filter (measured in mg/L) (HCR 2010). Ions often found dissolved in surface water include calcium, magnesium, sodium, iron, manganese, bicarbonate, chloride, sulfate, nitrate, carbonate, and other ion particles that will pass through a filter (HCR 2010). The dissolved solids within the surface water are reflective of the surrounding geology and soils (HCR 2010). Urban and agriculture runoff as well as wastewater and septic system effluent and soil erosion can also contribute to higher amounts of these solids (HCR 2010). Aquatic biota requires a relatively constant concentration of the major dissolved ions in the water such that if dissolved solids become too high or too low, survival, growth and reproduction are affected (Anderson et al. 1996). Dissolved solids can also absorb sunlight and increase the temperature of the surface water, in turn affecting the dissolved oxygen in the water (Anderson et al. 1996). The standard for Class 1B, 1C, 2A, 2B, and 2C waters is 500mg/L (Minnesota Office of the Revisor of Statutes 2012(a)).

Dissolved Oxygen: The amount of oxygen dissolved in the water column (measured in mg/L) (HCR 2010). Water's ability to maintain oxygen in solution is inversely proportional to the temperature of the water (EPA 1986; HCR 2010). For Class 2C waters in Minnesota, the standard minimum daily average is 5 mg/L between April 1 through November 30 and the daily minimum is less than 4.0 mg/L at all other times (Minnesota Office of the Revisor of Statutes 2012(a)). Dissolved oxygen is important for organisms inhabiting the area. Low dissolved oxygen reading can indicate high sediment loads (suspended and dissolved solids) or low productivity (Anderson et al. 1996; Gumbricht 2003). Oxygen is a necessary element to all forms of life. Once oxygen levels drop below 5mg/L, aquatic biota become stressed and oxygen levels below 1 to 2 mg/L for a few hours can lead to fish kills (species dependent) (MPCA 2004).

E. coli: A single species in the fecal coliform group and is used as an indicator of human or animal waste presence (EPA 2010). For Class 2A, B, and C waters in Minnesota, the standard is "not to exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31 (Minnesota Office of the Revisor of Statutes 2012(a)).

Nitrate + Nitrite: Derived from ammonia when it is broken down by bacteria (Carpenter 1983). Nitrite is formed initially and is then converted to the more stable and less toxic nitrate (Carpenter 1983). Nitrate typically occurs in low natural levels within surface waters; however, it is supplemented with nitrate from human-derived sources (Carpenter 1983). Excessive amounts of nitrate within water bodies are generated from the fertilizer applied to agricultural fields, grass clippings from lawns, and from wastewater discharge or runoff from feedlots (HCR 2010). Once in the water, nitrates can stimulate plant and algae growth, which can deplete the water of dissolved oxygen, adversely impacting fish and other aquatic biota (HCR 2010). Nitrate is regulated to protect human health as well as aquatic environments (MPCA 2004). The MPCA uses the EPA limits of 10 mg/L and 1.0 mg/L for nitrate and nitrite, respectively, in drinking water supplies (MPCA 2004). 10mg/L of total nitrates is the limit for Class 1B, 1C, 2A, 2B, 2C, and 4A waters (Minnesota Office of the Revisor of Statutes 2012(a)).

Ortho-phosphate: The phosphate molecule itself (the biologically available phosphorus) (HCR 2010). It is soluble and can be taken up readily by organisms. Sources of orthophosphate include sewage, runoff from agricultural industries, and fertilizer application on lawns (HCR 2010). Excessive amounts of ortho-phosphate can lead to extensive algal blooms and eutrophication (Carpenter 1983; HCR 2010).

Total Phosphorus: A measure of all forms of phosphorus in the sample (orthophosphate, condensed phosphate, and organic phosphate; biologically available and bound phosphorus) (Carpenter 1983). Phosphorus is a concern because it is in limited supply in surface waters so that even a modest increase can stimulate the growth of plants and algae (Carpenter 1983). Excessive algae growth, death, and decay can reduce the amount of dissolved oxygen available for other aquatic biota, endangering fish and other forms of aquatic life, along with out-competing native vegetation (Carpenter 1983). Sources of phosphorus include agricultural land, lawn fertilizers, erosion containing soil-bound phosphorus, yard waste, runoff from animal feedlots, stormwater, and certain industrial wastewaters (HCR 2010). To prevent eutrophication in Class 2B and C waters in Minnesota, total phosphorus standard limits are 30 μg/L (Minnesota Office of the Revisor of Statutes 2012(a)).

Total Suspended Solids: Consists of silt and clay particles, plankton, algae, fine organic debris, and other particulate matter that will not pass through a 2-micron filter (EPA 1997). These are generated from point (e.g. sanitary wastewater) and non-point sources (e.g. erosion from agriculture) (HCR 2010). Excess suspended solids within the water column decrease water clarity and increase water temperature by absorbing heat from the sun (Anderson et al. 1983; HCR 2010). In turn a raise in temperature affects the amount of oxygen dissolved in the water (EPA 1986). Excess suspended solids can clog the gills of fish, affecting growth rates and disease susceptibility, and smother fish eggs and other benthic biota (Anderson et al.1983). The water quality standard in Minnesota for Class 2 waters is 65 mg/L (Minnesota Office of the Revisor of Statutes 2012(a)).

Turbidity: A measure of water clarity, which is affected by suspended solids (HCR 2010). Suspended solids including clay, silt, inorganic and organic matter, and other compounds within the water column scatter light leading to higher values of turbidity (HCR 2010). Stormwater pollution, construction, active mining, and other similar activities can produce sediment that raises the turbidity of water (HCR 2010). For Class 2A waters in Minnesota, the existing turbidity water quality standard generally has a statewide value of 10 NTU (Nephelometric Turbidity Units) and 25 NTU for Class 2B, C, and D waters (Minnesota Office of the Revisor of Statutes 2012(a)). Turbidity values that exceed the standard can harm aquatic life by affecting foraging, gill function, and spawning beds (MPCA 2004).

The parameters described below were examined and determined to be unnecessary for sample analysis due to the information was either already provided from the above list of parameters or not relevant to the study. These parameters, therefore, will not be sampled or analyzed in this project.

Fecal Coliform: A group of bacteria that are used as an indicator of sewage contamination because they are found in human fecal matter (EPA 1997). Fecal coliform bacteria are not harmful to humans, but when present, may indicate the presence of disease carrying organisms which live in the same environment as the fecal coliform bacteria (EPA 2010). Sources of fecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and storm runoff (EPA 2010). In addition to bacteria and other pathogens, human and animal wastes contain high levels of other pollutants such as phosphorus, nitrogen, and oxygen demanding organic material (EPA 2010). A fecal coliform reading is expressed as the number of organisms per 100 mL (#/100mL). Minnesota's water quality standard for fecal coliform bacteria is not more than 200 fecal coliform colonies per 100 mL (Minnesota Office of the Revisor of Statutes 2012(a)). E. coli is one form/species of fecal coliform, therefore, both are not needed. Fecal coliform was eliminated from analysis in the post water quality improvement features monitoring since the local waters had impairments. The Cobb River has an E. coli impairment and CD 57 discharges into the Cobb River (MPCA 2010).

Suspended Volatile Solids: Solids lost on ignition (550°C), which provides a rough estimate as to the amount of organic matter (algae) within the waterbody (HCR 2010). Higher levels of organic matter lead to higher levels of turbidity (HCR 2010). Turbidity and total suspended solids are already being measured, thus suspended volatile solids were eliminated from the monitoring parameter list.

Post-BMP Installation Monitoring Methods

Following installation of the BMPs (fall 2011), all monitoring was performed by MSU's departments of Civil and Mechanical Engineering

Figure 15 - MSU Students Taking Water Quality Grab Samples

Figure 16 - MSU Students Performing Instrumental Readings

and Chemistry and Geology (2012-2014). Water samples in the open ditch were measured and collected from the thalweg. Water grab samples were collected via a sampling rod or taken from the ditch. The container was filled by placing the container in the upstream direction (into the flow) without touching the bottom of the pipe/ditch channel to avoid stirring up sediment and debris (*Figure 15*). The sampling bottles were clean and sterile. Water grab samples were collected for E. coli (in April and October only), nitrogen (nitrate + nitrite), total phosphorus, ortho-phosphate, total dissolved solids, and total suspended solids. After collection, bottles were placed in a cooler with ice to keep samples at or below 4°C and were transported to MSU's laboratory immediately after the sampling event for immediate analysis or transfer to MVTL for further analyses.

Field water quality measurements (pH, temperature, conductivity, dissolved oxygen, turbidity, and transparency tube) were collected and recorded at the site using a variety of instruments including Hanna Instruments HI 98129 and Hydrolab DS5 multi-probe sensors, Hanna HI 9142 Dissolved Oxygen Meter, and LaMotte 2020we/wi and YSI 600OMS turbidmeters. All probes were calibrated the day of sampling, before sampling begins. The probe was held at an intermediate depth in the water column without disturbing substrate materials and remained there until the probe had stabilized the reading. *Figure 16* shows MSU students taking instrument readings for the aforementioned parameters.

Locations

Pre-BMP Installation Monitoring Locations

There were three sites (1, 2A, and 2B) monitored prior to the installation of the water quality BMPs. These sites were used to measure flow and grab samples. Site 1 was located near the outlet of the CD 57 system near the Big Cobb River, corresponding to rate control weir location. Site 2A was located toward the northern end of the existing open ditch immediately upstream of the existing tile, which connected the open ditch sections split by TH 22. This location corresponds to the beginning of the two-stage ditch after its installation. Site 2B was located in the open ditch just north of TH 30. This site is located upstream of the Klein Pond. *Figure 17* shows the 3 pre-BMP installation monitoring locations throughout the CD 57 Watershed.

Post-BMP Installation Monitoring Locations

There are 12 post-BMP installation monitoring locations throughout the CD 57 system (*Figure 18*). These locations are generally located before and after the BMP improvements. Site 1 is located at the outlet of the system in the open ditch while Site 12 is located in a tile main at the upper end of the watershed. Post-installation monitoring Sites 1, 4, and 7 are located relatively close to the location of the pre-installation monitoring Sites 1, 2A, and 2B respectively. The post-installation monitoring locations will provide information on the effectiveness of each water quality BMP. All sample locations have a GPS coordinate to assure samples are taken at the same location throughout monitoring. All 12 locations had data logging devices installed which record stage, or the depth of water throughout the system. Of the 12 locations, 7 were selected as water quality locations for grab samples and instrument readings

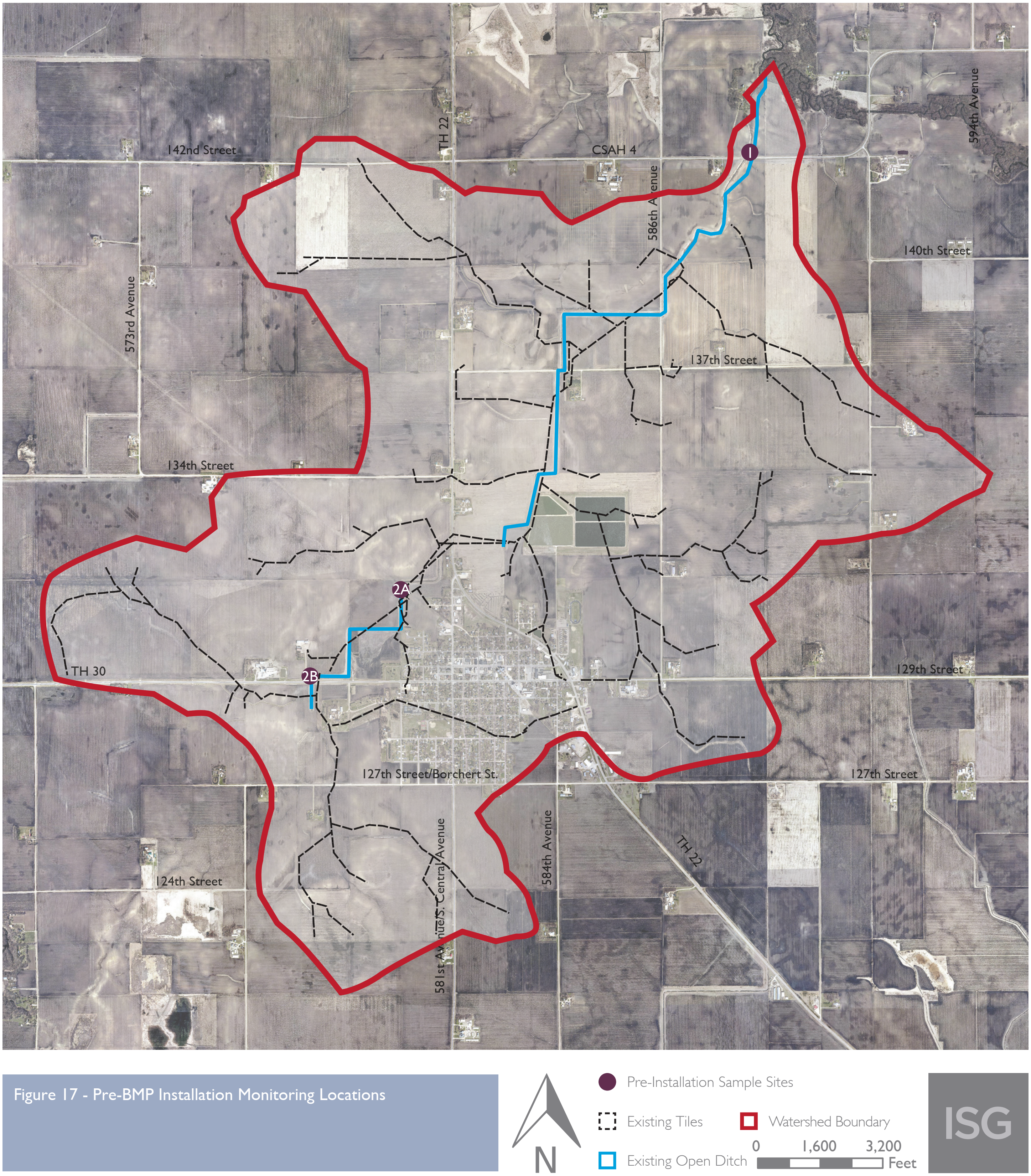


Figure 17 - Pre-BMP Installation Monitoring Locations

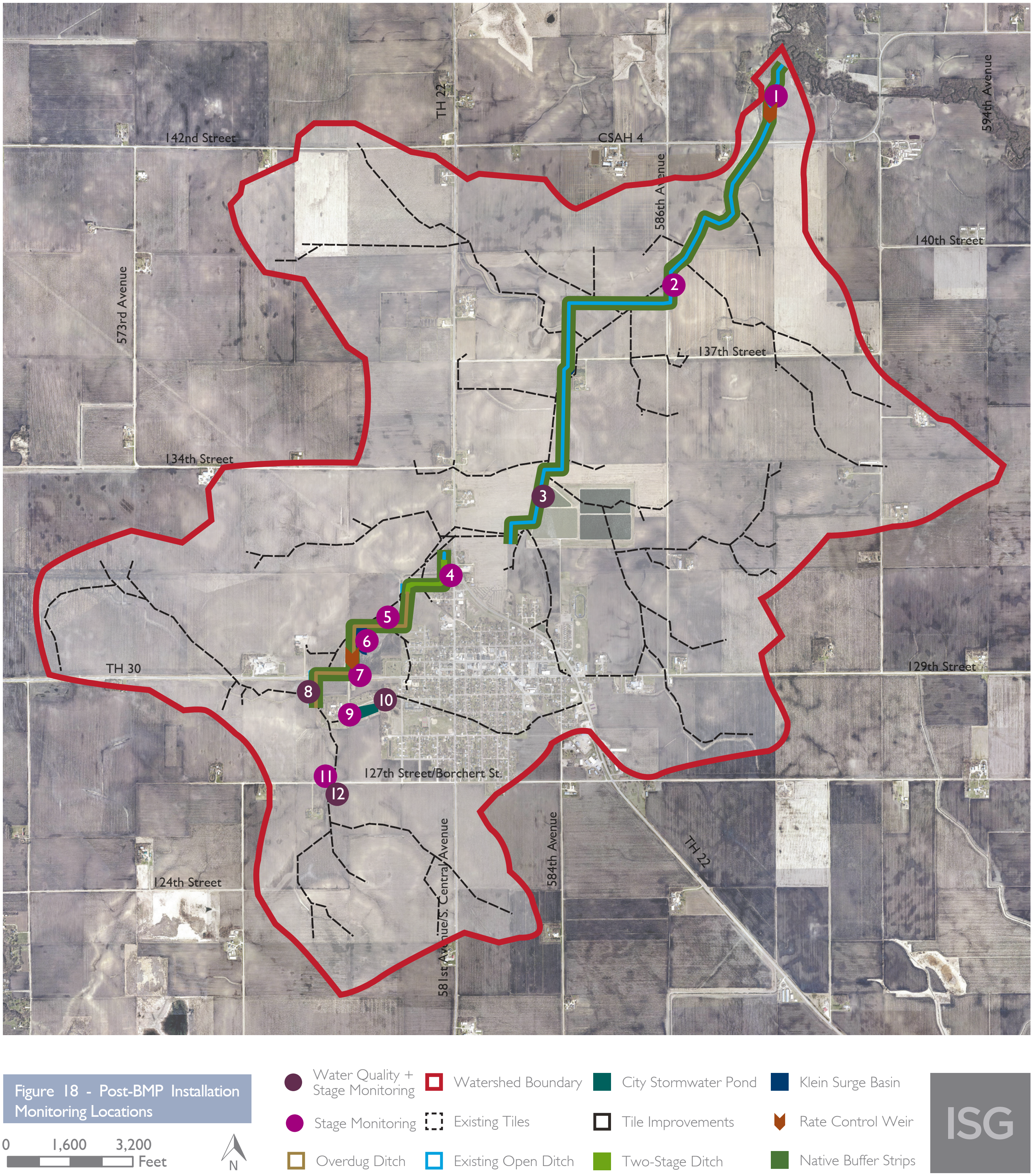


Figure 18 - Post-BMP Installation Monitoring Locations

MONITORING LOCATION ID	WATER QUALITY STRUCTURE/ MONITORING LOCATION	SAMPLING FORM	STAGE MEASURED	WATER QUALITY SAMPLED
1	Rate Control Weir/System Outlet	Concrete Weir	●	●
2	Native Grass Buffer Strips/Downstream Open Ditch	Open Ditch	●	●
3	City Wastewater Ponds	Open Ditch	●	
4	Two-Stage Ditch/End Two-Stage Ditch	Open Ditch	●	●
5	Downstream Klein Pond/Upstream Two-Stage Ditch	Open Ditch	●	●
6	Klein Surge Pond	Sediment Trap in Klein Pond	●	
7	Upstream of Klein Pond	Diversion Weir	●	●
8	Beginning of Open Ditch	Open Ditch	●	●
9	Outlet to the City Stormwater Pond	Manhole	●	●
10	City Stormwater Pond	Middle of City Pond	●	
11	Upper Watershed - Old Tile Main	Road Ditch Drop Intake	●	
12	Upper Watershed - New Tile Main	Road Ditch Drop Intake	●	●

Table 2 - Monitoring Activity Summary

SITE	TOTAL SUSPENDED SOLIDS CONCENTRATION (mg/L)	TOTAL DISSOLVED SOLIDS (mg/L)	TOTAL PHOSPHORUS (mg/L)	ORTHO-PHOSPHORUS (mg/L)	NITRATE (mg/L)	NITRITE (mg/L)
12	13.2	341	0.480	0.134	46.8	0.000
9	110.0	247	0.473	0.236	9.4	0.092
8	6.8	313	0.377	0.221	33.2	0.036
5	14.8	276	0.435	0.295	22.4	0.064
4	14.0	271	0.412	0.314	21.4	0.063
2	32.8	277	0.444	0.283	23.1	0.092
1	30.0	295	0.393	0.301	25.4	0.071

Table 3 - Water Chemistry Grab Sample for July 9, 2013

Frequency

Pre-Installation Monitoring Frequency

Monitoring events occurred from March, or ice-out, through October from 2009 to 2011. The majority of the samples taken were during baseflow conditions. Flow data was collected using pygmy-flow instruments during baseflow conditions since conditions were unsafe in the ditch to use this equipment after rain events.

Post-Installation Monitoring Frequency

Water quality samples were collected from 2012 through 2014 after the BMPs installations were completed. Sampling occurred from March, or after ice-out through October of each year. Baseflow samples of flow and water quality were taken once a month for quality assurance and calibration purposes. Samples were also taken within 24-hours of a 1-inch or greater rainfall event throughout the monitoring season.

Stage data were collected in 12 sites throughout the watershed by utilizing Hoboware Data logging devices that record atmospheric and hydrostatic pressure. These pressure data can then be converted to stage (depth), and incorporated into the hydrologic/hydraulic model to develop flowrates.

RESULTS

Results for water chemistry for all sampled rain events were tabulated for each site and parameter. *Tables 3* and *4* show an example of the raw water quality sampling for a July 9, 2013 rain event in which a rain event of 1.29 inches fell for a duration of 1 hour.

Recorded depths via the installed data logging devices were also tabulated for each site, date and time, and depth. This depth was used in conjunction with survey data acquired during site visits to convert

SITE	TEMPERATURE (°C)	pH	DISSOLVED OXYGEN (mg/L)	SPECIFIC CONDUCTIVITY (µS/cm)	TURBIDITY (NTU)	T-TUBE (cm)
12	17.36	6.70	8.47	750.6	5.5	60.0
9	23.15	7.41	7.39	536.8	13.9	28.2
8	19.89	6.83	7.33	665.4	12.7	34.2
5	21.60	6.86	6.73	587.0	26.2	19.1
4	21.59	6.88	6.66	588.1	25.6	26.8
2	20.77	6.73	6.28	592.5	43.6	11.0
1	19.95	6.91	6.91	630.7	38.7	13.0

Table 4 - Sonde Instrument Reading for July 9, 2013

TIME	RECORDED DEPTH	TIME	RECORDED DEPTH	TIME	RECORDED DEPTH
7:00	3.656	9:15	4.479	11:30	6.149
7:05	3.677	9:20	4.545	11:35	6.210
7:10	3.677	9:25	4.646	11:40	6.235
7:15	3.685	9:30	4.693	11:45	6.297
7:20	3.707	9:35	4.764	11:50	6.325
7:25	3.697	9:40	4.821	11:55	6.364
7:30	3.685	9:45	4.899	12:00	6.404
7:35	3.679	9:50	4.967	12:05	6.434
7:40	3.712	9:55	5.046	12:10	6.513
7:45	3.763	10:00	5.105	12:15	6.530
7:50	3.803	10:05	5.162	12:20	6.559
7:55	3.826	10:10	5.241	12:25	6.600
8:00	3.868	10:15	5.300	12:30	6.618
8:05	3.910	10:20	5.368	12:35	6.638
8:10	3.954	10:25	5.427	12:40	6.669
8:15	4.024	10:30	5.475	12:45	6.669
8:20	4.046	10:35	5.556	12:50	6.730
8:25	4.065	10:40	5.615	12:55	6.727
8:30	4.099	10:45	5.662	13:00	6.759
8:35	4.096	10:50	5.744	13:05	6.756
8:40	4.105	10:55	5.744	13:10	6.789
8:45	4.137	11:00	5.789	13:15	6.809
8:50	4.161	11:05	5.871	13:20	6.831
8:55	4.240	11:10	5.930	13:25	6.840
9:00	4.321	11:15	5.990	13:30	6.850
9:05	4.323	11:20	6.050	13:35	6.851
9:10	4.392	11:25	6.099	13:40	6.861

Table 5 - Recorded Depth of Water at Site 1 for July 9, 2013

it to an elevation of the flow line of water. This information was then used to calculate the flow rate, as described in the **Flow Section, Page 19**. *Table 5* shows a portion of recorded depth data for Site 1 on July 9, 2013, during a rain event reflecting an increase in depth.

ANALYSIS

Water chemistry samples were tabulated similarly to *Tables 3 and 4* for all six years of monitoring for the parameters described. Stage data for years 2012 through 2014 was also tabulated in the same format as *Table 5* and was then used to quantify flow. These data were then used for analysis by ISG for various assessments of storage and treatment, BMP reductions, pre- and post-BMP installation watershed hydraulics characterization, seasonal variations, and comparison to MPCA standards.

Compliance with this procedure was maintained and checked a minimum of twice a year throughout the monitoring time period. In addition to adhering to the specific requirements of this Water Quality Sampling and Monitoring Work Plan, the minimum Quality Assurance & Quality Control for this project was as follows:

Water samples

Quality assurances were provided to assure data users that quality control activities were implemented and that data of known quality were being generated. For this project, water quality samples were delivered to MVTL's laboratory in New Ulm, MN and MSU laboratory in Mankato, MN by field technicians. A sample submission sheet, provided by MVTL and MSU, was included for each sample sent to MVTL and MSU for analysis. This submission sheet contained all relevant information about the sample, including collector, date, time, location, and method of preservation (if needed). When samples were forwarded to MVTL, a chain-of-custody was also submitted with the samples. The chain-of-custody references the sample and allows that sample to be traced back to its collection. It documents the possession of the samples

Figure 19 - Photo Validating Data logging device Depth for Water Overtopping of Rate Control Weir

from the time they were collected until the sample analytical results were received. All water samples were maintained as close to sampling conditions as possible. Samples were preserved and stored in a cooler with ice (temperature of around °C) during transport to the MVTL's and MSU's facilities. Samples are transported to MVTL and MSU on the same day as collected to minimize holding times.

Laboratory

Field duplicate samples were taken at 10 percent of all sampling sites to guarantee MSU's and MVTL's data analysis. Blank samples consisting of distilled water were also sent to MVTL and MSU with site identification on the bottle (blind sample) to confirm the accuracy of MVTL's and MSU's data analyses.

Data Logging Devices & Onset Cameras

Data from the Hoboware data logging devices were transferred monthly from 2012 to 2014. At this time, the condition of the staff gauge in which the data logging device was mounted was verified and adjusted if damaged. Also at this time, a manual reading of the water depth was recorded as well as the elevation at which the data logging device was placed. This reading was used to manually adjust the water elevation of the collected data as necessary.

Photos from the onset cameras were also transferred monthly and the cameras were adjusted as necessary. The photos taken of the staff gauge and data logging device were also used to manually adjust the elevation of the collected data as necessary. *Figure 19* shows a photo from the July 9, 2013 rain event at the rate control weir. This photo was used to compare the depth recorded by the data logging device to insure that at this depth, the water level overtopped the weir. This process was used as necessary for all rain events to further insure the depth recorded by the data logging device.

PRECIPITATION

THEORY

Precipitation plays a major role in water quality monitoring and the need for accurate data is essential to determine rainfall, frequency, runoff depth, and surface flow. Most stream and river monitoring uses rain gauge stations that are placed in the surrounding area and are used to interpolate precipitation data throughout the watershed (MPCA 2012). This method is useful for interpolating precipitation on a large watershed scale; however, it may not be as accurate on a small watershed level like the CD 57 System. These rain gauge stations are established by the Minnesota Climatology Working Group through the Minnesota DNR.

Interpolating between nearby rain gauge stations for the CD 57 monitoring was not practical for analysis since the nearest rain gauge stations were over 10 miles away from the watershed. In lieu of using these rain gauge stations, a rain gauge was station was set up in the CD 57 watershed as part of the monitoring. This rain gauge was placed near the middle portion of the watershed in an attempt to depict the precipitation as accurately as possible for the entire watershed.

METHODOLOGY

The rain gauge station is located one half mile west of the Klein Pond that was utilized to measure amount and timing of rainfall to the nearest one hundredth of an inch. This gauge was an Onset® RG3 Data Logging Rain Gauge (*Figure 20*) which provided information on the precipitation of the project area. This rain gauge includes a HOBO® Pendant Event data logging device that records rainfall data to determine rainfall rates, times, and duration. The rain gauge recorded precipitation to the nearest hundredth of an inch for any duration of a rain event. Data from the HOBO® Pendant Event data logging device was downloaded to a computer at the same time stage data was collected.

RESULTS

As mentioned previously, post-BMP installation water quality sampling was based on rain events greater than 1-inch. This monitoring frequency was done for all three years of post-BMP installation water quality monitoring. *Figures 21-23* show the date of the rain events in which water sampling occurred for the 2012, 2013, and 2014 monitoring years.

Based on the rainfall events monitored, 2013 had the most water quality samples (8), followed by 2014 (7), followed by 2012 (4). *Figure 24* shows all water quality monitored events over the 3-year period.

Figure 20 - Onset® RG3 Data Logging Rain Gauge

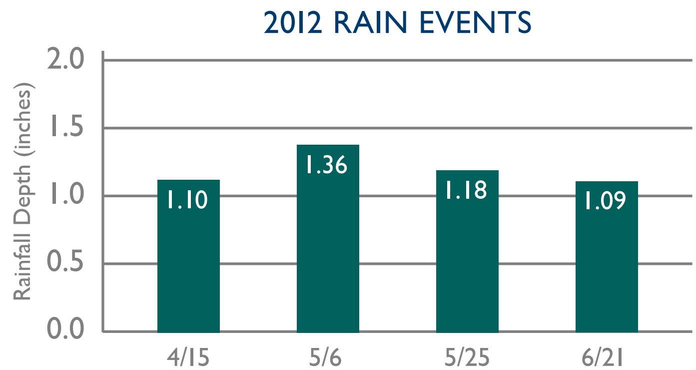


Figure 21 - 2012 Monitored Rain Events

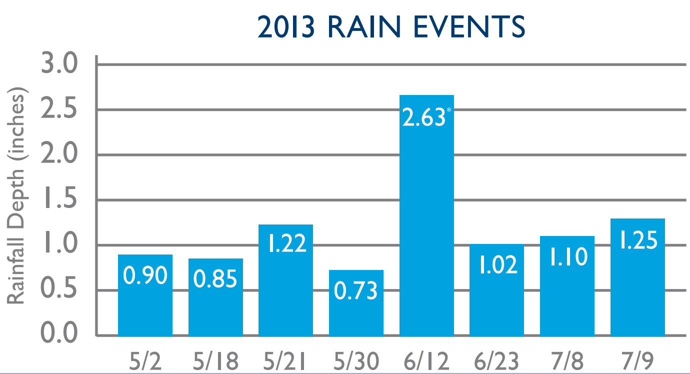


Figure 22 - 2013 Monitored Rain Events
(*NOAA 25-Year Recurrence Interval)

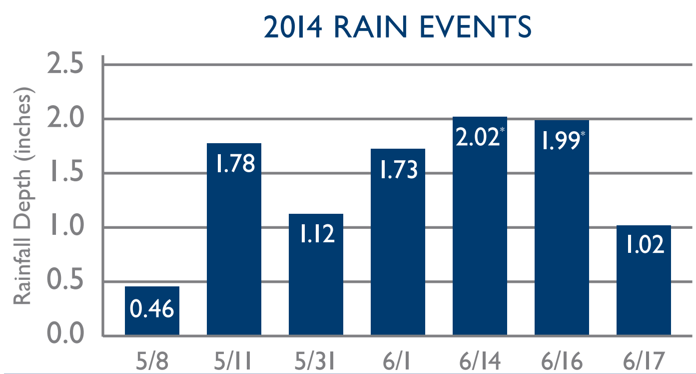


Figure 23 - 2014 Monitored Rain Events
(*NOAA 10-Year Recurrence Interval)

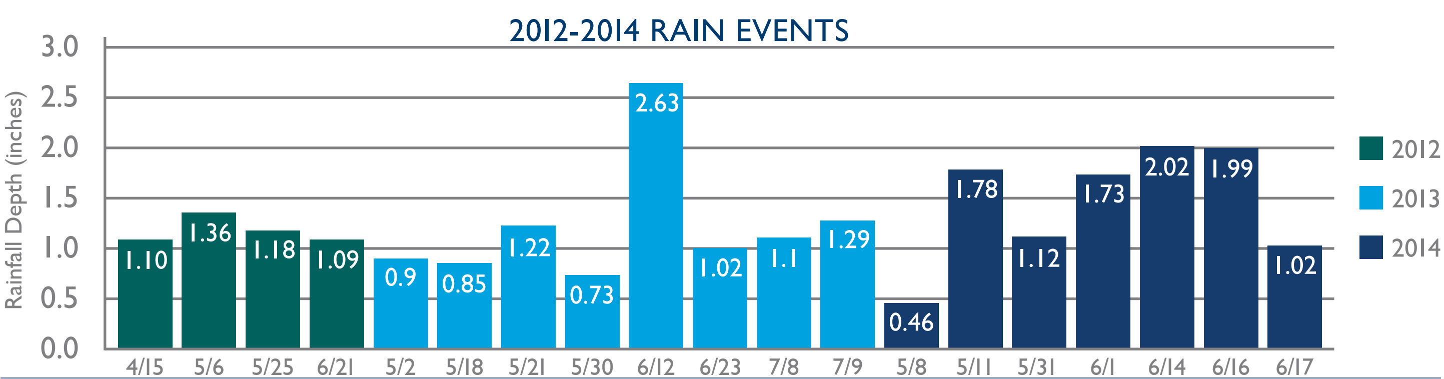


Figure 24 - All Monitored Rain Event

DATE	ONSET® RG3	MN CLIMATOLOGY WORKING GROUP	THE CLIMATE CORPORATION
4/15/12	1.10	1.10	1.11
5/6/12	1.36	1.46	1.56
5/25/12	1.18	1.30	1.24
6/21/12	1.09	1.12	1.08
5/2/13	0.90	0.97	0.79
5/18/13	0.85	0.81	0.80
5/21/13	1.22	0.97	1.20
5/30/13	0.73	0.85	0.64
6/12/13	2.63	2.47	2.67
6/23/13	1.02	0.86	1.19
7/8/13	1.10	1.04	0.97
7/9/13	1.29	1.24	1.21
5/8/14	0.46	0.42	0.58
5/11/14	1.78	1.80	1.70
5/31/14	1.12	1.41	0.95
6/1/14	1.73	1.50	1.76
6/14/14	2.02	1.71	2.05
6/16/14	1.99	2.75	1.94
6/17/14	1.02	0.86	0.99

Table 6 - Rainfall Comparison of Sources Measuring Rainfall

YEAR	DEPTH SAMPLED (in)	TOTAL GROWING SEASON RAINFALL (in)	PERCENT SAMPLED (%)
2012	4.73	13.89	34.0
2013	9.74	21.11	46.1
2014	10.12	20.44	49.5
Total	24.59	55.44	44.4

Table 7 - Sample Rainfall Compared to Growing Season Rainfall

ANALYSIS

In order to validate the precipitation recorded by the Onset rain gauge, a comparison to other records of precipitation generated by radar and state rain gauges was performed. The two other sources used for precipitation comparison are the Minnesota Climatology Working Group and the Climate Corporation. *Table 6* shows this comparison.

Using the rain gauge data for each year, the total rainfall amount for the growing season (April-August) was added and compared to the amount of rainfall that was sampled (1-inch rain events). *Table 7* shows this comparison.

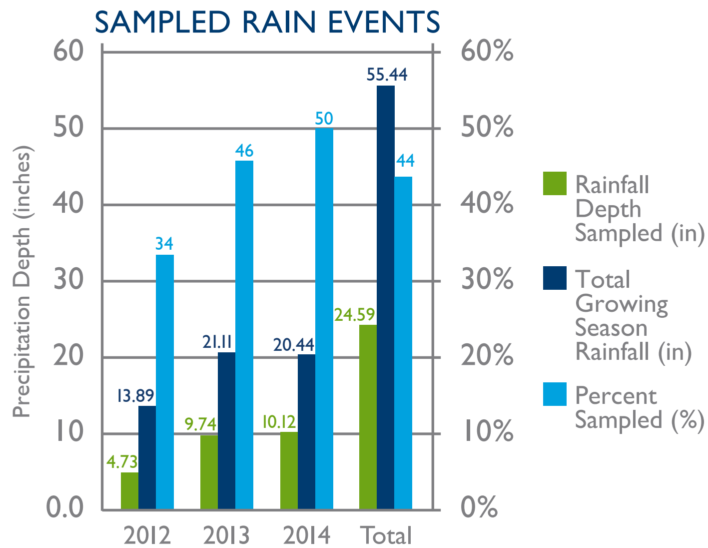


Figure 25 - Sampled Rain Events and Total Precipitation

Figure 25 shows a comparison of all three years of recorded precipitation and sampled events. As shown, overall 44 percent of the rainfall was sampled for water quality analysis.

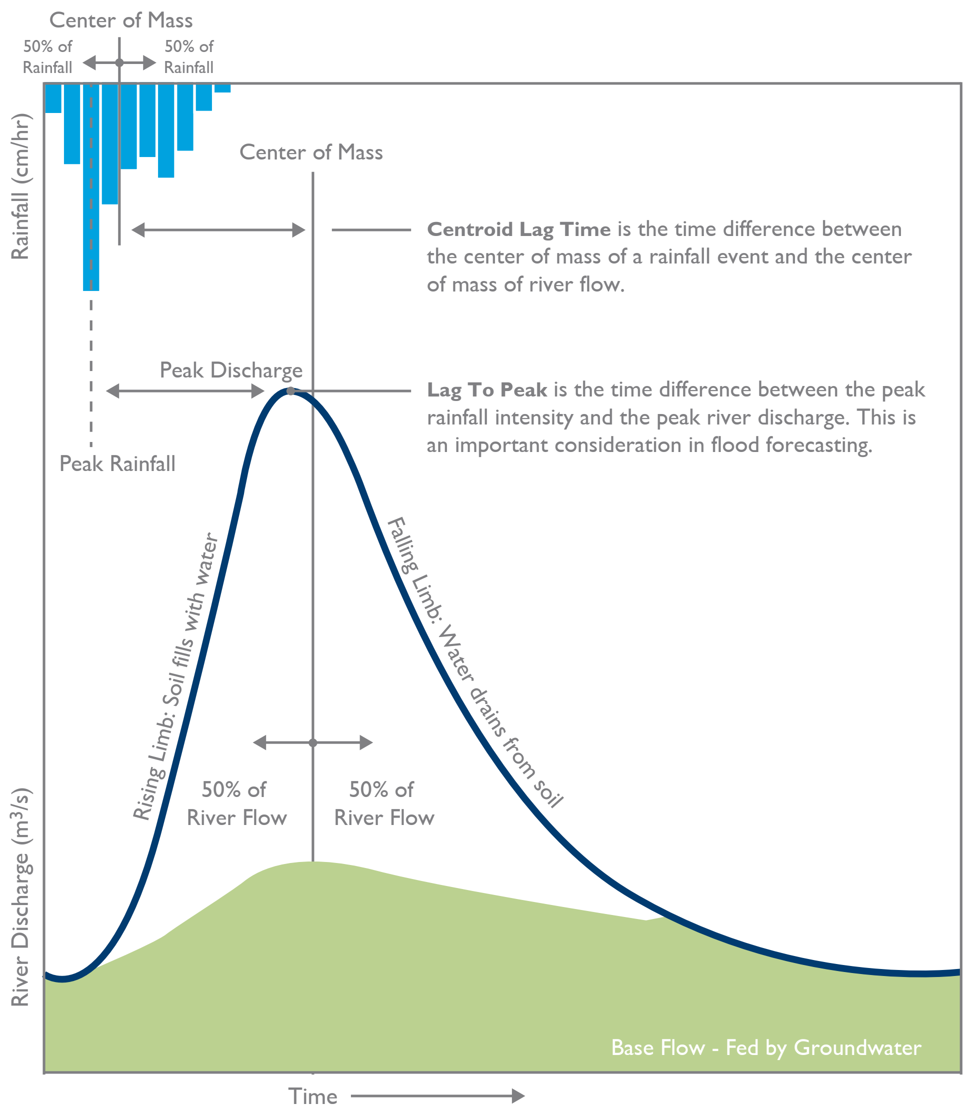
FLOW

THEORY

Flow is defined as the volume of water in either a pipe or open channel that passes a certain point per a unit of time. This is typically referred to as the flow in cubic feet per second (cfs) at a certain point. Flow is a valuable parameter to measure for any monitoring system because it provides the perspective of how much water is moving through the system and is used for the analysis of the following:

- Peak flow rate, or highest flow through the system
- Time and duration of flow
- Comparison to rainfall and runoff
- Total flow volume
- Determine of total loading of water chemistry

Flow for a river, stream, ditch, or tile is often described through a hydrograph. A hydrograph is a graph that compares precipitation, runoff, and time for a rain event. *Figure 26* shows a typical hydrograph.



During a **rainfall event**, the intensity at which precipitation falls on a landscape is often variable. The **peak rainfall**, a measure of the greatest intensity of rainfall, does not necessarily occur in the middle of a rainfall event. Therefore, the peak and the **center of mass** of rainfall (the point at which half of the total rainfall has fallen) often do not correspond.

As precipitation falls across a landscape, some **infiltrates** the soil and some **runs off** and enters river channels causing discharge and river stage to rise. As the soil fills with water, more precipitation enters river channels as runoff, groundwater flow and subsurface stormflow. Stage rises until reaching the **peak**, or maximum discharge resulting from a rainfall event. As water drains from soils and from the landscape, the river stage begins to fall, eventually returning to **base flow**, which reflects normal groundwater discharge to rivers in humid regions.

Figure 26 - Typical Hydrograph - Source: Dunne, Thomas and Leopold

As shown, after rainfall fills the soil profile to a point of saturation, the remainder of the rainfall runs off the landscape. Over time, the discharge risers until the precipitation ends, thus minimizing the runoff from the landscape.

A hydrograph analysis can be used for the following analyses:

- Determining peak flow rates for a rain event
- Determining the duration of a rain event
- Comparing discharge to precipitation
- Determining total volume of runoff for a rain event by calculating the area under the hydrograph curve

METHODOLOGY

Quantifying real time flow values is a difficult process. Real time flow measuring devices are more accurate at quantifying flow because they are physically placed in the line of flow and instantaneously record the flow passing the device. While these devices provide accurate flow data, they are also very expensive and require routine maintenance. Budgeting

Figure 27 - Hobo Data Logging Device (left) and Staff Gague with slotted PVC (behind) for data logging devices

Figure 28 - Camera, Staff Gague, and Data Logging Device Setup for Site 5

for these devices for all the required monitoring locations proved to be infeasible and outside of the project budget. Therefore, alternative methods were used for the CD 57 flow monitoring.

While real time flow measurements were not part of the monitoring of the CD 57 ditch system, real time data logging devices used to measure pressure were installed. These devices recorded stage (depth) measurements and were recorded every five minutes at each monitoring site throughout the watershed. Stage data were obtained at every site using Onset® HOBO U20 Water Level Loggers. Onset® HOBO U20 Water Level Logger Systems were installed in March every year or after ice out and remained deployed through October. A data logging device was stationed above the water level to record the barometric pressure to correct the water levels for atmospheric pressure. For quality assurance and quality control purposes, the water level was manually measured via a calibrated staff gauge when sampling was conducted. *Figure 27* shows the data logging devices and staff gauges used to monitor stage.

To insure the accuracy of the data logging devices, staff gauges with on-site automatic cameras were installed at non-manhole monitoring locations (Sites 1, 2, 3, 4, 5, 6, 7, 8, & 10). The on-site cameras were set to capture pictures every five minutes (the same setting as the water level loggers) so the stage of the ditch can be verified with pictures of the staff gauge and water level from the on-site cameras. ISG also performed yearly topographic surveys of the subject area to identify the horizontal and vertical locations of the monitoring equipment as well as changes to the cross sections of the ditch. *Figure 28* shows the camera, staff gauge, and data logging device setup for Site 5.

Although stage measurements do not directly measure flow rates through the system, depth can be used in conjunction with survey data, a hydrologic/hydraulic model, and Manning's equation for flow to quantify flow. *Equation 1* - Manning's equation for flow is as follows:

Equation 1

$$Q = \frac{1.49}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}}$$

- Q = flow rate
- n = roughness coefficient of media in which the flow passes over
- A = area of water in which the flow passes
- R = hydraulic radius of the flow area (area/wetted perimeter of flow)
- S = slope of the bed in which the flow passes

The only unknown in this equation from the CD 57 monitoring is flow (Q). Stage data can be used in conjunction with survey data to determine the area of flow (A), wetted perimeter of the flow area, thus hydraulic radius (R), and slope of the bed (S). Therefore, flow was approximated for each monitoring station.

A hydrologic/hydraulic model was also created for this watershed using HydroCAD, software which incorporates modeling of watersheds, open channels, pipe networks, and stormwater ponds. This model was developed using detailed survey, soil, land use, and landscape data from the watershed. The model was then calibrated from various rain events to match runoff hydrographs for elevation. This method was used since elevation depths of the runoff are well documented by the data logging devices.

After the hydrologic/hydraulic model was developed, it was used for:

- Comparing flow rates to those calculated by Manning's equation for flow
- Comparing flow volumes of each rain event
- Comparing runoff amounts for each rain event
- Calculating flow rates and runoffs of rain events where missing data occurred

Flow was also measured monthly via a tracer dye test to ensure accuracy in the calculated flow from measurements from the data logging devices and staff gauges. Methodology described in *Field Techniques for Estimating Water Fluxes between Surface Water and Ground Water* (LaBough & Rosenberry) were used when flow was measured utilizing a tracer dye test. A measuring tape was spread out for 100 meters along the ditch with the flow monitoring location in the middle. A tracer dye (fluorescent salt solution with a higher known conductivity) was dumped into the ditch. The amount of time required for the dye to travel 100 meters was recorded utilizing conductivity meter. Time is recorded when 20, 60, and 80 percent of the dye reaches the 100 meter mark (LaBough & Rosenberry). The velocity was then converted to flow based on the area the dye traveled.

These methods have underlying inconsistencies, primarily due to backwater effects from the Big Cobb River, culvert and field crossings, and added storage through ponds and restricted outlets. Therefore, flow using these methods must be verified by using alternative hydrological methods. These methods include comparing peak flow rates, accumulated flow volumes, and rainfall and runoff amounts. These comparisons are made in the following **Sections: Peak Flows, Flow Volume and Runoff**.

RESULTS

Utilizing Manning's equation, approximate flow rates for all three years were calculated based on the recorded depth from the data logging devices. The following example calculation is from the July 9, 2013 rain event. After rain began to fall and water ran off into the ditch, a depth

Figure 29 - 2.56 Foot Water Depth at Site 2

of 2.56 feet in the ditch was recorded at Site 2. Utilizing this depth and channel geometry from the topographic survey, Manning's equation was used to calculate flow in the trapezoidal channel.
First the wetted perimeter must be calculated using *Equation 2*

Figure 29 shows a cross section of the ditch for the given depth of 2.56 feet.

Equation 2

$$P_w = b + 2\sqrt{((S_s * d)^2 + d^2)}$$

Where

- P_w=wetted perimeter
- b=bottom width of the ditch
- S_s=side slope of ditch bank
- d=depth of water

Inputting the known values results in the following:

$$P_w = 6.47 + 2\sqrt{((1.43 * 2.56)^2 + 2.56^2)} \qquad P_w = 15.43\ ft$$

TIME	DEPTH IN DITCH-D (ft)	WETTED PERIMETER - P_W (ft)	TOP WIDTH - T (ft)	AREA - A (ft^2)	HYDRAULIC RADIUS - R (ft)	FLOW (cfs)
7:40	2.56	15.43	13.82	25.99	1.68	30.52
7:45	2.60	15.56	13.93	26.52	1.70	31.38
7:50	2.63	15.65	14.00	26.87	1.72	31.95
7:55	2.64	15.70	14.04	27.06	1.72	32.27
8:00	2.66	15.79	14.11	27.41	1.74	32.86
8:05	2.68	15.83	14.15	27.58	1.74	33.14
8:10	2.71	15.95	14.25	28.10	1.76	33.99
8:15	2.74	16.04	14.32	28.45	1.77	34.58
8:20	2.80	16.26	14.50	29.35	1.81	36.09
8:25	2.89	16.56	14.75	30.62	1.85	38.26
8:30	2.98	16.90	15.03	32.08	1.90	40.78
8:35	3.03	17.07	15.17	32.80	1.92	42.05
8:40	3.11	17.33	15.38	33.95	1.96	44.08
8:45	3.22	17.72	15.70	35.66	2.01	47.14
8:50	3.27	17.89	15.84	36.43	2.04	48.55
8:55	3.34	18.14	16.04	37.58	2.07	50.65
9:00	3.44	18.49	16.33	39.20	2.12	53.65
9:05	3.44	18.49	16.33	39.20	2.12	53.65
9:10	3.52	18.80	16.58	40.63	2.16	56.34
9:15	3.59	19.01	16.76	41.64	2.19	58.27
9:20	3.59	19.01	16.75	41.63	2.19	58.24
9:25	3.66	19.26	16.97	42.88	2.23	60.62
9:30	3.72	19.48	17.14	43.93	2.26	62.67

Table 8 - Calculated Flow for July 9, 2013 Rain Event

Next, the top width of the water surface must be calcluated using *Equation 3*.

Equation 3

$$T = b + 2(S_S * d)$$

Inputting the values into *Equation 3* results in the following:

$$T = 6.47 + 2(1.43 * 2.56) \qquad T = 13.82 \text{ ft}$$

area in which the flow passes is calculated using *Equation 4*.

Equation 4

$$A = 0.5 * (b + T) * d$$

Inputting the values into *Equation 4* results in the following:

$$A = 0.5 * (6.47 + 13.81) * 2.56 \qquad A = 25.99 \text{ ft}$$

Next, the hydraulic radius is calculated using *Equation 5*.

Equation 5

$$R = \frac{A}{P_w}$$

Inputting the values into *Equation 5* results in the following:

$$R = \frac{1.49}{15.42} \qquad R = 1.68 \text{ ft}$$

Lastly, assuming an n value of 0.022, using the surveyed bed slope of 0.0002, and using Equation 1 to calculate the flow results in the following:

$$Q = \frac{1.49}{0.022} * 25.96 * 1.63^{\frac{2}{3}} * 0.0002^{\frac{1}{2}} \qquad Q = 30.52 \text{ cfs}$$

This process was repeated for all measured depths and was tabulated in a similar format (*Table 8*) that shows several flow calculations for site 2 during the July 9, 2013 rain event.

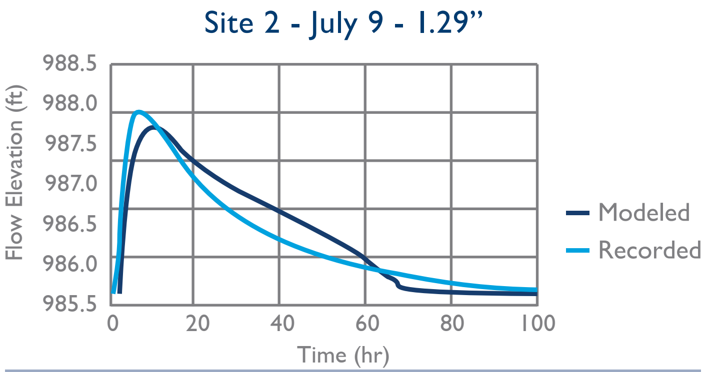


Figure 30 - Elevation Hydrograph for Site 2 of July 9, 2013 Rain Event

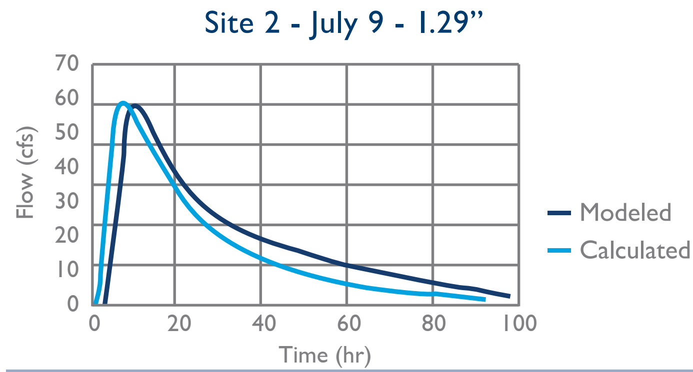


Figure 31 - Hydrograph for SIte 2 of July 9, 2013 Rain Event

This calculated flow data was used to develop a hydrograph for all recorded depths. *Figure 30* shows the recorded elevations from the data logging devices at Site 2 for the July 9, 2013 rain event. Elevations based on the Hydrocad model are also included in *Figure 30*. The modeled elevations are comparable the recorded elevations.

Figure 31 shows the calculated flow based on the recorded depths from the data logging devices and the flows developed through the hydrologic/hydraulic model. While the actual flows may be different than those included in this report, the modeled flows are comparable to those developed using the Manning equation. The similarity of the curves is an artifact of the theory used to develop flow.

ANALYSIS

The above method for calculating flow was used for all rain events in which stage data was recorded. Due to monitoring adjustments and equipment failure, a few rain events did not have recorded stage data. For these locations and events, the hydrologic/hydraulic model was used to simulate the rain event. This model was simulated, calibrated, and tested against recorded data and photos to develop an accurate depiction of the CD 57 system during rain events. An example comparison showing the accuracy of the model is shown for the July 9, 2013 rain event in which a 1 hour, 1.29-inch rain event was recorded (*Figure 31*). This rain event was used as a baseline for calibration of the hydrologic/hydraulic model for the CD 57 system. This event was used since the ditch system was primarily dry and at a slow baseflow condition. It was also chosen since the rain event provided enough precipitation and runoff to accurately calibrate the model. Calibration of the model included comparing water elevations for the recorded data and modeled data. This was verified by a detail topographic survey, calibration of the data logging devices via ambient pressure adjustments, and verification of depth and stage conditions throughout the CD 57 system by utilizing the onset cameras located throughout the watershed.

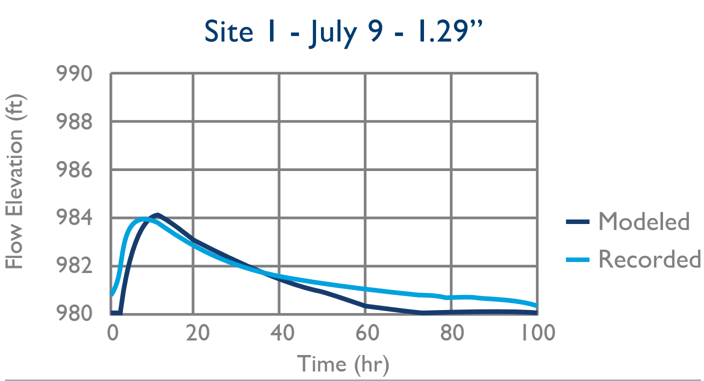


Figure 32 - Elevation Hydrograph for Site 1 of July 9, 2013 Rain Event

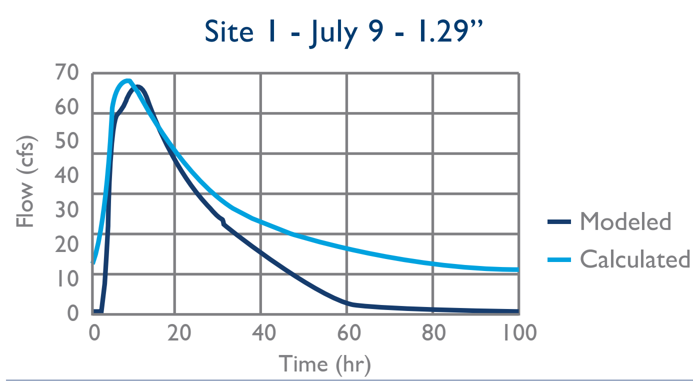


Figure 33 - Hydrograph for Site 1 of July 9, 2013 Rain Event

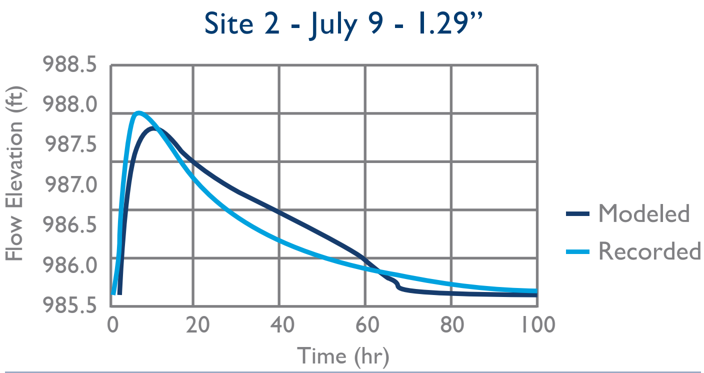


Figure 34 - Elevation Hydrograph for Site 2 of July 9, 2013 Rain Event

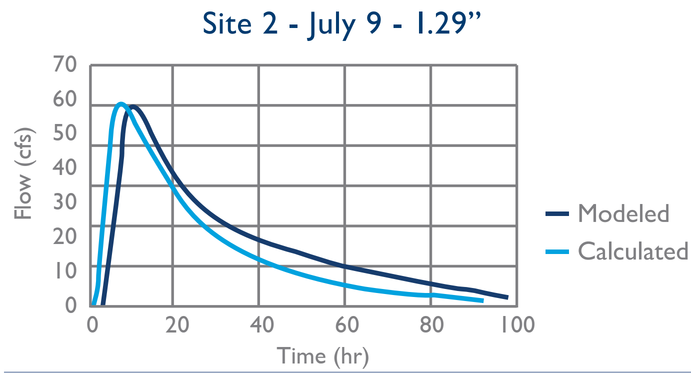


Figure 35 - Hydrograph for Site 2 of July 9, 2013 Rain Event

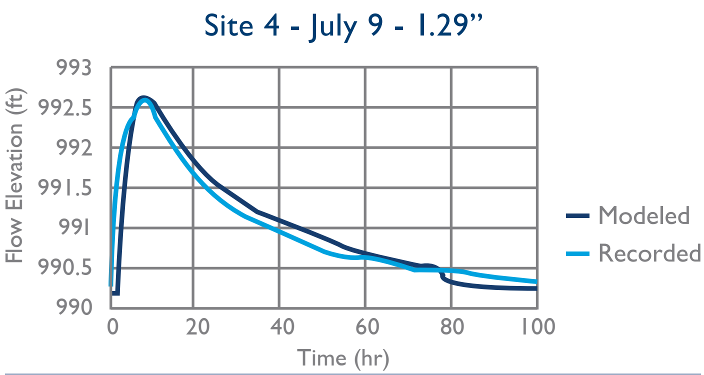


Figure 36 - Elevation Hydrograph for Site 4 of July 9, 2013 Rain Event

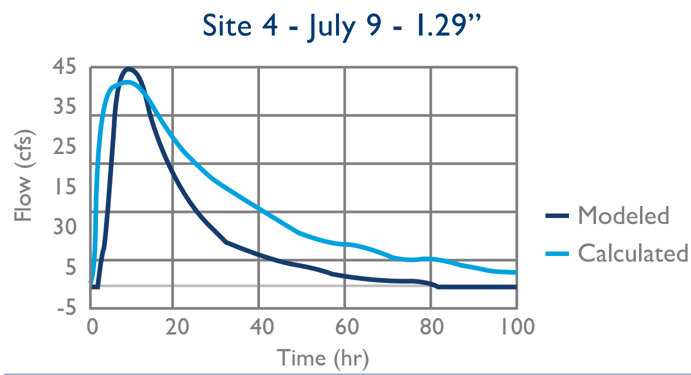


Figure 37 - Hydrograph for Site 4 of July 9, 2013 Rain Event

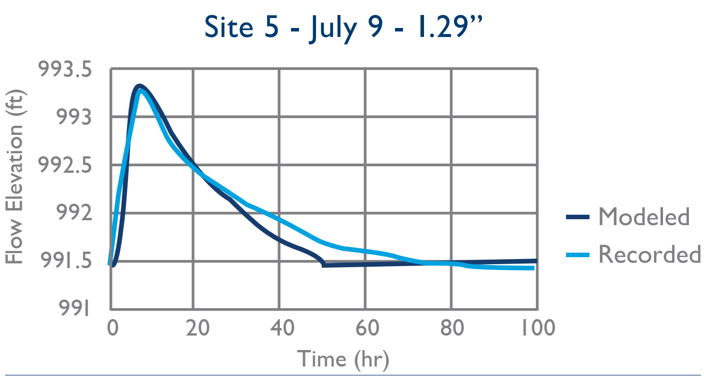


Figure 38 - Elevation Hydrograph for Site 5 of July 9, 2013 Rain Event

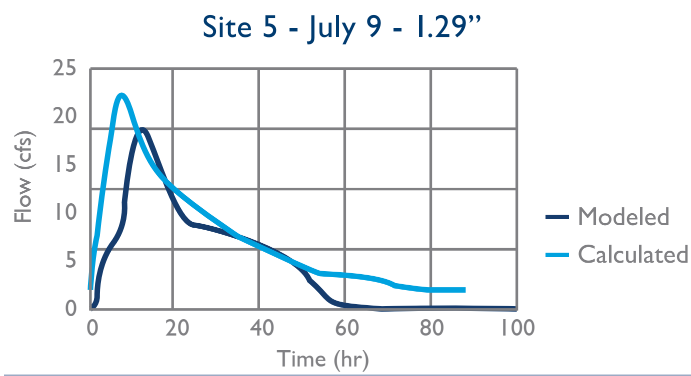


Figure 39 - Hydrograph for Site 5 of July 9, 2013 Rain Event

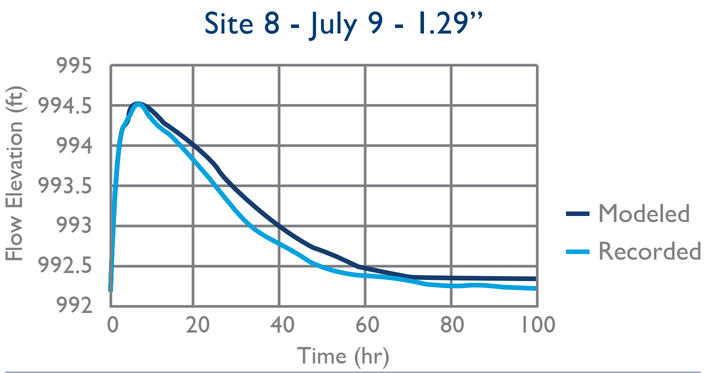


Figure 40 - Elevation Hydrograph for Site 8 of July 9, 2013 Rain Event

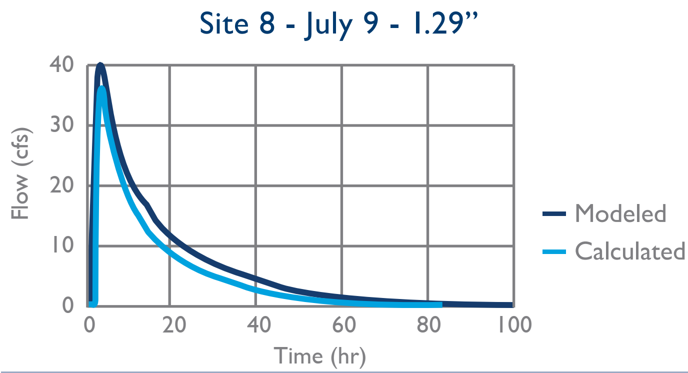


Figure 41 - Hydrograph for Site 8 of July 9, 2013 Rain Event

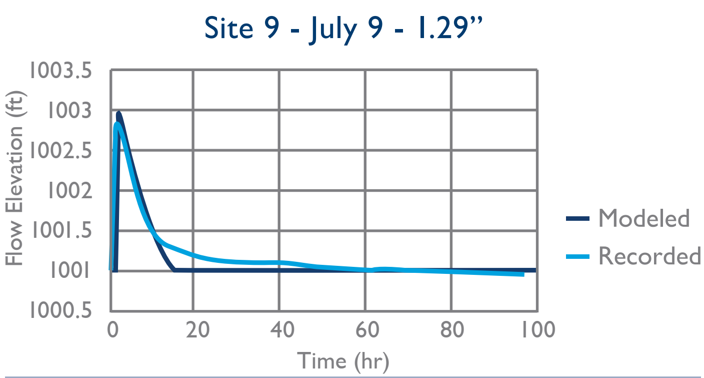


Figure 42 - Elevation Hydrograph for Site 9 of July 9, 2013 Rain Event

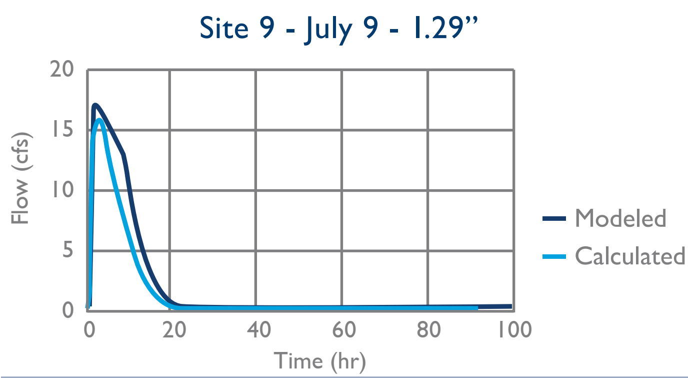


Figure 43 - Hydrograph for Site 9 of July 9, 2013 Rain Event

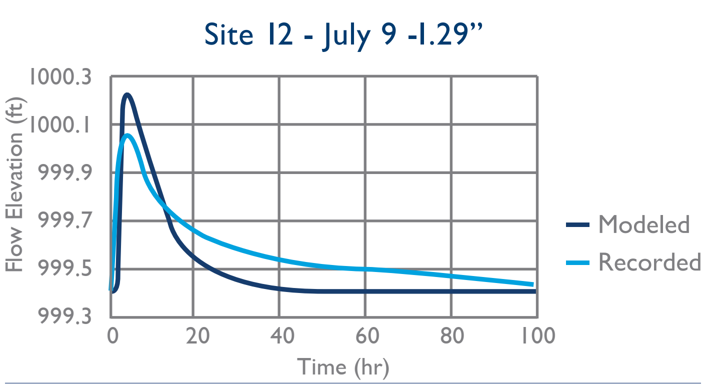


Figure 44 - Elevation Hydrograph for Site 12 of July 9, 2013 Rain Event

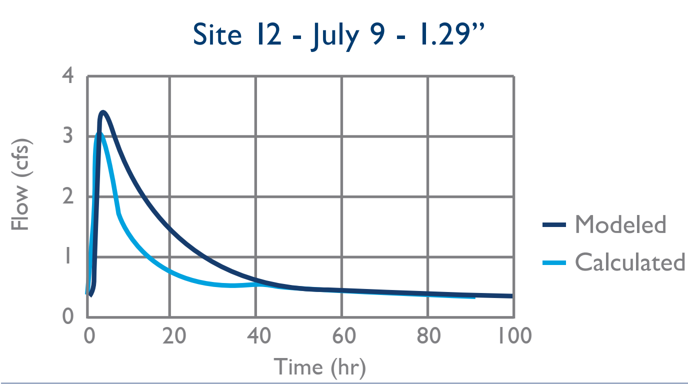


Figure 45 - Hydrograph for Site 12 of July 9, 2013 Rain Event

The previous figures compare the recorded water level elevations and flow rates to those elevations and flow rates that were modeled using the hydrologic/hydraulic model. These figures show the hydrographs or the water quality monitoring sites located throughout the watershed.

The elevation hydrographs and hydrographs (*Figures 32-45*) are very similar for both the modeled and recorded elevations. This proves that the hydrologic/hydraulic model developed for CD 57 accurately depicts the hydrology and hydraulic conditions throughout the watershed. Therefore, using this model for the rain events that were not measured with data logging devices will provide an accurate depiction of the system.

PEAK FLOWS

THEORY

Peak flow rates are defined as the highest volumetric flow rate that passes through a point on a system from a rain event. On a hydrograph, this is the top most point on the hydrograph. Peak flow rates are responsible for the following characteristics of flow in either a river, stream, or any open channel (MPCA, 2012):

- Erosion to ditch banks due to high water flow
- High nutrient loading
- High sediment loading
- Increased flooding to local and downstream waters

Peak flow rates can have damaging effects to both local and global watersheds, thus controlling peak flow rates is essential for improving water quality.

METHODOLOGY

Peak flow rates for the recorded stage depth were determined by using the previously mentioned Manning's equation for flow for the highest recorded depth during a rain event. Peak flow rates for the hydrologic/hydraulic model were taken from the top most point of the simulated hydrograph for the associated rain events.

RESULTS

Using the same July 9, 2013 rain event to for both the calculated and modeled peak flow rates provided similar results (*Figure 46*).

ANALYSIS

The peak flow rates from the model and the recorded peak flow rates calculated using Manning's equation were compared. The peak flow rates for both the modeled and recorded methods are nearly the same throughout the system. This further validates the methodology for computing flow from both the hydrologic/hydraulic model and

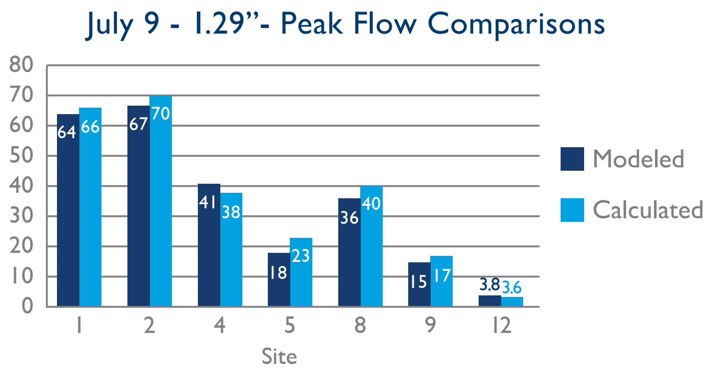


Figure 46 - Peak Flow Rates Comparison for Modeled and Calculated Flow Methods

calculating flow based on Manning's equation for flow.

FLOW VOLUME

THEORY

The total flow volume of a rain event at a given point is defined as the cumulative volume of water that passes through a point for a rain event. It is found by calculating the area under the hydrograph curve. Total flow volumes are used for the following:

- Comparing flow volumes for different monitoring points
- Computing runoff from the watershed
- Computing water chemistry loading of a variety of parameters (i.e. sediment, nutrients, etc.)

As watershed area increases to a stream network, the total flow volume is expected to increase as there is more runoff from a larger contributing watershed. Therefore, total runoff volumes from a rain event are expected to be largest at Site 1 and lower at upstream Sites 9 and 12.

METHODOLOGY

The total flow volume of a rain event is determined by calculating the area under the hydrograph curve. Using the hydrographs for both the modeled and recorded methods of the July 9, 2013 rain event, the total volume of each hydrograph was calculated. For the recorded method, some of the data logging devices contained areas of baseflow and pooled water due to culvert crossing and permanent water due to the overdug ditch. This area under starting and ending points of the hydrograph was subtracted since it does not accurately depict the discharge from the rain event (*Figure 47*).

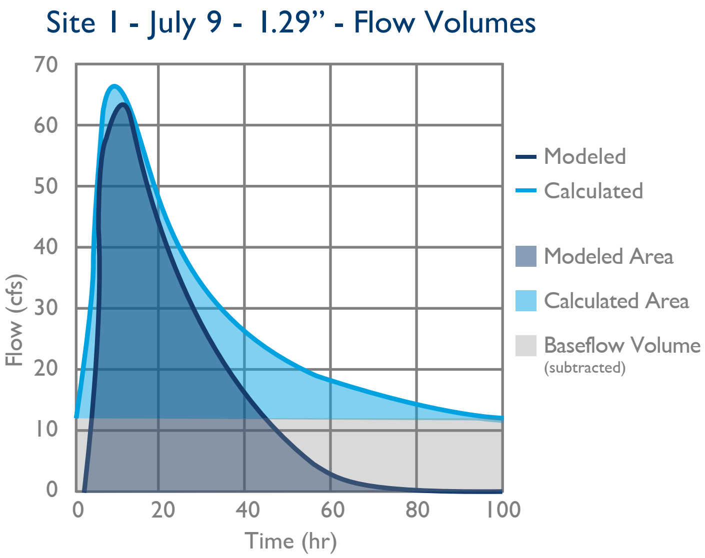


Figure 47 - Total Flow Volume Calculation

RESULTS

Figure 48 shows the total flow volumes calculated for the July 9, 2013 rain event. The total volumes are relatively close for each site for the modeled and recorded methods.

This method can also be used to compare the total flow through the system for each of the monitored years. *Figure 49* compares the total flow through the system for years 2012-2014.

ANALYSIS

The total flow volumes for both the model and the calculated methods for flow provide similar runoff volumes (*Figure 48*). This further validates the methods used in determining flow for the CD 57 system.

The total volume increases from upstream (Site 12) to downstream (Site 1), were as anticipated. Comparing the yearly flow volumes (*Figure 49*) shows that the most flow volume occurred in 2014 while the least amount occurred in 2012. This was expected as the highest rainfall occurred during 2014 while the least amount occurred during 2012.

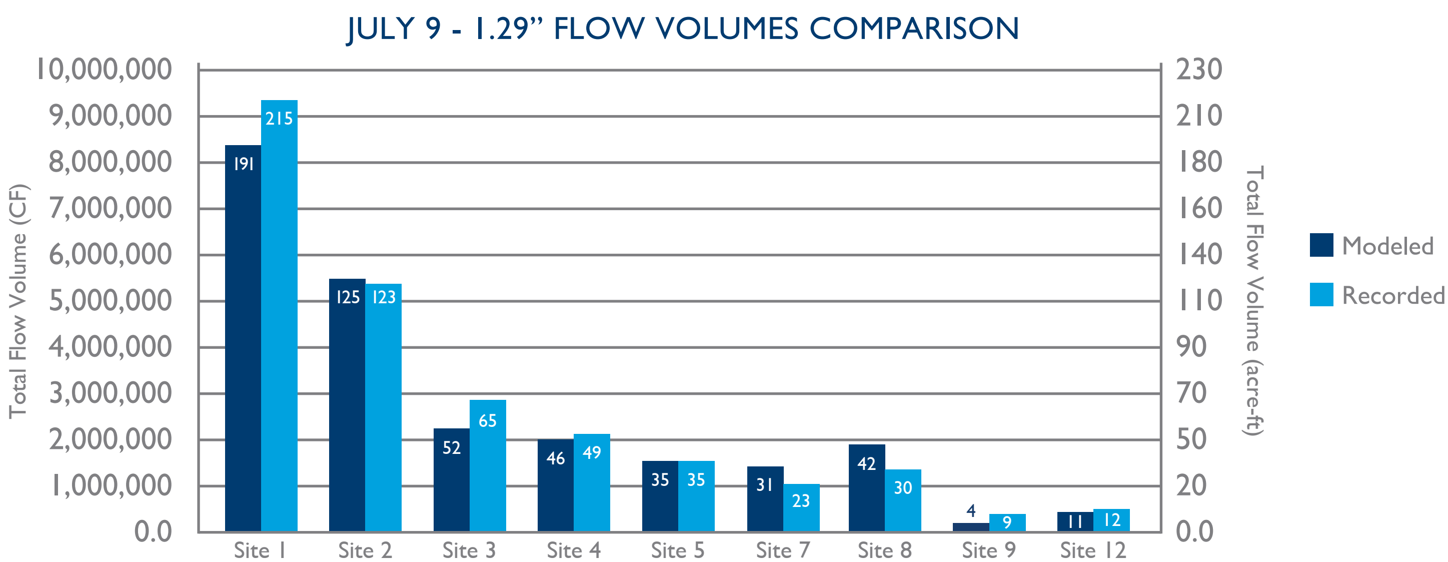


Figure 48 - Total Flow Volume Comparison for July 9, 2013 Rain Event

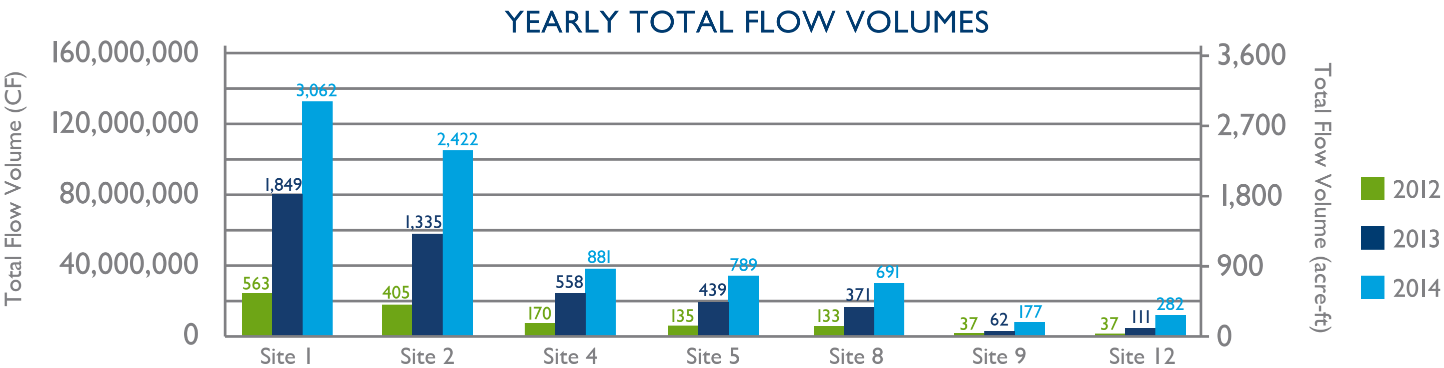


Figure 49 - Yearly Total Flow Volumes

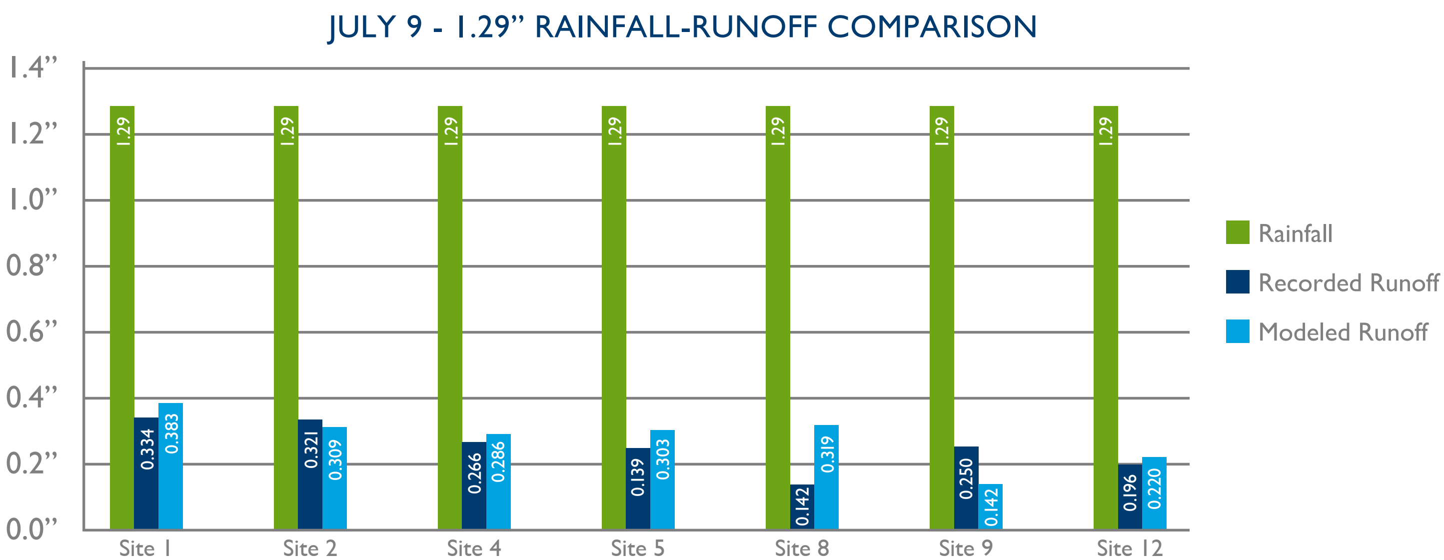


Figure 50 - Rainfall-Runoff Comparison for July 9, 2013 Rain Event

RUNOFF

THEORY

Rainfall and runoff can be directly related to each other in order to validate flow from the CD 57 system. Runoff, precipitation, and infiltration are related by the following equation (Gupta 2008) for direct runoff within a basin.

Equation 6

$$P = R + I$$

Here *P* represents precipitation, *R* represents runoff, and *I* represents infiltration. Runoff is calculated using *Equation 7*.

Equation 7

$$R(in) = \frac{Total\ Flow\ Volume\ ft^3}{Watershed\ Area(acres) * \frac{43560\ ft^2}{1\,acre}} * \frac{12\ in}{1\,ft}$$

Infiltration values are dependent on the soil saturation; therefore, runoff values are also dependent upon the soil conditions. When the soil is saturated, it is expected to have a higher runoff value. When the soil is dry and unsaturated, infiltration values are expected to be higher creating lower runoff values. Following *Equation 7*, runoff values should never exceed the rainfall amount. Since the monitoring for the CD 57 system did not include infiltration, it is to be expected that runoff values would be less than precipitation for monitored rain events.

METHODOLOGY

Using *Equation 7* and the total runoff volumes for the July 9, 2013, 1.29-inch rain event, a rainfall/runoff comparison was completed (*Figure 50*).

RESULTS

This process was repeated and done for the monitored rain events between 2012 and 2014. The results from these calculations were averaged throughout the entire system for each rain event using the flow from Manning's equation. *Figures 51-53* show the rainfall and runoff comparison for the sampled rain events between 2012 and 2014.

Summarizing these three years of rainfall and runoff is shown in *Figure 54*.

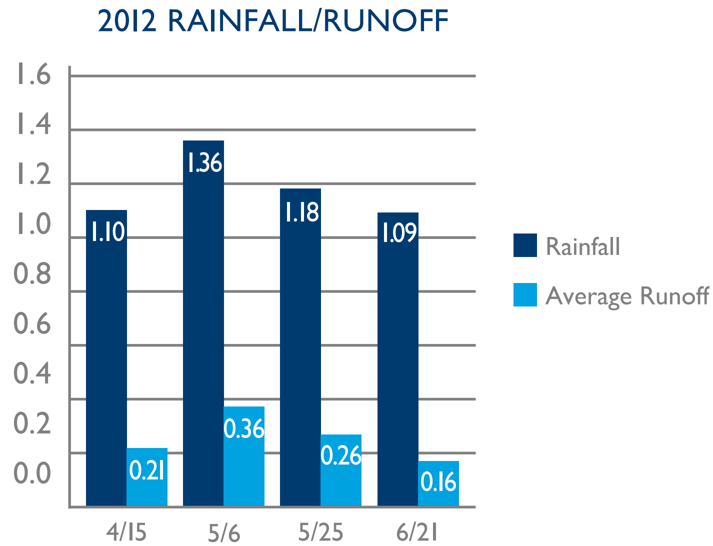


Figure 51 - 2012 Rainfall and Runoff Comparison

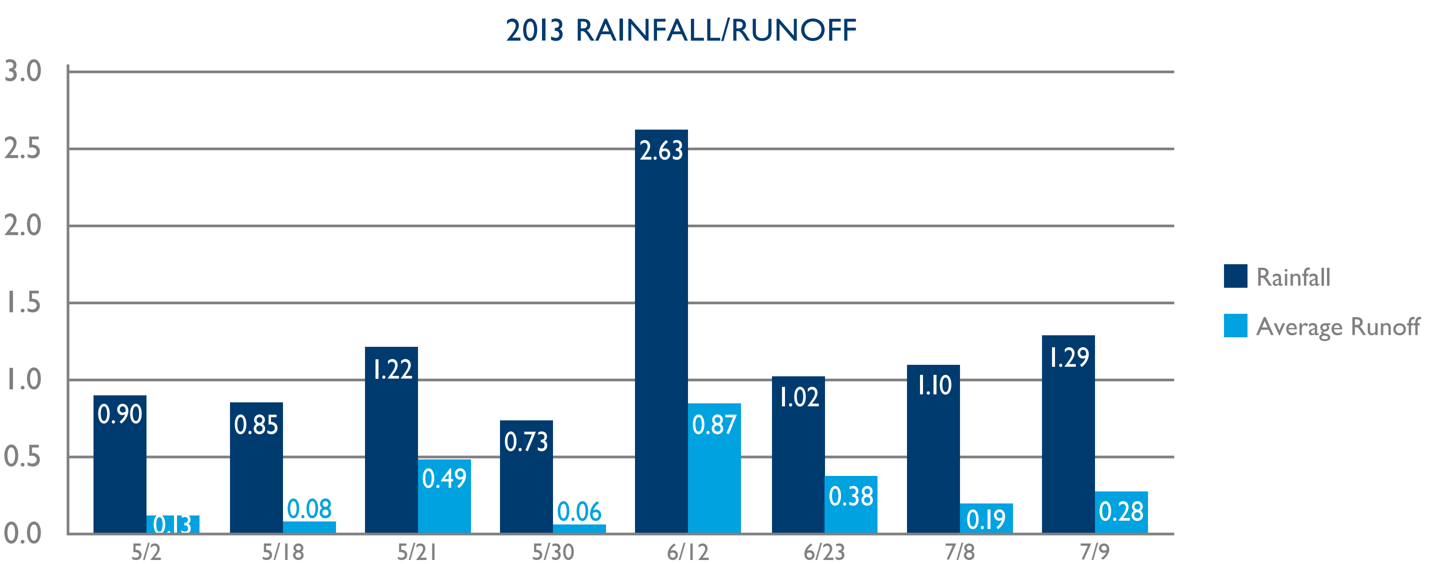


Figure 52 - 2013 Rainfall and Runoff Comparison

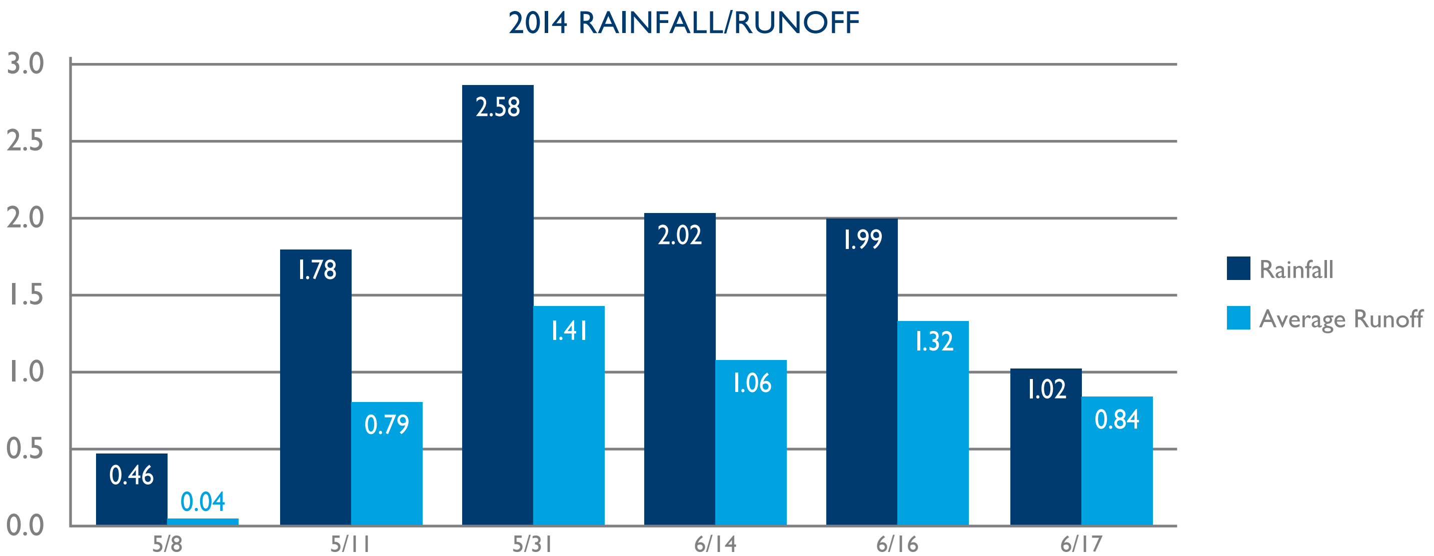


Figure 53 - 2014 Rainfall and Runoff Comparison

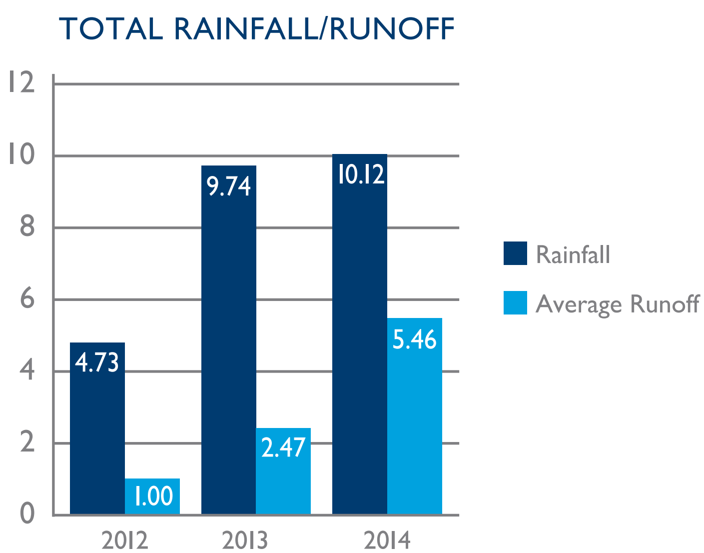


Figure 54 - Total Yearly Rainfall and Runoff Comparison

ANALYSIS

The runoff depths for both the modeled and calculated methods are similar and are less than the rainfall depth. As expected, the runoff depths are less than the rainfall depths, validating the flow data used in this analysis.

The three post-BMP installation monitoring seasons included both high and low rainfall levels (*Figure 54*). Very dry conditions occurred in 2012, with very little runoff and high infiltration throughout watershed. Of the monitored events in 2012, only one inch of runoff was recorded. The low amount of runoff in 2012 was as expected due to overly dry conditions, with the majority of the rainfall being infiltrated.

Moderate rainfall throughout the 2013 growing season provided a more typical season with 2.47 inches of runoff recorded and sampled. A 2.63-inch rainfall event within two hours occurred in 2013, which is equivalent to a NOAA 25-year rain event. In general, this accurately depicts the runoff for 2013 as little flooding occurred throughout the year.

Multiple heavy rainfall events and a few back to back rain events made 2014 a very wet year. There were many times where the entire CD 57 system was full of water and restricting flow throughout the watershed. The wet conditions lead to a large amount of runoff (53% of rainfall) and high flow volumes. For the majority of June 2014, there was significant flooding throughout the watershed. The rainfall runoff comparison for 2014 accurately depicts flow conditions for CD 57. With a 2.02 and a 1.99 inch rain event in two consecutive days, both were considered NOAA 10-year rain events.

RAIN EVENT	HYDROLOGIC/HYDRAULIC MODEL	RECORDED
4/15/2012	●	
5/6/2012	●	
5/25/2012	●	
6/21/2012	●	●
5/2/2013		●
5/18/2013		●
5/21/2013		●
5/30/2013		●
6/12/2013		●
6/23/2013		●
7/8/2013		●
7/9/2013		●
5/8/2014		●
5/11/2014	●	●
5/31/2014		●
6/1/2014		●
6/14/2014		●
6/16/2014		●
6//2014		●

Table10 - Flow Method Used for Analysis

FLOW SUMMARY

The two methods used for quantifying flow (hydrologic/hydraulic modeling and calculating based on recorded elevations) provide very similar results for flow, peak flow, total flow volume, and runoff depths. These methods were used to further validate the hydrologic/hydraulic model used for the CD 57 system. The calculated method of flow was used for analysis while the model was used as a reference and for validation purposes. However, there were multiple occurrences where the equipment used to record flow either malfunctioned, was not installed early enough, or was damaged. For these frequencies, the hydrologic/hydraulic model was used to simulate the sampled rain event. In some instances, both methods were used as some sites functioned properly while others did not. Each sampled rain event was documented along with the method used for measuring flow for analysis (*Table 10*).

LOADING

THEORY

To analyze the effectiveness of each BMP, the total loading of TSS, TN and TP are combined for upstream of the BMP, and downstream of the BMP. The total loading for each parameter was determined using the following equation.

Equation 8

$$Loading = \sum C_i * V_i$$

Where:

- Loading is the total amount of either TSS, TN, or TP (kg)
- Ci is the concentration of either TSS, TN, or TP at each site (mg/L)
- Vi is the total volume of flow at each site (L)

METHODOLOGY

The rate control weir loading will consist of the concentration of each parameter sampled from Site 1 and the total volume from upstream of the weir (Site 2). The total loading at Site 2 will consist of the concentration of each parameter at Site 2 and the total volume and Site 2. The total volume used for the loading is the same at each site since between Sites 1 and 2, 891 acres of runoff is added to CD 57 which contains untreated water and adds more sediment and nutrients to the system. This will properly analyze the loading of the water that travels downstream from Site 2 to Site 1, thus determining the rate control weir's impact on the loading in the water. *Figure 55* shows the watershed differences between Site 1 and Site 2.

Like the rate control weir, the two-stage ditch total loading is based on the same volume for the upstream point (Site 5) and downstream point (Site 4). Since 542 acres of untreated runoff is added to the end of the two-stage ditch near Site 4, it is inaccurate to incorporate this volume into analyzing the two-stage ditch effectiveness. *Figure 56* shows the watershed differences for the beginning of the two-stage ditch and the end of the two-stage ditch.

The Klein Pond is comprised of three sub watersheds upstream. Each watershed has its own sampling point and flow point to calculate the loading. *Figure 57* shows how the total loading upstream of the pond was determined. As shown, for the upstream tile watershed, Site 12 was used for both flow volume and concentrations. For the City Pond watershed, the outlet of the pond (Site 9) will also be used for flow volume and concentrations. For the western watershed, Site 8 will be used for the flow volume while Site 7 will be used for concentrations. At this point, the watershed area is the same as it is at Site 8. Also, at Site 7, flow rates are affected by the diversion weir, backwater from the pond, and inlet culvert. Site 8 provides a more accurate depiction of flow than Site 7 due to these circumstances.

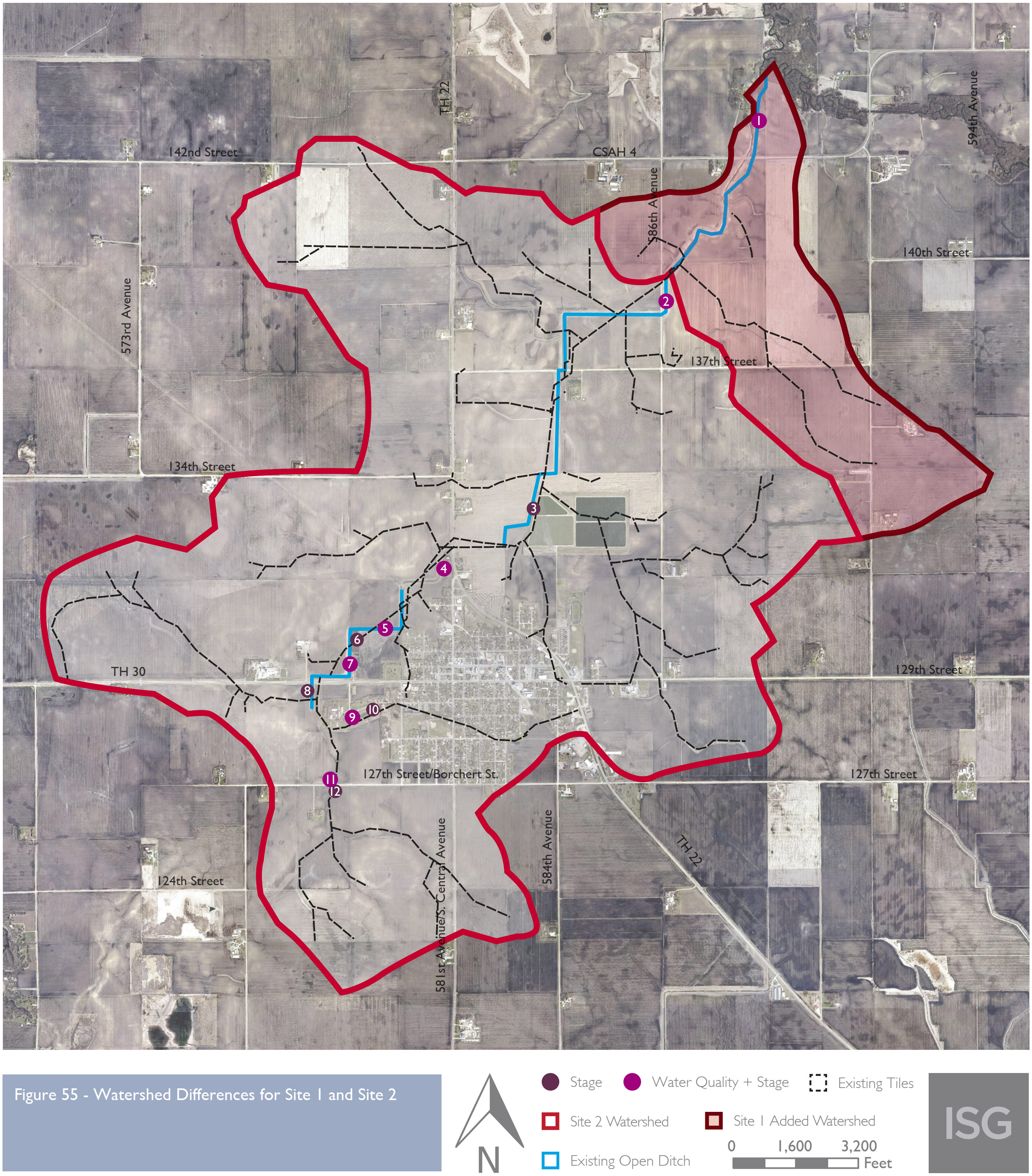


Figure 55 - Watershed Differences for Site 1 and Site 2

ISG

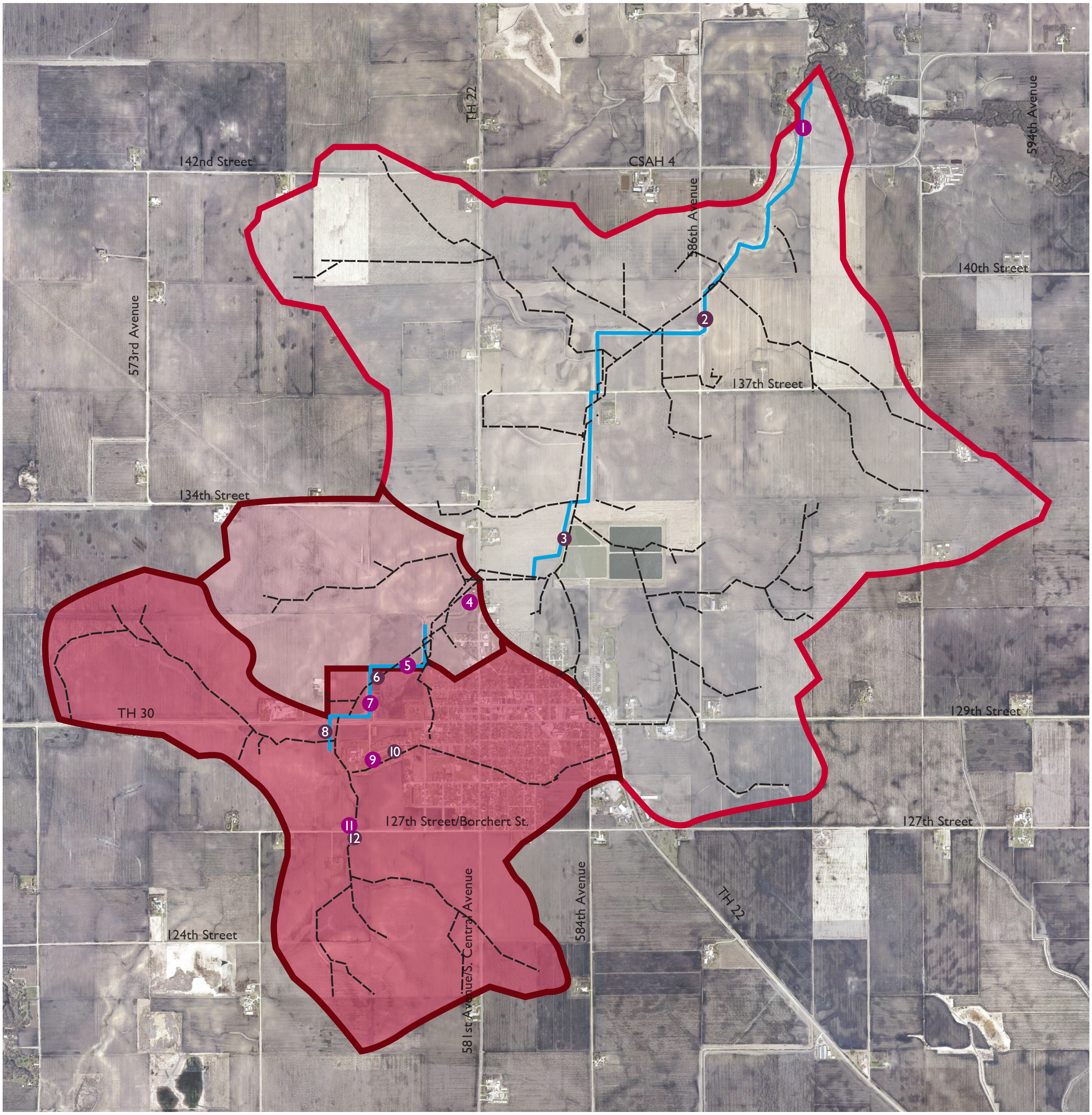


Figure 56 - Watershed Differences for Site 4 and Site 5

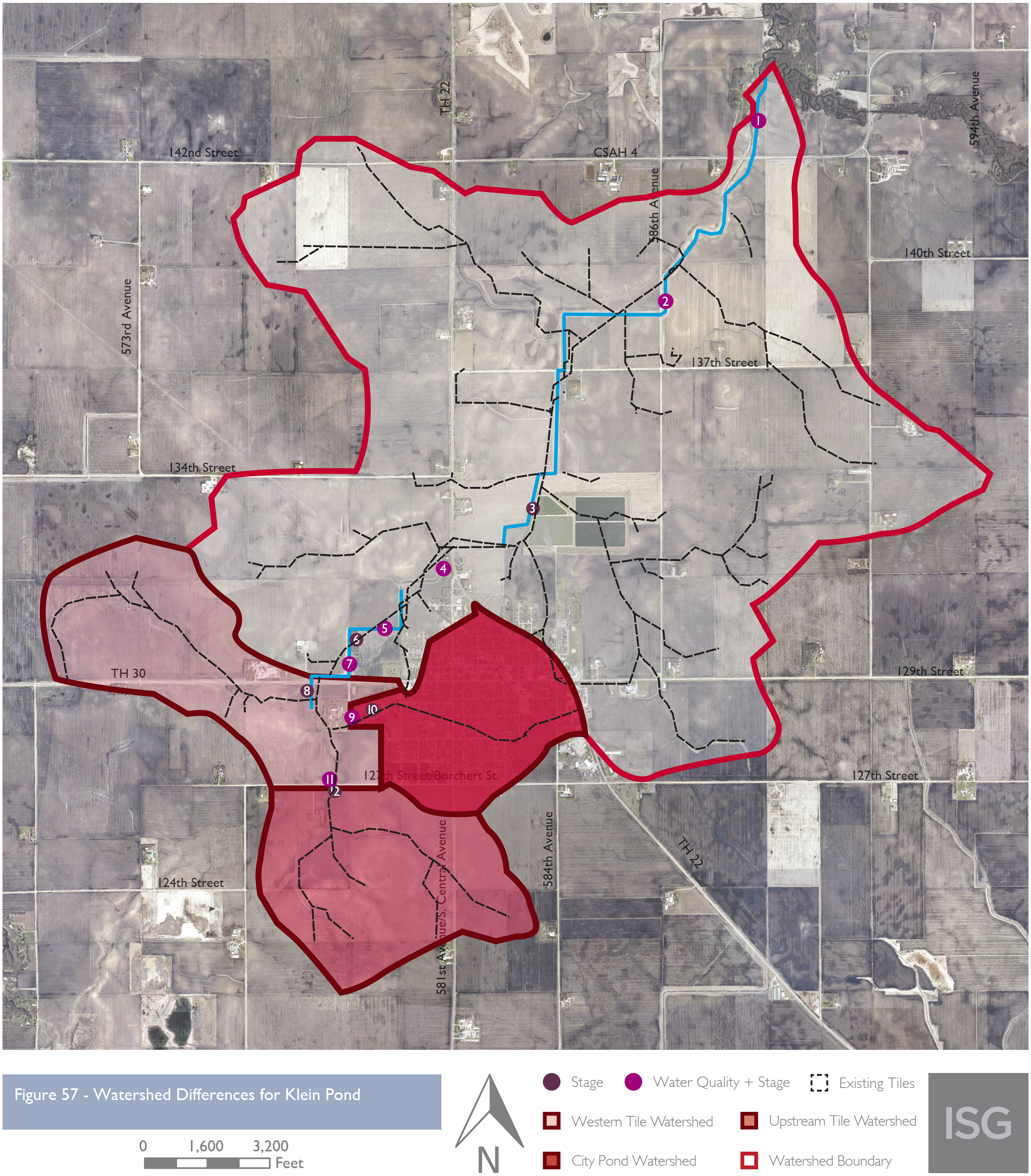


Figure 57 - Watershed Differences for Klein Pond

STATION	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Site 12	13.2	0.4810	46.8
Site 9	110.0	0.4730	9.5
Site 7	6.8	0.3769	33.2
Site 5	14.8	0.4346	22.5
Site 4	14.0	0.4128	21.4
Site 2	32.8	0.4442	23.3
Site 1	30.0	0.3929	25.5

Table 11 - Raw Water Quality Concentrations from July 9, 2013 Rain Event

STATION	FLOW VOLUME (ft^3)	FLOW VOLUME (L)
Site 12	419,762	11,886,313
Site 9	370,311	10,497,361
Site 7	805,192	22,800,473
Site 5	1,558,868	44,142,165
Site 4	1,558,868	44,142,165
Site 2	5,997,151	169,820,118
Site 1	5,997,151	169,820,118

Table 12 - Flow Volumes for July 9, 2013 Rain Event

STATION	TOTAL VOLUME (L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	TOTAL TSS (kg)	TOTAL TP (kg)	TOTAL N (kg)
Site 12	11,886,313	13.2	0.4810	46.8	157	5.71	556
Site 9	10,497,361	110.0	0.4730	9.5	1,155	4.97	100
Site 7	22,800,473	6.8	0.3769	33.2	154	8.59	758
Site 5	44,142,165	14.8	0.4346	22.5	654	19.19	992
Site 4	44,142,165	14.0	0.4128	21.4	618	18.20	947
Site 2	169,820,118	32.8	0.4442	23.3	5,570	75.44	3,955
Site 1	169,820,118	30.0	0.3929	25.5	5,095	66.73	4,326

Table 13 - Total Loading Determination for July 9, 2013 Rain Event

RESULTS

Sample Rain Event Analysis

The data in *Table 11* is a sample of the water quality analysis for the CD 57 system following the above methodology. This sample is from the same July 9, 2013 rain event used previously for analysis in which a 1-hour, 1.29-inch rainfall event occurred. Raw water quality concentrations for TSS, TP, and TN for this event are shown for each station in *Table 11*.

Using the same approach for flow data for stations 5, 4, 2, and 1, flow volumes were tabulated as shown in *Table 12*.

The raw water quality data and flow volumes from each of the above listed rain event can be combined to determine a total loading of TSS, TP, and TN. This can be done by multiplying the raw concentrations of TSS, TP, and TN by the total volume for each rain event at each location. *Table 13* summarizes the total loading for each parameter and each site for the July 9, 2013 rain event.

The total loading upstream of each BMP was compared to the total loading downstream of the BMP. For the Klein Pond, the total loading upstream included Sites 12, 9, and 8 and 7 while the downstream loading included Site 5. For the two-stage ditch, the total upstream loading included Site 5 while the downstream included Site 4. For the rate control weir, the total upstream loading includes Site 2 while the downstream includes Site 1. *Table 14* summarizes the total loading upstream and downstream of each BMP.

STATION	TOTAL TSS LOADING (kg)	TOTAL P LOADING (kg)	TOTAL N LOADING (kg)
Upstream Klein Pond	1,465	19.27	1,415
Downstream Klein Pond/ Upstream Two-Stage Ditch	654	19.20	992
Downstream Two-Stage Ditch	618	18.20	947
Upstream Rate Control Weir	5,570	75.44	3,955
Downstream Rate Control Weir	5,095	66.73	4,326

Table 14 - July 9, 2013 Total Loading Summary

Figure 58 shows the total loading results for the July 9, 2013 rain event.

The total loading removed by each BMP is the difference between the upstream and downstream loading of each BMP. *Figure 59* shows the removed amounts of TSS, TP, and TN for each BMP during the July 9, 2013 rain event.

Accumulated Loading

The total accumulated loading for TSS, TP, and TN was determined for each year. *Figures 60-62* show the total accumulated loading for TSS, TP and TN for years 2012 to 2014. Since the Klein Pond had significantly more total loading, two separate axis were used to show the results.

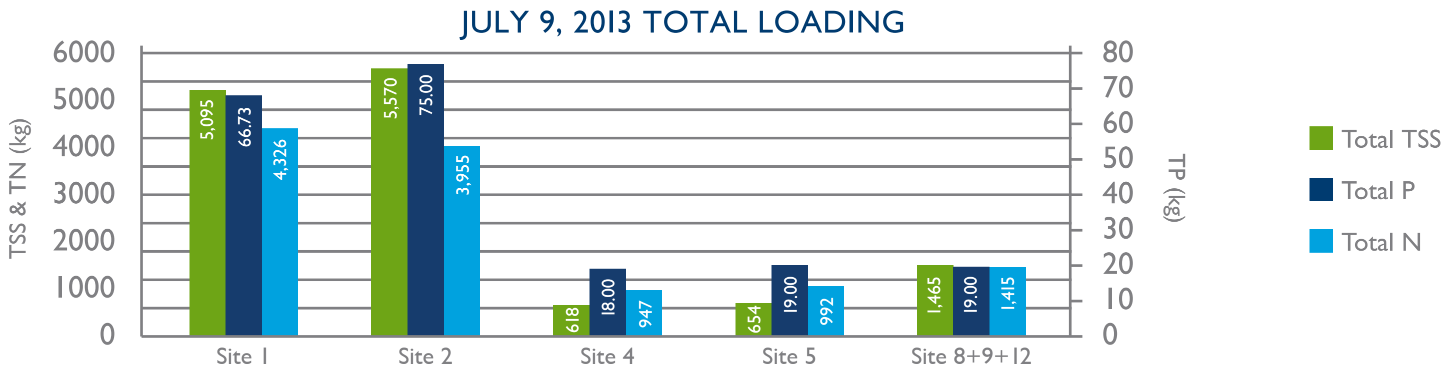


Figure 58 - July 9, 2013 Rain Event Total Loading

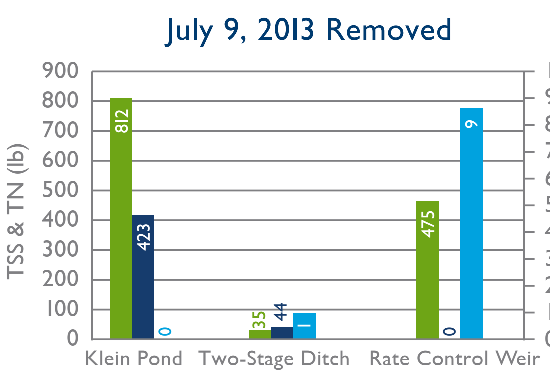


Figure 59 - July 9, 2013 Rain Event Total Loading Removed

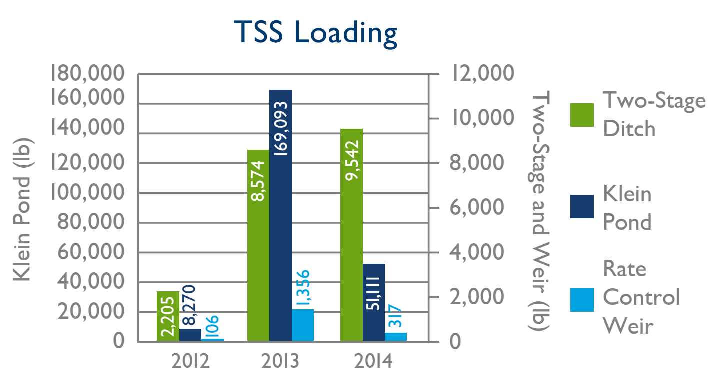


Figure 60 - Total Loading by Year for TSS

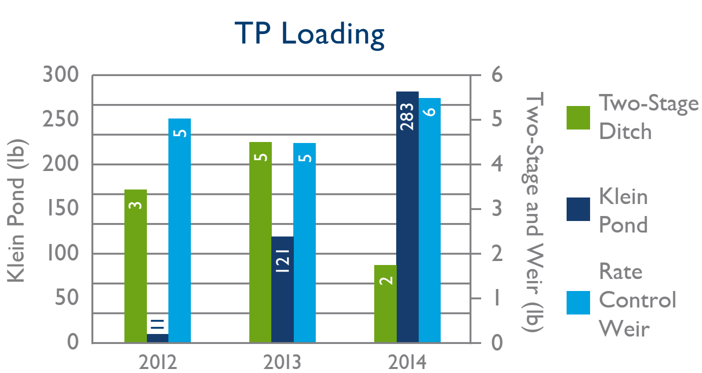


Figure 61 - Total Loading by Year for TP

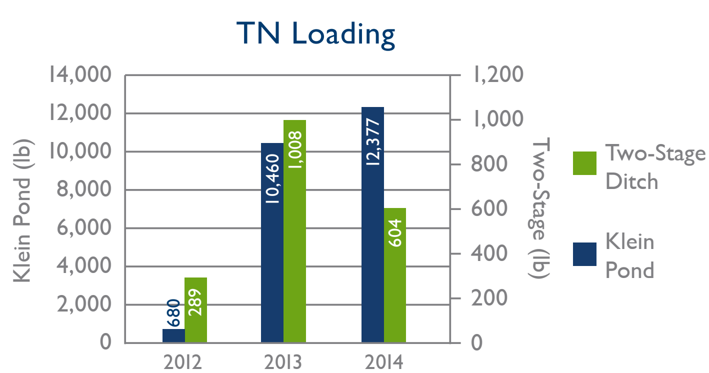


Figure 62 - Total Loading by Year for TN

ANALYSIS

The total loading for each parameter increases for each site moving downstream (*Figure 58*). This is as expected since as the ditch moves downstream, the watershed area and flow increase. However, it is noticeable that after the water passes a BMP, the total loading decreases, thus showing that the BMPs are reducing the loading of TSS, TP, and TN (*Figure 58*).

The Klein pond was most effective at reducing TSS and TN while the rate control weir was most effective at removing TP (*Figure 59*) for the July 9, 2013 rain event. The rate control weir did not see a reduction in TN for this rain event and for all sampled rain events. This is due to a large volume of water drained through county tiles is added, likely carrying the high concentrations of nitrogen. Nitrogen is always present in water. Unless a high retention time occurs on this water, the loading is not expected to be reduced when compared to the rate control weir.

The Klein Pond removed the most sediment in 2013 (*Figure 60*). This was expected as flow rates were closer to average when compared to the very low flows of 2012, and high flows and flooding of 2014. Like the Klein Pond, the rate control weir had the highest TSS removals for 2013, as the flow rates were more typical than the other two years. Also shown is that the two-stage ditch was more effective at removing sediment during 2014 than the other years. This is likely due to the outer benches of the two-stage ditch acting as a floodplain more often than the previous two years since there was more flow and flooding. This validates the effectiveness of the benches.

The Klein Pond was more effective at removing TP during 2014 than the other two years (*Figure 59*). This is contrary to the removals of TSS for the Klein Pond and may be due to the large flooding that occurred in the agricultural fields when more phosphorus bound soil particles had the opportunity to be removed. The two-stage ditch saw the highest removals for TP and TN during 2013 when flow were more average. This shows that the two-stage ditch is most effective at removing nutrients during average flows.

Topographic Survey

In November of 2014, a topographic survey was completed of the Klein Pond to compare the analytical data of accumulated sediment to what physically was occurring in the pond. The topographic survey compared the ground surface elevation of 2014 to the constructed elevation of the pond in 2012. From this survey, there was a volume difference of 725 cubic yards of material in the Klein Pond from the as-built to the 2014 survey. This was the amount of sediment that has accumulated in the pond and proves the effectiveness of the Klein Pond in removing sediment from the ditch.

To compare this value to what was monitored; the accumulated loading for TSS in the Klein Pond was used to approximate the volume of sediment in the pond. This was done by using and the wet density of sediment and multiplying that by the total accumulated TSS volume for each year. The wet density of sediment for the Klein Pond was sampled and analyzed to be 130 lb/ft3. *Table 15* summarizes the total sediment removed each year by the Klein Pond.

YEAR	TOTAL TSS (lb)	APPROXIMATED SEDIMENT (CY)
2012	8,270	5
2013	169,100	50
2014	51,200	15
Total	288,600	70

Table 15 - Total Accumulated Sediment in Klein Pond

By adding up the 2012, 2013, and 2014 analytical TSS removals based on flow data and TSS concentrations, a total of 70 cubic yards of estimated sediment was removed. This number is less than the actual surveyed volume; however, multiple ambiguities need to be considered. First, the analytical data for TSS removed was taken for rain events larger than 1 inch, which is roughly 40 percent of the rainfall that occurred from 2012 to 2014. Therefore, it is likely that more sediment accumulated than what was sampled from 2012 to 2014. Second, the grab samples were taken after the 1 inch rain events during the peak flow of the system. Studies have shown that TSS concentrations are much higher prior to, rather than at the peak flow, suggesting that the TSS grab samples performed in this monitoring may not have been the highest concentration of each rain event. This suggests that it is possible that even more TSS would have been removed based on the analytical analysis. Third, Site 7 was sampled near the pond which contained already clean water. Therefore, the concentration is likely higher entering the pond than what was sampled. Fourth, during the 25 year event of 2013, a 20 foot portion of the ditch upstream of the Klein Pond completely washed away and the sampling for this event occurred at a later time. Accounting for these items, it is very likely that the method used to determine the total accumulated sediment in the pond is an accurate depiction of its removal potential, based on the 2014 topographic survey.

Another method for determining the total accumulated sediment is based on the water chemistry data from Site 7, which is immediately upstream of the pond and is considered part of the pond due to the geometry and hydrology of the ditch. The total loading at Klein Pond was calculated for three years (*Table 16*).

YEAR	TOTAL TSS (lb)	APPROXIMATED SEDIMENT (CY)
2012	17,000	5
2013	713,200	205
2014	309,300	90
Total	1,024,200	300

Table 16 - Total Accumulated Sediment in Klein Pond based on site 7 Loading

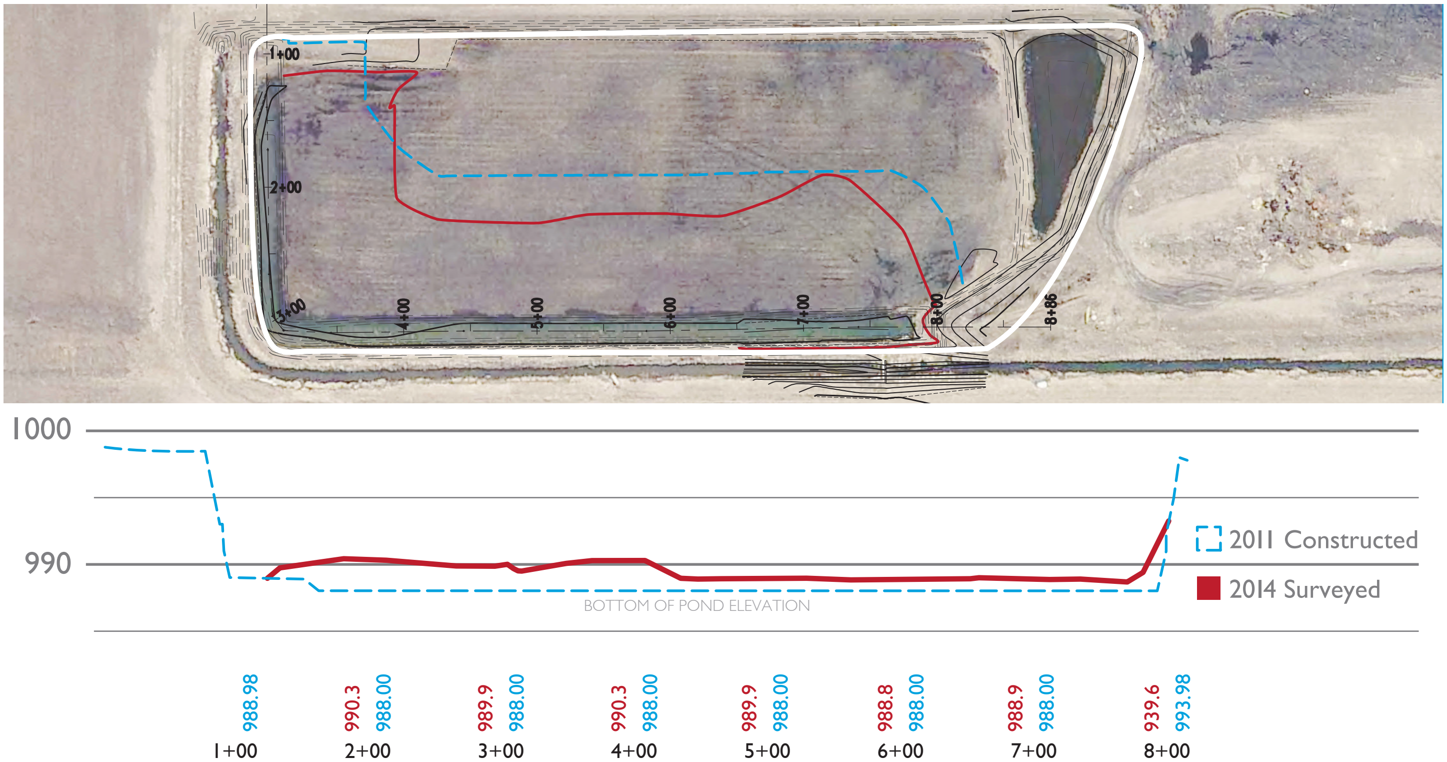


Figure 63 - Klein Pond Profile

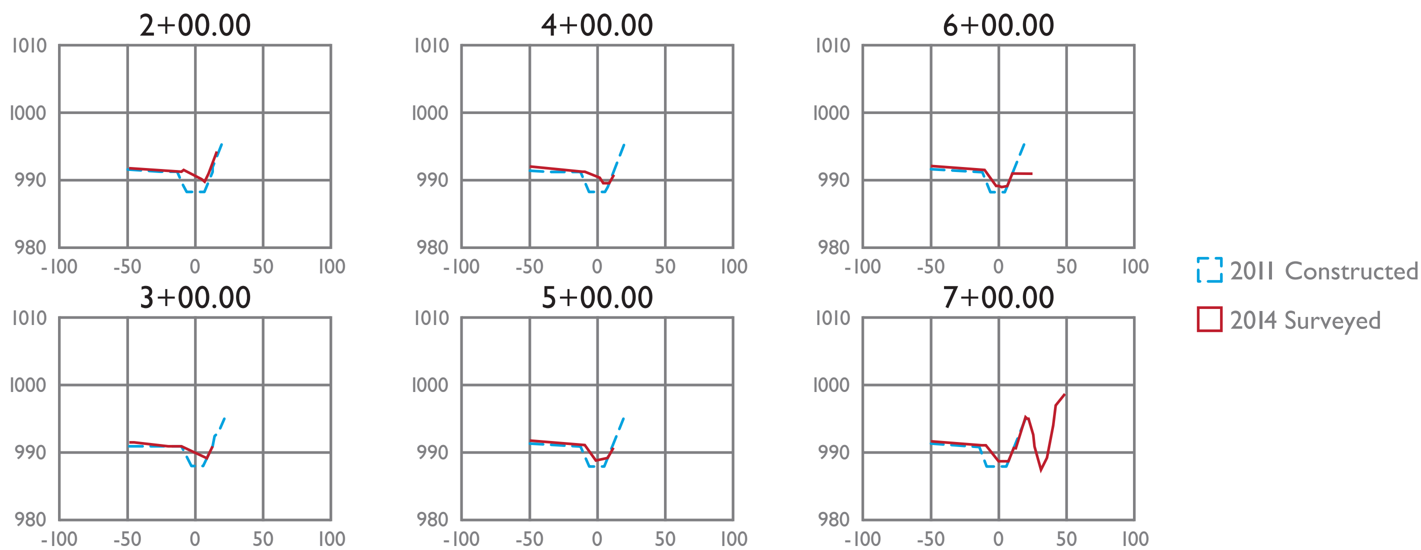


Figure 64 - Klein Pond Cross Sections

STATION	TOTAL TSS LOADING (kg)	TOTAL P LOADING (kg)	TOTAL N LOADING (kg)	PEAK FLOW RATE (cfs)
Upstream Klein Pond	1,465	19.27	1415	28
Downstream Klein Pond/ Upstream Two-Stage Ditch	654	19.20	992	22
Downstream Two-Stage Ditch	618	18.20	947	30
Upstream Rate Control Weir	5,570	75.44	3,955	75
Downstream Rate Control Weir	5,095	66.73	4,326	67

Table 15 - July 9, 2013 Total Loading and Peak Flow Summary

REDUCTIONS

THEORY

In recent years, more emphasis has been put on drainage and water quality in regards to sediment and nutrient loading (MPCA, 2012). Higher concentrations of these have been linked to poor water quality in downstream waters including eutrophication in streams, rivers, and lakes which in turn leads to algal blooms, oxygen depletion, and poor wildlife habitat for fish and waterfowl. Hypoxia and low oxygen conditions have also been linked to poor downstream water quality from these concentrations. Therefore, reducing the loading of sediment, phosphorus, and nitrogen is a key component impacting water quality.

Quantifying BMPs effectiveness in reducing these parameters helps to prove the effectiveness of each BMP in terms of its impact on water quality. It is challenging to visualize the physical amount of reduction for TSS, TP, and TN. Therefore, representing the reduction by a percentage is easier to quantify. *Equation 9* describes the calculation for determining the percent reduction of a BMP.

Equation 9

$$\text{Parameter Reduction}\,(\%) = \frac{\text{Influent Loading - Effluent Loading}}{\text{Influent Loading}} * 100\%$$

Similarly, the peak flow reduction for the rate control weir and Klein Pond can be calculated using *Equation 10*. Peak flow reduction for the two-stage ditch was not considered since its design and function is not to reduce peak flows.

Equation 10

$$\text{Peak Flow Reduction}\,(\%) = \frac{\text{Inlet Peak Flow Rate} - \text{Outlet Peak Flow Rate}}{\text{Inlet Peak Flow Rate}} * 100\%$$

METHODOLOGY

Parameter reductions were determined using *Equation 9* for each sampled rain event from 2012 to 2014 for TSS, TP, and TN. Peak flow reductions were determined using *Equation 10*.

The total loading and peak flow rates from the July 9, 2013 rain event were documented for five key stations (*Table 15*).

Calculating the percent reduction of TSS, TP, and TN for the Klein Pond is as follows using *Equation 9*.

$$\text{TSS Reduction}\,(\%) = \frac{1465\text{ kg} - 654\text{ kg}}{1465\text{ kg}} * 100\% = 55\%$$

$$\text{TP Reduction}\,(\%) = \frac{19.27\text{ kg} - 19.20\text{ kg}}{19.27\text{ kg}} * 100\% = 1\%$$

$$\text{TN Reduction}\,(\%) = \frac{1415\text{ kg} - 922\text{ kg}}{1415\text{ kg}} * 100\% = 30\%$$

Similarly for peak flow rate reduction for the Klein Pond using *Equation 10* results in the following.

$$\text{Peak Flow Reduction}\,(\%) = \frac{28\text{ cfs} - 22\text{ cfs}}{28} * 100\% = 21\%$$

This process was repeated for all four parameters for each sampled rain event from 2012 to 2014.

RESULTS

The percent reduction in TSS, TP, TN and Peak Flow were tabulated for each BMP for the July 9 rain event (*Table 16*). Each BMP and the associated reduction (%) for the July 9, 2013 1.29-inch rain event were tabulated to determine their effectiveness (*Figure 65*). The average reductions during three separate years for the Klein Pond, Two-Stage Ditch, and Rate Control Weir were measured to determine their effectiveness (*Figures 66-68*). Combining these three years of water quality monitoring, the overall average reductions for each BMP was determined (*Figure 69*).

BMP	TSS PERCENT REDUCTION (%)	TP PERCENT REDUCTION (%)	TN PERCENT REDUCTION (%)	PEAK FLOW REDUCTION (%)
Klein Pond	55	1	30	21
Two-Stage Ditch	5	5	4	no reduction
Rate Control Weir	9	12	0	11

Table 16 - July 9, 2013 Total Loading and Peak Flow Summary

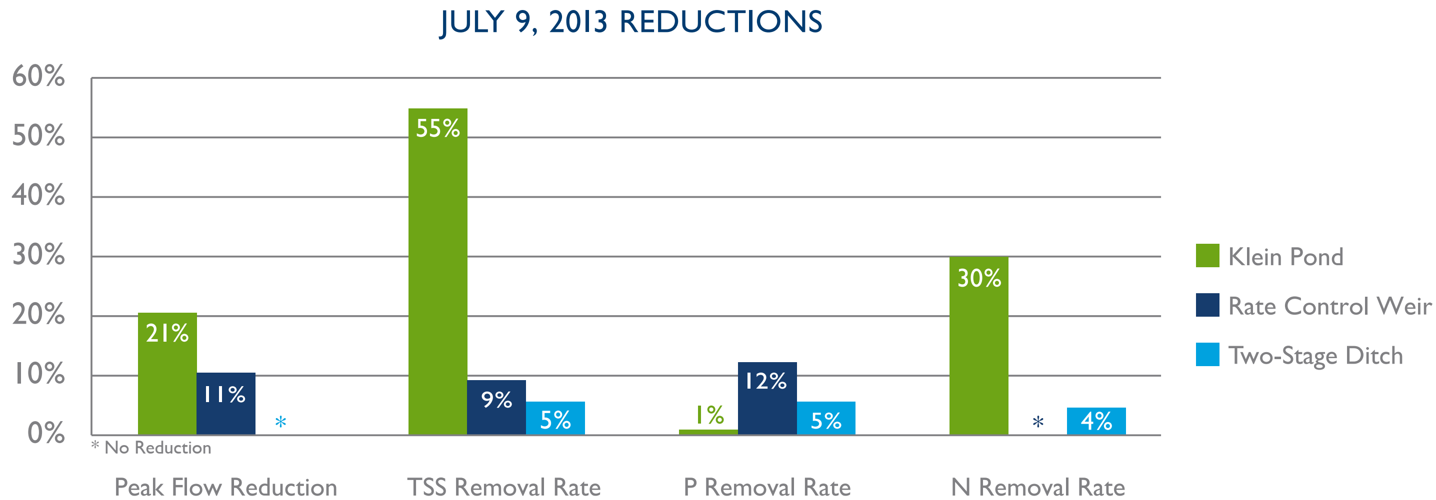


Figure 65 - 2014 Rainfall and Runoff Comparison

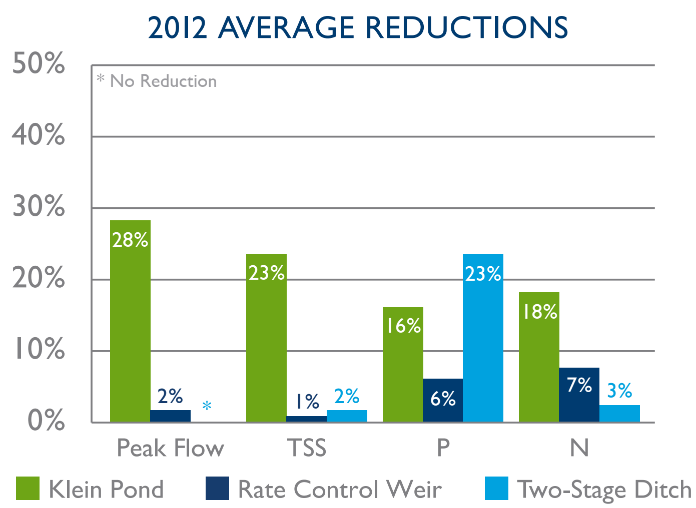


Figure 66 - 2012 Average Reductions from BMPs

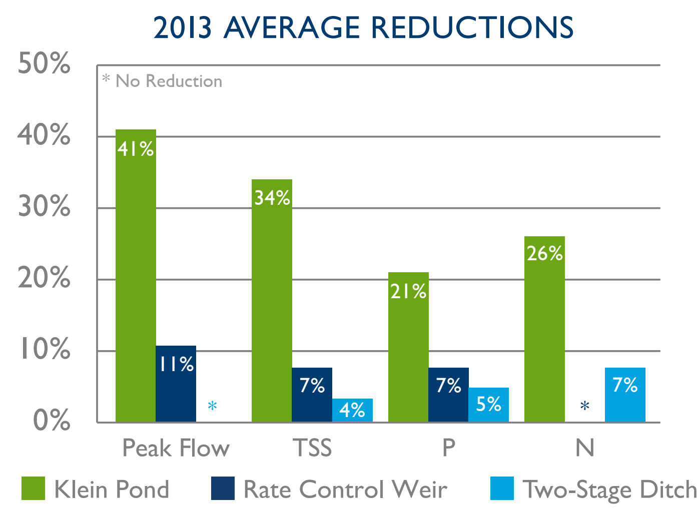


Figure 67 - 2013 Average Reductions from BMPs

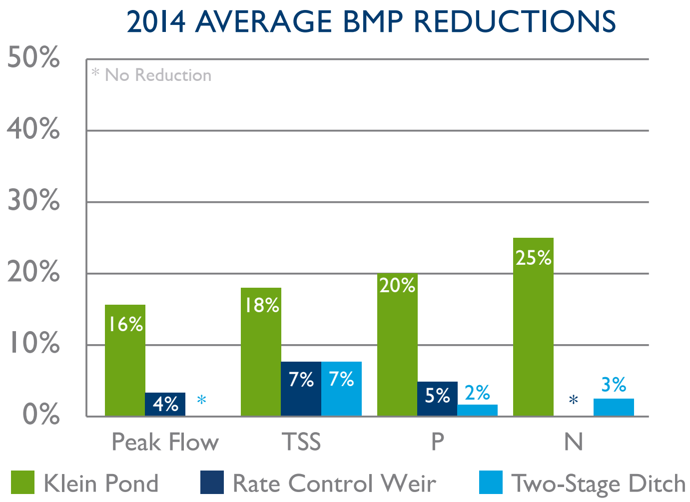


Figure 68 - 2014 Average Reductions from BMPs

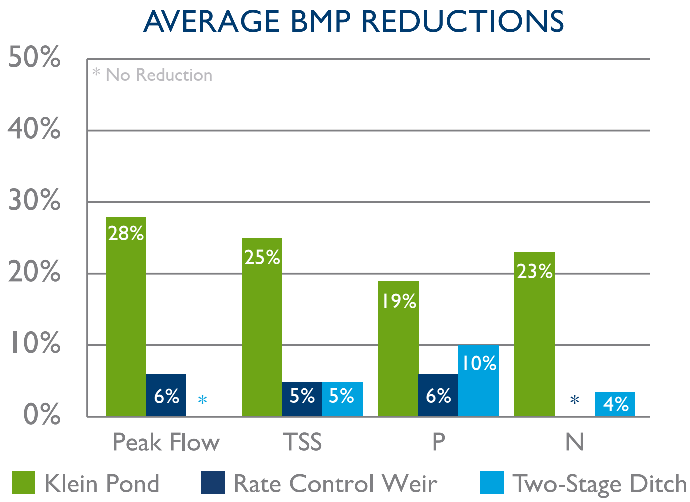


Figure 69 - Three Year Average Reductions from BMPs

ANALYSIS

The above methodology shows how effectiveness was determined for each BMP analyzed. This includes determining the load reduction for the parameters of TSS, TP and TN before and after each BMP. This is related to water quality as it shows the percentage of how much of each pollutant is reduced.

The three year averages for overall effectiveness of the three BMPs analyzed resulted in reductions of all three pollutants. Based on percent reductions, the most effective BMP was the Klein Pond, followed by the two-stage ditch and rate control weir. This can in turn be linked to peak flow reduction and storage. The Klein Pond has the most storage in the entire system at 26.3 acre-feet while the rate control weir provides 6.0 acre-feet of storage. The two-stage ditch does provide storage for a length 1,409 feet of the ditch, however it has a large (54 inch) outlet which does not reduce the flow as effectively as the rate control weir and Klein Pond. The two-stage ditch received added flows from a large watershed with untreated water, yet it still reduced pollutant loading.

While the rate control weir was designed to reduce peak flow rates, it also reduced TSS and TP loading. This had a benefit on the water quality of the system and further suggests that lowering peak flow rates has a positive effect on improving water quality.

The two-stage ditch were lower when compared to Klein Pond for the percent reductions in TSS, TP, and TN. This may or may not be an accurate depiction of the water quality benefits of a two-stage ditch. The two-stage ditch was located immediately downstream of the Klein Pond, thus it was receiving water that was already treated for TSS, TP, and TN. Also, a county tile branch line discharges into the end of the two-stage ditch, draining an area of 500 acres. The water draining into this point does not flow across the entire length of the two-stage ditch, thus may not have the potential to remove sediment and nutrients. However, with all these considerations and ambiguities, it is a major benefit to this system that the two-stage ditch did show notable water quality benefits.

The results for the analysis show that individually the BMPs are effective. While it was anticipated that these BMPs would improve water quality, there was not prior data indicating the extent of their effectiveness. The water quality goal was to reduce pollutant loading and this analysis showed that the BMPs substantially reduced pollutant loading, exceeding expectations. The approach of combining multiple BMPs in a drainage system can maximize the potential benefits of treating agricultural run-off while still increasing the capacity of the system.

CITY RUNOFF

THEORY

All watersheds have vary in terms of soils, hydrology, land cover, and many more parameters. The CD 57 watershed is consistent in soils, topography, and land cover, however a small portion of the watershed is occupied by the City of Mapleton. This portion of the watershed contains impervious surfaces which lead to urban runoff. Urban runoff typically contains more runoff due to the lower infiltration rates and impervious surfaces. It also primarily contains inorganic solids in the

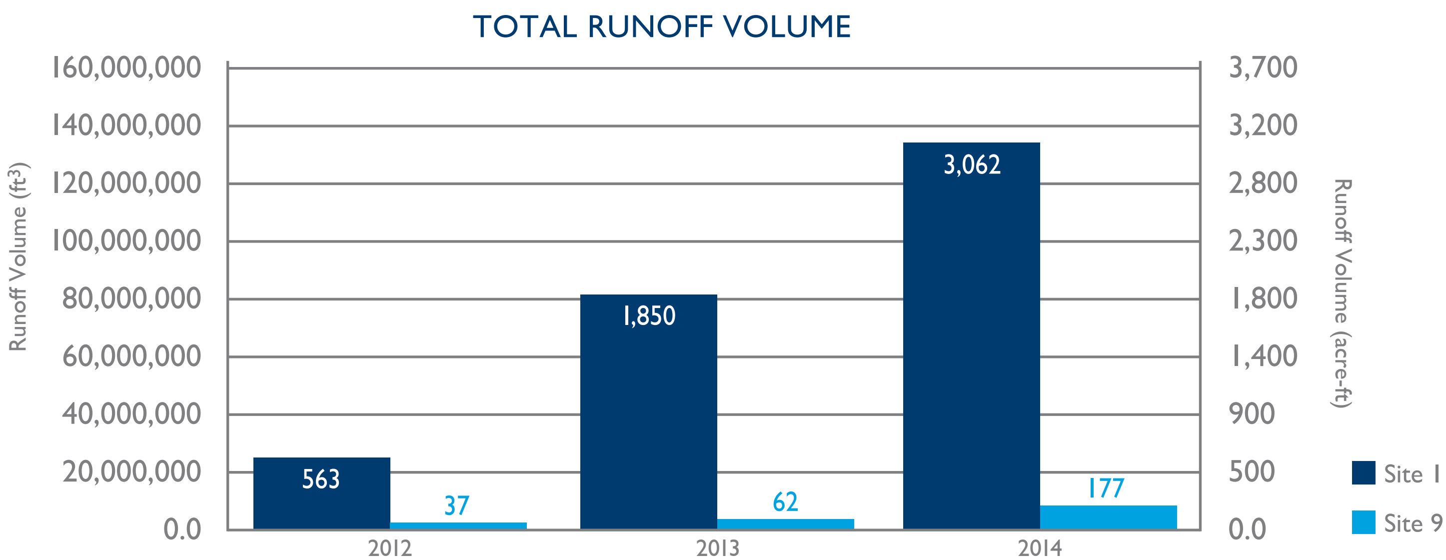


Figure 70 - Urban Runoff and Total Runoff Comparison

runoff such as grit, sand, and gravel.

Flow from urban runoff is primarily routed through storm sewers such as catch basins, manholes, and underground pipe networks. It is typically contained through detention and retention ponds, in which the runoff is stored and released slowly to reduce flooding.

Urban runoff from the City of Mapleton includes 425 acres and is routed through a storm sewer system. The City of Mapleton discharges to the CD 57 system in three locations. Two small stormwater ponds serving a small residential development in the northwest portion of the City discharge to the open ditch to the east of TH 22. The majority of urban runoff (400 acres) is routed through the City Pond and outlets into the open ditch south of TH 30. As part of a routine maintenance, the City of Mapleton discharges treated wastewater from the treatment lagoons to the open ditch twice a year in the east of TH 22.

METHODOLOGY

While the majority the water quality sampling and analysis dealt with agricultural runoff, it is important to compare the runoff from the urban and rural landscapes. Monitoring of urban runoff was limited, but included monitoring stage and water chemistry at the outlet of the pond in a storm manhole. Do to the limited monitoring, the best way to analyze the urban runoff is by comparing the percentage of total volume of runoff and total loading impact that the city runoff has on the entire watershed runoff. This was done by utilizing the flow volume (**Section 9**) and loading (**Section 12**) methods presented previously for Site 9 and Site 1, corresponding to the City Pond and watershed outlet.

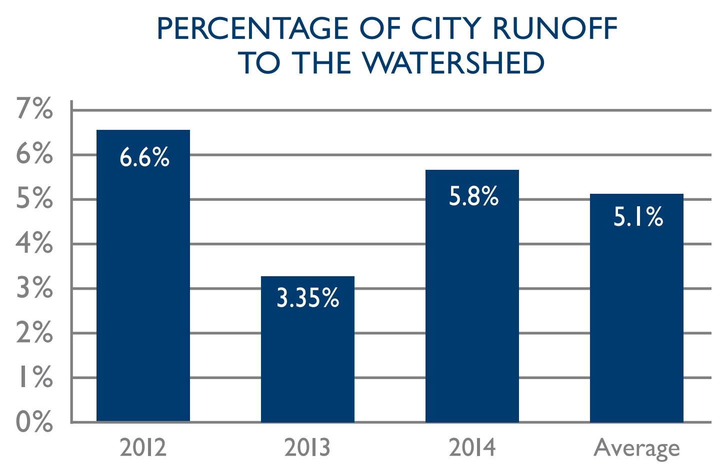


Figure 71 - Urban Runoff and Total Runoff Comparison as Percentage

RESULTS

The total runoff for all three years of monitoring is shown for the City runoff and the runoff from the entire watershed (*Figure 70*). Site 1 contains the flow volume from the entire watershed while Site 9 contains flow volume from the City runoff.

As expressed in a percentage, the urban runoff from the City compared to the entire watershed is shown in *Figure 71*.

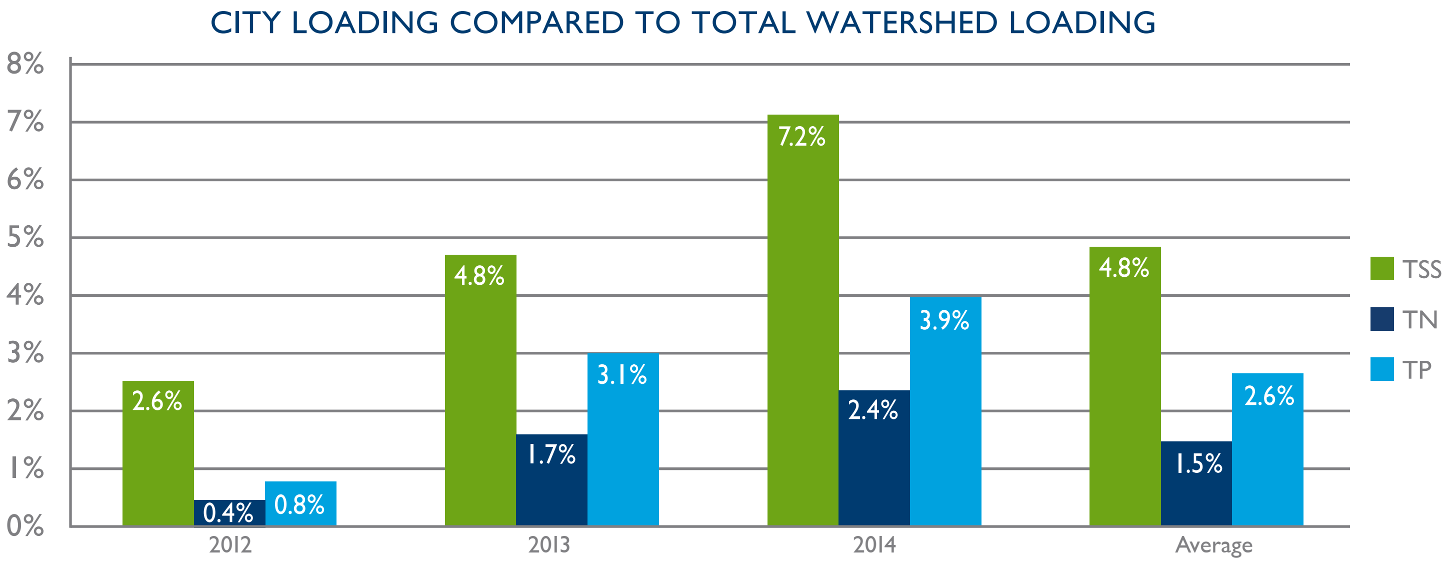


Figure 72 - Urban Loading Compared to Total Watershed Loading

* Does not include wate water treatment pond

The total loading of TSS, TP, and TN for all three years of monitoring is shown for the City runoff and the runoff from the entire watershed (*Figure* 72). The percentage of loading that the City contributes to the entire watershed is broken down by year and averaged.

ANALYSIS

As shown in *Figure 71*, on average the City contributes to only 5 percent of the total runoff to the entire watershed. This is as expected as the City watershed contributes to only 7 percent of the total watershed. The City Pond also stores all of the runoff and slowly releases it overtime. Some of this water is lost through evaporation and evapotranspiration while a portion is retained for the ponds maintained water level.

On average, the City contributes less than 5 percent of the pollutant loading to the watershed (*Figure* 72). The TSS loading contributed the most compared to the entire watershed over TP and TN. This is as expected since the majority of the runoff from urban watersheds contains solids such as grit, sand, and gravel.

The wastewater lagoons discharge directly into the open ditch twice a year. Water quality sampling was not performed at the time of sanitary discharge, therefore an analysis cannot be made on its impacts to the CD 57 system. Wastewater treatment systems are have strict water quality regulations. The City of Mapleton's lagoons have been in place and regulated for more than 25 years.

It is difficult to compare the water quality of the urban runoff to the agricultural runoff as pollutants, monitoring methods, and water quality standards are significantly different. Since urban runoff is part of the CD 57 watershed, there is an impact to water quality. However, to what extent can only be speculated. As shown in the results, the total volume and loading is insignificant compared to the rest of the watershed. A further study including sampling, monitoring, and analysis is needed to fully interpret the impacts that the urban runoff has to the CD 57 watershed.

BASEFLOW DATA COMPARISON

THEORY

River systems in southern Minnesota are comprised of watersheds that are heavily tiled by agriculture and comprised of multiple ditch systems. The geomorphology (soils) are comprised of heavy clay tend to hold water, which drain out over time. Cumulatively, these systems contribute to the baseflows that feed the rivers. Improving water quality during baseflow in ditch systems would improve the overall quality of the river.

While the main function of the ditch during high flows is to effectively drain the landscape for agricultural production, it also serves a function during low flow as an important habitat for wildlife. During low flow a variety of wildlife species including fish, reptiles, birds and small mammals utilize the hydrology effects of a ditch system. Healthy water quality with low pollutant loading is a major contributor to providing optimum conditions for wildlife habitat.

Figure 73 - Pre-BMP Installation Water Quality Grab Sampling (ISG)

Figure 74 - Pre-BMP Installation Flow Sampling (ISG)

METHODOLOGY

While the pre-BMP installation data did not consist of monitoring water chemistry and flow after rain events, it did consist of water quality grab samples of baseflow conditions throughout the system. Baseflow samples were also taken post-BMP installation.

Pre-BMP Installation Monitoring Methods

Water Quality

All pre-BMP installation monitoring was performed by ISG with water quality samples analyzed by Minnesota Valley Testing Labs (MVTL). Water quality samples and flow data were collected from the thalweg (deepest continuous inline within a water channel) of the open water channel. Water quality grab samples were collected for: total suspended solids, fecal coliform, E. coli, nitrogen (nitrate + nitrite), total phosphorus, ortho-phosphate, and suspended volatile solids. Samplings were collected by facing a clean, sterile sampling bottle upstream into the flow to ensure no influence of disturbed water due to wading; facing upside down, and submerging elbow deep water and inverting the bottle until filled (*Figure 73*). Nutrient bottles (nitrogen- nitrates + nitrites, total Kjeldahl nitrogen, and total phosphorus samples) contain 5 mL of 10 percent H_2SO_4 solution for preservation purposes. The bottles were narrow mouth, high-density polyethylene natural cylinder bottles with plastic and poly-foam 19 lined caps. After collection, bottles were placed in a cooler with ice to keep samples at or below 4°C. Samples were then transported to MVTL in New Ulm, Minnesota within 24 hours for analysis. A chain-of-custody was filled out before and while samples were at MVTL.

Field water quality measurements (pH, temperature, conductivity, and total dissolved solids) were also collected and recorded at the site using a Hanna Instruments HI 98129 multi-probe meter. All probes were calibrated the day of sampling, before sampling began. The probe was held at an intermediate depth in the water column without disturbing substrate materials and remained there until the probe has stabilized the reading.

Flow

For the monitoring period prior to construction, flow measurements were obtained for a cross section of the channel at each of the three monitoring locations. Flow was measured using the Pygmy Flow meter according to methodology described in Harrelson et al. (1994). Flow was measured at the same sampling location (identified by GPS) and was primarily recorded during baseflow conditions due to the hazard of sampling after rain events. To measure flow, a tape was spread from one side of the stream bank to the other. The tape was secured above the surface and pulled taught. The entire distance of the channel was recorded. Depth and velocity are recorded beginning at the edge of the bank where it meets the water (Harrelson et al. 1994). If no water was present at this location, 'no flow' was marked and subsequent measurements were taken at every 10 cm along the tape (Harrelson et al. 1994). The velocity measurements were converted to discharge using the formula provided by the manufacturer. *Figure 74* shows pre-BMP installation flow measurements in the open ditch portion of the system.

Post-BMP Installation Monitoring Methods

Post-BMP installation monitoring methods were described in the **Monitoring Section, Page 8**.

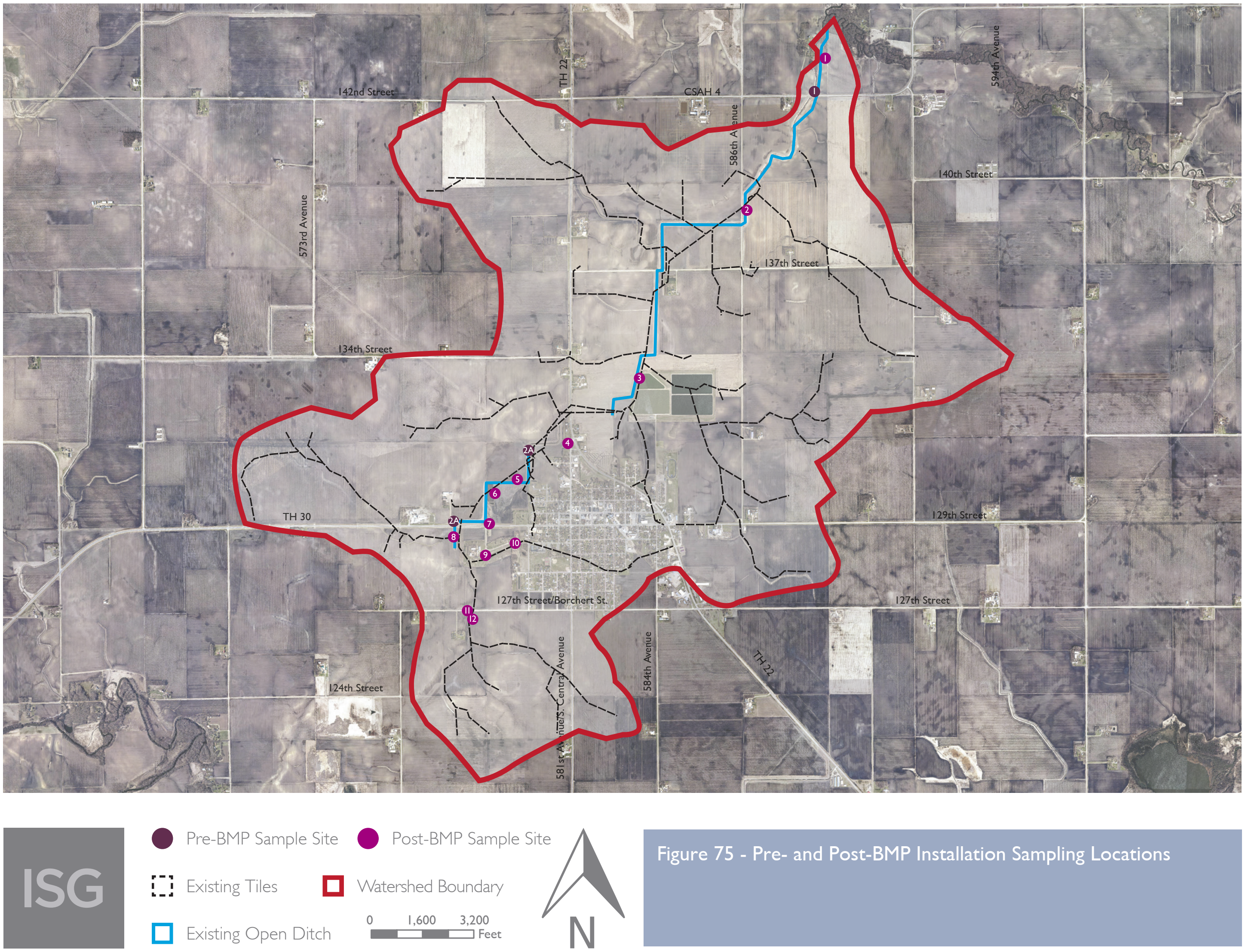


Figure 75 - Pre- and Post-BMP Installation Sampling Locations

PRE-CONSTRUCTION	POST-CONSTRUCTION
3/18/2010	7/17/2012
4/28/2010	7/26/2013
5/19/2010	8/9/2013
7/28/2010	5/22/2014
	7/16/2014

Table 17 - Baseflow Sample Dates

Pre- & Post- BMP Installation Data Comparison

There was limited pre-installation data from rain events, therefore the majority of flow data collected was similar to the post-BMP baseflow. In order to document changes in ditch water quality over time, baseflow samples from both pre-BMP installation and post-BMP installation were compared. Baseflow samples for pre- and post-BMP installation were collected (*Table 17*). These samples did not occur after a rain event and were taken when the stage of the entire ditch was relatively low.

Pre-construction baseflow samples were taken from three sites throughout the CD 57 watershed (sites 1, 2A and 2B). These sites were near the post construction monitoring locations of the rate control weir (1), after two-stage ditch (4), and before the Klein Pond (7). Therefore, these three locations were used to compare pre- and post-BMP installation baseflow water quality. Although flow data was taken for each baseflow sample, an overall volume of TSS, TN, and TP were not compared since no peak in flow rate occurred. The pre- and post-BMP installation sampling locations are identified on a map of the CD 57 system (*Figure 75*).

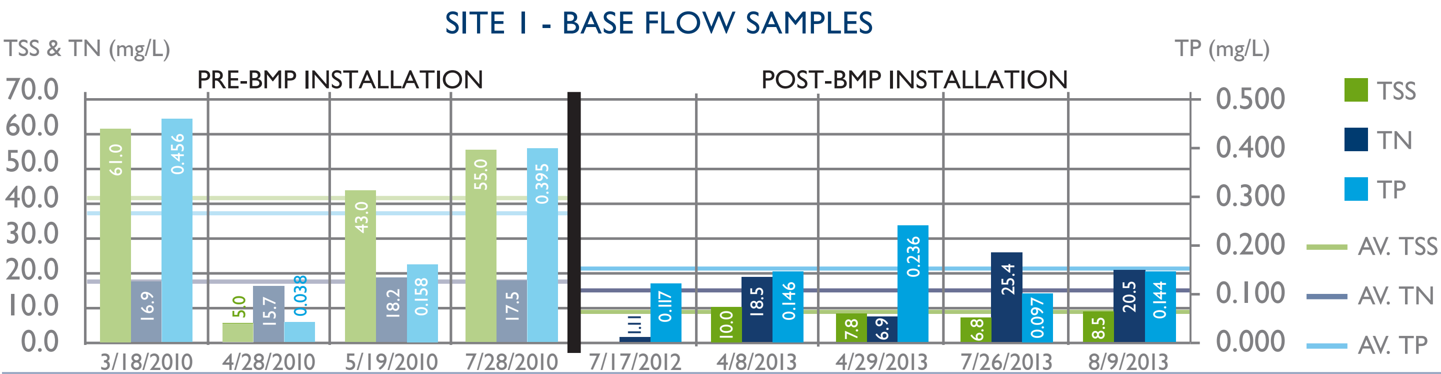


Figure 76 - Rate Control Weir: Site 1 Baseflow Samples

TSS Reduction = 33% TN Reduction = 3% TP Reduction = 12%

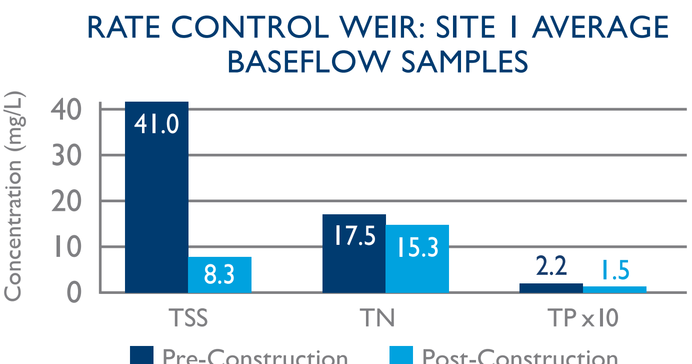


Figure 77 - Rate Control Weir: Site 1 Average Baseflow Samples

RESULTS

Site 1: Rate Control Weir

Both the pre-BMP installation and post-BMP installation baseflow samples at the rate control weir (Site 1) were compared (*Figure 76*). The pre-BMP installation was sampled near the location where the weir was installed while the post-BMP installation was sampled from the weir.

The average baseflow concentrations for TSS, TN, and TP for both the pre- and post-BMP installation samples at the rate control weir were compared (*Figure 77*). This shows the average concentration of each parameter sampled during baseflow events for the pre- and post-monitoring.

Site 4

Both the pre-construction and post-construction baseflow samples at the end of the two-stage ditch were compared (*Figure 78*). The pre-BMP

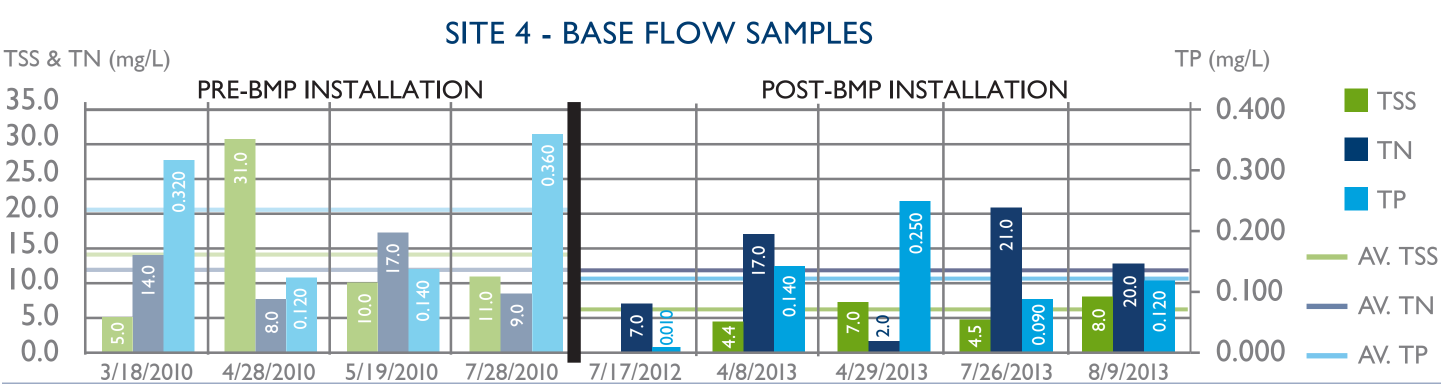


Figure 78 - Two-Stage Ditch: Site 4 Baseflow Samples

TSS Reduction = 9% TN Reduction = 0% TP Reduction = 10%

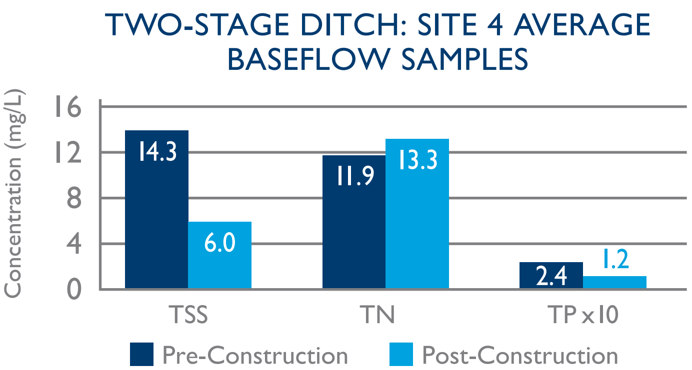


Figure 79 - Two Stage Ditch: Site 4 Average Baseflow Samples

installation was sampled at the end of the existing open ditch while the post-BMP installation was sampled at the end of the two-stage ditch.

The average concentrations for TSS, TN, and TP for both the pre- and post-construction samples at the end of the two-stage ditch (*Figure 79*). This shows the average concentration of each parameter sampled during baseflow events for the pre- and post-monitoring.

Site 7

The pre- and post-construction baseflow samples before the Klein Pond (Site 7) were compared (*Figure 80*). The pre-BMP installation was sampled north of TH 30 while the post-BMP installation was sampled upstream of the Klein Pond.

The average concentrations for TSS, TN, and TP for both the pre- and

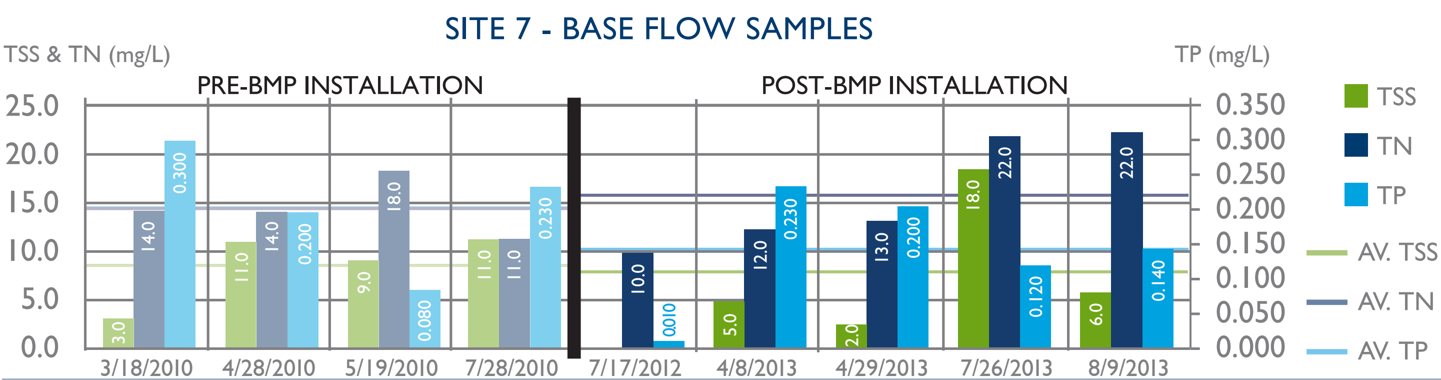


Figure 80 - Klein Pond: Site 7 Baseflow Samples

* No reduction in baseflow

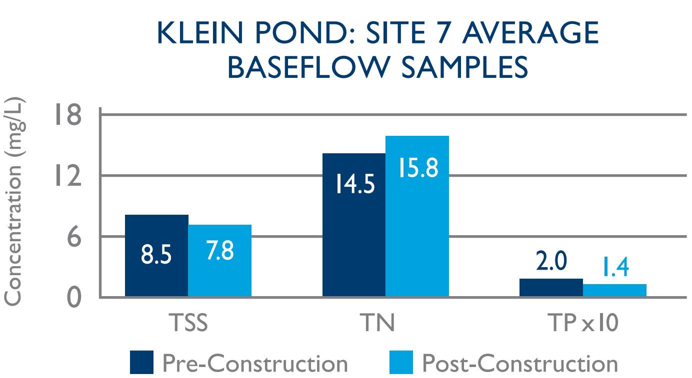


Figure 81 - Klein Pond: Site 7 Average Baseflow Samples

post-construction samples at the Klein Pond were compared (*Figure 81*). This shows the average concentration of each parameter sampled during baseflow events for the pre- and post-monitoring.

ANALYSIS

The baseflow results for the pre- and post-BMP installation were as anticipated. Sites 1 and 4 were downstream of the series of combined BMPs—considered a treatment train—including the Klein Pond, overdug ditch, two-stage ditch (Site 4), and rate control weir (Site 1). These BMPs were specifically designed to remove sediment from the water flowing through the system. As a result, overall concentrations of TSS and TP were lower for the post-BMP installation versus the pre-BMP installation. The majority of phosphorus traveling through the system is bound to sediment. Therefore, as sediment is removed from the constructed BMPs the concentration of TSS and TP also decreases.

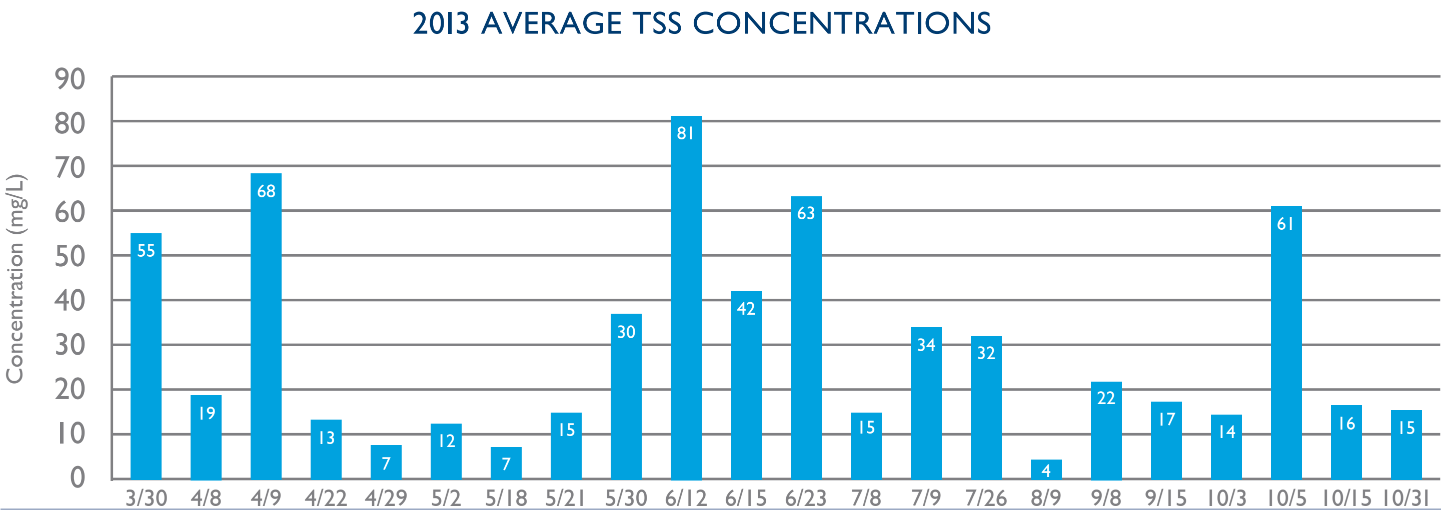


Figure 82 - Average TSS Concentrations for 2013

Nitrogen however, is not primarily attached to sediment particles and is dissolved into each water particle. Therefore, it is always present in drainage water and is expected to remain consistent as it travels downstream. The results shown by the Site 1 and Site 4 comparison supports this theory since the concentrations of both pre- and post-BMP installation samples for nitrogen were relatively consistent (*Figures 76-81*).

The results shown for the Site 7 pre- and post-BMP installation baseflow sampling were also as anticipated. The concentrations for all three parameters were nearly the same on average for this site (*Figure 81*). This sampling site is located before the BMP treatment train, thus the water at this point has not been treated for TSS, TP, and TN. This further supports the fact that the BMPs have a positive benefit for baseflow conditions.

While the major concern for sediment and nutrients in agricultural drainage systems occurs during peak runoff levels where TSS, TP, and TN concentrations are at their highest, it is important to analyze the baseflow conditions as well. The BMPs installed in this system were designed to reduce peak flow rates, thus reduce the loading of nutrients as well. This analysis contains data which supports the fact that these BMPs are both effective during rain events and peak flows, and are also effective during baseflow conditions. TSS and TP concentrations were significantly less during baseflow for the post-BMP installation sampling and thus can be attributed to the BMPs installed.

SEASONAL VARIATIONS

THEORY

It is anticipated that the CD 57 monitoring results had many seasonal variations for the analyzed parameters of TSS, TP, and TN. The beginning months of the growing season (April, May, and June) typically consist of wetter conditions with saturated soil and more flow in the ditch. With the higher runoff throughout the watershed and higher flow rates, it is anticipated the concentrations of these parameters are higher than later in the season when flow rates are lower.

METHODOLOGY

Each of the three monitoring years presented a variety of seasonal variations. Since rainfall varied significantly in depth, duration, and timing, seasonal variations throughout each year will be analyzed separately. For the sampled rain events, concentrations from each sampled site throughout the watershed were averaged. The averages were compared to all other average concentrations for each rain event.

RESULTS

The average TSS concentrations of all water chemistry sample sites for each sampled rain event for 2013 and 2014 were tabulated (*Figures 82-83*). The graphs show the average TSS concentration and the date it was sampled. In 2012, total dissolved solids (TDS) were sampled and not TSS, therefore, 2012 was left out of the analysis.

The average TP concentration of all water chemistry sample sites for each sampled rain event for the years 2012 to 2014 were tabulated (*Figures 84-86*). The graphs show the average TP concentration and the date it was sampled.

The average TP concentration of all water chemistry sample sites for each sampled rain event for the years 2012 to 2014 were tabulated (Figures 87-89). The graphs show the average TN concentration and the date it was sampled.

2014 AVERAGE TSS CONCENTRATIONS

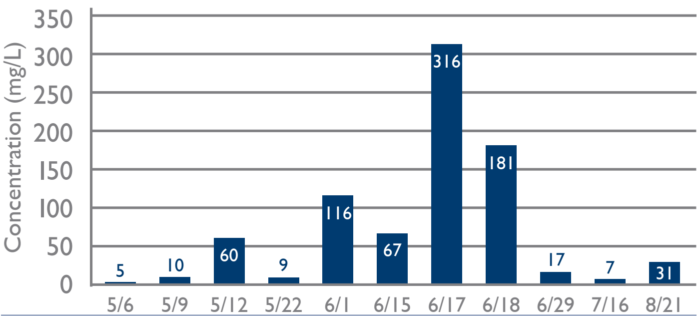


Figure 83 - Average TSS Concentrations in 2014

2012 AVERAGE TP CONCENTRATIONS

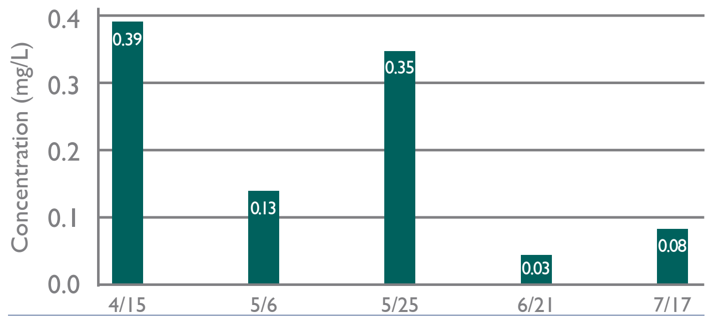


Figure 84 - Average TP Concentrations for 2012

2013 AVERAGE TP CONCENTRATIONS

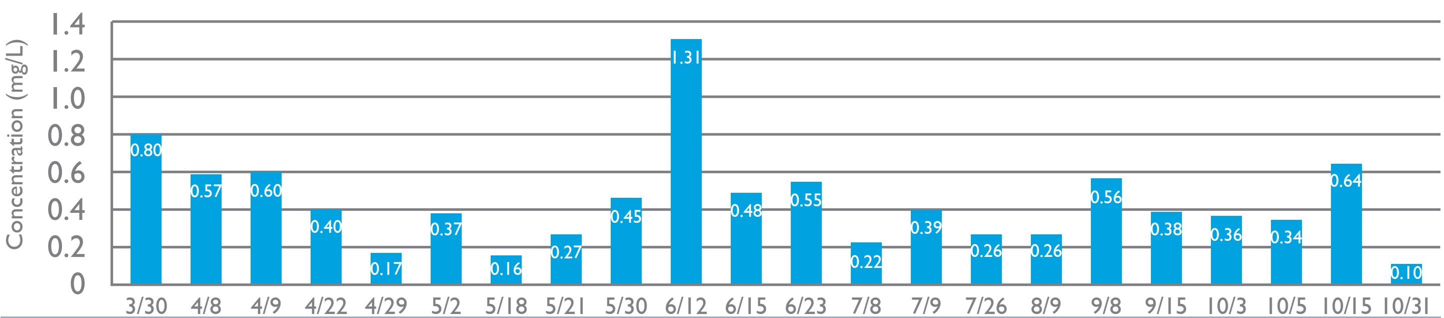


Figure 85 - Average TP Concentrations for July 2013

2014 AVERAGE TP CONCENTRATIONS

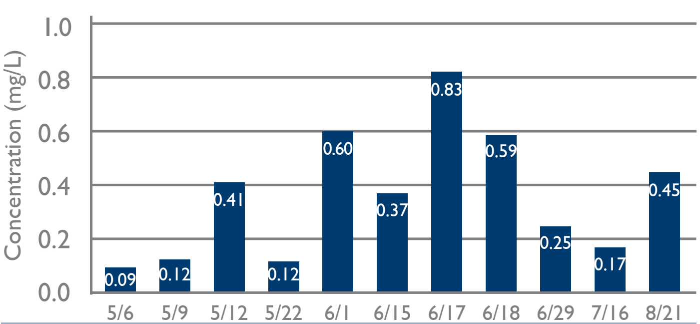


Figure 86 - Average TP Concentrations for 2014

2012 AVERAGE TN CONCENTRATIONS

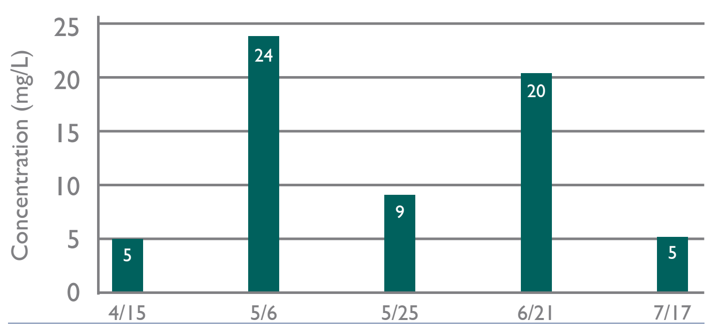


Figure 87 - Average TN Concentrations for 2012

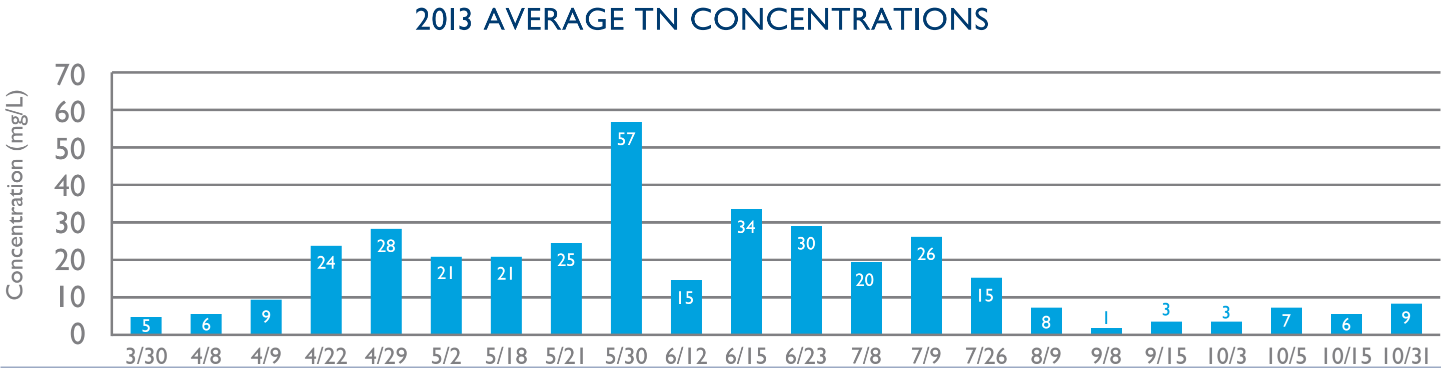


Figure 88 - Average TN Concentrations for 2013

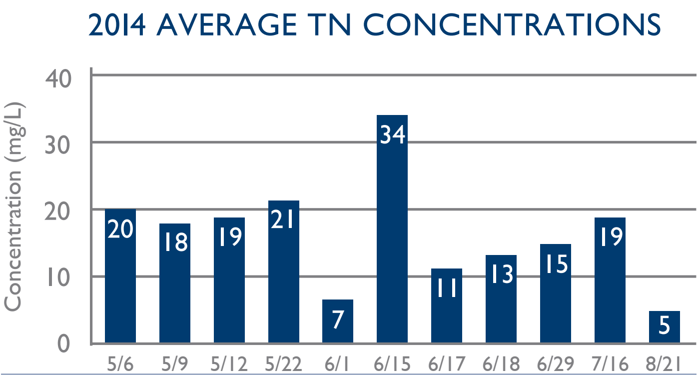


Figure 89 - Average TN Concentrations for 2014

ANALYSIS

In general, TSS concentrations follow the pattern of flow rate throughout the year. In spring and early summer when flow rates are higher, it is expected that TSS concentrations are high since more sediment is traveling through the system. In late summer and early fall as the flow rates decrease and in most cases shut off, TSS concentrations are expected to decrease. Therefore, it is expected that the seasonal variation is TSS follows the variation of flow with higher concentrations in the beginning of the year and tapering off later in the year.

In general, TSS concentrations from 2013 and 2014 followed the expected pattern. In 2013, higher average concentrations of TSS were sampled between mid-May and late July, however some events outside of this range also experienced a higher average TSS concentration. Late March, early April, and late October brought high average concentrations throughout the CD 57 system. This may be caused by the flow conditions of the system. Prior to these samples, the system was at a low or no flow stage. Therefore, with a sudden change in flow, settled sediment may have become suspended in the abrupt change in flow conditions.

The 2014 concentrations for TSS were almost exactly as expected. Flow patterns for this year begin moderately low with a major frequency of rain events in late June. As expected, with the high flows, higher TSS concentrations were recorded. As the year progressed into fall, flow rates diminished and with that, so did TSS concentrations.

Similar to the seasonal pattern of TSS, TP concentrations are also expected follow the same pattern as flow. Therefore, it is expected that average concentrations of TP are higher during spring and early summer when flow patterns are higher and concentrations are expected to diminish during late summer and early fall. The theory behind this is that the phosphorus is primarily bound to sediment as it travels through the system. Therefore, as TSS concentrations decrease, so do TP concentrations.

Average TP concentrations for 2012 gradually decreased throughout the monitoring season for the entire CD 57 system. During early April, high concentrations of TP were recorded and decreased until early May. During May, higher values of TP were recorded, but by the end of May TP values were decreasing and decreased through the rest of the summer. This corresponds to the flow through the system in 2012. After May, no significant rain events were recorded, thus allowing phosphorous bound sediment to remain out of suspension.

The 2013 and 2014 TP concentrations also followed the flow and TSS pattern throughout the year. TP concentrations in spring were relatively high and then peaked in June, corresponding to significant rain events.

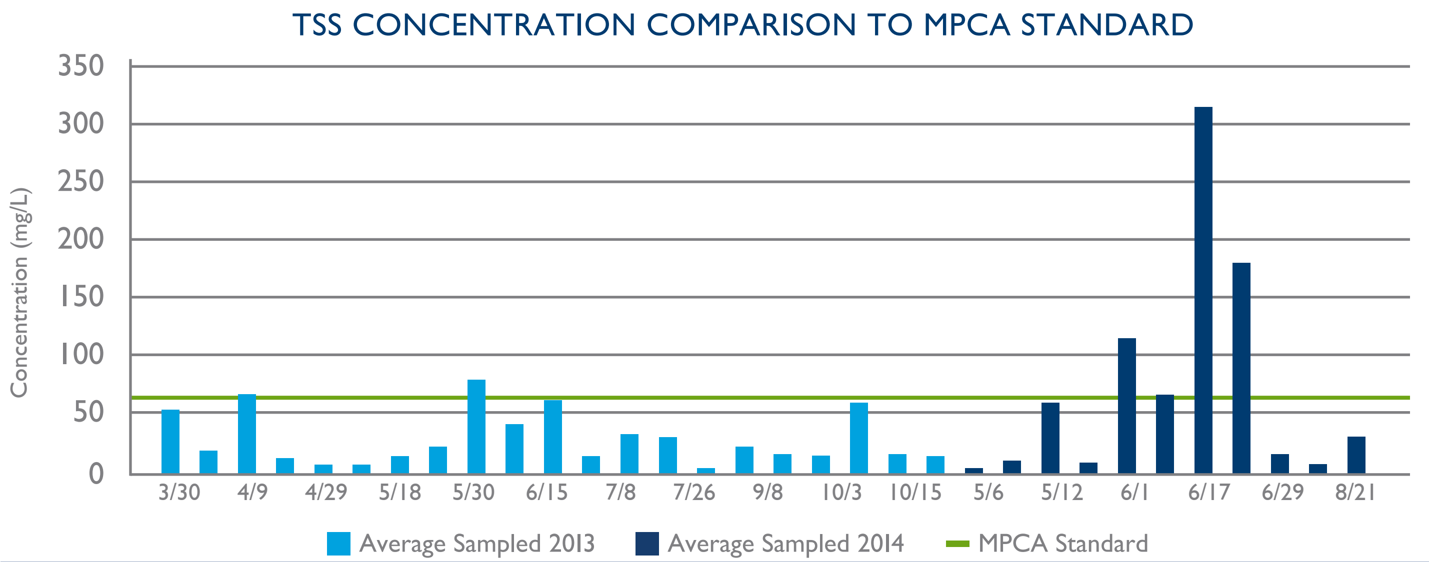


Figure 90 - TSS Concentration Comparison to MPCA Standard

As the year progressed, flows diminished, thus so did TP concentrations.

Among the sampled parameters, TN is expected to have the most notable seasonal variations. This is due to the application of nitrogen to the agricultural fields within the watershed. Nitrogen is always present in drainage water and more specifically leaches through the soil profile and into drainage tiles. It is typically applied in early spring before crops fully take root. As rainfall events occur, the nitrogen leaches into the soil profile. Some of it is consumed by the crop while the rest continues to leach through the soil, eventually into drainage tiles. As the year moves on, crop roots grow and can uptake more nitrogen. Also, with less rainfall and water, less nitrogen leaches to drainage tiles. Therefore, it is expected to have higher concentrations of nitrogen during the spring and early summer while a lower concentration during late summer and fall. *Figures 87-89* support this theory and show the season average concentrations for TN from 2012 to 2014. As expected, in all three years the TN concentrations were higher early in the year due to the bare ground and application of nitrogen, but were significantly lower late in the year as crops began to grow and runoff lessened.

MPCA COMPARISON

THEORY

The MPCA has developed standards for water quality in several different classes of water throughout the state. These standards are developed to classify each waterway for associated impairments for any of these parameters. These standards help develop practices to improve water quality in watershed that contribute to each classified waterway and may help when developing Total Maximum Daily Load (TMDL) or Watershed Restoration and Protection Strategy (WRAPS). For Class 2 waters in Minnesota, the standard concentrations for TSS, TP, and TN are 65 mg/L, 0.30 mg/L, and 10 mg/L respectively (MPCA, 2013).

METHODOLOGY

Similar to the methodology used in **Seasonal Variations Section, Page 49,** for the sampled rain events, the concentrations from each sample site throughout the watershed were averaged for the parameters of TSS, TP, and TN and were tabulated (*Figures 90-91*). Average sampled concentration values for each rain event for the three monitoring seasons were compared to the MPCA standards for the parameters of TSS, TP, and TN.

RESULTS

The average TSS concentrations for each sampled rain event for 2013 and 2014 were compared with the MPCA standard (*Figure 90*). The points on the graph show the average sampled concentration of TSS for rain events while the solid line represents the MPCA Standard.

The average TP concentrations for each sampled rain event were compared to the MPCA standard for 2012 to 2014 (*Figure 91*). The points on the graph show the average sampled concentration of TP for rain events while the solid line represents the MPCA Standard.

The average TN concentrations each sampled rain event for 2012 to 2014 were compared to the MPCA standard (*Figure 92*). The points

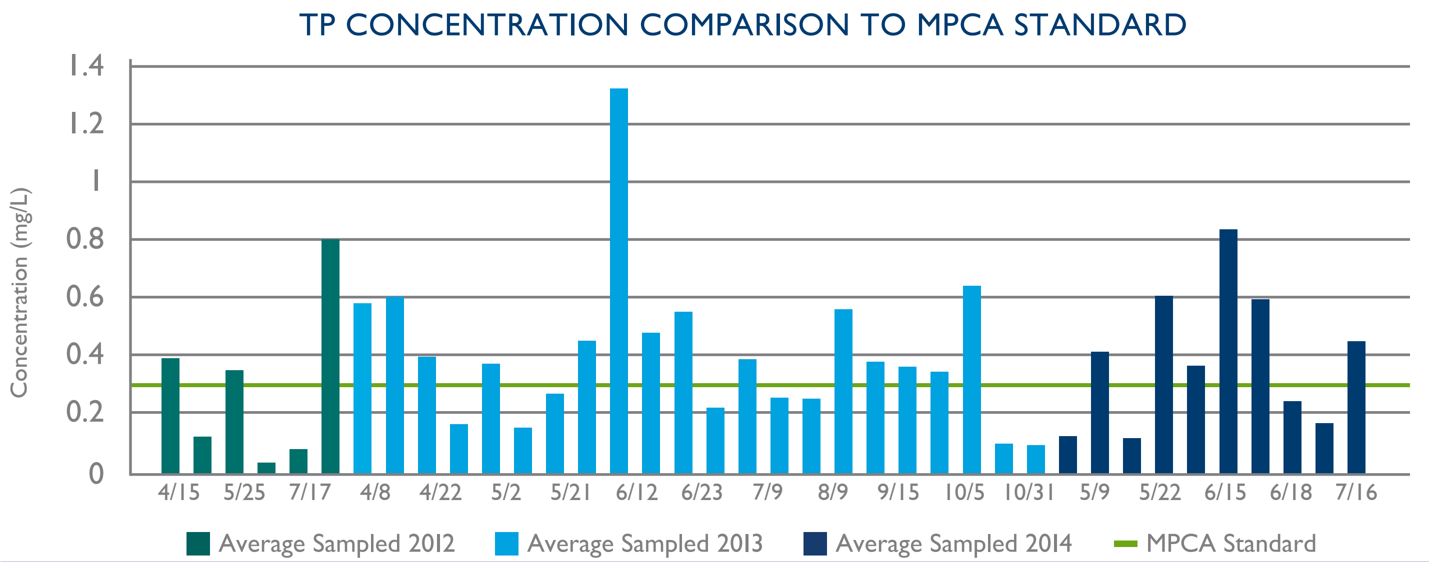


Figure 91 - TP Concentration Comparison to MPCA Standard

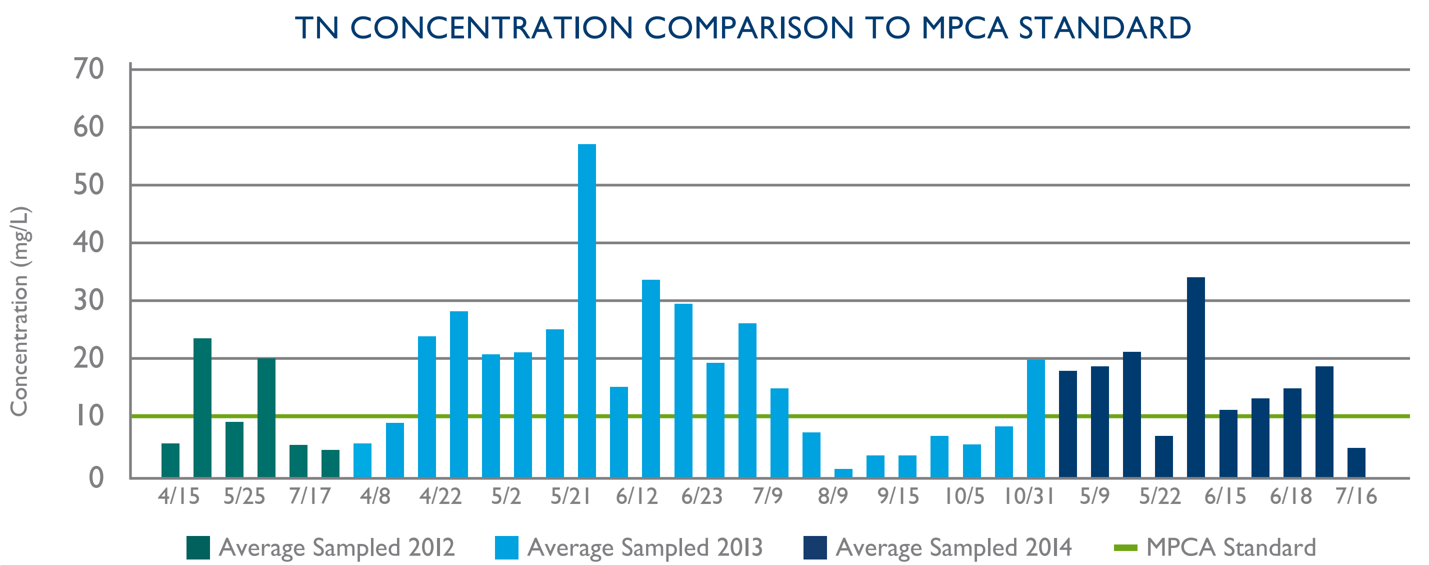


Figure 92 - TN Concentration Comparison to MPCA Standard

on the graph show the average sampled concentration of TN for rain events while the solid line represents the MPCA Standard.

ANALYSIS

The majority of average sampled events for TSS fall within the MPCA standard of 65 mg/L (*Figure 77*). There were a few samples that were outside of this standard. Three of these samples were above the MPCA standard by less than 15 mg/L while three others were much higher than the standard. These three samples occurred during the 2014 monitoring season during the three back to back rain events causing the entire

CD 57 system to fill. This limited the effectiveness of the BMPs until the water receded. Overall, the average sampled TSS concentrations between 2012 and 2014 were in compliance with the MPCA Standard.

Total phosphorus and total nitrogen were not in compliance for the majority of the 2012-2014 sampling period (*Figures 91-92*). TP concentrations were over the 0.30 mg/L MPCA standard concentration during 2013 and 2014. Concentration values during the 2012 season were much closer and in some cases in compliance with the standard. This was likely due to the non-typical low flows during the 2012 season. The higher concentrations during 2013 and 2014 can be attributed to the higher flows for these years.

Total nitrogen concentrations were significantly higher than the MPCA Standard of 10 mg/L during the entirety of the 2012-2014 monitoring seasons. It is unclear why these concentration values were much higher than the standard. One theory can be attributed to high nitrogen applications leaching of nitrates through the soil.

These average concentrations occurred during the peak flow of each rain event when the pollutant loading was at its highest. It can only be speculated how much higher these concentrations would be without the BMPs installed throughout the CD 57 system. Although the majority of the samples revealed TP and TN concentrations higher than the MPCA standards, concentrations of TSS were predominately in compliance with the standard. This is a significant benefit not only to the CD 57 system, but to the downstream receiving waters. High concentrations of sediment (i.e. TSS) have resulted in severe bank erosion, hyper eutrophication in downstream lakes and rivers, sediment accumulation and deposition, and poor water clarity. By reducing TSS concentrations to meet MPCA standards, water quality is improved as CD 57 water enters the receiving waters.

WEATHER CONDITIONS

With only 14 inches of rain throughout the growing season, 2012 was considered a very dry year with limited rainfall events and low flow conditions. The 2013 growing season was considered much more typical as a total of 21 inches of rainfall occurred and was spread relatively evenly throughout April and July. However, 2013 did experience a 2.63-inch rainfall event within 2 hours which is equivalent to a National Oceanic and Atmospheric Administration (NOAA) 25-year rain event.

Considered a very wet year, 2014 experience multiple heavy rainfall events and a few back to back rain events, which primarily occurred in May and June. A total of 21 inches of rain fell with the majority occurring early in the growing season. There were many times where the entire CD 57 system was full of water and restricting flow throughout the watershed. This year also received a 2.02 and a 1.99 inch rain event in back to back days. Both were equivalent to a NOAA 10-year rain event.

SUMMARY

The goal of the water quality portion of the CD 57 project was to design, construct, monitor, and evaluate the BMPs installed. Overall, water quality results of the BMPs proved to be effective at reducing peak flow rates, sediment, nitrogen, and phosphorus loading throughout the CD 57 system.

The Klein Pond, two-stage ditch, and rate control weir all have different functions and were placed in strategic locations throughout the watershed to improve water quality. The Klein Pond was designed to provide storage to the upper half of the CD 57 watershed to improve the drainage capacity while protecting the downstream landowners from flooding. It is functioning as designed and also provides significant water quality benefits to the system by reducing the sediment and nutrient loading. As an alternative to a standard ditch, the two-stage ditch was designed and installed to carry the perennial baseflows. Monitoring results showed that it functions similar to a natural stream and also reduced pollutant loading. Since construction was finished in 2011, the two-stage ditch has experienced very little sloughing or bank erosion, minimizing repair and maintenance costs. The rate control weir was designed to reduce peak flow rates from the system. Monitoring results showed that peak flow rates were indeed reduced and TSS and TP loading was also reduced. Together this combination of BMPs maximized the effectiveness of improving water quality.

An overall goal of the CD 57 project was to provide storage and reduce peak flow rates downstream. This was accomplished while increasing drainage capacity by constructing the Klein Pond and rate control weir. These BMPs stored water during rain events and reduced peak flow rates on average between 6 and 28 percent for the weir and Klein Pond respectively. While providing storage, the Klein Pond also removed over 70 dump truck loads of sediment over the three years of monitoring.

The effectiveness of the Klein Pond, two-stage ditch, and rate control weir were analyzed to determine their reduction of TSS, TP, and TN loading over the three years of monitoring. The Klein Pond was the most effective by reducing the loading of each between 19 and 25 percent. The two-stage ditch and rate control weir reduced the loadings between 4 and 10 percent of each parameter.

The TSS and TP concentrations were more than 30 percent lower during baseflow conditions for post sampling at the outlet of the system (Site 1) and the two-stage ditch (Site 4). The pre- and post- BMP installation sampling concentrations were similar at the beginning of the open ditch upstream (Site 7). At Sites 1 and 4, BMPs were present and concentrations of TSS and TP were lower during the post- monitoring compared to the pre monitoring. At Site 7, no BMPs were installed and the concentrations of TSS, TP, and TN were all similar for both the pre and post monitoring. This shows that the BMPs had a direct impact on water quality during baseflow conditions.

The CD 57 project is now a model for the future of agricultural drainage in the Midwest. This project showed that it is possible to increase drainage capacity while improving water quality. Monitoring the system also provided a baseline of methodology that can be incorporated into future projects relating to monitoring of county ditch systems. With many drainage projects in progress, BMPs can and should be incorporated into these projects to improve drainage capacity, agricultural production, and water quality.

LIMITATIONS

While there were several limitations with the CD 57 monitoring, this project still produced great results and an excellent experience for those involved. The collaboration between Blue Earth County, ISG and MSU was a great opportunity for both parties to develop and adjust methods to produce the best possible outcomes of the monitoring process. As with any research project, several limitations occurred and lessons were learned. The following sections deal with limitations that were experienced with the monitoring of the system.

Monitoring

The first year of post BMP monitoring and sampling was done by MSU's Department of Civil and Mechanical Engineering. There were challenges due to the complex ditch system, inexperience with monitoring equipment and methods, and a learning curve for college students in the first year. In the second year of monitoring, MSU's departments of Chemistry and Geology were added to assist in the sampling of water chemistry. At this time, the Department of Civil and Mechanical Engineering only managed equipment and maintenance. This technique resulted in excellent coordination of monitoring and sampling.

Only 3 BMPs analyzed

The three BMPs that were analyzed included the Klein Pond, two-stage ditch, and rate control weir. Other BMPs were installed in the CD 57 project but were not analyzed. They include native buffer strips, the City Pond, and an overdug ditch.

In order to analyze the BMPs for effectiveness, a sampling point is needed both upstream and downstream of that specific BMP. Native buffer strips were installed throughout the entire length of the open ditch. Therefore it was difficult to install monitoring stations upstream and downstream of this BMP. It was also difficult to sample surface runoff through the buffer strips since flow volumes were very low.

The City Pond also did not have a sampling point upstream of it. There were three different inlet points to the pond, requiring an additional three monitoring stations. Runoff from the City included primarily gravel and grit from the urban streets and impervious surfaces. This project focused on runoff from rural agricultural area, therefore the analysis of the City Pond was left out.

The overdug ditch section began at the beginning of the open ditch, south of TH 30 and spanned through the Klein Pond and ended at the two-stage ditch. It was difficult to analyze this BMP since it was a long segment with a varying watershed and included other BMPs within it.

Only analyzed 3 parameters

While several parameters were sampled for water chemistry, only 3 were included in this analysis. This project was aimed at water quality in an agricultural setting. These main parameters that are linked with rural agricultural runoff are TSS, TP, and TN. These parameters were selected because they also have the most significant impacts on water quality throughout the nation.

Monitoring stage not flow

Monitoring stage provided an accurate depiction of the water depth throughout the CD 57 system, however it didn't provide an accurate depiction of flow through the system. It many cases, backwater and ponding occurred in the ditch, altering flow rates. This was adjusted through hydrographs and photo reviews, however, the process of quantify flow would be much easier and more accurate if real time flow-velocity meters were installed in the ditch. If sufficient funding was available for equipment, data logging devices would have been replaced by flow-velocity meters to monitor flow instead of depth. This would result in more accurate flow readings and would avoid discrepancies with ponding and backwater effects.

Grab Sampling

Grab samples during the peak flow of a rain event were taken assuming that the pollutant loading was highest at this point. While this thesis has been proven in other studies, pollutant loading is not a linear relationship to flow. Rather than one grab sample at the peak flow of the rain event, a real time portable sampler could be installed at each monitoring site. This sampler would take water chemistry samples from the ditch at different intervals of a rain event. This would give more measurements on water chemistry associated with different flows throughout a rain event. Water chemistry could also be tested through a certified testing lab. This would provide a validated water quality analysis of the tested parameters.

Equipment

Equipment used for the monitoring of the CD 57 system experienced many issues over the course of the three years of post- BMP installation. In some instances, the data logging devices experienced internal flaws, which provided missing data or data that was out of range and could not be converted to flow. Onsite cameras provided a good back up for stage data with the staff gauges, however these devices could be easily damaged. In some cases, high winds and heavy rains damaged the cameras beyond recovery. At some monitoring sites, the cameras were tampered with in which the cameras were no longer focused on the staff gauges. Staff gauges were also damaged when large debris flowed through the ditch. Debris including sediment, grass, and trash would collect on the staff gauges and would shift the alignment of the staff gauge and data logging device.

Pre Installation Monitoring Data

It would have been beneficial to do more pre- BMP installation sampling during rain events. This would allow for more analyses on installed BMPs during similar rain events. It would have been best if the same party would have done both the pre and post sampling to insure consistency. Again, sufficient funding would have been required for this approach.

Weather

Weather significantly impacted the monitoring of the CD 57 system. This included damaging monitoring equipment and created unsafe conditions for water chemistry sampling. Timing of weather also impacted installation of the monitoring equipment, as snow and ice conditions damaged equipment. While the weather cannot be predicted or adjusted to fit the monitoring approach, it was, and will continue to be a limitation to monitoring of the CD 57 and similar ditch systems.

The need for future monitoring

With these limitations, it is evident that future monitoring is needed for ditch systems. The approach used in the CD 57 monitoring proved to be an effective method of water quality monitoring, however lessons were learned to further improve the monitoring approach. The next step in monitoring systems is not an easy one as it requires willing landowners, systems with BMPs included in them, and adequate funding for the monitoring.

GOING FORWARD

The results of the CD 57 monitoring showed that all BMPS were effective with the Klein Pond being the most effective BMP for reducing peak flow rates, TSS, TP, and TN loading. This practice took 4 acres of marginal farmland out of production to provide storage and treatment for a large ditch system and reduce flooding. It also increased the drainage capacity, optimizing drainage of agricultural land to enhance conditions for crop production while also protecting water quality. The theory used in urban drainage systems was replicated to store the water, reduce flow rates, and remove sediment from the flowing water. It was the most effective BMP since it stored and treated the largest volume of water.

The Klein Pond was part of a treatment train which was a series of BMPs that were designed to alter the hydraulics of the water to improve water quality. This treatment train included several BMPs designed for different functions as follows:

- Buffer Strips: Control surface runoff by controlling flow rates and trapping sediment
- City Pond: Trap sediment, grit and gravel from urban runoff
- Overdug ditch: Trap sediment passing within the ditch
- Klein Pond: Reduce peak flow rates, provide storage, remove sediment and nutrients
- Two-stage ditch: Provide perennial baseflow area mimicking natural streams to create a self-cleaning system
- Rate control weir: Reduce peak flows at the outlet

While this treatment train was beneficial to the CD 57 system, it is important to develop a specific management plan for each individual watershed. The blanket approach does not fit all agricultural drainage systems. Each BMP is designed for a specific purpose and must be placed in a strategic place in order to optimize its effectiveness. It is important for land managers, watershed groups, and drainage authorities to develop multi-purpose drainage management plans for each individual watershed when repairs and improvements are scheduled. By incorporating these BMPs to ditch systems throughout the Midwest, significant water quality improvements will be seen on both local and national scales.

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