2016 Project Abstract
For the Period Ending June 30, 2019

PROJECT TITLE: Completing National Wetland Inventory Update for Minnesota
PROJECT MANAGER: Steve Kloiber
AFFILIATION: Minnesota DNR
MAILING ADDRESS: 500 Lafayette Road, Box 25
CITY/STATE/ZIP: St. Paul, MN 55155
PHONE: 651-259-5155
E-MAIL: steve.kloiber@state.mn.us
WEBSITE: http://www.dnr.state/mn.us/eco/wetlands/nwi_proj.htm
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2016, Chp. 186, Sec. 2, Subd. 03e

APPROPRIATION AMOUNT: $ $1,500,000
AMOUNT SPENT: $1,489,060
AMOUNT REMAINING: $10,940

Sound bite of Project Outcomes and Results
Completing the statewide update of the National Wetland Inventory (NWI) was a key objective of the strategy to ensure healthy wetlands and clean water for Minnesota. These data are used by government, private industry and non-profit organizations for land use planning, wetland conservation, wetland permitting and environmental impact assessment.

Overall Project Outcome and Results
The National Wetlands Inventory (NWI) update project was a collaborative effort lead by the Minnesota DNR that:

- Developed new methods for integrating lidar data into wetland mapping,
- Created of a suite of lidar-derived topographic datasets to assist with wetland mapping,
- Acquired new statewide, high-resolution spring leaf-off aerial imagery,
- Completely re-mapped and classified all wetlands larger than 0.5-acre in size,
- Engaged stakeholders in the development and review of the updated data,
- Enhanced the NWI with additional attributes, and
- Efficiently delivered data to various user groups through multiple means.

These data replace the original 1980s NWI data. In this final phase of the overall effort, we updated wetland inventory maps for the remaining 20,700 square miles of northwestern Minnesota covering 19 counties. All the wetland data from each project phase has been edge-matched to create a single statewide wetland inventory containing nearly 2.4 million wetland polygons.

Quality assurance of the data included visual inspection, automated checks for attribute validity and consistency, as well as a formal accuracy assessment based on independent field data. The updated NWI data have a 95% user accuracy for wetland identification. Further details on the methods employed can be found in the technical procedures document for this project located on the DNR wetland-mapping website.

Project Results Use and Dissemination
Wetland map data developed by this project are freely available through web-based data distribution hubs and online viewing through web mapping applications including the Minnesota Geospatial Commons and the DNR Wetland Finder. The final statewide updated data were posted to these distribution points on May 31, 2019.

The DNR issued a press release on June 3, 2019 announcing the availability of the statewide NWI. The DNR also included social media posts regarding this release. The story was picked up by several media outlets. The DNR developed a web application to support ongoing stewardship of the NWI data. The web application provides a simple and consistent method for state and local wetland professionals to submit change requests to the DNR. DNR plans to incorporate these user requests into annual updates of the NWI.

The DNR also developed a NWI User Guide and Summary Statistics. This guide provides a brief overview of the potential uses, limitations, access and technical aspects of the Minnesota Wetland Inventory. This guide also provides summary statistics of wetland types by county and major watershed. Printed copies are being distributed to local Soil and Water Conservation Districts, BWSR wetland specialists, DNR area hydrologists, and others. In addition, the DNR developed and printed 1000 copies of a map poster. These are being sent to a broad array of potential users of the NWI including SWCDs and local government units.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2016 Work Plan

Date of Final Report: October 31, 2019

Date of Work Plan Approval: June 7, 2016

Project Completion Date: June 30, 2019

Does this submission include an amendment request? _No_

PROJECT TITLE: Completing National Wetland Inventory Update for Minnesota

Project Manager: Steve Kloiber

Organization: Minnesota DNR

Mailing Address: 500 Lafayette Road North, Box 25

City/State/Zip Code: St. Paul, MN 55155-4025

Telephone Number: (651) 259-5164

Email Address: steve.kloiber@state.mn.us

Web Address: http://www.dnr.state.mn.us/eco/wetlands/nwi_proj.html

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Location: Nineteen counties in northwestern Minnesota: Pope, Stevens, Traverse, Grant, Douglas, Otter Tail, Wilkin, Clay, Becker, Clearwater, Mahnomen, Norman, Polk, Red Lake, Pennington, Marshall, Kittson, Roseau, Lake of the Woods.

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$1,500,000**
	Amount Spent:	**$1,489,060**
	Balance:	**$10,940**

Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 03e

Appropriation Language:
$1,500,000 the second year is from the trust fund to the commissioner of natural resources to complete the update and enhancement of wetland inventory maps for counties in central and northwestern Minnesota. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Completing the National Wetland Inventory Update for Minnesota

II. PROJECT STATEMENT:

Over the past 100 years, about half of Minnesota's original 22 million acres of wetlands have been drained or filled. Some regions have lost more than 90 percent of their original wetlands. The function and quality of remaining wetlands are often impaired. Updating the National Wetland Inventory (NWI) is a key component of a strategy to monitor and assess wetlands to ensure healthy watersheds and clean water for Minnesota.

- NWI is the only comprehensive inventory of wetlands for Minnesota. To protect wetlands, we need to know how many wetland acres we have and where they are. Unfortunately, the original NWI is 30 years out-of-date and not very accurate in many locations, partly due to its age and partly due to the limitations of the mapping technology at the time it was produced.
- NWI is an important screening tool for land use planning and for evaluating potential wetland impacts. Having accurate wetland inventory data is critical for state, regional, and local agencies when evaluating the potential impact of proposed projects and striving to preserve the integrity of our remaining wetlands. Wetland programs such as Minnesota's Wetland Conservation Act and the US Army Corps' Clean Water Act Permit Program rely on the NWI as the initial resource for evaluating these impacts. Having accurate maps upfront prevents problems later on; saving time and money for permit applicants and wetland program managers as well as preventing wetland impacts.
- NWI is useful for wetland restoration and conservation planning. The NWI includes information about wetlands that helps identify potential restoration opportunities such as partially drained wetlands. In addition, the updated NWI will provide enhanced attributes to support assessment of wetland functions like flood storage capability, water quality protection, and wildlife habitat. Information on which wetlands are providing what benefits helps conservation professionals make better decisions about where to use restoration funding.

This project phase will:

- Complete the update NWI maps for the remaining 19 counties in northwestern Minnesota (20,700 mi^2)
- Conduct a pilot demonstration using the updated NWI to assess wetland function and develop a report

Through previous project phases, we have already acquired statewide high-resolution (0.5 meter & 1-foot) aerial imagery. Wetland maps will be produced by contractors under the supervision of the DNR. All wetland map data will be available free of charge to the public.

III. OVERALL PROJECT STATUS UPDATES:

Amendment Request (8/30/19) – Amendment Approved by LCCMR (10/3/19)

This final amendment request for this project is intended to reconcile unanticipated small negative balances in the software budget line ($488) and to add a line item for the conference registration fee to present the NWI project results at the 2018 MN Water Resources Conference ($250). Overall, the project has a net positive budget balance of $7,349.

Amendment Request (6/24/19) – Amendment Approved by LCCMR (6/25/19)

As the project winds down, there is a need to shift a small amount of funding from a budget item with an expected surplus to an item with an expected shortfall. We propose to shift $2,400 from graphical design and desktop publishing support to service level agreement with MNIT for project management and application development. The costs for the MNIT SLA is split 75% for activity 1 and 25% for activity 2, resulting in a shift of $600 from activity 1 to activity 2. There is no change to the overall budget.

Amendment Request (6/6/19)

The DNR has recomputed the Direct and Necessary Costs for this project and will not be charging for the remaining $5,891.53. We propose to redirect these funds to the MNIT service level agreement to help support project closeout, documentation, and archiving additional project related information. This will also allow us to prepare a copy of the data to submit to the federal wetland inventory database managed by the USFWS. This will provide an additional source for people to access the data. There is no change to the overall budget.

Amendment Request (3/8/19) – Amendment Approved by LCCMR (3/12/19):
As the NWI update project approaches completion, we have realized some cost savings. We are proposing to re-allocate these savings toward developing and publishing a user guide for the NWI data and a promotional wall map. The purpose of the user guide will be to help potential users of the NWI data understand the data and use it more effectively for natural resource analysis and decision support. The user guide will include information on how the data were developed, limitations, how to access the data, and example applications. We will also develop a poster or wall map of the NWI data conceptually similar to the one that was developed for the original NWI data in Minnesota in the mid-1980s. The poster will show the data and provide key messages about the variety of wetlands in Minnesota and their many ecological benefits. This will be done as part of the project outreach and to aid in disseminating the project results. We will move $9,000 from the budget line for IT support to a new budget line for DNR graphical design and desktop publishing support. In addition, we will shift the unspent balances from the budget lines for supplies and travel to a new budget line for printing costs. The total amount of this shift is $5,287.

Project Status as of January 31, 2017:
The project began with issuing a request for proposals for wetland mapping services. St. Mary's University (SMU) was selected as the best value proposal for the northwestern Minnesota NWI update. A service level agreement was also developed with the DNR Resource Assessment Program (RAP) to support the project. RAP will be pre-processing data and providing it to SMU. RAP will also be participating in field work and quality control review of draft NWI data. A sole source contract was also developed with the St. Croix Watershed Research Station (SCWRS) to develop, test, and disseminate methods for landscape level wetland functional assessments using the updated NWI data. A project kick-off meeting was held on October 7, 2016 to coordinate various aspects of this project.

SMU has developed a draft technical procedures document to guide the NWI update for northwestern MN. Initial field work was conducted to develop and refine wetland photo-interpretation signatures for the project area. In addition, SMU has developed draft wetland inventory data for 10 quarter quadrangle tiles for initial review by the DNR.

RAP has been working on compiling and pre-processing data. RAP has completed and delivered the several LiDAR derived layers for the NW NWI Study Area.

SCWRS has compiled and reviewed available data for the wetland functional assessment demonstration. In particular the availability of hydro-modified DEMs that are co-located with available updated NWI data in southern and east-central MN. The hydro-modified DEM is an important component of a potential wetland functional assessment because it can be used to analyze the flow paths and watersheds of wetlands. SCWRS has selected four pilot watershed areas for this part of the project; Yellow Medicine headwaters, Lake Wakanda, Madison Lake, and Browns Creek.

Amendment Request (6/2/2017) – Approved by LCCMR (6/27/2017):
As the NWI update project approaches completion, we have realized some cost savings. Savings for the northwest Minnesota update include $65,000 in IT personnel time as a result of the project being completed earlier than originally anticipated. We are proposing to re-allocate these savings to make some important improvements to the overall statewide data layer focusing on two tasks; improving and integrating the NWI data

for the Koochiching pilot study area and conducting a statewide quality assurance review of the database attributes to ensure consistency across project boundaries.

The very first effort on the statewide update of the NWI for Minnesota included a pilot study area covering an area defined by 50 USGS quarter quad maps in Koochiching County. This pilot was performed by the Resource Assessment Office of the Minnesota DNR as part of technology transfer involving the University of Minnesota and Ducks Unlimited. The data for the Koochiching pilot area have differences in terms of both the quality of the line work for wetland boundaries as well as some differences in how classifications were assigned. This pilot area requires additional editing and review to resolve these differences. This task will use the pilot data and other data sources including lidar elevation, imagery, and soils to create final updated NWI data for this area and to integrate it with the final NWI data for the adjacent areas through an edge-matching process. The data will undergo a complete QA/QC review including an evaluation using the U.S. Fish and Wildlife Service's QA/QC tool. Any issues found using this tool will be fixed prior to the edge-matching and integration. The additional cost for performing this work to finalize and integrate the NWI data for the Koochiching pilot area is $30,000. This work is proposed as a contract amendment under the current northwest Minnesota NWI update with St. Mary's University of Minnesota.

In addition, changes in personnel, federal mapping guidance, and method improvements over time have resulted in some inconsistencies in database attributes across project boundaries. This task will involve conducting a graphical and/or statistical analysis of key attribute variables across the assembled statewide NWI data layer to identify inconsistencies and to address these inconsistencies wherever possible. The attributes evaluated will include:

- Cowardin wetland classification codes and specific components including water regime classes and special modifiers
- Simplified hydrogeomophic classifications and specific components including landscape class, landform/waterbody class, and water flow path

The wetland mapping contractor will conduct a review and analysis of the data and prepare a technical memorandum describing the type and extent of issues found. The analysis will focus on ensuring that all attribute values are considered valid values and that the values are applied with reasonable consistency across the entire statewide data layer. We anticipate that some issues will be addressed with a simple search and replace text process, while other issues may require a more sophisticated selection process. The DNR, with input from the technical advisory committee, will prioritize the issues considering both the potential impact as well as the level of effort required to address the issue. The DNR will direct the contractor to address any issues using the prioritized issue list. If there are any issues that were identified that cannot be addressed within the budget and time constraints, they will be documented in the final metadata and added to a list of issues to be handled in the ongoing maintenance of the data. The additional cost for performing this additional QA/QC analysis and addressing these issues for the final statewide seamless data layer is $35,000. This work is proposed as a contract amendment under the current northwest Minnesota NWI update with St. Mary's University of Minnesota.

Project Status as of June 23, 2017:

SMU has completed draft data for 40 USGS quarter quads spread across the northwest project area as part of an effort to refine and review mapping procedures prior to full-scale map production. Subsequently, SMU has produced draft data for Traverse, Clay, Wilkin, and Stevens counties as well as for the western part of Marshall and Polk counties. Draft data are approximately 25% complete for the project area. SMU also conducted additional field work during the month of May to further refine the photo-interpretation guidelines for this region. The field work included visits to 110 additional sites.

The DNR has deployed the updated online review tool along with a user guide. The tool is being used by the DNR Resource Assessment Program (RAP) and the U.S. Fish and Wildlife Service (USFWS) to provide comments on the draft NWI data. Other project stakeholders are also being invited to use the tool to review and comment on the draft data. RAP and USFWS have reviewed draft NWI data for Traverse, Polk, and Marshall Counties. We also held a project status meeting in April with the project team for both the northwest and central update areas.

SCWRS has created a prototype procedure for the wetland functional assessment demonstration composed of ArcGIS and R functions/codes. The procedure identifies and delineates wetland depressions and their catchments (i.e., the direct drainage to the depression) as well as determines the network topological relationships between series of up- and downstream-connected depressions. Cumulative runoff into and out of each depression is determined based on depressional network topology, watershed runoff predicted from design storms, and each depression's storage volume. The functional assessment procedure was tested on the project's Yellow Medicine headwaters pilot watershed composed of approximately three HUC-12 subwatersheds. The pilot watershed consists of 1,100 wetland depressions aggregated into greater than fifty multi-depressional network watersheds.

Project Status as of January 31, 2018:
SMU has submitted draft data for a cumulative 54% of the project area. The DNR has provided review comments for about 39% of the submitted draft data (about 21% of the total project area). In addition, SMU has submitted an NWI update for the Koochiching pilot area. It is anticipated that approximately two counties of draft data will be delivered each month for the next several months.

SCWRS has continued development of a set of GIS tools and procedures to quantify wetland hydrologic and water quality function at individual-wetland to watershed scales. The pilot study area has been expanded to comprise several larger watersheds including all of the Lac qui Parle, Yellow Medicine and Le Sueur (HUC-8) watersheds and parts of the Blue Earth and Watonwan watersheds. The expanded study area is composed of approximately 20,000 NWI delineated wetlands, their respective drainage areas and their network connectivity with up- and downstream wetlands. Currently, analyses are underway to statistically mine this greatly expanded dataset to develop additional relationships between NWI wetland type and hydrologic and water quality function.

Project Status as of July 31, 2018:
SMU has submitted draft data for a cumulative 85% of the project area. The DNR has provided review comments for about 80% of the submitted draft data (about 68% of the total project area). SMU is on target to complete the project on time and within budget.

SCWRS expanded upon the previous data analysis by expanding it from the original four pilot areas to nearly the entire extent of hydrologically conditioned lidar DEMs in southern Minnesota. This expanded study area allows examination of a vastly larger (and variable) set of wetlands and soil, climate and landscape conditions to gain a better understanding of wetland function across Minnesota. Analysis results include the computation of wetland storage volumes, direct drainage areas and up/downstream neighbors for all NWI polygons within the study area. In addition, the fill-and-spill responses to 2yr/24hr and 10yr/24hr design storms have also been calculated.

Amendment Request (November 20, 2018) – Approved by LCCMR (11/27/2018):
The purpose of this amendment is to redirect funds from two budget line items that have come in under budget toward additional quality control and quality assurance efforts. The budget line for support from DNR Resource Assessment Program will be reduced by $30,000 and the budget line for support from MNIT will be reduced by $10,000. These funds will be redirected toward an amendment to the contract with St. Mary's University of Minnesota to perform additional analysis and improve the accuracy and completeness of the NWI. The contract amount will be increased by $40,000. In addition, $15,000 from the budget line for MNIT project management support will be used for MNIT application development. These funds will be directed at making minor modifications and enhancements to two web-based applications that have been developed to support the NWI program. Approximately, $2,500 will be used to make minor improvements to the Wetland Finder application, which is a public-facing web map that allows non-GIS users to access the NWI data. The remaining $12,500 will

be used to modify the NWI review tool to adapt it for ongoing data stewardship efforts. The modified tool will serve as a mechanism for users to report errors as well as wetland gains and losses to the DNR, so that updates may be made to the data. There is no change in the budget for this activity. These changes only involve shifting funds from one budget line to another.

Project Status as of January 31, 2019:
St. Mary's University completed wetland mapping for the northwest Minnesota project area (20,700 square miles). All draft data was finalized for this region and delivered to the DNR. Subsequently, SMU has edge-matched all of the NWI data for the various project regions into a statewide seamless NWI layer and delivered this to the DNR. SMU is working with the DNR to address potential inconsistency issues across project boundaries. An issue tracking system was developed and several issues have already been resolved. Efforts to ensure consistency and accuracy are ongoing and weekly meetings are held to discuss progress and new issues as they arise.

During this reporting period, the DNR reviewed data for the northwest project area covering approximately 4,200 square miles. An accuracy assessment was performed on the northwest project area using ground validation data. The overall accuracy for wetland mapping is 93%. Wetland classification accuracy is 78%. DNR staff reviewed approximately 26,800 square miles of the statewide seamless data layer. Project presentations were made at several locations around the state. DNR updated the metadata and published the statewide NWI data to MN Geospatial Commons. The data have also been made available through an updated web map (DNR Wetland Finder).

The SCWRS completed analyses for wetland flood storage, connectivity, providing estimates of permanent, and temporary storages across the project study of over 2 million acres in Southern Minnesota. Provisional wetland metrics for surface hydrologic and water quality functions were developed using results from wetland storage and connectivity analyses resulting in normalized metric scores based on relative ranking at different watershed scales. Current results were presented at the Water Resources Conference.

Overall Project Outcomes and Results:
The NWI update project was a collaborative effort lead by the Minnesota DNR that:

- Developed new methods for integrating lidar data into wetland mapping,
- Created of a suite of lidar-derived topographic datasets to assist with wetland mapping,
- Acquired new statewide, high-resolution spring leaf-off aerial imagery,
- Completely re-mapped and classified all wetlands larger than 0.5-acre in size,
- Engaged stakeholders in the development and review of the updated data,
- Enhanced the NWI with additional attributes, and
- Efficiently delivered data to various user groups through multiple means.

In this final phase of the overall effort, we updated wetland inventory maps for the remaining 20,700 square miles of northwestern Minnesota covering 19 counties. All the wetland data from each project phase has been edge-matched to create a single statewide wetland inventory containing nearly 2.4 million wetland polygons.

Quality assurance of the data included visual inspection, automated checks for attribute validity and consistency, as well as a formal accuracy assessment based on independent field data. The updated NWI data have a 95% user accuracy for wetland identification. Further details on the methods employed can be found in the technical procedures document (Attachment B) for this project located on the DNR wetland-mapping website.

The DNR finalized the NWI user guide (attachment C) and computed final summary statistics for the wetland data, computing area for the various wetland classifications systems by both county and major watershed.

These summary statistics are provided in the appendix of the NWI user guide. The DNR also developed and printed a promotional wetland poster.

The SCWRS submitted a final report (attachment D) summarizing the wetland functional assessment demonstration project. The previous water quality and water quantity functional assessment procedures were documented and the analysis was expanded to also include groundwater function and wildlife habitat function (i.e. dabbling duck habitat).

The completed statewide data were posted the MN Geospatial Commons and added to the DNR Wetland Finder web application at the end of May. The DNR issued a press release on June 3, 2019 to announce the availability of these data and the story was picked up by several media outlets (attachment E). A copy of the data was also provided to the USFWS to post on the federal Wetland Mapper website. Finally, the project was nominated for and received the Governor's Geospatial Commendation (attachment F).

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Updated Wetland Maps for Northwestern Minnesota
Description:
Produce updated wetland maps for 1,634 USGS quarter quadrangles (20,700 miles^2) for the remaining 19 counties in northwestern MN (see attached map). The map production will be conducted by contractors under the supervision of the DNR and will be based on recommendations for wetland mapping methods developed by the University of Minnesota (UMN) and refined through previous phases. This work will consist of digital photo-interpretation, topographic analysis of LiDAR data, and analysis of ancillary data such as soils maps and forest inventory maps, as well as quality control review. The project will require substantial input data and generate a large dataset. Secure, reliable data storage and back up will be provided by MN.IT. Completed digital map data will be available to the public through several websites, including the DNR and the U.S. Fish and Wildlife Service.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$1,243,650**
Amount Spent:	**$1,234,000**
Balance:	**$9,650**

Outcome	Completion Date
1. *Draft wetland maps for 19 counties*	September 2018
2. *Quality control review of draft data*	October 2019
3. *Finalized updated NWI data for 19 counties*	November 2019
4. *Statewide seamless NWI*	January 2019
5. *Printed user guide and wall map*	June 2019

Activity Status as of January 31, 2017:
The first report period of the project began with issuing a request for proposals for wetland mapping services. St. Mary's University (SMU) was selected as the best value proposal for the northwestern Minnesota NWI update. The contract with SMU includes two value-added enhancements; edge-matching data between the various completed project area and extended watercourse mapping for all watercourses contained within the DNR Public Water Inventory. A service level agreement was also develop with the DNR Resource Assessment Program (RAP) to support the project. RAP will be pre-processing data and providing it to DU. RAP will also be participating in field work and quality control review of draft NWI data. A sole source contract was also developed with the St. Croix Watershed Research Station (SCWRS) to develop, test, and disseminate methods for landscape level wetland functional assessments using the updated NWI data. A project kick-off meeting was held on October 7, 2016 to coordinate various aspects of this project.

SMU has developed a draft technical procedures document to guide the NWI update for northwestern MN. Initial field work was conducted to develop and refine wetland photo-interpretation signatures for the project area. In addition, SMU has developed draft wetland inventory data for 10 quarter quadrangle tiles for initial review by the DNR.

RAP has been working on compiling and pre-processing data. RA has completed and delivered the following LiDAR derived layers for the NW NWI Study Area:

- Average Intensity of 1st Returns 3m
- DEM 3m
- Hillshade 3m
- HPI 3m
- Max Height of 1st Returns 3m
- Slope in Radians 3m
- TPI 3m
- Percent Canopy Cover 3m
- Hydro Break Lines for the Following Counties: Big Stone, Swift, Pope, Douglas
- 2 ft Contour Lines
- CTI 15m
- CTI 3m

RA is also currently working on creating the following layers

- % Hydric Soils Layer
- SDA (Stochastic Depressional Analysis) Model

Activity Status as of June 23, 2017:
SMU has completed draft data for 40 USGS quarter quads spread across the northwest project area as part of an effort to refine and review mapping procedures prior to full-scale map production. Subsequently, SMU has produced draft data for Traverse, Clay, Wilkin, and Stevens counties as well as for the western part of Marshall and Polk counties. Draft data are approximately 25% complete for the project area. SMU also conducted additional field work during the month of May to further refine the photo-interpretation guidelines for this region. The field work included visits to 110 additional sites.

The DNR has deployed the updated online review tool along with a user guide. The tool is being used by the DNR Resource Assessment Program (RAP) and the U.S. Fish and Wildlife Service (USFWS) to provide comments on the draft NWI data. Other project stakeholders are also being invited to use the tool to review and comment on the draft data. RAP and USFWS have reviewed draft NWI data for Traverse, Polk, and Marshall Counties. We also held a project status meeting in April with the project team for both the northwest and central update areas.

Activity Status as of January 31, 2018:
SMU has submitted draft data for a cumulative 54% of the project area. The DNR has provided review comments for about 39% of the submitted draft data (about 21% of the total project area). In addition, SMU has submitted an NWI update for the Koochiching pilot area. It is anticipated that approximately two counties of draft data will be delivered each month for the next several months.

Activity Status as of July 31, 2018:
SMU has submitted draft data for a cumulative 85% of the project area. The DNR has provided review comments for about 80% of the submitted draft data (about 68% of the total project area). SMU is on target to complete the project on time and within budget.

Activity Status as of January 31, 2019:
St. Mary's University completed wetland mapping for the northwest Minnesota project area (22,000 square miles). All draft data was finalized for this region and delivered to the DNR. Subsequently, SMU has edge-

matched all of the NWI data for the various project regions into a statewide seamless NWI layer and delivered this to the DNR. Additional watercourse features from southern MN project area were incorporated into the statewide data layer. The contract with SMU has been extended to address potential inconsistency issues across project boundaries. As part of this effort, SMU developed an online tool for stakeholder review of statewide NWI data. An issue tracking system was developed and several issues have already been resolved. Efforts to ensure consistency and accuracy are ongoing and weekly meetings are held to discuss progress and new issues as they arise.

The Minnesota DNR continues to provide ongoing project coordination and quality control oversight. During this reporting period, the DNR reviewed data for the northwest project area covering approximately 4,200 square miles. An accuracy assessment was performed on the northwest project area using ground validation data. The overall accuracy for wetland mapping is 93%. Wetland classification accuracy is 78%. The DNR also amended the contract, per the work program amendment, to extend the contract with St. Mary's University to include additional effort to create a seamless statewide dataset and to ensure consistency in wetland classifications across the various project phases. DNR staff reviewed approximately 26,800 square miles of the statewide seamless data layer. Project presentations were made at the Water Resources Conference (St. Paul), GIS/LIS Conference (Duluth), and Minnesota Association of Watershed Districts annual meeting (Alexandria). DNR updated the metadata and published the statewide NWI data to MN Geospatial Commons. The data have also been made available through an updated web map (DNR Wetland Finder).

Final Report Summary:
During the final reporting period of this project St. Mary's University in collaboration with the DNR and the NWI technical advisory team reviewed the statewide dataset for accuracy and attribute consistency across project regions. Identified inconsistencies were corrected. Improvements were made to the water regime classification and landscape position as well as a number of other minor adjustments. This effort enhances the usefulness of the data for statewide applications.

The DNR finalized the NWI user guide (attachment C) and computed final summary statistics for the wetland data, computing area for the various wetland classification systems by both county and major watersheds. These summary statistics are provided in the appendix of the NWI user guide. The DNR also developed and printed a promotional wetland poster for distribution to local and state agency water/wetland resource personnel, educational institutions, conservation organizations, and the public.

ACTIVITY 2: Wetland Functional Assessment Demonstration & Training for Data Users
Description:
The updated NWI data are not only more current and spatially accurate than the original NWI, but they also include new attributes such as the hydro-geomorphic classification (HGM). These enhancements were included based on stakeholder requests and are intended to support wetland functional assessment. This activity includes a pilot demonstration to be conducted by the St. Croix Watershed Research Station (of the Science Museum of Minnesota) using the updated and enhanced National Wetland Inventory to assess the ecological functions of wetlands within a selected watershed in southern Minnesota. Various metrics will be derived from a combination of both the updated NWI data and lidar data, including, but not limited to; wetland surface area, mean depth, volume, watershed area, ratio of wetland area to watershed area, and ratio of wetland volume to watershed area. These metrics will be calculated for each wetland and summarized by HGM class. Correlations between these metrics and wetland hydrologic function will be developed through a combination of statistical analyses, modeling, and literature review. The procedures used for this analysis will be documented and presented to serve as guidance to natural resource managers for applications including flood analysis, water quality improvement, and wildlife habitat suitability assessment. This information will be disseminated through a combination of presentations and workshops.

Summary Budget Information for Activity 2: **ENRTF Budget: $256,350**
Amount Spent: $255,060
Balance: $1,290

Outcome	Completion Date
1. *Conduct a pilot test using the new NWI data to assess wetland functions*	July 2018
2. *Publish a report on the procedures and results from the pilot test*	April 2019
3. *Present procedures and results from pilot test at four conferences or workshops*	June 2019

Activity Status as of January 31, 2017:
SCWRS has compiled and reviewed available data for the wetland functional assessment demonstration. In particular the availability of hydro-modified DEMs that are co-located with available updated NWI data in southern and east-central MN. The hydro-modified DEM is an important component of a potential wetland functional assessment because it can be used to analyze the flow paths and watersheds of wetlands. SCWRS has selected four pilot watershed areas for this part of the project; Yellow Medicine headwaters, Lake Wakanda, Madison Lake, and Browns Creek.

Activity Status as of June 23, 2017:
SCWRS has created a prototype procedure for the wetland functional assessment demonstration composed of ArcGIS and R functions/codes. The procedure identifies and delineates wetland depressions and their catchments (i.e., the direct drainage to the depression) as well as determines the network topological relationships between series of up- and downstream-connected depressions. Cumulative runoff into and out of each depression is determined based on depressional network topology, watershed runoff predicted from design storms, and each depression's storage volume. The functional assessment procedure was tested on the project's Yellow Medicine headwaters pilot watershed composed of approximately three HUC-12 subwatersheds. The pilot watershed consists of 1,100 wetland depressions aggregated into greater than fifty multi-depressional network watersheds.

Activity Status as of January 31, 2018:
SCWRS has continued development of a set of GIS tools and procedures to quantify wetland hydrologic and water quality function at individual-wetland to watershed scales. The pilot study area has been expanded to comprise several larger watersheds including all of the Lac qui Parle, Yellow Medicine and Le Sueur (HUC-8) watersheds and parts of the Blue Earth and Watonwan watersheds. The expanded study area is composed of approximately 20,000 NWI delineated wetlands, their respective drainage areas and their network connectivity with up- and downstream wetlands. Currently, analyses are underway to statistically mine this greatly expanded dataset to develop additional relationships between NWI wetland type and hydrologic and water quality function.

Activity Status as of July 31, 2018:
SCWRS expanded upon the previous data analysis by expanding it from the original four pilot areas to nearly the entire extent of hydrologically conditioned lidar DEMs in southern Minnesota. This expanded study area allows examination of a vastly larger (and variable) set of wetlands and soil, climate and landscape conditions to gain a better understanding of wetland function across Minnesota. Analysis results include the computation of wetland storage volumes, direct drainage areas and up/downstream neighbors for all NWI polygons within the study area. In addition, the fill-and-spill responses to 2yr/24hr and 10yr/24hr design storms have also been calculated.

Note: An outstanding invoice was received for work performed in fiscal year 2018 that has not been processed yet. This will be reflected in the next semi-annual status report.

Activity Status as of January 31, 2019:

The SCWRS completed analyses for wetland flood storage and connectivity, providing individual to watershed-scale estimates of permanent and temporary storages from a set of design storms (1, 2, 5, 10, 25, 50, and 100 yr/24 hr) across the project study of over 2 million acres in Southern Minnesota. Provisional wetland metrics for surface hydrologic and water quality functions were developed using results from wetland storage and connectivity analyses resulting in normalized metric scores based on relative ranking at different watershed scales (e.g., Hydrologic Unit Code [HUC] 12 and 8). Current results were presented at the 2018 MN Water Resources Conference.

Final Report Summary:
The SCWRS submitted a final report (attachment D) summarizing the wetland functional assessment demonstration project. The previous water quality and water quantity functional assessment procedures were documented and the analysis was expanded to also include groundwater function and wildlife habitat function (i.e. dabbling duck habitat).

V. DISSEMINATION:
Description:
Wetland maps and related data developed by this project will be disseminated through web-based data distribution hubs and online viewing through web mapping applications. The primary data access website for the State of Minnesota is the Minnesota Geospatial Commons. The primary online mapping application for viewing the data will be Minnesota NWI Viewer. Furthermore, the data are likely to be picked up and served by other sites and applications beyond the ones listed here. Publicity for this effort will include presentations at professional conferences as well as publication in selected newsletters and journals. Conference presentations will include at least two of the following venues; the Minnesota Water Resources Conference, the Minnesota GIS/LIS Conference, the Annual Minnesota Wetlands Conference, and the Conference of the Minnesota Association of Watershed Districts.

Status as of January 31, 2017:
The updated NWI data for the northeast was added to a web service and a web application with the previously completed project areas for east-central and southern MN. This web application provides easy access to the data for non-expert users (http://www.dnr.state.mn.us/eco/wetlands/map.html).

Status as of June 23, 2017:
Potential reviewers from DNR and BWSR field offices have been invited to participate in the review of the draft NWI data. We will also be coordinating with these staff for a broader effort to engage local reviewers.

Status as of January 31, 2018:
We have reached out to numerous local data users to engage them in reviewing the draft data. We have contacted county GIS coordinators and SWCD wetland specialists in Clay, Douglas, Grant, Pope, Stevens, and Wilkins counties.

Status as of July 31, 2018:
We have continued to engage local project stakeholders to review the draft data using our web-based review tool. We are working on a communications plan for the final rollout of the NWI update and are planning to present at professional water resource and GIS conferences this fall.

Status as of January 31, 2019:
Presentations on the NWI were given at the Minnesota Water Resources Conference (St. Paul), the Minnesota GIS/LIS Conference (Duluth), and the Minnesota Association of Watershed Districts annual meeting (Alexandria). The DNR also launched an updated web-map application called Wetland Finder that provides an easy way for non-GIS professional to view the NWI data.

Final Report Summary:

The DNR posted the final statewide updated NWI data to the Minnesota Geospatial Commons and updated the data in the Wetland Finder application on May 31, 2019. The DNR issued a press release on June 3, 2019 announcing the availability of the statewide NWI. The DNR also included social media posts regarding this release. The story was picked up by several media outlets (attachment E). A copy of the data was also provided to the USFWS to post on the federal Wetland Mapper website.

The DNR developed a web application to support ongoing stewardship of the NWI data. The web application provides a simple and consistent method for state and local wetland professionals to submit change requests to the DNR. DNR plans to incorporate these user requests into annual updates of the NWI.

The DNR also developed a NWI User Guide and Summary Statistics (attachment C). This guide provides a brief overview of the potential uses, limitations, access and technical aspects of the Minnesota Wetland Inventory. This guide also provides summary statistics of wetland types by county and major watershed. Printed copies were provided to BWSR to distribute to local Soil and Water Conservation Districts and BWSR wetland specialists. The DNR will distribute copies to DNR area hydrologists and others. In addition, the DNR developed and printed 1000 copies of a map poster. These are being sent to potential NWI users including SWCDs and local government units. Finally, the project was nominated for and received the Governor's Geospatial Commendation (attachment F).

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Professional/Technical/Service Contracts:	$ 1,482,000	(1) MNIT project manager at 0.65 FTE for 2-years; ($200,000) (2) A service level agreement with DNR Resource Assessment Office for data processing, field work, quality assurance, and other support; ($177,000) (3) A sole source contract with the St. Croix Watershed Research Station for a wetland functional assessment demo; ($225,000) (4) A competitive bid contract for wetland mapping services; ($880,000)
Equipment/Tools/Supplies:	$ 2,002	
Travel Expenses in MN:	$ 3,600	
Other: DNR Direct and Necessary Support*	$ 12,398	
TOTAL ENRTF BUDGET:	**$1,500,000**	

* Direct and Necessary expenses include both Department Support Services (Human Resources, IT Support, Safety, Financial Support, Communications Support, Planning Support, and Procurement Support). Department Support Services are described in the agency Service Level Agreement, and billed internally to divisions based on rates that have been developed for each area of service. These services are directly related to and necessary for the appropriation. Department leadership services (Commissioner's Office and Regional Directors) are not assessed. Division Support Services include costs associated with Division business offices and clerical support. Those elements of individual projects that put little or no demand on support services such as large single-source contracts, large land acquisitions, and funds that are passed-thru to other entities are not assessed Direct and Necessary costs for those activities. For this work plan, single source contract activity with an associated cost of $602,000 has not been assessed Direct and Necessary costs. In addition, itemized costs captured in our proposal budget include Departmental Financial Support ($12,398) that is necessary to accomplishing funded programs/projects.

Explanation of Use of Classified Staff: The DNR contracts for project management services for this project through MN.IT Services. The MN.IT project manager was originally hired as an unclassified DNR employee. This position was reorganized to MN.IT Services under a statewide consolidation of IT services and is now a classified employee. The project management responsibilities of this position have been funded by the ENRTF program at a rate of 0.65 FTE. There is currently no other source of funding for managing the NWI project and once the project is complete the agency will secure other funds and re-assign this position to other responsibilities.

Explanation of Capital Expenditures Greater Than $5,000: N/A

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 0.65 FTE for 2-years (1.3 FTE) through a service level agreement with MNIT

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 7 FTE for two years (14 FTE)

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
	$0	$0	
State			
In-kind contribution from DNR wetland program coordinator	$10,000	$7,000	Project coordination and planning
TOTAL OTHER FUNDS:	**$10,000**	**$7,000**	

VII. PROJECT STRATEGY:

A. Project Partners: The St. Croix Watershed Research Station (SCWRS) is a partner on this project with responsibility for conducting the wetland functional assessment demonstration using the updated NWI data. An amount of $250,000 from this grant will be directed to the SCWRS for this effort. In addition, other state and federal agency partners support this project in a variety of capacities. These partners include the Minnesota Department of Natural Resources, the Minnesota Pollution Control Agency, the Minnesota Board of Water and Soil Resources, the U.S. Fish and Wildlife Service, and the Minnesota Dept. of Administration's Geographic Information Office.

B. Project Impact and Long-term Strategy:

This is the sixth phase of a multi-phase project to update the NWI for the entire state of Minnesota. The original estimated total budget for the project is $7.5 million. With this appropriation, the total amount received from ENTRF to date will be $7,150,000. Upon completion of this phase, our progress will be 100% completion for all tasks.

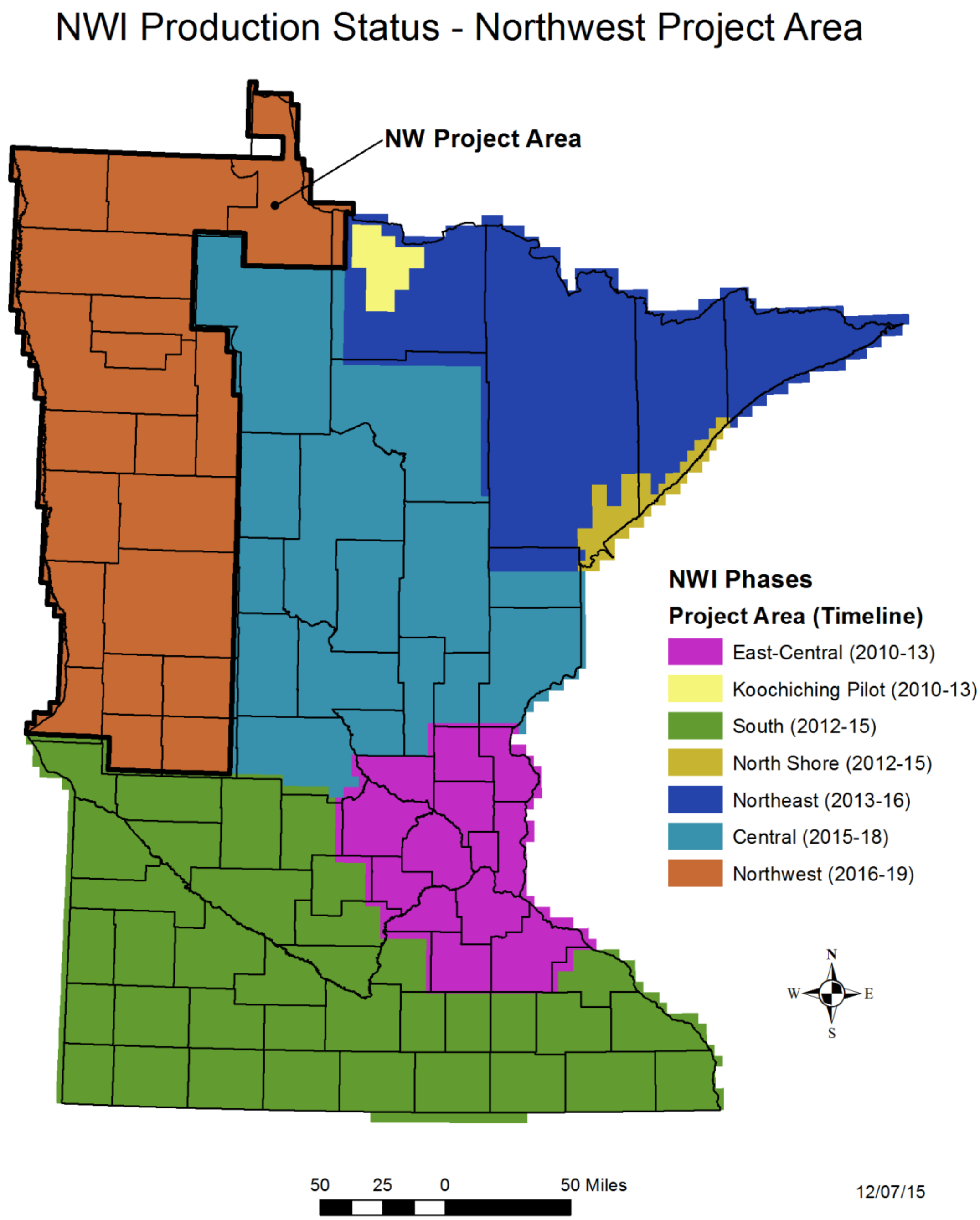
C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
ENRTF – Imagery, Methods, Standards	FY09-11	$550,000
ENRTF – Imagery, Wetland Mapping (east-central), Methods	FY11-14	$1,100,000
ENRTF – Imagery, Wetlands Mapping (southern)	FY13-15	$1,500,000
ENRTF – Imagery, Wetlands Mapping (northeast)	FY14-16	$1,000,000
ENRTF – Imagery, Wetlands Mapping (central)	FY16-18	$1,500,000
USGS/NGA – Imagery	FY10	$25,000
St. Louis County – Imagery	FY10	$24,999
MPCA Clean Water Legacy – Imagery	FY10	$111,000
DNR – Heritage Enhancement Fund – Imagery	FY10	$181,064

Funding Source and Use of Funds	Funding Timeframe	$ Amount
DNR/NOAA – Coastal Zone Program – Imagery	FY10	$24,227
USGS/NGA – Imagery	FY11	$75,000
Metropolitan Council – Imagery	FY11	$65,750
Metropolitan Mosquito Control District – Imagery	FY11	$7,000
McLeod County – Imagery	FY12	$24,000
Sibley County – Imagery	FY12	$29,000
Murray County – Imagery	FY12	$35,000
US Fish and Wildlife Service – Wetland Mapping (North Shore)	FY13-14	$75,000
Carlton County – Imagery	FY14	$23,475
Camp Ripley – Imagery	FY14	$8,898
Itasca County – Imagery	FY14	$86,841
Clay County – Imagery	FY14	$31,091
Wilkin County – Imagery	FY14	$23,266
Mille Lacs County – Imagery	FY14	$13,769
White Earth Reservation – Imagery	FY14	$34,231
Fond du Lac Reservation – Imagery	FY14	$3,000
Beltrami County – Imagery	FY15	$54,499
Polk County – Imagery	FY15	$59,863

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS: N/A

IX. VISUAL COMPONENT or MAP(S):



X. RESEARCH ADDENDUM: N/A

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than January 31, 2017, July 31, 2017, January 31, 2018, July 31, 2018 and January 31, 2019. A final report and associated products will be submitted between June 30 and August 15, 2019.

Environment and Natural Resources Trust Fund

M.L. 2016 Project Budget

ATTACHMENT A

Project Title: Completing National Wetland Inventory Update for Minnesota
Legal Citation: *M.L. 2016, Chp. 186, Sec. 2, Subd. 03e*
Project Manager: *Steve Kloiber*
Organization: Minnesota DNR
M.L. 2016 ENRTF Appropriation: $ 1,500,000
Project Length and Completion Date: *3 Years, June 30, 2019*
Date of Final Report: *October 31, 2019*

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	***Updating Wetland Maps***			***Functional Assessment Demo***				
Professional/Technical/Service Contracts								
Project Manager; Service Level Agreement with MNIT for 0.65FTE for 2 years (78% salary, 22% benefits)& Programmer SLA for 0.17FTE	$92,204	$90,179	$2,025	$31,350	$30,060	$1,290	$123,554	$3,315
Contract for Wetland Mapping Service - St. Mary's University of MN through competitive bid contract	$985,000	$984,500	$500				$985,000	$500
Service Level Agreement with DNR Resource Assessment Office for data processing and quality assurance support	$147,000	$147,000	$0				$147,000	$0
Sole Source Contract with St. Croix Watershed Research Station for wetland functional assessment demo& outreach				$225,000	$225,000	$0	$225,000	$0
DNR graphical design and desktop publishing support	$6,600	$4,950	$1,650				$6,600	$1,650
Equipment/Tools/Supplies								
Software maintenance for quality control review	$803	$803	$0				$803	$0
Printing guidebook and promotional wall map	$5,287	$3,402	$1,885				$5,287	$1,885
Travel expenses in Minnesota								
In-state mileage, travel expenses, and conference registration	$250	$250	$0				$250	$0
Other								
DNR's direct and necessary costs cover HR Support ($0), Safety Support ($0), Financial Support ($12,398), Communication Support ($0), IT Support ($0), Planning Support ($0), Procurement Support ($0), and division and regional program management ($0) that are necessary to accomplishing funded programs/projects.	$6,506	$2,915	$3,591				$6,506	$3,591
COLUMN TOTAL	$1,243,650	$1,234,000	$9,650	$256,350	$255,060	$1,290	$1,500,000	$10,940

ATTACHMENT B

Technical Procedures for Updating the National Wetlands Inventory of Northwest Minnesota

December 21, 2018

Saint Mary's University OF MINNESOTA

GeoSpatial Services

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Project Summary

This project, entitled "Updating the National Wetlands Inventory for Minnesota – Northwest Project Area", used geospatial techniques and image interpretation processes to remotely map and classify wetlands in Northwestern Minnesota. The project area included approximately the Northwest quarter of Minnesota. It consists of 1,634 quarter quadrangles (QQ) (408.5 USGS 7.5-minute quadrangle equivalents) across portions of the following nineteen counties: Becker, Clay, Clearwater, Douglas, Grant, Kittson, Lake of the Woods, Mahnomen, Marshall, Norman, Otter Tail, Pennington, Polk, Pope, Red Lake, Roseau, Stevens, Traverse, and Wilkin (Figure 1). Given that the National Wetland Inventory (NWI) update was based on 7.5-minute quadrangle boundaries, portions of these boundaries cross over into areas outside the designated project area. These areas include a small portion of Koochiching County in Minnesota, as well as small portions of South Dakota, North Dakota, and Canada. The total area updated as part of the Northwest Minnesota project area is approximately 20,700 square miles.

The purpose of this project was to update and enhance the Minnesota NWI using recently-acquired, high resolution digital imagery and a variety of high quality ancillary datasets. NWI attributes from "Classification of Wetlands and Deepwater Habitats of the Unites States" (Cowardin et al. 1979) and simplified plant community classifications from "Wetland Plants and Plant Communities of Minnesota and Wisconsin" (Eggers and Reed 1997) are included. A simplified hydro-geomorphic (HGM) classification using codes and descriptors from "Dichotomous Keys and Mapping Codes for Wetland Landscape Position, Landform, Water Flow Path, and Waterbody Type Descriptors: Version 2.0" (Tiner 2011) are also included as an enhancement. The final product is a seamless NWI dataset of the entire project area for inclusion in the National NWI master geodatabase.

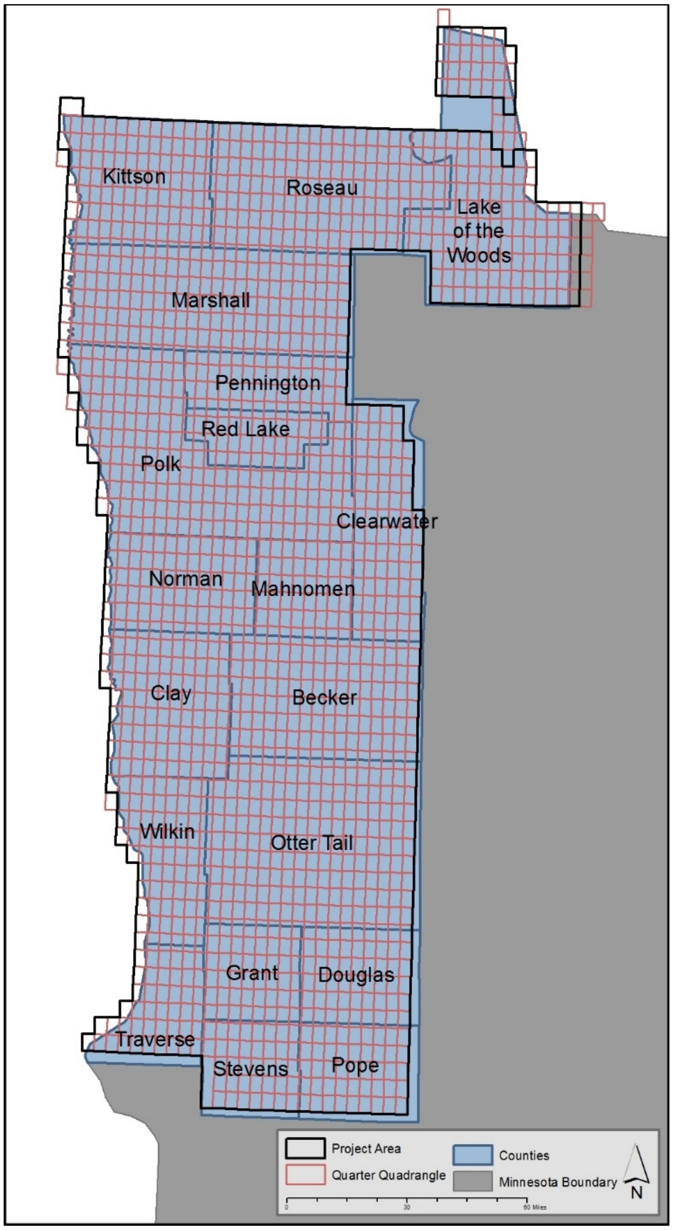


Figure 1. Minnesota NWI Update – Northwest Project Area.

This work resulted in the update of a wetland database that was created between 1980 and 1986 to the date of aerial photography used for this project (2013/14). Improved accuracy was achieved through the utilization of up-to-date GIS software and additional, highly accurate, ancillary datasets that were not available at the time of the previous mapping. The Minnesota Department of Natural Resources (MN DNR) Resource Assessment Program (RAP) personnel supported the project through pre-processing of ancillary datasets, Quality Assurance/Quality Control (QA/QC) support, and project documentation. The QA/QC support for this project provided by RAP included field work for photo-signature convention development, field work for data validation, and on-screen QA/QC review. It is anticipated that RAP’s contribution to the project will be distributed with about 25% of their available resources toward data processing and the remaining 75% directed toward QA/QC and project documentation. Total RAP effort was based on RAP’s available resources.

Data

The Northwest Minnesota NWI project utilized a variety of data types. Base data consisted of the most current 2013/2014 color-infrared (CIR) air photo imagery (high resolution, leaf-off, 4-band imagery). Ancillary datasets included the following: true color one-meter resolution satellite imagery (National Agriculture Imagery Program [NAIP] source), three-meter Light Detection and Ranging (LiDAR) elevation data (where available), ten-meter digital elevation data (U.S. Geological Survey [USGS]; used in areas where LiDAR is not available), soil data from the Soil Survey Geographic Database (SSURGO), digital topographic maps (digital raster graphic [DRG] format), the Minnesota Restorable Wetland Inventory (RWI), the MN DNR Public Waters Inventory (PWI), statewide data from the National Hydrology Dataset (NHD), surface hydrology (streams and lake), and existing NWI data.

Imagery

Several air photo imagery sources were utilized for this project; these include the most current 2013/2014 CIR and multiple years of true-color imagery from NAIP. The CIR was used as the base, or primary, data source for wetland delineation and classification decisions, while the NAIP imagery provided support in decision-making.

2013/2014 Color Infrared (CIR) Satellite Imagery

The CIR for this project was taken during the spring and has leaf-off, one-meter resolution. It covers the entire project area but can vary in color depending on the time in spring it was taken. There is a relatively small window in the spring, typically two to four weeks, when adequate CIR imagery may be taken; this window is after snow melt and before leaf flush. Depending on when during this two to four-week period the image was taken, some wetlands in the CIR will have red tones and the uplands have gray tones, while in other areas the opposite occurs where the uplands will have red tones and the wetlands have gray tones. Due to the large size of this project area, color variations in the CIR will occur and project mapping conventions will address these and other sources of imagery color hue variables.

National Agriculture Imagery Program (NAIP) Satellite Imagery

In addition to the spring CIR, multiple years of true-color NAIP imagery are available online through a Minnesota GeoSpatial Information Office (MnGeo) Web Mapping Service (WMS). As previously mentioned, this ancillary imagery was utilized as a secondary source to help in wetland delineation and classification decision-making. For example, imagery taken in the spring will not indicate the presence of aquatic bed (AB) wetlands, as the vegetation in those particular wetlands does not appear until later in the growing season. Due to NAIP imagery being taken later in the year, aquatic bed wetlands will appear in the imagery and can thus easily be delineated. Multiple years of NAIP imagery are available from MnGeo; the most recent summer imagery (2015) was the default when an ancillary imagery source was needed for proper wetland delineation and classification.

Soils, Topography, and Bathymetry

Soil Survey Geographic Database (SSURGO)

Two soil datasets were processed as inputs for this NWI update project. Along with providing insight into soil components that are cumulatively 85% (or higher) hydric and amount of organic matter, a series of queries, developed by the MN DNR, were calculated to create a continuous (quantitative) variable map based on a soil's water regime. A water regime value was determined through a concatenation of drainage class, April flood frequency, April pond frequency, and August pond frequency. For example, a soil component with a water regime of seven means the soil is very poorly drained with ponding throughout most of the year, while a water regime of zero means the soils is excessively or well drained with no flooding or ponding.

Table 1. Description of water regime classification used in defining the level of hydrology in soil components (MN DNR 2012).

Water Regime	Description
0	All excessively drained, somewhat excessively drained, and well drained soils as well as udorthents, udipsamments, pits, and gravel. This water regime level also includes moderately well drained soils and somewhat poorly drained soils that do not flood.
1	This water regime level includes moderately well drained soils and somewhat poorly drained soils that do flood at least rarely. (floodplain formations) This is similar to Cowardin's temporarily flooded "A" water regime.
2	Poorly drained and very poorly drained soils that neither flood nor pond. This is similar to Cowardin's saturated "B" water regime.
3	Poorly drained soils that occasionally flood during spring (almost all floodplain formations). Similar to Cowardin's "A" or "C" water regime depending on the length of flooding.
4	Very poorly drained soils with frequent spring flooding, but no ponding (almost all floodplain formations). Similar to Cowardin's seasonal "C" water regime.
5	Very poorly drained soils with frequent spring flooding and spring ponding (almost all floodplain formations). Similar to Cowardin's seasonal "C" water regime.

Water Regime	Description
6	Very poorly drained soils with no flooding, but that do have spring ponding (almost all depressional formations). Similar to Cowardin's seasonal "C" water regime.
7	Very poorly drained soils with ponding throughout most, if not all the year (marsh). Similar to Cowardin's "F" water regime.
8	Map units designated as water (non-soil). Similar to Cowardin "H" water regime.

U.S. Geological Survey (USGS) Topographic Maps (Digital Raster Graphic [DRG])

The USGS 1:24,000 scale topographic map series, also known as DRG, are not only used to verify the presence of hydrologic indicators through wetland symbology (i.e., marsh symbols, intermittent and perennial streams), but they can also be used to determine human-made changes to the landscape, such as new development. These maps also provide ten-foot elevation contours, which can be used for landscape-scale terrain analysis. For this project, the two foot contours and other topographic layers derived from LiDAR were the primary source for elevation analysis, while the DRGs were secondary.

MN DNR Lake Bathymetric Digital Elevation Model (DEM)

The MN DNR Lakes DEM data contain bathymetric data for select lakes throughout the state. The data are in raster format with cell values representing depth. The cell size in most cases is five square meters with some of the larger lakes resampled to ten square meters in order to keep file sizes down to a manageable size. There are a total of 6,096 lakes in the statewide database, of which 534 intersect the Northwest MN project area. This data was used to determine those classifications that are dependent on water depth, mainly the boundary between the limnetic (L1) and littoral (L2) subsystems within the lacustrine Cowardin et al. (1979) system. This supported a more efficient wetland delineation and classification decision-making process.

Light Detection and Ranging (LiDAR) Derived Products

LiDAR Digital Elevation Model (DEM)

In cases where three-meter LiDAR is available, there is both a regular DEM and a hillshade version. The hillshade version is useful for visual interpretation while the regular DEM is used in deriving other elevation data (i.e., contours). All portions of the project area that fell beyond the Minnesota state boundary (i.e., North Dakota, South Dakota, and Canada) did not have LiDAR coverage that could be used for this project (Figure 2).

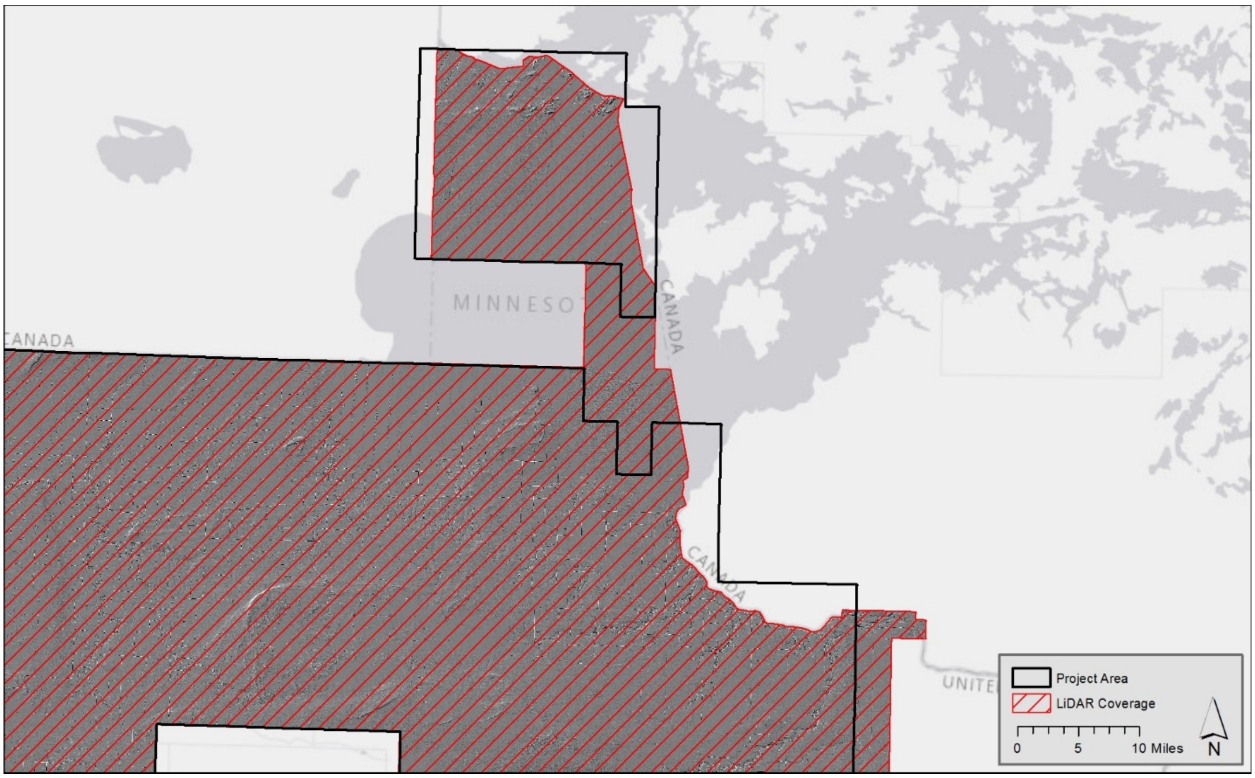


Figure 2. Gaps in LiDAR coverage occur in areas near the Canadian (above graphic), North Dakota, and South Dakota borders.

LiDAR Derived Datasets

Compound topographic index (CTI), Topographic Position Index (TPI), Maximum Vegetation Height, slope, and curvature are all raster datasets derived from the LiDAR data that can be used to aid photointerpretation. LiDAR can also be used to derive vector datasets, such as elevation contours, hydrologic flow networks, and a topographic basins layer, to aid in the classification process.

<u>Compound Topographic Index (CTI)</u>

Compound Topographic Index, also referred to as Topographic Wetness Index (TWI), is a hydrologic index that expresses the wetness of a particular location based on the ratio of upslope catchment area to the slope of a particular location; higher CTI values are more likely to collect water thus indicating the presence or potential of a wetland.

Topographic Position Index (TPI)

Topographic Position Index indicates the shape of the land at a given point by comparing the elevation of that point to the average elevation of the surrounding area. Definition in the size and shape of the surrounding area for the TPI analysis can affect its behavior. Positive TPI values indicate peaks or ridges while negative TPI values indicate valleys or depressions; a value of zero represents either flat areas or saddles. One particular useful application of TPI is for determining the level to which streams are incised into the landscape.

Maximum Height of First Return Points

LiDAR LAS data can provide relative measurements of physical height through the first return points. The maximum height of first return point raster layer generated by the MN DNR can provide insight into vegetation height and can be used to distinguish between forested and scrub-shrub areas. Time of day and year, sun angle, and cloud cover can influence the output intensity, thus this dataset is considered ancillary data and is best used on a local level.

Slope and Curvature

Slope and its derived curvature are both useful in making wetland classification decisions. For example, areas with high slope can often be eliminated from consideration for inclusion as a wetland while gently sloped areas can have saturated soils and are thus considered a potential wetland.

Elevation Contours

Two-foot elevation contours compliment the LiDAR datatset when determining elevation changes in the landscape. For example, when working in floodplains, the contours can help in keeping the delineation from going too far up a slope.

Hydrologic Flow Network

The hydrologic flow network is considered a compliment to existing linear flow network datasets (i.e., NHD, DRG stream display). It is derived from high resolution up-to-date LiDAR data and can be used to detect changes over time in linear flow network datasets. Due to the topographic nature of LiDAR derived products, caution is taken when viewing the hydrologic flow network. The presence of a flow line in the derived data does not necessarily mean that there is normally surface water flow associated with that linear feature.

Topographic Basins

Topographic basins are generated using a fill routine on high resolution DEM data. Basins can be derived to detect shallow and small depressions that fall under the resolution of other spatial layers such as the DRG. Basin mapping is also useful for finding small wetlands under tree canopy. Similar to the hydrologic flow network, LiDAR-derived basins do not necessarily indicate the presence of a wetland. They are useful in determining areas on the landscape where water could potentially pool and contribute to hydric soil development. Imagery signatures and other ancillary datasets are required to confirm the presence or absence of a wetland.

Stochastic Depression Analysis

Stochastic depression analysis uses high-resolution LiDAR data and Whitebox software's Geospatial Analysis Tools to identify depressions that may support wetland types that are normally difficult to detect. This method was successfully used to identify woodland vernal pools in Massachusetts (Wu et al. 2014). In the Northwest Minnesota project area, this layer was useful in locating wetlands under a thick wooded canopy.

National Wetland Inventory Historic Data

The existing NWI data, known as historic data, can aid in decision making. Most of the historic data are over thirty years old and were mapped at a scale of 1:60,000 or smaller using traditional analog photointerpretation methods. This dataset can provide insight into difficult situations where the wetland water regime or vegetation type is difficult to determine with the current ancillary data.

Additional Ancillary Data

Datasets such as public lands, NHD, and the Minnesota PWI are useful in situations where the interpreter needs to understand on a larger scale what is happening on the landscape. The age and scale of the ancillary data varies across the project area, limiting its usefulness in automated processes. In addition, some datasets are derived from information present on other ancillary datasets such as the NHD using the DRG for deriving stream networks.

Data Standards

Data Format

The entirety of this project was conducted in the Environmental Systems Research Institute (Esri) ArcGIS 10.4.1 software. All wetland data reside in a file geodatabase and are in the format of polygon feature classes.

Projection

Updated wetland data were created inside the North American Datum (NAD) 1983 Universal Transverse Mercator (UTM) Zone 15 North projection. In terms of data delivery, the NAD83 UTM Zone 15N was used as the dataset projection to the Minnesota DNR, while NAD83 Albers Equal Area Conic was used as the projection to the U.S. Fish and Wildlife Service (USFWS) and ultimately ended up in the National NWI dataset.

Horizontal Accuracy

Wetland boundaries are coincident with the base imagery. This means that 95% of defined boundaries (e.g., water-land boundaries) occur within 20 feet of the boundary position on the base imagery. This requirement is consistent with the National Map Accuracy Standard for maps with a scale of 1:6,000.

Classification Accuracy

The delivered wetland data meets the classification accuracy goals set in the Federal Geographic Data Commission (FGDC) Wetland Mapping Standard. These accuracy goals include an interpreter's accuracy greater than or equal to 98% for wetland features larger than one-half acre that are visible on the imagery and an overall classification accuracy greater than or equal to 85% for the Cowardin class level. In addition, the delivered wetland maps have a user's accuracy greater than or equal to 92% for wetland features. Evaluation of this goal will be conducted by comparing wetland maps to set validation points developed from an independent analysis conducted by the State of Minnesota and the University of Minnesota. Results from this analysis will be included in the final metadata.

Target Mapping Unit

Wetlands greater than one-half acre are subject to the accuracy assessment goals described above. Any independent wetland features that are less than one-half acre, and visible at a 1:6,000 scale, were mapped but are not subject to the above accuracy standards.

Cartographic Standards

Wetland feature boundaries are represented with a level of detail at the scale of 1:6,000. Features smaller than one-twentieth of an acre (~200 square meters) were not mapped as independent features. Instead they were incorporated into the predominant adjacent class. Upland features were not mapped. In terms of the line work, the wetland feature boundaries were delineated using the Esri ArcGIS standard editing construction tools and should not have a jagged appearance or sharp edges.

Data Verification

The delivered data is logically consistent and topologically complete. It is comprised of simple feature polygons with no overlaps and no gaps between adjacent polygons. A seamless coverage was created through an edge-matching process between all 1,634 quarter quadrangles (QQ) (408.5 USGS 7.5-minute quadrangle equivalents) and to other adjacent Minnesota project areas. The NWI Verification Toolset attribution and topology rules, as well as internal error checking scripts, was again applied to the dataset in order to ensure integrity of the final product.

Metadata Information

Metadata meet the requirements of the Minnesota Geographic Metadata Guidelines. It includes a statement of tested classification accuracy, an error matrix, a full description of the data lineage, and spatial reference information. In addition, a final version of the mapping conventions document that includes all modifications to the mapping procedures was prepared and delivered to MNDNR.

Documentation

Saint Mary's University of Minnesota GeoSpatial Services (GSS) documented their mapping methods and provided this documentation to the MN DNR for approval. If any substantial mapping methods took place, approval by the MN DNR occurred.

Training

GSS ensured that all interpreters working on this project had adequate training both in the office and out in the field. All training documentation and interpreter productivity was kept in records and available for the MN DNR to review if necessary. Interpreters working for GSS could demonstrate proper spatial editing for wetland delineation and had proficient knowledge in wetland classification according to the Cowardin et al. (1979) standards.

Data Management

GeoSpatial Services maintains a secure system to manage input data, intermediate products, and final wetland data with provisions for full data back-up and restoration. All input data not being viewed from the MnGeo Web Mapping Services resides on dedicated network attached storage (NAS) devices. All project work (i.e., created wetland data, ancillary datasets) resides on the GSS project server that is differentially backed up daily with a full back up performed weekly and stored in multiple locations. Data were tracked through a work flow by the project manager (see section "Project Workflow"). Interpreters were given checkouts that were comprised of any number of QQs. Copies of these checkouts were saved at major milestones (i.e., initial editing session, QA/QC approval). Once the final data are delivered, GSS will maintain a copy of the data for at least one year.

Classification

This project classified wetland features using three different classification systems:

- Cowardin Classification (Kloiber and Macleod 2011)
    - Modified from Classification of Wetlands and Deepwater Habitats of the United States by (Cowardin et al. 1979)
- Simplified Hydro-Geomorphic Classification (SHGM) (Kloiber and Macleod 2011)
    - Modified from Landscape Position, Landform, Water Flow Path, and Waterbody Type (LLWW) by (Tiner 2011)
- Simplified Plant Community Classification (SPCC) (Kloiber and Macleod 2011)
    - Modified from Wetland Plants and Plant Communities of Minnesota and Wisconsin by (Eggers and Reed 1997)

Cowardin Classification

Modifications to the Cowardin et al. (1979) classification system, as specified in Kloiber and Macleod (2011), were used to classify all Minnesota wetlands in this project (Table 2). Where appropriate, wetland classifications included a system, subsystem, class, sub-class, water regime, and special modifier. Table 2 below contains the modified Cowardin et al. (1979) classification codes valid for the project. Since the Cowardin et al. (1979) system is the most explicit and highly resolved of all three classifications systems used for this project, it served as the foundation for determining the other two classification systems.

Table 2. Valid Cowardin Classification codes (Kloiber and Macleod 2011).

System	Subsystem	Class	Subclass	Water Regime	Special Modifier
L	1	UB		H, K	h, x
L	2	UB		F, H, K	b, d, h, x
		AB		F, H, K	b, d, h, x
		EM	2	F, H, K	b, d, h, x
		US		A, C, K	b, d, h, x
		RS		A, C, K	b, d, h, x
		RB		F, H, K	b, d, h, x
P		UB		F, H, K	b, d, h, x
		AB		F, H, K	b, d, h, x
		EM	1	A, B, C, F, K	b, d, f, h, x, q
			2	C, F, H, K	b, d, h, x
		FO	1, 2, 3	A, B, C, F, K	b, d, h, x, q
		SS	1, 2, 3, 4	A, B, C, F, K	b, d, h, x, q
		US		A, C, K	b, d, h, x
		RB		F, H, K	b, d, h, x
		ML		B	d, q
R	2	UB		H	h, x
		AB		H	h, x
		EM	2	F, H	h, x
		US		A, C	h, x
		RS		A, C	h, x
		RB		F, H	h, x
R	3	UB		F, H	h, x
		US		A, C	h, x
		RS		A, C	h, x
		RB		F, H	h, x
R	4	SB		A, C	h, x

Simplified Hydro-Geomorphic Classification (SHGM)

Modifications to the LLWW classification system, as specified in Kloiber and Macleod (2011), were also used to classify all Minnesota wetlands in the project. This simplified hydro-geomorphic system (SHGM) classifies wetlands and water bodies based on landscape position, surface hydrology, and relationship to nearby landscape features including other wetlands and waterbodies. In a similar manner to Cowardin et al. (1979), SGHM uses codes to describe wetland characteristics but it differs from the full LLWW classification in that no special modifiers are applied. In SHGM, and LLWW, a wetland feature can be put into one of two categories: wetlands or waterbodies. A wetland feature coding schema can take two different forms depending on what category the feature is put into. The two schema forms are described below with their descriptive keys.

Wetlands = Landscape Position | Landform | Water Flow Path

SHGM codes for this category are six characters in length. Landscape Position is an uppercase two-letter code that describes whether the wetland is associated with a lake, a river, or surrounded by uplands. Wetlands associated with lakes are defined as lentic (**LE**). Wetlands associated with flowing water are classified as lotic streams (**LS**) or lotic rivers (**LR**), depending upon their size. Wetlands that are surrounded by uplands as part of an isolated basin are classified as terrene (**TE**) (Table 3).

Table 3. SHGM Landscape Position Dichotomous Key (Kloiber and Macleod 2011).

	Landscape Position Dichotomous Key	
1a	Wetland lies along a river, stream, lake, or reservoir, or in-stream pond; or within a relatively flat plain contiguous to a waterbody	2
1b	Wetland does not lie along one of these waterbody types; it is surrounded by upland or borders a pond that is surrounded by upland	Terrene
2a	Wetland lies along a lake or reservoir or within its basin (i.e. the relatively flat plain contiguous to the lake or reservoir)	Lentic
2b	Wetland lies along a river, stream, or in-stream pond	3
3a	Wetland is the source of the river or stream and this watercourse does not flow through the wetland	Terrene
3b	A river or stream flows through or alongside the wetland	4
4a	Wetland is periodically flooded by river or stream	5
4b	Wetland is not periodically flooded by the river or stream	Terrene
5a	River or stream that flows through wetland is represented by a single line on USGS 7.5-minute topographic map	Lotic Stream
5b	River or stream that flows through a wetland is represented by a polygon on USGS 7.5-minute topographic map	Lotic River

Landform is the second portion of the code and is also made up of two uppercase letters. Landform refers to the geomorphic structure on or in which the wetland resides. There are six inland landforms present in Northwest MN. These are slope (**SL**), island (**IL**), fringe (**FR**), floodplain (**FP**), basin (**BA**), and flat (**FL**) (Table 4). The interfluve (IF) landform is not included for this project.

Table 4. SHGM Landform Dichotomous Key (Kloiber and Macleod 2011).

Landform Dichotomous Key		
1a	Wetland occurs on a slope greater than 2%	Slope
1b	Wetland does not occur on a slope greater than 2%	2
2a	Wetland forms an island completely surrounded by water	Island
2b	Wetland does not form an island	3
3a	Wetland occurs in the shallow water zone of a permanent waterbody	Fringe
3b	A river or stream flows through or alongside the wetland	4
4a	Wetland forms a non-vegetated bank or is within the banks of a river or stream	Fringe
4b	Wetland is a vegetated stream bank or is not within the banks	5
5a	Wetland occurs on the active alluvial floodplain along a river	Floodplain
5b	Wetland does not occur on an active floodplain	6
6a	Wetland occurs in a distinct depression	Basin
6b	Wetland occurs on a nearby level landform	Flat

Water flow path refers to how and if the wetland feature is part of the surface hydrology network. Common examples of the water flow path code include inflow (**IN**), outflow (**OU**), and throughflow (**TH**). Wetlands that are not connected to the surface hydrology network are classified as isolated (**IS**) (Table 5).

Table 5. SHGM Water Flow Path Dichotomous Key (Kloiber and Macleod 2011).

Water Flow Path Dichotomous Key		
1a	Wetland is typically surrounded by upland; receives precipitation and runoff from adjacent areas with no apparent outflow	Isolated
1b	Wetland is not geographically isolated	2
2a	Wetland is a sink receiving water from a river, stream, or other surface water source lacking surface water outflow	Inflow
2b	Wetland is not a sink; surface water flows through or out of the wetland	3
3a	Wetland flows out of the wetland, but does not flow into this wetland from another source	Outflow
3b	Water flows in and out of the wetland, or the water table fluctuates due to the presence of a lake or stream	4
4a	Water flows through the wetland through an identifiable channel	Throughflow
4b	Wetland occurs along a lake or reservoir and not along a river or stream; its water levels are subject to the rise and fall of lake or reservoir levels	Bidirectional-Nontidal

Some examples of complete codes in the wetland category are shown below:

LEBABI: This is a basin (**BA**) wetland associated with a lake (**LE**). It has bidirectional flow (**BI**), which is the type of flow associated with fluctuating lake levels.

LSFRTH: This wetland is located on the fringe (**FR**) of a stream (**LS**). It has throughflow (**TH**).

LRFRTH: This wetland is located on the fringe (**FR**) of a river (**LR**). As might be expected for many of these types of wetlands, it has throughflow (**TH**).

TEBAIS: This code refers to a terrene (**TE**) wetland or a wetland surrounded by uplands. It is in a basin (**BA**), and because it is disconnected from the surface hydrology network, it is given the isolated (**IS**) water flow path.

Waterbody = Waterbody | Water Flow Path

SHGM codes for this category are four characters in length. Water Body consists of an uppercase two letter code. Four waterbody types are present in Northwest MN; these are lake (**LK**), river (**RV**), stream (**ST**) and pond (**PD**). When a feature is classified as a water body, there is no landform code applied because the water body can be considered its own landform (Table 6).

Table 6. SHGM Waterbody Dichotomous Key (Kloiber and Macleod 2011).

	Waterbody Dichotomous Key	
1a	Waterbody is predominantly flowing water	2
1b	Waterbody is predominantly standing water	3
2a	Waterbody is represented by a polygonal feature on the USGS 7.5-minute topographic map	River
2b	Waterbody is represented by a linear feature on the USGS 7.5-minute topographic map	Stream
3a	Waterbody is permanently flooded, greater than 6.6 feet deep at low water, and is not associated with a morainal “kettle” or a “bog pond”	Lake
3b	Waterbody is less than 6.6 feet deep at low water, or is associated with a morainal “kettle” or a “bog pond”	4
4a	Waterbody is less than 20 acres is size	Pond
4b	Waterbody is greater than or equal to 20 acres is size	Lake

Water flow path refers to how and if the wetland feature is part of the surface hydrology network. Common examples of the water flow path code include throughflow (**TH**), inflow (**IN**) and outflow (**OU**). Wetlands that are not connected to the surface hydrology network are classified as isolated (**IS**) (See Table 5 above).

Some examples of complete codes under this category are shown below:

> **LKIN**: This water body is a lake (**LK**) with surface water flowing into it, but not out of it; thus inflow (**IN**) is the water flow path.
>
> **PDIS:** This code refers to a water body that is a pond (**PD**) that is isolated (**IS**) from the rest of the surface hydrology network.

Most of the water flow path codes are the same for both wetlands and water bodies. However, there are small differences between them, which makes following the SHGM keys crucial when assigning codes. It should be emphasized that this classification can only consider surface hydrology. Subsurface hydrologic connectivity is not considered because these characteristics cannot be assessed through image interpretation. The SHGM codes that are expected to be found in Northwestern MN are shown in Table 7.

Table 7. Valid Simplified Hydro-Geomorphic (SHGM) Classification codes (Kloiber and Macleod 2011).

Landscape Position Code (Description)	Landform Code (Description)	Water Flow Path Code (Description)	Waterbody Code (Description)
LE (Lentic)	SL (Slope)	VR (Vertical Flow)	LK (Lake)
LR (Lotic River)	IS (Island)	IN (Inflow)	RV (River)
LS (Lotic Stream)	FR (Fringe)	OU (Outflow)	ST (Stream)
TE (Terrene)	FP (Floodplain)	TH (Throughflow)	PD (Pond)
	BA (Basin)	BI (Bidirectional-Nontidal)	
	FL (Flat)		

As previously mentioned, the wetland features created during the Cowardin classification process served as the foundation for creating SHGM data. The wetland feature class had an additional field added to the attribute table which was populated with the proper SHGM codes. The entire procedure for SHGM classification is outlined in the succeeding Project Workflow section below.

Simplified Plant Community Classification (SPCC)

A simplified plant community classification (SPCC) based on a modified version of the Eggers and Reed (1997) classification system was also applied to all wetland features. The attribution inside the feature class was applied as described by Kloiber and Macleod (2011) (Table 8). It should be noted that features classified with the artificially flooded (K) water regime were not included in any of the plant community classes. These were attributed with “N/A” in the SPCC attribute field.

Table 8. Simplified Plant Community Classes (SPCC), cross-referenced to Eggers and Reed (1997)

MN Simplified Plant Community		Eggers and Reed (1997) Plant Community	
Type	**Class**	**Type**	**Class**
1	Seasonally Flooded Basin	16B	Seasonally Flooded Basin
2	Wet Meadow	13A	Sedge Meadow
		15B	Fresh (Wet) Meadow
		15A	Wet to Wet-Mesic Prairie
		14A	Calcareous Fens (Herbaceous Type)
3	Shallow Marsh	13B	Shallow Marsh
4	Deep Marsh	12B	Deep Marsh
5	Shallow Open Water Community	16A	Shallow Open Water Community
6	Peatland	10A	Open Bog (Herbaceous Type)
		7A	Open Bog (Shrub Type)
		4A	Coniferous Bog
7	Shrub Wetland	8B	Shrub-Carr
		8A	Alder Thicket
		7B	Calcareous Fens (ShrubType)
8	Hardwood Wetland	3B	Hardwood Swamps
		3A	Floodplain Forests
9	Coniferous Swamps	4B	Coniferous Swamps
10	Non-Vegetated Aquatic	N/A	N/A

The SPCC attributes were added to the final data after the Cowardin and SHGM classifications were applied, and all delineations were reviewed and approved. In a similar fashion to the addition of the SHGM descriptors, the Cowardin classification and delineation provided the spatial foundation to which the SPCC descriptors were added. A series of SQL database queries based on the relationships defined in Table 9 were used to populate the SPCC descriptor field. The entire procedure for the addition of the SPCC identifiers is outlined in the succeeding Project Workflow section below.

Table 9. Simplified Plant Community Classification (SPCC), Cross-referenced to Cowardin Classification.

Simplified Plant Community Class	Cowardin Codes
Coniferous Bog	PFO2Bq, PFO4Bq
Coniferous Wetland	PFO2B, PFO4B
Deep Marsh	L2EM2G, L2EM2H, PEM2G, PEM2H, R2EM2G, R2EM2H
Hardwood Wetland	PFO1A, PFO1B, PFO1C
Non-Vegetated Aquatic Community	L1UBH, L2RSC, L2USA, L2USC, PUSA, PUSC, R2UBF, R2UBG, R2UBH, R2USA, R2USC, R3UBG, R4SBA, R4SBC, L2UBF, L2UBG, L2UBH, PUBF, PUBG, PUBH
Open Bog	PEM1Bq, PSS1Bq, PSS2Bq, PSS3Bq, PSS4Bq
Seasonally Flooded/Saturated Emergent Wetland	PEM1A, PEM1B
Shallow Marsh	L2EM2F, PEM1C, PEM1F, PEM2F, R2EM2F
Shallow Open Water Community	L1ABH, L2ABF, L2ABG, L2ABH, PABH, R2ABG, R2ABH, PABF, PABG
Shrub Wetland	PSS1A, PSS1B, PSS1C, PSS1F, PSS2B, PSS3B, PSS4B
Artificially Flooded Hardwood Wetland	PFO1K
Artificially Flooded Non-Vegetated Aquatic Community	L1UBK, PUSK, L2UBK, PUBK
Artificially Flooded Shallow Marsh	PEM1K
Artificially Flooded Shallow Open Water Community	L2ABK, PABK
Artificially Flooded Deep Marsh	L2EM2K, PEM2K
Artificially Flooded Shrub Wetland	PSS1K, PSS3K

Project Workflow

Introduction

This project was broadly divided into two phases. The first phase consisted of initial field visits, developing a photo-interpretation guide, and documenting the technical procedures, while the second phase consisted of data production, which can be subdivided into draft data production and final data preparation. Data quality was evaluated with respect to the data standards (please see Data Standards Section above). Field visits were used to correlate photo-signatures and other indicators present in the digital data to the presence and classification of wetlands on the ground. Field visits also helped to identify factors unique to the study area. Draft data were used to prototype the technical procedures and photo-interpretation guide. Once the draft data were approved and the technical procedures were finalized, data production began.

The production work flow is outlined in Figure 3. The workflow was divided into draft data development, and final QA/QC and processing. There are several places in the work flow where the data were assessed against the project standards. If it did not meet the standards, it was revised based on the feedback of the reviewing party.

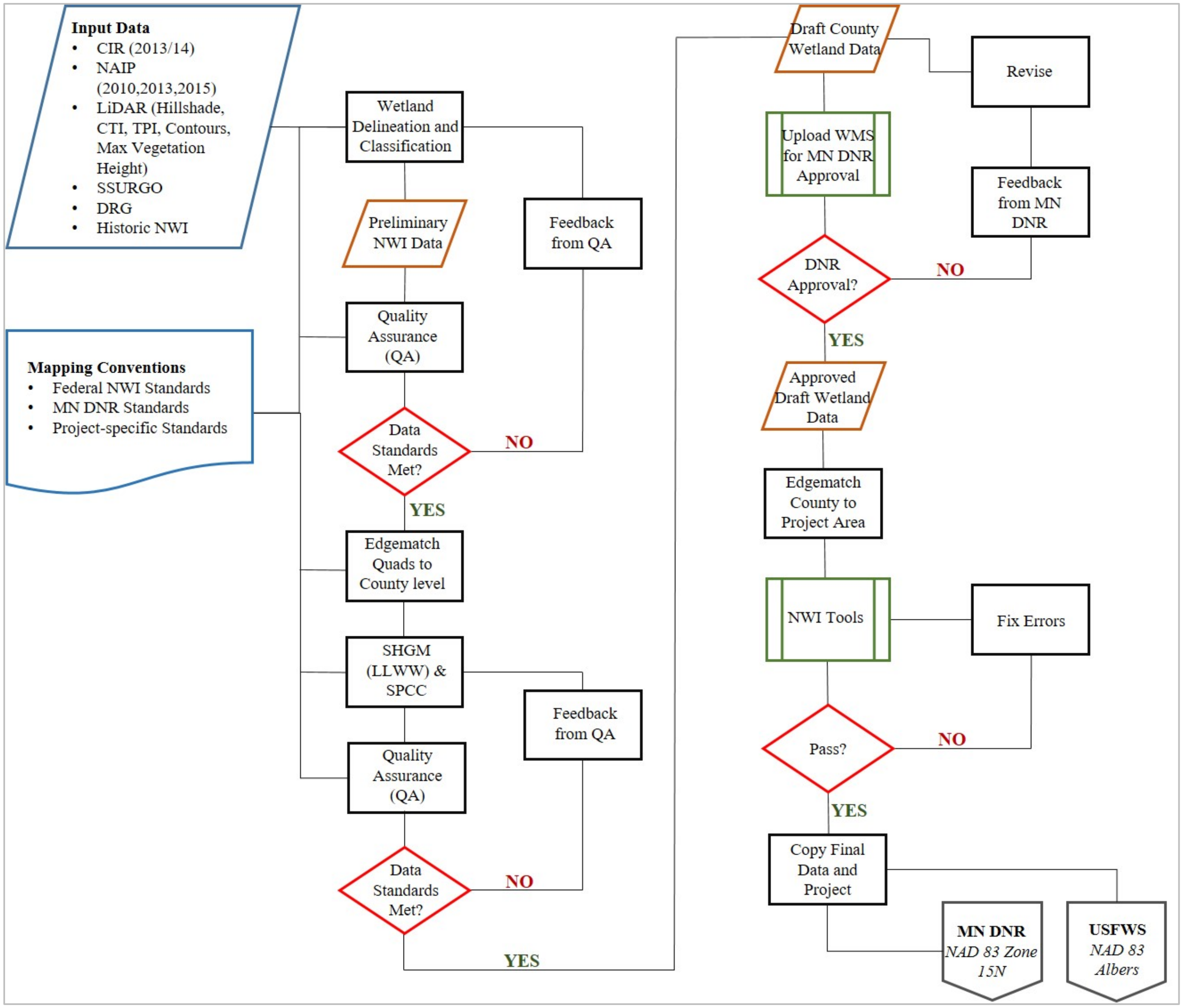


Figure 3. Northwest Minnesota NWI Update Work Flow.

Process Documentation

This document defines the delineation and classification process for this project. The Technical Procedures portion explains the standards and procedures of the project while the Photointerpretation Guide (Appendix A) provides specific direction on particular signatures and classification.

Field Verification and Review

Field verification is a vital part of the photointerpretation process with several objectives:

1. Document commonly occurring signatures and habitats.
2. Document unusual but important signatures.
3. Determine and verify the classification of difficult to distinguish signatures, including distinguishing between upland and wetland.
4. Verification of water regimes.
5. Document variability in photo-signatures due to variability in the imagery and location within the study area (i.e., multiple ecoregions).

Field sites were selected to meet these objectives. The process of selecting sites involved reviewing the imagery and creating points in a feature class of the site locations. The site locations were then used to plan the logistics of each field trip and uploaded to a GPS for navigational purposes. Field visits occurred in the spring after the ground had thawed, but before vegetation leaf flush was complete. This makes it easier to observe conditions on the ground. For sites on public land, formal documentation was possible which could include a collection of a GPS point at the site location, a soil probe test, and completion of a field data sheet which records information like location, ownership, soil test results, vegetation species, etc. Informal documentation was all that could be performed for sites on private land, which consisted of examination of the site from a public right of way. In both cases, ground level photographs documenting the site and notes and/or delineations on hard copy maps were gathered.

Data Production

Data production utilized on-screen digitizing methods, which were the same methods used to generate the draft data. Figure 3 above represents the production workflow and its four stages. Delineation and classification using the FGDC Cowardin Classification system was the first stage and the most labor-intensive portion of data production. This stage occurred at the 7.5-minute quadrangle level. It included initial delineation and attribution by an editor and internal QA/QC by GSS staff, concluding with the edgematching of quad data to the county level. The second stage was assigning SHGM (referred to as “LLWW” in workflow) and SPCC (referred to as “modified plant community classification” in workflow) attributes at the county level. The third stage was the MN DNR draft review phase. At this stage the draft data were submitted by county to MN DNR WMS for review and feedback (external QA/QC). If not approved, GSS incorporated MN DNR’s feedback and resubmitted for review. Once approved, the data moved to the fourth and final stage of processing. The approved county level data were edgematched to create a seamless dataset for the entire project area. The NWI QA/QC tools were applied to the data and any errors were fixed. Upon successful completion of the NWI QA/QC tools, two copies of the data were made, one for the MN DNR (in

NAD83 UTM Zone 15N projection) and another for the USFWS (in NAD83 Albers Equal Area Conic projection) to be put into the nation-wide NWI database.

Software and Data Management

Esri ArcGIS 10.4.1 was the GIS software utilized for this project. A file geodatabase was used to house and organize the wetland data. A hard copy form called a routing sheet was generated for each 7.5-minute quadrangle checkout. The routing sheet was used to document the interpreter's checkout information, hours, and polygons created. The Project Lead and QA/QC Specialist were responsible for assigning checkouts, generating the routing sheet, and maintaining the digital data file structure. Each interpreter had a folder in a working directory. When a new checkout was assigned, a blank file geodatabase holding an empty feature class (titled "CONUS_wet_poly") for wetland data creation, along with a shapefile of the checkout boundary, was put into an interpreter's folder. All edits took place within this file geodatabase. As each stage of production was completed, the Project Lead made a copy of the data which was then stored in a different location to serve as a "snapshot" of the data for that particular stage of production. Once the checkout was approved through the QA/QC process, an additional copy was made in another location in order to segregate completed data from in-process data. This was in addition to GSS' organization-wide data back-up system explained in the previous Data Standards section of this document.

The collateral data for this project resided in two locations: a dedicated NAS device and the MnGeo aerial imagery WMS. The WMS was used for the true color NAIP imagery sources and as a back-up for the Spring 2013/14 CIR. The NAS device was the source for all other collateral data (LiDAR and associated products, DRGs, SSURGO, Lake DEMs) and the primary source for the Spring CIR imagery. By accessing the Spring CIR from the NAS device, GSS was able to apply a standard deviation stretch to the imagery to make the wetland signatures more distinctive. This was not possible when accessing the same data from the WMS. In order to ensure the collateral data were not inadvertently edited, permissions were set on the NAS device so that only the project lead had write privileges.

On-Screen Photointerpretation Process

Delineation & Cowardin Classification

This project used an on-screen, heads-up, digitizing process. This approach takes advantage of the editing tools available through ArcMap to delineate and classify wetland features based on photosignatures in ortho-rectified imagery, and supporting collateral data. The Photointerpretation Guide (Appendix A) explains the specifics of how the source imagery and collateral data were applied to delineate and classify each Cowardin wetland type in the Northwest MN project area.

1. The interpreter started by creating a new ArcMap map document. The first data added to the map document was the blank wetlands file geodatabase in order to ensure the data frame was set to the NAD83 UTM Zone 15 North projection. Imagery and collateral data sources were added next. The end result was an ArcMap window similar to the example in Figure 4. Beyond the initial wetlands file geodatabase, it was up to the interpreter to organize in the

Table of Contents and symbolize the data to their liking; this created a unique editing environment to help optimize productivity.

Figure 4

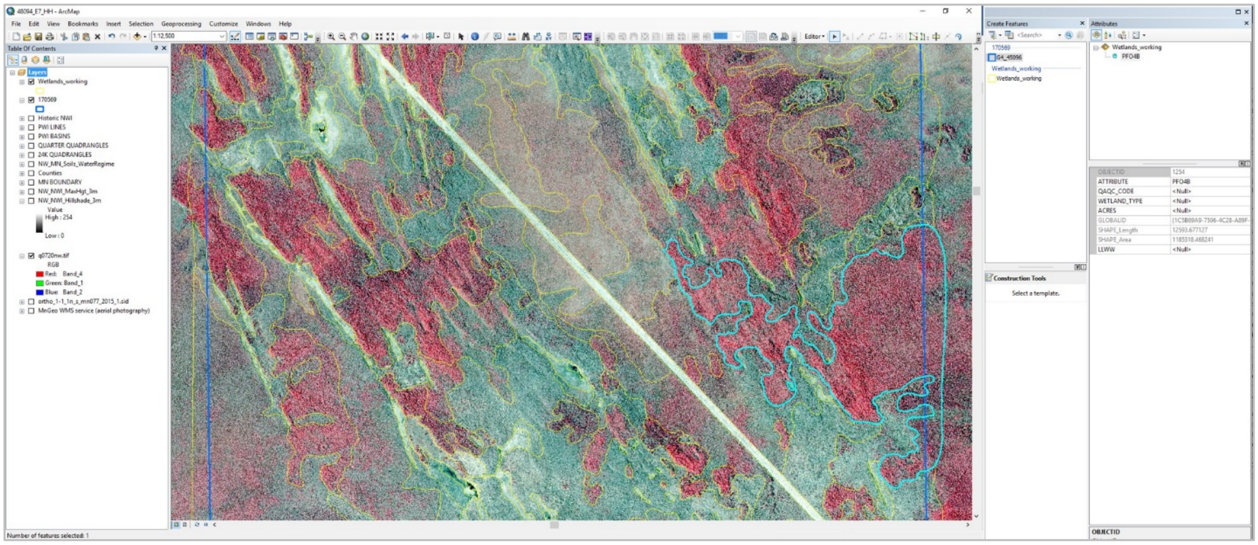
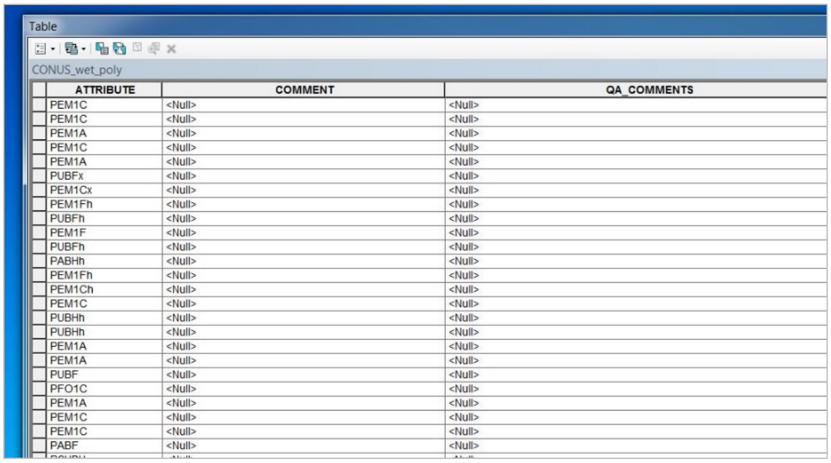


Figure 4. Example ArcMap map document window.

2. To clearly see wetland signatures, the edited wetland feature polygon must be displayed as hollow with a line weight between one-half and one in a line color that contrasts with the background imagery. The CIR must be set to display the red band as band #4, the green band as band #1, and the blue band as band #2. This is a spectral enhancement that allows the use of the near infrared band. A standard deviation stretch of two was also applied to the CIR at this time to help make the wetland signatures, especially emergent signatures, easier to distinguish. Display of the other data layers was at the discretion of the interpreter. However, any display color or technique that interfered with photointerpretation was not allowed, such as non-contrasting colors, and excessively heavy line weights.
3. The entire extent of the assigned checkout was examined for wetlands. This was accomplished through a “mowing the lawn” technique where the interpreter started in the northwest corner of the assigned checkout at the mapping scale of ~1:6,000. This extent was examined for presence of wetlands based on the signatures and other indicators outlined in the Photointerpretation Guide (Appendix A). Where wetlands were found, they were delineated as a polygon feature using the standard ArcMap editing tools.

Wetland classification utilized the Cowardin Classification system and occurred by directly editing the *ATTRIBUTE* field in the CONUS_wet_poly feature class’ attribute table (Figure 5). Wetland classes were assigned as individual wetland polygons were delineated.



Table

CONUS_wet_poly

ATTRIBUTE	COMMENT	QA_COMMENTS
PEM1C	<Null>	<Null>
PEM1C	<Null>	<Null>
PEM1A	<Null>	<Null>
PEM1C	<Null>	<Null>
PEM1A	<Null>	<Null>
PUBFx	<Null>	<Null>
PEM1Cx	<Null>	<Null>
PEM1Fh	<Null>	<Null>
PUBFh	<Null>	<Null>
PEM1F	<Null>	<Null>
PUBFh	<Null>	<Null>
PABHh	<Null>	<Null>
PEM1Fh	<Null>	<Null>
PEM1Ch	<Null>	<Null>
PEM1C	<Null>	<Null>
PUBHh	<Null>	<Null>
PUBHh	<Null>	<Null>
PEM1A	<Null>	<Null>
PEM1A	<Null>	<Null>
PUBF	<Null>	<Null>
PFO1C	<Null>	<Null>
PEM1A	<Null>	<Null>
PEM1C	<Null>	<Null>
PEM1C	<Null>	<Null>
PABF	<Null>	<Null>

Figure 5. Screen shot of CONUS_wet_poly feature class attribute table.

The interpreter was allowed to zoom in to a scale of 1:3,500 if necessary to make edits, but no closer. After all the wetlands in the 1:6,000 extent were found, delineated, and classified, the interpreter panned across the checkout from west to east by one extent with a slight overlap to the previous extent, making sure no areas were missed. The process was repeated for each extent, until the eastern edge of the work area was reached. At this point the interpreter panned south one "row" and started the next pass, moving from east to west. Along the edges of the checkout, the interpreter consulted with the interpreter of the neighboring checkout to help assure consistency across the project area. Any delineation along the edge is overlapped by 100 to 200 meters outside of the work area to expedite edgematching. The panning process continued until the entire checkout had been examined and all wetland features were delineated and classified. At this point the interpreter was required to perform a series of finalization tasks to prepare the checkout for QA/QC.

Interpreter Finalization Tasks

The interpreter checkout finalization tasks were equivalent to the first stages of the QA/QC process. These tasks can be viewed as a "self QA" by the interpreter. Beyond that, it was a vital step in making sure the data being produced met the project standards. The objective of this procedure was to eliminate as many errors and issues as possible before the data were sent to QA/QC. This helped QA/QC focus their efforts on more difficult tasks rather than spending time on mundane, easily addressed issues. After completing photo-interpretation and classification edits, the assigned checkout was finalized by performing the following steps:

1. All CONUS_wet_poly features (edited wetland feature class) were selected and exploded to split any multi-part features into separate polygons. This step may have been repeated multiple times until there were no multi-part features to explode.
2. The CONUS_wet_poly (edited wetland feature class) attribute table was sorted on the *ATTRIBUTE* field in ascending order in order to find null and blank entries. A null or blank entry in the attribute field could occur for a couple reasons. The interpreter may have neglected to assign a classification code to the wetland feature. It could also occur when a "ghost" polygon is created, which means an entry was created in the attribute table, but there is no associated geometry for the feature class. They are created when, inside the attribute table, an interpreter hits the enter key after making an entry. Missing attributes were populated by the interpreter and "ghost" polygons were deleted.

3. The CONUS_wet_poly (edited wetland feature class) attribute table was then sorted on *SHAPE_Area* field in ascending order. The smallest polygons were brought to the top of the attribute table, making it easier for the interpreter to verify whether any polygons less than a quarter-acre (~1,000 square meters) exist. This is mainly to find and address sliver polygons, which were merged with an adjacent polygon, or deleted if not associated with a wetland. In other cases, wetland features less than one-tenth of an acre (~400 square meters) that are part of a complex were merged with the adjacent wetland feature. However, wetland features less than one-tenth of an acre that are easily visible at a scale of 1:6,000 and easily delineated at a scale of 1:3,500 could be retained (i.e., PUBF farm ponds).
4. A check for erroneous attributes was conducted by using "Select by Attribute" on the *ATTRIBUTE* field of the CONUS_wet_poly (editing wetland feature class) table. This was a quick way of getting a list of unique classification code present in the data. Once the Select by Attribute graphical user interface was open (Figure 6), "ATTRIBUTE" was selected in the field list, then the"Get Unique Values" button was selected to populate the values list as shown in the figure. The interpreter reviewed these values and looked for attribution errors. Common errors included invalid attributes (refer to Table 2 for valid attributes), capitalization errors (PeM1A versus PEM1A), missing code components (RUSC versus R2USC), and typographic errors such as using a zero for the letter O (PF01C versus PFO1C). Erroneous attributes were directly edited in the table to fix errors, which may have required looking back to the imagery for verification.

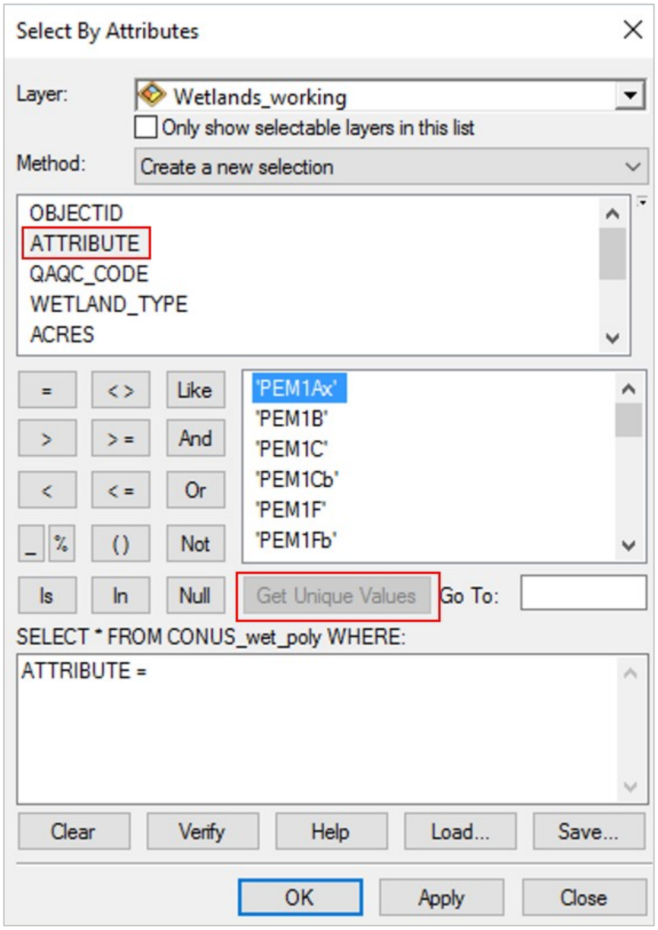


Figure 6. Screen shot of the Select by Attribute graphical user interface.

5. Topology was used to look for geometry issues and at this point, the only rule applied by the interpreter was "must not overlap." The "must not have gaps" was applied later by the QA/QC specialist. The interpreter then validated topology and fixed errors as many times as needed until all polygon overlaps were corrected.

6. After successfully completing steps 1-5, the checkout was considered complete and ready for QA/QC. The interpreter's last step was to record their hours, polygons created, and any relevant notes on the routing sheet and return it to the Project Lead.

The checkout was considered complete when all of the above steps had been executed, errors fixed and the finalization tasks all came back error-free. If the steps were not completed, the QA/QC Specialist immediately returned the checkout back to the interpreter to finish all required steps. As a final step before QA/QC, the Project Lead made a backup copy of the data that was stored in a separate folder.

<u>Quality Assurance/Quality Control (QA/QC)</u>

Wetland Delineations and Cowardin Classification

After finalization tasks, the checkout was sent through the QA/QC process. This process was performed by the Project Lead or the QA/QC Specialist.

1. Opening the interpreter's map document, the Project Lead or QA/QC Specialist verified that all of the interpreter's finalization tasks had been successfully completed. If not, the checkout was returned to the interpreter to complete the tasks. The map document was saved to a different folder as a separate QA/QC map document.
2. Using the QA/QC map document, the entire checkout was reviewed at a 1:6,000 scale using the "mow the lawn" technique to guarantee the entirety of the checkout was reviewed. QA/QC had the same data available to them that the interpreter had when performing the delineations and classifications. QA/QC was verifying that the data met the standards described above (Data Standards), checking the following:
    a. Accurate delineations – the wetlands boundaries are correct based on signatures and supporting collateral data. No wetlands were omitted. No uplands were included.
    b. Correct Cowardin Classifications – attribute values match photo signatures based on imagery and supporting collateral data. All attributes are valid. There are no nulls, and split classes are applied appropriately.
    c. Line work - smooth with no jagged edges. Feature sizes are in line with the minimum mapping unit guidelines, and there are no multi-part features. There are no incorrect (sliver) gaps between polygons and no polygons that overlap adjacent polygons.
    d. General accuracy and consistency – interpreter has consistently and correctly delineated and classified similar signatures across the checkout; decisions conform to the Northwest MN mapping standards.
3. When issues were identified, QA/QC used the QA_COMMENTS field in the CONUS_wet_poly (edited wetland feature class) attribute table and box graphics in the map document to provide feedback. Not all errors were necessarily identified, but enough were highlighted to illustrate any patterns of errors present in the data. If necessary, QA/QC reviewed the issues with the interpreter and returned the checkout and routing sheet so the interpreter could perform revisions. The interpreter performed the requested revisions, repeated the finalization tasks and gave the checkout and routing sheet back to the Project Lead or QA/QC Specialist to start the QA/QC process again. Generally, it was not the

QA/QC's responsibility to perform revisions to the data; however, if there were just a few isolated errors that were not part of a systematic pattern, QA/QC may have performed the revisions rather than returning it to the interpreter.

4. The checkout was finalized and the finalization tasks and checks were run against the data again by QA/QC. During the topology checks, the data were additionally checked for "must not have gaps" along with "must not overlap". This was accomplished by adding a "universal polygon" around the checkout (Figure 7), adding the "must not have gaps" rule to the topology, and verifying topology. The universal polygon was temporary and was created by drawing a box around the entire work area using the auto-complete editor tool. Addition of the universal polygon allowed the "must not have gaps" topology rule to be applied without creating a large number of false positive errors at wetland/upland boundaries. There may still be false positive "must not have gaps" errors where there are uplands surrounded by wetland. This approach reduced the number of false positives while still locating the true gap errors, many of which were tiny sliver gaps that were difficult to locate in a visual inspection. The topology error inspector was used to locate and resolve the flagged topology errors. False positives were set as exceptions and edits were performed to fix the true errors. Topology was verified again and errors fixed until the data were free of topological errors. The universal polygon was then deleted.
5. A backup copy was created and stored in a different location from the working data. The data were then considered complete in regards to delineation and FGDC classification.

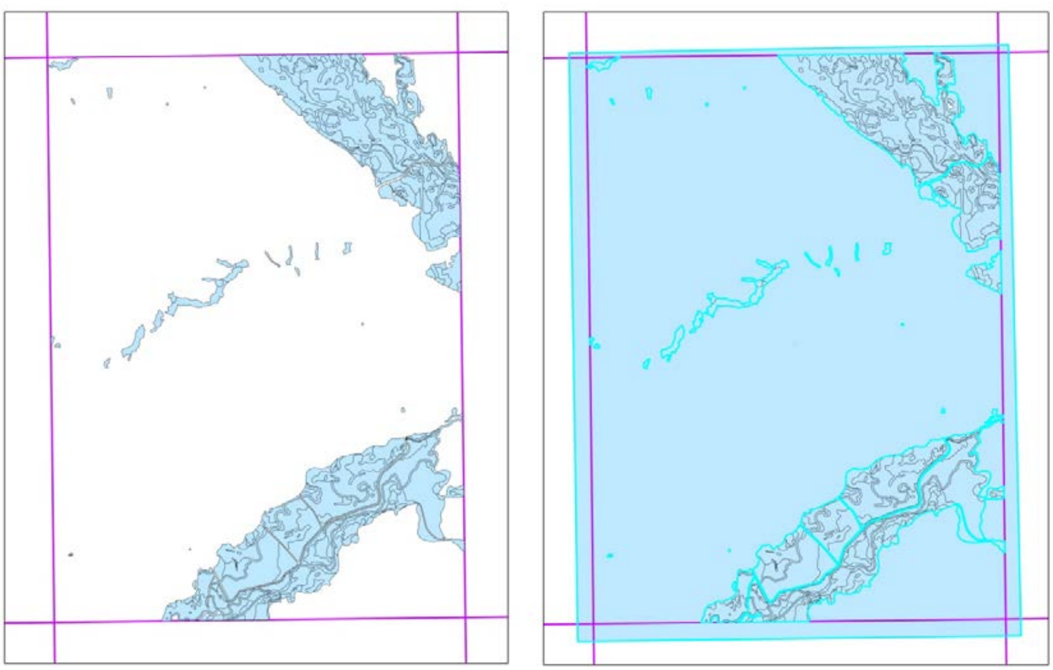


Figure 7. Universal polygon (highlighted in light blue on right) before and after topology.

The Cowardin Classification system served as the foundation for the other classification systems; no additional wetland polygons were created for SHGC or SPCC. It was expected that, with the exception of edgematching, there would be no further geometry edits required of the data.

Edgematching

7.5 Minute Quadrangle Checkouts to County

Since the next production phases of SHDP and SPCC classifications were completed at a landscape level, the 7.5-minute quadrangle checkouts were appended and edgematched into county-wide datasets. Esri Simple Data Loader was utilized to perform the append process. After each checkout was appended, edgematching was performed by panning along the checkout boundaries at a scale of 1:6,000 and using the ArcMap editing tools to merge those wetland polygons that are split by the boundary, creating seamless data. The edits required to both classification and geometry were expected to be minimal, given that both checkouts were edited and QA/QCed to the same standard. Edgematching occured incrementally as checkouts were approved by QA/QC. Checkouts crossing county boundaries were not cut at those boundaries, but included with the county that covered the majority of the checkout.

On-Screen Photointerpretation Process

Simplified Hydro-Geomorphic (SHGM) Classification

Simplified Hydro-Geomorphic Classification is a landscape level classification that is performed at smaller scales (1:10,000 and smaller) than the Cowardin classification; therefore, applying the classification to the seamless county-sized data is reasonable. SHGM attributes were added in a separate field (*SHGM_ATTRIBUTE*) inside the CONUS_wet_poly (edited wetland feature class) attribute table to the county-wide dataset. Using similar panning techniques, the interpreter worked through the county at a scale of 1:10,000. Given the landscape nature of SHGM and its more system-wide focus, the interpreter had latitude to zoom as far in or out as required to make decisions. In most cases the classification scale was between 1:5,000 and 1:20,000. Large complexes of wetland polygons were often classified very similarly, if not identically. Therefore, it is often possible to assign SHGM attributes quickly.

Simplified Plant Community Classification (SPCC)

The Simplified Plant Community Classification is based entirely on the cross-reference relationships between the Cowardin and the SPCC outlined in Table 9. It is a relatively straight forward exercise in using SQL database queries in the ArcMap “Select by Attribute” GUI to first select features based on their Cowardin Classification and then using the ArcMap field calculator to populate the *SPCC_ATTRIBUTE* field in the wetlands geodatabase. Each SPCC class required a separate query, or in some cases a series of queries was more efficient. Figure 8 shows an example of one of the simpler queries, which is for the Hardwood Wetland SPCC class. The data for each county was examined in order to gain an understanding of which Cowardin Classification codes were present to make sure all codes were addressed by the queries.

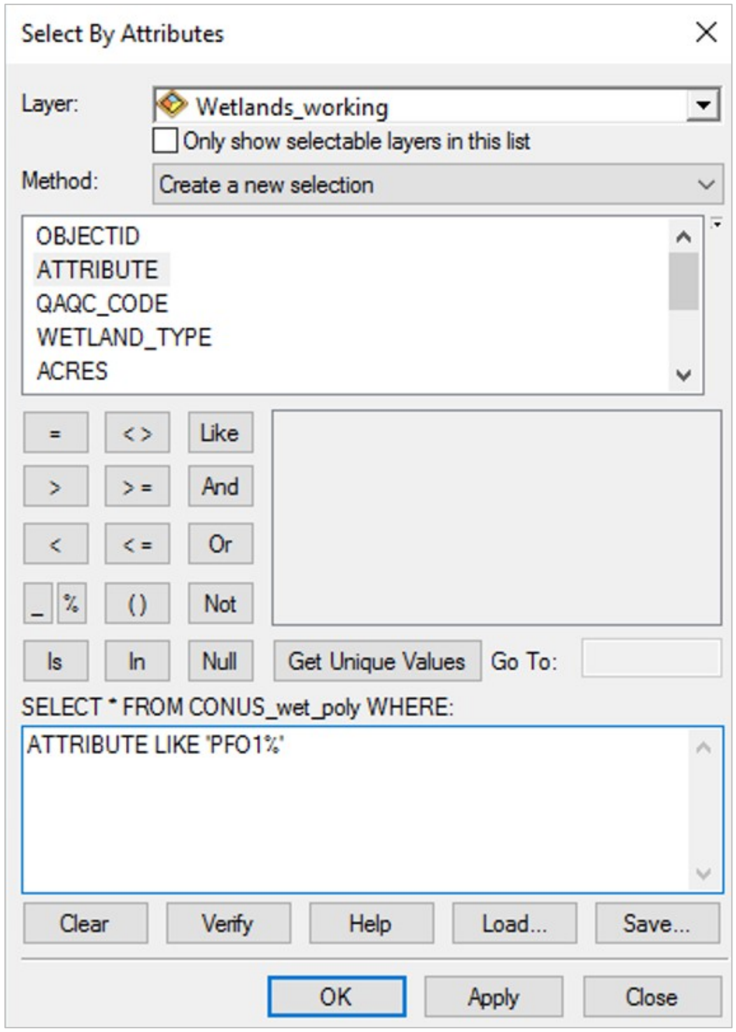


Figure 8. SPCC query for Hardwood Wetland Class.

Draft Data Approval

The QA/QC assessment, as previously described, was repeated on the county-wide data after all classifications (NWI, Wetland Type, and SPCC) were performed. Upon QA/QC approval, the draft county-wide data were then submitted to the MN DNR through a WMS for review. After review, MN DNR either approved the data or provided feedback from which GSS made necessary revisions and resubmitted. It should be noted that changes to the Cowardin Classifications could impact the SHGP and, more likely, the SPCC classification. QA/QC was performed before any resubmissions.

Final Processing

Upon approval by MN DNR, the county-wide data was appended to the project area-wide dataset and edgematched. The end result was a seamless dataset with coverage of the entire Northwest Minnesota project area (refer to Figure 1). The NWI Verification Tool developed by the USFWS NWI Program was then run against the seamless dataset. These tools were not expected to find many errors due to the previous QA/QC checks performed. If any errors were found, the data was revised and the tools run again until all errors were identified and addressed or documented. Upon successful completion of the NWI QA/QC tools, two copies of the data were made for delivery, one to MN DNR (in NAD83 UTM Zone 15N projection) and another to the USFWS (in NAD83 Albers Equal Area Conic projection) to be put into the nationwide NWI database.

Updating the National Wetlands Inventory for Minnesota: Northwest Project Area

Appendix A: Photointerpretation and Classification Guide

September 30, 2018

Saint Mary's University OF MINNESOTA

GeoSpatial Services

Introduction

The purpose of the Photointerpretation and Classification Guide is to provide guidance on the application of imagery and collateral data in the photointerpretation process for mapping wetlands within the Northwest Minnesota National Wetlands Inventory Update. Examples of important signatures and guidance on applying available data are provided. This should not be considered an exhaustive list of signatures, but instead provide examples to provide a better basis for consistent delineation and classification of wetlands across the study area.

Seven ecological subsections can be found inside the project area: Agassiz Lowlands, Aspen Parklands, Chippewa Plains, Hardwood Hills, Minnesota River Prairie, Pine Moraines & Outwash Plains, and the Red River Prairie (Figure 9). Tree species common in the northeast portion of the project area include tamarack (*Larix laricina*) and black spruce (*Picea mariana*), which can be found in the large forested bogs.

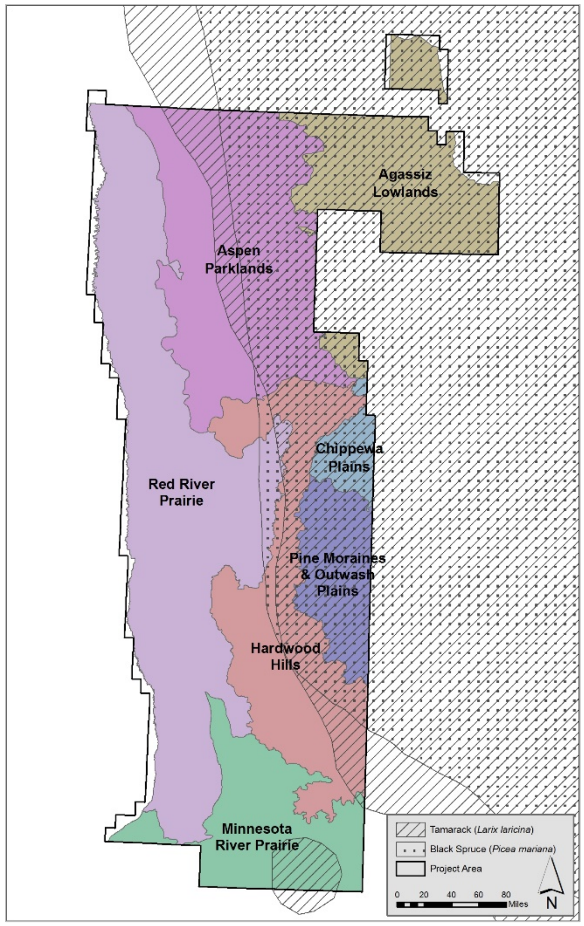


Figure 9. Ecoregion subsections found inside the Northwest MN project area, with range boundaries for tamarack and black spruce species.

Peatlands are dominant inside the Agassiz Lowlands and extend west into the Aspen Parklands. Inside the Aspen Parklands subsection, in areas where agriculture is not present, tall grass prairies exist. Moving further west into the Red River Prairie subsection, relatively flat land supports a dominant land use of agriculture. In more natural areas of the subsection, tall grass prairie is the dominant vegetation type. The Hardwood Hills subsection is defined by steep slopes, high hills, and lakes with oak savannas, tall grass prairies, and oak forests being the dominant vegetation types. The Chippewa Plains subsection is characterized as gently rolling lake plains and till plains, while the Pine Moraines and Outwash Plains subsection is a mix of end moraines, outwash plains, till plains, and drumlin fields. At the southernmost portion of the project area, the Minnesota River Prairie subsection consists largely of rolling ground moraine with tallgrass prairies.

The following pages contain imagery and relevant ancillary data examples of common wetland signatures present in the Northwest MN project area, as well as descriptions of some specific relevant situations, such as large forested bogs and areas of farmland.

Lacustrine System

The lacustrine system refers to lake environments. The following items apply to mapping lacustrine systems:

1. The lacustrine system is divided into two subsystems, limnetic (L1), which refers to deep water habitats and littoral (L2), which refers to shallower habitats.
2. In Northwest Minnesota, valid classes for the littoral (L2) subsystem are unconsolidated bottom (UB), unconsolidated shore (US), rocky shore (RS), rock bottom (RB), aquatic bed (AB) and non-persistent emergent (EM2). Of these, only the UB class is valid in the limnetic system (L1).
3. To be classified as lacustrine, the features must be larger than 20 acres (80,000 square meters) in size. This includes the combined area of the UB, US, RS, RB, AB, and EM2 classes.
4. Wetlands with the characteristics described in 2 and 3, but less than 20 acres in size are considered lacustrine if at least a portion of the boundary is active wave-formed shoreline or bedrock.

L1/L2 Boundaries

Not all characteristics required for classification are easily distinguished from remotely sensed imagery, such as deciding where to divide the lacustrine system between its littoral (L2) and limnetic (L1) subsystems. For this determination, a variety of collateral data and the following protocol were used. The goal is to use the best data that are available to determine the location of the L1/L2 boundary or to determine if the entire basin is L2. If a reliable determination is impossible, the last step of the protocol is to assume the entire basin is L2.

1. Check the MN DNR Hydrography feature class for maximum depth value. This data is the DNR Lakes Data joined to MN DNR fisheries survey maximum depth data. If the value is present and less than eight feet, classify the entire water body as L2.
    a. If the maximum depth is absent, null, or greater than or equal to eight feet proceed to step 2 below. A cutoff of eight feet was chosen since it is impossible to determine from the location and shape of area with depths ranging from six and one-half to eight feet. Also, in many cases the maximum depth may only occur at one location.
2. If the maximum depth in the MN DNR Hydrography layer is null or greater than or equal to eight feet, the Minnesota DNR Lake Bathymetry DEM data will be utilized where available to find the two-meter depth contour, or possibly provide information to indicate if the entire lakebed is less than two meters in depth. Lake Bathymetry data are grouped in folders by county, and it may require some trial and error to find the data for the particular lake in question. After the data is located and added to the ArcMap document, it needs to be classified and symbolized to show the two-meter (6.5 foot) contour line. This is done by classifying the data into two classes and specifying a class break of -6.5 feet, with the deeper class (≤ -6.5 feet) symbolized with a dark color (represents L1) and the shallower class (> -6.5 feet) with a light color (represents L2) (Figure 13). This data is available for 288 lakes

within the study area. All L1/L2 areas greater than two meters deep and larger than 0.1 acres (400 square meters) in size will be mapped.

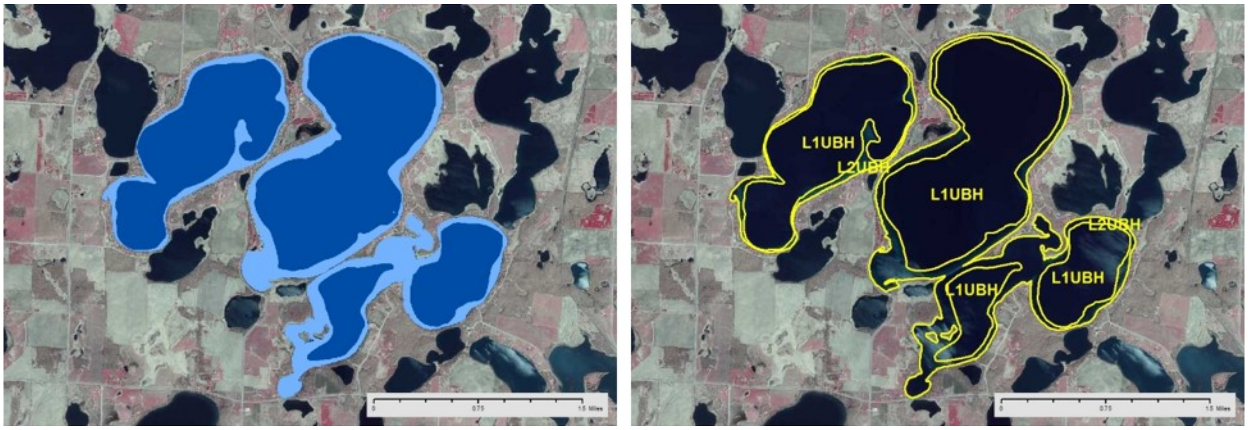


Figure 10. Symbolized Lake DEM data with a 6.5-foot class break (left) can help determine L1UBH/L2UBH boundaries for a lacustrine environment (right).

3. In the absence of bathymetry DEMs, the DRG will be the next choice for determining the L1/L2 boundary. If the feature is not present as a water body on the DRG, it will be classified as L2 if the signature indicates open water (UB) in all of the imagery and it meets the 20-acre size criteria for lacustrine. If it is not present as a water body on the DRG or does not exhibit open water on **all** imagery (2013/14 CIR, 2015 NAIP, 2013 NAIP, 2010 NAIP), it will be classified as palustrine.
4. If the feature is present as a water body on the DRG and if bathymetric contours are present, the 5- foot contour will serve as a guide to visually interpolate the 2 meter (6.5 foot) contour based on the approximate shape of the lake basin as shown in Figure 14.

Figure 11. Lake contours on the DRG can help in determining the L1/L2 boundaries.

5. In the absence of contours, spot soundings on the DRG will serve as the guide for visual interpolation as shown in Figure 15.

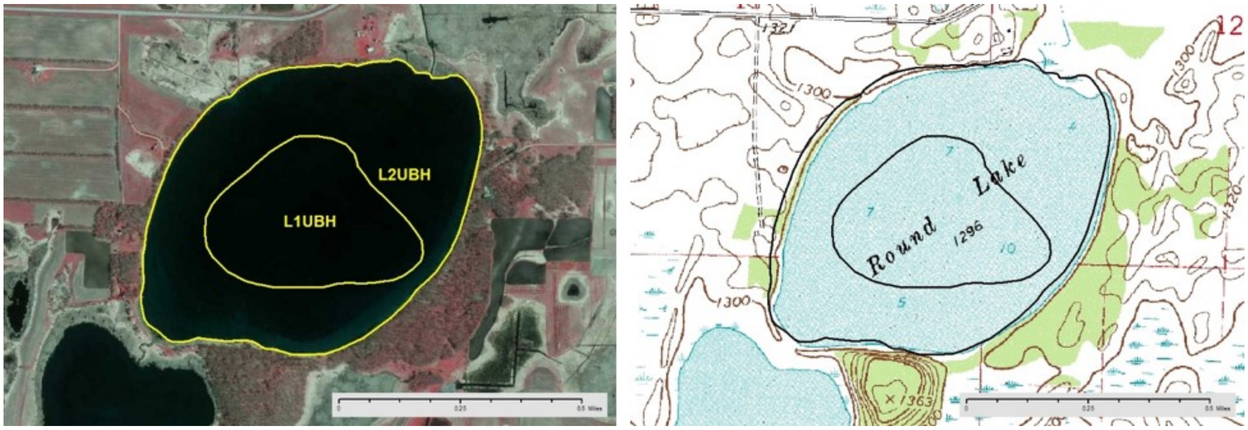


Figure 12. Utilizing DRG spot soundings for determining L1/L2 boundaries.

6. In the absence of both bathymetric contours and spot soundings on the DRG, a company called Navionics developed a web application that visually displays lake depth contours (Navionics 2018). This web application can be used as a side-by-side comparison for determining the L1/L2 boundaries of a lake, similar to a DRG (Figure 16).

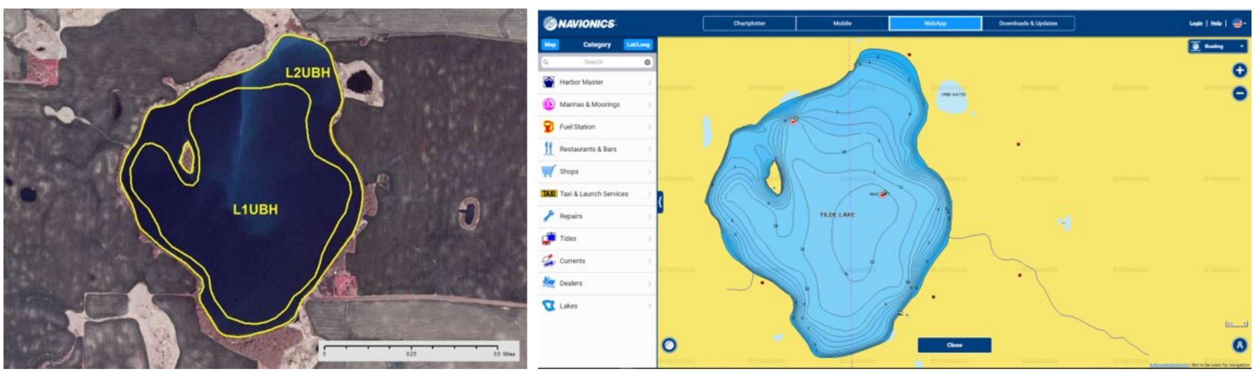


Figure 13. Lake depth contours from Navionics can be used to determine L1/L2 boundaries (Navionics 2018).

7. If previous steps do not result in a valid determination, visual cues on the imagery and other cues on the DRG will be used to attempt a determination. This includes, but is not limited to, visual evidence of submerged vegetation, shallow water signatures, infrastructure, etc. Lack of recreational infrastructure and presence of an undeveloped natural shoreline indicate L2.
8. If all the above steps do not lead to a determination, the L1/L2 boundary in the historical NWI will be assumed to be correct.
9. If all the above steps do not lead to a determination and there is no historic NWI, the entire water body will be classified as L2.

L1UBH

System: Lacustrine

Subsystem: Limnetic

Class: Unconsolidated Bottom

Water Regime: Permanently Flooded

L1UBH features are deep zones in natural lakes that are more than two meters (6.5 feet) deep (Figure 10**)**. In Northwest Minnesota, they occur in natural depressions as well as dammed river channels. Typical photosignatures are flat with dark blue to almost black tones on the Spring CIR and/or NAIP imagery. Additionally, they will also present with dark green to brown tones on the true color NAIP. Sometimes glare will cause a bright white signature, and wind-blown areas will present with some roughness. Flat brown signatures will also occur if imagery was acquired at a time of high turbidity such as after a precipitation or melting event.

Collateral data include imagery, LiDAR DEM, and DRGs. Where available, the MN DNR lake DEMs are used within the protocol defined above (L1/L2 Boundaries) to find those areas that are greater than 2 meters (6.5 feet) in depth. The presence of a hydrologically enforced water body on the LiDAR DEM is also an indication of L1UB.

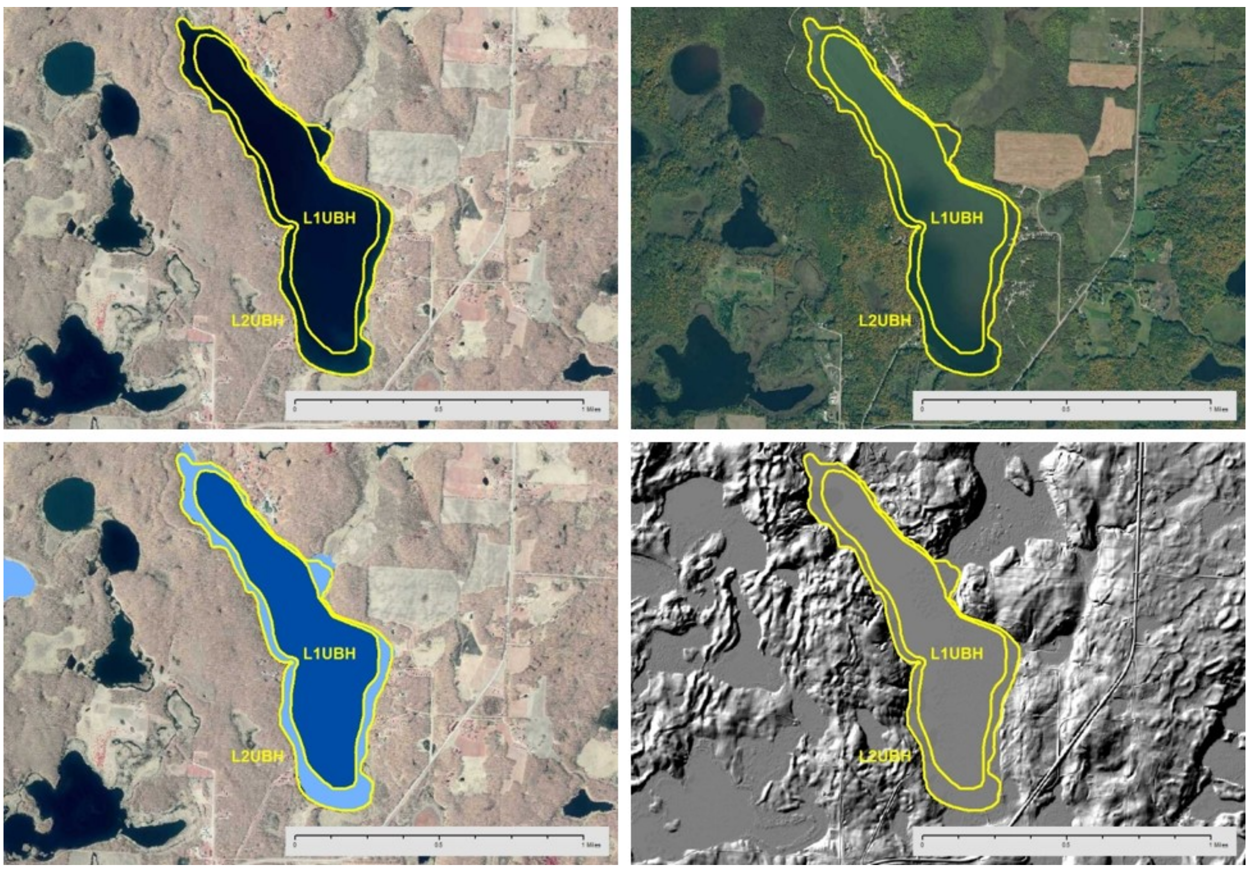


Figure 14. L1UBH/L2UBH signature example; 2013/14 Spring CIR (upper left), 2015 NAIP (upper right), MN DNR Lake DEM (lower left), 3-meter LiDAR hillshade (lower right).

L2ABH

System: Lacustrine

Subsystem: Littoral

Class: Aquatic Bed

Water Regime: Permanently Flooded

L2ABH features are those open water areas that are less than two meters (6.5 feet) in depth and are covered by at least 50% floating vegetation such as duckweed (*Lemna* spp.). They often occur along the edges and in sheltered areas of lacustrine basins (Figure 11). L2ABH signatures are not present on the Spring CIR because the signatures do not present themselves until later in the growing season. Typical signatures on the true-color NAIP are flat in texture and bright green in tone, although in some cases they present as flat dark brown. The location of the aquatic bed in the imagery can vary considerably from year to year, in which case the 2015 NAIP takes priority in defining boundaries.

Collateral data include imagery and DRG. Additionally, where available, the MN DNR lake DEMs are used within the protocol defined above (L1/L2 Boundaries) to find those areas that are less than 2 meters (6.5 feet) in depth.

Figure 15. L2ABH signature example; 2013/14 Spring CIR (left) and 2015 NAIP (right).

L2UBF

System: Lacustrine
Subsystem: Littoral
Class: Unconsolidated Bottom
Water Regime: Semi-Permanently Flooded

L2UBF features are those open water areas that are less than 2 meters (6.5 feet) in depth and semi-permanently flooded. They normally occur in basins that are entirely less than two-meters deep. Aquatic bed wetlands are often associated with them. In Northwest Minnesota, they typically occur in natural depressions. Typical photosignatures are flat in texture and blue/black in tone on the Spring CIR, but are often lighter than similar signatures for L1UBH. On the true color NAIP imagery, signatures are again flat, but tend to lighter brown or green in tone (Figure 12).

Collateral data includes imagery and DRGs. The main indication, if any, on the DRG is marsh symbols. Secondary indicator is a depression rather than a blue water body on the DRG. The presence of a hydrologically enforced water body on the LiDAR DEM is also an indicator, but may not occur as often as for an L1UBH. Additionally, where available, the MN DNR lake DEMs are used within the protocol defined above (L1/L2 Boundaries) to find those areas that are less than 2 meters (6.5 feet) in depth.

L2ABF

System: Lacustrine

Subsystem: Littoral

Class: Aquatic Bed

Water Regime: Semi-Permanently Flooded

L2ABF features are those open water areas that are less than 2 meters (6.5 feet) in depth and are covered by at least 50% floating vegetation such as duckweed. They often occur along the edges and in sheltered areas of lacustrine basins, but are also likely to occur in irregular patterns as compared to L2ABH (Figure 12). L2ABF signatures are typically not present on the Spring CIR because the signatures do not present themselves until later in the growing season. Typical signatures on the true-color NAIP are flat in texture and bright green in tone, although in some cases they present as mottled tan or brown. The location of the aquatic bed on the imagery may vary considerably from year to year, in which case the 2015 NAIP takes priority in defining boundaries.

Collateral data include imagery and DRG. A water body is likely not present on the DRG, but there may be marsh symbols or a depression. Where available, the MN DNR lake DEMs are used within the protocol defined above (L1/L2 Boundaries) to find those areas that are less than two meters (6.5 feet) in depth.

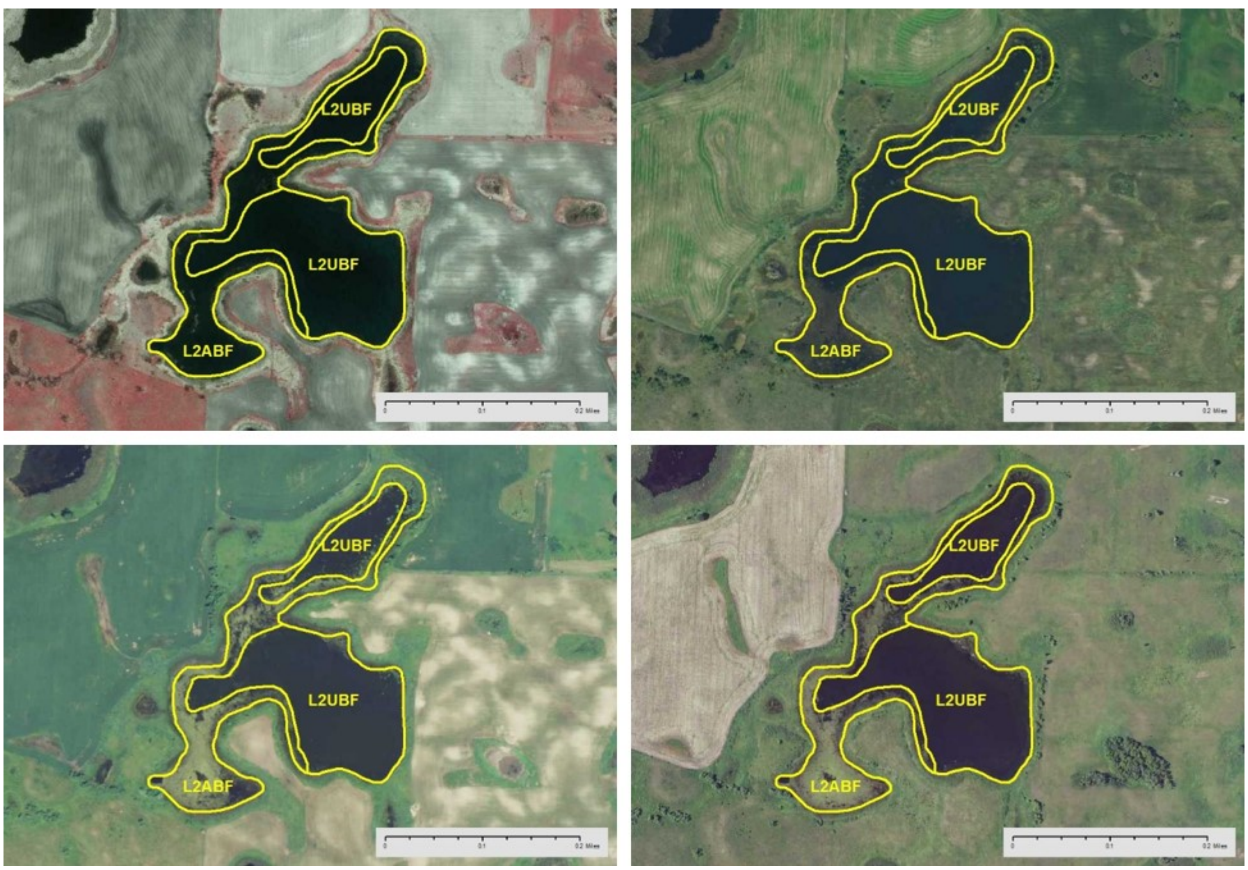


Figure 16. L2UBF/L2ABF signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 2013 NAIP (lower left), 2010 NAIP (lower right).

Riverine System

The riverine system refers to stream and river environments that have flowing water. The following factors should be considered for riverine environments in the project area:

1. The riverine system has three subsystems that are defined by the gradient of the stream or the frequency of the presence of surface water. These subsystems include:
    a. Lower Perennial (R2) **–** Low gradient (gentle elevation change) defined by slow-moving water with sand or mud substrates. This subsystem tends to be associated with developed floodplains through which the main flow meanders if left in its natural state. Valid classes are UB, US, AB, EM2, RS, and RB.
    b. Upper Perennial (R3) **–** High gradient (steep elevation change) defined by fast-moving water and substrates such as gravel, cobble, or bedrock that do not erode in a higher energy environment. This system typically contains little to no floodplain with little meandering. The non-vegetated classes UB, US, RS, and RB are valid for this subsystem.
    c. Intermittent (R4) **–** This subsystem applies to channels that do not carry water all of the time. In times of no flow, surface water, if present, is likely to be in isolated pools. The only valid class is streambed (SB).
2. Streams greater than or equal to 4.6 meters (15 feet) in width are mapped. Wherever possible, stream networks are mapped to avoid a series of disconnected polygons that are actually part of the same stream. However, there are cases with the smallest streams where tree cover makes it impossible to consistently and accurately map these features. In those cases, what is visible is mapped, even if it results in a disjointed river network.
3. Riverine systems are not split where they pass under bridges if collateral data indicates connectivity.
4. Features are classified based on the substrate or vegetation in the channel, not what is present on the edges of the channel.

R2UBH

System: Riverine
  Subsystem: Lower Perennial
    Class: Unconsolidated Bottom
      Water Regime: Permanently Flooded

R2UBH features are low gradient rivers. They are normally associated with well-developed floodplains and exhibit meanders and evidence of meander scars in surrounding floodplain areas. Surrounding floodplain areas may be in their natural state, but are often drained for agriculture. Typical photosignatures are flat with dark blue to almost black tones on the Spring CIR or NAIP imagery (Figure 17). They will also present with dark green to brown tones on the true color NAIP, depending on the turbidity level of the water. In rare instances, a bright white signature due to glare will be present. R2UBH features vary greatly in size; therefore, sinuosity and supporting collateral data are the best indicators of the R2 system.

Collateral data include imagery, LiDAR DEM, and DRGs. Both the DRG and the LiDAR products indicate gradient. R2UBH attributes are often represented as polygon features on the DRG, however the smallest R2UBH features may be represented as a solid blue line.

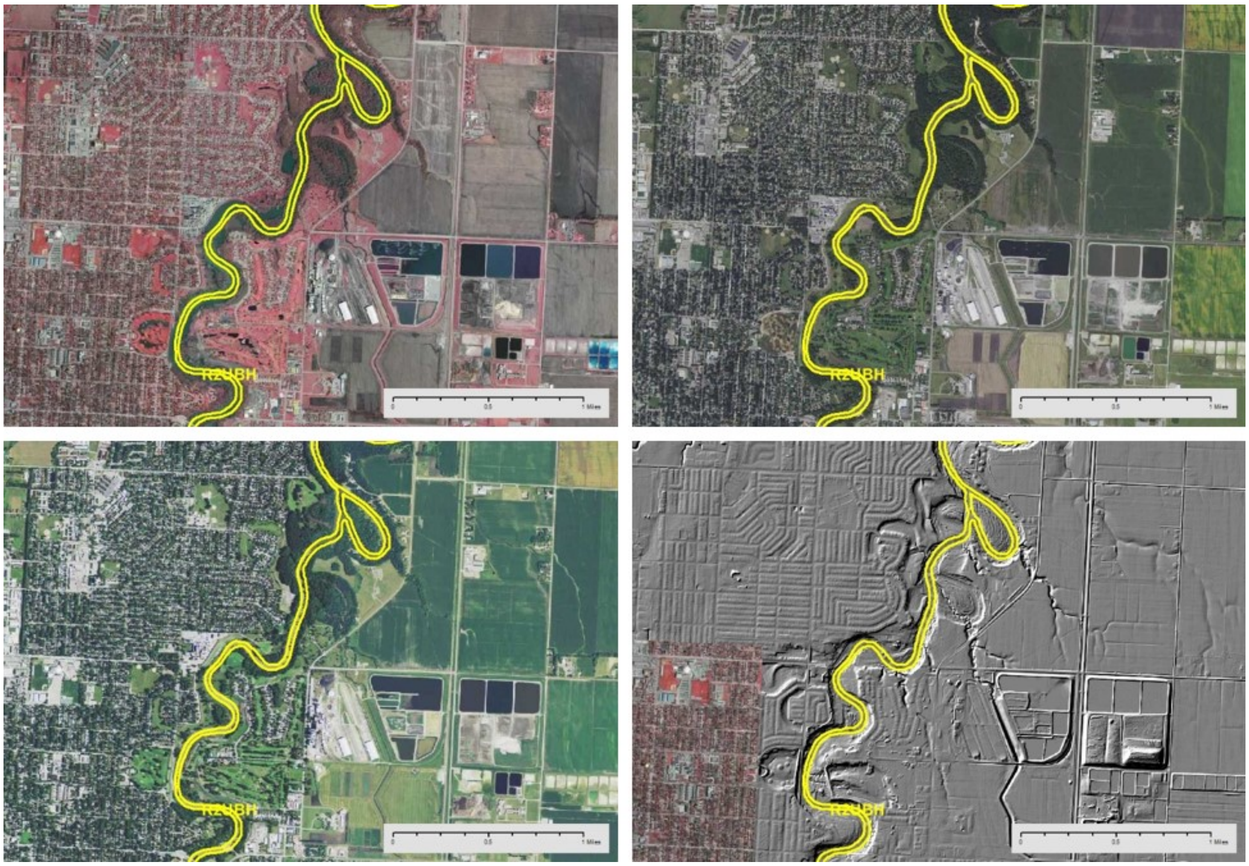


Figure 17. R2UBH signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 2013 NAIP (lower left), and 3-meter LiDAR hillshade (lower right).

R2UBHx

System: Riverine

Subsystem: Lower Perennial

Class: Unconsolidated Bottom

Water Regime: Permanently Flooded

Special Modifier: Excavated

R2UBHx features are low gradient rivers whose natural course has been altered through excavation. They are normally associated with well-developed floodplains but do not exhibit meanders, because they have been channelized into straight sections. It should be noted that, over time, channelized R2 rivers will revert back to their natural state and the channel will begin to meander. There is often evidence of past meanders in the surrounding areas. Surrounding floodplain areas are often drained for agriculture. Typical photosignatures are identical to a natural R2UBH, flat with dark blue to almost black tones on the Spring CIR or NAIP imagery (Figure 18). They will also present with dark green to brown tones on the true color NAIP, depending on the turbidity of the water. In rare instances, a bright white glare signature will be present. R2UBHx features vary greatly in size, but natural R2UBH sections are often connected by channelized R2UBHx sections within the same river system.

Collateral data include imagery, LiDAR DEM, and DRGs. Both the DRG and the LiDAR products indicate gradient. R2UBHx rivers are often represented as polygon features on the DRG, but the smallest R2UBHx features may be represented as a solid blue line.

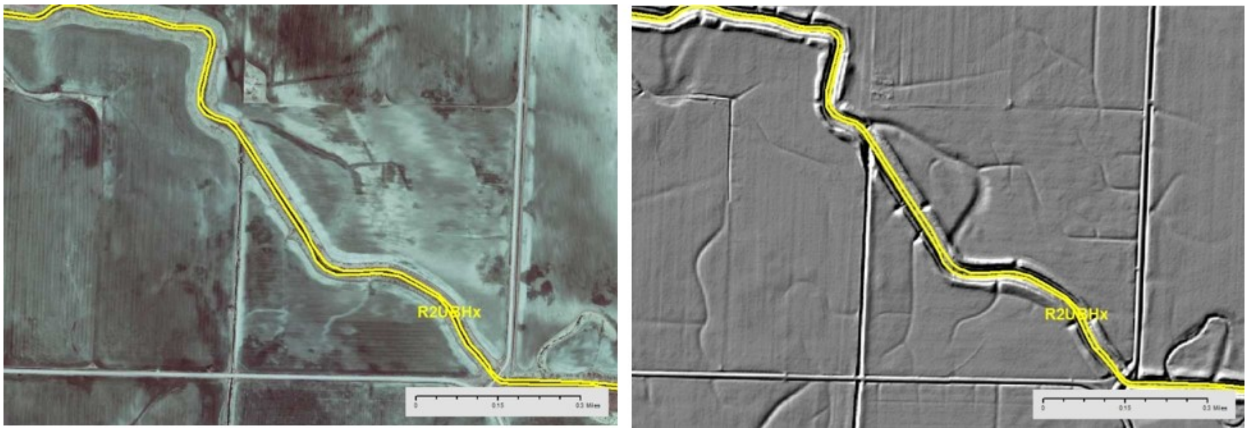


Figure 18. R2UBHx signature example; 2013/14 CIR (left) and 3-meter LiDAR hillshade (right).

Palustrine System

The palustrine system refers to wetlands that are dominated by persistent emergent, scrub-shrub, or forested vegetation, or lacking vegetation and are less than 20 acres (80,000 square meters) in basins with a maximum depth of less than 2 meters. The following factors should be considered for palustrine environments in the project area:

1. No subsystem is applied to the palustrine system.
2. Valid classes include: unconsolidated bottom (UB), unconsolidated shore (US), aquatic bed (AB), emergent (EM), scrub-shrub (SS), forest (FO), rock bottom (RB), and moss-lichen (ML).
3. Subclasses will be applied to the EM, SS, and FO classes with valid attributes listed in Table 2.
4. Valid water regimes for each class are also listed in Table 2.
5. Special modifiers will be applied based on the valid lists in Table 2.
6. The PEM1Af attribute will only be applied to farmed wetlands meeting a specific set of circumstances as described below (Farmed Wetlands). Features where hydrophytic vegetation is dominant will not be classified as farmed.
7. Palustrine wetlands can exist as inclusions within lacustrine basins and riverine floodplains.
8. Wetlands larger than 20 acres can be classified as palustrine if vegetated and the maximum depth of the basin is less than 2 meters.

PUBH
System: Palustrine
Class: Unconsolidated Bottom
Water Regime: Permanently Flooded

PUBH features are open water, pond environments. Photosignatures are the normal open water signatures: flat, with dark blue to almost black tones on the Spring CIR or NAIP imagery (Figure 20). They will also present dark green to brown tones on the true color NAIP, depending on the turbidity level of the water. In rare instances, a bright white signature due to glare will be present. To be classified as PUBH, it must be flooded in all but the most extreme drought. For Northwest Minnesota, this means flooded on all three years of NAIP imagery, and the 2013/14 Spring CIR.

Collateral data include imagery, LiDAR DEMs and DRGs. The DRG will often show a water body if the PUBH is a natural, well-established wetland. The LiDAR should show a flat, hydro-enforced, flooded basin.

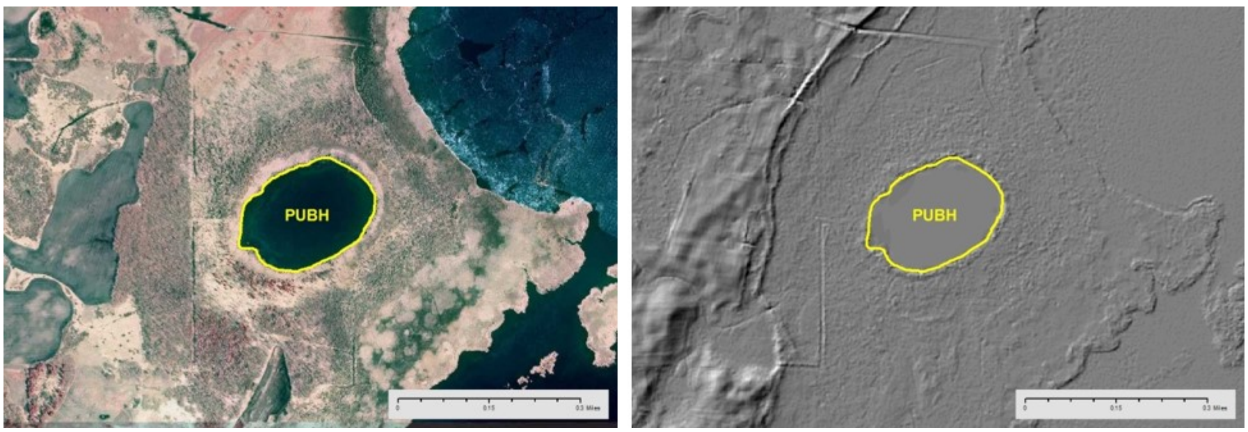


Figure 19. PUBH signature example; 2013/14 CIR (left) and 3-meter LiDAR hillshade (right).

PUBF
System: Palustrine
Class: Unconsolidated Bottom
Water Regime: Semi-Permanently Flooded

PUBF features are open water, pond environments. They often occur as open water portions of marsh basins associated with cattail marshes and aquatic bed wetlands. Photosignatures are the normal open water signatures, flat with dark blue to almost black tones on the Spring CIR or NAIP imagery (Figure 21). They will also present with dark green to brown tones on the true color NAIP, depending on the turbidity level of the water. In rare instances, a bright white signature due to glare will be present. To be classified as PUBF, it must exhibit the open water signature on a majority of the three years of NAIP imagery, and especially on the 2015 NAIP. They tend to be smaller in size than PUBH wetlands.

Collateral data include imagery, LiDAR DEMs, and DRGs. The DRG will often show marsh symbols for these features. The LiDAR should show a flat flooded basin.

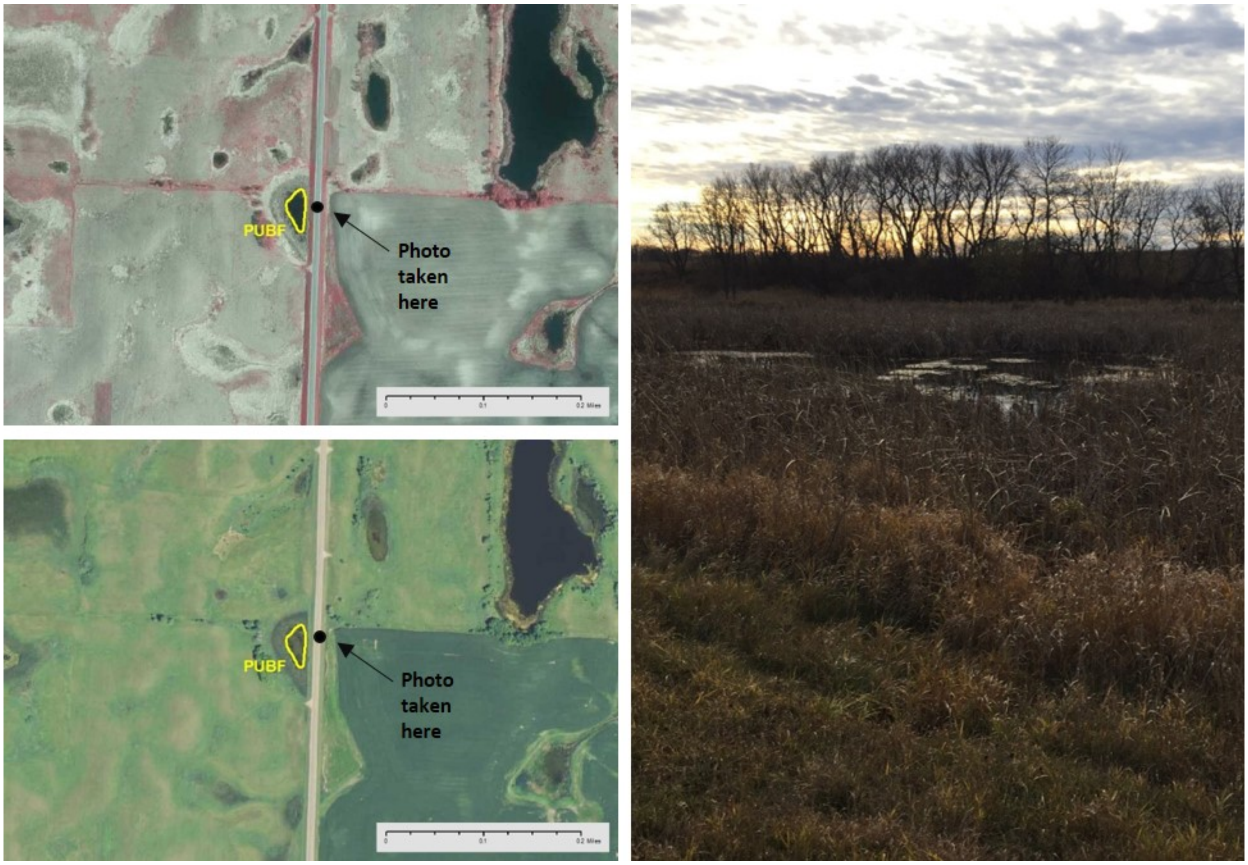


Figure 20. PUBF signature example; 2013/14 CIR (upper left), 2013 NAIP (lower left), ground-level oblique (right).

PUBFx

System: Palustrine

Class: Unconsolidated Bottom

Water Regime: Semi-Permanently Flooded

Special Modifier: Excavated

PUBFx features are open water, pond environments that have been gouged, blasted, dug, or suctioned through artificial means. They may be intentionally created wetlands as is the case on golf courses and ornamental ponds in residential developments, or they may be the incidental result of other activity such as mining. Photosignatures are the typical open water signatures, flat with dark blue to almost black tones on the Spring CIR or NAIP imagery (Figure 22). They will also present with dark green to brown tones on the true color NAIP, depending on the turbidity level of the water. Depending on substrate, these wetlands can also show as a lighter blue when the water is shallow enough that sunlight is reflected off a sandy substrate. In rare instances, a bright white signature due to glare will be present. These wetlands will often have regular polygonal shapes, such as rectangular or square. Semi-permanently flooded (PUBF) wetlands tend to be smaller and often shallower than their permanently flooded (PUBH) counterparts. To be classified with the semi-permanently flooded “F” water regime, it must be flooded in at least two out of three NAIP images. To be classified with the excavated “x” modifier, there should be evidence of digging, such as a pile of fill in the immediate vicinity of the wetland. Evidence of mining is another indicator, in which case the visible water is actually the exposed surface of the water table.

LiDAR is the primary collateral data for making the excavated determination. Evidence of excavation such as fill piles, or gravel pits are easily identified on the LiDAR hillshade, and if large enough, on the LiDAR contours. The DRG often will not show these features if they were recently created, however, gravel pits are often marked on the DRG.

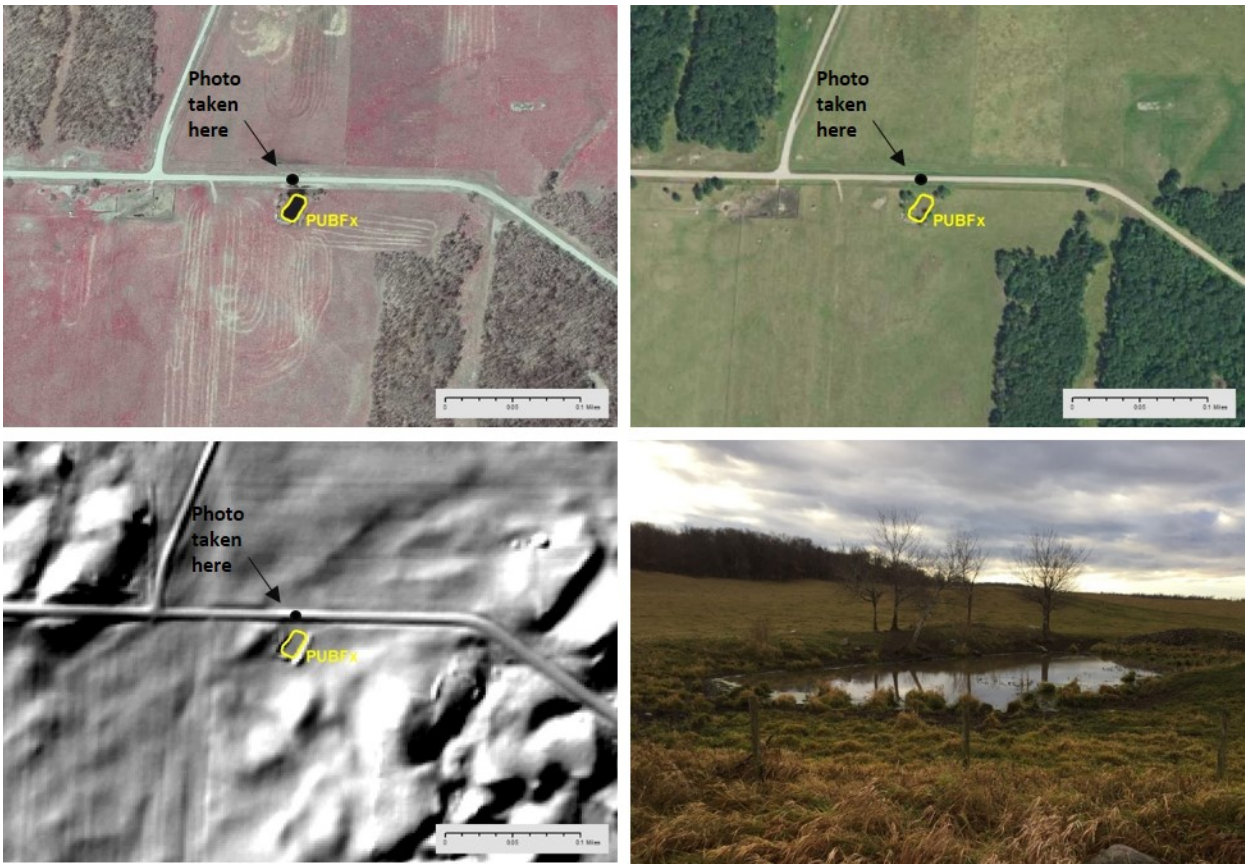


Figure 21. PUBFx signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 3-meter LiDAR hillshade (lower left), ground-level oblique (lower right).

PUBKx

System: Palustrine

Class: Unconsolidated Bottom

Water Regime: Artificially Flooded

Special Modifier: Excavated

This classification is reserved for open water features associated with sewage treatment ponds, industrial cooling ponds, fish hatcheries or any other situation where the water level is altered using siphons or pumps. Photosignatures when flooded are the typical open water signatures, flat with dark blue to almost black tones on the Spring CIR or NAIP imagery, but often other signatures will be present if a pond has been pumped down (Figure 23). In a majority of cases, they will have regular geometric shapes and be surrounded by a dike system. The surrounding land use also provides clues to their existence. Sewage treatment ponds are often in or near urban areas, and fish hatcheries will tend to be near cold water streams. Large manure storage pits are near large farms. In cases where artificially flooded features are larger than 20 acres in size, they should be classified as L2UBKx.

LiDAR and the DRG are the primary collateral data for identifying these wetlands. Any associated dike system or regular polygonal shape is easily identified on the LiDAR hillshade. The DRG is useful because sewage treatment ponds and fish hatcheries are often identified. However, given the age of the DRGs, this is not always the case because newer facilities will not be present.

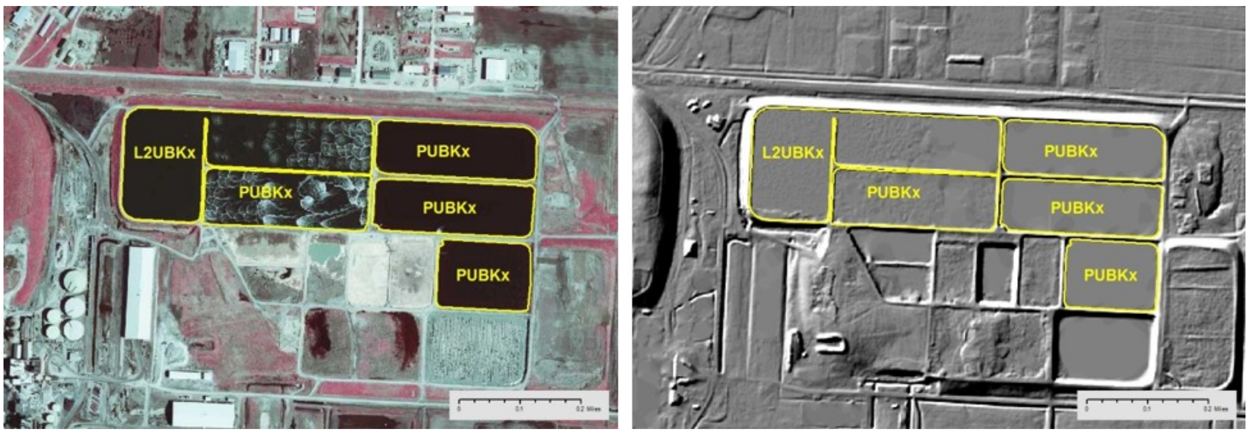


Figure 22. PUBKx signature example; 2013/14 CIR (left), 3-meter LiDAR hillshade (right).

PABH

System: Palustrine

Class: Aquatic Bed

Water Regime: Permanently Flooded

PABH features are permanently inundated open water areas that are less than two meters (6.5 feet) in depth, not part of a lacustrine basin, and covered by at least 50 percent floating vegetation such as duckweed. They can occur as stand-alone wetlands but are often part of larger palustrine wetlands complexes. Figure 24 is an example of a PABH wetland occurring in a relatively isolated morainal basin. PABH signatures are not present on the Spring CIR because the signatures do not present themselves until later in the growing season. Typical signatures are flat in texture and bright green in tone on the true-color NAIP, although in some cases they present as flat dark brown. The location of the aquatic bed on the imagery can vary considerably within a wetland complex from year to year, in which case the 2015 NAIP takes priority in defining boundaries.

Collateral data include LiDAR and DRG. LiDAR will often show the presence of surface water. The DRG will likely show open water or marsh symbols.

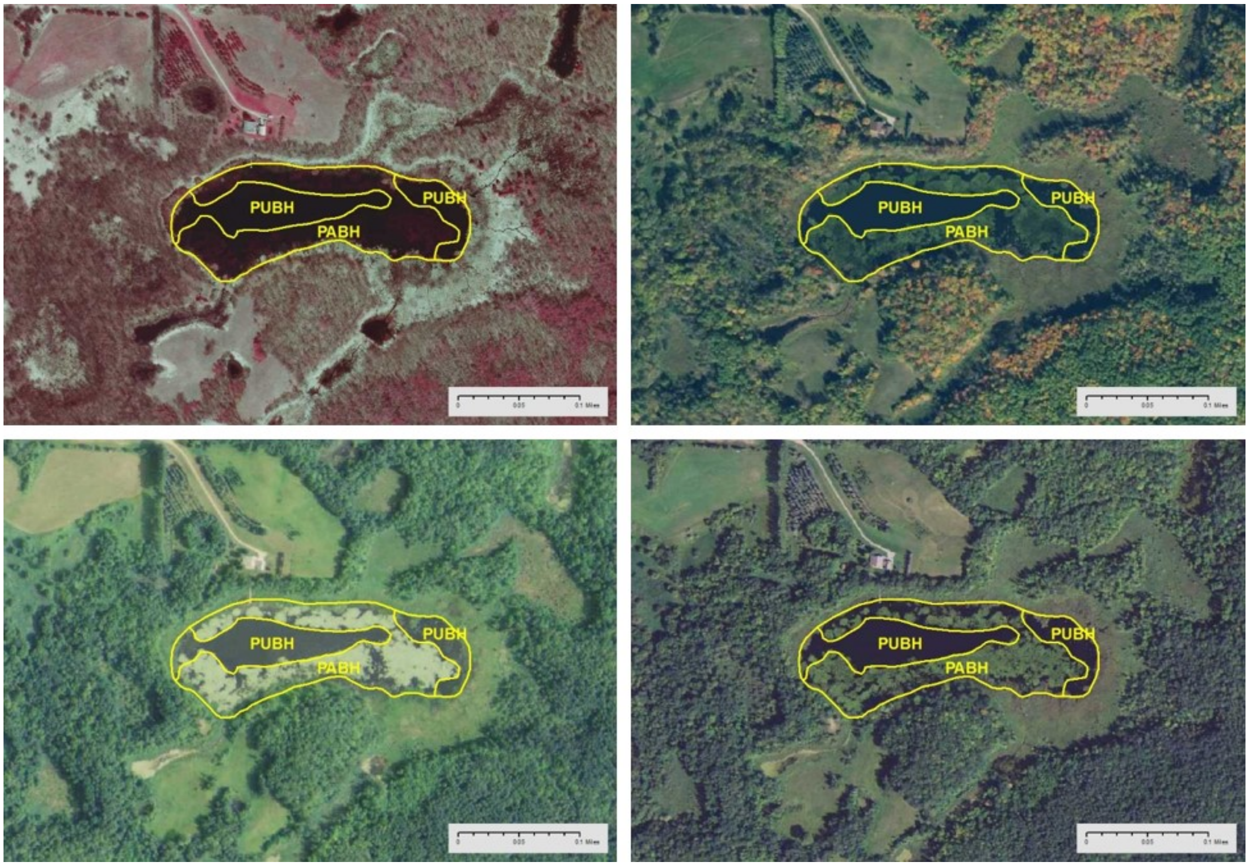


Figure 23. PABH signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 2013 NAIP (lower left), 2010 NAIP (lower right).

PABF

System: Palustrine

Class: Aquatic Bed

Water Regime: Semi-Permanently Flooded

PABF features are open water areas that are less than 2 meters (6.5 feet) in depth, nearly always inundated, not part of a lacustrine basin, and covered by at least 50% floating vegetation. They can occur as stand-alone wetlands, but are often the aquatic bed portion of a semi-permanently flooded wetland complex and are therefore often associated with PEM1F and PEM1C wetlands (Figure 25). PABF signatures are not present on the Spring CIR because the signatures do not present themselves until later in the growing season. Typical signatures are flat in texture and bright green in tone on the true-color NAIP, although in some cases they present as flat dark brown. The location of the aquatic bed on the imagery can vary considerably within a wetland complex from year to year, in which case the 2015 NAIP takes priority in defining boundaries. Special modifiers should be added as indicated by the imagery and collateral data.

Collateral data include LiDAR and DRG. LiDAR will often show the presence of surface water. The DRG will most likely have marsh symbols or open water, but in rare cases there will be no indication on the DRG.

Figure 24. PABF signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 2013 NAIP (lower left), ground-level oblique (lower right).

PEM1F

System: Palustrine

Class: Emergent

Subclass: Persistent

Water Regime: Semi-Permanently Flooded

PEM1F wetland features are dominated by persistent emergent vegetation and have standing water for the majority of the growing season in most years. Species common in PEM1F wetlands include cattail (*Typha* spp.), and bulrush (*Scirpu*s spp.). They are often located on the edges of lacustrine basins or within large river floodplains, but they can occur in isolated basins. On the imagery, the signature has a rough, spiky texture with small tendrils or patches of open water intermixed. Tone on the CIR can vary from light gray to darker browns and grays to almost black, depending on the thickness of the vegetation and the presence of standing water beneath it. Muskrat houses are also an indicator of PEM1F. Photosignatures on the NAIP tend to also exhibit a rough texture, but with green or brown tones (Figure 26). Aquatic bed signatures will often be present intermixed with the emergent vegetation on the NAIP.

Collateral data primarily include the DRG, SSURGO soils and LiDAR DEM. Marsh symbols are often present on the DRG. Soils will be hydric and the LiDAR DEM will indicate a basin, without a hydrologically enforced water surface.

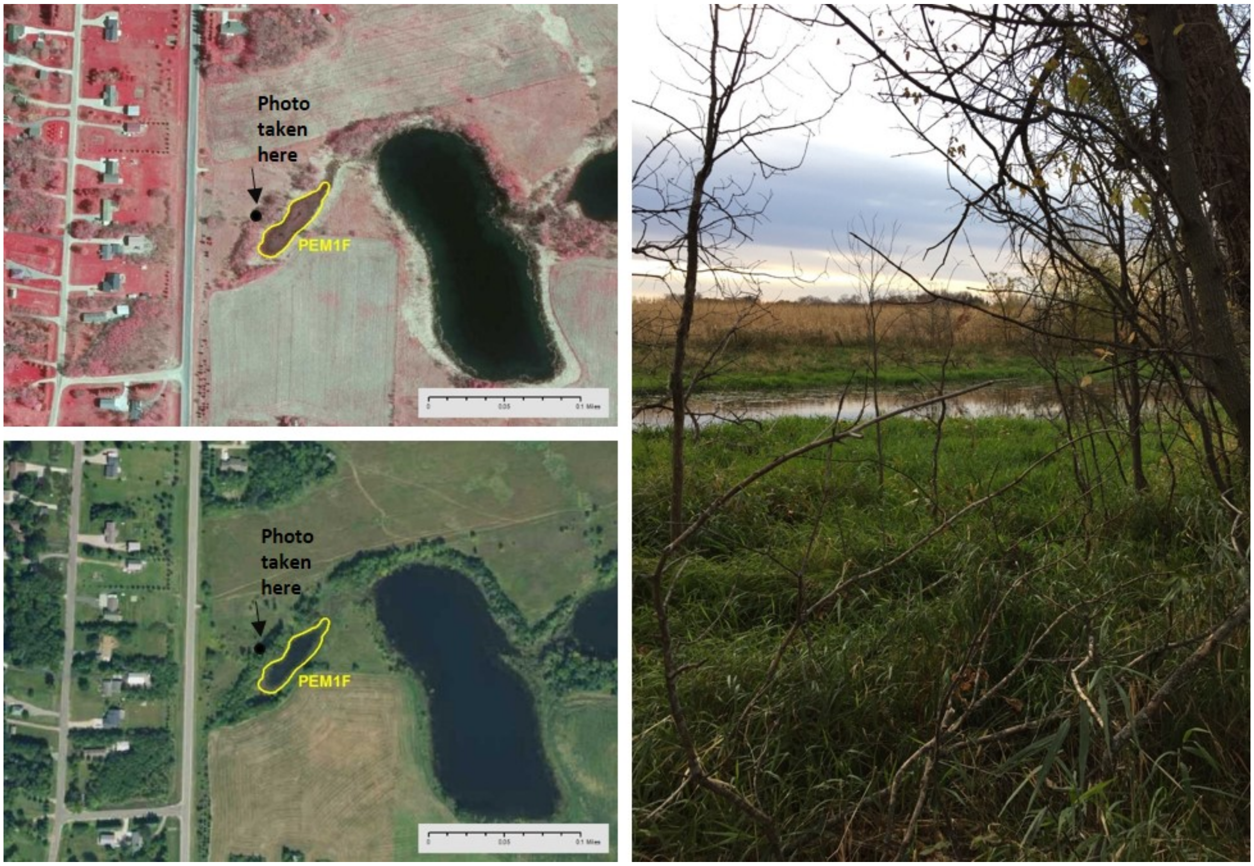


Figure 25. PEM1F signature example; 2013/14 CIR (upper left), 2015 NAIP (lower left), ground-level oblique (right).

PEM1C

System: Palustrine

Class: Emergent

Subclass: Persistent

Water Regime: Seasonally Flooded

PEM1C wetland features are dominated by persistent emergent vegetation and regularly have standing water early in the growing season but may not have surface water later in the growing season. When surface water is not present, the soil is often saturated very near the surface. Reed canary grass (*Phalaris arundinacea*) is a common species present in these wetlands. They occur in a variety of locations, but tend to occur on seasonally flooded basins, including meander scars. Photosignatures tend to have a puffy texture, with tone varying significantly depending on the amount of surface water present at imagery acquisition. The typical signature on CIR imagery is a light gray to white in tone, but where surface water is present may be much darker (Figure 27). Photosignatures on the NAIP tend to also have a puffy texture with a deeper green tone than surrounding temporarily flooded wetlands or uplands. Hybrid cattail (*Typha x glauca*), which will tolerate dry conditions, will also grow in PEM1C wetlands and will exhibit a very similar signature to cattails growing in a PEM1F wetland, but will be much denser without any open water or aquatic bed pockets present, and muskrat houses will not be present.

Collateral data primarily include the DRG, SSURGO soils, and LiDAR DEM. Marsh symbols might be present on the DRG, but are not as likely as for semi-permanently flooded wetlands. Hydric soils are highly likely to be present. The LiDAR DEM and contour lines will, in a majority of cases, show a basin. There generally will not be any indication of a hydrologically enforced water surface on the LiDAR DEM.

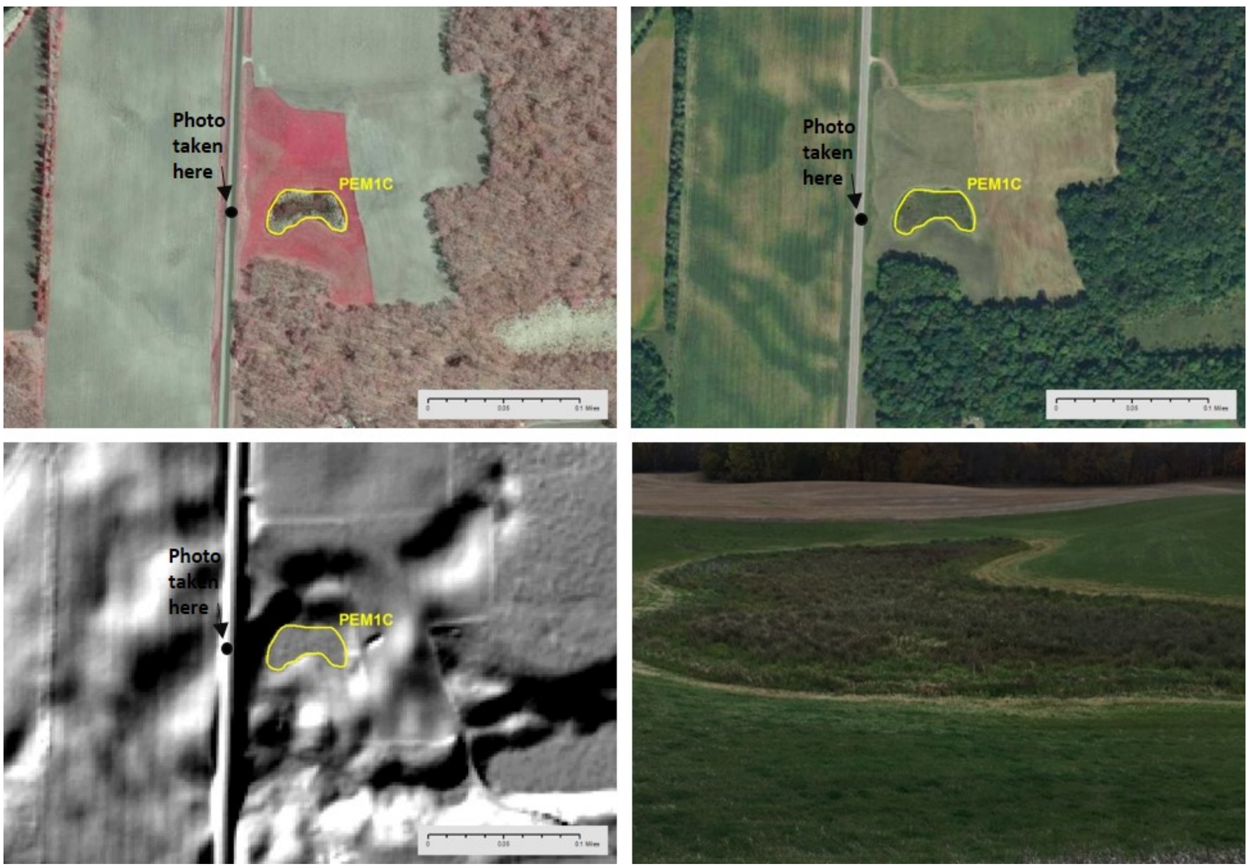


Figure 26. PEM1C signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 3-meter LiDAR hillshade (lower left), ground-level oblique (lower right).

PEM1A

System: Palustrine

Class: Emergent

Subclass: Persistent

Water Regime: Temporarily Flooded

PEM1A wetlands are dominated by persistent emergent vegetation and have surface water for only a short time during the growing season, generally two weeks or less. The soil is not usually saturated very near the surface when surface water is absent. Both wetland and upland plants are often present in these wetlands. Due to its ability to thrive in both wet and dry environments, reed canary grass is a common species present in these wetlands. They most often occur in relatively flat areas, but do occur on the edges of wetland basins. Photosignatures tend to be smoother than PEM1C wetlands. Tones on the CIR tend to be darker gray or white tones (Figure 28) or, on some imagery for the Northwest MN project, pink to red in tone. Tones on the true-color NAIP imagery tend to be a lighter green as compared to PEM1C wetlands.

Collateral data primarily include the LiDAR DEM and SSURGO. The LiDAR DEM will show a relatively flat area, including raised shelf structures along drainage ways. SSURGO will often indicate hydric soils, but this is not as sure of an indicator as for wetter PEM1 wetlands.

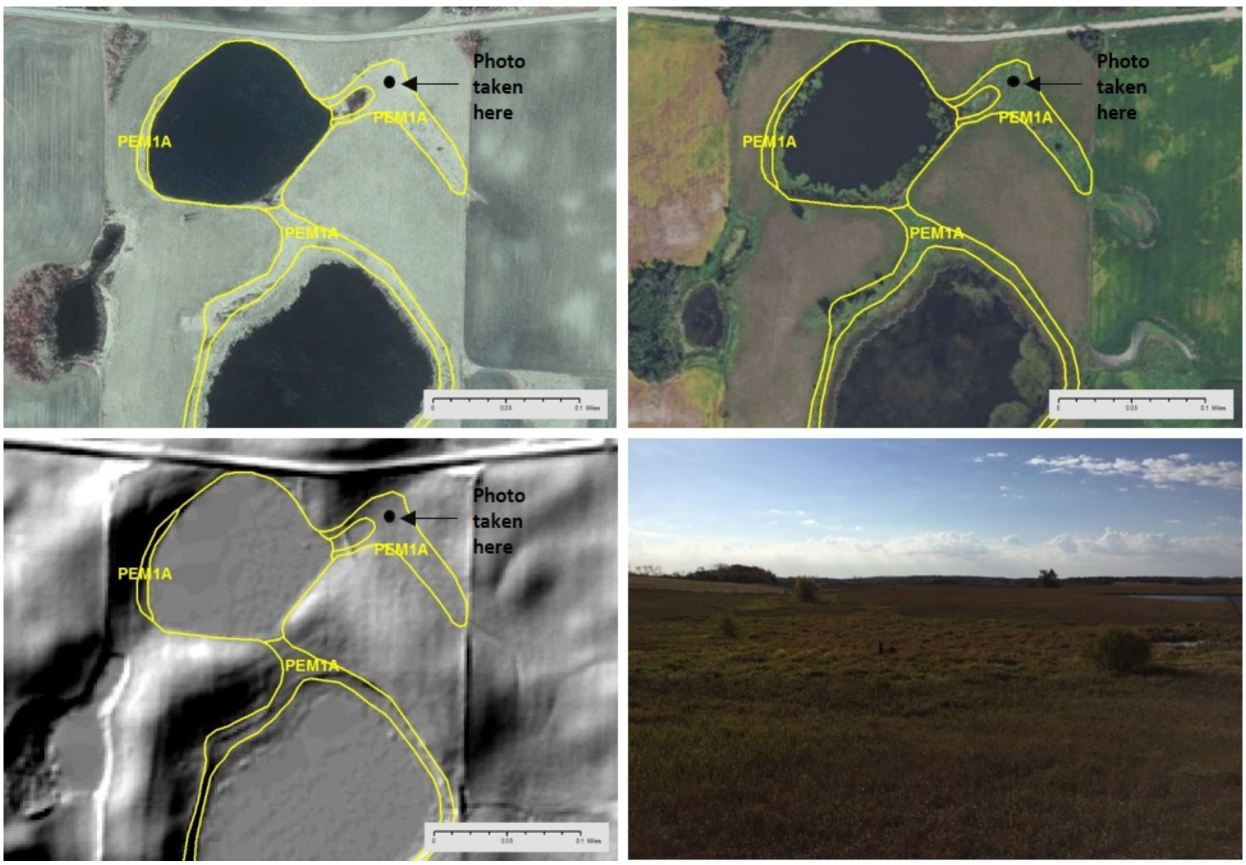


Figure 27. PEM1A signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 3-meter LiDAR hillshade (lower left), ground-level oblique (lower right).

PSS1C
System: Palustrine
Class: Scrub-Shrub
Subclass: Broad-Leaved Deciduous
Water Regime: Seasonally Flooded

PSS1C wetland features are dominated by deciduous woody vegetation less than 20 feet tall. In many cases, they are transitional successional communities between emergent and forested stages, but there are some mature communities made up of scrub-shrub vegetation. There is regularly standing water early in the growing season, but there may not be surface water present later in the growing season. When surface water is not present, the soil is often saturated very near to the surface. Both bushy shrub species and juvenile trees are included in this class. Examples of the former include willow (*Salix* spp.), red osier dogwood (*Cornus sericea* ssp. *sericea*), and the invasive buckthorns (*Rhamnus* spp.). Examples of the latter include the saplings of American elm (*Ulmus americanus*) and green ash (*Fraxinus pennsylvannica*). They occur in a variety of locations, but tend to occur in seasonally flooded basins, including meander scars (Figure 29). Photosignatures have a fine, rough, stippled texture without distinct tree crowns. The typical signature on CIR imagery is a light gray, white or brown on CIR acquired earlier in the growing season and pink to red on later CIR. Photosignatures on the NAIP tend to have a similar pattern, with green to deep green tones. The leaf-on conditions of the NAIP also produce more distinct shadows, which provide a visual cue to the height of the vegetation. The NAIP imagery is probably most useful for making the PSS1 determination.

Collateral data primarily include SSURGO soils and the LiDAR DEM. Hydric soils are highly likely to be present. The LiDAR DEM and contour lines will depict a basin or meander scar in most cases. There will not be any indication of a hydrologically enforced water surface on the LiDAR DEM.

Figure 28. PSS1C signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 2013 NAIP (lower left), ground-level oblique (lower right).

PFO1C

System: Palustrine

Class: Forested

Subclass: Broad-Leaved Deciduous

Water Regime: Seasonally Flooded

PFO1C wetlands are dominated by trees adapted for life in wet conditions. Vegetation greater than 20 feet in height distinguishes these wetlands from PSS1 wetlands. There is regularly standing water early in the growing season, but there may not be surface water later in the growing season. When surface water is not present, the soil is often saturated very near to the surface. Examples of species present in these wetlands include black willow (*Salix nigra*), silver maple (*Acer saccharinum*), and eastern cottonwood (*Populus deltoides*). They occur in seasonally flooded basins (Figure 30), including meander scars in smaller river floodplains. Large areas of PFO1C wetlands occur in the floodplains of major rivers as well. They can also occur on fringes of larger palustrine and lacustrine basins. Photosignatures have a coarse, rough, stippled texture. An indication of PFO1 wetlands are distinct tree crowns. Large cottonwoods in particular are easily distinguished on the imagery. The typical signature on CIR imagery is a gray or brown for CIR acquired earlier in the growing season and pink to red on later CIR. Photosignatures on the NAIP tend to have a similar pattern, with green to deep green tones. The leaf-on conditions of the NAIP also produce more distinct shadows, which provide a visual cue to the height of the vegetation. The NAIP imagery is probably most useful for distinguishing PFO1 wetlands from PSS1 wetlands, especially where the spring imagery was acquired before leaf out.

Collateral data primarily include SSURGO soils and the LiDAR DEM. Hydric soils are highly likely to be present. The LiDAR DEM and contour lines will typically indicate a basin, meander scars, or flood plain boundaries.

Figure 29. PFO1C signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 3-meter LiDAR hillshade (lower left), ground-level oblique (lower right).

PFO1A

System: Palustrine

Class: Forested

Subclass: Broad-Leaved Deciduous

Water Regime: Temporarily Flooded

Similar to PFO1C, PFO1A wetlands are dominated by trees adapted for life in wet conditions. Vegetation greater than 20 feet in height distinguishes these wetlands from PSS1 wetlands. They typically are only flooded for one or two weeks during the growing season. Examples of species present in these wetlands include black willow (*Salix nigra*), silver maple (*Acer saccharinum*), and Eastern cottonwood (*Populus deltoides*). They occur primarily on flat locations, which is the main distinguishing characteristic from PFO1C wetlands (Figure 31). They also occur on fringes of larger palustrine and lacustrine basins. Photosignatures have a course, rough, stippled texture. An indication of PFO1 wetlands are distinct tree crowns. Large cottonwoods in particular are easily distinguished on the imagery. The typical signature on CIR imagery is a gray or brown for CIR acquired earlier in the growing season and pink to red on later CIR. Photosignatures on the NAIP tend to have a similar pattern, with green to deep green tones. The leaf-on conditions of the NAIP also produce more distinct shadows, which provide a visual cue to the height of the vegetation. The NAIP imagery is probably most useful for distinguishing PFO1 wetlands from PSS1 wetlands, especially where the spring imagery was acquired before leaf out.

Collateral data primarily include SSURGO soils and the LiDAR DEM. Hydric soils are likely to be present. The LiDAR DEM and contour lines will typically indicate a flat or very gently sloping area.

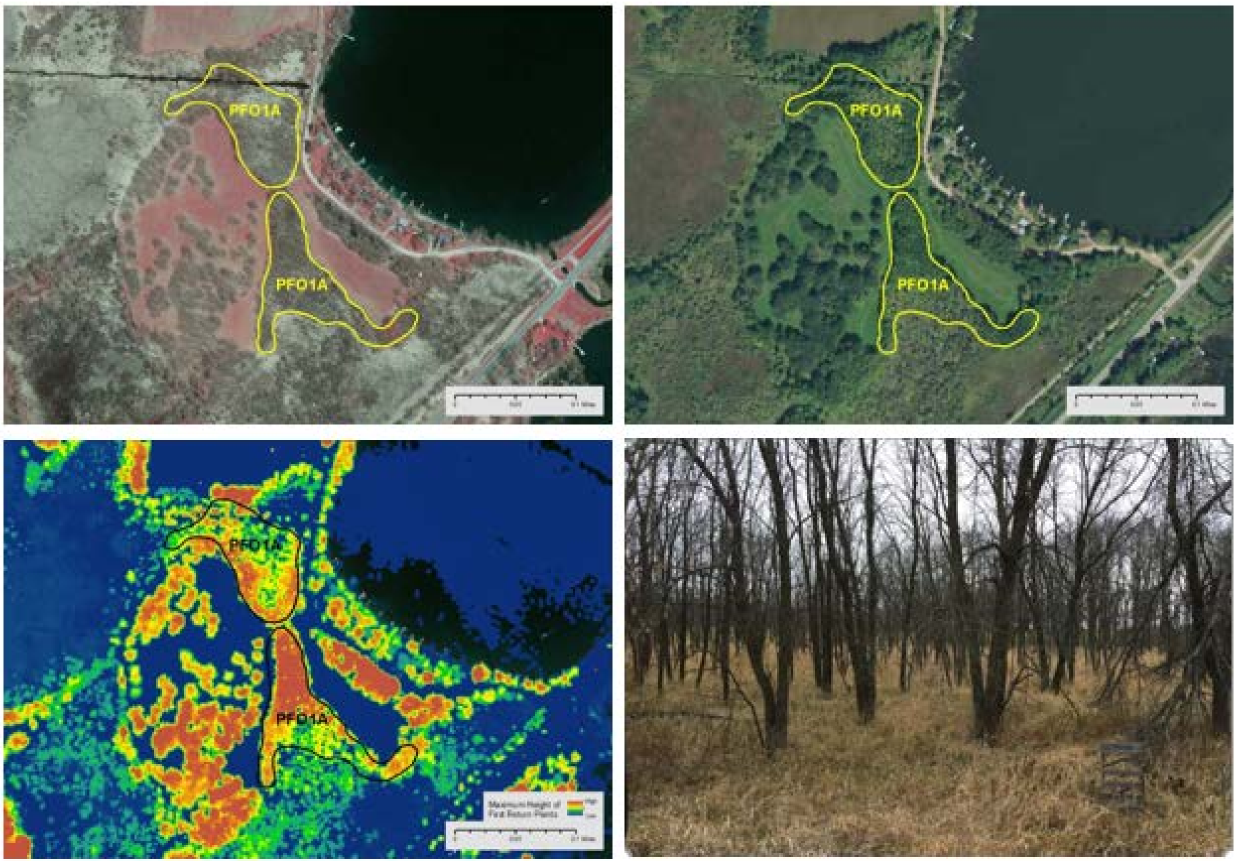


Figure 30. PFO1A signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), maximum height of first return points (lower left), ground-level oblique (lower right).

B (Saturated) Water Regime

The saturated water regime rarely floods, but has wet, saturated soil to the surface for extended periods during the growing season. Unlike other wetland types, which tend to have hydrology dominated by surface water, saturated wetlands exist primarily due to ground water sources. The following wetland types all have the B water regime assigned to them.

<u>PSS2B</u>

System: Palustrine

Class: Scrub-Shrub

Subclass: Needle-Leaved Deciduous

Water Regime: Saturated

PSS2B wetlands are defined by the presence of needle-leaved deciduous trees, such as small-form tamarack. Saturation occurs throughout the entire year and can sometimes flood when precipitation is high. Photosignatures appear light pink (Figure 32) due to the needle-leaved deciduous trees starting to bud in the spring CIR. The maximum height of first return points data can provide insight into the height of the vegetation; vegetation in PSS2B wetlands will appear shorter than vegetation in PFO2B wetlands.

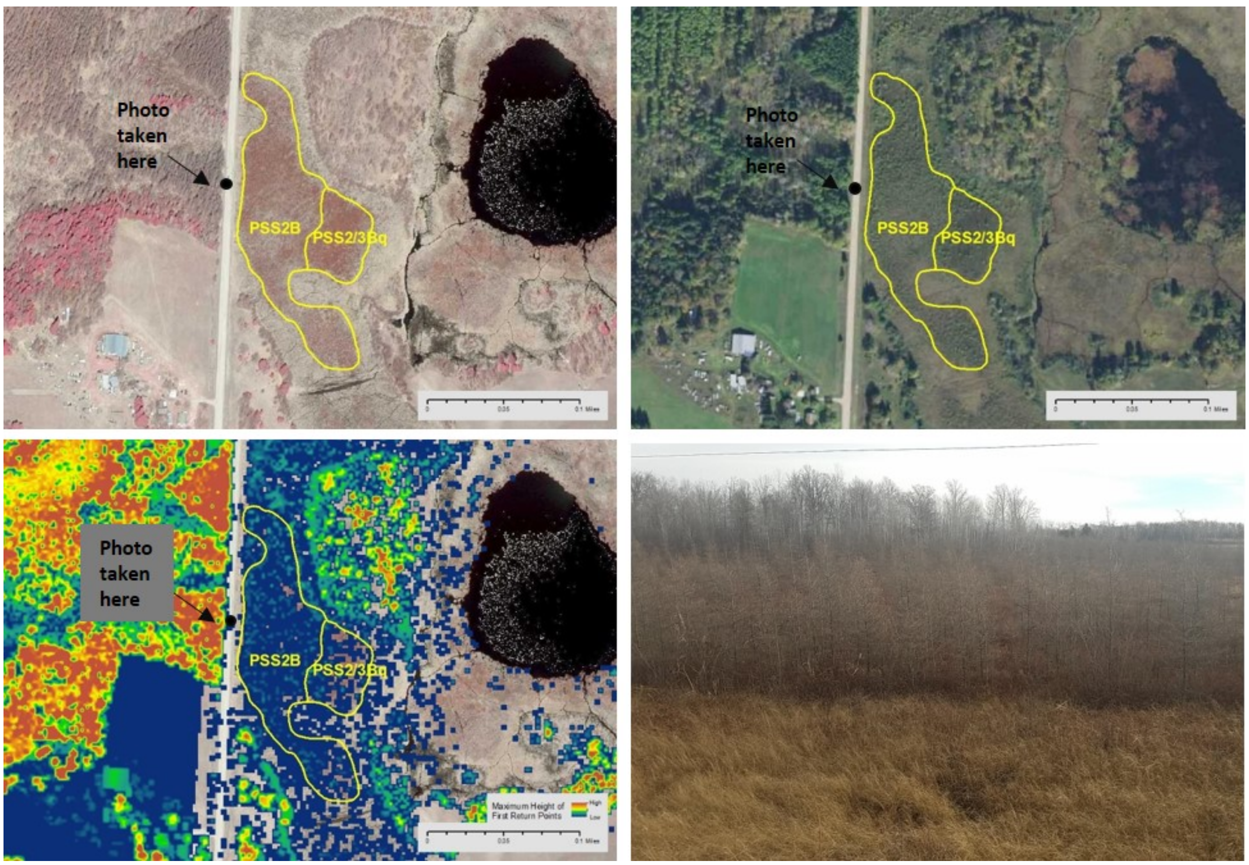


Figure 31. PSS2B signature example; 2013/13 CIR (upper left), 2015 NAIP (upper right), maximum height of first return points (lower left), ground-level oblique of small-form tamarack (lower right).

PFO2B

System: Palustrine

Class: Forested

Subclass: Needle-Leaved Deciduous

Water Regime: Saturated

Defined by species such as full-grown tamarack trees, PFO2B wetlands are saturated all of the time and can have standing water if an increase in precipitation occurs. Photosignatures in the spring CIR can appear light-gray to pink depending on what time in the spring the CIR was generated (Figure 33). Full-grown tamarack trees will appear pink/red before other deciduous trees, which will have predominately a tone of gray due to their leaves not budding yet in the spring, but not as red as needle-leaved evergreen trees (PFO4), which hold their needles all year around. The maximum height of first return points data can provide insight into the height of the vegetation; vegetation in PFO2B wetlands will appear taller than vegetation in PSS2B wetlands.

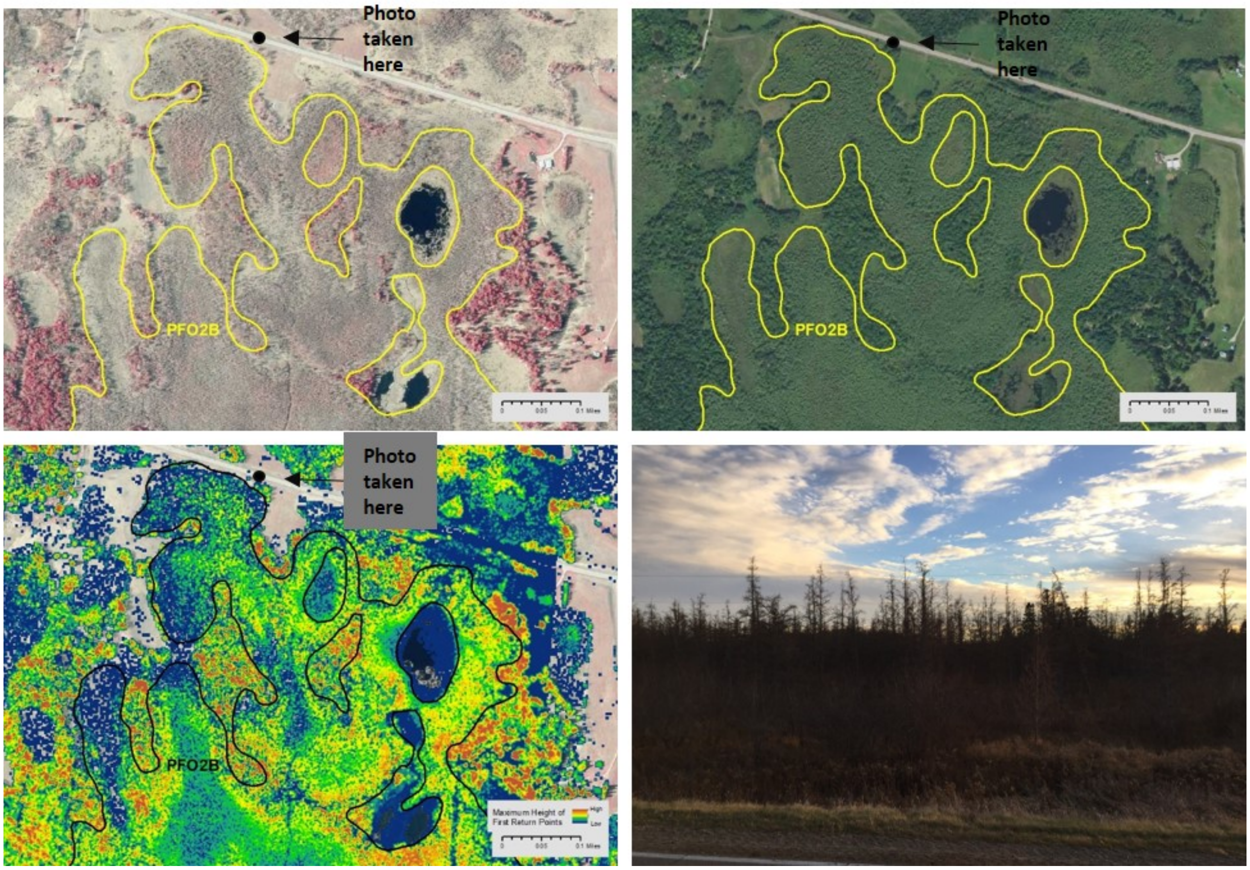


Figure 32. PFO2B signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), maximum height of first return points (lower left), ground-level oblique of full-grown tamarack (lower right).

PSS3B

System: Palustrine

Class: Scrub-Shrub

Subclass: Broad-Leaved Evergreen

Water Regime: Saturated

Broad-leaved evergreen shrubs, such as bog rosemary (*Andromeda polifolia*) and leatherleaf (*Chamaedaphne calyculata*), are vegetation that can be found in the PSS3B wetland type. Photosignatures appear light pink similar to PSS2B wetlands, yet have a smoother texture compared to the rougher looking PSS2B (Figure 34).

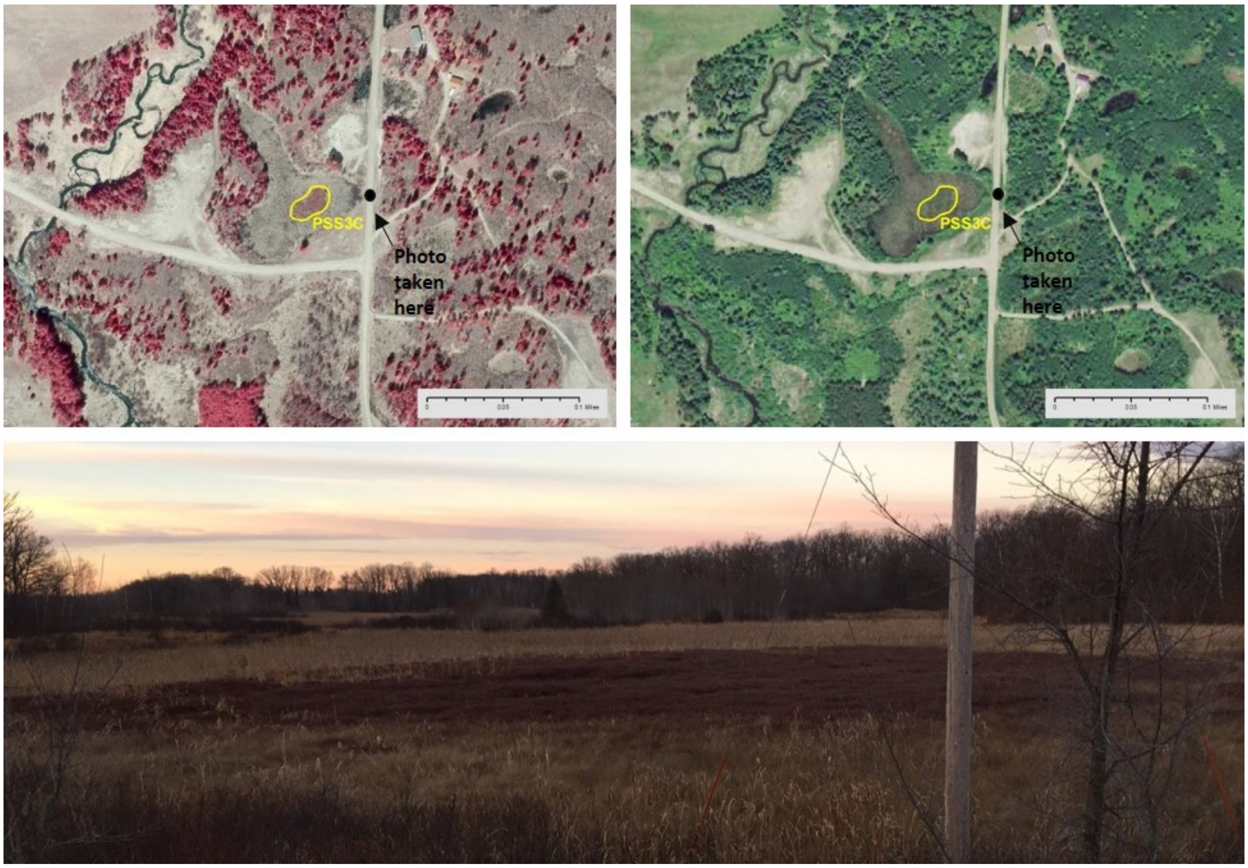


Figure 33. PSS3B signature example; 2013/14 CIR (upper left), 2013 NAIP (upper right), ground-level oblique of leatherleaf (bottom).

<u>PSS4B</u>

System: Palustrine

Class: Scrub-Shrub

Subclass: Needle-Leaved Evergreen

Water Regime: Saturated

PSS4B wetlands are defined by the presence of needle-leaved evergreen trees, such as small-form black spruce. Saturation occurs throughout the entire year and can sometimes flood when precipitation is high. Tamarack (PSS2B) and black spruce (PSS4B) can be difficult to distinguish from one another; a deciding factor can be the amount of red wetland signature. Black spruce will appear a brighter red while tamarack can appear light pink or gray due to their needles starting to bud in the spring. To differentiate PSS4B and PFO4B, the maximum height of first return points data can provide insight; vegetation in PSS4B wetlands will appear shorter than vegetation in PSS4B wetlands (Figure 35).

<u>PFO4B</u>

System: Palustrine

Class: Forested

Subclass: Needle-Leaved Evergreen

Water Regime: Saturated

Tamarack (PFO2B) and black spruce (PFO4B) can be difficult to distinguish from one another; a deciding factor can be the amount of red wetland signature and the density of the vegetation. Like mentioned above, tamarack can appear light pink due to their needles starting to bud in the spring. Black spruce will appear bright red and appear denser because they retain their needles year-round. To differentiate PFO4B from PSS4B, the maximum height of first return points data can provide insight; vegetation in PFO4B wetlands will appear taller than vegetation in PSS4B wetlands (Figure 35).

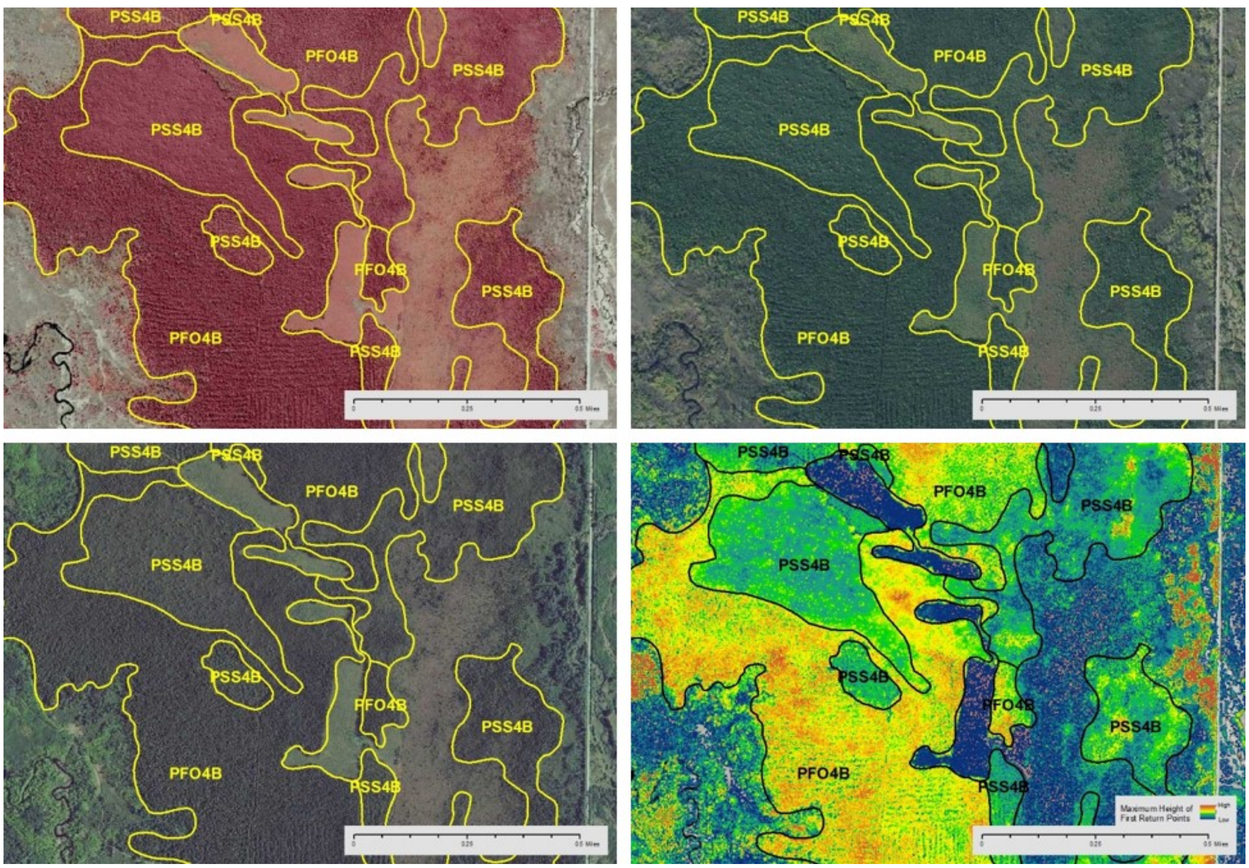


Figure 34. PSS4B and PFO4B signature examples; 2013/14 CIR (upper left), 2015 NAIP (upper right), 2010 NAIP (lower left), maximum height of first return points (lower right).

Mixed Wetland Classes

In situations where it is difficult to delineate separate vegetation classes, mixed classes are used to classify wetlands that have an even mixture of two vegetation classes. Below are a few examples of what could be encountered during this NWI update in Northwest Minnesota.

PSS1/EM1B

System: Palustrine

Class: Scrub-Shrub/Emergent

Subclass: Broad-Leaved Deciduous/Persistent

Water Regime: Saturated (Figure 36)

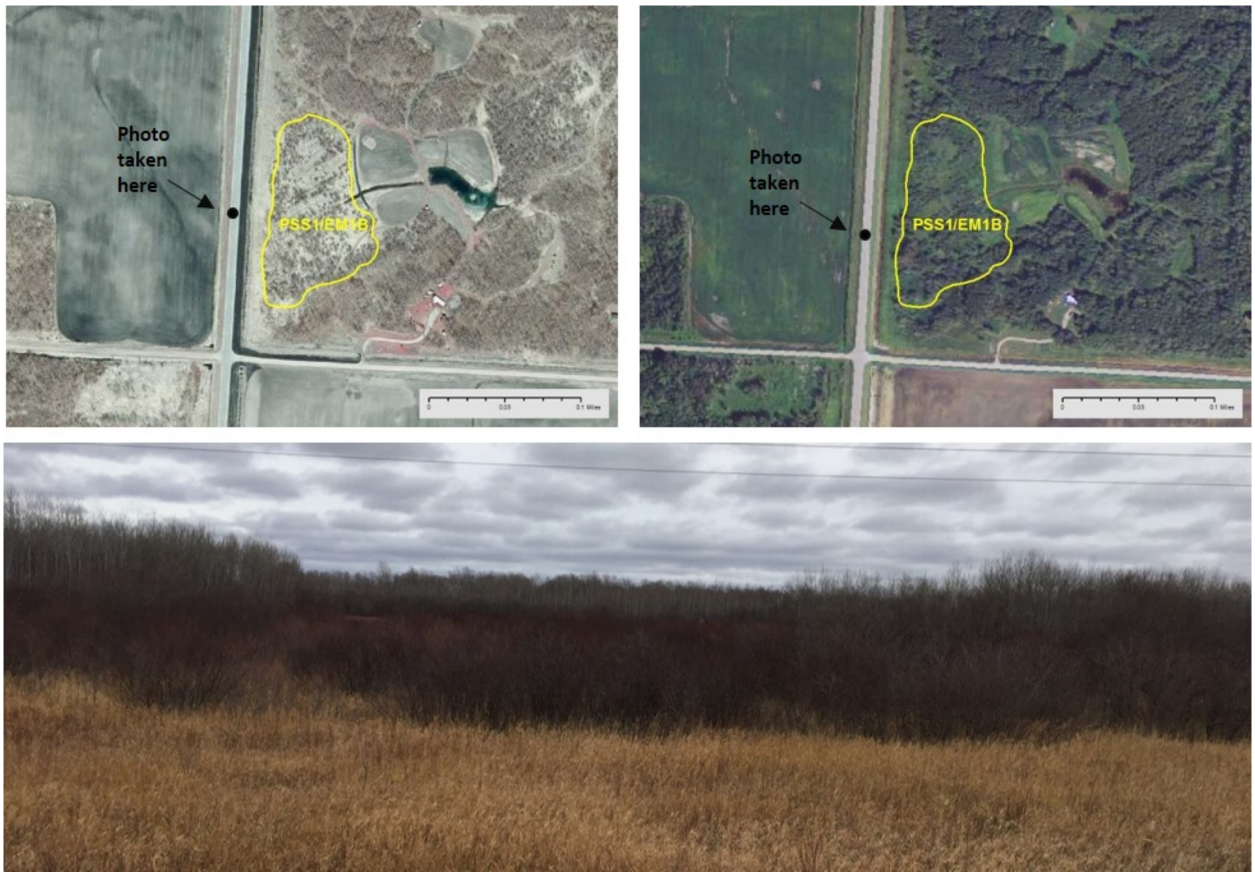


Figure 35. PSS1/EM1B signature examples; 2013/14 CIR (upper left), 2010 NAIP (upper right), ground level oblique (bottom).

PFO1/SS1B

System: Palustrine

Class: Forested/Scrub-Shrub

Subclass: Broad-Leaved Deciduous

Water Regime: Saturated (Figure 37)

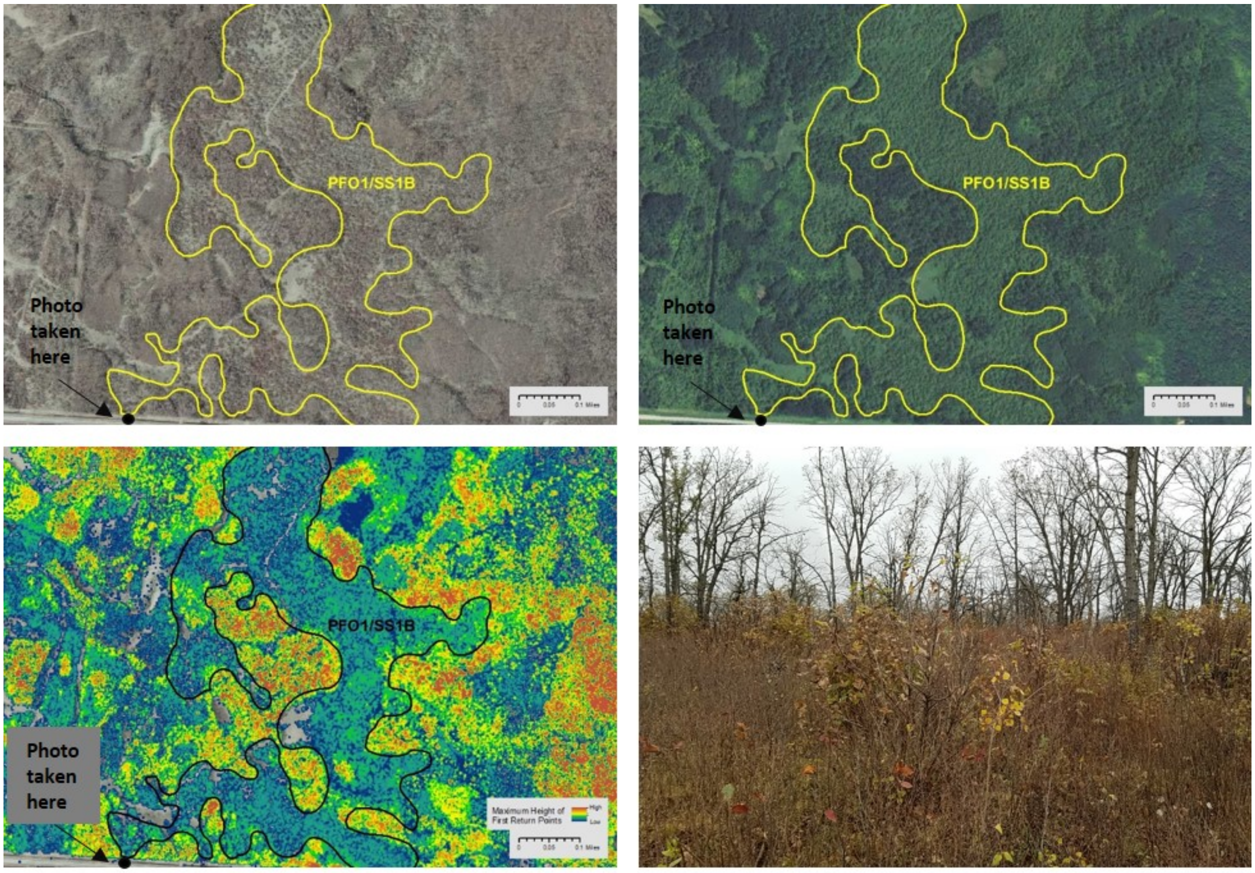


Figure 36. PFO1/SS1B signature examples; 2013/14 CIR (upper left), 2013 NAIP (upper right), maximum height of first return points (lower left), ground level oblique (lower right).

Farmed Wetlands

Farmed wetlands will be designated by the PEM1Af classification. The main distinguishing factor between a farmed wetland and a wetland that happens to be located within an agricultural area is the presence/absence of hydrophytic vegetation. If a wetland contains hydrophytic vegetation, it should be classified using the previously defined protocols. If there is no hydrophytic vegetation present and it meets the conditions outlined below, it should be mapped as a farmed wetland (PEM1Af):

1. Inundation (standing water) or evidence of heavy saturation on the 2013/14 Spring CIR, and,
2. Evidence of crop stress, drown out, or otherwise altered crop pattern on at least 2 out of the 3 NAIP (2015, 2013, 2010) images.

Generally, soil signatures will be dark in comparison to the surrounding area and can sometimes have a thin white border around at least part of the area. The white is crop chaff and debris that was floating on standing water and was blown to one side by the wind before the water drained away. Farmed wetlands will only occur in depressions and other low level areas. The LiDAR hillshade is helpful in identifying these areas. Figure 38 below illustrates the difference between areas that should be considered for mapping as PEM1Af ("PEM1Af") and areas that should not be considered ("NOT

PEM1Af"). When determining boundary locations, the "average" location of crop stress/drown out/disturbance should be used, not necessarily the dark soil signature boundary on the CIR imagery.

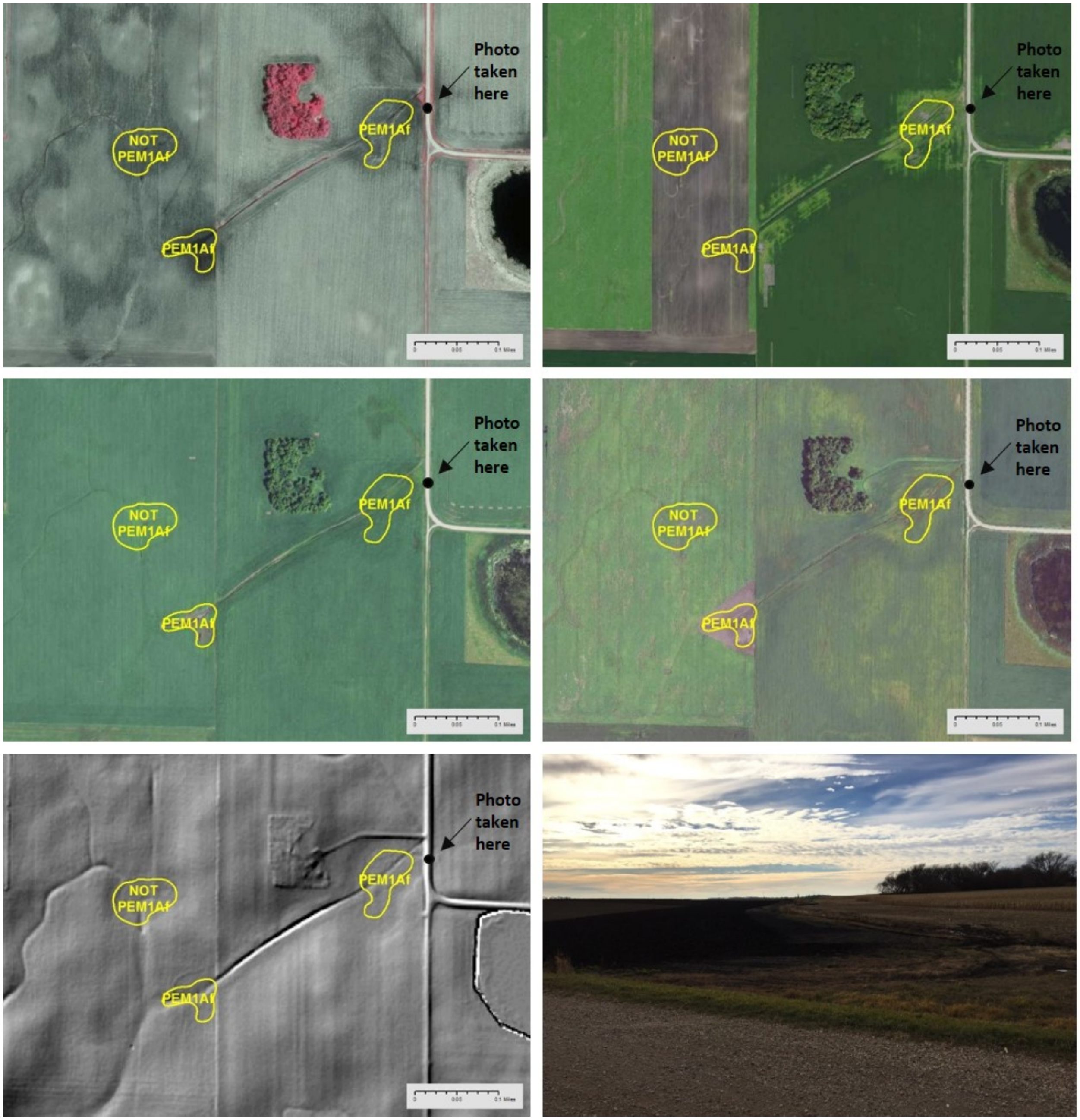


Figure 37. PEM1Af signature example; 2013/14 CIR (upper left), 2015 NAIP (upper right), 2013 NAIP (center left), 2010 NAIP (center right), 3-meter LiDAR hillshade (lower left), ground-level oblique of PEM1Af not farmed in 2016 (lower right). Notice the two PEM1Af wetlands have soil scarring 2 out of 3 NAIP years while the polygon labeled "NOT FARMED" does not have 2 out of 3 years of soil scaring.

Partially Drained/Ditched Wetlands

The partly drained ("d") special modifier is applied to those areas where the water level has been artificially lowered due to ditching or drain tile, but still have enough soil moisture to support hydrophytes. If soil moisture has been lowered to the point that it no longer supports hydrophytes, it is no longer classified as wetland. In the historic NWI data, the partly drained modifier was used more frequently than the previously mentioned farmed (“f”) special modifier and should not be relied upon as an indicator of current conditions. The “d” modifier should be used in situations like the example below (Figure 39). When there is a ditch or drain tile associated with a wetland, a determination must be made as to whether the ditch/tile is draining out of the wetland or into the wetland. In this case, the contours indicate the ditch is pulling water from the wetland and the “d” modifier should be used. Additional indications include the wetland is getting smaller in extent and/or drier in terms of water regime over time, as compared to the historic NWI data.

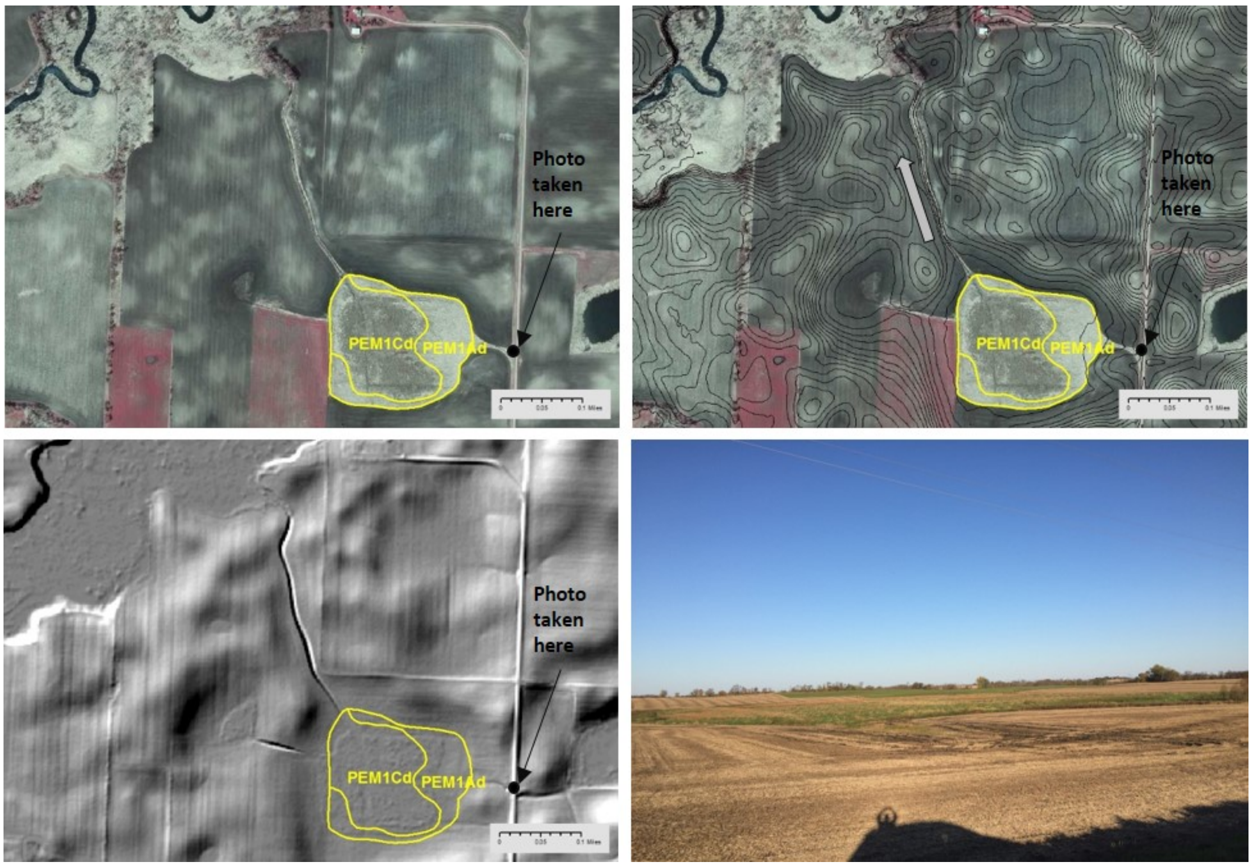


Figure 38. Drained wetland signature example; 2013/14 CIR (upper left), 2013/14 CIR with 2-foot contours (upper right), 3-meter LiDAR hillshade (lower left), ground-level oblique (lower right).

Peatland Wetlands

For this particular project, peatlands can be found in the northeast corner of the project area. In terms of the Cowardin Classification, wetlands that are considered peatlands receive the “q” modifier and can cross all classes (PEM, PSS, and PFO). They will always be assigned the “B” water regime due to their ability to hold water. Tree species such as tamarack (see PFO2B above) and black spruce or shrub species such as leatherleaf that are found growing on a bed of sphagnum moss are considered peatlands and will be classified appropriately (Figure 40).

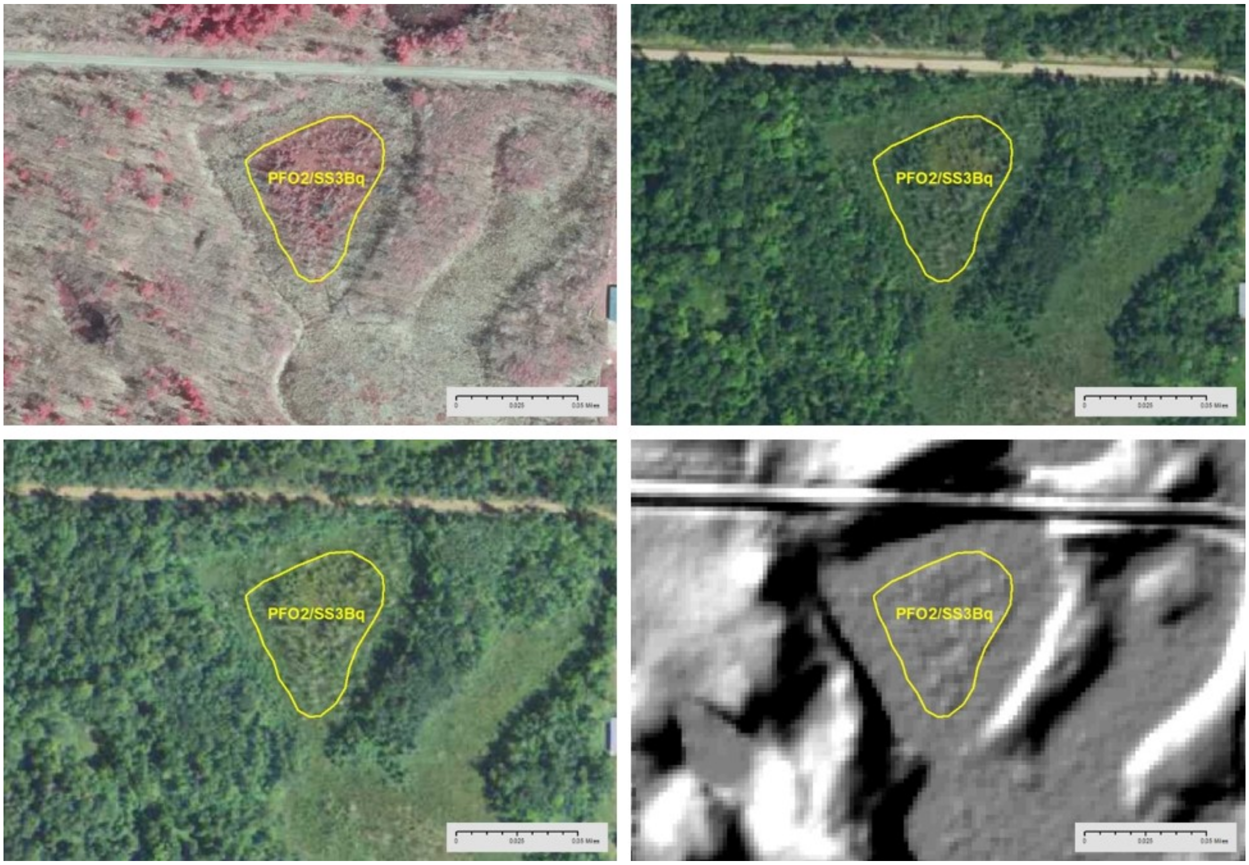


Figure 39. Inside this basin, a peatland signature (PFO2/SS3Bq) can be found with the presence of tamarack and a broad-leaved evergreen shrub, like leatherleaf.

Unusual Signatures

These signatures are documented in the interest of reducing confusion when they are encountered. In some cases, they mimic other wetland signatures.

Ice

On the Spring CIR imagery, there are a few examples of winter ice still present on lakes and ponds. The example below (Figure 41) shows a pocket of ice on Lake of the Woods in Lake of the Woods County. The 2010 NAIP also shown below indicates a lacustrine unconsolidated bottom (UB) classification. Where ice is present, the NAIP imagery is the primary image source.

Figure 40. Lake ice example on Lake of the Woods; 2013/14 CIR (left) and 2015 NAIP (left).

Peat Harvesting

Northern Minnesota supports a peat industry that produces and harvests peat for horticultural purposes (e.g., greenhouse use). In aerial imagery, peat harvest areas often appear unnatural in shape and may show a series of straight lines from machinery operations (Figure 41). These areas are mapped as PEM1B, with an excavated (x) modifier added once an area was harvested.

Figure 41. Peat harvest example, 2013/14 CIR; note unnatural geometric shapes and lines from machinery in some areas.

Wild Rice Plantations

Northern Minnesota also supports wild rice farming, where rice is cultivated in purposely flooded fields. Like peat harvest areas, wild rice plantations often appear unnatural in shape. They will appear totally or partially flooded on spring CIR, since wild rice is a non-persistent plant, but are usually green on NAIP imagery. These areas are mapped as PEM2Kx (non-persistent emergent vegetation, artificially flooded, excavated).

Figure 42. Wild rice plantation example, 2013/14 CIR; note unnatural shapes and black or dark blue (flooded) color.

Beaver activity

Beavers are “ecosystem engineers”, capable of manipulating the vegetation and hydrology of their habitat. In the Northwest Minnesota project area, beavers have converted some forested areas to meadows and their damming activity has created ponds or made wetlands even wetter (e.g., A to C or C to F). The graphics below show an area cleared of trees by beavers (upper wetland) and a more recently dammed area (lower wetland), where felled trees are still visible and the dam is seen as a straight line at the top of the pond (Figure 43).

Figure 43. Example of beaver activity in 2013/14 CIR (left) and 2010 NAIP (right). The beaver dam and felled trees are visible in the CIR of the lower right wetland.

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ATTACHMENT E

Press Release for the National Wetland Inventory Update

DNR releases Minnesota's National Wetlands Inventory update

June 3, 2019

10-year project will help protect wetlands

The Minnesota Department of Natural Resources has completed a 10-year effort to provide much more accurate maps of Minnesota’s wetlands. The update of the state’s National Wetlands Inventory (NWI) used new technologies to produce a clearer picture of Minnesota’s wetlands, lakes, rivers and streams.

The updated NWI gives resource managers and landowners a vital tool to aid wetland protection and restoration. "These new maps are much more accurate, capture more detail and provide more information than the original NWI maps," said Steve Kloiber, the DNR manager of the NWI update project.

The new statewide GIS dataset reveals that there are 14.2 million acres of combined lake and wetland area in Minnesota. Of this total, 12.2 million acres are wetland, which are distinguished by having relatively shallow water or saturated soils with permanent vegetation under normal conditions.

The U.S. Fish and Wildlife Service originally mapped wetlands in Minnesota in the late 1970s and early 1980s as part of the National Wetlands Inventory. The just-completed DNR mapping project is the first time the NWI has been updated in Minnesota. The new maps reflect the latest technology in remote sensing and mapping, including high-resolution aerial imagery and Light Detection and Ranging (LiDAR) data.

The new wetland map data are available through an interactive mapping application on the DNR’s website (https://arcgis.dnr.state.mn.us/ewr/wetlandfinder/) and can also be downloaded, free of charge, for use in geographic information system applications through the Minnesota Geospatial Commons.

Besides showing the location, size and type of each wetland, the updated map data include information on other wetland characteristics, such as depth, duration and frequency of flooding, and how the wetland is situated in the overall landscape. That information is useful in assessing wetland benefits such as water quality improvement, flood storage, and fish and wildlife habitat. The map data are widely used by landowners, local governments and state and federal agencies for land use planning, wetland permit screening and natural resource management.

As noted by Dillon Hayes, Mille Lacs County environmental resources manager, "We use wetland maps for many of our county functions, like water and transportation planning, shoreland management and wetland permitting. Having accurate, up-to-date wetland map data will be very helpful to the county."

While the new wetland map data are an improvement over the original NWI and are useful for planning and identifying the potential need for wetland permits, they are not sufficiently accurate on their own to determine all applicable wetland regulations.

Landowners considering work that may affect wetlands should contact their county soil and water conservation district or the DNR for advice on determining whether wetlands are present and the exact location of the regulated wetland boundary.

It is not possible to accurately compare the updated wetland data to the original NWI, because of the significant advances in remote imagery and mapping techniques. A 1984 University of Minnesota study based on soil analysis estimated that Minnesota has lost about half of the wetlands that existed prior to European settlement. Recent monitoring conducted by the DNR shows that the state's wetland acreage has been holding steady since 2006, although there has been a net conversion of higher quality, vegetated wetlands to open water ponds.

The NWI update project was funded by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources. Other partners included the U.S. Fish and Wildlife Service, the University of Minnesota, St. Mary's University, Ducks Unlimited and the St. Croix Watershed Research Station.

Media Mentions of NWI

https://www.redwoodfallsgazette.com/news/20190612/dnr-releases-national-wetlands-inventory-update

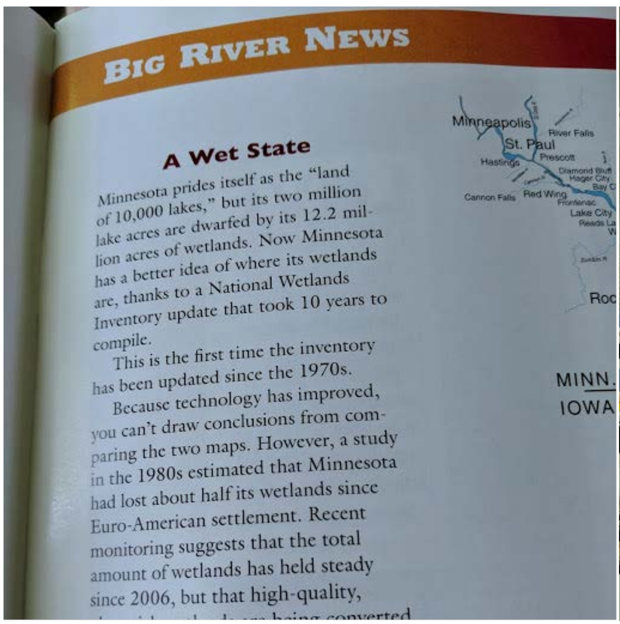
https://www.swnewsmedia.com/jordan_independent/news/sports/better-more-accurate-maps-to-view-wetlands/article_d0c03792-8d61-5dc0-8e31-bafab0c69d2f.html

http://news.dnr.state.mn.us/2019/06/03/dnr-releases-minnesotas-national-wetlands-inventory-update/

http://boblamboutdoors.com/index.php/outdoorsgeneral/outdoors/1368-dnr-releases-minnesota%E2%80%99s-national-wetlands-inventory-update.html

https://www.keyc.com/video/2019/06/22/areas-southern-minnesota-have-lost-percent-or-more-their-original-wetlands-new-data-finds/

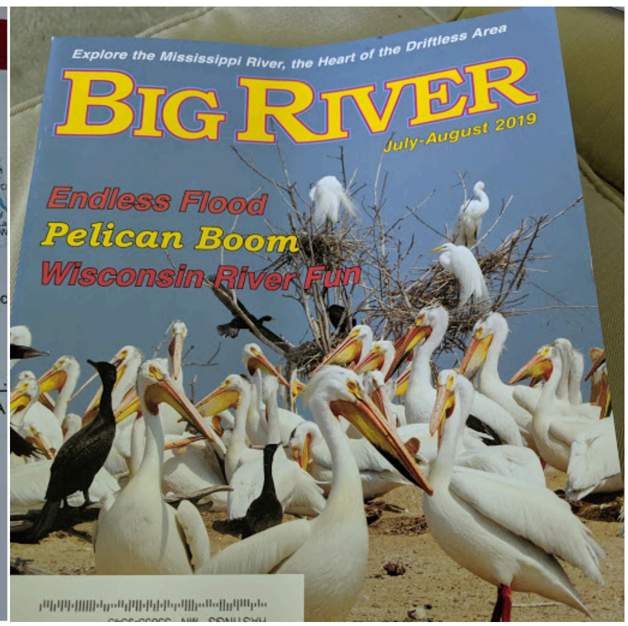
https://www.bigrivermagazine.com/riverlinks.html


BIG RIVER NEWS

A Wet State

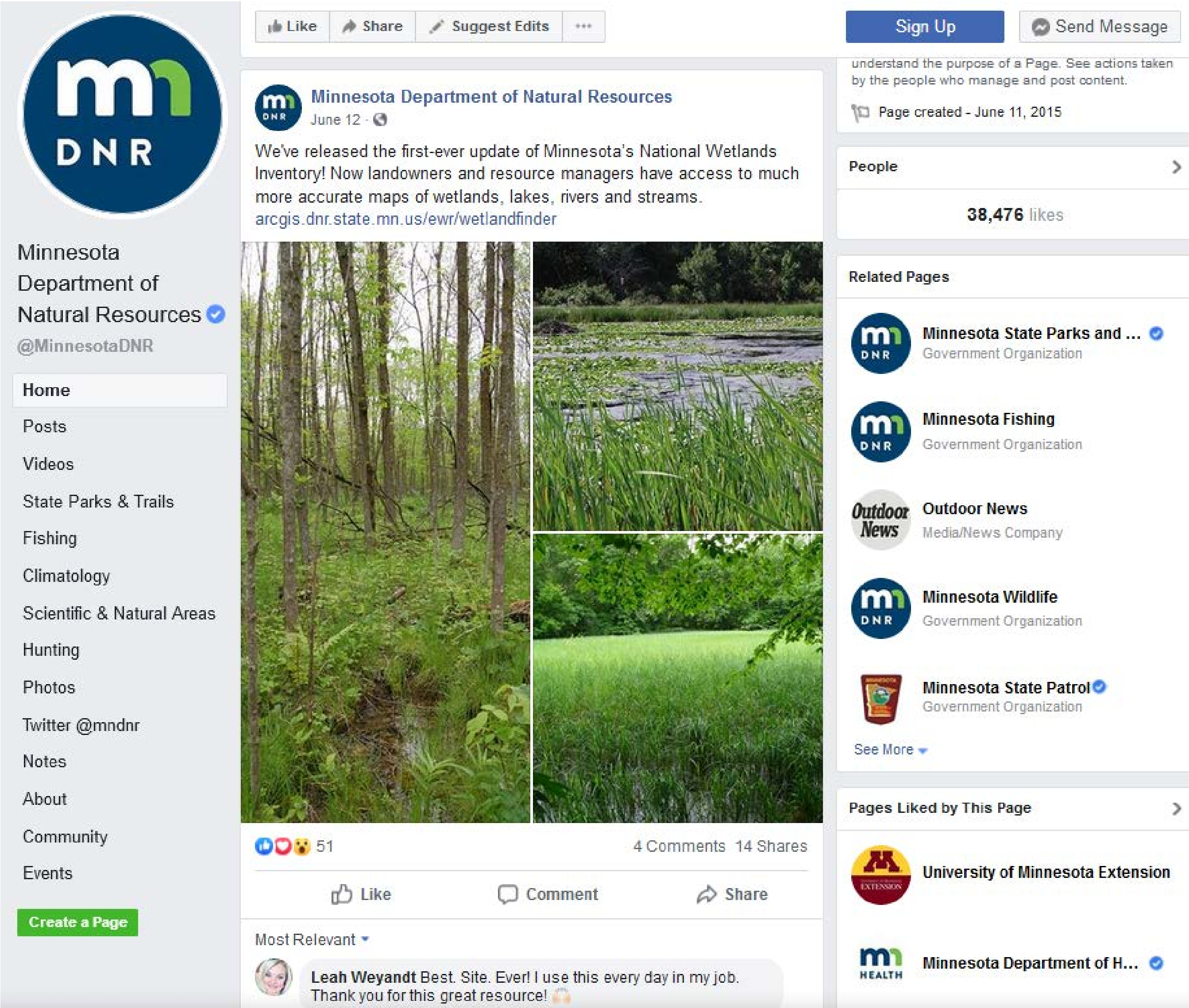
Minnesota prides itself as the "land of 10,000 lakes," but its two million lake acres are dwarfed by its 12.2 million acres of wetlands. Now Minnesota has a better idea of where its wetlands are, thanks to a National Wetlands Inventory update that took 10 years to compile.

This is the first time the inventory has been updated since the 1970s. Because technology has improved, you can't draw conclusions from comparing the two maps. However, a study in the 1980s estimated that Minnesota had lost about half its wetlands since Euro-American settlement. Recent monitoring suggests that the total amount of wetlands has held steady since 2006, but that high-quality,



Social Media

Minnesota DNR Facebook



Minnesota DNR Twitter

Tweets	Following	Followers	Likes
8,959	382	32.9K	1,971

Show this thread

Minnesota DNR @mndnr · Jun 12

Check out the first-ever update of Minnesota's National Wetlands Inventory! Find more accurate maps of #wetlands, lakes, rivers and streams. arcgis.dnr.state.mn.us/ewr/wetlandfin...

1 8

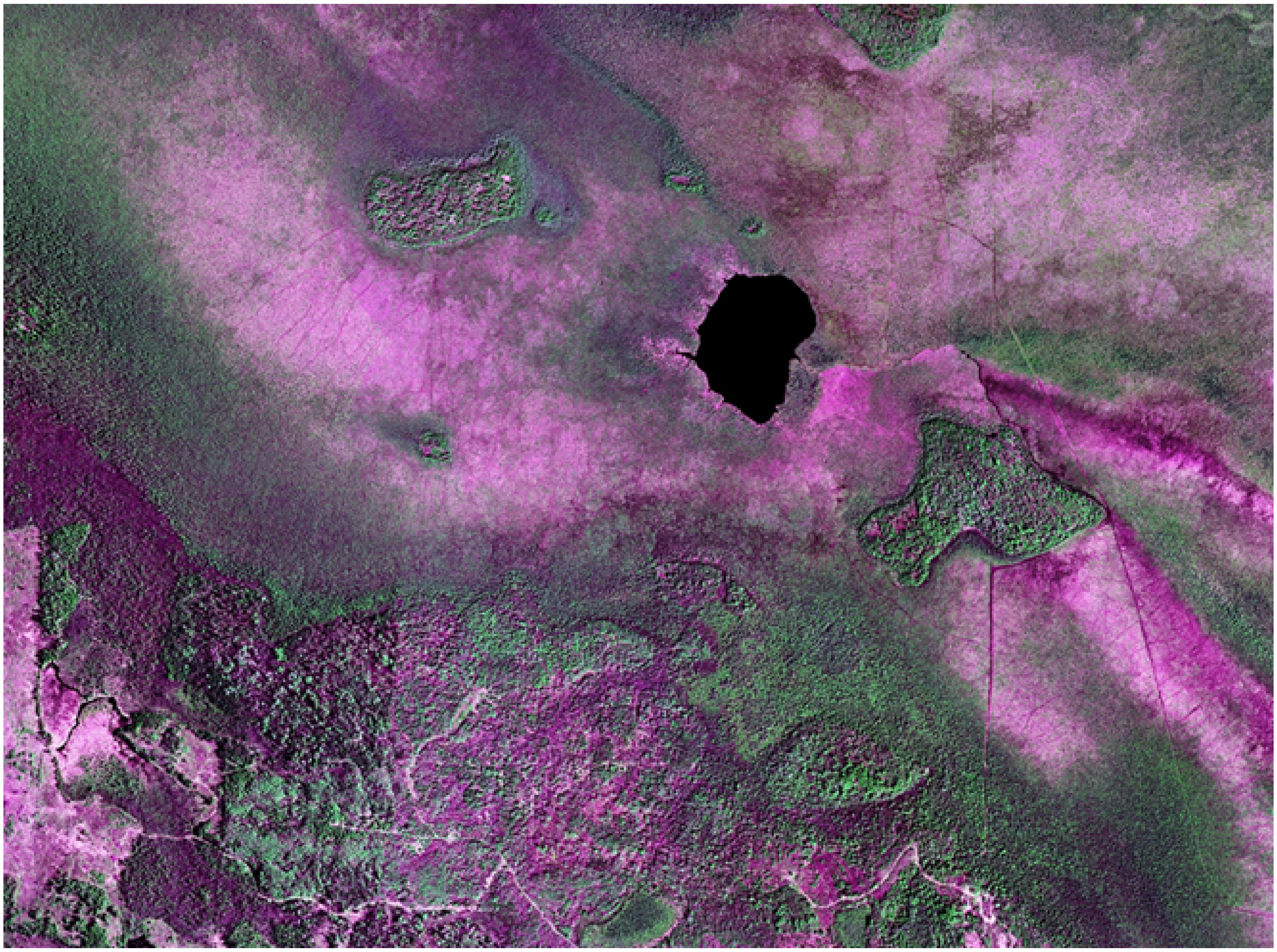
ATTACHMENT F

Nomination for the Governor's Geospatial Commendation Award

An Updated and Enhanced National Wetland Inventory for Minnesota

Project Duration: July 2008 – June 2019

https://www.dnr.state.mn.us/eco/wetlands/nwi_proj.html



DEPARTMENT OF NATURAL RESOURCES

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

1 INTRODUCTION

1.1 WHY IT MATTERS

The National Wetland Inventory (NWI) updated for Minnesota is the most comprehensive and up-to-date inventory of wetlands and water ecosystems in the country. It is an important dataset for many natural resource planning and management efforts within Minnesota. These wetland data are used across all levels of government, as well as by private industry and non-profit organizations as an aid in wetland regulation and management, land use and conservation planning, environmental impact assessment, and natural resource inventories. Among other things, the NWI has been used to assess impacts of regulatory policy, identify flood storage, evaluate carbon storage potential and climate change impacts, and estimate waterfowl and amphibian population distribution.

The original NWI was completed in the mid-1980s, but over the decades, it had become considerably out-of-date. In addition, mapping technology has changed considerably. Updating the inventory was critical for continued support of wetland planning and management needs. With over two million polygons in the dataset, it is also one of the largest GIS datasets for Minnesota.

1.2 PROJECT DESCRIPTION

Under this project, the Environmental and Natural Resources Trust Fund provided $7 million to the Minnesota Department of Natural Resources (DNR) to coordinate a collaborative effort and conduct a comprehensive, statewide update of the National Wetland Inventory for Minnesota. This effort included:

- Developing new methods for integrating lidar data into wetland mapping through the research efforts at the University of Minnesota, Remote Sensing and Geospatial Analysis Laboratory,
- Acquisition of new statewide, high-resolution digital stereo spring leaf-off aerial imagery to serve as the base imagery,
- Engaging federal, state, and local partners to enhance the imagery acquisition effort
- Creation of a suite of statewide lidar-derived topographic datasets to assist with wetland mapping,
- A complete re-mapping and classification of all wetlands in Minnesota larger than 0.5-acre in size,
- Engaging stakeholders to participate in the development and review of the updated wetland inventory,
- Engaging stakeholders in field visits designed to ensure accurate mapping and classification of wetlands,
- Enhancing the wetland inventory data with additional attributes, including alternative wetland classification systems, and attributes relating to wetland function, and
- Efficiently delivering data freely to various user groups through multiple means.

1.3 AWARD CRITERIA & PROJECT GOALS

This project meets multiple award criteria:

1. Yielded tangible benefits and exceptional results
2. Had a significant impact outside the home organization
3. Efficient investment in geospatial information that serve multiple purposes and users
4. Development of geospatial data as a public resource, widely available at reasonable cost
5. Use of GIS as an instrument for policy and decision-making

2 Uses & Benefits

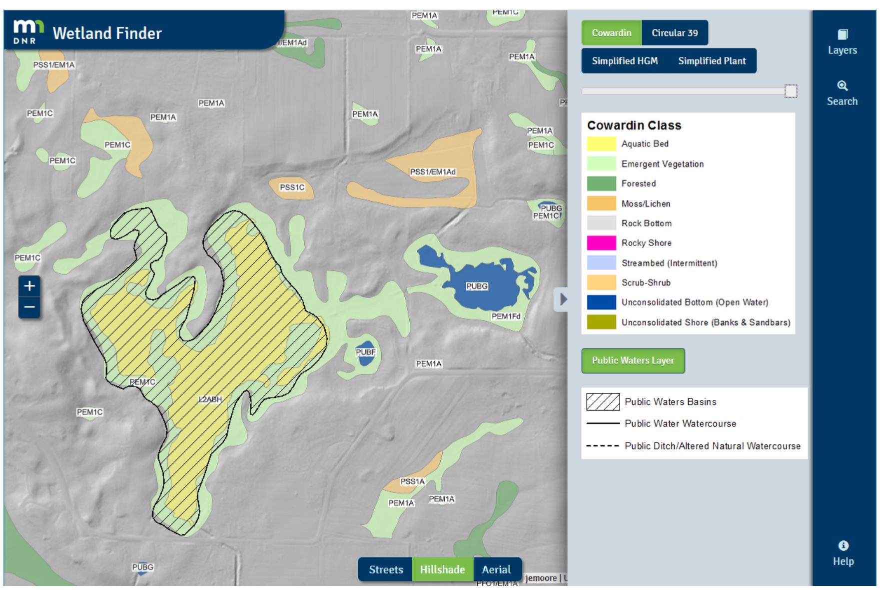
The following section illustrates some of the many applications and benefits of the NWI update project.

2.1 Land use and development planning

One of the most common wetland questions we get from landowners, developers, and real estate professionals is, “Are there wetlands on my property?” While the NWI isn’t a regulatory wetland determination, it is usually the first place to turn to begin to answer this question. Unsurprisingly, most of the people that ask this question aren’t GIS experts. The DNR developed the Wetland Finder application to meet the needs of these groups.

Wetland Finder provides a simple method for the non-GIS user to view the updated National Wetland Inventory (NWI) data. People use this application to check location, how many, and what types of wetlands are present in a given area. Users can search the map for a specific address and view wetland data from the NWI as well as public waters from the Public Waters Inventory (PWI). Users can choose to display the data according to any of four different wetland classifications and they can click on any wetland to get additional information. The information window provides links to regulatory contacts including the local government unit (LGU) contact list for the Wetland Conservation Act as well as to DNR area hydrologists for questions about public waters.

- Doug Norris, Wetland Program Coordinator, Minnesota DNR



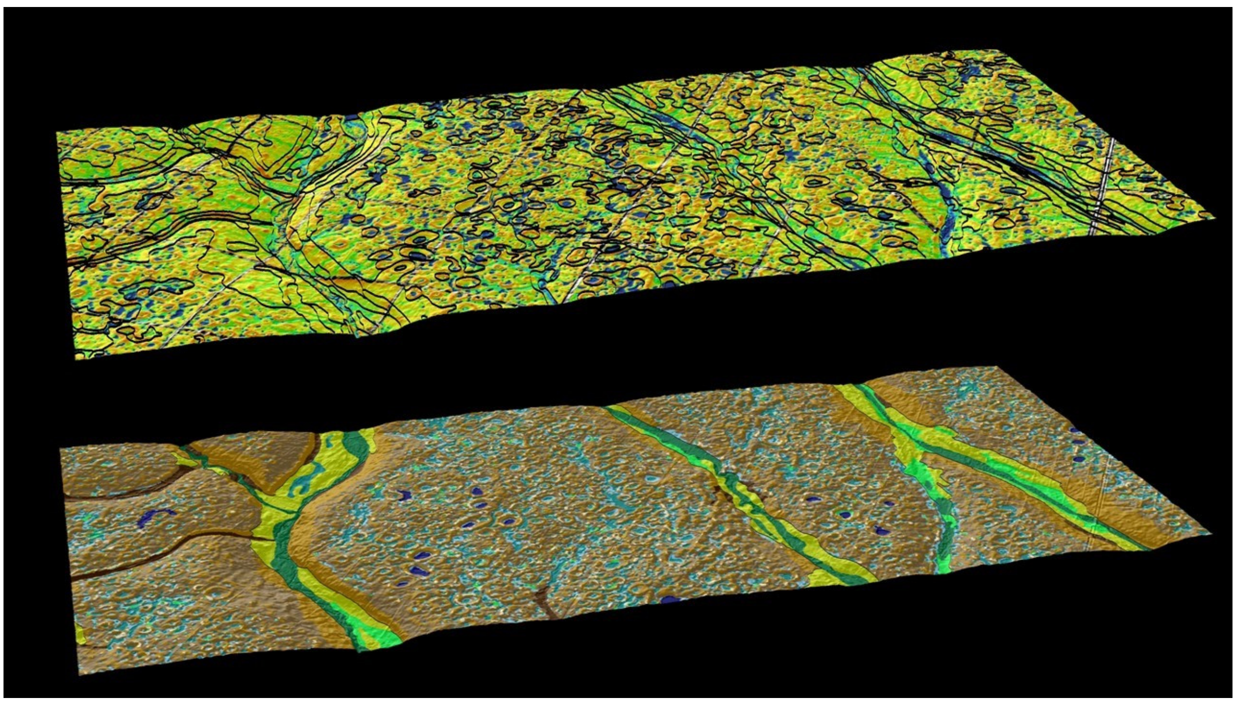
Screenshot of the Wetland Finder application

2.2 UPDATING THE SOIL SURVEY

The Natural Resources Conservation Service (NRCS) creates and maintains soil survey data that include detailed maps of soil units along with descriptions and tables of soil properties. Soil surveys are used by farmers, real estate agents, land use planners, engineers and others who need information about soil resources. Soils form over time under the influence of parent material, climate, topography, and biological activity. These are some of the same forces involved in the formation of wetlands. Therefore, it's not surprising that there is considerable correlation between the presence or absence of wetlands and the presence or absence of certain soil types.

Soil Scientists have found the new enhancements to the NWI and associated classifications critical in developing strategies for identifying, classifying and sampling wet soils. This data has also been beneficial in modeling efforts to develop consistent and repeatable soil survey information.

- Danielle Evans, MLRA Soils GIS Specialist, NRCS



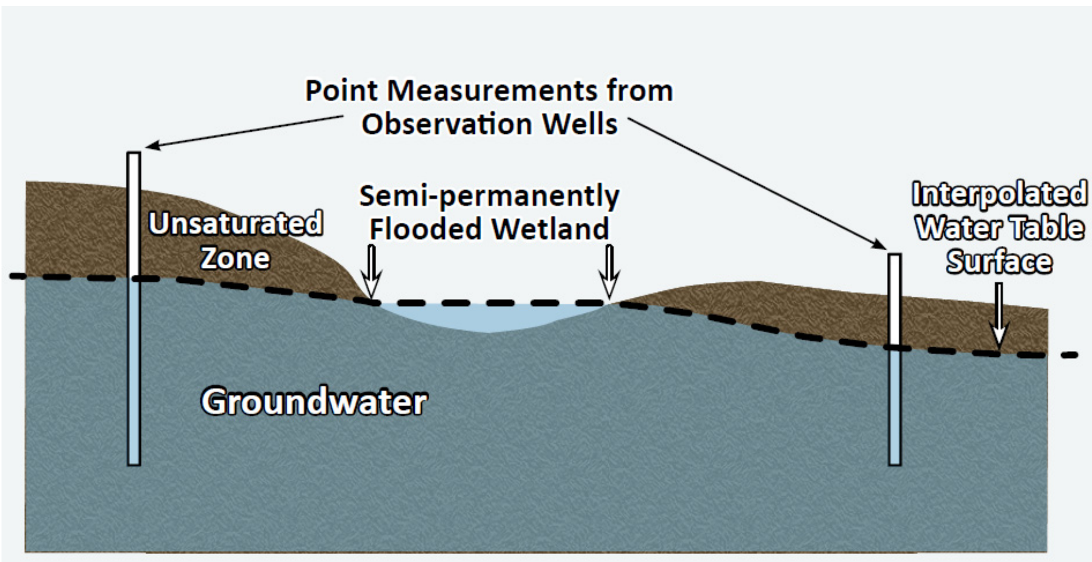
Oblique view of updated soils maps

2.3 MAPPING GROUNDWATER

The water table is defined as the surface below which sediment is saturated with groundwater. Water table elevation and depth to water table are important considerations in construction projects and land use programs. The groundwater portion of the County Geologic Atlas uses selected wetlands from the NWI as an input for water-table elevation maps. The wetlands extracted from the NWI are important for filling data gaps from other sources. Wetlands that are flooded semi-permanently to permanently are usually closely connected to the water table.

The NWI provides information on the size and location of wetlands as well as information on water regime. The County Geologic Atlas extracts the shoreline for these wetland features and combines with other sources such as measured water-table elevations from the DNR's groundwater monitoring well network. Water-table elevations in between these input data are interpolated using GIS.

- Todd Peterson, Hydrogeologist, Minnesota DNR



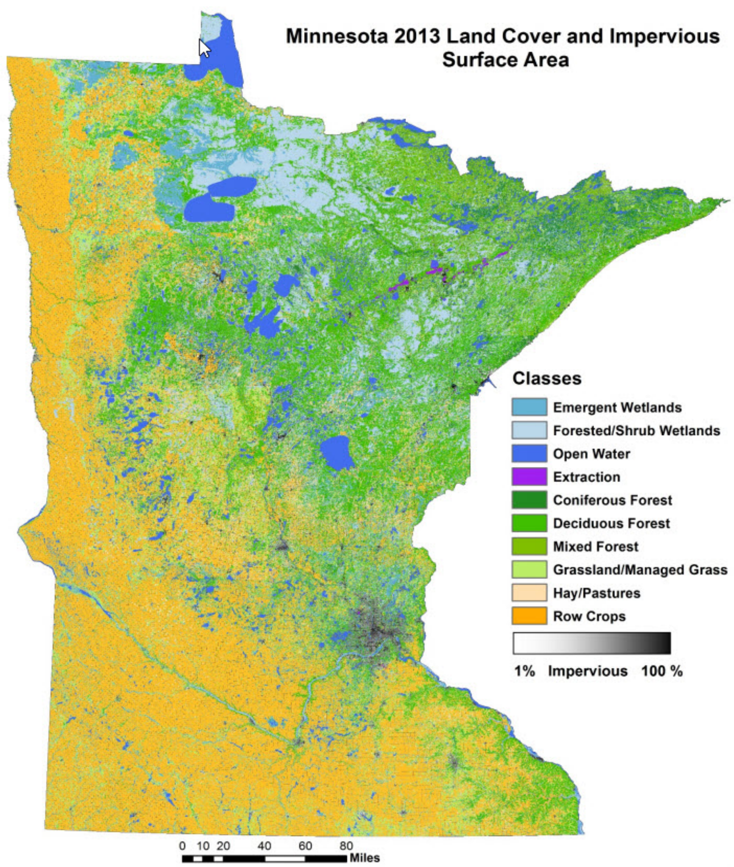
Schematic diagram of water table interpolation

2.4 DEVELOPING LAND COVER MAPS

Land cover data play an important role in many land planning and natural resource management programs, but keeping these data up-to-date and accurate can be a challenge. Wetlands and water comprise about 25% of all area in Minnesota. Wetlands are also known to be somewhat difficult to accurately map and classify using purely conventional remote sensing techniques.

From 2011 to 2013, the University of Minnesota's Remote Sensing and Geospatial Analysis Laboratory conducted a project funded by Minnesota's Environment and Natural Resources Trust Fund to update the statewide land cover. The update was based on Landsat satellite imagery, the statewide lidar, and additional datasets such as the NWI. This new statewide land cover map was necessary because the previous map was completed in 2000, which meant that natural resource managers and other stakeholders had gone thirteen years without updated and comprehensive knowledge of how Minnesota was changing. The updated NWI was foundational to the accuracy of this important land cover product. Accurately classifying wetlands using geospatial data is a challenging task, which was substantially improved by incorporating the updated NWI. We estimate that the accuracy of the wetland class in our statewide land cover update improved by at least 20% using the new NWI compared to using the other datasets alone. This resulted in a product that is far better and more usable as a tool to manage Minnesota's natural resources.

- Dr. Joe Knight, Professor and Director of Remote Sensing Laboratory, University of Minnesota



Overview of the updated land cover data for Minnesota

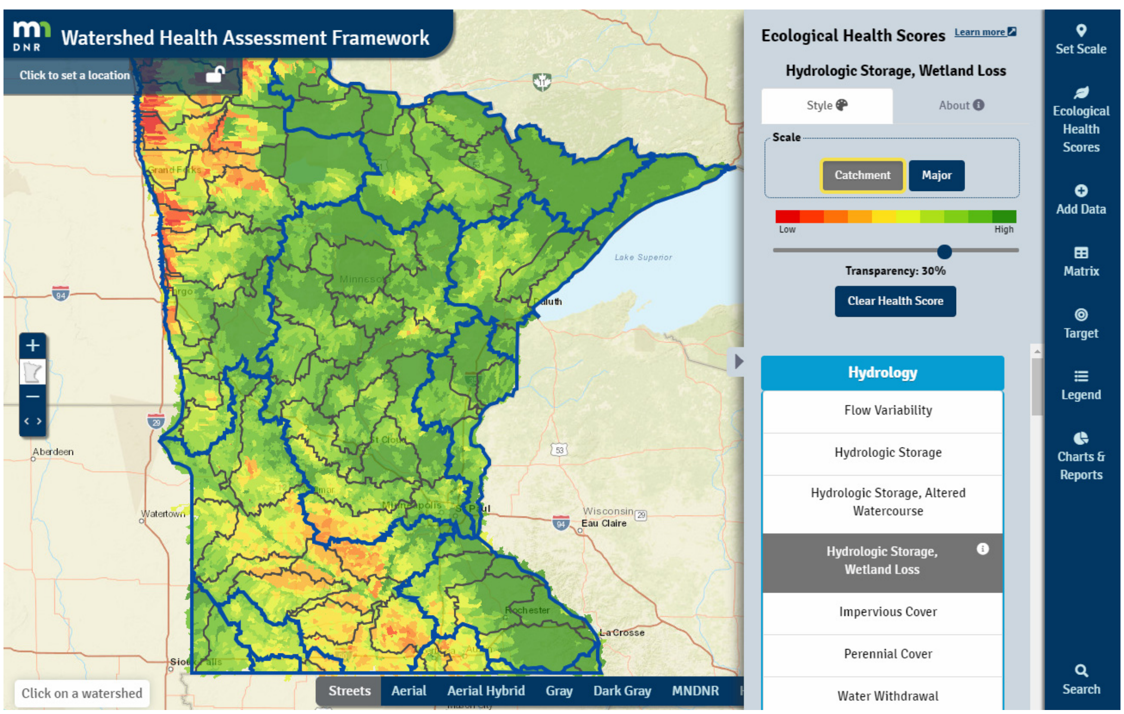
2.5 WATERSHED HEALTH ASSESSMENT

The Minnesota DNR developed a web application known as the Watershed Health Assessment Framework (WHAF) to help promote greater understanding of the factors affecting watershed health and to foster innovative ideas to improve the health and resilience of natural and human communities. WHAF uses a five-component framework to allow users to understand and evaluate watershed health. These components include biology, hydrology, geomorphology, connectivity, and water quality. The NWI data are used as part of the watershed hydrology health scoring.

The NWI data play a key role in calculating several watershed health scores available in the WHAF tool. The *loss of hydrologic storage* health score is comprised of two metrics; loss of wetlands and watercourse alteration. The loss of hydrologic storage potential due to the loss of wetlands is computed by subtracting current wetland extent (as defined by the NWI) from an estimate of historic wetland extent derived from hydric soils (from a combination of SSURGO and STATSGO databases). The wetland loss metric is combined with a metric for the percent of watercourses that have been altered. The watershed health score is provided to help watershed stakeholders identify areas to focus on restoring natural hydrology through both wetland and stream restoration programs.

In addition, the *terrestrial habitat quality* and *terrestrial habitat connectivity* scores also use the NWI data. These metrics are calculated from a model of likely habitat for sensitive wildlife species from each region of the state. The NWI data is a key input used to better identify wetland-dependent habitat needs.

- Ben Gosack, Senior Natural Resources Specialist, Minnesota DNR



Screenshot of the wetland loss metric for the Watershed Health Assessment Framework

2.6 WETLAND RESTORATION PRIORITIZATION

Minnesota has lost about half of its original 22 million acres of wetlands since 1850. Many of these wetlands were drained to support agricultural production, while others have been lost to other activities including urban development, mining, and road construction. Historically, wetlands were viewed as an impediment to development, but in recent decades, we have come to appreciate the many benefits they provide including flood reduction, water quality improvement, and wildlife habitat. Subsequently, federal, state, and local agencies as well as non-profit conservation organizations have expended considerable resources to restore wetlands. Careful planning is required to ensure that wetland restoration projects meet program objectives and are cost-effective.

Restoration programs frequently seek to identify multiple restoration opportunities in a targeted area. The NWI is useful resource to identify potential restoration sites and evaluate their feasibility. The Natural Resources Research Institute (NRRI) developed an online decision support system that uses the NWI and other GIS layers to evaluate ecological stresses and potential wetland restoration benefits (www.mnwetlandrestore.org). As a part of this effort, the NRRI developed a statewide wetland probability model to identify all lands that are likely to be or to have been wetlands. The new NWI data are used to separate out existing wetlands from potentially restorable wetlands.

- Lucinda Johnson, Associate Director, Natural Resources Research Institute

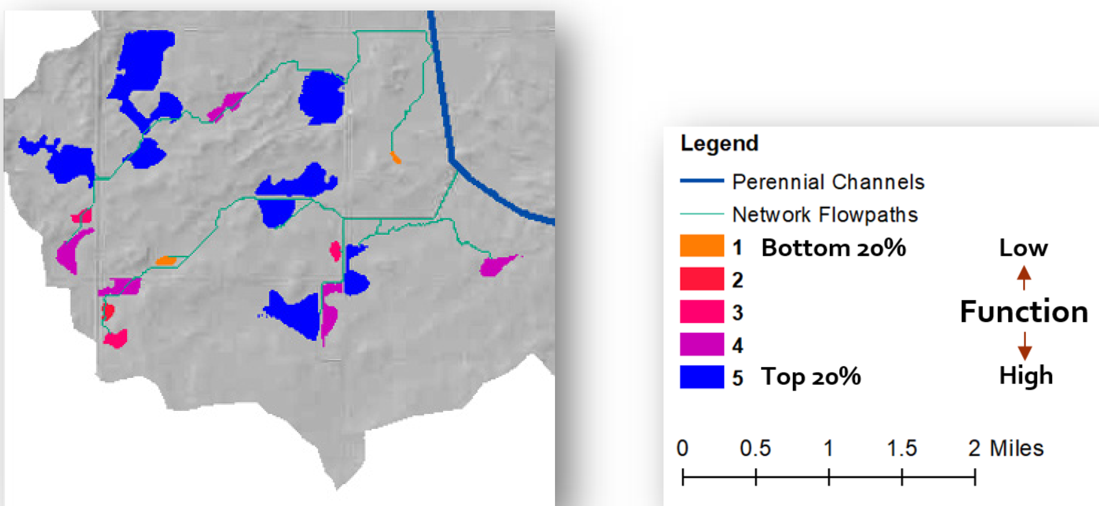
Photo of blue flag iris in a wet meadow type wetland

2.7 FLOOD STORAGE ANALYSIS

Floods are one of the most common types of disasters in Minnesota. Flooding from heavy rain or snowmelt events causes significant damage and the frequency of such events appears to be increasing. Wetlands can play a vital role in mitigating such damage. Depressional wetlands can temporarily store runoff and slowly release it over time, reducing flood peaks.

The St. Croix Watershed Research Station (SCWRS) has combined the NWI data with high-resolution elevation data from lidar to evaluate the runoff storage capacity of wetlands on a watershed wide basis. The overall effectiveness of flood storage for wetlands for a given watershed depends on not only wetland size (area, depth, and volume), but also their hydrologic connections with each other. Researchers at SCWRS modeled wetland connectivity networks for a set of study watersheds comprising over 2 million acres in Southern Minnesota. They calculated available storage volume, direct drainage area for wetlands, and then simulated each wetland's fill-and-spill response to runoff for various design storms. The results from this can be used to estimate the existing flood storage capacity for wetlands as well as to help identify areas that could use additional flood storage capacity.

- Jason Ulrich, Assistant Scientist, St. Croix Watershed Research Station



Relative flood storage ranking of wetlands

2.8 Wildlife Habitat Surveys

There are numerous state and federal programs, as well as non-profit conservation organizations, dedicated to protecting wildlife and wildlife habitat. The NWI data have been frequently used for assessing habitat and population health of wetland dependent species. One example of this type of use is in designing duck surveys. These surveys provide essential information for waterfowl managers.

Wildlife research biologists Hannah Specht and Todd Arnold from the University of Minnesota, in collaboration with Ducks Unlimited and the USFWS, have used the NWI to identify characteristics of wetlands that correspond to whether they're used by waterfowl. Their research relied on developing correlations between waterfowl observations and basin-specific habitat characteristics including wetland size, edge complexity, water regime, and adjacent land cover. The wetland variables were derived from the NWI. Wetland size is positively correlated to duck abundance. The degree of edge complexity (the ratio of the wetland perimeter to the perimeter of a circle with the same area) is correlated to the amount of shallow water habitat used by dabbling ducks. Dabbling ducks also show a preference for seasonally flooded wetlands during certain times. As a result, wetland management efforts for waterfowl can be focused on wetlands most likely to be occupied.

- Dr. Hannah Specht, Postdoc at University of Montana, PhD in Conservation Sciences, University of Minnesota

Photo of mixed flock of ducks in a wetland

3 Ancillary Benefits

3.1 Aerial imagery Uses

Spring leaf-off imagery is the preferred base imagery for wetland mapping because it provides a better view of ground conditions beneath the vegetative canopy and it corresponds with seasonally high water tables, making wetlands easier to identify. As part of the NWI update, this project acquired high-resolution, 4-band, spring leaf-off imagery for the entire state of Minnesota. The ENRTF was used to fund a baseline resolution of 1/2 –meter resolution imagery. The imagery acquisition team reached out to dozens of potential partners interested in buying up to 0.3-meter (1-foot) resolution imagery.

This was the first statewide spring leaf-off imagery acquisition in Minnesota since the 1991 black and white imagery. Imagery were acquired between 2009 and 2014. All the imagery was made freely available through the MnGeo imagery service (https://www.mngeo.state.mn.us/chouse/wms/geo_image_server.html). The spring aerial imagery acquired through this program averaged 1.23 million image requests per month from July 2017 through February 2019, showcasing the high value of this dataset.

3.1.1 Watershed Restoration and Protection Strategy

The Minnesota Pollution Control Agency helped fund the acquisition of higher resolution imagery for northeastern Minnesota. The MPCA used this imagery to help develop a Watershed Restoration and Protection Strategy (WRAPS) by identifying pollution sources and other stressors such as feedlots adjacent to streams and lakes.

- Jesse Anderson, Research Scientist, MPCA

3.1.2 Digital Surface Modeling for Land Change Analysis

The Minnesota DNR Division of Forestry received a US Forest Service Landscape Scale Restoration (LSR) grant to develop an innovative technique for mapping land cover change using stereo imagery to develop digital surface models (DSMs) and looking for changes over time. The imagery acquired by the NWI is a unique dataset in that it provides statewide stereo coverage at 0.5-meter resolution or better. The stereo imagery data from the NWI project will be used by this LSR project as well as an associated Great Lakes Restoration Initiative (GLRI) project to create a statewide multi-temporal DSM and fill in gaps where satellite stereo and fall color stereo aerial coverage hasn't been acquired yet.

- Dr. Jennifer Corcoran, Remote Sensing Program Consultant, Minnesota DNR

3.2 People Trained

3.2.1 St. Mary's University of Minnesota – academic apprenticeship

GeoSpatial Services (GSS) is a project center within Saint Mary's University of Minnesota that integrates professional services and academic apprenticeships in the areas of natural resource assessment, geographic analysis, and contemporary digital mapping. This integration employs the technical and problem-solving skills of full-time staff, fosters practical work experience, and provides non-traditional education for students. The NWI Update project for Minnesota provided 26 students with the opportunity to learn about geospatial technologies and geographic data production in a mentored business environment. Students who participated on this project developed unique and marketable technical software skills and professional experience in a consulting business setting, while earning money to support their education. They also gained a significant appreciation for the diverse natural resources of Minnesota. Out of the many students that worked on the MN NWI project and at the time of writing this document, we know that nine have gone on to professional careers in the geospatial industry and five have registered for advanced degrees in geographic information science. This apprenticeship truly has been a springboard for their transition into professional life.

3.2.2 University of Minnesota – graduate research assistantship

The NWI project was extraordinarily important to the development of students and staff at the University of Minnesota. These include three doctoral students (Jennifer Corcoran, Lian Rampi, Keith Pelletier), six Master's students (Courtney Blouzdis, Josh Dunsmoor, James Klassen, Bryan Tolcser, Margaret Voth, Yan Wang) and one research staff (Trent Erickson). In addition, twelve undergraduate students participated in the project as field sampling crewmembers, which gave them skills important to their career development. The project provided the data and methods for eight peer-reviewed journal articles and numerous conference presentations. The graduate students supported have gone on to make important contributions to the geospatial field based on the knowledge and experience gained through their participation in the NWI project, including one holding a postdoctoral fellowship at NASA JPL and others landing successful careers at the MN DNR, environmental consulting firms, and geospatial non-profit organizations.

4 Data Dissemination

The NWI is available electronically in two basic forms: (1) the data can be viewed through easy-to-use online wetland map applications; or (2) the GIS data can be downloaded and used by desktop GIS software. The data can be downloaded from the Minnesota Geospatial Commons or the USFWS Wetland Mapper. The Minnesota DNR and the U.S. Fish and Wildlife Service both maintain online wetland mapping applications.

For links to download data and online maps, see the DNR wetlands maps web page: https://www.dnr.state.mn.us/wetlands/maps.html

The spring imagery acquired under this project is also being shared through the MnGeo web service.

Other web mapping applications are also using these data including the Watershed Health Assessment Framework from the DNR and the Wetland Restoration Prioritization Tool from the Natural Resources Research Institute.

4.1 Publications and Conference Presentations

The information developed through this project was widely shared through local and national conference presentations, workshops, peer-reviewed journals, book chapters, and other publications. The information dissemination benefits not only potential users of the data, but also other professionals engaged in related wetland and natural resources mapping efforts. Publications generated by the Minnesota NWI update have been cited in 231 other publications to-date. Wetland mapping methods developed during this project are also being used in many mapping efforts in other states and countries.

4.1.1 Publications

Kloiber, S.M., Macleod, R.D., and Wang, G. (2018) An automated procedure for extending the NWI classification system for wetland functional assessment in Minnesota, United States. In "Wetland and Stream Rapid Assessments: Development, Validation, and Application", Ralph Tiner Ed. Chapter 2.2.5.

Kloiber, S.M., Macleod, R.D., Smith, A.J., Knight, J.F., and Huberty, B.J. (2015) A semi-automated, multi-source data fusion update of a wetland inventory for east-central Minnesota, USA. Wetlands. 35(2): 335-348. (22 citations)

Knight, J., Corcoran, J. Rampi, L., Pelletier, K. 2015. Theory and Applications of Object-Based Image Analysis and Emerging Methods in Wetland Mapping. In Tiner, R., Lang, M., Klemas, V. Remote Sensing of Wetlands: Applications and Advances. CRC Press, 2015.

Corcoran, J., Knight, J., Pelletier, K., Rampi, L., Wang, Y. 2015. The Effects of Point or Polygon Based Training Data on RandomForest Classification Accuracy of Wetlands. Remote Sensing, Special Issue: Towards Remote Long-Term Monitoring of Wetland Landscapes. Remote Sensing. 2015(7), DOI: 10.3390/rs70404002.

Rampi, L.P., Knight, J.F., and Pelletier, K.C. (2014) Wetland mapping in the Upper Midwest United States: an object-based approach integrating lidar and imagery data. Photogrammetric Engineering and Remote Sensing, 80(5): 439-449. (28 citations)

Rampi, L.P., Knight, J.F., and Lenhart, C.F. (2014) Comparison of flow direction algorithms in the application of the CTI for mapping wetlands in Minnesota. Wetlands, 34(3): 513-525. (16 citations)

Knight, J.F., B. Tolcser, J. Corcoran, and L. Rampi. (2013) The effects of data selection and thematic detail on the accuracy of high spatial resolution wetland classifications. Photogrammetric Engineering and Remote Sensing, 79(7): 613-623. (22 citations)

Rampi, Lian Pamela. (2013). Evaluating state-of-the-art remotely sensed data and methods for mapping wetlands in Minnesota. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/162515.

Corcoran, Jennifer Marie. (2013). Integrating data from several remotely sensed platforms to accurately map wetlands. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/152862.

Corcoran, J.M., Knight, J.F., and Gallant, A.L. (2013) Influence of Multi-Source and Multi-Temporal Remotely Sensed and Ancillary Data on the Accuracy of Random Forest Classification of Wetlands in Northern Minnesota. Remote Sensing, 5(7): 3212-3238. (87 citations)

Corcoran, J.M, Knight, J.F., B. Brisco, S. Kaya, A. Cull, K. Murhnaghan. (2011) The integration of optical, topographic, and radar data for wetland mapping in northern Minnesota. Canadian Journal of Remote Sensing, 27(5): 564-582. (56 citations)

4.1.2 Presentations

Kloiber, S.M. and Ulrich, J. (2018) Wetland Functional Assessment Using Minnesota's New and Improved Wetland Inventory. Minnesota Water Resources Conference. St. Paul, MN.

Kloiber, S.M. (2018) Using Minnesota's New and Improved Wetland Inventory for Geospatial Analysis. 28th Annual Conference of the Minnesota GIS/LIS Consortium. Duluth, MN.

Kloiber, S.M. (2015) An Improved National Wetland Inventory for Southern Minnesota. 25th Annual Conference of the Minnesota GIS/LIS Consortium. Duluth, MN.

Kloiber, S.M. (2013) Assessing Wetland Quantity Changes for Minnesota from 2006 to 2011. The 2013 Society of Wetland Scientists Annual Meeting. Duluth, MN.

Macleod, R.M. and Kloiber, S.M. (2013) Automating a Hydrogeomorphic (HGM) Classification for the National Wetlands. 23rd Annual Conference of the Minnesota GIS/LIS Consortium. Rochester, MN.

Rampi, L. and Knight, J. (2013) Wetland mapping in Minnesota: An object-based approach to integrate lidar and multispectral imagery. 23nd Annual Conference of the Minnesota GIS/LIS Consortium. Rochester, MN.

Corcoran, J.M.; Knight, J.F.; (2013). "Mapping and Monitoring Wetland Ecosystems More Accurately by Integrating Data from Several Remotely Sensed Platforms". American Association of Geographers, Los Angeles, CA.

Kloiber, S.M. (2012) A Case Study of Quality Assurance for GIS Data Development Using the National Wetland Inventory. 22nd Annual Conference of the Minnesota GIS/LIS Consortium. St. Cloud, MN.

Cialek, C., Kloiber, S.M., Jenkins, P., Wencl, R., and Bloomquist, J. (2012). Panel on New Aerial Imagery in Minnesota Progress Reports; Visioning a Long-Term Statewide Program. 22nd Annual Conference of the Minnesota GIS/LIS Consortium. St. Cloud, MN.

Corcoran, J. and Knight, J. (2012) The Influence of Multi-Platform, Multi-Frequency, and Multi-Temporal Remote Sensing and Field Reference Data Quality on the Accuracy of Decision Tree Classification of Wetlands. 22nd Annual Conference of the Minnesota GIS/LIS Consortium. St. Cloud, MN.

Corcoran, J.M.; Knight, J.F.; (2012). “Incorporating Data from Several Remotely Sensed Platforms to Map Current and Potentially Restorable Wetlands”, INTECOL International Wetlands Conference, Orlando, FL.

Corcoran, J.M.; Knight, J.F. (2012). “Integration is Modernization: On Incorporating Data from Several Remotely Sensed Platforms to Accurately Map Current and Potential Wetlands”, American Society for Photogrammetry and Remote Sensing, Sacramento, CA.

Cialek, C., Kloiber, S.M., Jenkins, P., Brandt, D. and Wencl, R. (2011). Panel on Aerial Imagery in Minnesota – Continued Progress, Improved Collaboration. 21st Annual Conference of the Minnesota GIS/LIS Consortium. St. Cloud, MN.Kloiber, S.M. (2011). A Sneak Preview of the National Wetland Inventory Update. 21st Annual Conference of the Minnesota GIS/LIS Consortium. St. Cloud, MN.

Kloiber, S.M. (2010) Mapping the Probability of Wetland Occurrence with LiDAR. 20th Annual Conference of the Minnesota GIS/LIS Consortium. Duluth, MN.

Corcoran, J.M.; Knight, J.F. (2011). "Data Integration of Fully Polarimetric Synthetic Aperture Radar (SAR), Optical Imagery & Topographic Data for Wetland Mapping", American Society for Photogrammetry and Remote Sensing, Milwaukee, WI.

Corcoran, J. and Knight, J. (2010). "Synthetic Aperture Radar (SAR) Polarimetry for Wetland Mapping and Change Detection". RADARSAT-2 Annual Workshop, Montreal, QC.

Corcoran, J. and Knight, J. (2010) Synthetic Aperture Radar (SAR) for Wetland Mapping and Change Detection. 20th Annual Conference of the Minnesota GIS/LIS Consortium. Duluth, MN.

5 PEOPLE & PARTNERS

5.1 FUNDING PARTNERS

Major funding for the update of the NWI in Minnesota came from the Minnesota Environmental and Natural Resources Trust Fund (ENTRF) as recommended by the Legislative and Citizen Commission on Minnesota Resources (LCCMR). The ENTRF provided $7,150,000 for this effort over a period of 10 years. Numerous partners made financial contributions totaling over $1 million (Table). Most of these partner contributions were directed toward enhancing the spring imagery acquisition.

Funding Source and Use of Funds	Funding Timeframe	$ Amount
MN Environmental & Natural Resources Trust Fund – Imagery Acquisition, Methods Development, Defining User Requirements, Wetlands Mapping, Quality Control, Demonstration, and Outreach	FY09 through FY19	$7,150,000
USGS/NGA – Imagery	FY10	$25,000
St. Louis County – Imagery	FY10	$24,999
MPCA Clean Water Legacy – Imagery	FY10	$111,000
DNR – Heritage Enhancement Fund – Imagery	FY10	$181,064
DNR/NOAA – Coastal Zone Program – Imagery	FY10	$24,227
USGS/NGA – Imagery	FY11	$75,000
Metropolitan Council – Imagery	FY11	$65,750
Metropolitan Mosquito Control District – Imagery	FY11	$7,000
McLeod County – Imagery	FY12	$24,000
Sibley County – Imagery	FY12	$29,000
Murray County – Imagery	FY12	$35,000
US Fish and Wildlife Service – Wetland Mapping	FY13-14	$75,000
Carlton County – Imagery	FY14	$23,475
Camp Ripley – Imagery	FY14	$8,898
Itasca County – Imagery	FY14	$86,841
Clay County – Imagery	FY14	$31,091
Wilkin County – Imagery	FY14	$23,266
Mille Lacs County – Imagery	FY14	$13,769
White Earth Reservation – Imagery	FY14	$34,231
Fond du Lac Reservation – Imagery	FY14	$3,000
Beltrami County – Imagery	FY15	$54,499
Polk County – Imagery	FY15	$59,863

5.2 Participants

There were about 100 people from a dozen different organizations directly involved with the NWI update.

5.2.1 Project Coordination (DNR)

The project was coordinated by the DNR Division of Ecological and Water Resources. Ann Pierce was the executive sponsor, Doug Norris was the business sponsor, Steve Kloiber was the project manager, and Andrea Bergman was the technical data steward. Coordinating a project this large over such a long period was a significant challenge. In the end, the project was brought in on schedule and within budget.

5.2.2 Technical advisory committee (multiple agencies)

A technical advisory committee was formed from federal, state, and local partners to provide guidance on the project.

Joe Knight (UMN)	Susanne Maeder (MnGeo)
Brian Huberty (USFWS)	Nancy Read (MMCD)
Doug Norris (DNR)	Steve Eggers (USACE)
Less Lemm (BWSR)	Mark Gernes (MPCA)
Ken Powell (BWSR)	Rob Sip (MDA)

5.2.3 Methods development and field validation (University of Minnesota)

The Remote Sensing and Geospatial Analysis Laboratory at the University of Minnesota provided key services including research and development of wetland mapping methods. The results from this effort included technical reports to the DNR, peer-reviewed publications on remote sensing of wetlands, and multiple local and national technical presentations. The principal investigator for the UMN was Dr. Joe Knight. Research was carried out by graduate students including Bryan Tolscer, Dr. Jennifer Corcoran, Dr. Lian Rampi, and Josh Dunsmoor. In addition, the UMN also acquired an independent set of field validation data that was used to assess the data quality of the final NWI product.

UMN NWI Field Interns

Sheena Ahrar	Aaron Job
Matthew Billings	Wolf Ruhmann
Jaime Borotz	Mickey Rush
Vanessa Borotz	Steven Sovinski
Heidi Eaves	Cody Venier
Brandon Hull	Kia Yang

5.2.4 Data processing & QA/QC (DNR Resource Assessment Program)

The DNR Forestry Resource Assessment Program (RAP) in Grand Rapids provided support for this project including compiling and pre-processing data as well as field and in-office quality control review of wetland classification data. RAP developed several derived data products from lidar including; slope, topographic position index, compound topographic index, max height of first return, return intensity, and hillshade. These data along with other ancillary data on soils were provided to the mapping contractors as part of the input for their work. Draft NWI data were reviewed by RAP and comments provided to the mapping contractors.

DNR Resource Assessment NWI Project Staff

Molly Shoberg	Dr. Jennifer Corcoran
Tyler Kaebisch	Dennis Kepler
Dr. Scott Hillard	Mike Hoppus
Bonnie Delare	Tim Aunan
	Dr. Ram Deo

5.2.5 Production mapping (Ducks Unlimited and St. Mary's University)

While project coordination, methods development, data pre-processing, and QA/QC are all important, the core of the project is to map and classify wetlands for the entire state of Minnesota, one of the most wetland-rich areas of the country. This work was conducted by two competitively bid contracted organizations: Ducks Unlimited and Geospatial Services of St. Mary's University of Minnesota. Their work involved dozens of people from project managers, geospatial analysts, senior photo-interpreters, and numerous student workers.

Ducks Unlimited

Robb Macleod	Anna Wahl	Erica Smith	Christy Kelly
Gang Wang	Lucian Murphy	Adam Brzak	Martina Schneider
Aaron Smith	Leah Harrison	Matthew Burud	James Steward
Rob Paige	Mitchell Diltz	Matthew Girbach	Bill Bond
Alek Kreiger	Sean Wylie	Brandon Baird	Danielle Forsyth
Mat Halliday	Ashley Suiter	Jordan Duft	Jes Skillman
Emily Doerner	Caitlin Boon	Kristin Bahleda	Mike Mitchell
Jack McDonald	Brian Kearns	Teresa Pilon	Nick Smith

Geospatial Services of St. Mary's University of Minnesota

Andy Robertson	Keith Bollinger	Hannah Hutchins	Reed Fry
Dave Rokus	Jensen Connor	Christine Wiggins	Darren Omoth
Chad Richtman	Joey Nadeau	Amanda Momeni	Matt Hogan
Kathy Allen	Rick Debbout	Zack Ansell	Nick Shelquist
Jeff Knopf	Matt Anderson	Peter McColl	Zach Loechler
Kevin Stark	Kyle Good	Katie Ethen	Toan Tran
John Anderson	Derrick Sailer	Conner Morgan	James Loken
Roger Meyer	Jena Happ	Klaus Friedli	Eric Lindquist
Nick Lemcke	Seth Webinger	Christine Neumann	

5.2.6 Field visit participants

The project was conducted in phases, divided up by geographic region. Each region included initial fieldwork to develop site-specific photo-interpretation guidance, collect training data, and familiarize the staff involved in mapping with the landforms and wetland types. We invited other project stakeholders to join these field visits. Some of these additional stakeholder participants are listed below.

- Brian Huberty (USFWS) – east-central, south, northeast
- Mark Gernes (MPCA) – east-central
- Kane Radel (BWSR) – south MN
- Clint Little (DNR) – northeast MN
- John Jereczek (DNR) – northeast MN
- Daryl Weirzbinski (USACE) - northeast
- Tom Hollenhorst (EPA) – northeast
- Ralph Tiner (USFWS) – special hydrogeomorphic workshop

Photos of field visit participants for the NWI

5.2.7 Draft data review outside participants

As part of the NWI project, we developed an application to share the draft data with project stakeholders. We invited stakeholders to review and comment on the draft data using this web mapping application. By inviting stakeholders to review the draft data, we were able to leverage their knowledge of local conditions to catch potential errors early enough in the process to incorporate corrections before the full public release of the data. The process we followed was when a new block of draft data was posted we would send email invitations to county wetland specialists. Reviewers that had registered accounts for the draft data review tool are listed below.

Registered Users for the NWI Draft Data Review Tool

Colleen Allen	Matthew Danzl	Beth Hippert	Darren Newville
Mike Becker	Phil Doll	Steven Hofstad	Tyler Orgon
Nicole Bernd	Craig Erickson	Jared House	Joe Pallardy
Robert Bohland	Kelly Erickson	Brian Huberty	Jon Peterson
Joseph Brennan	Danielle Evans	Travis Janson	Donald Prom
Mitch Brinks	Brianna Forcier	John Kostreba	Nancy Read
Jamin Carlson	Lynn Foss	Dane Lynch	Becky Sovde
Lance Chisholm	Mark Gernes	Bryan Malone	Josh Stromlund
Ryan Clark	Rusty Griffin	Tyler Marthal	David Thill
Ed Clem	Dan Haasken	Jeremy Maul	Doug Thom
Kelly Condiff	Aaron Habermehl	Helen McLennan	Kevin Trappe
Jim Dahl	Jerome Haggenmiller	Mark McNamara	Teresa Wickeham
Maranda Dahl	Tanya Hanson	Peter Mead	Nathan Williams
Thomas Daniels	Dillon Hayes	Aaron Neubert	Scott Zwick

5.2.8 Functional assessment demo & outreach (St. Croix Watershed Research Station)

The updated NWI data are not only more current and accurate than the original NWI, but they also include new attributes like the hydrogeomorphic classification (HGM). These enhancements will support additional uses such as wetland functional assessment. However, given that this type of information is new to Minnesota wetland scientists, there is little experience and knowledge regarding the use of HGM to conduct landscape-level wetland functional assessments. The St. Croix Watershed Research Station (SCWRS) lead an effort to demonstrate some of the potential uses of the enhanced NWI data. Key project staff for SCWRS in this effort included Jim Almendinger and Jason Ulrich.

5.2.9 Application Development and Data Distribution

MNIT Services at DNR also provided support for the NWI project. Application development for a data review tool was provided by Craig Perreault. Application development for the Wetland Finder was provided by Jeremy Moore and Jessica Schultz. Mike Tronrud created the tile cached web services (both the NWI data and the spring imagery). Zeb Thomas assisted with data management and publication to the MN Geospatial Commons.

5.2.10 Imagery Acquisition Workgroup (MnGeo, MNDOT, DNR)

The spring leaf-off imagery acquisition for the NWI project presented a significant opportunity to leverage this imagery for multiple users and multiple benefits. We developed an imagery acquisition workgroup to help lead this aspect of the project. The DNR collaborated with MnGeo to help administer and coordinate the imagery acquisition. Chris Cialek was the point person for MnGeo, overseeing communications between the DNR, local partners, and imagery vendors. Nancy Rader and Jim Krummrie provided support for administration and quality control. Pete Jenkins of MNDOT was also part of the imagery acquisition workgroup. MNDOT staff also helped coordinate positional accuracy testing of the imagery deliverables.

6 LETTERS OF SUPPORT

The following organizations have provided letters of support for this nomination:

- US Fish and Wildlife Service (Brian Huberty, NWI Coordinator)
- Minnesota Board of Water and Soil Resources (Ken Powell, WCA Operations Coordinator)
- Minnesota Pollution Control Agency (Katrina Kessler, Assistant Commissioner)
- University of Minnesota Remote Sensing and Geospatial Analysis Laboratory (Dr. Joe Knight, Professor)
- Ducks Unlimited (Nick Wiley, Chief Conservation Officer)
- St. Mary's University of Minnesota (Andrew Robertson, Executive Director, Geospatial Services)
- Mille Lacs County Environmental Resources (Dillon Hayes, Environmental Resources Manager)
- Shakopee Mdewakanton Sioux Community (Ferin Davis, Lead Environmental Scientist)

March 1, 2010

Dan Ross
Minnesota Chief Geospatial Information Officer
Minnesota Geospatial Information Office
658 Cedar Street, Room 300
St. Paul, MN 55155

Dear Governor's Geospatial Commendation Awards Committee:

The Minnesota Department of Natural Resources has been and continues to be a leader for mapping Minnesota's wetlands in partnership with local governments, NGO's, tribes and federal agencies. I am writing this letter in support of the nomination of the Minnesota Department of Natural Resources (DNR) for the Governor's Commendation Award for the development and public release of an updated, upgraded and enhanced wetland inventory for Minnesota. Ten years and about ten million dollars were invested to better define the dynamic and geospatial state of wetlands throughout Minnesota.

Wetlands provides clean water, flood storage, recreation opportunities such as hunting and fishing, food as in wild rice, carbon storage as well as habitat for a multitude of fish and wildlife species. Wetlands help define the landscape of our state as well as being a component of our infrastructure.

As the National Wetlands Inventory (NWI) Coordinator for the U.S. Fish & Wildlife Service, I can attest to their value with a couple of examples. Wetland maps are critical for habitat assessment and landscape management across all ownerships and across North America. Wetland maps document where they lie across the state as well as their type, and condition. They are essential for proper conservation management.

The original NWI was based on 1970's and 1980's aerial photography. In this digital age, much has changed not only with wetlands but also with the digital approach to map wetlands. End users are now demanding more current and accurate delineations. The new method led by the DNR for the new Minnesota National Wetland Inventory (MN NWI) map has provided much more accurate estimates of wetland type, function and location that would be impossible to derive by any other means.

The use of original NWI and new MN NWI wetland maps span all sectors across Minnesota. The Minnesota Department of Transportation uses them for highway planning, airport management and the proposed North Star high speed rail corridor. The Minnesota Army National Guard Base at Camp Ripley uses wetland maps for training exercises and for conservation management. Tribes across the state use wetland maps for hunting and fishing as well as for wild rice management. Individual citizens are also frequent users of wetland maps for hunting, fishing, home development and private land conservation.

Given the scale and demands of this project to map such dynamic features which are constantly changing, the outcomes will provide the citizens of Minnesota a clearer picture of where our wetland features reside across the landscape. It is my pleasure to nominate the Minnesota Department of Natural Resources to receive the Governor's Geospatial Commendation.

Sincerely,

Brian Huberty, National Wetland Inventory Coordinator
U.S. Fish & Wildlife Service, Midwest Region
5600 American Blvd; Suite 990
Bloomington, MN 55437
brian_huberty@fws.gov
612-713-5332

BOARD OF WATER AND SOIL RESOURCES

April 17, 2019

Dan Ross
Minnesota Chief Geospatial Information Officer
Minnesota Geospatial Information Office
658 Cedar Street, Room 300
St. Paul, MN 55155

Dear Governor's Geospatial Commendation Awards Committee:

I am writing this letter in support of the nomination of the Minnesota DNR for a Governor's Commendation Award for the development and public release of an updated and enhanced wetland inventory for Minnesota.

I am the Wetland Conservation Act Operations Coordinator for the Minnesota Board of Water and Soil Resources (BWSR). The Wetland Conservation Act (WCA) is the state's most comprehensive wetland regulatory program that affects every county and municipality. Being able to identify and classify wetlands is absolutely essential to implementing the WCA and conserving wetlands for the important functions they provide such as protecting water quality, storing floodwaters, providing wildlife habitat and many others.

A national effort to map wetlands in the 1980's (the National Wetland Inventory or NWI) appeared to provide a solid dataset for wetland conservation planning and regulatory implementation. However, it soon became apparent that there were significant inaccuracies and inconsistencies in the mapping data due to lack of technology and policy-influenced data collection methods adopted at the time. In addition, the mapping data became dated and less useful with the passage of time.

DNR's successful update and enhancement to wetland mapping provides a valuable resource for implementation of the WCA and wetland conservation in general. Landowners, regulators, natural resource planners, developers, farmers and many others who interact with wetlands and the wetland regulatory program now have an accurate and reliable resource to identify wetlands on the landscape. Wetland mapping data is now used in many aspects of the WCA program where it was missing prior to DNR's update. Landowners can now rely on this mapping resource to reasonably approximate the extent of regulated wetland resources on their property as they contemplate land use changes and associated regulatory implications. The updated wetland inventory is a reliable resource for regulatory staff to use in evaluating land use applications from their desktop, thereby improving the timing and efficiency of regulatory review. BWSR is also using this data to develop watershed-based plans to prioritize wetland restorations. The DNR's incorporation of new hydrogeomorphic descriptors adapted for Minnesota provides a new and improved way of evaluating wetland functions.

The Minnesota DNR should be recognized for their diligent and highly professional work to develop this important wetland mapping data, and I support them receiving the Governor's GIS Award.

Sincerely,

Ken Powell
WCA Operations Coordinator

CC: Doug Norris, DNR

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May 3, 2019

Dan Ross
Minnesota Chief Geospatial Information Officer
Minnesota Geospatial Information Office
658 Cedar Street, Room 300
St. Paul, MN 55155

Dear Dan Ross:

I am writing in support of nominating the Minnesota Department of Natural Resources (DNR) for a Governor's Geospatial Commendation for their leadership updating and enhancing Minnesota's National Wetland Inventory (NWI). Completion of this project to map and inventory Minnesota's surface waters including wetlands, lakes, larger streams, and rivers, took over 10 years and 8 million dollars to complete. This effort also included significant in-kind time from well over 100 partners and collaborators.

In its final form, Minnesota's NWI is one of the largest geospatial datasets in the state, including some 2.2 million polygon features spread across Minnesota. Project completion required the acquisition of high resolution recent spring leaf-off color infra-red and true color base imagery. This data is now publically available through the Minnesota Geospatial Commons.

Dozens of planning, permitting, monitoring, and research staff within the Minnesota Pollution Control Agency routinely use the leaf-off base imagery and the NWI data to support many parts of our agency work. Having current coverage and enhanced wetland classification and functional assessment attributes has improved efficiency and outcomes in agency activities and decisions; three examples are highlighted below.

- Total maximum daily load modeling uses wetland extent data to help determine water quality pollutant load allocations.

- Surface water monitoring staff rely on the NWI to support surveys to provide estimates of wetland quality across Minnesota. This improves our understanding of how the condition or health of wetland water quality affects stream and lake quality.

- Staff in the Section 401 Water Quality certification program regularly rely on accurate NWI data to inform and facilitate regulatory decisions on projects proposing to dredge or fill Minnesota waters.

Thank you for the opportunity to show support for this recently completed comprehensive geospatial project. If you have any questions or need additional details feel free to contact Mark Gernes in our Surface Water Monitoring Section at mark.gernes@state.mn.us or via phone at 651-757-2387.

Sincerely,

Katrina Kessler

Katrina Kessler
Assistant Commissioner

KK/PA/MG:vs

UNIVERSITY OF MINNESOTA

Twin Cities Campus

Department of Forest Resources

College of Food, Agricultural and Natural Resource Sciences

115 Green Hall
1530 Cleveland Ave. N
St. Paul, MN 55108-6112

612-624-3400
Fax: 612-625-5212

May 16, 2019

Mr. Dan Ross
Minnesota Chief Geospatial Information Officer
Minnesota Geospatial Information Office
658 Cedar Street, Room 300
St. Paul, MN 55155

Dear Governor's Geospatial Commendation Awards Committee members:

I write to express my enthusiastic support for the nomination of the Minnesota Department of Natural Resources (DNR) for the Governor's Commendation Award for the updated and enhanced Minnesota wetlands inventory. The University of Minnesota's Remote Sensing and Geospatial Analysis Laboratory (RSGAL) was an early partner in the Minnesota National Wetlands Inventory (NWI) project. We conducted the methods development research that contributed to the successful wetland mapping done by contractors. We further performed the field sampling that created the validation products used to assess the accuracy of the new NWI.

A primary part of the mission of the University of Minnesota is educating future leaders. The NWI project supported the education of several Master's students, doctoral students, and research staff, who are named in the nomination letter. These former students and staff are now working in positions throughout Minnesota, including in state agencies, environmental consulting firms, geospatial services companies, and in academia. Working on the NWI project greatly influenced the careers of numerous people, who are now making important contributions to the state.

A second part of the University's mission is research. The new NWI has been an important piece of many additional research projects in the RSGAL. For example, in 2011 we were funded by Minnesota's Environment and Natural Resources Trust Fund to update the statewide land cover. This update of the previous layer from 2000 resulted in new data products that provide natural resource managers and other stakeholders with much-needed information about the current land cover of the state, and how it has changed. Such information is critical for management and conservation of our natural resources, among many other uses. The updated NWI was foundational to the accuracy of this important land cover product. Including the new NWI resulted in a product that is much better and more usable than it would have been without the NWI.

A third part of our University mission is extension. We are tasked with transferring knowledge and methods to the public. Since wetlands are such vital pieces of our statewide landscapes – providing benefits like wildlife habitat, recreation, food and water sources, flood mitigation, and carbon sequestration – it is important that we have the tools and information necessary to communicate about them with the public. The NWI project has given us both updated information about Minnesota's wetlands and an easy-to-use tool, the Wetland Finder, with which to improve our extension mission.

It is rare, in my experience, to participate in a project that involves such a large number of participants, from so many different agencies and groups, over a period as long as eleven-years. That breadth has allowed the NWI project to touch many lives, all over the state. The NWI project was an extraordinary partnership, bringing together wetlands scientists, natural resource managers, non-government stakeholders, and the public. The project and its resulting data products have had significant and long-lasting benefits to Minnesota. Therefore, the NWI project has my unreserved recommendation for the Governor's Commendation Award. Please do not hesitate to contact me if I can be of further assistance to your deliberations.

Sincerely,

Joseph Knight
Associate Professor and Director
Remote Sensing and Geospatial Analysis Laboratory

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May 1, 2019

Dan Ross
Minnesota Chief Geospatial Information Officer
Minnesota Geospatial Information Office
658 Cedar Street, Room 300
St. Paul, MN 55155

Dear Governor's Geospatial Commendation Awards Committee:

I am writing this letter in support of the nomination of the Minnesota Department of Natural Resources (DNR) for the Governor's Commendation Award for the development and public release of "An Updated and Enhanced National Wetlands Inventory for Minnesota".

Ducks Unlimited prides itself on being a science-based organization and utilizing the best possible information to "fill the skies with waterfowl today, tomorrow and forever". While our mission is focused on wetland conservation, our work restoring, enhancing and protecting wetlands supplies many other benefits for other wildlife and humans. To do this work, DU needs accurate and timely geospatial information on the location, type and trends of wetlands throughout North America. Unfortunately, most of the US Fish and Wildlife Service's National Wetlands Inventory (NWI) is 30 years old, including the original NWI for Minnesota.

This project was a significant undertaking (lasting 11 years with 100 staff and costing over 7 million) and exemplary geospatial activity (over 40 undergraduate, graduate and post graduate students trained; seven peer-reviewed papers, and 13 presentations; consistent, state-wide, detailed wetlands delineation with three different classification systems for users). It has already yielded tangible benefits for Ducks Unlimited as we plan for future restoration efforts. The project also met five of the eight goals of the commendation.

Ducks Unlimited is in a unique position to support this nomination as we were involved in the creation of the data and are current and future users of the data. The results of this work will support efforts to continue our landscape planning efforts and on-the-ground habitat conservation work. The Minnesota DNR was a pleasure to work with on the project and were highly professional throughout. The way the project incorporated the research aspect with the University of Minnesota and the local and regional stakeholder in the quality control was and outstanding way to leverage expertise and generate support for the resulting products.

I fully endorse the nomination of the Minnesota DNR's "An Updated and Enhanced National Wetlands Inventory for Minnesota" for the Governor's Geospatial Commendation.

Sincerely,

Nick Wiley
Chief Conservation Officer

Saint Mary's University OF MINNESOTA

March 18, 2019

Mr. Dan Ross
Minnesota Chief Geospatial Information Officer
Minnesota Geospatial Information Office
658 Cedar Street, Room 300
St. Paul, MN 55155

Dear Governor's Geospatial Commendation Awards Committee:

I write to you today in support of the nomination of the Minnesota Department of Natural Resources (DNR) for the Governor's Commendation Award for the development and public release of an updated, upgraded and enhanced wetland inventory for Minnesota. The completion and release of this data has been a multi-year public-private partnership initiative that has resulted in the creation of a critical spatial database for land use and habitat management in our state.

GeoSpatial Services is a project center within Saint Mary's University of Minnesota. Our mission is to provide experiential learning opportunities and 'real-world' work experience for our students. In order to provide these opportunities, we work with our nationwide partners on wetland inventory, spatial data analysis and watershed planning. As one of the contractors involved in the National Wetland Inventory update for Minnesota, we recognize the incredible value that this data represents for resource and habitat management, land use planning and decision support statewide.

We incorporate updated National Wetland Inventory data in most of the planning and resource management projects that we participate in with our partners. For many parts of the U.S., the wetland inventory is out of date and unsuitable for the types of analyses that we complete. Recent NWI updates such as the one in Minnesota provide improved accuracy and temporal consistency, which leads to enhanced decision support. In a recent example, GeoSpatial Services completed a spatial analysis highlighting the impact of proposed changes to the Waters of the U.S. Rule (WOTUS) under the Clean Water Act. Three watersheds were chosen for this analysis nationwide based on having current wetland data, and the Cottonwood River Watershed in Southwestern Minnesota was part of that showcase. This important project shed significant light on the impacts of the changes to the clean water rule. Minnesota was front and center in the process because of the new statewide, enhanced wetland inventory.

GEOSPATIAL SERVICES • SAINT MARY'S UNIVERSITY OF MINNESOTA
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This is only one example of the value that an updated wetland inventory provides to the agencies and citizens of Minnesota. These data also support: improved project screening by state and federal agencies; more comprehensive and informed land use planning decisions (e.g., One Watershed One Plan initiatives); improved insight into habitat changes and focal areas for resource management; and, increased confidence for stakeholder engagement. It is for these reasons and many more that I strongly support the nomination of the Minnesota Department of Natural Resources for the Governor's GeoSpatial Commendation Award. Please do not hesitate to reach out if you require further information.

Sincerely,

Andrew Robertson
Executive Director, GeoSpatial Services
Saint Mary's University of Minnesota
700 Terrace Heights, #7
Winona MN 55987
aroberts@smumn.edu
507-457-8746

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Phone: (320) 983-8232

Dillon Hayes
Environmental Resources Manager
Administrative Services Office
dillon.hayes@millelacs.mn.gov

April 18, 2019

Dan Ross
Minnesota Chief Geospatial Information Officer
Minnesota Geospatial Information Office
658 Cedar Street, Room 300
St. Paul, MN 55155

Dear Governor's Geospatial Commendation Awards Committee,

I am writing this letter in support of the nomination of the Minnesota DNR for a Governor's Commendation Award for the development and public release of an updated and enhanced wetland inventory for Minnesota.

I serve as the Local Government Unit representative for the administration of the Wetland Conservation Act (WCA) in Mille Lacs County. Being able to identify and classify wetlands is absolutely essential to implementing the WCA, and the ability to do so with greater certainty from my desktop is one of the ways in which the WCA can be implemented locally with greater efficiency.

A national effort to map wetlands in the 1980's (the National Wetland Inventory or NWI) appeared to provide a solid dataset for wetland conservation planning and regulatory implementation. However, it soon became apparent that there were significant inaccuracies and inconsistencies in the mapping data due to lack of technology and policy-influenced data collection methods adopted at the time. In addition, the mapping data became dated and less useful with the passage of time.

The DNR's successful update and enhancement to wetland mapping provides a valuable resource for implementation of the WCA and wetland conservation in general. The updated wetland inventory is a reliable resource for regulatory staff to use in evaluating land use applications from their desktop, thereby improving the timing and efficiency of regulatory review. Mille Lacs County is also using this data to influence the development of both local and watershed-based plans to prioritize efforts to protect and restore water resources.

The Minnesota DNR should be recognized for their diligent and highly professional work to develop this important wetland mapping data, and I support them receiving the Governor's GIS Award.

Sincerely,

Dillon Hayes

Dillon Hayes
Environmental Resources Manager

Shakopee Mdewakanton Sioux Community

2330 Sioux Trail NW • Prior Lake, Minnesota 55372
Tribal Office: 952.445.8900 • Fax: 952.233.4256

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May 14, 2019

Dan Ross
Minnesota Chief Geospatial Information Officer
Minnesota Geospatial Information Office
658 Cedar Street, Room 300
St. Paul, MN 55155

Dear Governor's Geospatial Commendation Awards Committee,

I am writing this letter in support of the nomination of the Minnesota Department of Natural Resources (MNDNR) for a Governor's Commendation Award for the development and public release of an updated and enhanced wetland inventory for Minnesota.

I am the Lead Environmental Scientist for the Shakopee Mdewakanton Sioux Community (SMSC) Land and Natural Resources Department located in Scott County, Minnesota. I am primarily responsible for the maintenance and restoration of natural resources throughout the Community. An updated and enhanced wetland inventory in our region is an essential resource the SMSC will use for wetland conservation and planning purposes. The Community plans to utilize the MNDNR's new National Wetland Inventory data to update SMSC's current local wetland inventory and prioritize areas to assess and determine wetland conditions based on ecological and cultural values through hydrogeomorphic mapping methods and field site assessments. With this information the SMSC will be able to create watershed-level plans to conserve and restore wetlands and other surface and subsurface water resources.

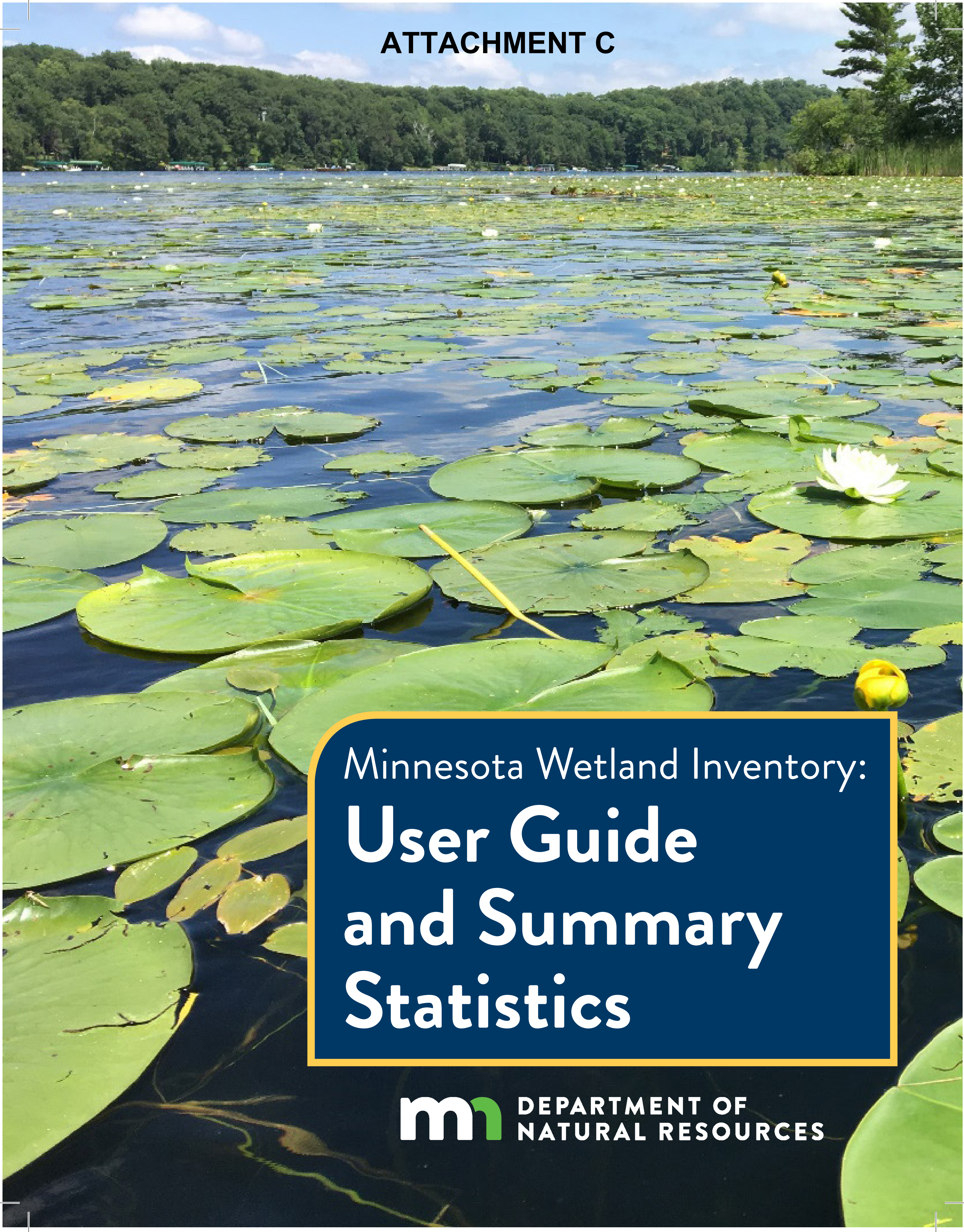
Again, I wish to express my complete support of the MNDNR's nomination for the Governor's Commendation Award. The development and execution of this vital inventory will be utilized by many to protect, enhance and restore wetland resources.

Sincerely,

F. Davis

Ferin Davis
Lead Environmental Scientist
2330 Sioux Trail NW
Prior Lake, MN 55372
(952) 496-6183

ATTACHMENT C



Minnesota Wetland Inventory:

User Guide and Summary Statistics

DEPARTMENT OF NATURAL RESOURCES

Acknowledgements

This document was developed for the Minnesota update of the National Wetland Inventory, which is primarily funded by the Environmental and Natural Resources Trust Fund as recommended by the Legislative and Citizens Commission on Minnesota Resources (LCCMR). Authors are Steve Kloiber, Doug Norris, and Andrea Bergman. This document should be cited as:

Kloiber, S.M., Norris, D.J., and Bergman, A.L. 2019. Minnesota Wetland Inventory: User Guide and Summary Statistics [June, 2019]. Minnesota Department of Natural Resources, St. Paul, MN. 66 pp.

The authors gratefully acknowledge the contributions from reviewers including Greg Husak and Tom Klein of the DNR Ecological and Water Resource Division. Assistance with graphics, accessibility and print-and-web publishing was also provided by Tom Klein.

For comments and questions about this document, please contact:

Steve Kloiber,
DNR Wetland Monitoring Coordinator
651-259-5164
steve.kloiber@state.mn.us

Purpose of this Guide and the Minnesota Wetland Inventory Data

This guide provides a brief overview of the potential uses, limitations, access, and technical aspects of the Minnesota Wetland Inventory. It serves as an introduction to wetland inventory data and a starting point to find additional detailed information.

The Minnesota Wetland Inventory is based on the framework for the National Wetland Inventory (NWI). These data meet or exceed the federal wetland-mapping standard. It is an important dataset for natural resource planning and management efforts within Minnesota. These wetland data are used across all levels of government, by private industry and non-profit organizations as an aid in wetland regulation and management, land use and conservation planning, environmental impact assessment, and natural resource inventories. Among other things, the NWI has been used to assess impacts of regulatory policy, identify flood storage, evaluate carbon storage potential and climate change impacts, and estimate waterfowl and amphibian population distribution.

History

The original NWI was completed for Minnesota in the early to mid-1980s under a program of the U.S. Fish and Wildlife Service (USFWS). Federal funding for the NWI has declined over time and the original NWI was not updated to reflect changes in land alterations or other changes that affected wetlands. The Minnesota Department of Natural Resources (DNR), with funding from the Environment and Natural Resources Trust Fund, began a statewide update of the NWI and completed the statewide update in 2019.

Cautions

There are various ways to define wetlands. Any effort to map or identify wetlands is affected by how wetlands are defined. The updated NWI for Minnesota used the same wetland definition as was used for the original NWI (adapted from Cowardin et al., 1979):

> *"Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season each year."*

Federal, state, and local regulatory agencies with jurisdiction over wetlands may define wetlands in a different manner than this inventory. This wetland inventory does not attempt to define the limits of the jurisdiction of wetland regulatory programs for federal, state, or local government agencies. Anyone engaging in activities involving land alterations within or adjacent to potential wetland areas should seek the advice of appropriate federal, state, or local agencies concerning regulatory programs and the jurisdictions that may affect such activities.

The updated NWI for Minnesota was developed using the best available remote sensing data. Methods included high-resolution spring aerial imagery (acquired between 2009 and 2014), summer aerial imagery, and digital elevation models derived from light detection and ranging (lidar). Every reasonable effort has been made to follow industry standard practices for ensuring the accuracy of these data; however, there is an inherent uncertainty associated with mapping wetlands from remote sensing data.

Detailed ground-based analysis of specific sites may result in a different wetland representation and classification.

Wetland Permitting Programs

There are three main wetland permitting programs in Minnesota. These programs have different jurisdictions that sometimes overlap, and they are administered by different agencies.

Public Waters Work Permit Program - The Minnesota DNR oversees the Public Waters Work Permit Program. This program regulates water development activities below the ordinary high water level in waters that have been designated as public waters and public waters wetlands. The Public Waters Inventory map published by the DNR indicates which waters and wetlands are covered by this program. The basic rule is that a public waters work permit must be obtained from the DNR for work affecting the course, current, or cross-section of public waters, including public waters wetlands.

Minnesota Wetland Conservation Act - Most wetlands in Minnesota that are not covered by the Public Waters Work Permit Program are covered by the Minnesota Wetland Conservation Act (WCA). WCA was enacted to protect wetlands not protected under the DNR public waters permit program and to provide no net loss of Minnesota's remaining wetlands. This program is administered by a network of local units of government (LGUs) with oversight from the Minnesota Board of Water and Soil Resources (BWSR). The basic requirement is that wetlands must not be drained or filled unless replaced by restoring or creating a wetland area of equal public value under an approved replacement plan. BWSR maintains a list of the LGUs that act as the permitting authorities under WCA.

Federal Clean Water Act Section 404 Permit Program - A permit must be obtained from the United States Army Corps of Engineers for discharges of dredged or fill material into waters of the United States, including jurisdictional wetlands. Section 404 permits also require a water quality certification (or waiver) from the Minnesota Pollution Control Agency. Jurisdictional determinations for the 404 Permit Program can be complex.

Data Access

The NWI data are available electronically in two basic forms: Easy-to-use online wetland map applications, and a download for use with desktop GIS software. The DNR does not distribute paper maps of the NWI.

The Minnesota DNR and the U.S. Fish and Wildlife Service both maintain online wetland mapping applications as well as provide

The NWI has many uses including...

- assessing potential impacts from proposed development projects
- estimating flood storage capacity
- mapping waterfowl and amphibian habitat
- evaluating carbon storage potential

download access to the GIS data. The basic geometry and attributes are the same; however, there are some differences between the version of the NWI distributed by the Minnesota DNR and the federal version of the data.

For links to download data and online maps, see the DNR wetlands maps web page: https://www.dnr.state.mn.us/wetlands/maps.html

Technical Overview

Format

The NWI data are vector GIS polygons. The data are available as a file geodatabase, a proprietary data format developed by Environmental Systems Research Institute (ESRI) for their GIS software (e.g., ArcGIS). The data are also available in GeoPackage format, which is an open source GIS data format that works with most GIS software.

Differences between the State and Federal Versions

Minnesota provides the data using the Universal Transverse Mercator coordinate system (UTM Zone 15, North American Datum 1983). Knowing the coordinate system is generally required to ensure that the data align properly with other GIS data. The USFWS provides the data using the Albers Equal Area coordinate system. The version of the NWI provided by Minnesota has additional attribute fields that are not available in the federal version of the data because they go beyond the federal data standard. Users who want the full set of attributes should obtain the data through the Minnesota Geospatial Commons. In addition, the USFWS modifies all NWI data by adding more watercourse features from the National Hydrography Dataset (NHD). This involves buffering watercourse features from the NHD, removing areas where they overlap with the NWI, and then merging the two feature classes together. This can provide some additional information on hydrologic connectivity, but because the NHD is based on watercourse mapping that was done in the 1960s and 1970s, it has frequent misalignments. As such, the DNR has chosen not to add watercourses in this manner.

Scale, Minimum Size, and Positional Accuracy

Wetland features and boundary lines were mapped with a level of detail that was appropriate for an approximate user-scale of 1:6,000. The scale for digitizing and quality control review varied; but was generally performed at zoom scales closer than the user-scale of 1:6,000. The goal of the NWI is to map all wetlands and deepwater habitats (lakes and rivers) larger than ½-acre in area. Wetlands smaller than ½-acre that are readily visible at 1:6,000-scale are also mapped, but there is no assurance that all wetlands smaller than ½-acre are included. Long, narrow features (e.g., swales, ditches, streams, and rivers) wider than 15-feet are also included in the NWI. Very small wetlands ($<\frac{1}{20}$-acre) and very narrow wetlands are not mapped.

The location of wetland boundaries are approximate. The imagery used as the mapping base for the updated NWI has a typical positional accuracy of about ±7.5 feet (root mean square error). In addition, some uncertainty is inherent in the process of mapping the wetland boundaries. Determining precise wetland boundaries can be difficult even in the field. In cases where there are clearly visible wetland boundaries, these are generally mapped within ±15 feet of their true position. More obscure wetland

NWI STORIES

Wetland Finder

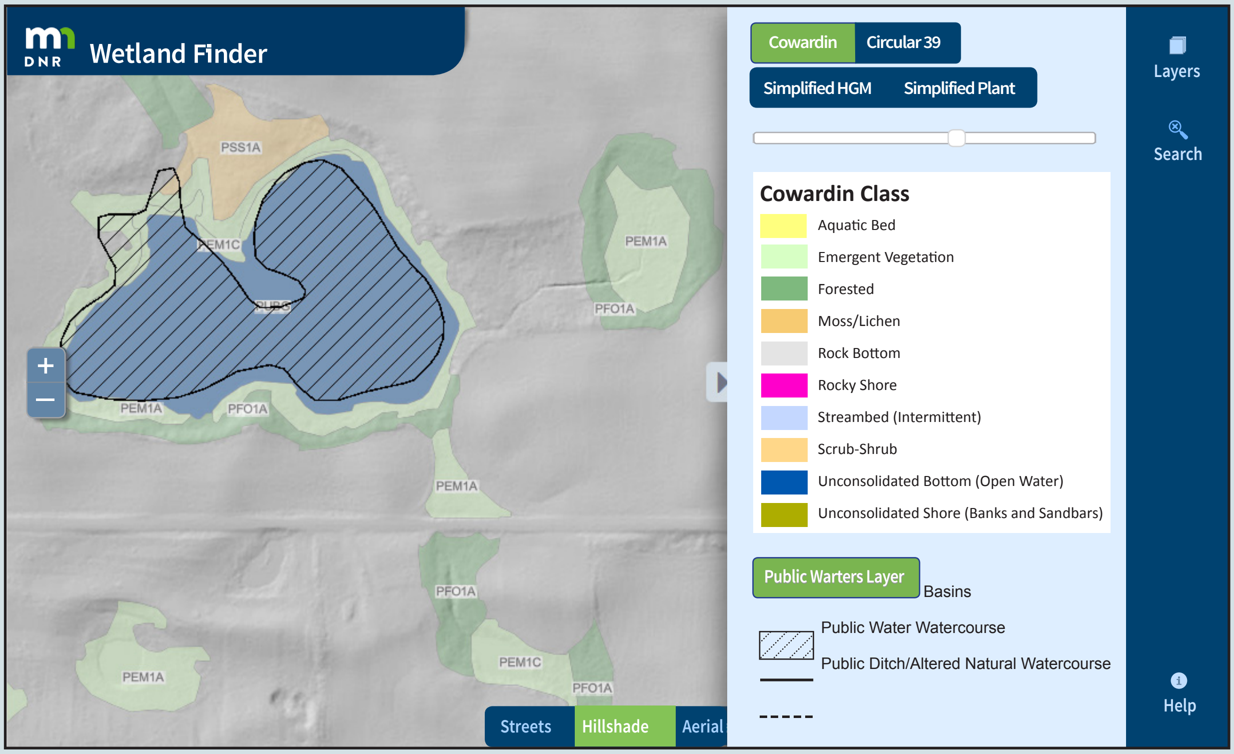
One of the most common wetland questions we get from landowners, developers, and real estate professionals is, "Are there wetlands on my property?" While the NWI isn't a regulatory wetland determination, it is usually the first place to turn to begin to answer this question. Unsurprisingly, most of the people that ask this question aren't GIS experts. For these folks, we developed the DNR Wetland Finder Application.

The Wetland Finder provides a simple method for the non-GIS user to view the updated National Wetland Inventory (NWI) data. People can use this application to get a quick initial view of the how many and what types of wetlands are present in a given area.

Users can search the map for a specific address and view the wetland data from the NWI as well as public waters from the DNR's Public Waters Inventory (PWI).

Users can choose to display the data according to any of four different wetland classifications or they can click on any wetland and get additional attribute information. The attribute pop-up window also provides links to wetland regulatory contacts including the local government unit (LGU) contact list for the Wetland Conservation Act as well as to DNR area hydrologists for questions about public waters.

-Steve Kloiber
Wetland Monitoring Coordinator
Minnesota DNR



Minnesota has 12.2 million acres of wetlands, the second most in the Lower 48 states behind Florida!

boundaries may have larger positional errors when compared to field based wetland delineations.

Data Structure

The basic data structure for the NWI is a GIS polygon data layer with an associated attribute table with one attribute record for every polygon (Table 1). Please note; the file geodatabase version provided through the MN Geospatial Commons also includes a series of extended attribute tables that can be joined to the primary attribute table based on a key field.

The principal classification attribute for the NWI uses a complex alphanumeric code to describe wetland types. These wetland types are described by supporting documentation such as "The Classification of Wetland and Deepwater Habitats" by Cowardin et al. (1979), which describes a hierarchy of wetland types. Wetland types at each level of this hierarchy are given coded values and linked into a single field. This system is further described later in this guide.

The uses of coded values makes for concise map labels, but it presents issues for the casual data user. Users who are unfamiliar with these codes will have difficulty understanding the data and will need to rely on outside references to look-up the full description of the various wetland types.

The state's version of the data provide associated look-up tables that split these codes into separate fields for each component. Full text description is provided for each part. These tables can be joined to the base table using the key field [ATTRIBUTE]. This structure makes querying the data simpler and more robust.

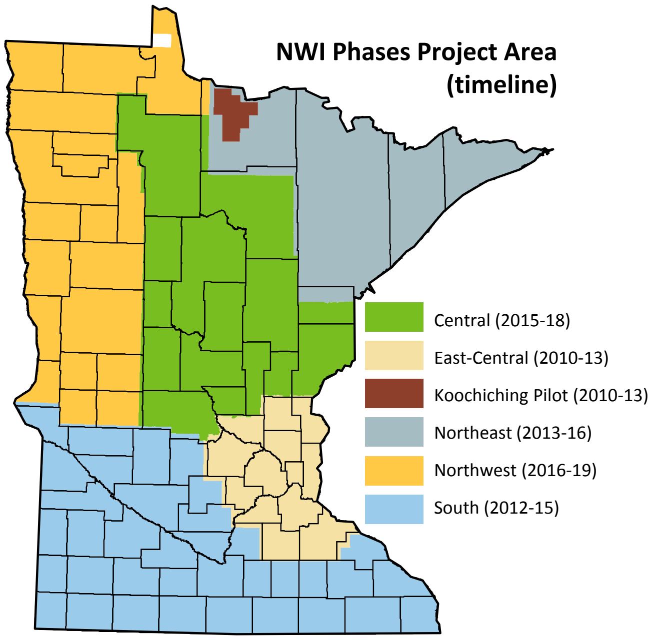
Overview of Input Data and Mapping Procedures

The update of the NWI was conducted in several geographic phases between 2008 and 2018 with funding from the Environment and Natural Resources Trust Fund. Project oversight, coordination, and quality control were provided by the Minnesota DNR, with the map production work handled through a series of five competitive bid contracts. Ducks Unlimited provided mapping services for east-central, northeast, and central Minnesota. St. Mary's University of Minnesota provided wetland mapping services for southern and northwestern Minnesota (Figure 1).

Table 1. Field names and definitions for the primary attribute table

FIELD NAME	Definition
OBJECTID	An internal number for each object that is assigned automatically
Shape	An internal database pointer to the object's geometry data
ATTRIBUTE	An alphanumeric code identifying the wetland classification of the polygon using the system described by Cowardin et al. (1979)
WETLAND_TYPE	General description of the wetland classification based on the Cowardin classification.
ACRES	The area of the polygon in acres.
HGM_CODE	The hydrogeomorphic classification code based on a simplified version of the system described by Tiner (2003)
HGM_DESC	The full text description of the hydrogeomorphic classification
SPCC_DESC	The simplified plant community classification based on a simplified version of the system described by Eggers and Reed (2011)
COW_CLASS1	The wetland class from the Cowardin system without the water regime and special modifiers
CIRC39_CLASS	The wetland classification based on the system described by USFWS Circular 39
HGM_SYMBOL	Simplified Landscape Position category based on the hydrogeomorphic classification
Shape_Length	The length of object perimeter in internal units (meters)
Shape_Area	The area of object in internal units squared (meters^2)

Figure 1. Geographic phases of the NWI update project



While the exact mapping methods may vary from region to region, each vendor relied on the same input data and each was required to meet the same performance-based mapping standards, which were based on the federal wetland mapping standard (FGDC 2009).

The standard input data used for the NWI update included:

- **High-resolution, spring, leaf-off aerial imagery**. The spring imagery data has four spectral bands including red, green, blue, and near-infrared bands. Spring infrared imagery is generally considered the preferred primary data source for wetland mapping. Spring, leaf-off conditions allow for mapping wetlands that might occur beneath tree canopy. Spring also provides a snapshot at a seasonally high water table, which makes wetland identification easier. The spatial resolution of this imagery was either 1-foot (30 centimeters) or ½-meter. This imagery was acquired between spring 2009 and spring 2014 by the DNR through competitive bid contracts.

- **High-resolution, summer aerial imagery** acquired by the Farm Service Agency through the National Aerial Imagery Program (NAIP). Acquisition years for NAIP imagery included 2008, 2009, 2010, 2013, and 2015. NAIP imagery from 2008, 2013, and 2015 included both natural color (red, green, blue) bands as well as the near-infrared band. Imagery from 2009 and 2010 only included natural color bands. All of these imagery data have a spatial resolution of 1-meter. The summer imagery were primarily used to assign certain wetland classifications that depend on the appearance of certain vegetation conditions in summer (e.g., aquatic bed wetlands and farmed wetlands).

- **High-resolution elevation data** from lidar systems along with derived datasets from lidar. The primary elevation data used is a digital elevation model with a 3-meter spatial resolution, which is a regular grid-based elevation dataset (also known as a raster GIS dataset). Several derivatives were created from the lidar digital elevation model (DEM) including grids for slope, a topographic position index (TPI), and a compound topographic index (CTI). The TPI shows elevation differences based on a local neighborhood to highlight local high and low elevations. The CTI combines factors for slope and the catchment area. The CTI is sometimes referred to as the topographic wetness index.

- **Soil survey data** from the U.S. Department of Agriculture (USDA) was also a standard input for the NWI update for all areas of Minnesota where it existed at the time of the NWI update. It includes most of the state except portions of northeast Minnesota and Pine County. The primary soil attributes of interest for the NWI update include the soil drainage class and hydric soil class. Soils that are poorly drained, very poorly drained, or extremely poorly drained comprise the bulk of the class of soils that are considered hydric. Hydric soils are inundated or saturated at a

Wetland Restoration

Minnesota has lost about half of its original wetlands since 1850. Many of these wetlands were drained to support agricultural production, while others have been lost to other activities including urban development, mining, and road construction. Historically, wetlands were viewed as an impediment to development, but in recent decades, we have come to appreciate the many benefits they provide including flood reduction, water quality improvement, and wildlife habitat. Subsequently, federal, state, and local agencies as well as non-profit conservation organizations have expended considerable resources to restore wetlands. Careful planning is required to ensure that wetland restoration projects meet program objectives and that they are cost-effective.

Restoration programs frequently seek to identify multiple restoration opportunities in a targeted area. The NWI is a useful resource to identify potential restoration sites and evaluate their feasibility. The Natural Resources Research Institute (NRRI) developed an online decision support system that uses the NWI and other GIS layers to evaluate ecological stresses and potential wetland restoration benefits (www.mnwetlandrestore.org). As a part of this effort, the NRRI developed a statewide wetland probability model to identify all lands that are likely to be or to have been wetlands. The new NWI data are used to separate out existing wetlands from potentially restorable wetlands.

- Lucinda Johnson
Associate Director
Natural Resources Research Institute

At 4 million acres in area, forested wetlands are the most common wetland type in Minnesota.

duration or frequency such that they typically support the growth of wetland vegetation (hydrophytes).

- Other data that were commonly used for the NWI update include the original NWI, various hydrography data (e.g., DNR Public Water Inventory, and the DNR watercourse data), and scanned USGS topographic quadrangle maps.

Quality Assurance and Quality Control

The Minnesota NWI update project used a rigorous quality assurance program that included measurable objectives and a framework that integrated quality assurance throughout the map production process. Quality assurance efforts included multiple levels of visual data review, field-checks, and crowd-source data review. The primary goal of the quality assurance reviews was to identify any potential systematic errors in either wetland delineation or classification, to correct these errors, and prevent future occurrences.

Mapping contractors conducted review of all (100%) of the photo-interpreter's work by a senior imagery analyst. After an internal review by the mapping contractors, the draft data were provided to the DNR. The DNR and other stakeholders reviewed these data using an online review tool. Comments from this process were reviewed by the NWI project manager and forwarded to the mapping contractor for revision as needed. In addition to manual review, a series of automated GIS checks were also performed. This included the use of the USFWS QAQC toolbox in ArcGIS.

Once the data passed all the manual and automated checks, the final data were submitted to the DNR. The DNR reviewed these data for completeness and repeated the automated checks. Finally, the DNR conducted a classification accuracy assessment by comparing the NWI data to an independent set of field validation data acquired by the University of Minnesota specifically for this project. Statewide there were more than 7,000 field validation data points. The final NWI data were found to have an accuracy of 91% for identifying wetlands and an accuracy of 74% for assigning wetland classes.

Classification Systems

There are many types of wetlands in Minnesota. Likewise, there are numerous wetland classification systems. The Minnesota updated NWI data includes four different classification systems. The DNR created four layer files that symbolize the GIS data using these different classification systems. The data can be displayed based on (1) the Cowardin wetland classification, (2) the USFWS Circular 39 classification, (3) the simplified hydrogeomorphic classification system, and (4) the simplified plant community class.

Cowardin Classification

The principal classification system for the National Wetland Inventory and was originally described in detail by Cowardin et al. (1979). Minor revisions were published in 2013 by the Federal Geographic Data Commission (FGDC 2013).

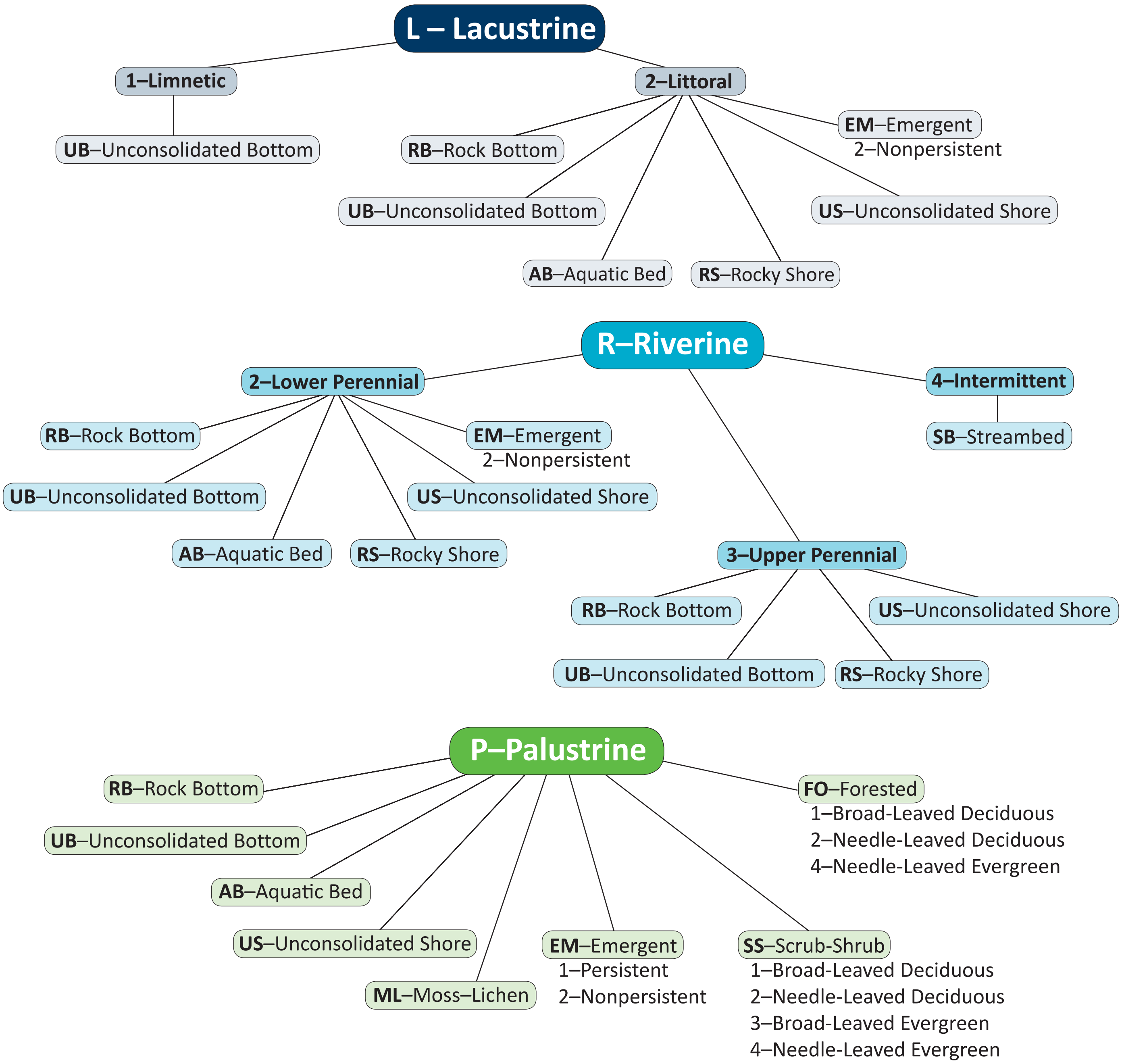
This classification system has multiple levels that nest within each other. The highest level is the ecological system. In Minnesota, this classification includes only three of these systems; riverine, lacustrine, and palustrine. Within the riverine and lacustrine systems there are also subsystems. For example, lacustrine (lake) systems are subdivided into littoral (shallow areas) and limnetic (deep areas). The next level includes classes based primarily on the plant community or the substrate if it lacks a plant community. The Cowardin classification system also provides information for the frequency, depth, and duration of flooding or saturation by water as well as potential modifier attributes to indicate a variety of special cases such as a wetland that is partially drained or ditched.

Because the NWI was originally a paper map, it was convenient to assign letter or number codes to represent each part of the classification system. They were appended into a single combined code, which could be used as a concise label on a paper map. This was convenient and space saving; but, it makes the data hard to understand for those unfamiliar with these codes. The figure below shows the Cowardin classification system for wetland classes found in Minnesota, along with the letter and number codes (Figure 2).

Circular 39 Classification

The classification system known as Circular 39 is an older system developed primarily for the inventory and classification of waterfowl habitat (Shaw and Fredine, 1956). Wetlands are classified based on the frequency and depth of inundation as well as vegetation community. This classification system has 20 different wetland types, of

Figure 2. Schematic diagram showing a portion of the Cowardin classification system for wetlands and deepwater habitat. Coded values are given next to the descriptive classification (e.g., the code for palustrine system wetland is “P”).



which eight are present in Minnesota (Table 2). The types are numbered and named.

Table 2. Circular 39 wetland types in Minnesota

Type Number	Type Name
1	Seasonally flooded basins or flats
2	Inland fresh meadows
3	Inland shallow fresh marshes
4	Inland deep fresh marshes
5	Inland open fresh water
6	Shrub swamp
7	Wooded swamp
8	Bogs
80	Municipal and industrial ponds
90	Rivers and streams

The use of this wetland classification system has declined in recent decades in favor of the other three classification systems incorporated in the Minnesota NWI. There are still some statutory references to the Circular 39 wetland types (e.g., Minnesota Statutes, Section 103G.005 – Public Water Inventory). Therefore, we have included it in the updated NWI. The Circular 39 wetland attributes were added using a standardized attribute crosswalk that matches the Cowardin classification attributes to one of the eight Circular 39 wetland types. Two additional codes were created for the NWI because the Circular 39 classification system doesn't include municipal and industrial ponds or rivers and streams.

Simplified Hydrogeomorphic Classification

The hydrogeomorphic (HGM) classification system is a wetland classification system developed by Mark Brinson (1993) for the U.S. Army Corps of Engineers. This system classifies wetlands not based on their plant communities, but rather based on their geomorphic setting (i.e., landscape position), water source, and hydrodynamics. Water flows and wetland landscape position are closely linked. This system defined seven broad wetland classes, six of which occur in Minnesota. These types include wetlands that are depressional, riverine, lacustrine fringe, mineral flats, organic flats, and slopes. These wetland classes are frequently divided further into subclasses that are correlated to key wetland functions.

Brinson's HGM system was adapted by Ralph Tiner for inclusion in remote sensing based wetland inventories like the NWI. This system classifies wetlands based on their landscape position, landform, waterbody type, and water flow path (LLWW). In Minnesota, we have incorporated a simplified version of Tiner's classification system (Table 3).

Table 3. Simplified hydrogeomorphic wetland classes in Minnesota

Landscape Position	Landform/Waterbody	Water Flow Path
Lentic (LE) Lotic (LO) Terrene (TE)	Basin (BA) Flat (FL) Floodplain (FP) Fringe (FR) Island (IL) Peatlands (PT) Slope (SL)	Inflow (IN) Outflow (OU) Throughflow (TH) Bi-directional non-tidal (BI) Vertical (VR)
	Lake (LK) Pond (PD) River (RV)	

Use of the HGM and LLWW classifications have increased in recent years due to the need to assess wetland functions. State and federal wetland policy aim to achieve no net-loss of quantity or quality of wetlands. For policy and regulatory purposes, the quality of wetlands is usually defined by the function or ecosystem services that they provide. Therefore, wetland protection and replacement efforts frequently require assessment of these functions. These classification methods provide a means to conduct these assessments.

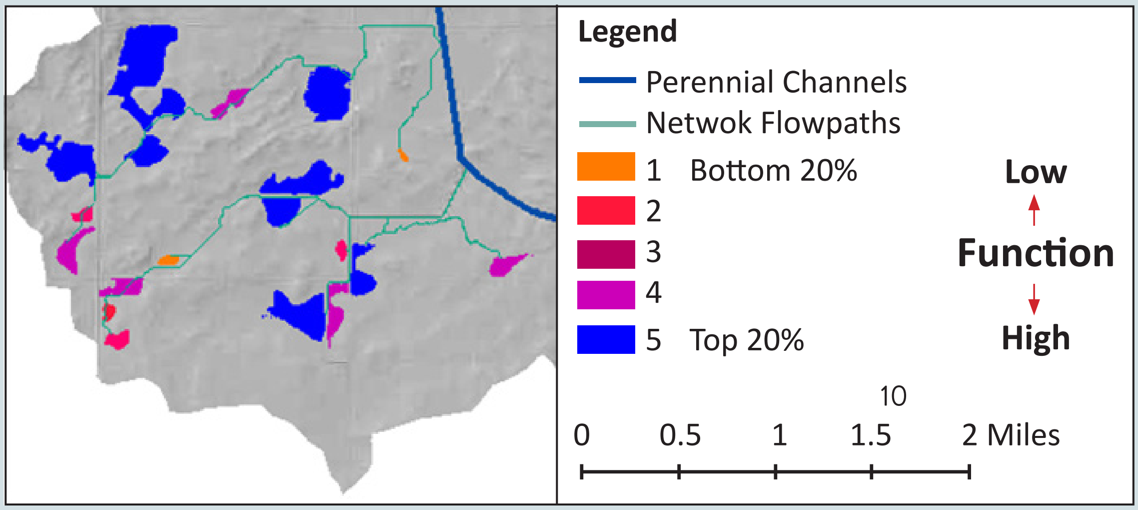
NWISTORIES

Flood Storage Analysis

Floods are one of the most common types of disasters in Minnesota. Flooding from heavy rain or snowmelt events causes significant damage and the frequency of such events appears to be increasing. Wetlands can play a vital role in mitigating such damage. Depressional wetlands can temporarily store runoff and slowly release it over time, reducing flood peaks.

The St. Croix Watershed Research Station (SCWRS) has combined the NWI data with high-resolution elevation data from lidar to evaluate the runoff storage capacity of wetlands on a watershed wide basis. The overall effectiveness of flood storage for wetlands for a given watershed depends on not only wetland size (area, depth, and volume), but also their hydrologic connections with each other. Researchers at SCWRS modeled wetland connectivity networks for a set of study watersheds comprising over 2 million acres in Southern Minnesota. They calculated available storage volume, direct drainage area for wetlands, and then simulated each wetland's fill-and-spill response to runoff for various design storms. The results from this can be used to estimate the existing flood storage capacity for wetlands as well as to help identify areas that could use additional flood storage capacity.

-Jason Ulrich,
Assistant Scientist
St. Croix Watershed Research Station



Simplified Plant Community Classification

The fourth wetland classification system that has been incorporated into the updated NWI for Minnesota is based on the Wetland Plants and Plant Communities of Minnesota and Wisconsin (Eggers & Reed 2011). This system describes 15 different wetland plant communities and provides a dichotomous key to classify wetlands accordingly. Some of the distinctions between these plant community classes are difficult to assess reliably using remote sensing data. For the NWI, we have simplified this system to nine vegetated classes and one non-vegetated aquatic class (Table 4).

Eggers and Reed has found use in the wetland management community, particularly with regard to quantifying potential wetland impact and setting wetland replacement goals.

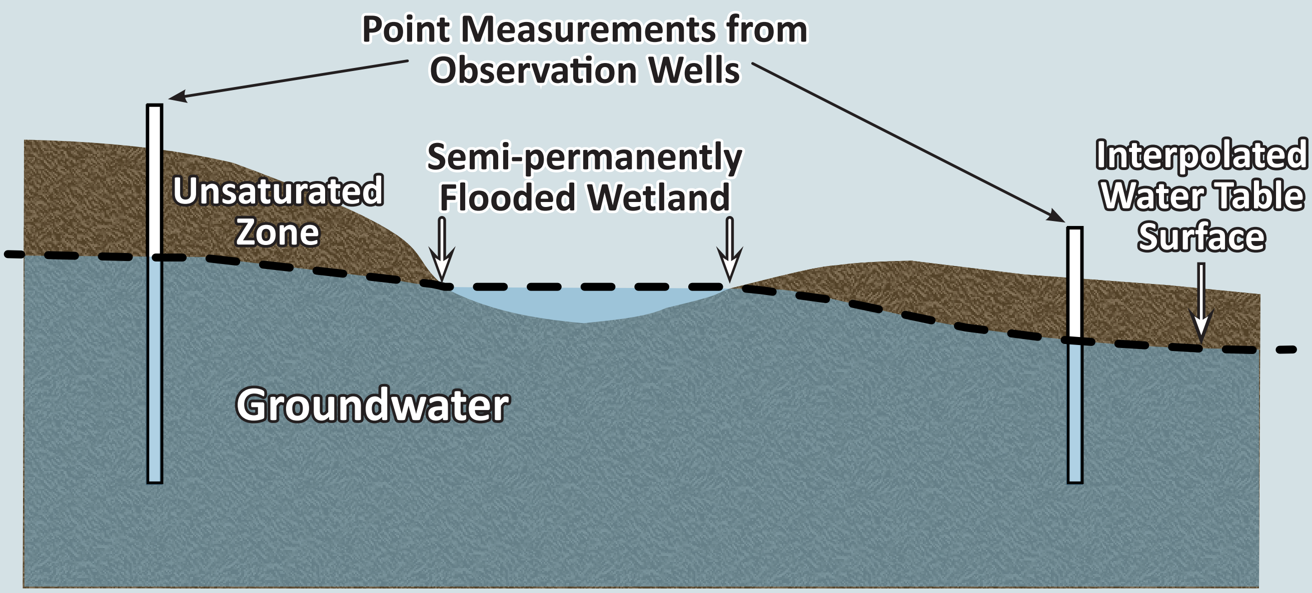
Table 4. simplified plant community classes in Minnesota

Simplified Plant Community Class
Seasonally flooded/saturated emergent wetland
Shallow marsh
Deep marsh
Shallow open water community
Non-vegetated aquatic community
Coniferous wetland
Hardwood wetland
Shrub wetland
Bog
Artificially flooded

Mapping Groundwater

The water table is defined as the surface below which sediment is saturated with groundwater. Water-table elevation and depth to water table are important considerations in construction projects and land use programs. The groundwater portion of the County Geologic Atlas uses selected wetlands from the NWI as an input for water-table elevation maps. The wetlands extracted from the NWI are important for filling in data gaps from other sources. Wetlands that are flooded semi-permanently to permanently are usually closely connected to the water table. The NWI provides information on the size and location of wetlands as well as information on water regime. The County Geologic Atlas extracts the shoreline for these wetland features and combines with other sources such as measured water-table elevations from the DNR's groundwater monitoring well network. Water-table elevations in between these input data are interpolated using GIS.

-Todd Petersen
Hydrogeologist, Minnesota DNR



Three-fourths of all Minnesota's remaining wetlands are located in the northeast (roughly north of Interstate 94 and east of U.S. Highway 59).

More Information from the DNR

GIS metadata–provides an overview of the NWI dataset along with important technical information. Metadata for the National Wetlands Inventory Update for Minnesota can be found on the Minnesota Geospatial Commons - https://gisdata.mn.gov/dataset/water-nat-wetlands-inv-2009-2014

Technical procedures documents–Links to the detailed technical procedures used in each of five mapping phase are provided on the NWI project web page of the DNR's website - https://www.dnr.state.mn.us/eco/wetlands/nwi_proj.html

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Wildlife Habitat Surveys

There are numerous state and federal programs, as well as non-profit conservation organizations, dedicated to protecting wildlife and wildlife habitat. The NWI data have been frequently used for assessing habitat and population health of wetland dependent species. One example of this type of use is in designing duck surveys. These surveys provide essential information for waterfowl managers.

Wildlife research biologists Hannah Specht and Todd Arnold from the University of Minnesota, in collaboration with Ducks Unlimited and the USFWS, have used the NWI to identify characteristics of wetlands that correspond to whether they're used by waterfowl. Their research relied on developing correlations between waterfowl observations and basin-specific habitat characteristics including wetland size, edge complexity, water regime, and adjacent land cover. The wetland variables were derived from the NWI. Wetland size is positively correlated to duck abundance. The degree of edge complexity (the ratio of the wetland perimeter to the perimeter of a circle with the same area) is correlated to the amount of shallow water habitat used by dabbling ducks. Dabbling ducks also show a preference for seasonally flooded wetlands during certain times. As a result, wetland management efforts for waterfowl can be focused on wetlands most likely to be occupied.

-Dr. Hannah Specht,
Postdoc, University of Montana
PhD in Conservation Sciences,
University of Minnesota

There are 2.9 million acres of lacustrine (lake) habitat in Minnesota.

Additional Tables

1. Crosswalk table from Cowardin classification codes to the simplified plant community classification

2. Crosswalk table from Tiner's LLWW codes to Brinson's hydrogeomorphic classification

3. Crosswalk table from Cowardin classification codes to Circular 39 wetland types

1 Crosswalk table from Cowardin classification codes to the simplified plant community classification

Simplified Plant Community Class	Cowardin Codes
Coniferous Bog	PFO2Dq, PFO4Dq
Coniferous Wetland	PFO2D, PFO4D
Deep Marsh	PEM2G, L2EM2G, L2EM2H, PEM2H, R2EM2G, R2EM2H
Hardwood Wetland	PFO1A, PFO1C, PFO1D
Non-Vegetated Aquatic Community	L1UBH, L2RSC, L2USA, L2USC, PUSA, PUSC, R2UBF, R2UBG, R2UBH, R2USA, R2USC, R3UBG, R4SBA, R4SBC, L2UBF, L2UBG, L2UBH, PUBF, PUBG, PUBH
Open Bog	PEM1Dq, PSS1Dq, PSS2Dq, PSS3Dq, PSS4Dq
Seasonally Flooded/Saturated Emergent Wetland	PEM1A, PEM1D
Shallow Marsh	L2EM2F, PEM1C, PEM1F, PEM2F, R2EM2F
Shallow Open Water Community	L1ABH, L2ABF, L2ABG, L2ABH, PABH, R2ABG, R2ABH, PABF, PABG
Shrub Wetland	PSS1A, PSS1C, PSS1D, PSS1F, PSS2D, PSS3D, PSS4D
Artificially Flooded Hardwood Wetland	PFO1K
Artificially Flooded Non-Vegetated Aquatic Community	L1UBK, PUSK, L2UBK, PUBK
Artificially Flooded Shallow Marsh	PEM1K
Artificially Flooded Shallow Open Water Community	L2ABK, PABK
Artificially Flooded Deep Marsh	L2EM2K, PEM2K
Artificially Flooded Shrub Wetland	PSS1K, PSS3K

The relationship between these two classification systems is an approximation. It is not possible to equate these two systems directly because the criteria used to establish these classification systems are different. Shaded values are for artificially flooded wetland systems.

2 Crosswalk table from Tiner's LLWW codes to Brinson's hydrogeomorphic classification

HGM	Landscape-Landform (LLWW)
Depression	TEBA, TEFR, TEIL, TEPD
Lentic	LEBA, LEFL, LEFR, LEIL, LELK, LEPD
Lotic	LOBA, LOFL, LOFP, LOFR, LOIL, LOLK, LOPD, LORV, LOST
Mineral Flat	TEFL
Peatland	TEPT
Slope	TESL

The relationship between these two classification systems is an approximation. It is not possible to equate these two systems directly because the criteria used to establish these classification systems are different. The crosswalk relationship between these two systems only depends on the landscape position and landform and not the water flow path.

3 Crosswalk table from Cowardin classification codes to Circular 39 wetland types

Circular 39 Type	Description	Cowardin Codes
1	Seasonally Flooded Basin or Flat	PEM1A, PFO1A
2	Wet Meadow	PEM1D
3	Shallow Marsh	PEM1C, PEM1F, PUSA, PUSC
4	Deep Marsh	PABF, PABG, PEM2F, PEM2G, PEM2H, PUBF, L2ABF, L2EM2F
5	Shallow Open Water	L1ABH, L1UBH, L2ABG, L2ABH, L2EM2G, L2EM2H, L2RSC, L2USA, L2USC, L2UBF, L2UBG, L2UBH, PABH, PUBG, PUBH
6	Shrub Swamp	PSS1A, PSS1C, PSS1D, PSS1F, PSS2D, PSS4D
7	Wooded Swamp	PFO1C, PFO1D, PFO2D, PFO4D
8	Bog	PEM1Dq, PFO2Dq, PFO4Dq, PSS1Dq, PSS2Dq, PSS3Dq, PSS4Dq
80	Artificially Flooded	L1UBK, L2ABK, L2EM2K, L2UBK, PABK, PEM1K, PEM2K, PFO1K, PSS1K, PSS3K, PUBK, PUSK
90	Riverine	R2ABG, R2ABH, R2EM2F, R2EM2G, R2EM2H, R2UBF, R2UBG, R2UBH, R2USA, R2USC, R3UBG, R3UBH, R4SBA, R4SBC

The relationship between these two classification systems is an approximation. It is not possible to equate these two systems directly because the criteria used to establish these classification systems are different. Shaded values are for systems that are not covered by the Circular 39 wetland classification system.

Minnesota Wetland Inventory:
Summary Statistics

Wetland Acreage by County—Cowardin Classification

County	Lacustrine		Palustrine			
	Limnetic (Deepwater)[1]	Littoral	Aquatic Bed	Emergent	Forested	Scrub-Shrub
Aitkin	85,585	21,054	1,402	103,385	250,909	198,823
Anoka	2,505	8,646	1,100	42,503	12,882	13,124
Becker	36,368	44,871	2,529	99,958	30,254	26,496
Beltrami	311,744	43,111	786	194,043	306,646	388,063
Benton	778	939	330	25,349	5,760	8,106
Big Stone	9,644	14,978	210	37,910	1,145	602
Blue Earth	2,142	6,611	370	18,613	11,506	2,197
Brown	263	4,100	157	14,164	5,566	1,695
Carlton	3,200	4,326	308	19,970	80,510	80,750
Carver	5,322	6,375	696	21,864	4,228	2,028
Cass	162,968	79,704	4,651	131,466	125,540	117,133
Chippewa	1,727	2,027	263	12,576	3,542	1,965
Chisago	6,184	7,937	567	29,198	14,856	11,450
Clay	711	5,653	651	40,596	6,474	4,433
Clearwater	5,004	12,702	786	93,077	39,454	66,911
Cook	49,651	38,214	762	16,677	106,981	39,065
Cottonwood	785	4,463	141	14,435	1,740	568
Crow Wing	61,480	35,279	1,093	59,296	36,126	52,719
Dakota	1,315	3,398	1,009	13,674	8,428	2,201
Dodge		24	42	5,479	3,468	1,263
Douglas	25,631	30,063	809	50,876	6,396	5,385
Faribault	142	4,090	140	15,011	5,462	823
Fillmore		45	25	10,648	8,222	1,061
Freeborn	58	10,781	196	20,185	2,097	736
Goodhue	570	3,647	254	8,226	10,316	2,021
Grant	4,446	17,818	167	22,241	1,186	339
Hennepin	16,921	11,247	2,143	33,120	7,774	2,414
Houston		1,668	644	14,748	11,213	1,956
Hubbard	25,951	18,652	702	34,397	22,953	27,482
Isanti	2,029	5,560	1,125	36,395	21,477	18,575
Itasca	112,242	57,895	4,056	87,788	323,139	172,848
Jackson	1,465	9,229	424	17,877	1,359	871
Kanabec	2,165	3,160	766	33,756	13,609	27,580
Kandiyohi	20,587	20,352	861	44,739	3,815	3,429
Kittson	217	477	4	68,491	15,574	34,302
Koochiching	13,108	13,041	661	90,629	782,128	435,001
Lac qui Parle	4,825	4,281	266	39,606	3,372	1,314

Palustrine		Riverine		Total for All NWI Features	Total for Wetland Features	Total for Deepwater Features
Unconsolidated Bottom	Unconsolidated Shore	Riverine	Riverine (Deepwater)[1]			
3,873		39	9,985	**675,056**	**579,486**	**95,570**
2,629		4	2,792	**86,185**	**80,889**	**5,297**
9,908	3	3	909	**251,300**	**214,023**	**37,277**
3,828		250	6,913	**1,255,385**	**936,729**	**318,656**
685		4	2,313	**44,265**	**41,174**	**3,091**
3,668	6	15	361	**68,539**	**58,534**	**10,005**
1,132	4	143	4,753	**47,472**	**40,577**	**6,895**
585	7	90	2,072	**28,698**	**26,364**	**2,335**
2,190		5	3,567	**194,825**	**188,059**	**6,767**
1,507		20	1,400	**43,440**	**36,718**	**6,723**
6,160		549	5,603	**633,775**	**465,204**	**168,571**
695	2	20	1,332	**24,148**	**21,089**	**3,059**
1,214		10	2,380	**73,796**	**65,232**	**8,564**
4,802	3	31	1,870	**65,223**	**62,643**	**2,580**
6,191	3	26	1,135	**225,290**	**219,150**	**6,140**
7,816		367	2,789	**262,321**	**209,882**	**52,439**
835	5	58	1,343	**24,373**	**22,245**	**2,128**
3,704		616	5,213	**255,526**	**188,833**	**66,693**
2,600		37	6,093	**38,754**	**31,346**	**7,408**
317	6	8	862	**11,471**	**10,609**	**862**
6,510	2		468	**126,139**	**100,040**	**26,099**
600	5	5	2,020	**28,298**	**26,137**	**2,162**
717	3	247	2,240	**23,209**	**20,969**	**2,240**
1,220	9	1	581	**35,864**	**35,225**	**639**
501		71	10,880	**36,486**	**25,036**	**11,450**
3,013	13		484	**49,708**	**44,778**	**4,930**
3,545	6	9	3,110	**80,289**	**60,258**	**20,031**
730	17	866	4,543	**36,386**	**31,843**	**4,543**
3,594		224	1,667	**135,620**	**108,002**	**27,617**
1,299	<1	13	1,429	**87,902**	**84,445**	**3,458**
9,375		641	8,908	**776,892**	**655,742**	**121,150**
1,018		26	1,376	**33,644**	**30,804**	**2,841**
1,352		20	2,213	**84,623**	**80,245**	**4,378**
3,853	12	33	454	**98,135**	**77,093**	**21,041**
1,301	1	25	1,975	**122,367**	**120,174**	**2,193**
6,323	<1	22	12,684	**1,353,598**	**1,327,806**	**25,792**
1,235	3	13	1,785	**56,700**	**50,090**	**6,610**

Wetland Acreage by County—Cowardin Classification (continued)

County	Lacustrine		Palustrine			
	Limnetic (Deepwater)[1]	Littoral	Aquatic Bed	Emergent	Forested	Scrub-Shrub
Lake	49,815	59,640	2,118	33,329	239,585	84,761
Lake of the Woods	271,640	34,297	81	79,980	242,666	325,965
Le Sueur	6,878	8,547	425	25,961	6,459	1,910
Lincoln	3,614	5,069	52	28,895	1,202	351
Lyon	1,025	4,585	93	22,231	3,342	679
Mahnomen	3,864	11,095	538	51,837	4,794	9,290
Marshall	23	9,822	86	103,132	46,190	81,307
Martin	2,800	10,483	188	11,500	3,009	664
McLeod	1,343	6,771	167	20,021	3,591	867
Meeker	8,844	13,697	442	37,411	7,121	3,105
Mille Lacs	60,834	6,726	475	45,020	21,508	38,175
Morrison	6,369	5,584	1,843	93,625	20,709	48,123
Mower	32	143	56	7,671	4,146	553
Murray	2,432	7,147	157	25,601	1,149	451
Nicollet	744	4,176	151	16,772	6,424	3,556
Nobles	739	4,030	110	19,682	329	234
Norman		443	71	18,456	8,694	3,422
Olmsted	274	768	44	11,175	8,679	966
Otter Tail	81,382	86,619	2,828	137,320	27,290	44,005
Pennington		448	27	24,177	9,731	8,027
Pine	6,727	4,600	841	82,217	73,113	110,344
Pipestone		111	6	18,295	118	112
Polk	2,996	13,939	1,109	84,779	18,807	22,153
Pope	12,068	21,236	353	49,291	4,150	3,612
Ramsey	4,122	3,846	512	4,983	1,595	1,149
Red Lake		371	4	8,686	6,973	3,962
Redwood	134	949	123	11,050	4,061	1,325
Renville	840	1,817	195	11,586	3,551	2,108
Rice	5,867	5,518	1,222	21,777	2,262	1,725
Rock		114	24	13,478	806	240
Roseau	117	2,159	64	131,706	96,207	160,301
Scott	2,513	5,042	988	23,029	6,820	2,514
Sherburne	2,365	5,380	1,137	29,770	12,359	10,008
Sibley	43	5,977	103	16,990	4,348	1,332
St. Louis	196,652	124,085	4,308	139,278	718,590	434,269
Stearns	14,038	12,706	3,352	81,906	17,808	17,090
Steele	94	1,051	101	11,439	2,440	1,086
Stevens	1,372	10,053	108	23,002	1,094	351

Palustrine		Riverine		Total for All NWI Features	Total for Wetland Features	Total for Deepwater Features
Unconsolidated Bottom	Unconsolidated Shore	Riverine	Riverine (Deepwater)[1]			
7,748		457	4,409	481,862	427,638	54,224
1,023	9	420	2,915	958,995	684,440	274,555
1,128	19	45	1,528	52,900	44,493	8,407
1,228	2	125	505	41,045	36,925	4,120
1,390	6	29	1,237	34,617	32,355	2,262
3,923		<1	824	86,164	81,476	4,688
2,145	24	6	3,231	245,967	242,712	3,255
751	3	8	1,118	30,525	26,607	3,918
1,479	4	1	992	35,235	32,900	2,335
1,846	18	8	870	73,362	63,647	9,715
1,232		10	2,215	176,196	113,147	63,049
2,467		316	6,236	185,272	172,666	12,606
523	1	5	1,182	14,313	13,098	1,214
1,336	4	51	957	39,285	35,896	3,389
705	4	68	1,865	34,463	31,855	2,609
783		83	837	26,827	25,251	1,576
809	6	53	2,075	34,031	31,955	2,075
859	34	123	1,350	24,273	22,649	1,624
19,280	18	30	1,967	400,738	317,389	83,348
440	7	5	1,210	44,072	42,862	1,210
3,991		237	7,265	289,334	275,343	13,992
577	3	133	618	19,973	19,355	618
4,638	7	92	3,588	152,108	145,524	6,584
5,755	2	5	876	97,347	84,403	12,944
1,061		7	1,283	18,558	13,153	5,405
311		21	1,770	22,099	20,328	1,770
861	13	16	1,930	20,463	18,399	2,065
964	28	31	1,830	22,949	20,279	2,670
1,050		21	1,288	40,730	33,575	7,155
532	4	177	1,114	16,490	15,375	1,114
1,449	2	138	1,866	394,008	392,025	1,983
1,773		45	1,716	44,440	40,212	4,229
1,528	1	14	3,196	65,758	60,198	5,561
779	22	92	1,585	31,271	29,643	1,628
21,354		2,405	21,639	1,662,579	1,444,288	218,291
3,147	1	41	6,316	156,405	136,051	20,354
790	17	4	494	17,516	16,928	587
2,106	<1		383	38,469	36,714	1,754

Wetland Acreage by County—Cowardin Classification (continued)

County	Lacustrine		Palustrine			
	Limnetic (Deepwater)[1]	Littoral	Aquatic Bed	Emergent	Forested	Scrub-Shrub
Swift	816	5,563	128	29,955	3,823	1,982
Todd	12,372	8,309	2,108	75,686	15,941	35,091
Traverse	4,889	5,079	107	12,270	1,022	139
Wabasha	261	2,777	515	8,015	9,661	1,301
Wadena	980	1,407	298	31,826	15,390	37,997
Waseca	2,706	2,742	117	14,783	2,956	759
Washington	5,547	6,936	1,612	15,013	3,428	3,107
Watonwan	197	2,582	53	6,265	2,920	224
Wilkin		215	100	24,975	1,459	758
Winona	98	1,354	401	8,573	9,076	1,079
Wright	18,459	15,531	2,247	48,060	10,554	3,850
Yellow Medicine	121	3,239	103	21,769	3,752	601
Total	**1,776,778**	**1,111,199**	**63,385**	**3,497,216**	**4,017,805**	**3,272,710**

[1] Deepwater habitats include all lacustrine limnetic features (L1) and riverine unconsolidated bottom features (R2UB and R3UB)

Note: The acreage summary data shown here include some features that are either not natural or do not fit traditional concepts of wetlands or deepwater habitats, such as mine pits, sewage lagoons, and rice farms. The acreage of these features is relatively insignificant on a statewide scale, and can be further identified by consulting the full NWI data available through the Geospatial Commons.

Palustrine		Riverine		Total for All NWI Features	Total for Wetland Features	Total for Deepwater Features
Unconsolidated Bottom	Unconsolidated Shore	Riverine	Riverine (Deepwater)[1]			
1,334	6	9	1,191	**44,806**	**42,799**	**2,007**
1,739			2,430	**153,677**	**138,875**	**14,802**
909	8	28	583	**25,033**	**19,561**	**5,472**
532	9	1,243	11,473	**35,787**	**24,053**	**11,734**
724		22	2,488	**91,132**	**87,664**	**3,468**
507	6	2	766	**25,345**	**21,873**	**3,472**
2,397	5	98	8,831	**46,974**	**32,596**	**14,378**
498		5	1,073	**13,818**	**12,547**	**1,271**
769	3	1	1,486	**29,766**	**28,281**	**1,486**
584	14	1,456	6,721	**29,355**	**22,535**	**6,819**
2,634		14	2,988	**104,337**	**82,891**	**21,447**
1,105	12	116	1,575	**32,394**	**30,697**	**1,697**
228,021	**431**	**12,828**	**258,390**	**14,238,764**	**12,203,596**	**2,035,168**

Wetland Acreage by Watershed—Cowardin Classification

Watershed	Lacustrine		Palustrine			
	Limnetic (Deepwater)[1]	Littoral	Aquatic Bed	Emergent	Forested	Scrub-Shrub
Lake Superior - North (1)	33,705	24,059	495	16,365	126,580	38,058
Lake Superior - South (2)	260	3,047	386	7,547	48,008	17,093
St. Louis River (3)	20,000	25,144	963	55,510	414,792	280,679
Cloquet River (4)	11,061	16,831	465	14,351	94,613	41,703
Nemadji River (5)	788	833	41	5,006	22,500	18,745
Mississippi Riv - Headwaters (7)	123,710	50,208	989	82,715	126,735	91,040
Leech Lake River (8)	110,952	54,822	1,181	66,302	77,666	54,554
Mississippi Riv - Grand Rapids (9)	44,296	33,289	2,518	77,733	232,659	184,769
Mississippi Riv - Brainerd (10)	34,114	21,288	2,521	109,603	94,104	102,899
Pine River (11)	35,195	22,582	1,894	36,050	31,293	37,983
Crow Wing River (12)	41,589	38,880	3,217	106,444	41,175	85,796
Redeye River (13)	2,617	5,445	727	64,440	25,284	48,420
Long Prairie River (14)	25,695	15,756	1,503	67,776	14,656	25,562
Mississippi Riv - Sartell (15)	5,564	7,091	1,541	78,026	18,417	30,708
Sauk River (16)	15,642	13,328	2,558	60,624	7,649	11,661
Mississippi Riv - St. Cloud (17)	9,840	12,168	2,622	74,355	21,294	20,309
North Fork Crow River (18)	33,662	27,544	2,310	103,044	18,593	11,431
South Fork Crow River (19)	9,922	19,402	792	50,575	7,658	2,439
Mississippi Riv - Twin Cities (20)	23,178	18,945	2,965	50,644	12,983	8,654
Rum River (21)	128,053	18,570	2,457	109,375	55,386	69,087
Minnesota Riv - Headwaters (22)	14,625	17,850	389	56,662	2,499	2,123
Pomme de Terre River (23)	11,985	35,328	577	41,505	2,998	1,521
Lac Qui Parle River (24)	620	2,953	178	34,920	3,115	660
Minn River - Yellow Med Riv (25)	4,518	10,595	454	52,455	9,735	3,133
Chippewa River (26)	21,886	48,368	1,118	106,273	10,271	5,085
Redwood River (27)	2,746	3,978	114	20,547	2,333	652
Minnesota River - Mankato (28)	2,973	10,136	440	36,361	16,084	7,890
Cottonwood River (29)	789	4,258	208	26,228	5,882	772
Blue Earth River (30)	2,576	8,279	292	20,245	10,124	1,617
Watonwan River (31)	823	6,187	118	14,175	4,620	524
Le Sueur River (32)	3,510	10,423	383	28,618	8,265	1,446
Lower Minnesota River (33)	6,910	21,638	2,636	75,599	21,252	7,322
Upper St. Croix River (34)	222	824	378	27,244	34,237	47,624
Kettle River (35)	6,321	4,469	596	44,175	71,525	90,338
Snake River (36)	3,685	3,875	886	67,077	48,933	67,497
Lower St. Croix River (37)	11,343	15,785	1,891	59,913	24,697	22,267

Palustrine		Riverine		Total for All NWI Features	Total for Wetland Features	Total for Deepwater Features
Unconsolidated Bottom	Unconsolidated Shore	Riverine	Riverine (Deepwater)[1]			
5,775		411	3,348	**248,796**	**211,743**	**37,053**
1,685		28	1,039	**79,093**	**77,794**	**1,299**
7,082		421	12,734	**817,324**	**784,591**	**32,734**
2,099		5	2,473	**183,601**	**170,068**	**13,534**
982		5	995	**49,894**	**48,111**	**1,783**
5,351		1,140	4,855	**486,743**	**358,178**	**128,565**
3,122		53	2,713	**371,367**	**257,702**	**113,664**
5,491		57	8,959	**589,770**	**536,515**	**53,255**
4,655		711	10,639	**380,533**	**335,780**	**44,753**
2,577		198	1,812	**169,584**	**132,578**	**37,007**
6,714	<1	278	4,932	**329,025**	**282,504**	**46,521**
2,443	6		1,250	**150,632**	**146,765**	**3,867**
3,460			1,866	**156,273**	**128,712**	**27,561**
2,215		151	5,669	**149,384**	**138,150**	**11,233**
2,245	1	12	3,541	**117,260**	**98,077**	**19,183**
3,321	13	38	6,250	**150,210**	**134,119**	**16,091**
5,090	12	46	3,525	**205,258**	**168,071**	**37,187**
2,820	5	10	2,047	**95,669**	**83,700**	**11,969**
6,433	11	111	12,649	**136,572**	**100,746**	**35,827**
4,016	<1	25	5,463	**392,433**	**258,917**	**133,516**
4,545	13	17	1,046	**99,769**	**84,098**	**15,671**
7,140	10	11	927	**102,003**	**89,091**	**12,912**
1,262	5	69	1,457	**45,239**	**43,162**	**2,077**
3,468	38	187	4,255	**88,838**	**80,066**	**8,773**
12,364	9	17	2,483	**207,873**	**183,504**	**24,369**
1,062	3	27	1,231	**32,693**	**28,716**	**3,978**
1,986	38	146	4,938	**80,992**	**73,082**	**7,911**
1,395	8	136	2,631	**42,307**	**38,887**	**3,420**
1,194	8	28	4,222	**48,585**	**41,787**	**6,798**
846	1	21	1,837	**29,152**	**26,492**	**2,660**
1,352	8	66	2,858	**56,930**	**50,561**	**6,369**
5,873	25	194	6,459	**147,909**	**134,540**	**13,370**
1,191			2,864	**114,583**	**111,497**	**3,086**
3,098		<1	4,123	**224,646**	**214,202**	**10,444**
2,294		257	4,068	**198,573**	**190,819**	**7,754**
3,151		38	8,167	**147,253**	**127,742**	**19,510**

Wetland Acreage by Watershed—Cowardin Classification (continued)

Watershed	Lacustrine		Palustrine			
	Limnetic (Deepwater)[1]	Littoral	Aquatic Bed	Emergent	Forested	Scrub-Shrub
Mississippi Riv - Lake Pepin (38)	256	4,540	645	9,969	10,434	2,177
Cannon River (39)	13,011	10,996	1,523	50,860	11,583	4,632
Mississippi Riv - Winona (40)	98	4,048	795	12,801	12,273	1,886
Zumbro River (41)	535	1,406	173	17,632	16,044	2,735
Mississippi Riv - La Crescent (42)		742	197	2,961	2,141	523
Root River (43)		77	99	22,794	16,186	2,275
Mississippi River - Reno (44)		894	434	6,398	5,115	656
Upper Iowa River (46)		23	10	2,927	722	268
Upper Wapsipinicon River (47)				17		1
Cedar River (48)	32	1,772	72	10,283	4,019	737
Shell Rock River (49)	58	5,218	148	10,120	1,137	325
Winnebago River (50)		1,619	16	1,890	206	37
Des Moines Riv - Headwaters (51)	2,785	16,842	486	42,706	2,495	1,495
Lower Des Moines River (52)		118	7	635	323	41
East Fork Des Moines Riv (53)	292	3,920	32	3,149	497	126
Bois de Sioux River (54)	4,866	5,066	187	12,522	898	128
Mustinka River (55)	1,256	14,091	225	25,900	1,038	229
Otter Tail River (56)	96,727	81,894	2,903	111,493	23,367	23,302
Upper Red Riv of the North (57)		489	45	11,524	1,334	442
Buffalo River (58)	4,464	18,354	1,269	66,338	7,179	5,679
Red Riv of the N - Marsh Riv (59)		294	19	4,800	3,608	1,077
Wild Rice River (60)	7,969	20,487	1,085	94,264	19,243	26,624
Red Riv of the N - Sandhill Riv (61)	860	5,482	376	21,361	5,085	4,459
Upper/Lower Red Lake (62)	277,933	25,694	422	73,534	294,611	170,011
Red Lake River (63)	336	2,317	244	106,571	44,386	58,760
Thief River (65)	166	9,328	69	97,331	52,034	143,390
Clearwater River (66)	4,680	12,482	1,093	96,410	32,929	48,578
Red Riv of the N - Gr Marais Crk (67)		739	1	10,704	1,680	613
Snake River (68)		112	14	28,974	8,986	13,385
Red Riv of the N - Tamarac Riv (69)	23	579	7	28,088	12,500	20,304
Two Rivers (70)	217	595	2	81,279	23,113	49,786
Roseau River (71)	302	1,436	65	98,504	76,705	132,359
Rainy River - Headwaters (72)	111,737	91,767	2,790	41,221	203,898	93,406
Vermilion River (73)	53,539	26,283	869	23,609	83,690	39,203
Rainy River - Rainy Lake (74)	73,998	20,485	651	23,838	93,565	32,127
Rainy River - Black River (75)		<1	10	24,562	124,479	108,037
Little Fork River (76)	6,765	25,166	1,341	40,489	290,909	136,283

Palustrine		Riverine		Total for All NWI Features	Total for Wetland Features	Total for Deepwater Features
Unconsolidated Bottom	Unconsolidated Shore	Riverine	Riverine (Deepwater)[1]			
1,592	2	102	15,570	**45,286**	**29,461**	**15,826**
2,456	19	74	3,379	**98,534**	**82,143**	**16,390**
625	5	1,919	9,483	**43,934**	**34,353**	**9,581**
1,438	47	524	3,708	**44,240**	**39,998**	**4,242**
130	7	144	2,554	**9,398**	**6,844**	**2,554**
1,393	14	521	4,090	**47,451**	**43,360**	**4,090**
242	7	765	2,685	**17,196**	**14,511**	**2,685**
176	2	17	203	**4,349**	**4,145**	**203**
2			2	**22**	**20**	**2**
625	1	2	1,036	**18,580**	**17,511**	**1,069**
660	8	<1	307	**17,981**	**17,616**	**365**
115			89	**3,971**	**3,882**	**89**
2,346	9	65	2,700	**71,928**	**66,443**	**5,485**
103		11	257	**1,495**	**1,238**	**257**
131		1	174	**8,322**	**7,856**	**466**
735	7		592	**25,002**	**19,544**	**5,458**
2,074	5	25	568	**45,411**	**43,587**	**1,824**
16,961	13	35	2,244	**358,938**	**259,967**	**98,971**
757	2		1,159	**15,751**	**14,592**	**1,159**
7,553	4		1,391	**112,231**	**106,376**	**5,856**
256	3	<1	1,003	**11,060**	**10,057**	**1,003**
6,983	1	85	2,144	**178,883**	**168,771**	**10,113**
1,810	3	37	1,305	**40,779**	**38,614**	**2,165**
2,736		18	3,781	**848,740**	**567,026**	**281,714**
1,693	11	79	4,309	**218,707**	**214,062**	**4,646**
1,692	1	1	2,369	**306,382**	**303,846**	**2,535**
4,576	<1	27	1,748	**202,524**	**196,096**	**6,428**
429	6		1,110	**15,282**	**14,172**	**1,110**
519	22	4	885	**52,901**	**52,016**	**885**
716	2	1	1,481	**63,701**	**62,197**	**1,504**
1,156	<1	24	1,080	**157,253**	**155,955**	**1,298**
961	1	97	1,637	**312,067**	**310,127**	**1,940**
11,909		723	4,375	**561,826**	**445,714**	**116,112**
3,707		1,629	2,996	**235,525**	**178,989**	**56,535**
3,128		13	2,047	**249,851**	**173,807**	**76,044**
292			2,864	**260,244**	**257,380**	**2,864**
6,358			6,434	**513,745**	**500,547**	**13,198**

Wetland Acreage by Watershed—Cowardin Classification (continued)

Watershed	Lacustrine		Palustrine			
	Limnetic (Deepwater)[1]	Littoral	Aquatic Bed	Emergent	Forested	Scrub-Shrub
Big Fork River (77)	35,006	20,526	1,914	56,559	434,801	193,393
Rapid River (78)		20	22	67,454	158,159	313,408
Rainy River - Baudette (79)		218	39	14,832	49,398	74,049
Lake of the Woods (80)	271,582	34,608	37	35,356	117,087	122,926
Upper Big Sioux River (81)			1	1,967	14	21
Lower Big Sioux River (82)		111	2	16,239	126	139
Rock River (83)		309	33	29,165	964	377
Little Sioux River (84)	1,703	5,553	208	8,698	192	244
Total	**1,776,575**	**1,110,878**	**63,385**	**3,497,216**	**4,017,768**	**3,272,709**

[1] Deepwater habitats include all lacustrine limnetic features (L1) and riverine unconsolidated bottom features (R2UB and R3UB)

Note: The acreage summary data shown here include some features that are either not natural or do not fit traditional concepts of wetlands or deepwater habitats, such as mine pits, sewage lagoons, and rice farms. The acreage of these features is relatively insignificant on a statewide scale, and can be further identified by consulting the full NWI data available through the Geospatial Commons.

Palustrine		Riverine		Total for All NWI Features	Total for Wetland Features	Total for Deepwater Features
Unconsolidated Bottom	Unconsolidated Shore	Riverine	Riverine (Deepwater)[1]			
5,629	<1	89	7,100	**755,016**	**712,910**	**42,106**
462	<1		2,345	**541,873**	**539,527**	**2,345**
287	6	395	1,520	**140,745**	**139,225**	**1,520**
587	3	66	769	**583,022**	**310,671**	**272,351**
64		11	39	**2,116**	**2,077**	**39**
515	1	136	654	**17,922**	**17,268**	**654**
1,082	6	272	1,652	**33,861**	**32,208**	**1,652**
563		3	226	**17,389**	**15,460**	**1,929**
228,021	**431**	**12,829**	**258,390**	**14,238,203**	**12,203,238**	**2,034,964**

Wetland Acreage by County—Circular 39 Classification

County	1–Seasonally-Flooded Basin	2–Wet Meadow	3–Shallow Marsh	4–Deep Marsh	5–Shallow Open Water
Aitkin	19,673	46,370	36,866	823	111,756
Anoka	21,248	1,284	28,126	547	14,470
Becker	15,925	19,453	67,108	5,107	88,574
Beltrami	12,731	127,930	52,788	1,744	354,952
Benton	12,738	10,243	5,268	46	2,574
Big Stone	23,512	1,041	14,262	1,020	27,354
Blue Earth	17,939	732	7,065	644	9,503
Brown	13,138	1,041	3,453	462	4,484
Carlton	3,336	8,952	8,937	395	9,581
Carver	15,544	65	9,684	106	13,736
Cass	25,267	76,311	32,690	2,726	253,244
Chippewa	10,325	324	4,799	603	4,094
Chisago	24,177	2,865	11,419	237	15,586
Clay	14,545	11,394	17,877	2,604	8,889
Clearwater	7,000	51,088	28,501	2,891	21,930
Cook	556	7,117	9,172	775	95,737
Cottonwood	9,869	1,880	3,789	433	5,657
Crow Wing	9,594	31,391	20,233	2,053	101,340
Dakota	15,292	6	5,849	196	8,074
Dodge	5,476	1,930	236	146	227
Douglas	18,801	2,676	31,535	2,957	59,910
Faribault	14,496	402	4,039	256	4,453
Fillmore	10,370	4,756	472	507	275
Freeborn	14,699	1,311	5,757	600	11,582
Goodhue	12,059	3	3,769	66	4,863
Grant	9,877	714	11,726	879	24,210
Hennepin	19,807	225	20,340	224	33,616
Houston	8,026	2,110	7,524	547	2,489
Hubbard	6,561	15,878	11,183	2,067	48,746
Isanti	29,645	2,976	17,149	476	9,764
Itasca	13,276	20,329	58,117	2,335	176,706
Jackson	10,506	718	7,243	466	11,499
Kanabec	10,127	19,711	6,980	269	7,349
Kandiyohi	24,972	1,027	21,887	1,407	44,122
Kittson	15,699	33,565	23,174	788	1,082
Koochiching	8,354	43,660	44,433	1,242	31,591
Lac qui Parle	27,206	1,190	13,961	711	9,857

6–Shrub Swamp	7–Wooded Swamp	8–Bogs	Municipal-Industrial	Riverine	Total
134,349	89,540	215,572	10,082	10,024	**675,056**
12,723	2,728	2,162	102	2,796	**86,185**
21,526	13,105	19,495	94	912	**251,300**
241,807	105,547	343,701	7,023	7,163	**1,255,385**
7,997	2,660	298	123	2,317	**44,265**
602	246		127	376	**68,539**
2,197	4,387		109	4,896	**47,472**
1,695	2,105		160	2,161	**28,698**
61,135	33,975	64,813	129	3,572	**194,825**
2,021	752	48	64	1,420	**43,440**
82,360	34,591	120,221	215	6,152	**633,775**
1,965	672		14	1,352	**24,148**
10,793	2,902	3,266	161	2,390	**73,796**
4,419	3,254	17	323	1,901	**65,223**
59,277	18,497	27,635	7,309	1,162	**225,290**
26,468	16,659	102,666	16	3,155	**262,321**
568	643		133	1,401	**24,373**
39,399	16,834	28,476	377	5,829	**255,526**
2,201	912	26	70	6,129	**38,754**
1,263	1,310		12	870	**11,471**
5,087	3,826	730	150	468	**126,139**
823	1,541		263	2,024	**28,298**
1,061	3,275		6	2,488	**23,209**
736	524		74	582	**35,864**
2,020	2,698	14	43	10,951	**36,486**
337	710	2	770	484	**49,708**
2,373	376	171	39	3,119	**80,289**
1,956	8,318		6	5,409	**36,386**
23,231	5,829	20,111	124	1,891	**135,620**
17,756	3,274	5,398	22	1,443	**87,902**
124,315	97,409	267,628	7,229	9,549	**776,892**
871	769		171	1,401	**33,644**
25,422	7,933	4,556	42	2,233	**84,623**
3,429	680		125	487	**98,135**
34,302	11,627		129	2,000	**122,367**
158,744	136,519	915,537	813	12,706	**1,353,598**
1,314	625		38	1,798	**56,700**

Wetland Acreage by County—Circular 39 Classification (continued)

County	1–Seasonally-Flooded Basin	2–Wet Meadow	3–Shallow Marsh	4–Deep Marsh	5–Shallow Open Water
Lake	1,506	12,110	20,250	981	116,861
Lake of the Woods	2,266	65,427	13,494	854	306,124
Le Sueur	18,457	1,543	9,913	518	16,178
Lincoln	16,274	6,991	6,422	551	9,343
Lyon	14,490	3,253	6,907	542	6,407
Mahnomen	7,921	11,986	33,199	1,902	17,440
Marshall	13,994	53,908	38,035	1,533	10,324
Martin	9,255	342	3,368	279	13,852
McLeod	16,996	84	6,319	622	8,982
Meeker	25,288	936	17,059	1,004	23,778
Mille Lacs	12,501	27,293	9,231	440	68,992
Morrison	24,594	49,915	23,647	372	16,047
Mower	9,478	1,431	527	256	381
Murray	16,506	2,257	7,589	431	10,515
Nicollet	8,562	256	10,835	413	5,304
Nobles	14,099	2,528	3,223	238	5,221
Norman	8,789	5,752	7,434	553	666
Olmsted	8,573	7,064	633	374	1,559
Otter Tail	19,862	26,028	93,838	8,207	181,788
Pennington	8,259	11,822	4,581	385	153
Pine	27,049	45,655	19,422	1,115	15,505
Pipestone	8,999	7,750	1,573	316	238
Polk	29,264	23,677	34,761	2,515	19,078
Pope	16,122	3,745	30,706	2,709	36,539
Ramsey	2,242	109	3,627	40	9,452
Red Lake	7,147	3,642	1,304	208	164
Redwood	11,010	641	2,614	483	1,448
Renville	10,285	367	3,671	635	2,898
Rice	13,481	57	10,295	197	13,444
Rock	8,625	3,307	2,026	199	408
Roseau	11,971	96,815	26,242	1,454	2,443
Scott	17,841	89	10,380	233	9,921
Sherburne	21,702	956	16,671	479	10,058
Sibley	13,403	49	6,341	311	6,326
St. Louis	19,873	39,066	90,028	4,486	321,513
Stearns	57,970	5,192	29,730	231	32,508
Steele	10,674	686	2,053	320	1,695
Stevens	13,109	495	9,975	850	12,554

6–Shrub Swamp	7–Wooded Swamp	8–Bogs	Municipal-Industrial	Riverine	Total
49,595	38,944	235,080	1,668	4,866	**481,862**
192,305	97,919	276,729	542	3,335	**958,995**
1,910	2,524		284	1,573	**52,900**
351	412		69	631	**41,045**
679	928		145	1,266	**34,617**
7,608	2,241	2,965	78	824	**86,164**
78,463	38,693	7,179	601	3,237	**245,967**
664	1,546		92	1,126	**30,525**
867	217		156	993	**35,235**
3,100	1,235	30	54	878	**73,362**
34,278	12,574	8,443	220	2,225	**176,196**
43,583	10,483	9,937	142	6,552	**185,272**
553	382		117	1,187	**14,313**
451	403		126	1,009	**39,285**
3,556	3,547		58	1,933	**34,463**
234	161		203	920	**26,827**
3,422	5,177		110	2,129	**34,031**
966	3,617		13	1,474	**24,273**
42,049	19,211	7,491	268	1,997	**400,738**
8,027	8,758	1	872	1,214	**44,072**
92,144	26,351	54,297	295	7,501	**289,334**
112	94		139	751	**19,973**
21,771	12,098	1,159	4,104	3,680	**152,108**
3,511	2,654	251	229	881	**97,347**
1,145	580	18	54	1,291	**18,558**
3,962	3,566		314	1,791	**22,099**
1,325	856		139	1,946	**20,463**
2,108	842		283	1,861	**22,949**
1,725	187	18	17	1,310	**40,730**
240	330		63	1,291	**16,490**
136,259	63,801	52,824	194	2,004	**394,008**
2,507	1,528	8	174	1,761	**44,440**
9,860	1,979	759	83	3,210	**65,758**
1,332	1,567		265	1,677	**31,271**
280,624	151,095	709,175	22,675	24,044	**1,662,579**
16,700	4,144	2,995	578	6,357	**156,405**
1,086	483		22	498	**17,516**
349	518	2	234	383	**38,469**

Wetland Acreage by County—Circular 39 Classification (continued)

County	1–Seasonally-Flooded Basin	2–Wet Meadow	3–Shallow Marsh	4–Deep Marsh	5–Shallow Open Water
Swift	23,265	847	9,206	592	7,219
Todd	23,456	27,451	28,761	211	24,192
Traverse	7,014	351	5,387	400	10,548
Wabasha	8,993	981	3,813	533	3,537
Wadena	11,292	18,788	7,142	17	3,331
Waseca	12,631	288	4,494	344	5,727
Washington	8,093	465	8,477	245	16,269
Watonwan	5,772	59	2,137	146	3,092
Wilkin	12,008	7,854	6,085	309	634
Winona	7,016	2,264	2,844	476	1,947
Wright	32,297	438	24,802	305	38,521
Yellow Medicine	17,729	2,388	4,773	724	3,707
Total	**1,260,368**	**1,138,065**	**1,383,254**	**80,891**	**3,068,706**

6–Shrub Swamp	7–Wooded Swamp	8–Bogs	Municipal-Industrial	Riverine	Total
1,982	466		30	1,200	**44,806**
33,668	8,768	4,419	322	2,430	**153,677**
139	548		36	611	**25,033**
1,301	3,896		16	12,716	**35,787**
37,386	5,252	5,339	75	2,510	**91,132**
759	333		2	768	**25,345**
2,883	983	612	18	8,929	**46,974**
224	1,218		92	1,078	**13,818**
758	490		141	1,487	**29,766**
1,079	5,536		16	8,177	**29,355**
3,808	900	165	98	3,002	**104,337**
601	639		142	1,691	**32,394**
2,252,550	**1,187,926**	**3,522,434**	**73,351**	**271,218**	**14,238,764**

Wetland Acreage by Watershed—Circular 39 Classification

Watershed	1–Seasonally-Flooded Basin	2–Wet Meadow	3–Shallow Marsh	4–Deep Marsh	5–Shallow Open Water
Lake Superior - North (1)	728	7,450	8,485	795	63,309
Lake Superior - South (2)	900	3,134	3,902	279	3,426
St. Louis River (3)	11,654	18,168	32,690	1,187	48,186
Cloquet River (4)	1,443	3,938	9,739	357	30,120
Nemadji River (5)	641	1,686	2,951	358	2,286
Mississippi Riv - Headwaters (7)	12,640	31,017	38,492	2,782	179,324
Leech Lake River (8)	10,754	38,915	17,264	2,034	169,933
Mississippi Riv - Grand Rapids (9)	14,283	33,409	34,439	1,080	74,804
Mississippi Riv - Brainerd (10)	24,117	52,062	34,820	1,377	62,300
Pine River (11)	7,780	17,639	11,128	1,773	62,185
Crow Wing River (12)	21,139	56,534	33,751	2,370	89,264
Redeye River (13)	12,459	30,603	25,553	1,306	9,835
Long Prairie River (14)	17,377	22,070	31,235	1,575	44,687
Mississippi Riv - Sartell (15)	27,577	32,139	23,772	193	16,133
Sauk River (16)	37,105	2,398	26,565	282	33,288
Mississippi Riv - St. Cloud (17)	46,950	8,763	34,590	673	27,255
North Fork Crow River (18)	70,806	1,840	46,356	1,775	66,476
South Fork Crow River (19)	37,093	311	20,138	1,195	31,510
Mississippi Riv - Twin Cities (20)	28,117	575	32,344	454	50,983
Rum River (21)	53,847	40,032	35,465	1,174	152,393
Minnesota Riv - Headwaters (22)	33,701	1,901	23,008	1,525	35,772
Pomme de Terre River (23)	18,000	1,209	23,749	2,148	52,633
Lac Qui Parle River (24)	25,496	2,747	9,233	656	4,249
Minn River - Yellow Med Riv (25)	39,327	5,280	15,637	1,779	16,817
Chippewa River (26)	48,928	5,066	58,128	5,201	78,218
Redwood River (27)	13,466	2,728	5,951	555	7,274
Minnesota River - Mankato (28)	25,914	1,995	17,150	1,232	13,945
Cottonwood River (29)	21,023	3,111	6,862	641	5,693
Blue Earth River (30)	21,116	631	4,888	526	11,641
Watonwan River (31)	11,828	618	4,437	350	7,460
Le Sueur River (32)	23,706	747	10,264	728	14,661
Lower Minnesota River (33)	58,256	667	32,351	939	35,613
Upper St. Croix River (34)	8,504	13,137	9,259	347	2,496
Kettle River (35)	11,302	26,500	10,553	566	14,102
Snake River (36)	18,686	40,634	13,181	499	10,467
Lower St. Croix River (37)	39,555	6,420	28,407	736	31,636

6–Shrub Swamp	7–Wooded Swamp	8–Bogs	Municipal-Industrial	Riverine	Total
26,695	19,502	118,058	16	3,759	**248,796**
14,525	28,225	21,961	1,673	1,068	**79,093**
172,806	81,149	433,715	4,613	13,155	**817,324**
33,055	20,438	82,034		2,478	**183,601**
15,884	11,672	13,418		1,000	**49,894**
67,555	32,175	115,887	877	5,994	**486,743**
32,013	19,014	78,571	104	2,766	**371,367**
123,455	73,337	211,211	14,736	9,016	**589,770**
83,189	42,015	62,941	6,362	11,349	**380,533**
24,775	9,922	32,335	37	2,010	**169,584**
77,515	13,506	29,487	249	5,210	**329,025**
46,788	15,561	7,182	95	1,250	**150,632**
23,737	9,192	4,255	280	1,866	**156,273**
28,854	8,965	5,650	279	5,820	**149,384**
11,375	1,307	1,132	255	3,553	**117,260**
20,074	4,188	1,185	245	6,288	**150,210**
11,410	2,436	190	396	3,572	**205,258**
2,430	590	113	232	2,057	**95,669**
8,410	1,917	854	157	12,760	**136,572**
63,047	22,691	18,009	286	5,489	**392,433**
2,123	564		112	1,062	**99,769**
1,518	1,555	4	249	938	**102,003**
660	558		113	1,527	**45,239**
3,133	1,985		440	4,442	**88,838**
5,050	4,350	60	373	2,500	**207,873**
652	738		72	1,258	**32,693**
7,890	7,425		358	5,084	**80,992**
772	1,119		319	2,767	**42,307**
1,617	3,743		173	4,250	**48,585**
524	1,912		164	1,858	**29,152**
1,446	2,175		279	2,924	**56,930**
7,284	5,566	51	530	6,653	**147,909**
41,012	12,801	24,150	13	2,864	**114,583**
70,921	28,056	58,251	270	4,123	**224,646**
58,124	23,852	28,625	179	4,325	**198,573**
21,072	5,077	5,973	171	8,205	**147,253**

Wetland Acreage by Watershed—Circular 39 Classification (continued)

Watershed	1–Seasonally-Flooded Basin	2–Wet Meadow	3–Shallow Marsh	4–Deep Marsh	5–Shallow Open Water
Mississippi Riv - Lake Pepin (38)	12,831	136	4,756	165	6,806
Cannon River (39)	39,385	1,085	19,894	872	27,013
Mississippi Riv - Winona (40)	8,978	2,735	5,994	588	4,957
Zumbro River (41)	21,497	5,794	1,491	674	2,835
Mississippi Riv - La Crescent (42)	831	196	2,196	57	1,012
Root River (43)	20,435	10,009	1,602	981	566
Mississippi River - Reno (44)	1,719	559	4,592	228	1,339
Upper Iowa River (46)	2,565	844	75	109	80
Upper Wapsipinicon River (47)	16	1		1	
Cedar River (48)	11,348	588	1,974	308	2,095
Shell Rock River (49)	6,928	910	3,064	346	5,688
Winnebago River (50)	1,432	29	607	66	1,680
Des Moines Riv - Headwaters (51)	27,416	3,096	13,391	903	21,269
Lower Des Moines River (52)	686	60	93	14	97
East Fork Des Moines Riv (53)	2,361	39	986	37	4,318
Bois de Sioux River (54)	6,621	327	5,521	551	10,059
Mustinka River (55)	15,679	231	10,689	764	16,764
Otter Tail River (56)	14,980	13,949	85,338	7,537	190,928
Upper Red Riv of the North (57)	6,119	3,262	3,128	339	651
Buffalo River (58)	22,901	13,005	33,371	4,075	27,382
Red Riv of the N - Marsh Riv (59)	2,704	869	2,241	184	318
Wild Rice River (60)	18,253	25,888	54,275	3,425	32,945
Red Riv of the N - Sandhill Riv (61)	9,001	3,158	11,264	863	7,626
Upper/Lower Red Lake (62)	9,329	26,616	37,312	483	301,983
Red Lake River (63)	12,065	81,504	17,348	838	2,726
Thief River (65)	5,061	63,313	29,973	1,013	10,265
Clearwater River (66)	25,008	35,297	29,443	2,942	19,778
Red Riv of the N - Gr Marais Crk (67)	4,836	2,266	4,075	298	493
Snake River (68)	7,922	15,783	6,688	428	52
Red Riv of the N - Tamarac Riv (69)	8,940	13,843	7,095	423	824
Two Rivers (70)	12,144	51,579	20,564	877	1,007
Roseau River (71)	8,491	67,372	24,770	988	1,906
Rainy River - Headwaters (72)	1,687	11,921	28,010	1,646	216,995
Vermilion River (73)	1,258	4,798	17,635	1,005	81,995
Rainy River - Rainy Lake (74)	1,571	1,876	21,258	654	98,067
Rainy River - Black River (75)	459	19,457	5,021	161	140
Little Fork River (76)	6,354	12,927	24,125	907	27,120

6–Shrub Swamp	7–Wooded Swamp	8–Bogs	Municipal-Industrial	Riverine	Total
2,177	2,674	<1	70	15,672	**45,286**
4,632	2,065	30	105	3,453	**98,534**
1,886	7,370		24	11,401	**43,934**
2,733	4,939	2	45	4,232	**44,240**
523	1,887			2,697	**9,398**
2,275	6,949		22	4,611	**47,451**
656	4,651		3	3,450	**17,196**
268	168		21	220	**4,349**
1			1	2	**22**
737	392		99	1,038	**18,580**
325	362		49	307	**17,981**
37	28		3	89	**3,971**
1,495	1,306		287	2,765	**71,928**
41	119		116	269	**1,495**
126	259		20	174	**8,322**
128	544		658	592	**25,002**
229	344		118	593	**45,411**
21,327	13,305	9,068	228	2,279	**358,938**
442	351		301	1,159	**15,751**
5,443	3,545	925	193	1,391	**112,231**
1,077	2,596		67	1,004	**11,060**
22,210	8,005	11,491	163	2,229	**178,883**
4,424	3,026	36	40	1,342	**40,779**
94,469	68,819	298,159	7,771	3,799	**848,740**
56,868	34,304	7,641	1,026	4,389	**218,707**
132,697	43,222	18,454	13	2,370	**306,382**
46,437	18,342	12,318	11,184	1,775	**202,524**
613	1,193		397	1,110	**15,282**
13,098	6,884	632	526	889	**52,901**
20,283	10,539	193	78	1,482	**63,701**
49,736	19,289	866	86	1,104	**157,253**
107,694	43,179	55,774	158	1,734	**312,067**
47,692	18,774	229,904	101	5,097	**561,826**
26,820	22,824	72,676	1,889	4,626	**235,525**
19,245	29,829	75,272	20	2,059	**249,851**
25,782	27,003	179,356	1	2,864	**260,244**
78,203	54,698	291,103	11,875	6,434	**513,745**

Wetland Acreage by Watershed—Circular 39 Classification (continued)

Watershed	1–Seasonally-Flooded Basin	2–Wet Meadow	3–Shallow Marsh	4–Deep Marsh	5–Shallow Open Water
Big Fork River (77)	6,822	14,755	38,862	1,531	62,533
Rapid River (78)	1,648	57,027	9,504	348	157
Rainy River - Baudette (79)	1,135	12,198	2,377	244	250
Lake of the Woods (80)	1,880	27,147	7,591	569	306,250
Upper Big Sioux River (81)	898	1,043	29	61	4
Lower Big Sioux River (82)	7,575	7,508	1,191	272	211
Rock River (83)	18,995	6,751	3,956	408	881
Little Sioux River (84)	5,385	241	3,150	259	7,744
Total	**1,260,368**	**1,138,065**	**1,383,254**	**80,891**	**3,068,181**

6–Shrub Swamp	7–Wooded Swamp	8–Bogs	Municipal-Industrial	Riverine	Total
90,210	80,616	452,459	40	7,189	**755,016**
127,835	39,269	303,260	479	2,345	**541,873**
49,392	22,688	50,495	51	1,915	**140,745**
80,116	61,643	96,981	11	835	**583,022**
21	10			50	**2,116**
139	91		145	790	**17,922**
377	434		135	1,924	**33,861**
244	113		23	229	**17,389**
2,252,550	**1,187,924**	**3,522,399**	**73,351**	**271,219**	**14,238,203**

Wetland Acreage by County—Plant Community Classification

County	Artificially Flooded	Coniferous Bog	Deep Marsh	Hardwood Wetland	Non-Vegetated Aquatic Community
Aitkin	10,082	151,649	6,458	99,239	110,750
Anoka	102	1,761	1,933	11,120	12,102
Becker	94	14,525	1,135	15,728	85,793
Beltrami	7,023	197,551	12,095	109,095	348,782
Benton	123	189	35	5,572	4,553
Big Stone	127			1,145	28,454
Blue Earth	109			11,506	14,513
Brown	160			5,566	6,868
Carlton	129	45,199	1,504	35,311	11,585
Carver	64	41	235	4,187	13,312
Cass	215	85,448	28,827	40,093	220,609
Chippewa	14			3,542	5,548
Chisago	161	2,609	988	12,247	15,150
Clay	323	2	1	6,471	12,346
Clearwater	7,309	20,002	3,360	19,452	21,205
Cook	16	90,070	2,247	16,911	96,464
Cottonwood	133			1,740	7,143
Crow Wing	377	15,156	11,599	20,970	92,809
Dakota	70	26	113	8,403	12,379
Dodge	12			3,468	1,208
Douglas	150	432	3	5,965	61,540
Faribault	263			5,462	6,528
Fillmore	6			8,222	3,246
Freeborn	74			2,097	12,195
Goodhue	43	12	102	10,303	15,167
Grant	770			1,186	25,213
Hennepin	39	130	263	7,644	31,919
Houston	6			11,213	5,669
Hubbard	124	15,860	9,108	7,093	39,149
Isanti	22	4,578	1,690	16,899	7,639
Itasca	7,229	219,152	18,899	103,946	150,868
Jackson	171			1,359	12,816
Kanabec	42	2,398	987	11,211	7,533
Kandiyohi	125			3,815	43,737
Kittson	129			15,574	3,867
Koochiching	813	639,281	5,966	142,847	38,893
Lac qui Parle	38			3,372	11,841

Open Bog	Seasonally Flooded/ Saturated Emergent Wetland	Shallow Marsh	Shallow Open Water Community	Shrub Wetland	Total
63,923	56,345	36,866	5,396	134,349	**675,056**
401	14,140	28,126	3,777	12,723	**86,185**
4,970	32,754	67,936	6,838	21,526	**251,300**
146,149	137,112	52,788	2,982	241,807	**1,255,385**
109	20,070	5,268	349	7,997	**44,265**
	23,654	14,256	300	602	**68,539**
	11,552	7,061	533	2,197	**47,472**
	10,718	3,446	245	1,695	**28,698**
19,614	10,952	8,937	460	61,135	**194,825**
7	12,175	9,684	1,716	2,021	**43,440**
34,774	96,075	32,690	12,684	82,360	**633,775**
	7,779	4,796	504	1,965	**24,148**
656	17,697	11,419	2,076	10,793	**73,796**
15	22,722	17,874	1,050	4,419	**65,223**
7,634	57,133	28,524	1,394	59,277	**225,290**
12,596	7,420	9,172	956	26,468	**262,321**
	10,652	3,784	353	568	**24,373**
13,320	36,849	20,233	4,815	39,399	**255,526**
	7,807	5,849	1,907	2,201	**38,754**
	5,248	230	42	1,263	**11,471**
298	19,338	31,533	1,793	5,087	**126,139**
	10,977	4,034	211	823	**28,298**
	10,179	469	26	1,061	**23,209**
	14,437	5,748	577	736	**35,864**
2	4,457	3,769	611	2,020	**36,486**
2	10,114	11,720	366	337	**49,708**
42	12,763	20,334	4,784	2,373	**80,289**
	7,241	7,507	2,793	1,956	**36,386**
4,251	21,174	11,183	4,447	23,231	**135,620**
819	18,997	17,149	2,354	17,756	**87,902**
48,477	27,068	58,117	18,822	124,315	**776,892**
	10,634	7,243	551	871	**33,644**
2,158	26,560	6,980	1,331	25,422	**84,623**
	22,863	21,876	2,290	3,429	**98,135**
	45,317	23,174	4	34,302	**122,367**
276,257	45,685	44,432	679	158,744	**1,353,598**
	25,649	13,957	528	1,314	**56,700**

Wetland Acreage by County—Plant Community Classification (continued)

County	Artificially Flooded	Coniferous Bog	Deep Marsh	Hardwood Wetland	Non-Vegetated Aquatic Community
Lake	1,668	199,914	5,117	39,671	114,026
Lake of the Woods	542	143,070	487	99,596	309,187
Le Sueur	284		88	6,459	17,144
Lincoln	69			1,202	10,322
Lyon	145			3,342	8,093
Mahnomen	78	1,283		3,510	19,543
Marshall	601	4,335		41,855	14,838
Martin	92			3,009	14,828
McLeod	156			3,591	10,246
Meeker	54	25	29	7,096	24,785
Mille Lacs	220	4,546	2,462	16,962	68,636
Morrison	142	5,398	2,314	15,311	17,649
Mower	117			4,146	1,770
Murray	126			1,149	11,629
Nicollet	58			6,424	7,298
Nobles	203			329	6,231
Norman	110			8,694	3,142
Olmsted	13			8,679	3,395
Otter Tail	268	5,535	280	21,755	184,121
Pennington	872	1		9,731	1,740
Pine	295	36,096	1,478	37,016	20,934
Pipestone	139			118	1,303
Polk	4,104	777	18	18,030	23,947
Pope	229	150	58	4,000	39,268
Ramsey	54	13	150	1,581	9,684
Red Lake	314			6,973	2,159
Redwood	139			4,061	3,752
Renville	283			3,551	5,169
Rice	17	18	665	2,244	12,481
Rock	63			806	1,881
Roseau	194	28,782	146	67,425	5,366
Scott	174	1	625	6,819	9,107
Sherburne	83	610	1,225	11,748	10,601
Sibley	265			4,348	8,052
St. Louis	22,675	555,595	21,222	162,993	323,486
Stearns	578	2,622	376	15,186	31,622
Steele	22			2,440	2,297
Stevens	234			1,094	13,597

Open Bog	Seasonally Flooded/ Saturated Emergent Wetland	Shallow Marsh	Shallow Open Water Community	Shrub Wetland	Total
35,166	12,890	20,250	3,565	49,595	**481,862**
133,659	66,016	14,029	104	192,305	**958,995**
	16,066	9,894	1,057	1,910	**52,900**
	22,476	6,420	205	351	**41,045**
	15,330	6,902	128	679	**34,617**
1,682	18,638	33,199	623	7,608	**86,164**
2,844	64,740	38,033	259	78,463	**245,967**
	8,135	3,365	433	664	**30,525**
	13,706	6,315	355	867	**35,235**
5	20,363	17,042	863	3,100	**73,362**
3,897	35,405	9,231	559	34,278	**176,196**
4,540	69,680	23,647	3,008	43,583	**185,272**
	7,146	526	56	553	**14,313**
	18,017	7,585	330	451	**39,285**
	5,940	10,831	356	3,556	**34,463**
	16,459	3,223	148	234	**26,827**
	11,024	7,455	185	3,422	**34,031**
	10,575	600	45	966	**24,273**
1,956	43,345	94,168	7,261	42,049	**400,738**
	19,109	4,573	20	8,027	**44,072**
18,200	62,038	19,422	1,710	92,144	**289,334**
	16,726	1,570	6	112	**19,973**
382	47,010	34,756	1,312	21,771	**152,108**
101	18,521	30,704	804	3,511	**97,347**
4	1,351	3,627	948	1,145	**18,558**
	7,382	1,304	4	3,962	**22,099**
	8,447	2,601	139	1,325	**20,463**
	7,943	3,643	253	2,108	**22,949**
	11,481	10,295	1,805	1,725	**40,730**
	11,456	2,022	22	240	**16,490**
24,042	105,163	26,530	101	136,259	**394,008**
7	12,638	10,380	2,183	2,507	**44,440**
148	12,890	16,671	1,921	9,860	**65,758**
	10,671	6,319	284	1,332	**31,271**
153,579	47,040	90,028	5,335	280,624	**1,662,579**
373	52,120	29,729	7,100	16,700	**0.3125 in**
	9,403	2,036	232	1,086	**17,516**
2	13,028	9,980	184	349	**38,469**

Wetland Acreage by County—Plant Community Classification (continued)

County	Artificially Flooded	Coniferous Bog	Deep Marsh	Hardwood Wetland	Non-Vegetated Aquatic Community
Swift	30			3,823	8,885
Todd	322	2,996	2,155	12,945	20,232
Traverse	36			1,022	11,391
Wabasha	16			9,661	12,953
Wadena	75	4,728	978	10,662	4,407
Waseca	2			2,956	6,477
Washington	18	388	322	3,040	22,126
Watonwan	92			2,920	4,190
Wilkin	141			1,459	2,339
Winona	16			9,076	8,637
Wright	98	123	613	10,431	35,837
Yellow Medicine	142			3,752	5,738
Total	**73,351**	**2,503,073**	**148,358**	**1,514,668**	**3,115,934**

Open Bog	Seasonally Flooded/ Saturated Emergent Wetland	Shallow Marsh	Shallow Open Water Community	Shrub Wetland	Total
	20,754	9,201	131	1,982	**44,806**
1,423	46,729	28,761	4,446	33,668	**153,677**
	6,891	5,379	176	139	**25,033**
	4,209	3,805	3,842	1,301	**35,787**
612	24,670	7,142	472	37,386	**91,132**
	10,295	4,488	368	759	**25,345**
224	6,501	8,472	3,001	2,883	**46,974**
	4,128	2,137	126	224	**13,818**
	18,892	6,083	95	758	**29,766**
	5,741	2,831	1,976	1,079	**29,355**
42	23,204	24,802	5,379	3,808	**104,337**
	17,003	4,765	394	601	**32,394**
1,019,361	**2,071,691**	**1,384,929**	**154,850**	**2,252,550**	**14,238,764**

Wetland Acreage by Watershed—Plant Community Classification

Watershed	Artificially Flooded	Coniferous Bog	Deep Marsh	Hardwood Wetland	Non-Vegetated Aquatic Community
Lake Superior - North (1)	16	106,696	2,751	19,885	64,342
Lake Superior - South (2)	1,673	19,394	17	28,614	4,358
St. Louis River (3)	4,613	325,909	6,544	88,882	54,384
Cloquet River (4)		73,386	2,870	21,227	29,475
Nemadji River (5)		10,557		11,943	3,582
Mississippi Riv - Headwaters (7)	877	92,401	22,387	34,334	152,647
Leech Lake River (8)	104	56,030	16,477	21,637	154,310
Mississippi Riv - Grand Rapids (9)	14,736	149,991	8,452	82,625	67,098
Mississippi Riv - Brainerd (10)	6,362	43,746	9,817	50,338	58,601
Pine River (11)	37	19,127	9,066	12,166	53,153
Crow Wing River (12)	249	21,206	11,905	19,969	76,124
Redeye River (13)	95	5,550	31	19,734	10,197
Long Prairie River (14)	280	2,430	1,551	12,226	43,779
Mississippi Riv - Sartell (15)	279	3,814	2,142	14,603	17,208
Sauk River (16)	255	845	497	6,803	31,529
Mississippi Riv - St. Cloud (17)	245	950	1,298	20,344	27,538
North Fork Crow River (18)	396	169	462	18,424	65,250
South Fork Crow River (19)	232	105	89	7,553	33,191
Mississippi Riv - Twin Cities (20)	157	610	639	12,373	56,300
Rum River (21)	286	11,970	5,210	43,416	149,091
Minnesota Riv - Headwaters (22)	112			2,499	37,749
Pomme de Terre River (23)	249			2,998	55,022
Lac Qui Parle River (24)	113			3,115	6,154
Minn River - Yellow Med Riv (25)	440			9,735	21,921
Chippewa River (26)	373	25	58	10,246	83,503
Redwood River (27)	72			2,333	8,964
Minnesota River - Mankato (28)	358			16,084	19,210
Cottonwood River (29)	319			5,882	8,678
Blue Earth River (30)	173			10,124	16,059
Watonwan River (31)	164			4,620	9,354
Le Sueur River (32)	279			8,265	17,612
Lower Minnesota River (33)	530	13	1,136	21,240	35,725
Upper St. Croix River (34)	13	17,538	425	16,699	4,592
Kettle River (35)	270	38,834	1,330	32,691	16,354
Snake River (36)	179	19,252	1,352	29,681	12,268
Lower St. Croix River (37)	171	4,778	2,586	19,919	33,273

Open Bog	Seasonally Flooded/ Saturated Emergent Wetland	Shallow Marsh	Shallow Open Water Community	Shrub Wetland	Total
11,363	7,794	8,485	770	26,695	**248,796**
2,567	3,645	3,902	397	14,525	**79,093**
107,806	22,089	32,690	1,601	172,806	**817,324**
8,648	4,591	9,739	610	33,055	**183,601**
2,861	2,055	2,951	61	15,884	**49,894**
23,486	41,498	38,492	13,066	67,555	**486,743**
22,541	47,046	17,264	3,945	32,013	**371,367**
61,221	38,403	34,439	9,351	123,455	**589,770**
19,195	67,855	34,820	6,608	83,189	**380,533**
13,208	23,175	11,128	3,750	24,775	**169,584**
8,281	71,210	33,759	8,807	77,515	**329,025**
1,632	38,889	25,550	2,166	46,788	**150,632**
1,825	36,412	31,235	2,799	23,737	**156,273**
1,836	54,079	23,772	2,797	28,854	**149,384**
286	34,007	26,564	5,098	11,375	**117,260**
235	39,557	34,576	5,393	20,074	**150,210**
21	56,658	46,345	6,123	11,410	**205,258**
8	30,442	20,133	1,486	2,430	**95,669**
244	18,237	32,333	7,270	8,410	**136,572**
6,039	73,154	35,465	4,754	63,047	**392,433**
	33,667	22,995	623	2,123	**99,769**
4	17,766	23,746	699	1,518	**102,003**
	25,686	9,232	279	660	**45,239**
	36,857	15,599	1,155	3,133	**88,838**
35	48,098	58,119	2,367	5,050	**207,873**
	14,598	5,949	126	652	**32,693**
	19,249	17,112	1,090	7,890	**80,992**
	19,370	6,855	431	772	**42,307**
	15,366	4,880	366	1,617	**48,585**
	9,738	4,437	315	524	**29,152**
	18,363	10,255	710	1,446	**56,930**
39	43,250	32,326	6,368	7,284	**147,909**
6,612	17,743	9,259	691	41,012	**114,583**
19,417	33,167	10,553	1,107	70,921	**224,646**
9,373	53,491	13,181	1,671	58,124	**198,573**
1,195	31,133	28,407	4,719	21,072	**147,253**

Wetland Acreage by Watershed—Plant Community Classification (continued)

Watershed	Artificially Flooded	Coniferous Bog	Deep Marsh	Hardwood Wetland	Non-Vegetated Aquatic Community
Mississippi Riv - Lake Pepin (38)	70		198	10,434	21,330
Cannon River (39)	105	30	666	11,553	27,978
Mississippi Riv - Winona (40)	24			12,273	11,346
Zumbro River (41)	45			16,044	7,613
Mississippi Riv - La Crescent (42)				2,141	2,806
Root River (43)	22			16,186	6,041
Mississippi River - Reno (44)	3			5,115	3,154
Upper Iowa River (46)	21			722	401
Upper Wapsipinicon River (47)	1				3
Cedar River (48)	99			4,019	3,342
Shell Rock River (49)	49			1,137	5,946
Winnebago River (50)	3			206	1,805
Des Moines Riv - Headwaters (51)	287			2,495	24,242
Lower Des Moines River (52)	116			323	373
East Fork Des Moines Riv (53)	20			497	4,362
Bois de Sioux River (54)	658			898	10,824
Mustinka River (55)	118			1,038	17,719
Otter Tail River (56)	228	7,093	986	16,274	191,427
Upper Red Riv of the North (57)	301			1,334	2,084
Buffalo River (58)	193	689	18	6,490	29,034
Red Riv of the N - Marsh Riv (59)	67			3,608	1,353
Wild Rice River (60)	163	7,077	2,808	12,166	34,242
Red Riv of the N - Sandhill Riv (61)	40	1		5,085	9,392
Upper/Lower Red Lake (62)	7,771	222,724	2,018	71,887	302,922
Red Lake River (63)	1,026	5,749	44	38,637	7,674
Thief River (65)	13	7,761	117	44,273	13,290
Clearwater River (66)	11,184	10,178	843	22,751	22,076
Red Riv of the N - Gr Marais Crk (67)	397			1,680	1,906
Snake River (68)	526	345		8,641	1,355
Red Riv of the N - Tamarac Riv (69)	78	172		12,328	2,724
Two Rivers (70)	86	816		22,297	2,986
Roseau River (71)	158	31,110	88	45,595	4,150
Rainy River - Headwaters (72)	101	184,190	6,288	19,707	213,170
Vermilion River (73)	1,889	60,293	5,020	23,397	81,704
Rainy River - Rainy Lake (74)	20	62,389	1,998	31,176	97,995
Rainy River - Black River (75)	1	97,101		27,378	3,156
Little Fork River (76)	11,875	233,022	10,039	57,887	22,875

Open Bog	Seasonally Flooded/ Saturated Emergent Wetland	Shallow Marsh	Shallow Open Water Community	Shrub Wetland	Total
	5,207	4,754	1,117	2,177	**45,286**
	30,982	19,876	2,712	4,632	**98,534**
	6,809	5,990	5,606	1,886	**43,934**
2	16,185	1,445	175	2,733	**44,240**
	772	2,189	967	523	**9,398**
	21,207	1,587	132	2,275	**47,451**
	1,813	4,585	1,871	656	**17,196**
	2,855	72	10	268	**4,349**
	17			1	**22**
	8,310	1,973	100	737	**18,580**
	7,064	3,056	404	325	**17,981**
	1,283	607	29	37	**3,971**
	29,324	13,382	704	1,495	**71,928**
	542	93	7	41	**1,495**
	2,163	986	167	126	**8,322**
	6,595	5,513	386	128	**25,002**
	15,216	10,689	401	229	**45,411**
1,975	25,960	86,200	7,469	21,327	**358,938**
	8,398	3,126	67	442	**15,751**
236	32,961	33,652	3,514	5,443	**112,231**
	2,562	2,261	132	1,077	**11,060**
4,414	39,980	54,286	1,538	22,210	**178,883**
35	10,101	11,261	442	4,424	**40,779**
75,435	32,878	37,312	1,325	94,469	**848,740**
1,892	89,235	17,339	244	56,868	**218,707**
10,693	67,323	29,972	243	132,697	**306,382**
2,140	55,895	29,469	1,549	46,437	**202,524**
	6,614	4,070	1	613	**15,282**
287	21,947	6,688	14	13,098	**52,901**
21	20,994	7,093	7	20,283	**63,701**
50	60,715	20,564	2	49,736	**157,253**
24,665	73,447	25,057	103	107,694	**312,067**
45,714	12,674	28,010	4,280	47,692	**561,826**
12,383	5,483	17,635	901	26,820	**235,525**
12,883	2,101	21,258	787	19,245	**249,851**
82,254	19,541	5,021	10	25,782	**260,244**
58,081	16,092	24,125	1,547	78,203	**513,745**

Wetland Acreage by Watershed—Plant Community Classification (continued)

Watershed	Artificially Flooded	Coniferous Bog	Deep Marsh	Hardwood Wetland	Non-Vegetated Aquatic Community
Big Fork River (77)	40	349,277	7,587	85,524	57,755
Rapid River (78)	479	117,687		40,472	2,829
Rainy River - Baudette (79)	51	25,839		23,559	1,982
Lake of the Woods (80)	11	54,170	544	62,917	306,899
Upper Big Sioux River (81)				14	114
Lower Big Sioux River (82)	145			126	1,269
Rock River (83)	135			964	3,191
Little Sioux River (84)	23			192	7,979
Total	**73,351**	**2,503,038**	**148,358**	**1,514,667**	**3,115,409**

Open Bog	Seasonally Flooded/ Saturated Emergent Wetland	Shallow Marsh	Shallow Open Water Community	Shrub Wetland	Total
103,183	16,668	38,862	5,910	90,210	**755,016**
185,572	57,472	9,503	22	127,835	**541,873**
24,657	12,461	2,766	38	49,392	**140,745**
42,810	27,753	7,739	63	80,116	**583,022**
	1,938	29	1	21	**2,116**
	15,049	1,190	4	139	**17,922**
	25,215	3,950	29	377	**33,861**
	5,548	3,150	253	244	**17,389**
1,019,361	**2,071,691**	**1,384,929**	**154,850**	**2,252,550**	**14,238,203**

Wetland Acreage by County—Hydrogeomorphic Classification

County	Depression	Lentic	Lotic	Mineral Flat	Peatland	Slope	Total
Aitkin	43,856	113,776	47,388	250,777	215,783	3,477	**675,056**
Anoka	28,335	23,485	8,570	22,436	1,213	2,147	**86,185**
Becker	67,827	97,214	10,029	53,732	19,495	3,002	**251,300**
Beltrami	46,762	382,348	29,313	446,574	346,097	4,290	**1,255,385**
Benton	5,805	1,761	13,225	23,072	298	105	**44,265**
Big Stone	11,457	19,037	16,672	20,198		1,175	**68,539**
Blue Earth	6,432	10,950	18,181	10,546		1,362	**47,472**
Brown	2,881	5,258	12,553	6,581		1,425	**28,698**
Carlton	17,409	8,984	17,847	82,158	64,788	3,640	**194,825**
Carver	10,334	14,653	10,853	6,591	36	974	**43,440**
Cass	34,875	268,271	40,240	163,923	119,489	6,978	**633,775**
Chippewa	3,657	812	11,840	7,395		444	**24,148**
Chisago	17,302	18,130	13,836	20,727	1,570	2,230	**73,796**
Clay	22,153	7,542	8,727	25,507	17	1,277	**65,223**
Clearwater	30,017	36,235	7,855	116,502	27,721	6,959	**225,290**
Cook	19,590	88,504	8,888	31,709	102,574	11,057	**262,321**
Cottonwood	2,562	6,362	8,880	4,471		2,098	**24,373**
Crow Wing	20,596	107,030	24,186	56,609	28,423	18,684	**255,526**
Dakota	7,947	3,568	19,844	5,738	14	1,644	**38,754**
Dodge	589	118	5,530	1,666		3,567	**11,471**
Douglas	33,393	62,718	3,919	24,577	730	801	**126,139**
Faribault	2,577	5,576	10,973	8,666		506	**28,298**
Fillmore	993	45	12,557	1,419		8,195	**23,209**
Freeborn	4,337	13,659	4,546	11,648		1,673	**35,864**
Goodhue	2,379	917	29,569	1,605	3	2,013	**36,486**
Grant	9,510	26,137	4,924	8,701	2	436	**49,708**
Hennepin	19,482	31,839	14,180	12,138	139	2,511	**80,289**
Houston	1,357	69	27,678	2,471		4,810	**36,386**
Hubbard	16,179	49,289	12,473	34,455	19,745	3,479	**135,620**
Isanti	20,811	11,330	12,306	36,318	3,127	4,011	**87,902**
Itasca	63,931	189,055	53,264	201,192	267,159	2,291	**776,892**
Jackson	4,078	13,815	9,056	5,774		921	**33,644**
Kanabec	10,003	6,218	13,382	49,536	4,556	928	**84,623**
Kandiyohi	18,883	48,241	5,781	23,582		1,647	**98,135**
Kittson	24,586	2,964	8,225	85,448		1,144	**122,367**
Koochiching	61,225	30,223	36,095	305,417	915,592	5,047	**1,353,598**
Lac qui Parle	7,263	3,479	25,825	18,764		1,369	**56,700**

Wetland Acreage by County—Hydrogeomorphic Classification (continued)

County	Depression	Lentic	Lotic	Mineral Flat	Peatland	Slope	Total
Lake	31,281	113,707	15,263	75,745	234,820	11,045	**481,862**
Lake of the Woods	7,850	308,311	12,167	349,196	276,733	4,738	**958,995**
Le Sueur	8,583	18,380	11,727	11,459		2,752	**52,900**
Lincoln	6,091	9,851	6,083	11,670		7,350	**41,045**
Lyon	6,411	6,791	9,633	8,050		3,731	**34,617**
Mahnomen	30,044	22,617	6,848	20,501	2,965	3,190	**86,164**
Marshall	20,267	38,253	8,255	170,805	7,179	1,208	**245,967**
Martin	3,477	13,974	7,540	5,103		430	**30,525**
McLeod	5,130	11,393	7,344	11,045		323	**35,235**
Meeker	10,349	29,600	12,649	18,317	18	2,429	**73,362**
Mille Lacs	9,590	70,298	14,994	72,300	8,426	588	**176,196**
Morrison	28,604	13,775	27,645	104,892	9,927	429	**185,272**
Mower	986	273	9,363	2,032		1,658	**14,313**
Murray	5,857	11,087	12,030	7,980		2,332	**39,285**
Nicollet	2,684	14,339	11,391	5,313		737	**34,463**
Nobles	2,664	5,273	9,609	6,711		2,571	**26,827**
Norman	8,368	679	7,484	16,860		640	**34,031**
Olmsted	1,183	1,248	9,424	1,225		11,193	**24,273**
Otter Tail	99,559	186,354	15,226	89,332	7,491	2,775	**400,738**
Pennington	5,251	451	2,370	35,118	1	881	**44,072**
Pine	24,333	12,139	49,981	144,906	54,319	3,656	**289,334**
Pipestone	1,365	136	8,787	1,800		7,886	**19,973**
Polk	38,477	20,856	15,483	73,768	1,159	2,364	**152,108**
Pope	27,838	40,905	8,712	15,494	251	4,148	**97,347**
Ramsey	4,960	8,243	3,860	1,282	16	197	**18,558**
Red Lake	1,962	374	5,470	13,955		338	**22,099**
Redwood	3,201	1,466	8,287	6,511		998	**20,463**
Renville	3,746	2,773	9,230	6,577		623	**22,949**
Rice	13,587	13,727	5,210	6,128	3	2,076	**40,730**
Rock	1,296	114	9,397	2,300		3,383	**16,490**
Roseau	16,532	19,956	10,956	290,176	52,824	3,565	**394,008**
Scott	10,157	9,679	15,057	7,517	8	2,022	**44,440**
Sherburne	19,080	11,743	12,837	19,913	502	1,684	**65,758**
Sibley	2,493	9,680	10,592	8,237		270	**31,271**
St. Louis	124,112	330,048	92,313	391,701	709,276	15,129	**1,662,579**
Stearns	28,203	33,357	41,836	48,035	2,983	1,990	**156,405**
Steele	2,304	1,647	5,803	6,653		1,109	**17,516**
Stevens	8,791	13,315	3,718	12,125	2	518	**38,469**

Wetland Acreage by County—Hydrogeomorphic Classification (continued)

County	Depression	Lentic	Lotic	Mineral Flat	Peatland	Slope	Total
Swift	6,757	7,265	12,483	17,129		1,172	**44,806**
Todd	28,905	25,763	25,572	68,662	4,409	366	**153,677**
Traverse	4,185	4,794	10,164	5,551		338	**25,033**
Wabasha	3,199	355	27,798	1,640		2,795	**35,787**
Wadena	8,065	3,228	16,680	57,484	5,339	336	**91,132**
Waseca	2,626	7,719	6,474	8,082		443	**25,345**
Washington	12,945	14,810	11,587	5,834	391	1,407	**46,974**
Watonwan	1,748	3,452	5,707	2,830		81	**13,818**
Wilkin	5,553	223	6,098	17,638		253	**29,766**
Winona	980	130	22,496	890		4,859	**29,355**
Wright	25,720	40,576	12,683	21,102	160	4,096	**104,337**
Yellow Medicine	3,522	3,752	11,394	11,056		2,669	**32,394**
Total	**1,432,244**	**3,228,490**	**1,322,919**	**4,487,252**	**3,517,770**	**250,089**	**14,238,764**

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Wetland Acreage by Watershed—Hydrogeomorphic Classification

Watershed	Depression	Lentic	Lotic
Lake Superior - North (1)	16,557	58,233	10,589
Lake Superior - South (2)	7,384	3,397	4,767
St. Louis River (3)	49,503	47,676	47,059
Cloquet River (4)	13,354	29,708	11,257
Nemadji River (5)	9,596	1,818	5,794
Mississippi Riv - Headwaters (7)	33,723	192,965	31,253
Leech Lake River (8)	19,359	185,897	14,492
Mississippi Riv - Grand Rapids (9)	44,377	85,430	48,813
Mississippi Riv - Brainerd (10)	37,708	65,880	41,439
Pine River (11)	13,345	61,582	13,715
Crow Wing River (12)	37,449	90,023	35,162
Redeye River (13)	27,647	10,443	15,525
Long Prairie River (14)	32,749	46,715	16,677
Mississippi Riv - Sartell (15)	26,865	15,710	29,742
Sauk River (16)	23,907	34,823	26,647
Mississippi Riv - St. Cloud (17)	37,473	28,827	30,510
North Fork Crow River (18)	38,219	75,503	32,543
South Fork Crow River (19)	16,367	38,704	13,897
Mississippi Riv - Twin Cities (20)	34,562	53,152	24,178
Rum River (21)	40,980	155,516	34,110
Minnesota Riv - Headwaters (22)	16,177	17,208	37,213
Pomme de Terre River (23)	23,918	53,079	7,658
Lac Qui Parle River (24)	6,297	4,765	14,596
Minn River - Yellow Med Riv (25)	14,447	16,055	24,402
Chippewa River (26)	53,275	84,290	21,513
Redwood River (27)	5,325	7,920	7,732
Minnesota River - Mankato (28)	8,015	24,242	30,529
Cottonwood River (29)	6,184	6,532	15,361
Blue Earth River (30)	4,715	11,642	20,200
Watonwan River (31)	3,379	8,767	9,850
Le Sueur River (32)	6,815	18,804	15,643
Lower Minnesota River (33)	29,510	34,742	51,501
Upper St. Croix River (34)	10,147	1,174	22,749
Kettle River (35)	13,570	11,551	26,132
Snake River (36)	17,282	9,076	26,190
Lower St. Croix River (37)	39,470	37,147	24,040

Mineral Flat	Peatland	Slope	Total
35,265	117,931	10,221	**248,796**
35,805	21,964	5,775	**79,093**
232,602	433,873	6,611	**817,324**
45,926	82,023	1,334	**183,601**
18,660	13,422	604	**49,894**
108,020	115,251	5,529	**486,743**
70,174	77,960	3,485	**371,367**
197,526	211,263	2,361	**589,770**
160,739	63,060	11,707	**380,533**
40,376	32,252	8,314	**169,584**
131,934	29,107	5,350	**329,025**
88,659	7,182	1,176	**150,632**
55,029	4,256	848	**156,273**
69,878	5,645	1,543	**149,384**
30,194	1,121	567	**117,260**
49,189	952	3,260	**150,210**
52,191	186	6,616	**205,258**
24,985	111	1,607	**95,669**
21,459	460	2,760	**136,572**
138,402	16,307	7,117	**392,433**
27,074		2,097	**99,769**
16,190	4	1,154	**102,003**
16,531		3,052	**45,239**
27,736		6,198	**88,838**
42,675	60	6,060	**207,873**
8,731		2,986	**32,693**
14,841		3,365	**80,992**
10,563		3,667	**42,307**
11,145		882	**48,585**
6,405		751	**29,152**
14,572		1,096	**56,930**
27,893	45	4,219	**147,909**
55,272	24,165	1,076	**114,583**
111,335	58,259	3,799	**224,646**
115,443	28,582	1,999	**198,573**
39,708	2,879	4,009	**147,253**

Wetland Acreage by Watershed—Hydrogeomorphic Classification (continued)

County	Depression	Lentic	Lotic
Zumbro River (41)	3,683	2,358	21,267
Mississippi Riv - La Crescent (42)	95		8,771
Root River (43)	2,485	77	23,983
Mississippi River - Reno (44)	250	37	15,393
Upper Iowa River (46)	218	47	2,470
Upper Wapsipinicon River (47)	2		15
Cedar River (48)	1,756	2,585	8,347
Shell Rock River (49)	2,684	6,591	1,865
Winnebago River (50)	299	2,172	541
Des Moines Riv - Headwaters (51)	9,546	23,795	20,431
Lower Des Moines River (52)	221	118	719
East Fork Des Moines Riv (53)	936	4,509	1,358
Bois de Sioux River (54)	4,038	4,423	9,919
Mustinka River (55)	8,556	18,714	4,816
Otter Tail River (56)	89,439	197,897	12,412
Upper Red Riv of the North (57)	3,462	575	3,398
Buffalo River (58)	38,162	28,290	9,081
Red Riv of the N - Marsh Riv (59)	2,580	500	2,178
Wild Rice River (60)	51,756	39,082	14,843
Red Riv of the N - Sandhill Riv (61)	12,145	7,701	6,478
Upper/Lower Red Lake (62)	36,565	307,888	21,147
Red Lake River (63)	17,117	20,930	9,211
Thief River (65)	12,965	43,924	3,134
Clearwater River (66)	32,131	29,136	12,787
Red Riv of the N - Gr Marais Crk (67)	3,680	585	3,189
Snake River (68)	6,882	621	3,616
Red Riv of the N - Tamarac Riv (69)	6,922	1,877	5,016
Two Rivers (70)	21,333	3,677	4,983
Roseau River (71)	15,063	18,939	9,197
Rainy River - Headwaters (72)	41,066	209,021	15,644
Vermilion River (73)	22,337	81,298	15,150
Rainy River - Rainy Lake (74)	24,886	100,574	9,838
Rainy River - Black River (75)	2,635	<1	5,258
Little Fork River (76)	40,635	32,753	22,847

Mineral Flat	Peatland	Slope	Total
4,305	2	12,626	**44,240**
58		474	**9,398**
3,900		17,006	**47,451**
357		1,158	**17,196**
522		1,092	**4,349**
4		1	**22**
5,141		750	**18,580**
5,673		1,167	**17,981**
911		47	**3,971**
14,788		3,369	**71,928**
353		85	**1,495**
1,476		43	**8,322**
6,355		268	**25,002**
13,097		228	**45,411**
47,443	9,068	2,679	**358,938**
8,197		119	**15,751**
34,310	925	1,464	**112,231**
5,585		218	**11,060**
56,062	11,491	5,649	**178,883**
13,578	36	841	**40,779**
182,295	298,239	2,606	**848,740**
162,019	7,741	1,689	**218,707**
225,998	20,096	266	**306,382**
111,742	12,315	4,414	**202,524**
7,649		180	**15,282**
40,538	632	611	**52,901**
48,972	193	722	**63,701**
125,400	866	994	**157,253**
209,972	55,774	3,121	**312,067**
56,375	229,666	10,053	**561,826**
41,742	72,663	2,335	**235,525**
37,486	75,283	1,784	**249,851**
70,009	179,356	2,986	**260,244**
125,017	291,106	1,388	**513,745**

Wetland Acreage by Watershed—Hydrogeomorphic Classification (continued)

County	**Depression**	**Lentic**	**Lotic**
Big Fork River (77)	48,417	61,171	30,821
Rapid River (78)	6,949	20	8,386
Rainy River - Baudette (79)	1,159	300	4,359
Lake of the Woods (80)	5,380	308,573	4,116
Upper Big Sioux River (81)	94		854
Lower Big Sioux River (82)	960	136	7,170
Rock River (83)	2,733	477	19,292
Little Sioux River (84)	2,206	8,219	3,411
Total	**1,432,244**	**3,227,966**	**1,322,919**

Mineral Flat	Peatland	Slope	Total
160,530	452,443	1,635	**755,016**
221,488	304,040	988	**541,873**
83,427	50,495	1,004	**140,745**
164,766	96,981	3,206	**583,022**
98		1,071	**2,116**
1,993		7,663	**17,922**
4,522		6,838	**33,861**
3,290		264	**17,389**
4,487,250	**3,517,734**	**250,089**	**14,238,203**

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DEPARTMENT OF NATURAL RESOURCES

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651-296-6157 or 888 -MINNDNR (646-6367)
www.mndnr.gov

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ATTACHMENT D

2019

Minnesota Wetland Inventory: Wetland Functional Assessment Final Report & Guidance Handbook

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For comments and questions about this document, please contact:
Steve Kloiber
DNR Wetland Monitoring Coordinator
651-259-5164
steve.kloiber@state.mn.us.

Jason Ulrich
Scientist
St. Croix Watershed Research Station
Science Museum of Minnesota
651-433-5953
julrich@smm.org

[1] St. Croix Watershed Research Station, Science Museum of Minnesota, 16910 152nd St N, Marine on St Croix, MN.
[2] Minnesota Department of Natural Resources, St. Paul, MN.

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1 PURPOSE OF THIS DOCUMENT

The Minnesota Department of Natural Resources (MN-DNR) with funding from the Environment and Natural Resources Trust Fund commissioned an update of the National Wetland Inventory (NWI) resulting in the Minnesota Wetland Inventory. Project oversight, coordination, and quality control of the NWI update were provided by the DNR. Ducks Unlimited provided mapping services for east-central, northeast, and central Minnesota. St. Mary's University of Minnesota provided wetland mapping services for southern and northwestern Minnesota. More detailed information on the Minnesota Wetland Inventory, its development, and key enhancements is provided in Kloiber et al. (2019; https://files.dnr.state.mn.us/eco/wetlands/nwi-user-guide.pdf and https://www.dnr.state.mn.us/eco/wetlands/nwi_proj.html).

The updated NWI for Minnesota has mapped and identified the diversity of wetland types with much improved accuracy. These improvements make the updated NWI extremely valuable to resource managers. During the planning phase of the NWI update, surveys of potential data users identified landscape level wetland functional assessment as an important application. As a result, the NWI update project included enhanced wetland classification attributes that describe hydrogeomorphic characteristics that are often related to wetland function. Nonetheless, these functional assessments are often limited to qualitative evaluations based on best professional judgment.

This project was designed to demonstrate how to use the updated and enhanced NWI as the foundation for conducting watershed-based preliminary functional assessments of Minnesota wetlands. Furthermore, this project seeks to extend previous landscape level wetland functional assessments by incorporating terrain analysis of LiDAR data and other supporting data. This semi-quantitative level of assessment is meant to highlight higher functioning wetlands at watershed scales of management interest, and serve as a precursor to more rigorous in-field evaluations of individual wetland function.

This document proposes several different functional assessment approaches that construct semi-quantitative metrics of wetland function. A metric as defined in this project is a numerical index proportional to the degree of wetland functioning. Example metric datasets are presented for a selection of watersheds totaling over 2 million acres in southern Minnesota. We describe the GIS workflows and scripting methodologies used to build these datasets, which are available on the web (provide URL when available). This report also discusses several approaches for defining metrics based on the desired endpoint of the user as well as several possible alternative GIS/analytical methods for generating any one metric. Throughout the document, we reference existing GIS-based toolsets and functional assessment methodologies that were either used directly or adapted for use in the project, or that provide complementary alternatives for reproducing the data and results presented here.

2 INTRODUCTION

2.1 BACKGROUND

Wetlands provide multiple ecosystem services through their physical, chemical, and biotic functioning. Physically, they can attenuate peak flows, reduce total flows by promoting evapotranspiration, and generate groundwater recharge in some settings. Wetlands improve water quality by trapping suspended sediment, assimilating or adsorbing phosphorus, and removing nitrate by denitrification. In fact, our ability to address nonpoint-source pollution -- arguably the single largest cause of water-quality impairments in Minnesota today -- has been limited by our lack of understanding of how overland flow paths are intercepted by wetlands and how they treat the incoming runoff. Biologically, wetlands provide habitat for fish, wildlife and native plants, including rare species. In particular, wetlands promote biodiversity in agricultural regions dominated by monocultures of row crops where most wetlands have been already lost by drainage.

Because of differences in geometry, topographic setting, hydrology, and vegetation, wetlands are highly diverse and have different capacities for performing these ecosystem services. We believe that there is an overarching landscape-scale knowledge gap in our understanding of wetland physico-chemical hydrologic functioning: How is the functioning of a given wetland affected by any upstream wetlands connected to it by ephemeral overland flowpaths? How do these networks of connected wetlands that fill with runoff and, if they exceed their storage volume, spill over into the next downstream wetland behave in sum at different watershed scales? Understanding the importance and dynamics of connected wetlands using a “fill-and-spill” concept has been the subject of much research (e.g., Shaw et al. 2012; Spence 2007; Shook et al. 2013; Spence et al. 2010; Pomeroy et al. 2014; Cohen et al. 2016) but with little consensus about the aggregate impact of network connectivity on wetland function. The primary aim of this project is to demonstrate the value of the newly updated NWI through an example project that implements terrain analysis and a hydrological fill-and-spill based approach to quantify aggregate landscape-scale wetland function in light of network connectivity.

2.2 SIMPLIFIED HYDROGEOMORPHIC CLASSIFICATION

A key enhancement of the updated NWI was development of the *simplified hydrogeomorphic* classification attributes (SHGM). The SHGM for Minnesota’s NWI is a modification of that developed by R. Tiner (2014) for the northeastern United States over the last 15+ years. Tiner’s SHGM methodology is based on the more detailed hydrogeomorphic (HGM) assessment process developed by M. Brinson (1993) for the US Army Corps of Engineers in the 1990s. As discussed by Kloiber at al. (2019), the SHGM approach classifies Minnesota wetlands by their landscape position, landform/waterbody type, and water flow path (referred to as the “bare bones LLWW”). Within each of these broad categories, sub-classifications in Minnesota are shown in the table below. A crosswalk table that relates each SHGM LLWW class to Brinson’s HGM classes is available in Kloiber at al. (2019).

Table 1. Simplified Hydrogeomorphic (SHGM) classes of Minnesota. From Kloiber et al. (2019).

Landscape Position	Landform/Waterbody	Water Flow Path
Lentic (LE)	Basin (BA)	Inflow (IN)
Lotic (LO)	Flat (FL)	Outflow (OU)
Terrene (TE)	Floodplain (FP)	Throughflow (TH)
	Fringe (FR)	Bi-directional non-tidal (BI)
	Island (IL)	Vertical (VR)
	Peatlands (PT)	
	Slope (SL)	
	Lake (LK)	
	Pond (PD)	
	River (RV)	

Using SHGM data, watershed based preliminary assessments of function have been conducted in many areas of the United States. The Association of State Wetland Managers maintains a compiled list of these assessment reports (mainly authored by Tiner) on their website (https://www.aswm.org/wetland-science/wetlands-one-stop-mapping/5044-nwi-reports). A list of functions commonly assessed in these past studies is presented below.

- Surface water detention
- Streamflow maintenance
- Nutrient transformation
- Carbon sequestration
- Sediment and other particulate retention
- Bank and shoreline stabilization
- Provision of fish and aquatic invertebrate habitat
- Provision of waterfowl and waterbird habitat
- Provision of other wildlife habitat
- Provision of habitat for unique, uncommon or highly diverse wetland plant communities.

For more detailed information and rationale for these wetland functions the reader is referred Mitsch and Gosselink (2007) and Tiner (2005).

3 PROJECT PURPOSE AND OVERVIEW

The purpose of this project was to develop watershed-level functional assessment methodologies for wetlands by combining terrain analysis and hydrological concepts with the updated NWI dataset. The proposed semi-quantitative, hydrology-based approach presented in this document -- while more complex to implement -- seeks to improve upon more generalized, qualitative approaches to functional assessment such as those based solely on the SHGM. More intensive assessment approaches have incorporated in-field functional evaluation of reference wetlands and correlation to HGM attributes (e.g., Whigham et al. 2007; Cole, Brooks, and Wardrop 1997); however, their applicability on a broad scale is limited by time and financial constraints.

The work of Tiner in many regions of the US has demonstrated use of the SHGM in the "Watershed-based Preliminary Assessment of Wetland Functions" (W-PAWF) approach. These SHGM-based functional assessments assign a "Moderate" or "High" rating based predominantly on correlations between SHGM classifications/sub-classifications and different wetland functions at a defined watershed scale (See Tiner 2003, 2011). Preliminary assessments like W-PAWF are "Level 1" types of assessment, meant for broader scale assessment and planning, and as a precursor to more rigorous in-field evaluations of individual wetland function (Levels 2 and 3; e.g., MnRAM; Minnesota Board of Soil and Water Resources 2010).

However, the generalized scope of SHGM based assessments limits the evaluation of two important functional variables: (1) the upstream watershed conditions that determine surface water and pollutant inputs to a given wetland, and (2) a wetland's ability to affect these inputs as pertains to its designated functions. Building on Tiner's work, Miller et al. (2017) proposed a more rigorous approach that considered these functional variables implicitly and integrated SHGM correlations with GIS derived metrics for a functional assessment of Wisconsin's wetlands. Our project can be seen as building upon the work of Miller et al. conceptually, and so we chose to adopt this terminology as well.

3.1 OVERALL APPROACH

For this project, a set of four hydrology-dependent functions were chosen based on the knowledge gap discussed above and Minnesota's focus on reducing runoff, increasing groundwater recharge, improving water quality, and restoring habitat in degraded urban and agricultural watersheds. The selected functions and their primary assessment criteria are listed in the table below.

Table 2. Selected Wetland Functions and Assessment Criteria

Project Function	Example Functions	Assessment Criteria
Surface water	Flood abatement	Storage and/or attenuation of upland surface runoff
Water quality	Sediment/particulate P retention, denitrification	Non-point source pollutant reduction based on surface runoff storage
Groundwater	Watershed drinking water supply, streamflow maintenance	Extent of recharge vs. discharge based on surface runoff storage

Project Function	Example Functions	Assessment Criteria
Habitat	Waterfowl, fish and aquatic habitat	Wetland water level bounce and inter-wetland connectivity based on surface runoff storage and fill-and-spill flowpath results

The overall project approach seeks to extend the enhancements of the updated NWI by using LiDAR geospatial analysis and hydrologic modeling concepts to better infer wetland surface-water, water-quality, groundwater, and habitat functions. The primary conceptual steps of this approach are these:

1. Quantify Wetland Storage by identifying topographic depressions and calculating depressional geometry in each wetland.
2. Predict Wetland Inputs by delineating direct drainage areas of wetlands and simulating runoff and pollutant delivery to each wetland.
3. Map Wetland Connectivity by analyzing the upstream and downstream linkages between wetlands, and between wetlands and the watershed outlet.
4. Quantify Interactions between Steps 1-3 by simulating the flow of runoff and pollutants through each connected wetland's storage to the watershed outlet using a fill-and-spill approach.
5. Analyze Results and Derive Functional Metrics from Step 4 by calculating a suite of proposed "raw" and ranked metrics relevant to each assessed function at multiple watershed scales.

The workflow of Steps 1-4 characterize the "fill-and-spill" behavior of individual wetlands and those connected in a network. Fill-and-spill is a process-based wetland hydrologic concept that describes the integrated effects of storage, runoff and network connectivity on wetland and watershed scale hydrology. Each wetland receives runoff from its direct drainage area, "filling" its available storage volume. If the runoff volume exceeds the wetland's storage volume the wetland "spills". Further, because of connectivity with other wetlands the filling and spilling of any given wetland is also dependent on the outputs ("spills") from any upstream connected wetlands. The fill-and-spill concept is most applicable to ephemerally connected wetlands (i.e., only connected during runoff events), commonly Terrene and Lentic wetlands. Consequently, Terrene and Lentic wetlands are the focus of this project with Lotic function analyzed less rigorously by using an ancillary approach discussed later in the document. Further, this approach is more directly applicable to surface-water and water-quality functions than groundwater and habitat functions. As a result, surface-water and water-quality functional metrics developed in this project are more diverse and detailed in their scope when compared to groundwater and habitat metrics.

3.2 Concept and Use of Wetland Complexes

In many cases, a given NWI polygon will share a boundary with one or more adjacent wetlands that are slight variants differing only in vegetation stature, water depth, or frequency of saturation. Common examples include associations of Terrene Fringe, Flat and Basin wetlands, Lotic Floodplain and River, and Lentic Lake, Fringe and Basin wetlands. In many cases, numerous wetlands of all three SHGM Landscape Position types may all be adjacent forming a large and complex association composed of many different functions and levels of function. In addition, the presence of depressions under portions of these complexes can further aggregate function. For example, the surface-water storage capacity of a basin wetland is based on depressional topography and is an aggregate function of the entire basin, not of the component wetland types, and nor is the associated function (once determined) easily partitioned back among the component types.

The aggregate effect of these associations on specific wetland functions across selected watershed scales necessitated defining wetland “complexes”. As used here, complexes may be composed of multiple adjacent SHGM Landscape Position types (Terrene, Lentic, Lotic) and can comprise a considerable areal extent. Further, complexes are aggregated with any LiDAR derived depressions that lie outside their areal boundary owing to cases where mapped NWI polygons were not able to take into account depressional indicators. Thus, complexes were the spatial unit for developing and assigning function metrics for all parts of the project. The complex constituents' individual functional contribution could be roughly estimated (by disaggregating results by individual NWI polygon area or depressional storage), but this was not included in the scope of this project.

In Practice

Complexes need not be aggregated *across* Terrene, Lentic, Lotic SHGM landscape types as done in this project. Perhaps a better approach would be to aggregate *per* SHGM landscape type (Terrene or Lotic or Lentic but not combined) resulting in more functionally distinct NWI complexes that are easier to disaggregate for individual wetland functional assessment. However, adjacent complexes of different landscape types would have to be spatially altered (i.e., separated from each other) via additional GIS development in order for NWI complex subwatershed and connectivity delineation to be conducted.

3.3 Selection of Study Area

A study area was selected for development and analysis of functional metrics (see Figure 1). The extent was increased over the course of the project to comprise 21 watersheds of varying sizes totalling over 2 million acres. The large areal extent of the study area was an advantage for (1) enabling examination of proposed wetland function methodologies in a diverse range of soil, climate and landscape conditions representative of southern Minnesota's watersheds, and for (2) generating example results relevant and usable to the broadest audience possible. A primary requirement was availability of hydro-modified LiDAR data with appropriate level of accuracy (discussed below) at the time of the project start.

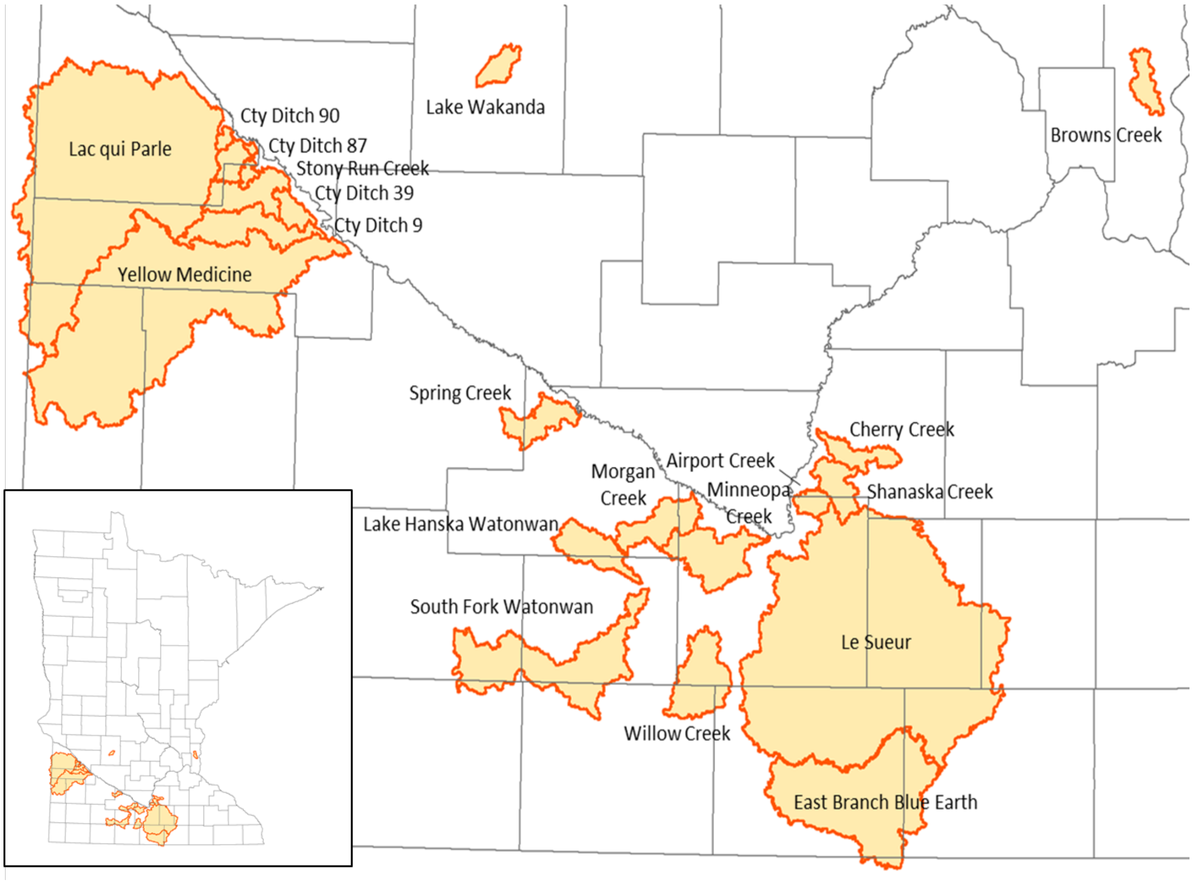

Figure 1: Watersheds of the Project Study Area

4 Methods

The overall project approach was implemented in the following steps:

1. Hydro Conditioning/Modification of LiDAR DEMs
2. Existing Tools and Methodologies Selection
3. Depressional Analysis
4. Wetland and Watershed Connectivity Analysis
5. Fill-and-Spill Analysis
6. Extension of Fill-and-Spill Analysis for Water Quality
7. Analysis of Results and Development of Functional Metrics

A summary of each step is presented in the sections below. More detailed information is available in the Appendices where noted.

4.1 Hydro Conditioning/Modification of LiDAR DEMs

LiDAR hydro-modification was a necessary step in the project, being critical for ensuring the most accurate watershed-scale flow direction, wetland flow path connectivity, and identification of wetland depressions and storage volumes. LiDAR is hydro-modified to re-route flowpaths by "burning" manually digitized vector lines into the DEM thereby breaching artificial dams (primarily road/driveway embankments that actually have culverts or bridges) that create erroneous impoundments. The hydro-modified LiDAR DEMs used in the project were generated using these vector lines with the Manual Cutter tool available in the ACPF DEM Preparation toolset (version 3). For this project, we used three-meter resolution DEMs, which produced similar results as 1-m DEMs but required much less processing time.

Rick Moore and Sean Vaughn of the MN-DNR provided consultation regarding availability and quality of existing breachline datasets. Jessica Nelson of the Water Resource Center at Minnesota State University provided the Yellow Medicine and Lac-qui Parle/Yellow Bank Watershed District datasets. Karen Kill, administrator of Brown's Creek Watershed District (through Emmons and Olivier Resources Inc.) provided the Brown's Creek dataset; Rick Moore provided the remainder of the datasets.

In Practice

Hydro-modification can be a costly and time consuming effort. For this project, the most rigorous level of modification available ("Level 3") was used. Less rigorous modifications were not evaluated but could suffice depending on the number of wetlands and potential flow obstructions that impact depressional storage volume and flow path connectivity. Related information is discussed in the Depressional Analysis section below.

4.2 Existing Tools and Methodologies Selection

We used existing tools and methodologies where possible. In some cases, methodologies implemented in existing tools were adapted for use in the project without using the tools directly. ArcGIS 10.6 was the primary application used for project development. Within ArcGIS, Spatial Analyst and ArcHydro extensions were implemented in manual operations and used to construct ModelBuilder workflows. In a few cases, ArcHydro python codes were modified for key operations. Amongst several existing ArcGIS toolsets used in the project, the ACPF (Tomer et al. 2015) and PTMapp (BWSR 2016) toolsets were particularly useful. ACPF tools were used for LiDAR hydro-modification and depressional analysis, while several PTMapp approaches to GIS-based hydrology and water-quality modeling were adapted for use in the project. Where ArcGIS could not easily produce needed outputs, codes were written in R open source statistical software (R Core Team 2014). Use of specific tools and methodologies are noted in the sections below.

4.3 Depressional Analysis

Identification of depressions and quantification of depressional geometry – principally, volume – was a critical component of generating the fill-and-spill methodology (discussed above and outlined in detail in subsequent sections).

Depressions are generally identified by subtracting a LiDAR DEM from a filled version of the same DEM using raster GIS tools. However, spurious sinks and depressions are present on most LiDAR DEMs (despite hydro-modification) requiring a process to separate "real" depressional features from artifacts. An advantage of the updated NWI is that one can constrain where depressions can exist thereby reducing errors and saving considerable processing time. Our analysis assumed that depressions (1) must intersect NWI polygons or complexes and (2) not extend beyond a 100-meter buffer around the NWI polygons/complexes. These assumptions facilitated efficient computer processing time by excluding non-wetland areas in the DEM while allowing for depression extents that did not exactly conform to the boundaries of the NWI complexes. Depression locations were further constrained by a minimum surface area of 0.02 acres and a maximum depth of at least 15 cm, corresponding to the smallest NWI polygon surface area in the southern and east-central NWI regions and the reported elevation RMSE of LiDAR datasets in the project study area, respectively. ACPF Depression Identification and Drainage Area tools were used for this step.

Characterization of depressional volume as permanent (i.e., retention) and temporary (i.e., detention) storage was necessary to best predict hydrologic and water-quality impact of wetlands at local and watershed scales. Optimally, wetlands provide permanent storage, which reduces downstream runoff volumes and maximally traps pollutants, while temporary storage can reduce runoff rates resulting in smaller flood peaks and trap a lesser proportion of pollutants per unit volume. However, temporary storage can be mischaracterized as permanent storage if the depression's natural outlet is not large or prominent enough to be captured by LiDAR. Engineered outlets (covered and uncovered) on lakes are another common example of this LiDAR mischaracterization (unless breached by hydro-modification). Similarly, altered agricultural wetlands may be drained via ditches or more problematically by subsurface drain tiles. Efforts were taken to constrain what was characterized as permanent vs. temporary storage by using the updated NWI attributes such as the Cowardin 'd' ("partly drained/ditched") and 'f' ("farmed") flags (i.e., assumed drained by surface or sub-surface drainage =

temporary) as well as the SHGM Water Flow Path (e.g., depressional volume in *Isolated/Vertical* and *Inflow* wetlands = permanent; *Outflow*, *Throughflow, Bi-Directional* = temporary). In cases where permanent storage was designated (by existence of a depression and the Cowardin and SHGM criteria), temporary storage was assumed also be present. Temporary storage was estimated using the median elevation of linear boundary of the NWI complex polygon, which was assumed to be representative of the temporary storage inundation area/elevation. Using this elevation, a raster Fill operation calculated the resulting storage geometry. However, not knowing the true topography of the temporary "basin" and more importantly the outlet geometry, the temporary storage depth was capped at 25 cm for Terrene and Lentic non-lake features and 75 cm for Lentic Lakes features. More detailed information on determining depressional storage volumes is presented in Appendix B: Procedures and Algorithms.

In Practice

This project took a conservative approach to estimating permanent storage, especially in agricultural watersheds where a substantial number of wetlands are known to have been altered to convert permanent storage to temporary. Consequently, considerable effort was put into identifying depressional volumes that are most likely "true" permanent storage for purposes of estimating flood storage and water-quality functioning as accurately as possible. However, this identification and the SHGM/Cowardin attribute approach used in the procedure are not necessarily required for this step if a different endpoint or level of rigor is desired, or if other constraints or professional judgement can be applied.

4.4 Wetland and Subwatershed Connectivity Analysis

This step began with creation of wetland complexes introduced in 3.2. Complexes of adjacent NWI polygons were first aggregated in GIS using an iterative Dissolve operation, and then aggregated with intersecting depressions using a Union operation. This operation produced 20,188 complexes over the study area.

Next, subwatersheds for each complex were delineated using the ACPF Depressional Drainage Area tool producing a patchwork of 20,188 subwatersheds each terminating at the downstream outlet (pour point; point of maximum flow accumulation) of the complex. Connectivity between subwatersheds and down to each watershed's ultimate outlet was mapped using a Cost Path approach whereby downstream flowpaths from each complex were identified using Flow Direction data. ArcHydro was then used (1) to delineate subwatersheds for the remaining areas of each study watershed that did not contain an NWI complex, and (2) to assign next-downstream subwatershed connectivity. These operations resulted in a mosaic of 48,272 subwatersheds with connectivity and depressional geometry attributes where needed for the fill-and-spill analysis (i.e. for the 20,188 NWI complex subwatersheds).

In Practice

The resulting NWI complex subwatershed layer is distinctly different from a typical subwatershed delineation that is dictated by a derived stream network, using an arbitrary drainage area threshold. The project subwatershed layer is designed specifically to delineate each NWI complex direct drainage area and the flowpath connectivity between complexes, leading ultimately to the study watershed outlet. As such, this step relies on a somewhat different set of tools and procedures than a typical subwatershed delineation. See Appendices.

4.5 Fill-and-Spill Analysis

The Fill-and-Spill analysis was used to simulate the flow of runoff through all wetland complexes in the project study area. The procedure utilized the previously derived wetland complexes, storage volumes, and mapped up/downstream connectivity. An R code (R Core Team 2014) loops through all wetland complex watersheds starting with those in the headwaters (i.e., no upstream wetland, first order). Runoff from a set of design storms (1, 2, 5, 10, 25, 50 and 100 year/24 hour) to each wetland complex from its direct drainage subwatershed was predicted via the NRCS curve number method (AMC II) and whatever runoff spilled from the wetland complex permanent storage was routed to the next downstream complex; this upstream to downstream looping continued until a study watershed pour point outlet was reached. Runoff contributing to permanent vs. temporary storage was accounted for and stored as output. Detailed information on this procedure is presented in Appendix B: Procedures and Algorithms.

This approach assumes all runoff is generated simultaneously in all subwatersheds and propagates through the fill-and-spill network instantaneously. As such, a disadvantage is that it does not account for *rates* of runoff generation, runoff routing and wetland filling/spilling. Depending of the variability of wetland sizes and distances between them within a network, our approach will underestimate wetland storage because it assumes all the processes and rates mentioned above occur and propagate downstream to the pour point instantaneously, ignoring potential losses to infiltration and evaporation. Not considering rates also ignores backwater effects whereby a wetland depression could conceivably fill and merge with one or more upstream depressions (decreasing their utilizable storage) or flow into adjacent depressional networks not normally linked topologically (Chu et al. 2013).

In short, the approach does not take into account the complex hydraulic behavior that depends on parameters not generally known for each NWI complex (e.g., outlet geometry, water surface, rates of runoff flowing into the wetland). Nonetheless, the project approach remains a significant improvement for more explicitly estimating and comparing hydrologic function within and between wetlands/complexes.

In Practice

The use of an average “antecedent moisture condition” - AMC II - for the curve number modeling was potentially impactful because it assumed drier conditions than might be expected on average in the spring. Under spring conditions more runoff would generally be expected, potentially limiting the amount of runoff stored in wetlands as a proportion of total runoff. Application of the fill-and-spill approach would likely benefit from use of the wetter “AMC III” for runoff calculation depending on the context of the analysis. Equations exists to convert AMC II curve numbers available for the state via PTMapp (BWSR 2016) to AMC III (or the drier AMC I).

4.6 Extension of Fill-and-Spill Analysis for Water Quality

The water-quality function of a wetland complex is its ability to trap or reduce incoming pollutants, commonly nonpoint-source sediment and nutrients. Part of this function depends on factors external to the wetland complex, namely, the load of sediment and nutrients delivered to the wetland. All other factors remaining equal, a larger pollutant load implies at least the potential for larger removal, i.e., a greater water-quality function. Water-quality function also depends on factors internal to the wetland complex, especially the hydraulic residence time, which in turn depends on both flow rates and storage volumes. A larger residence time would generally imply a greater water-quality function.

To most explicitly predict sediment erosion and transport as it pertains to wetland trapping processes, event based simulations that incorporate flow rates are most appropriate. However, the widely used RUSLE model (e.g., as implemented within PTMapp) is an annualized prediction model and therefore cannot take into account event-based runoff rates and volumes for erosion prediction. A more appropriate method is the event-based MUSLE model (Williams 1975, and used in the model SWAT; Arnold et al. 1998) which uses the same multiplicative factors for as the RUSLE model (R, C, K, LS, P) except that it replaces the annual rainfall erosivity factor R with a runoff factor that is composed of peak runoff rate and total runoff volume. This approach avoids the necessity of estimating a sediment delivery ratio.

In this project, flow rates were estimated to the extent that peak flows could be derived. Peak flows are important for developing a relatively simple but explicit approach for simulating sediment and phosphorus erosion masses for each subwatershed for a representative design storm event. These pollutant masses served to identify subwatershed source hotspots (relative to a larger watershed scale) and provide estimates of pollutant inputs to NWI complexes for estimation of relative water-quality function. Summaries of the steps in the methodology are presented below. More detailed information is presented in the Appendices.

4.6.1 Estimation of subwatershed peak flows

Subwatershed peak flows required for MUSLE modeling were calculated using an approach that estimated subwatershed flow velocities across each 3 meter pixel in the LiDAR DEMs and analyzed the resulting statistical distribution of these flow velocities in terms of each pixel's travel time to the subwatershed outlet. From this information, estimated flow hydrographs were constructed for a 2yr/24hr design storm. General steps in this process are listed below and presented in more detail in the Appendices.

1. Calculate per-pixel travel times based on MnDNR Travel Time Tool.
2. Calculate accumulated travel times to each subwatershed outlet and output resulting travel time distributions using custom ModelBuilder workflow.
3. Convert subwatershed travel time distributions to runoff hydrographs using R code.

In Practice

The project approach for calculating peak flows is relatively complex and requires advanced GIS skills and development of codes in a python or R environment. Peak flow rates are a required input of the MUSLE model but may be estimated using less complex methods based on available variables such as runoff volume and subwatershed drainage area (USDA 1986; Chow 2010).

4.6.2 Prediction of water quality pollutant export and fill-and-spill integration

An existing GIS toolset (Blaszczynski 2003) designed to implement MUSLE using subwatershed peak runoff rates and total runoff volumes while also accounting for subwatershed Flow Accumulation patterns was adapted to predict sediment erosion mass from each design storm delivered to the subwatershed outlet. Primary inputs for this modeling approach were the total runoff volume (from curve number runoff calculation in fill-and-spill approach) and peak runoff discharge rate (calculated in previous step). Phosphorus mass was predicted by applying concentration factors to sediment mass whereby a unit mass of phosphorus was generated per unit mass sediment and the results incorporated in the fill-and-spill methodology. General steps in this process are listed below and presented in more detail in the Appendices.

1. Predict design storm sediment/phosphorus loads using GIS enabled MUSLE model.
2. Extend design storm sediment loads to include associated phosphorus.
3. Incorporate flow rates and sediment/phosphorus transport into fill-and-spill methodology.

4.7 Analysis of Results and Development of Functional Metrics

These sections present the approaches for analyzing results and generating a suite of proposed metrics meaningful for assessing wetland functions. However, these approaches and proposed metrics are not intended to limit or exclude other potential interpretations or adaptations. Rather they are intended as a starting point to promote further development as needed that can take into account scales and functions of individual interest, and factor in professional judgement as appropriate.

4.7.1 Surface Water and Water Quality function

The foundation for developing metrics of wetland function was the hydrologic and water quality fill-and-spill analysis. The analysis produced a considerable number of outputs, each with potential application for inferring wetland function. Examples of numerical outputs generated for each NWI complex are listed below.

Predicted hydrology functional metrics for each design storm (1, 2, 5, 10, 25, 50, 100yr/24hr):

1. Runoff from subwatershed (direct drainage area)
2. Runoff received from upstream subwatersheds (from upstream wetland "spills")
3. Volume and ratio of runoff stored permanently
4. Volume and ratio of runoff stored temporarily
5. Total volume of runoff spilled downstream
6. A Yes/No flag indicating whether NWI complex subwatershed contributed flow to outlet

Predicted water quality (WQ: sediment, particulate phosphorus, nitrate) functional metrics for 2yr/24hr design storms:

1. WQ inputs direct drainage area
2. WQ inputs received from upstream (from upstream "spills")
3. WQ inputs mass and trapping efficiency ratio stored permanently
4. WQ inputs mass and trapping efficiency ratio stored temporarily

Visualized using GIS, these results provide a first cut at assigning individual NWI complexes a relatively high or low function; however, potentially more useful metrics were also derived by percentile ranking each NWI complex result within different watershed scales (HUC-8, -10, -12) of common management focus. Further, results were *normalized* by watershed scale sums to add additional context for interpreting watershed function. Examples include:

1. Percent of total watershed runoff and WQ mass received by each NWI complex
2. Percent of total watershed runoff and WQ mass trapped or reduced by each NWI complex

A possible further step in metric analysis would be converting numeric outputs or percentile ranks at watershed scales into a metric based scoring system for a simpler conveying of metric results (e.g., 1=Low=0-33%, 2=Medium=33-66%, 3=High=66-100%). However, inferring function from the metric results requires some oversight from the user. Distributions of results within watershed scales may not vary enough to justify grouping metric numeric outputs or percentile rankings uniformly (i.e., Low,Medium,High) or at all (i.e., one score for the entire set of outputs). Creating scoring "rubrics" based on the shape of metric distributions (e.g., normal, log-normal, uniform) will create more realistic and useful interpretation and valuation of NWI wetlands/complexes. A helpful tool for visualizing metric data is ArcGIS which by default creates symbology using the Jenks natural breaks classification method, a form of cluster analysis that seeks to create groups (clusters) such that the variance between data *within* groups is minimized while the variance *between* groups is maximized.

4.7.2 Groundwater function

Groundwater interaction with wetlands is critically important but difficult to demonstrate, at least in detail. Groundwater can play a key role in wetland hydrologic function and thus influence the ability of wetlands to improve water quantity, quality or to provide good habitat.

The project approach for deriving metrics of groundwater function focused specifically on determining the extent to which a given NWI complex provides groundwater recharge versus discharge capability. The assumption is that both recharging and discharging wetlands can provide valuable functions (e.g., groundwater supply, drought resilience, baseflow maintenance, etc.). In some cases, recharging and discharging functions are coupled whereby recharging function provides the wherewithal for discharging function.

The approach aimed to leverage the results from the surface water function fill-and-spill results whereby the degree to which a wetland permanently stores runoff volume (i.e., a function of permanent/retention storage and total incoming upstream runoff volume) is the principal indicator of groundwater (recharge) function. The relative amount of recharge occurring in a given NWI complex in relation to recharge occurring in other watershed scale wetlands (via permanent storage of runoff) plus uplands (via infiltration) was a primary functional metric-- i.e. if a watershed infiltrates a relatively large volume of water prior to runoff generation, recharge from runoff stored in downstream NWI complexes is less important than in a watershed with less infiltration capacity.

Following this approach, groundwater function was assessed in the following steps:

1. Create subset of NWI complexes that contain Terrene features with available permanent storage and determine amount of runoff stored from a representative design storm (from fill-and-spill results; assume 1yr/24hr).
2. Rank NWI complexes based on estimated volume recharged based on runoff volume stored as a fraction of total watershed (HUC-12/10/8) design storm precipitation.

4.7.3 Habitat function

As with the other approaches in this project, deriving metrics of habitat function specifically leveraged the results from the surface water function fill-and-spill procedure. We therefore propose approaches at assessment based on the extent of runoff permanently stored in NWI complexes (i.e., determined by the available permanent storage volume and the amount of runoff that flows into it).

For example, the measure of water level stability (or "bounce") is important for predicting where temporary hydrologic conditions dependent on overland flow inputs provide safe habitat for shallow-water, ground-nesting birds and aquatic-obligate organisms (e.g., dabbling ducks, their food sources and nesting locations). In these temporary wetlands (in which temporary is defined in longer – e.g., seasonal – time scales and is associated with *permanent* storage as defined in this project), water level should be high enough to promote food gathering and nesting but not too high.

Additional predictive factors for suitable shallow water habitat were explored in Specht et al. (2018) using the updated NWI in east-central Minnesota. Of those factors, edge complexity (the ratio of wetland perimeter to the perimeter of a perfect circle with equal area) was determined to be a significant positive predictor of dabbling duck feeding and nesting success. Edge complexity aims to quantify shoreland nesting availability whereby increasing complexity indicates a larger area of nesting habitat in proportion to wetland surface area (as discussed in Specht et al. 2018 citing Mauser et al. 1994).

Using these concepts, this project used the following approach to estimate the degree of temporary, shallow water habitat suitability in each NWI complex:

1. Create subset of NWI complexes that contain Terrene wetlands with a Cowardin moisture regime of A, B, or C ("Temporarily Flooded", "Saturated" or "Seasonally Flooded", respectively).
2. Determine available permanent storage and amount of runoff stored from a representative design storm (assume 1yr/24hr).
3. Rank NWI complexes based on their deviation (higher or lower) from an assumed optimal (mean) depth of 10 inches (i.e., targeting dabbling ducks and associated species).
4. Rank NWI complexes based on degree of edge complexity (of the depressional feature(s) comprising the permanent storage volume).

A second approach more generally assessed fish and aquatic habitat function associated with the degree of connectivity between temporary terrene, lentic and lotic features and perennial, open water Lentic/Lotic NWI features. The general approach is used in the context of individual wetlands in the work of Miller et al. (2017), but applied in this project, assumes function in NWI complexes increases with the (1) diversity (e.g., lotic, lentic, terrene) and (2) potential for seasonal flooding/inundation (expressed in this project as permanent storage) of adjacent features in NWI complexes.

As such, the second approach assessed habitat function in the following ways:

1. Identify NWI complexes with (1) Lentic or Lotic open water NWI features <u>and</u> (2) permanent storage associated with Terrene or non-open water Lentic features.
2. Rank NWI complexes based on indexes composed of ratios of Terrene or non-open water Lentic area to overall NWI complex area and permanent storage to overall NWI complex area.

5 Study Area Results and Applications

Results were derived for the 21-watershed study area using the methods described above. These data are downloadable for review and use by interested readers. This section presents examples of these results data for a single HUC-12 watershed, and demonstrates hypothetical/proposed applications of the data. In addition, applications of the methods and results data for areas *outside* the study area are discussed. Tables 4 - 6 contain fill-and-spill results for each of the 21 study area watersheds.

5.1 Study Area results and demonstration

Example project results from the study area are presented for a watershed within the Le Sueur HUC-8 watershed. The Le Sueur is an agriculturally dominated watershed that has been heavily altered hydrologically, and is the subject of much research on its runoff and pollutant export to the Minnesota and Mississippi Rivers. Within the Le Sueur, the “Little Le Sueur” headwaters HUC-12 watershed (15,485 acres) was selected to demonstrate example results at an interpretable scale (See Figures 2 and 3) for a single design storm (2yr/24yr; 2.7 inches). The Little Le Sueur is predominantly agricultural with some significant inclusions of grassland in the west and east central areas of the watershed. Soils are generally loams, silt loams, clay loams and silty clay loams with a hydrologic soil group of ‘B’. The resulting curve numbers of the watershed are shown in Figure 6.

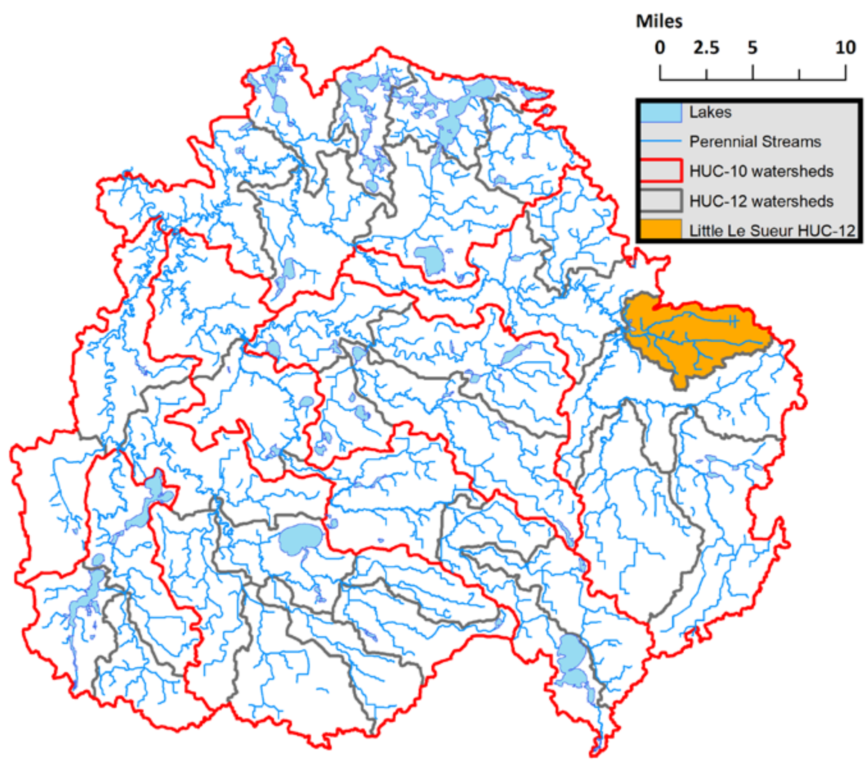

Figure 2: Le Sueur HUC-8 watershed with example HUC-12 watershed (Little Le Sueur) highlighted in orange.

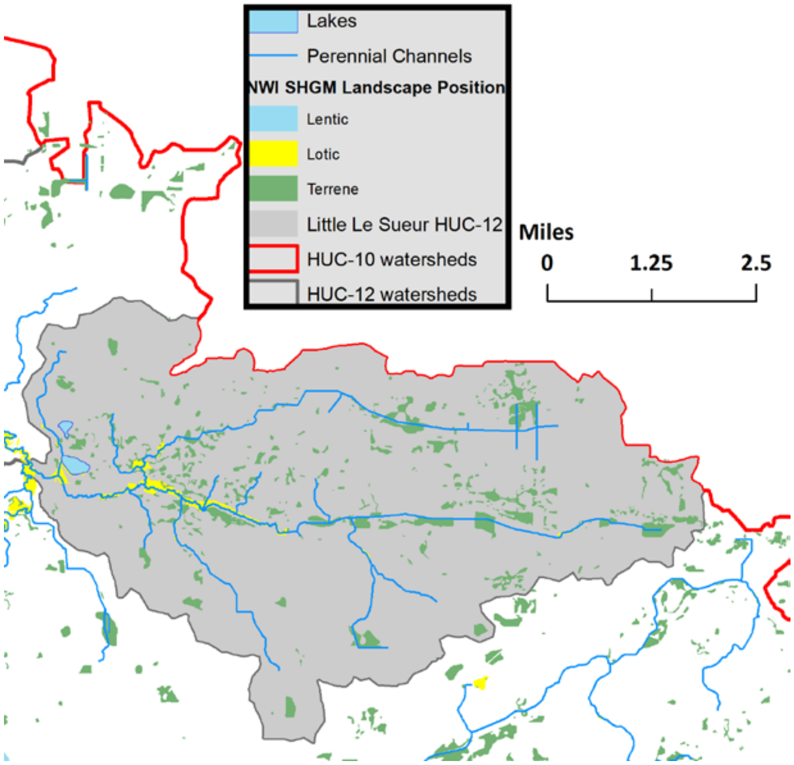

Figure 3: Little Le Sueur Watershed showing NWI SHGM Landscape Position distribution. Note: watershed outlet (pour point) is on the western side of the watershed.

5.1.1 Surface Water and Water Quality Function

For the fill-and-spill analysis, NWI complexes, connecting flowpaths and resulting subwatersheds were derived as discussed in the Methods section. Figures 4 and 5 depict the 325 NWI complexes and connecting flowpaths, and 707 subwatersheds (325 containing NWI complexes) that were delineated for the watershed. Depressional analysis quantified storage volume in the watershed; however, as most NWI complexes in the watershed were composed of ditched/partly drained or farmed (Terrene) wetlands ('d' and 'f' Cowardin modifiers, respectively), a significant proportion of depressional volume was designated as 'temporary' rather than 'permanent' for purposes of the fill-and-spill modeling. Constraining the depressional storage in this manner resulted in significant shifts in level of wetland function at the NWI complex scale and watershed scale (i.e., the assumption that permanent storage is weighted higher than temporary). Figures 6 and 7 show the distribution of estimated permanent and temporary storage in the watershed.

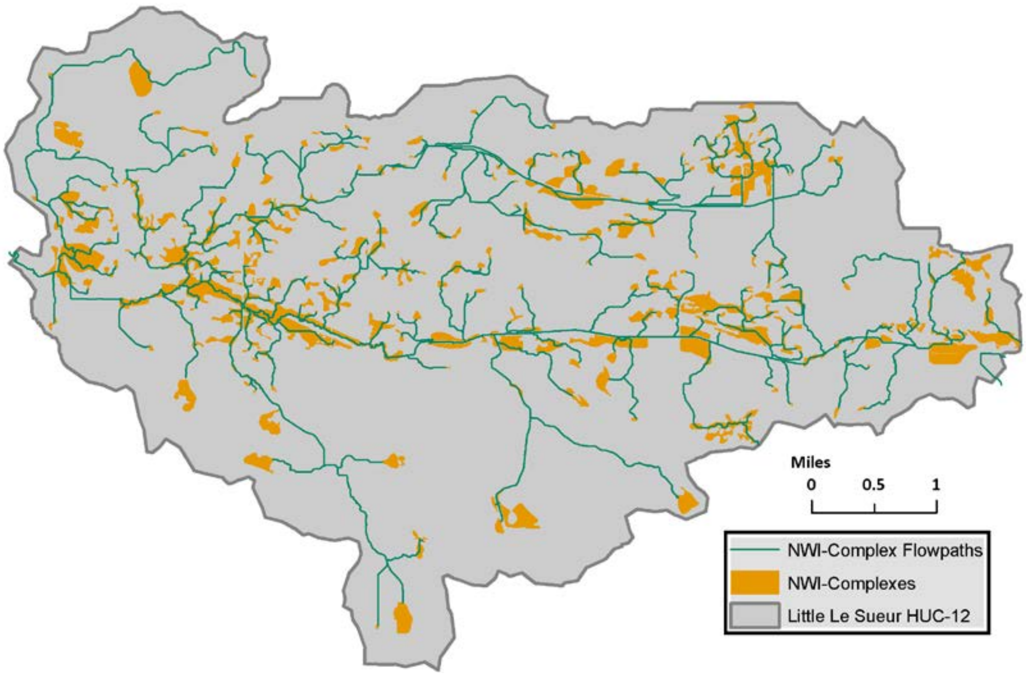

Figure 4. NWI complexes and connecting flowpaths for Little Le Sueur HUC-12 watershed

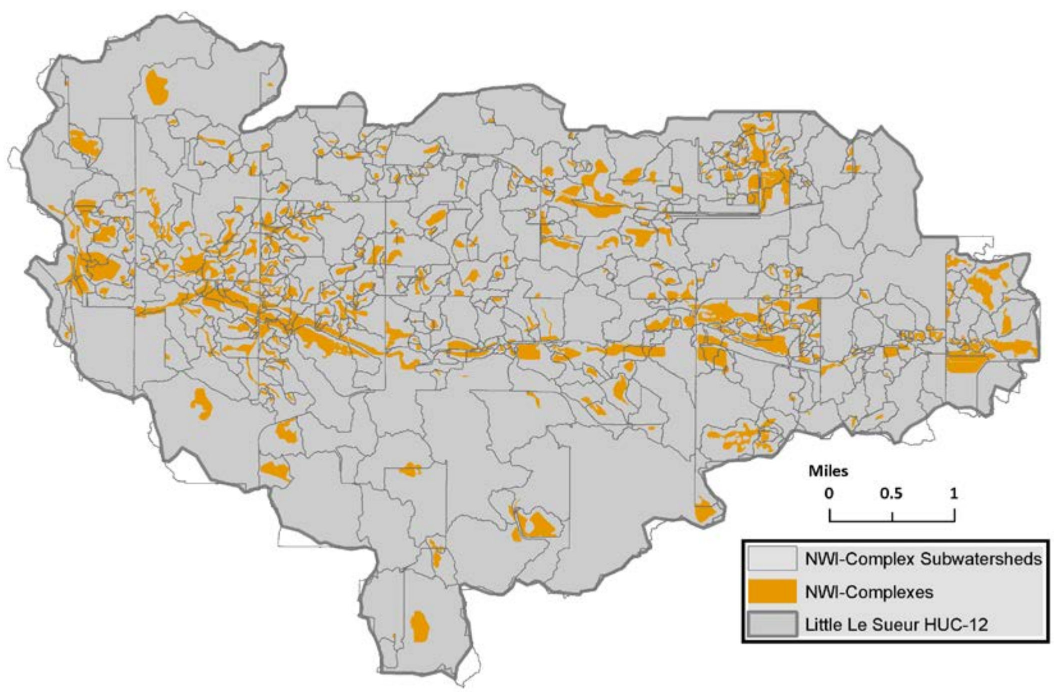

Figure 5: NWI complexes and direct drainage subwatersheds for Little Le Sueur HUC-12 watershed

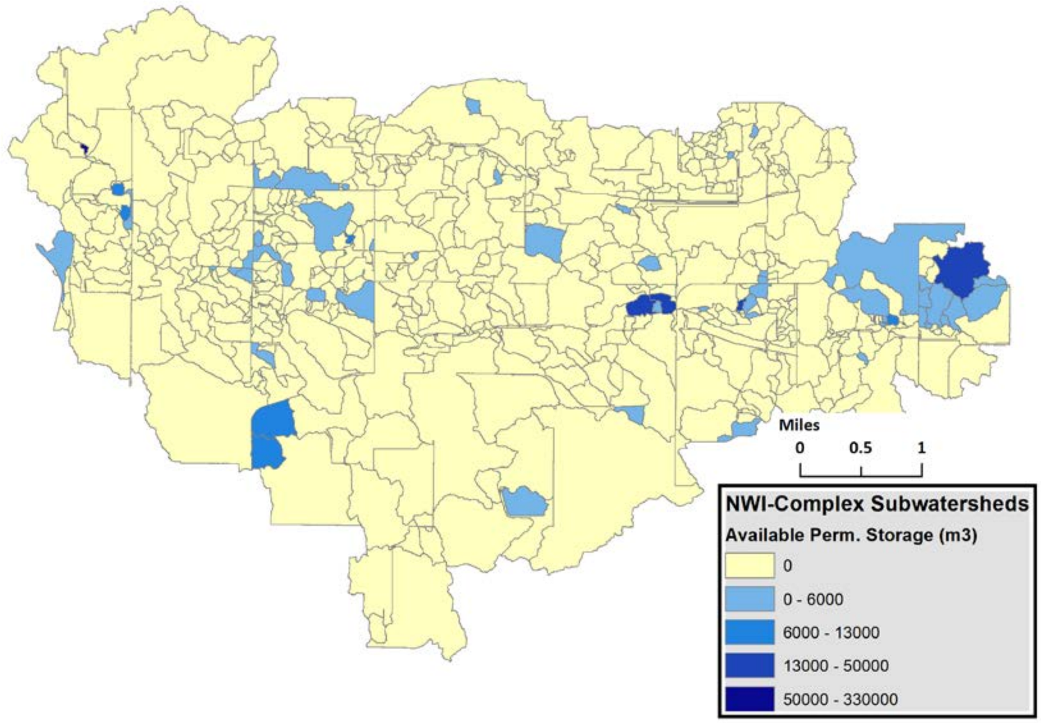

Figure 6: Available permanent storage volume for NWI complexes (but displayed for clarity at subwatershed scale) for Little Le Sueur HUC-12 watershed

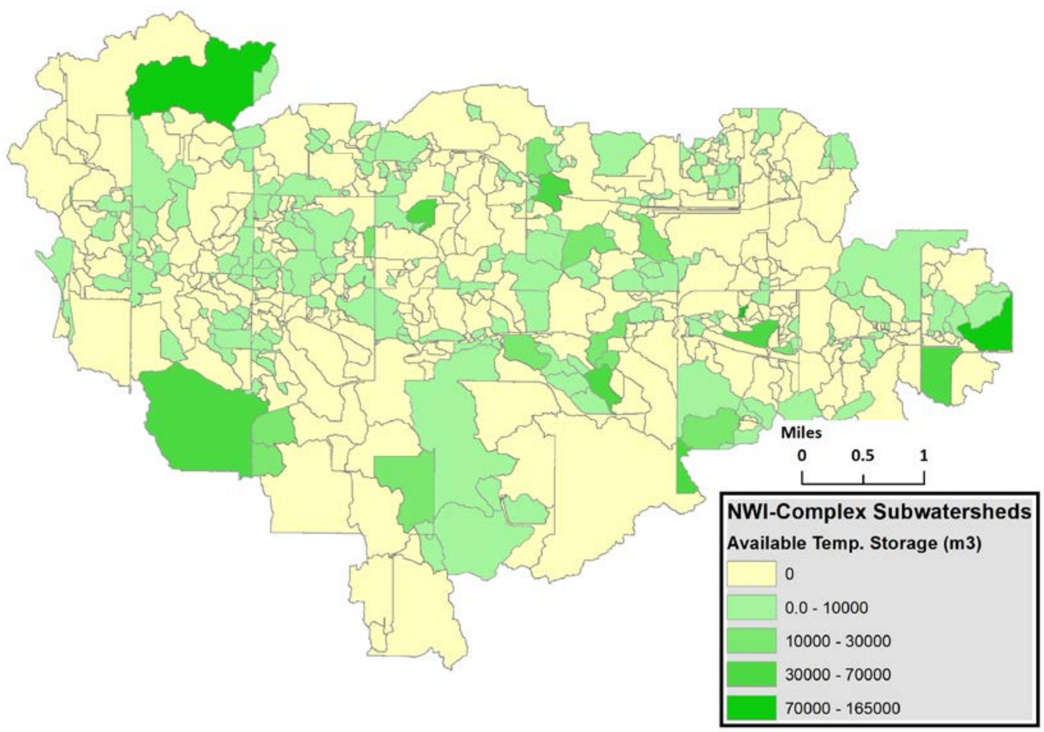

Figure 7: Available temporary storage volume for NWI complexes (but displayed for clarity at subwatershed scale) for Little Le Sueur HUC-12 watershed

Results of the runoff and sediment fill-and-spill analysis for a 2yr/24hr design storm are shown in Figures Figure 8 -12. The 2yr design storm (i.e., 50% chance of occurring in a given year) was selected as a demonstration because it is generally assumed to produce a significant flow event, and in smaller watersheds, a low magnitude river/stream flood event (i.e., over-bank). Predicted runoff for each NWI complex subwatershed (i.e., runoff originating in the subwatershed before "filling" and "spilling") is mainly a function of subwatershed size as the variability of curve numbers was low over most of the watershed. Predicted eroded sediment mass is a function of predicted subwatershed peak flow rate and total runoff volume, slope and soil type (USLE K factor). Wetland results intended for use as functional metrics include predicted runoff and sediment storage – in terms of volumes/masses as well as percentages normalized by HUC-12 aggregated sums. Note: erosion and storage of particulate phosphorus and nitrate were analyzed as well (See Methods), and are included as part of the study area results, but are not presented here.

Example figures presented here illustrate the types of NWI complex scale assessment possible with the approach and results data (but do not include all generated outputs). Possible applications of these results data include:

- Areas in the watershed with most and least wetland storage relative to their runoff and sediment inputs
- Areas to target wetland restoration
- Wetlands that need special focus because of high function (e.g., wetlands that store their direct drainage runoff as well as significant upstream inputs from "spills")
- Areas contributing and not-contributing during specific design storms
- Areas where wetland function is high and redundancy is present

At the watershed scale, aggregated function can assessed for an overall picture and/or for comparison with other watersheds of the same scale. The table below presents select outputs aggregated for the Little Le Sueur HUC-12 watershed.

Table 3: Example Metric Results for Little Le Sueur HUC-12 Watershed

Metric	**Value**
Area of watershed (ac)	15,485
NWI wetland area (ac)	978
NWI wetland/complex area as percent of total watershed area	6
Runoff:	
Precipitation depth from 2yr/24hr storm design storm (in.)	2.7
Predicted runoff from 2yr/24hr storm (m^3)	960,092
Available NWI perm. storage vol. (m^3)	646,550
Available NWI perm. storage vol. as % of predicted runoff	67
Available NWI perm. storage vol. utilized for predicted runoff (m^3)	75,736
% Predicted runoff stored in available NWI perm. storage	8
% Available NWI perm. storage vol. utilized for predicted runoff	12
Sediment:	
Predicted sediment erosion mass from design storm (ton)	18,152
Predicted sediment erosion mass trapped by NWI perm. and temp. storage (ton)	7,890
% Predicted sediment erosion mass trapped by NWI perm. and temp. storage	43

Results in Table 3 show that while wetlands comprise 6% of the watershed by area, their permanent storage volume is perhaps a surprising 67% of the predicted runoff from a 2yr/24hr storm event. However, the fill-and-spill modeling results estimate that only 8% of this predicted runoff is actually stored (i.e., intersects dominant runoff flowpaths) and 88% of the total available storage volume is not utilized (i.e., 100%-12%). These results reinforce that wetland storage and inter-wetland connectivity is not often distributed uniformly in a watershed with respect to its runoff distribution. However, 43% of predicted eroded sediment from the design storm is estimated to be trapped in wetland permanent and temporary storage (as predicted by the relationship between available storage volume and incoming runoff volume – See Methods). This relatively high sediment storage proportion would seem to indicate that wetland storage is located in areas downstream/-gradient of dominant sediment erosion sources (i.e., row-crop agriculture with relatively high slopes and erodible soils). Note: fill-and-spill sediment erosion modeling was only conducted for the 2yr/24hr design storm; however, runoff modeling was conducted for all design storms (See Methods).

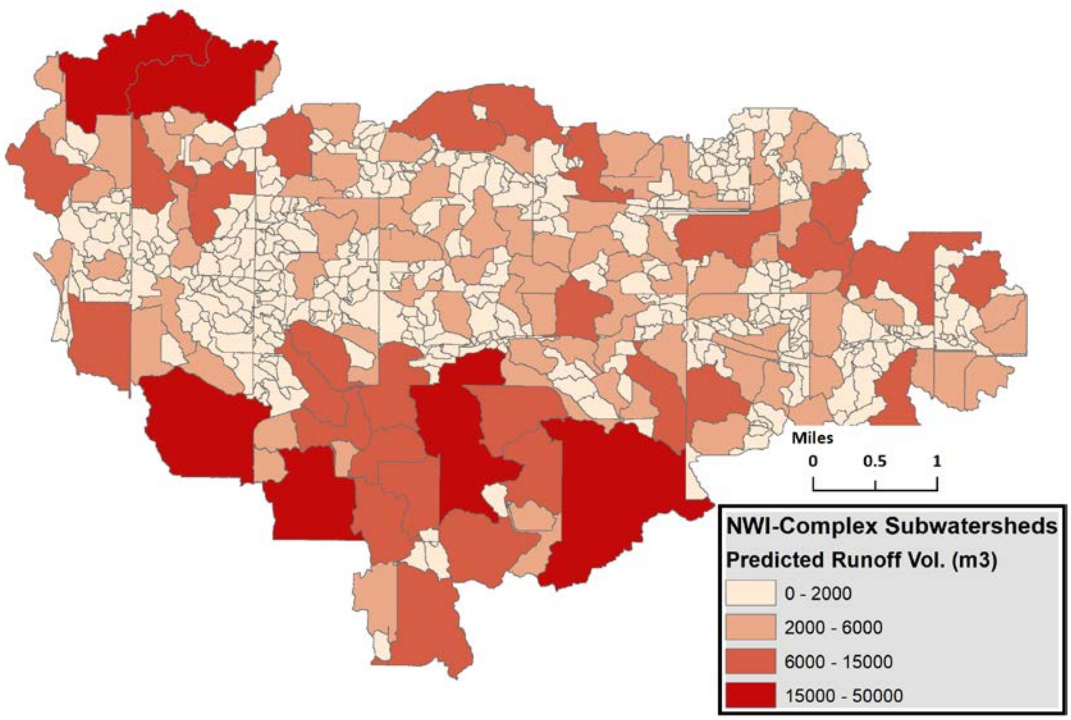

Figure 8: Predicted runoff volume for each NWI complex subwatershed for Little Le Sueur HUC-12 watershed. Because relative uniformity of soil and landuse conditions, runoff volume variability is mainly a result of subwatershed size.

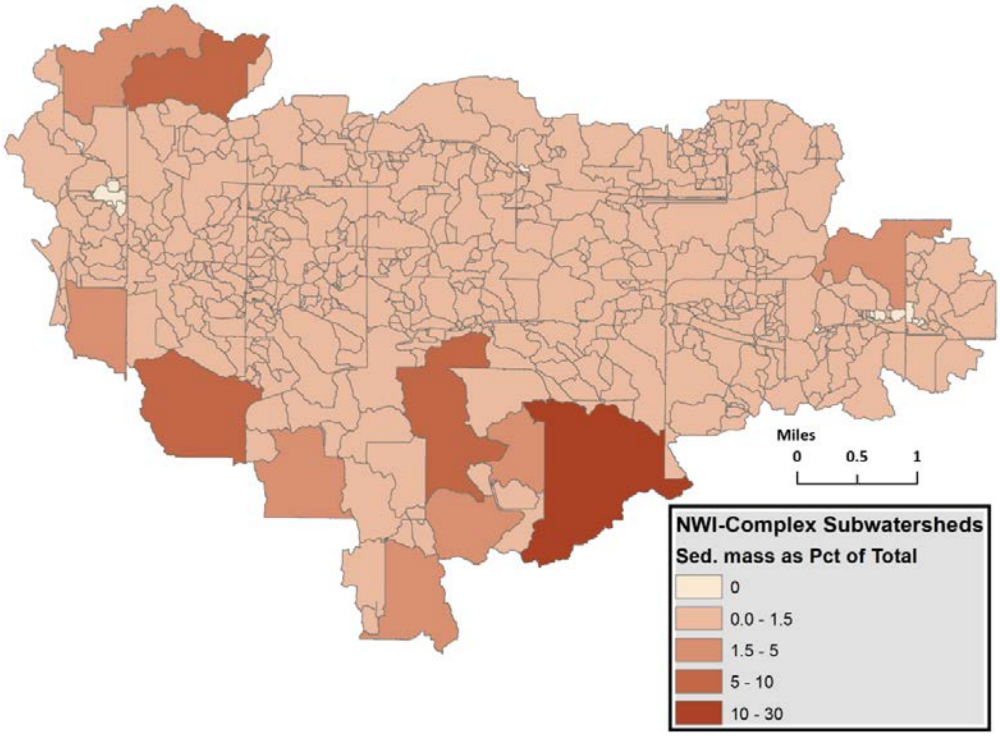

Figure 9: Predicted sediment erosion mass in NWI complex subwatersheds for Little Le Sueur HUC-12 watershed. Expressed as percent of total predicted sediment mass across entire HUC-12.

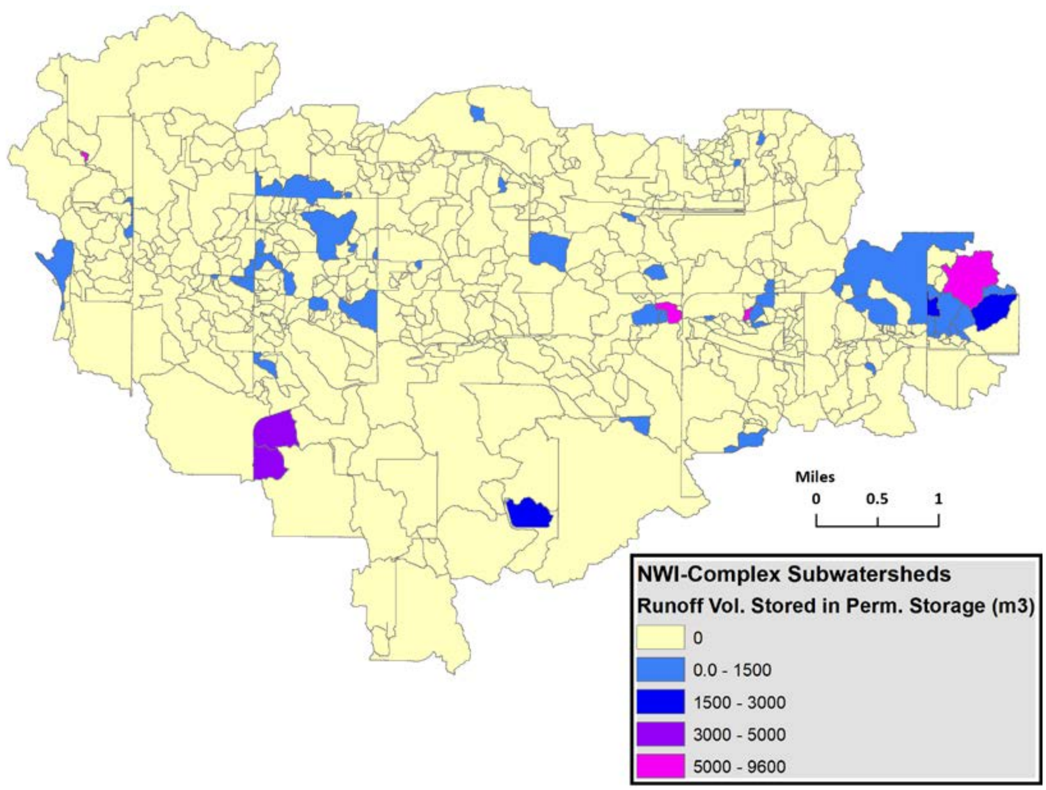

Figure 10: Predicted runoff volume stored in NWI complex permanent storage per subwatershed.

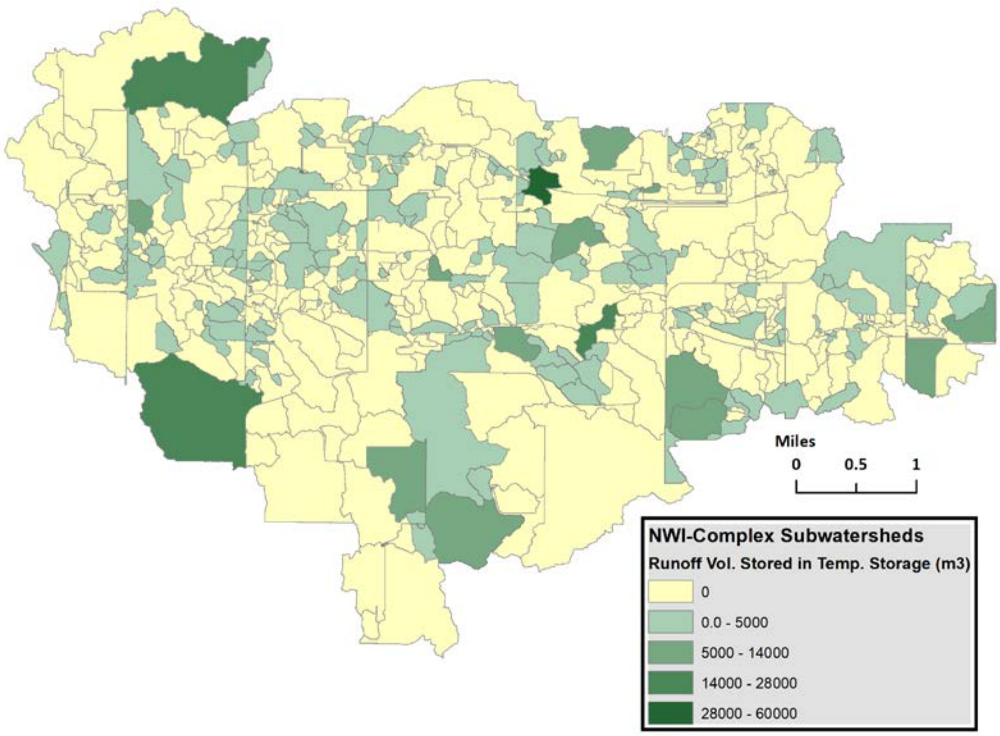

Figure 11: Predicted runoff volume stored in NWI complex temporary storage per subwatershed.

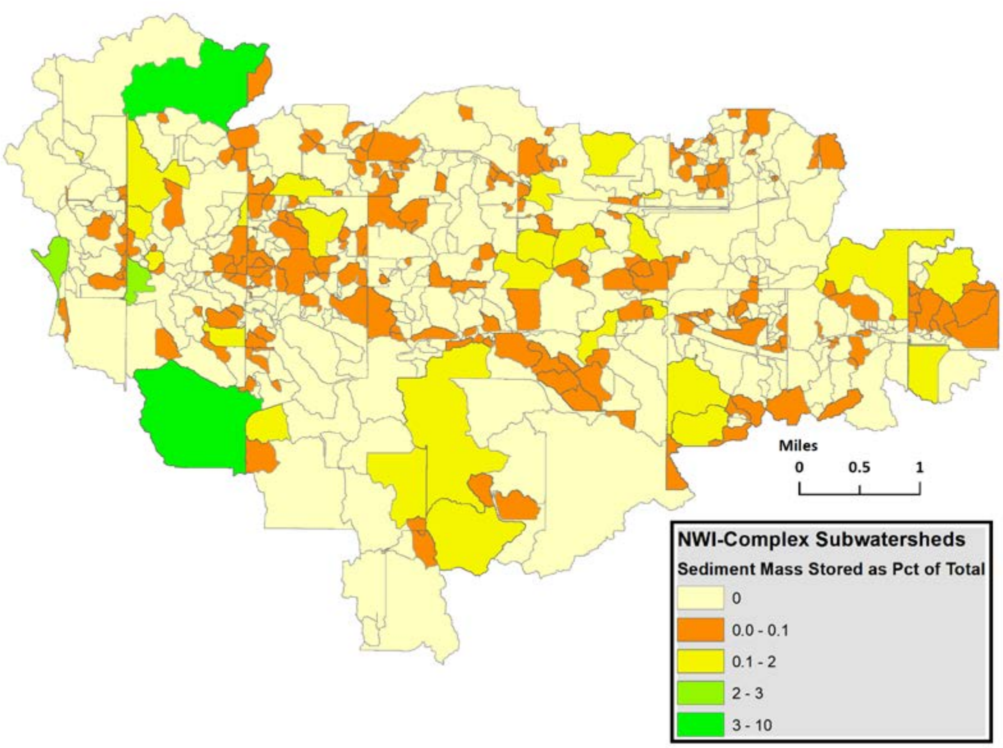

Figure 12: Predicted sediment mass trapped in NWI complex permanent and temporary storage per subwatershed as a percent of total watershed sediment trapped.

5.1.2 Groundwater Function

As discussed in the Methods, relative degree of recharge potential is the primary function targeted by the project approach. Figure 13 presents a proposed metric of potential recharge in 57 NWI complexes with permanent storage in the Little Le Sueur HUC-12 watershed. The potential is expressed as the fraction of total HUC-12 precipitation from a 1yr/24hr design storm stored as runoff in permanent storage based on the fill-and-spill results. Potential recharge fraction of design precipitation in NWI complexes ranged from near zero to 0.2% of total precipitation volume. Estimates of proportionalities of where recharge may be occurring (and where it may not be occurring) can be particularly important in altered landscapes like the Le Sueur, where a disproportionate amount of precipitation leaves the watershed as surface runoff, thereby bypassing groundwater recharge opportunities.

Other possible indicators of recharge potential could be explored with the existing approach and are included in the study area dataset. Examples include estimations of which NWI complexes with recharge potential as defined above have the highest saturated conductivity (soil K_{sat}) and total depressional perimeter – indicators of potential recharge rate and active recharge area, respectively.

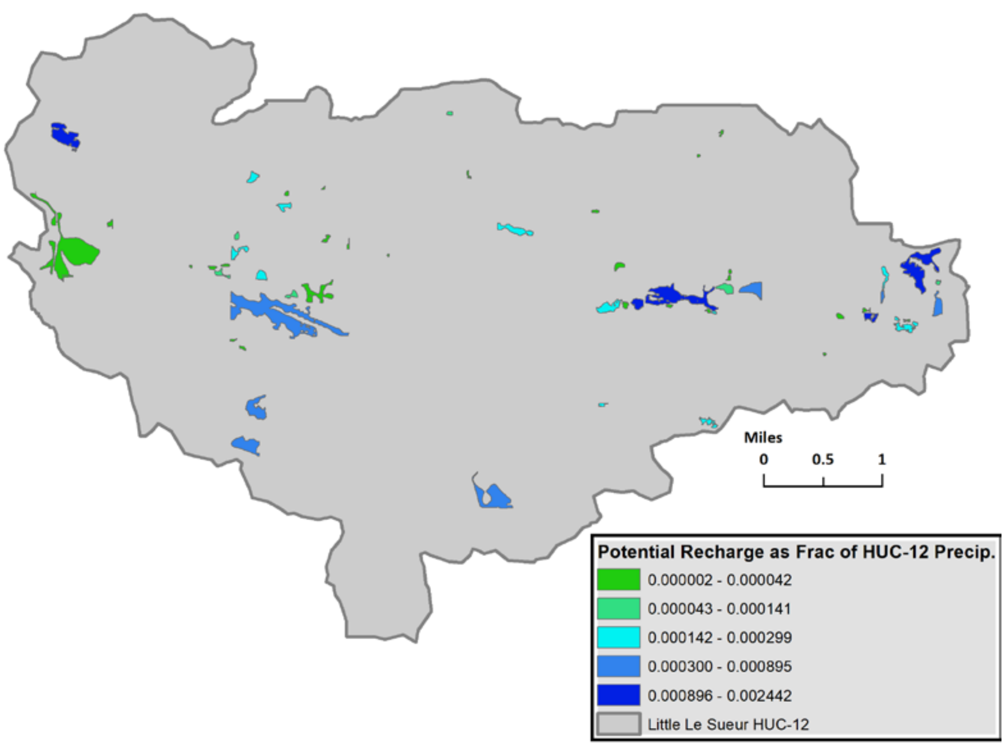

Figure 13. NWI complexes estimated to have greatest recharge potential based on permanent runoff volume stored for 1yr/24hr design storm as a fraction of total design storm precipitation for Little Le Sueur HUC-12.

5.1.3 Habitat Function

Habitat function was assessed using the fill-and-spill results to estimate runoff storage depth in temporary wetlands and the resulting inundation area at depths of 5 to 25 cm as an indicator of dabbling duck habitat suitability. Figure 14 presents these results for the Little Le Sueur HUC-12 watershed. Of the 325 NWI complexes in the Little Le Sueur, 38 were estimated to have optimal storage depth areas greater or equal to 0.25 acres (mean = 1.16 acres).

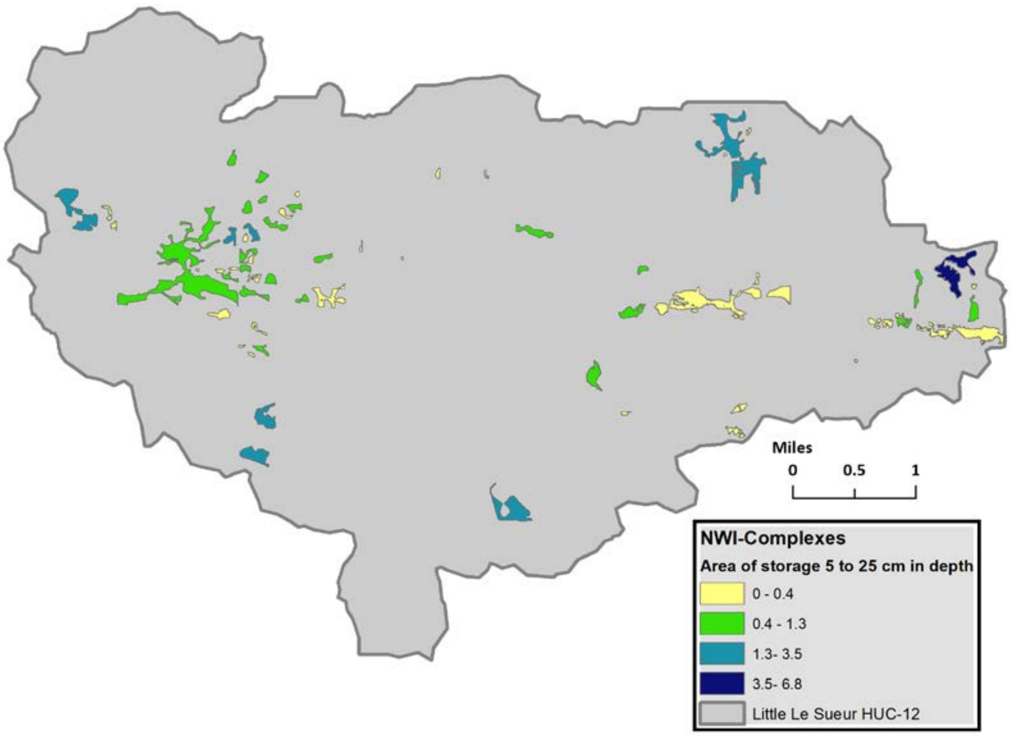

Figure 14: Estimates of dabbling duck habitat expressed as the area (acres) of NWI complexes at a depth range of 5 to 25 cm as a result of permanent storage of runoff from a 1yr/24hr design storm.

5.2 APPLICATION IN AREAS OUTSIDE STUDY AREA

Implementing the approaches outlined in this document outside the project's study area will require additional effort and development, as the project did not result in a set of GIS tools. This is particularly important in the case of the fill-and-spill modeling that is central to the project's functional assessment approach. However, here we suggest options to assess wetland function in areas outside the study area, while still leveraging the updated NWI:

1. **Use the project approaches as outlined in this document.** Implementation can use approaches directly *or in a simplified way*. Both these options are covered in the Methods and Appendices sections but require additional intermediate to advanced GIS skill/development.

2. **Use an established approach based mainly or exclusively on the SHGM attributes.** As discussed in the introductory sections, preliminary functional assessment methodologies have been developed that provide simplified, qualitative results using the SHGM attributes exclusively. Readers are directed to the work of Miller et al. (2017) and Tiner (2011). In addition, Miller et al. document a series of GIS based procedures to add further spatial context to SHGM based functional assessments.

3. **Extend results from the project study area.** This option entails using study area fill-and-spill results to help inform functional assessments outside the study area by means of statistical relationships. The following section discusses extending results to other watersheds to estimate aggregate hydrologic and water quality function, e.g., flood storage, sediment retention.

5.2.1 Extending project results from the study area

One approach for inferring watershed-scale wetland function is to correlate GIS variables that can be derived relatively easy with the study area fill-and-spill results—particularly, those estimating aggregated watershed permanent storage (applicable to estimates of flood storage, etc.). Example results presented above discussed the significantly greater *total* watershed permanent storage (from depressions) when compared to the storage predicted to be *utilized* during runoff events (resulting from uneven distribution of storage, inter-wetland connectivity, and runoff sources). Thus, given total storage, it would be of potential value to watershed planners, engineers, hydrologic modelers, etc. to be able to estimate the more applicable *utilized* wetland storage ("effective") available for runoff under a range of design storms.

To use the approach it is required that depressional analysis be conducted at known NWI polygon locations using a hydro-modified LiDAR. Depressional analysis will yield total "raw" permanent storage volume. As discussed in the Methods, this project used "corrected" permanent storage volume for fill-in-spill modeling. Corrected permanent storage was considerably less than raw due to certain depressional volumes being designated as temporary storage based on SHGM and Cowardin criteria.

Reviewing Table 5 reveals 17% of raw permanent storage being designated as corrected (representative) permanent storage across the 21 study watersheds (median percent of per-watershed percents). In other words, this project approach (through application of SHGM and Cowardin attributes) estimated over 80% of GIS derived depressional storage was actually not permanent but contained a surface or subsurface outlet not discernible using 3 meter LiDAR. If realistic, this is an important distinction when estimating potential watershed storage from depressional analysis, or more commonly, using total wetland/lake surface area as a proxy for watershed storage.

However, the extension of results lies in the percent of permanent storage volume (corrected) utilized to store runoff during design storms shown in Table 6. A median percent of 19% of watershed permanent storage is utilized as runoff storage for a 1yr/24 event and 53% for a 100yr/24hr event. Using these percentages as adjustment factors, analyses of raw or corrected depressional analyses can be extended to account for fill-and-spill behavior. An interpretation is that distribution of depressional storage is not uniform with respect to distribution of runoff, resulting in overestimates of flood storage at even small watershed scales if wetland fill-and-spill behavior/wetland network connectivity are not accounted for.

Further statistical analysis of the project study area results could yield additional insights. One example, similar to the approach above but without requiring LiDAR analysis, would relate study area results of total watershed flood storage from watershed different scales with the areal extent of NWI SHGM types constrained in the project to contain permanent storage (See Methods). Thus, a relationship between runoff stored in permanent storage and NWI polygons could be established to estimate watershed scale flood storage without the need for more detailed GIS analysis. Additionally, statistical relationships could be investigated such as the relationship between watershed area, shape, drainage density, landuse, slope and number and type of NWI features.

Table 4: Fill-and-Spill modeling inputs for 21-watershed study area: watershed area in acres; available raw and corrected permanent storage volumes as watershed depth, percent of raw perm. vol. as corrected perm. vol.; available temporary storage volumes expressed as watershed depths; precip depths of design storms per return period

Name	Acres	Perm. Vol. (in)			Temp. Vol (in)	Design storm depth (in) per return period (yr)						
		Raw	Corr	Pct		1	2	5	10	25	50	100
Airport Creek	10,544	1.35	0.33	24%	1.95	2.5	2.7	3.5	4.2	5.3	6.2	7.1
Browns Creek	16,473	16.1	12.71	79%	0.88	2.4	2.6	3.4	4.1	5.2	6.1	7.2
Cherry Creek	19,805	0.64	0.07	11%	2.72	2.5	2.7	3.5	4.2	5.3	6.2	7.2
East Branch Blue Earth	183,066	0.67	0.09	13%	0.74	2.6	2.8	3.8	4.6	5.9	6.9	8.1
Lac qui Parle	504,186	1.01	0.21	21%	0.86	2.2	2.4	3.1	3.7	4.6	5.3	6.1
Lake Hanska Watonwan	32,694	0.44	0.32	73%	1.84	2.4	2.6	3.4	4.1	5.1	6	6.9
Lake Wakanda	13,621	0.29	0	0%	0.71	2.5	2.6	3.3	4	5	5.8	6.7
Le Sueur	704,078	0.97	0.17	18%	1.25	2.5	2.7	3.6	4.4	5.6	6.5	7.6
Minneopa Creek	51,940	0.71	0.11	15%	1.31	2.5	2.7	3.5	4.2	5.3	6.2	7.2
Morgan Creek	35,503	0.43	0.09	21%	0.39	2.4	2.6	3.4	4.1	5.2	6	7
Shanaska Creek	23,644	3.31	0.4	12%	4.04	2.5	2.7	3.5	4.2	5.3	6.2	7.2
SF Watonwan	123,194	0.59	0.22	37%	0.6	2.5	2.6	3.5	4.2	5.3	6.2	7.2
Spring Creek	27,728	0.29	0.14	48%	0.16	2.4	2.5	3.3	3.9	4.9	5.7	6.5
Willow Creek	51,638	0.24	0.08	33%	0.2	2.6	2.7	3.6	4.4	5.5	6.5	7.6
YM1 - CD90	4,058	0.09	0.01	11%	0.1	2.2	2.4	3.1	3.7	4.6	5.4	6.2
YM2 - CD87	14,405	0.09	0	0%	0.1	2.3	2.4	3.1	3.7	4.7	5.5	6.3
YM4 – Unn. Creek	6,556	0.34	0.03	9%	0.27	2.3	2.4	3.1	3.8	4.7	5.6	6.5
YM4 - Stony Run Creek	35,088	0.15	0.02	13%	0.15	2.3	2.4	3.2	3.8	4.8	5.6	6.5
YM5 - CD39	13,147	0.08	0.05	63%	0.11	2.3	2.5	3.2	3.9	4.9	5.8	6.8
YM6 - CD09	47,445	0.7	0.11	16%	0.6	2.3	2.4	3.2	3.8	4.8	5.7	6.6
YM7- Yellow Medicine	427,121	0.64	0.16	25%	0.71	2.3	2.5	3.3	3.9	4.9	5.7	6.6
AVERAGES	**111,711**	**1.39**	**0.73**	**26%**	**0.94**	**2.40**	**2.57**	**3.36**	**4.04**	**5.09**	**5.96**	**6.91**
MEDIANS	**32,694**	**0.59**	**0.11**	**18%**	**0.71**	**2.4**	**2.6**	**3.4**	**4.1**	**5.1**	**6**	**6.9**

Table 5: Fill-and-Spill modeling results for 21-watershed study area. Predicted runoff depth and Runoff stored as permanent storage as watershed depth

Name	Predicted Runoff Depth (in) per design storm (yr)							Runoff Depth (in) stored in Perm. Vol. per design storm (yr)						
	1	2	5	10	25	50	100	1	2	5	10	25	50	100
Airport Creek	0.63	0.74	1.25	1.75	2.61	3.34	4.16	0.11	0.12	0.21	0.26	0.27	0.27	0.28
Browns Creek	0.44	0.54	0.97	1.41	2.17	2.87	3.7	0.42	0.51	0.91	1.3	1.93	2.42	2.98
Cherry Creek	0.69	0.81	1.34	1.86	2.74	3.49	4.32	0.02	0.02	0.03	0.03	0.03	0.03	0.03
East Branch Blue Earth	0.62	0.75	1.36	1.94	2.93	3.79	4.81	0.02	0.02	0.03	0.03	0.04	0.05	0.05
Lac qui Parle	0.5	0.59	1.02	1.43	2.09	2.68	3.35	0.03	0.04	0.05	0.06	0.07	0.08	0.09
Lake Hanska Watonwan	0.51	0.61	1.08	1.53	2.29	2.98	3.76	0.02	0.02	0.03	0.04	0.06	0.07	0.09
Lake Wakanda	0.68	0.74	1.2	1.7	2.45	3.16	3.94	0	0	0	0	0	0	0
Le Sueur	0.69	0.82	1.42	2.01	2.94	3.78	4.72	0.04	0.04	0.05	0.06	0.07	0.08	0.09
Minneopa Creek	0.55	0.66	1.15	1.65	2.45	3.18	4	0.03	0.03	0.04	0.05	0.06	0.07	0.08
Morgan Creek	0.47	0.56	1.03	1.49	2.27	2.96	3.74	0.01	0.01	0.02	0.03	0.04	0.04	0.05
Shanaska Creek	0.82	0.95	1.51	2.05	2.96	3.73	4.58	0.1	0.11	0.15	0.19	0.25	0.3	0.32
South Fork Watonwan	0.51	0.6	1.09	1.59	2.4	3.14	4	0.04	0.05	0.07	0.09	0.11	0.13	0.14
Spring Creek	0.52	0.57	1.04	1.47	2.18	2.82	3.55	0.01	0.01	0.02	0.02	0.03	0.04	0.04
Willow Creek	0.69	0.8	1.38	1.96	2.88	3.71	4.65	0.03	0.03	0.04	0.05	0.05	0.05	0.05
YM1 - CD90	0.41	0.51	0.91	1.3	1.95	2.56	3.25	0	0	0	0	0	0	0
YM2 - CD87	0.46	0.52	0.92	1.32	2.03	2.66	3.39	0	0	0	0	0	0	0
YM3 - Unnamed Creek	0.48	0.53	0.95	1.41	2.11	2.76	3.52	0.02	0.02	0.02	0.02	0.02	0.02	0.03
YM4 - Stony Run Creek	0.44	0.5	0.93	1.35	2.06	2.71	3.48	0.01	0.01	0.01	0.01	0.02	0.02	0.02
YM5 - CD39	0.43	0.53	0.93	1.39	2.13	2.82	3.63	0	0	0	0	0	0	0.01
YM6 - CD09	0.43	0.51	0.93	1.36	2.09	2.76	3.53	0.02	0.02	0.03	0.03	0.04	0.05	0.05
YM7- Yellow Medicine	0.51	0.62	1.09	1.55	2.31	2.98	3.74	0.03	0.03	0.04	0.05	0.06	0.06	0.07
AVERAGES	**0.55**	**0.64**	**1.12**	**1.60**	**2.38**	**3.09**	**3.90**	**0.05**	**0.05**	**0.08**	**0.11**	**0.15**	**0.18**	**0.21**
MEDIANS	**0.51**	**0.6**	**1.08**	**1.53**	**2.29**	**2.98**	**3.74**	**0.02**	**0.02**	**0.03**	**0.03**	**0.04**	**0.05**	**0.05**

Table 6: Fill-and-Spill Modeling results for 21-watershed study area. Percent of corrected and raw permanent storages storing predicted runoff per design storm

Name	Percent of Corrected Perm. Vol Storing Runoff per design storm (yr)							Percent of Raw Perm. Vol Storing Runoff per design storm (yr)						
	1	2	5	10	25	50	100	1	2	5	10	25	50	100
Airport Creek	33%	36%	64%	79%	82%	82%	85%	8%	9%	16%	19%	20%	20%	21%
Browns Creek	3%	4%	7%	10%	15%	19%	23%	3%	3%	6%	8%	12%	15%	19%
Cherry Creek	29%	29%	43%	43%	43%	43%	43%	3%	3%	5%	5%	5%	5%	5%
East Branch Blue Earth	22%	22%	33%	33%	44%	56%	56%	3%	3%	4%	4%	6%	7%	7%
Lac qui Parle	14%	19%	24%	29%	33%	38%	43%	3%	4%	5%	6%	7%	8%	9%
Lake Hanska Watonwan	6%	6%	9%	12%	19%	22%	28%	5%	5%	7%	9%	14%	16%	20%
Lake Wakanda	--	--	--	--	--	--	--	0%	0%	0%	0%	0%	0%	0%
Le Sueur	24%	24%	29%	35%	41%	47%	53%	4%	4%	5%	6%	7%	8%	9%
Minneopa Creek	27%	27%	36%	45%	55%	64%	73%	4%	4%	6%	7%	8%	10%	11%
Morgan Creek	11%	11%	22%	33%	44%	44%	56%	2%	2%	5%	7%	9%	9%	12%
Shanaska Creek	25%	27%	37%	48%	62%	75%	80%	3%	3%	5%	6%	8%	9%	10%
South Fork Watonwan	18%	23%	32%	41%	50%	59%	64%	7%	8%	12%	15%	19%	22%	24%
Spring Creek	7%	7%	14%	14%	21%	29%	29%	3%	3%	7%	7%	10%	14%	14%
Willow Creek	38%	38%	50%	62%	62%	62%	62%	12%	12%	17%	21%	21%	21%	21%
YM1 - CD90	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
YM2 - CD87	--	--	--	--	--	--	--	0%	0%	0%	0%	0%	0%	0%
YM3 - Unnamed Creek	67%	67%	67%	67%	67%	67%	100%	6%	6%	6%	6%	6%	6%	9%
YM4 - Stony Run Creek	50%	50%	50%	50%	100%	100%	100%	7%	7%	7%	7%	13%	13%	13%
YM5 - CD39	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%	0%	0%	0%	12%
YM6 - CD09	18%	18%	27%	27%	36%	45%	45%	3%	3%	4%	4%	6%	7%	7%
YM7- Yellow Medicine	19%	19%	25%	31%	38%	38%	44%	5%	5%	6%	8%	9%	9%	11%
AVERAGES	**22%**	**22%**	**30%**	**35%**	**43%**	**47%**	**53%**	**4%**	**4%**	**6%**	**7%**	**9%**	**9%**	**12%**
MEDIANS	**19%**	**22%**	**29%**	**33%**	**43%**	**45%**	**53%**	**3%**	**3%**	**5%**	**6%**	**8%**	**9%**	**11%**

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7 Appendix A: Project Study Area Information

Watershed name	Watershed area (ac)	NWI-complex total area (ac)[1]	Lentic (ac)	Lotic (ac)	Terrene (ac)
Airport Creek	10,595	1,509	449	45	921
Browns Creek	16,592	3,566	739	402	1,592
Cherry Creek	20,262	3,525	1,295	559	1,602
East Branch Blue Earth	183,508	11,914	1,774	3,878	4,986
Lac qui Parle	504,542	50,960	4,968	14,600	27,687
Lake Hanska Watonwan	32,815	2,936	2,093	127	575
Lake Wakanda	13,652	1,557	0	35	1,523
Le Sueur	704,481	60,437	18,590	15,357	22,370
Minneopa Creek	52,095	4,343	2,111	350	1,548
Morgan Creek	35,530	915	271	119	406
Shanaska Creek	24,065	6,317	4,111	346	1,728
South Fork Watonwan	123,586	6,725	1,879	2,498	1,880
Spring Creek	27,884	300	78	8	153
Willow Creek	51,732	1,294	26	508	635
YM1 - CD90	4,056	43	0	0	35
YM2 - CD87	14,402	165	0	14	115
YM3 - Unnamed Creek	6,555	281	0	108	161
YM4 - Stony Run Creek	35,081	1,019	0	325	614
YM5 - CD39	13,145	220	0	21	178
YM6 - CD09	47,432	1,759	36	106	1,215
YM7- Yellow Medicine	426,887	38,889	4,962	9,310	22,551

[1] NWI complexes are composed of dissolved NWI polygons combined with intersecting depressional areas; as a result, total complex area can exceed sum of Lentic, Lotic and Terrene areas.

8 APPENDIX B: PROCEDURES AND ALGORITHMS

8.1 OVERALL FILL-AND-SPILL PROCEDURE

#	Action	Tool	Description
1	Selectively Fill DEM	ArcGIS ArcHydro	• Create DEM with only NWI-complex + 100 m buffer – null-out raster in other locations. • Fill DEM
2	Identify Depressions and combine with intersecting NWI-complexes	ArcGIS ACPF	• Identification based on/constrained by intersection with NWI-complex polygons above using ACPF toolset • UNION depressions with intersection NWI-complexes
3	Calculate NWI Complex permanent depth and volume	ArcGIS Spatial Analyst	• Raster Calc: Sink Filled (ACPF) DEM - NWI filled DEM (ArcHydro) = depth • Convert Raster to Polygon: ACPF depressions • Create Zonal Stats raster: mean depth of each ACPF depression
4	Calculate NWI Complex temporary depth and volume	ArcGIS Spatial Analyst	• Convert NWI-complex outer boundary to polylines; convert to raster • Run Zonal Stats to get median elevation • Subtract median elevation from Filled-DEM to get temporary depth
5	*Create Drainage Points*	ArcGIS ArcHydro	Creates pourpoints intersecting max flow accumulation and NWI complex watershed boundary
6	*Cost Path*	ArcGIS Spatial Analyst	Creates least cost path raster between Drainage Points using (unfilled) DEM and Flow Direction as input and backlink rasters respectively
	Create Point Connectivity (Customized)	ArcGIS ArcHydro	• Convert Cost Paths to DrainageLines with up and downstream relationship attributes • Delineate Catchments for pour points and stream junctions • Results in NWI-complex network connectivity model

#	Action	Tool	Description
7	*Spatial Join* Catchments to NWI-complexes	ArcGIS	Uses zonal statistics: create linkage between ArcHydro Catchment and ACPF depression DA IDs
8	Join other important attributes	ArcGIS	Join Curve Number and dep geometry params (area, depth, volume, DA)
9	Export to CSV	ArcGIS	Make available to R
10	Process topology and calc fill and spill	R	R does the heavy lifting and exports a csv back to ArcGIS to be joined to depressional layers
11	Import CSV with results back into ArcGIS from R; Join to NWI Complex layer	ArcGIS	Make results viewable in ArcGIS

8.2 Fill-and-Spill Coding Approach

This appendix section lays out the procedural coding approach used for routing runoff through each NWI complex in the fill-and-spill analysis. As discussed in the Methods, a code was developed in R that used inputs from ArcGIS and resulted in outputs to be imported back into ArcGIS for visualization and analysis. However, the implemented code is at best a rough prototype and not in a form usable or discernible by potential users. Yet, using the pseudo-code below a code could be written to simulate the fill-and-spill methodology as implemented in the project using R, Python (in ArcGIS or QGIS) or Excel VBA. As with many programming problems, there are many ways to solve it coding wise; the methods presented here are but one way. The reader is encouraged to develop codes accordingly to their own logical understanding of the problem and the available data.

The approach requires an input file (the code relied on attribute table data exported as .csv files) of all NWI complex subwatersheds (1-row per subwatershed) with the following pieces of data:

Variable Description	Pseudo-Code Abbreviation
NWI Complex Subwatershed ID	SubID
Next Downstream NWI Complex Subwatershed ID	NextDownSubID
Available Permanent Storage Volume (m^3)	PermVol
Available Temporary Storage Volume (m^3)	TempVol
Curve Number	CN
Rain Event precipitation (in.)	Pcp

Calculate Runoff for each Subwatershed

We will need to compute the estimated runoff for each subwatershed resulting from a desired rain event using the NRCS curve number method. This could be done in ArcGIS prior to exporting the subwatershed attribute data (attribute table Field Calculation), in the exported .csv (using Excel and re-saving the file as .csv) or in the code/script. The formula, using Pcp in inches, is:

Runoff depth (in.) =

$RO = \frac{(Pcp - I_a)^2}{Pcp - I_a + S}$ for $Pcp > Ia$

$RO = 0$ for $Pcp \leq Ia$

Where $S = \dfrac{1000}{CN - 10}$ and $I_a = 0.2S$

This can be generally written programmatically as:

S = max moisture storage after runoff begins = 1000/CN – 10

Ia = initial abstraction = 0.2*S

RO = ifelse (Pcp > Ia, (Pcp - Ia)^2 / (Pcp - Ia + S), 0)

About Accessing and Modifying Variables Stored in Data Structures

An important provision of R data structures as well as SQL databases is the ability to find/access and modify many pieces of data simultaneously based on a set of query criteria; this is in contrast to a "conventional" procedural programming where if a given set of data needed to be modified, the individual rows/array elements would be found and selected, and then a routine would have to loop through each element, changing the data one element at a time. The approach used here assumes the ability to modify data (and add new data) in any number of elements simultaneously. This entails using query-like operations that can easily find specific subsets of data to be modified. The pseudo-codes below assume this ability and do not discuss it in detail. This type of data access/modification can be done easily in R using data.frames or in ArcGIS/QGIS python using collections or by modifying filegeodatabase tables directly using sql commands constructed and executed in python. An analogue for Excel may be possible but cannot be confirmed here.

Assign Subwatershed Order

First, a coding loop to assign an "order" for the main program to progress through each subwatershed (sub) starting from upstream to downstream. Each headwater sub (i.e., has no upstream subs) is assigned a 0, the next downstream subs are assigned a 1, the next downstream subs a 2, and so on until a watershed outlet is reached (i.e., no downstream sub available) which is assigned a -1. This ordering is necessary so that the code does not progress past any one sub until all of that sub's upstream subs (and their upstream subs and so on) have been processed and their resulting runoff outputs routed into that sub in sum.

Pseudo-code

1. Set all sub order variables to 0 to start (whether headwater or not).
2. Loop 1: Loop through each subwatershed (SubID) that is assigned the current loop order number (starts with 0)
   2.1. Find the immediate downstream sub associated with each subwatershed in the loop (there will only one sub immediately downstream) using the NextDownSubID and assign the downstream sub the current order number + 1.

2.2. Proceed with next pass through loop with new order equal to the current order + 1
2.3. Continue looping until watershed outlet is reached

Fill-and-Spill Processing

The fill-and-spill modeling starts with the headwater subs (assigned an order of 0) and loops through each order from 0 to the max order determined above. In each loop pass, the direct drainage runoff (calculated above or at this point in the code using the curve number method discussed above) is routed through any NWI complex permanent storage associated with the sub – not every sub has an NWI complex, and not every NWI complex has permanent or temporary storage volume. Any runoff exceeding the sub's permanent storage volume is assigned as part of the accumulated runoff inputs to the next downstream sub (i.e., is "spilled" into the next downstream sub). After the headwater subs have been processed (loop pass 1; order = 0), the runoff to be potentially stored in next downstream sub is the sum of its own direct drainage runoff plus the sum of all spills from any upstream subs connected to it (the sum of all spills is accumulated incrementally as each upstream sub is processed in turn). This process is continued until the last sub in the watershed has been reached. Runoff stored temporarily is passed to the next downstream sub (unlike permanently stored runoff) but this storage amount is recorded for post-processing analysis.

Pseudo-code

1. Set variable maxord = to the maximum order in all subs.
2. Loop 1: Loop through every order from 0 to maxord
    2.1. Loop 2: Loop through every sub (SubID) assigned to the current order
        2.1.1. Determine next downstream sub using NextDownSubID
        2.1.2. Calc total runoff to sub = direct drainage runoff + any upstream accumulated spill runoff
        2.1.3. If permanent storage volume (PermVol) exists, substract this volume from total runoff volume
            2.1.3.1. If this difference <= 0, then no runoff passes downstream and this sub and all its upstream connected subs are non-contributing to the watershed outlet for the rain event.
            2.1.3.2. If this difference is > 0, this is amount of runoff spilled and is added to the *accumulated* inputs for the next downstream sub (next downstream sub inputs = next downstream sub inputs + runoff spills from current sun)
            2.1.3.3. If this difference is > 0, subtract any temp storage volume (TempVol) from this amount and assign the difference to the current sub

8.3 Extension of Fill-and-Spill Modeling Approach for Water Quality

8.3.1 Estimation of subwatershed peak flows

1. **Calculate per-pixel travel times based on MnDNR Travel Time Tool.**

This python-based ArcGIS tool (Loesch 2017) uses manning's equation to estimate velocity-based travel times across every LiDAR pixel (in this case, 3 meter resolution). The tool uses 15-meter landuse (resampled to 3-meter) as a determinant of manning's *n* roughness on a per pixel basis, LiDAR derived slope, and accounts for different tiers of hydraulic radius based on Flow Accumulation thresholds (as a proxy for decreasing flow retardance due to flow convergence) as well as known, mapped channels. The output of this workflow was a travel time raster (time to travel across each pixel) for each of the study area's 48,000+ subwatersheds. The approach is based on that implemented in PTMapp (BWSR 2016).

2. Calculate accumulated travel times to each subwatershed outlet and output resulting travel time distributions using custom ModelBuilder workflow.

A ModelBuilder tool was constructed to iterate through and clip each subwatershed's required LiDAR derived rasters, determine the accumulated travel time from every LiDAR pixel to its closest downstream subwatershed outlet, and export the output as binned histogram data. The Flow Length tool (Spatial Analyst) was used to calculate accumulated downstream travel times; the process uses Flow Direction as the main input and the previously generated travel time raster as the optional weight raster. The Flow Length approach is based on that implemented in PTMapp.

The resulting raster for each subwatershed was processed using the Zonal Statistics to Histogram tool which split each travel time distribution into 256 bins (each bin representing a time increment equal to 1/256 the maximum accumulated travel time for each subwatershed). Lastly, the model exported the histogram data as a .dbf database table file unique to each subwatershed.

3. Convert subwatershed travel time distributions to runoff hydrographs in R.

An R code was developed to generate runoff hydrographs for each subwatershed outlet. The code incorporates (1) the design storm total rainfall depths with (2) gridded Atlas 14 rainfall distribution curves for 24-hour storms (all design storms used in this project were 24 hours in duration) and, (3) travel time distributions derived in the process above.

The Atlas 14 (NOAA 2013) curves disaggregate the 24-hour design storm total precipitation depths into a 15-min interval time series -- i.e., a hyetograph. It was decided that a representative timestep for the resulting runoff hydrographs would be 1-minute as it was observed that the lowest range of maximum travel times (i.e., the maximum time from any pixel to the outlet)) for all project subwatersheds was commonly 10 minutes and less. Thus, the rainfall hyetograph was further disaggregated (using linear interpolation) into 1-minute timesteps, and resulting runoff volume per-timestep simulated using the curve number method. Since travel time distribution intervals varied widely (i.e., each interval being 1/256 of the maximum travel time for each subwatershed), these intervals were either aggregated or disaggregated (using linear interpolation) to produce a 1-minute travel time distribution for each subwatershed. (Aggregation vs. disaggregation applied depending on whether maximum travel time was greater than or less than 256 minutes, respectively.)

Last, the runoff hydrographs for each subwatershed were generated by "overlaying" the runoff volume vs. hyetograph time series with the travel time distributions whereby the each timestep's runoff volume was "lagged" by the travel times in the travel time distribution. The resulting hydrographs aided in quantifying the fill-and-spill timing of NWI complexes with permanent and temporary storage. In addition, peak flows from the hydrographs were a necessary input to the MUSLE erosion model. A similar approach for deriving travel time distributions is found in Usul and Yilmaz (2002). Project applications of the runoff hydrographs are described in more detail below.

8.3.2 Prediction of water quality pollutant export and fill-and-spill integration

1. Prediction of design storm sediment loads using GIS enabled MUSLE model

An important consideration of wetland water quality function is how much sediment a wetland receives. For example, a wetland of otherwise equivalent geometry and trapping efficiency compared to another wetland will have a higher level of function if it receives a higher mass of sediment. To most explicitly predict sediment erosion and transport as it pertains to wetland trapping processes, event based simulations that incorporate flow rates are most appropriate. However, the widely used RUSLE model (used in PTMapp) is an annualized prediction model and therefore cannot take into account event based runoff rates and runoff volumes for erosion prediction. A less frequently implemented but more appropriate approach is to use the event based MUSLE model (used in the model SWAT; Arnold et al. 1998) which uses the same multiplicative factors for as the RUSLE model (R, C, K, LS, P) except that it replaces the annual rainfall erosivity factor R with a runoff factor that is composed of peak runoff rate and total runoff volume. This approach avoids the necessity of estimating a sediment delivery ratio. An existing ArcGIS approach (Blaszczynski 2003) designed to implement MUSLE using subwatershed peak runoff rates and total runoff volumes while also accounting for subwatershed Flow Accumulation patterns was adapted to predict sediment erosion mass from each design storm delivered to the subwatershed outlet.

2. Extending design storm sediment loads to include associated phosphorus.

Many approaches for estimating phosphorus loading assume a landuse-specific event mean concentration or annual per unit area mass yield. However, as phosphorus mass is tied to sediment mass to a considerable degree, and that sediment mass was already estimated in previous steps, an approach directly relating phosphorus to sediment was used. An example of this approach is the HSPF model which uses a sediment-phosphorus potency factor that relates sediment mass to phosphorus mass (per landuse) by use of a ratio – i.e., phosphorus mass per unit mass of sediment. As such, MPCA’s Minnesota River watershed HSPF model documentation was consulted for potency parameter values, and a lookup table created relating the project study area’s landuse raster values to potency factor. Mean subwatershed potency factors were then computed using Zonal Statistics and multiplied by the predicted subwatershed sediment mass to calculate phosphorus eroded and delivered to the subwatershed outlet.

3. Incorporate flow rates and sediment/phosphorus transport into fill-and-spill methodology.

Once subwatershed runoff rates and associated sediment and phosphorus were estimated for design storms, the methodology was integrated into the existing fill-and-spill R code to enable routing of sediment and phosphorus through any NWI complexes present in the subwatersheds and to any downstream subwatersheds. The code first checks to see if any NWI complex permanent and/or temporary storage exists in the subwatershed. If so, the sediment/phosphorus is routed through the storage uniformly distributed with the runoff hydrograph (i.e., concentrations of sediment and phosphorus are constant over all timesteps of the hydrograph). It was assumed for this analysis that filling and spilling occurred instantaneously rather than in a lagged manner -- i.e., when spilling occurred during a timestep, volume spilled equaled volume filled. Therefore, the driver of residence time was the time it took for the NWI complex storage to fill to the point of spilling, rather than also including the likely reduction in spill rate relative to fill rate because of the flow (hydraulic) characteristics of the natural wetland outlet.

Sediment and phosphorus settling behavior of NWI complexes required some simplifications both because of the simplification of filling and spilling rates discussed above but also because of the inherent complexities and unknowns involved in predicting settling in water bodies irrespective of flow rates, e.g., incoming sediment particle size distributions, turbulence, resuspension, effects of vegetation, “short-circuiting” of storage volume preventing “stirred reactor” assumptions, etc. A relatively easy approach was adapted from PTMapp that was reasonably representative of important variables but not parametrically or computationally intensive. In PTMapp, trapping efficiency of a water body is a function of the ratio between incoming flow volume and permanent storage expressed as a user-defined analytical curve that varies trapping efficiency between zero and a maximal value based on literature – in this project, it was assumed maximal trapping efficiency to be a relatively conservative 75% based on literature values presented in the MDA Ag BMP Handbook (Lenhart and Peterson 2017).

An additional consideration was also included in the rate-based fill-and-spill code that acknowledges that sediment/phosphorus deposition occurs irrespective of intersections with depressional wetland storage as a function of the distance traveled from the point of erosion to the nearest downstream watershed outlet. Here, subwatershed travel time distributions were used again to implement another PTMapp approach to reduce sediment and phosphorus masses based on analytical curves formulated using concepts of exponential decay. Adopting this additional approach prevented wetlands from being the sole source of deposition and therefore their water quality function overvalued in watershed scale analyses.