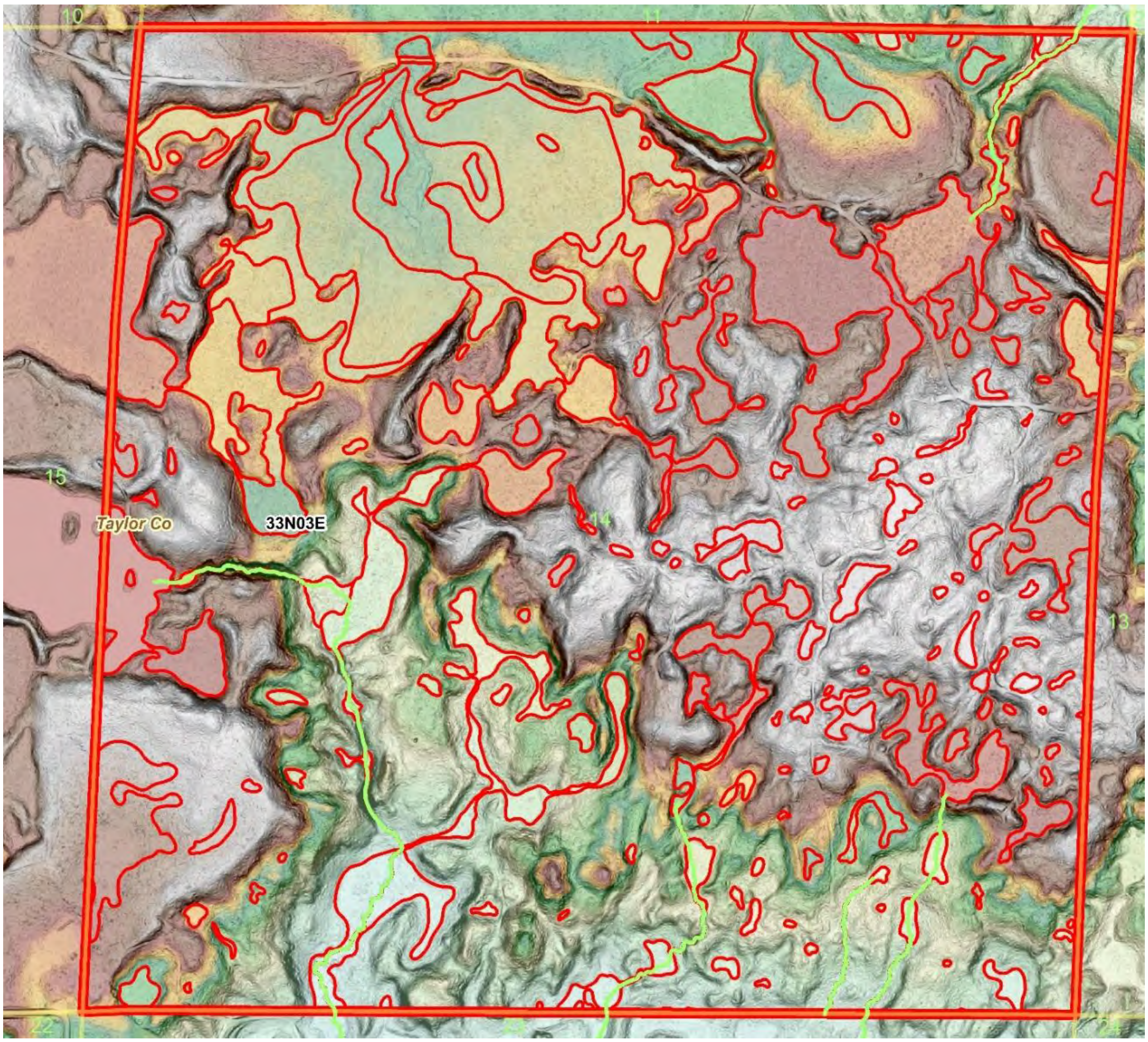
WDNR Integrated Wetland and Surface Waters Pilot Study: Progress Toward an Improved, Modernized GIS Data Production Model for the Wisconsin Wetland Inventory (WWI)



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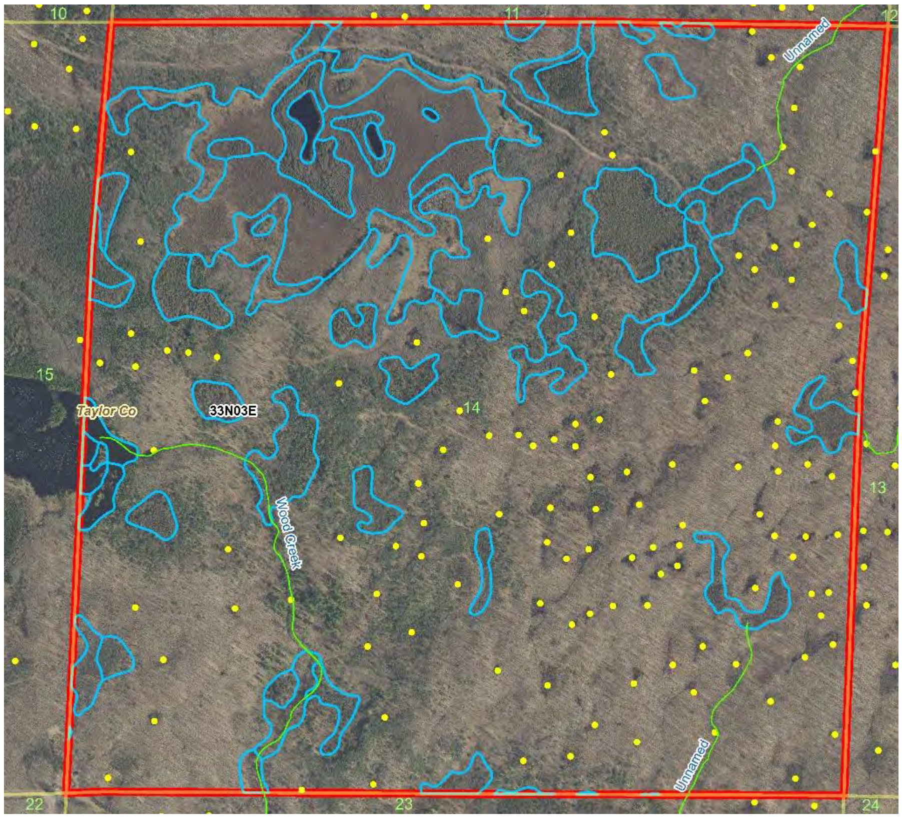

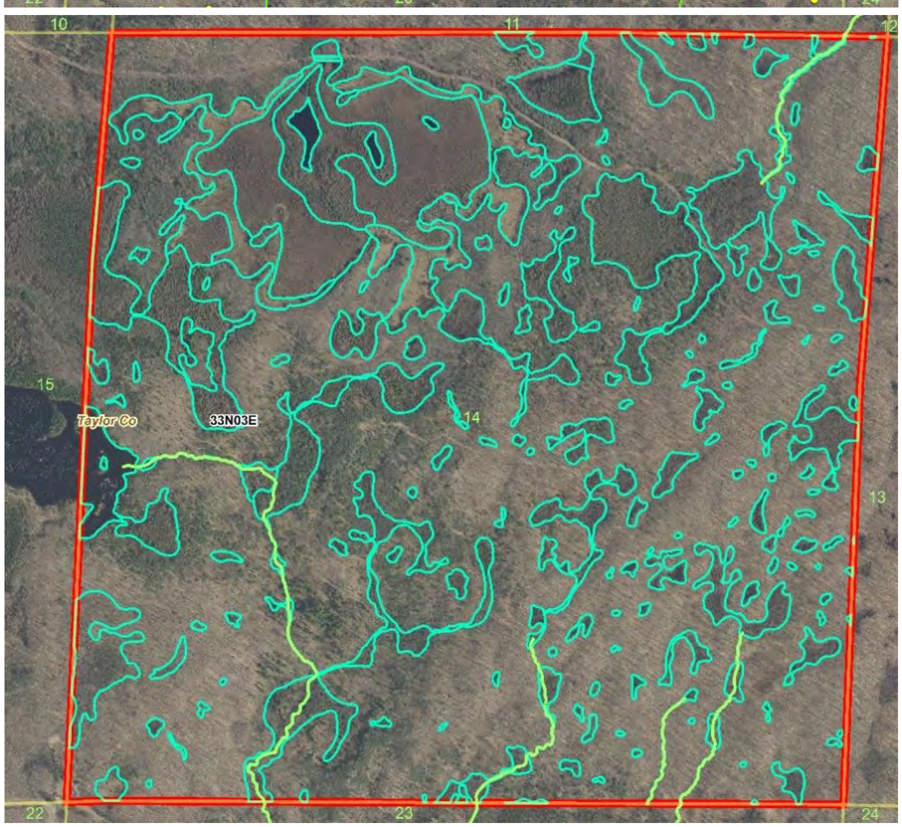

WDNR Integrated Wetland and Surface Waters Pilot Study: A Framework for Creating an Improved, Modernized GIS Data Production Model for the Wisconsin Wetland Inventory (WWI)

Wisconsin Department of Natural Resources
Final Report to USEPA- Region V
December 2020

Final Report to the United States Environmental Protection Agency Region 5 documenting completion of "Component 3" of the WDNR FY 2016 EPA Wetland Program Development Grant. Prepared by Wisconsin Department of Natural Resources and funded under EPA Wetland Program Development Grant #CD00E02075

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Front Cover Image *– LiDAR visualization using semi-transparent color-stretched elevation overlaid with slope. This combination allows for viewing and interpretation of the landscape in unprecedented detail.*

Inside Cover Images *- Comparison of analog hard-copy data drafting (top) end-product with new lidar and high-res image-based product (bottom) within a 1 square mile section of Taylor Co (T33N 3E Sec 14). Expert staff required 2 hours and 50 minutes to remap this square mile, much longer than average. For this effort, point symbols have been upgraded to accurate boundaries which, along with improved boundaries elsewhere, captured fifty-three additional acres (8.2% of the total section area) of wetland in addition to two added intermittent streams over what was captured with previous WWI methods.*

Disclaimers, Statements, and Acknowledgements

Statement Regarding Data Produced with Grant Funding for this Project

As of December 2020 – Wetland GIS Data produced for the WDNR Wisconsin Wetland Inventory (WWI) and discussed in this document have completed linework production and passed internal review using NWI QA/QC tools, however as of writing individual watersheds are still undergoing official review by USFWS National Wetland Inventory staff and contractors and as a result cannot be considered "final". This means data produced for this report will not be publicly available for download or viewing until various dates in 2021. To request data in the meantime, contact Calvin Lawrence (calvin.lawrence@wisconsin.gov). The WWI has a GovDelivery account for the purposes of communicating updating stakeholders. To receive emails regarding WWI updates, please follow the steps below.

1.) Visit https://public.govdelivery.com/accounts/WIDNR/subscriber/new and submit your email.
2.) Expand the "Water" sub-group
3.) Scroll down to the "Wisconsin Wetland Inventory" and check the box
4.) Click "Submit" at the bottom of the page.

Statement Regarding Origins and Authorship of Data Production Methods Developed Herein

Staff from Geospatial Services (GSS) at St. Mary's University in Winona, MN were contracted to provide WDNR staff beginning education about NWI standards and conventions, draft preliminary production methods for WDNR to follow, and consulted WDNR staff on their initial wetland map production efforts through the end of 2018. Following the conclusion of this initial contract and delivery of their final report (Start et al. 2019), WDNR staff independently reviewed the methods contributed by GSS staff while continuing to refine and develop methods internally. Unless specifically noted, the majority of methods and procedures developed under this grant project, outlined in this report, and documented in the WWI's Standard Operating Procedures (SOP) manual were developed, curated, and refined by WDNR staff and represent their preferred data production methods for the foreseeable future.

All methods developed for this project are intended to comply with base National Wetland Inventory (NWI) standards and conventions initially developed by Cowardin et al. (1979) and further refined by the Federal Geographic Data Committee (2013).

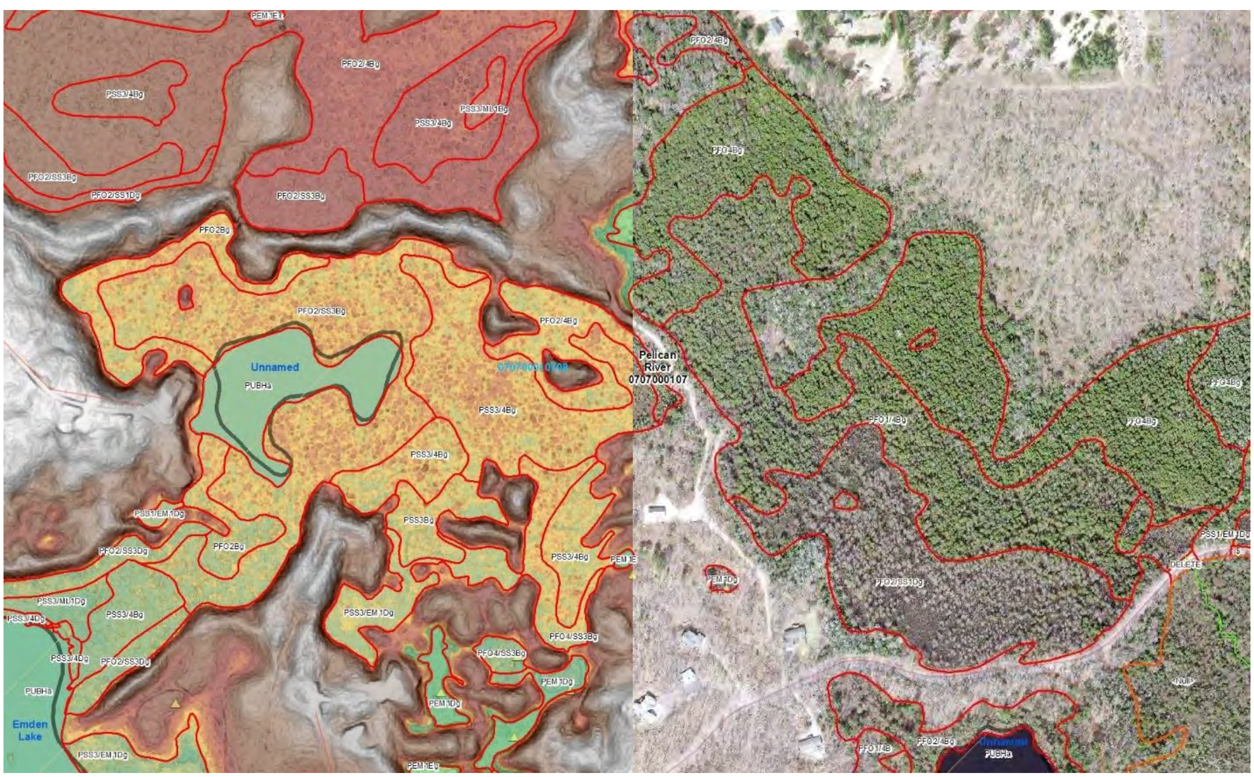
Christopher Noll conceptualized and documented all LiDAR visualization & wetland interpretation methods described in this report except for Hydrography Position Index (HPI) modeling, drafted Wisconsin-specific & NWI-compatible polygon attribution classes, designed feasibility data production methods, performed data analysis, organized and authored the bulk of the SOP, programmed all Python Add-In toolbars & scripts for ArcMap, and provided ongoing instruction & guidance to WDNR colleagues to ensure the quality of new wetland data being produced.

Calvin Lawrence documented and refined HPI production methods and provided insights on the historical context of the existing WWI and documented efforts to verify mapped wetlands in the Flynn Lake HUC-12 watershed in Bayfield Co.

Christopher J Smith made significant contributions to fulfilling mapping objectives through the production of final GIS data for several watersheds, verifying linework in the field, and working through early efforts to determine various flow accumulation modelling techniques presented a cost-effective approach to capturing hydrography data.

Acknowledgements

The authors thank our partners, colleagues, and friends who made this project possible. None of this would have happened without a generous grant from the U.S. Environmental Protection Agency, Region 5 Watersheds and Wetlands Branch. Special thanks to Tom Bernthal (DNR Wetland Monitoring and Assessment Coordinator *Emeritus*) who was able to transform the original idea for this effort into a successful grant proposal and Lois Simon, long-time WWI Program Coordinator, who led the charge to secure funding to finish mapping the state under the previous under the old standard before retiring in 2016. In addition, we also thank the staff of Geospatial Services at St. Mary's University for sharing their experience, efforts training WDNR staff, and drafting the first round of pilot mapping methods. The WDNR is also grateful for the ongoing discussions, feedback, and support provided by the US Fish and Wildlife Service National Wetlands Inventory National Standards and Support Team. The authors also wish to acknowledge our appreciation for the long-term grant support of the NOAA Coastal Management Program and their willingness to allow time to be spent on developing these new methods that will eventually be applied to coastal counties. Lastly, we offer our sincere thanks to the many additional individuals who have helped this effort along the way and apologize for their unintentional omission here.



Above *– Side-by-side comparison of two adjacent wetland complexes viewed with aerial imagery and LiDAR visualization (histogram-equalized bare earth elevation raster set to 50 percent transparency overlaid with a grayscale slope raster). LiDAR visualization accentuates the slope inflection point signaling the transition from upland soils to sloping plains of organic, hydric soils and allows for clear interpretation and capture of wetland boundaries with exquisite detail in this kettle-bog landscape.*

Project Summary

From 1979 until 2017, the Wisconsin Wetland Inventory (WWI) produced wetland polygon and point data using hard-copy drafting and digitization techniques. While drafting and digitization methods were refined and improved over time, the overall workflow and polygon attribution remained consistent as outlined in the 1992 Wisconsin Wetland Inventory Classification Guide (PUBL-WZ-WZ023). The primary strength of the hard copy drafting methods rested in the ability to view stereo pairs. The capacity for infrared-sensitive stereo pairs to emphasize localized wet depressions in the landscape was a valuable feature that was not easily replicated in the desktop GIS realm until the widespread commercialization of Light Detection and Ranging (LiDAR) technology beginning around 2005 which eventually led to entire, contiguous counties being mapped with high-accuracy bare earth digital elevation models.

With statewide data coverage from this hard-copy standard completed as of 2017, the increasing obsolescence of monochrome film-based image acquisition materials, and significant advances in GIS data & availability, the time was ripe to consider major changes to the WWI for the program to continue producing wetland maps relevant to agency and customer needs.

During this overhaul process, a major area of consideration was how to attribute polygons. Because the WDNR's wetland mapping efforts began around the same time as those of the NWI and old habits die hard, Wisconsin maintained its own wetland classification system for decades as 49 other states adopted using the standards set by the Cowardin Classification System (Cowardin et al. 1979). While the systems were roughly equivalent, they diverged in the WWI's relative lack of hydrologic modifiers versus the NWI's more numerous and descriptive modifiers which caused translational issues when attempting to port attribute data from one system to another.

Due to this history, in early phases of this pilot project it was not clear if an attempt should be made to maintain the WWI Classification System alongside NWI-standard Cowardin (et. al 1979). However, since a primary objective of this Pilot Study was to create wetland maps that are fully compatible with NWI standards, by default WWI staff had no option but to attribute wetland polygons using the Cowardin Classification System for all data produced. This requirement created two possible attribution scenarios. The first, more complex scheme would entail maintaining the WWI and Cowardin classification systems in parallel and require significant expenditures in time and money to dual-attribute potentially millions of future polygons. The second scenario would require only using the Cowardin Classification and retire the old WWI classification system.

The second scenario was preferred form a production standpoint, however with decades of history and use behind the WWI Classification System the decision was made to proceed cautiously before abandoning it altogether. To get a sense of stakeholder opinions, in spring 2018 WWI staff surveyed users on how they interacted with wetland map data. This questionnaire was distributed at the 2018 Wisconsin Wetland Association's Wetland Science Conference in Lake Geneva and at two 2018 Critical Methods workshops. Ninety-three responses were tallied. Of these results, only 2% of respondents thought switching to the Cowardin Classification System would have a negative impact. This result lent strong support for the decision to discontinue use of the WWI Classification System and adopt NWI FGDC (2013) mapping standards and the "Cowardin" classification system.

As part of the WDNR's FY2016 EPA Wetland Program Development Grant, "Component 3" funds were designated for the pilot wetland mapping study described in this report to "design, test, and evaluate a process to map wetlands and surface waters in tandem from the same data sources, to produce a single Integrated Surface Waters and Wetlands GIS Layer." A primary goal of this project was to create improved, modernized methods and a viable operating model for the Wisconsin Wetland Inventory (WWI) to follow. Specific objectives laid out in the original grant proposal and work done to satisfy them are outlined below.

Description of Work Completed Toward Objectives

As originally written, the Pilot Study aimed to complete three primary objectives:

1.) *Create a "new integrated surface water and wetland GIS layer for 10 watersheds and one county in the pilot study"*
   a. Mapping 10 pilot watersheds: Completed. See "Appendix A".
      i. Five WDNR-produced HUC-12 watersheds were mapped in addition to five St. Mary's watersheds which integrate surface waters and wetlands that satisfy the most updated NWI standards (FGDC 2013). In total, 199,284 acres were mapped toward this objective. See "Appendix A" and "Appendix C".
   b. Mapping one county: Completed, with a caveat. 361,739 acres mapped toward this objective. See "Appendix A" and "Appendix C".
      i. The WDNR took a different track with respect to the original wording of this deliverable and instead sought to map the *equivalent area* of a Wisconsin County. The average area of a Wisconsin County is 498,500 acres, with a standard deviation of 197,511 acres. The 361,739 acres mapped to satisfy this objective fall well within the realm of a typical Wisconsin county in terms of area. The primary reason for this change owed to the fact that new mapping project boundaries were based on HUC-12 watersheds which do not align with political boundaries. WDNR staff also felt that greater opportunities for outreach and partner engagement could be created by distributing new mapping projects across the state. As a result, WDNR staff were able to engage USFS staff with new mapping in the Chequamegon Nicolet National Forest, partners involved with Sheboygan River EPA Area of Concern, Water Resources staff for the Lac Du Flambeau Tribe, and map in widely divergent landscapes like the Driftless Area, glaciated north woods, central sands, and agriculture-dominated plains of the southeast.

2.) *"Perform an accuracy assessment of the new GIS layers."*
   a. Accuracy assessment completed for some, but not all, pilot and county equivalent watersheds.
      i. Most county equivalent watersheds were produced during the winter of 2019/2020, and the ensuing Covid-19 pandemic in 2020. As a result, WDNR staff ability to engage in field work and overnight travel was severely constrained.

ii. WDNR staff conducted field reconnaissance for the purpose of confirming mapping decisions in Mud Creek (Monroe Co), Duck Creek (Adams Co), Pheasant Branch (Dane Co), N. Fork Main Creek (Rusk Co), and Flynn Lake.

iii. During Covid-19 work from home orders, WDNR staff received assistance from US Forest Service Chequamegon Nicolet National Forest Staff in the four HUC-12 project area covering the Upper Rat River in Forest Co.

iv. Where possible, WDNR staff referred to Timed Meander Survey data captured during the Wetland Floristic Quality Benchmarks Study (Marti et al. 2019), effectively serving as ground-truth data.

3.) *Assemble "A set of cost estimates for applying the pilot mapping techniques to new areas and a report discussing feasibility issues and making recommendations for implementation of new techniques."*

   a. Completed by means of test-mapping nearly 100 randomly selected PLSS sections stratified across three categories of density: Low, Medium, and High under controlled, timed conditions. See discussion under the "Statewide Feasibility Mapping and Cost Estimate" section of the report below.

Lastly, the intended outcome of "Component 3" was stated as:

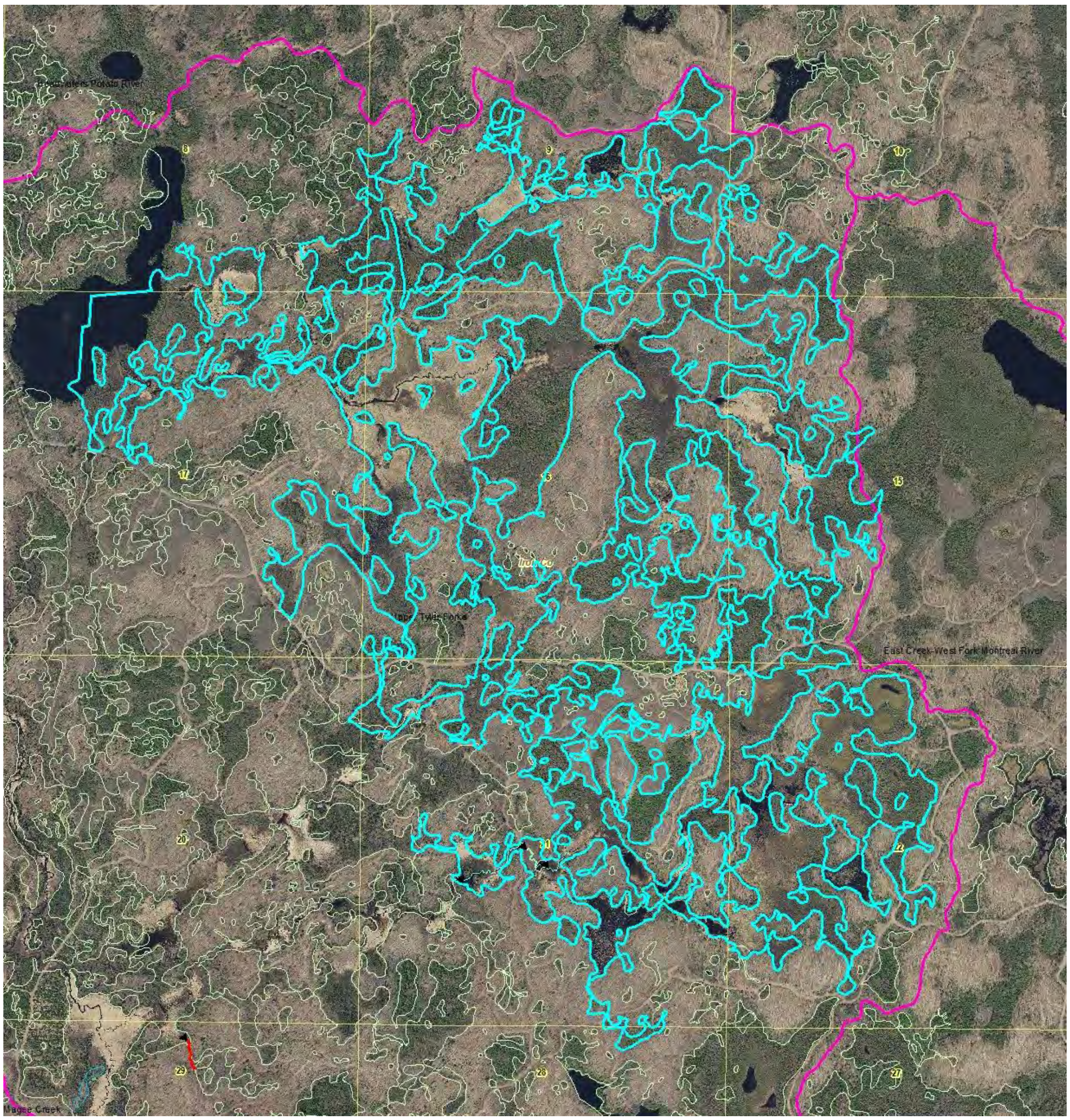
1. *"Improved mapping and data integration methods will improve the watershed approach decision support tools currently in development and provide better data to a wide variety of users that can lead to more effective protection measures and more successful restoration projects."*

   a. The authors are cautiously optimistic this will be the case, but there is great uncertainty in terms of future funding and acknowledge a truer test of success will be decided in future years.

      i. The LiDAR-based wetland mapping tools, processes and procedures developed under this grant project doubtlessly allow WDNR staff to capture wetland boundaries with far greater accurately, consistently, and completeness than is possible with the base photointerpretation standards outlined by NWI FGDC standards (2013). The authors are also confident that that LiDAR based wetland mapping methods do a far better job of capturing important qualities of wetlands like connectivity with surface water and hydrogeomorphic position.

      ii. Improving decision support tools for watersheds will require the consistent, efficient production of high-quality maps in order to cover all 1,826 HUC-12 watersheds that intersect Wisconsin's boundary in a realistic time frame of 10-20 years. Accomplishing this task will require forward looking vision, investments in team building, and attention to retaining, supporting, and advancing quality staff over a timeframe of years. As of the writing of this report, wetland mapping at the WDNR is funded almost entirely by federal grants and capacity for WDNR to retain more than one full time mapping staff beyond 2021 is uncertain. While measures have been taken to document recently developed tools and procedures as thoroughly as possible so that new staff will be able to learn them in the absence of the original authors, the value and role of retaining expertise and investing in team-building are intangibles that cannot be overstated for the long term success of a mapping program.

The authors feel confident that the methods and procedures produced for this pilot project constitute a solid foundation for the future production of NWI-compatible surface water and wetland maps by the Wisconsin Wetland Inventory. They are intended to be forward looking and able to evolve and adapt with future advances in mapping technologies. Rebuilding an improved, comprehensive statewide layer from this foundation will, much like constructing a house from drawings, instructions, and pile of materials, nonetheless rely heavily on the capabilities of talented, experienced staff working as a team and consistent support to ensure an outcome of success.

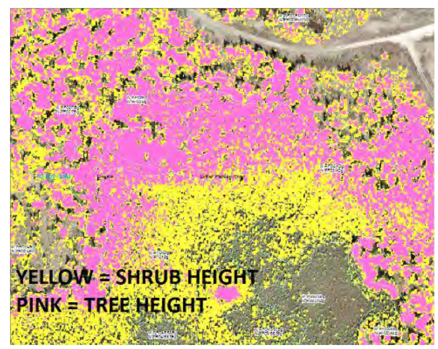


***Above** – An in-progress production view of a single large, highly-interconnected polygon in the Upper Tyler Forks watershed of Iron Co. This view illustrates the degree of connectedness that can be accurately represented through interpretation of LiDAR data and observation of "pour points" or bottlenecks where at least seasonal hydrology exists to link wetland basins that might otherwise be mapped separately. Had initial work of subdividing this polygon not already started, the connected area would be significantly larger. Future work may include the development of a wetland complex meta-layer identifying wetlands linked through surface*

Overview of Updated WWI Methods and Standards Modernization

Significant updates and advances were developed for the purpose of drafting new wetland data for the WWI. Most, if not all these updates are described in the WWI Wetland Mapping Draft S.O.P. (2019).

- Cowardin Classification is now used for all polygon attribution.
  - Wisconsin-specific vegetation subclasses have been drafted that allow for dual attribution of base Cowardin definitions. See Appendix B in the WWI Wetland Mapping S.O.P. (2019)
- Visualized bare earth LiDAR overlaid with a slope raster, as detailed in the "LiDAR Data" section WWI Wetland Mapping S.O.P. (2019), now informs high percentage of wetland boundary decisions
- Lidar visualization has improved the accuracy of assigning Hydrologic Regime Codes and Organic Soils ("g") special modifiers by giving the cartographer a clear representation of wetland hydrogeomorphic position. Inundation is not likely to pool across a "B" or "D" seepage slope, and the plains of organic hydric soils built up by saturated vegetation over thousands of years are now clearly interpretable.
- Lidar first-return data was successfully used to improve the drawing of Emergent (EM), Scrub Shrub (SS), and Forested (FO) through normalization of canopy height (**First Return** – **Bare Earth Elevation** = **Canopy Height**) rasters and reclassification according to FGDC (2013) defined height classes.



- Mapping at 1:2000 nominal scale provides roughly 4x greater detail and fidelity over wetland and surface water maps produced at 1:5000, and greatly reduce omissions due to minimum mapping unit size.
- Breaklines, a type of polygon data used to cleanly represent low information surface water areas, are being incorporated wherever quality and availability allows in new maps to help build a hydrographic "backbone" and helps to reduce time spent manually digitizing these features.
- Topologically valid polyline flow networks are being produced with much greater accuracy than existing 1:24,000 geodatabases and may serve as source data for eventual hydrography updates, however progress on this front has stalled at the time of writing due to capacity limitations.
- Many springs are easily spotted in bare earth lidar data and are now captured as points where surface water is observed flowing from them. These springs also tend to include newly mapped streams.
- Hydrographic Position Index (Vaughn 2017) visualization and reclassification techniques are being used to help find stream courses under thick forest canopies. Work continues on reclassification routines that can accurately isolate stream bottoms for the purpose of digitizing high-quality centerlines using the ArcScan extension. See Appendix A in the WWI Wetland Mapping S.O.P. (2019).
- Efficiency and accuracy-improving semi-automated terrain analysis methods for the purpose of mapping wetland outer boundaries are in development.

Statewide Mapping Feasibility Assessment

By early 2020, WDNR staff capacity for map production was built-up to the point where a concerted effort to conduct a feasibility study for statewide expansion of the wetland layer was attempted. To assess the feasibility of expanding this layer to the entire state, a study design was drafted according to the criteria below.

Study Area - The study area encompassed all non-SEWRPC counties within Wisconsin that have accessible and usable (typically 2010 onward) LiDAR data. See Map 2 in "Appendix A"

Spatial Unit of Assessment - The base unit area of assessment consisted of PLSS sections (generally consistent but somewhat variable 1x1 square mile blocks). The target population of PLSS sections was all PLSS sections within Wisconsin that intersect at least one wetland polygon from the current NWI 2.0 geodatabase. The Wisconsin NWI 2.0 geodatabase was used to calculate mapped wetland density instead of the existing WWI dataset because it best approximates the intended final map product that WDNR staff aim to create.

Sampling Strategy - Because Wetland density varies widely across Wisconsin's landscapes and wetland-dense areas were expected to take longer to map than drier areas due to increases in complexity, the whole spectrum from dry to wet had to be considered in order to create accurate time and cost estimates. As a result, section selections were stratified across low, medium and high-density areas of wetland cover.

To create these categories, PLSS Sections were intersected with NWI 2.0 wetland and surface water polygons and a percent cover of mapped area was tabulated. Sections with 0% cover were excluded. The remaining sections on list were sorted by increasing percent cover and divided into three Jenks Natural Breaks strata representing low, medium, or high-density sections. These strata covered the following ranges:

PLSS Section Count	Density Strata	Min % mapped wetland & H2O Poly Cover	Max % mapped wetland & H2O Poly Cover
1635	NONE	0	0
34841	LOW	0.0001	21.2999
17738	MEDIUM	21.3	58.7999
3714	HIGH	58.8	100

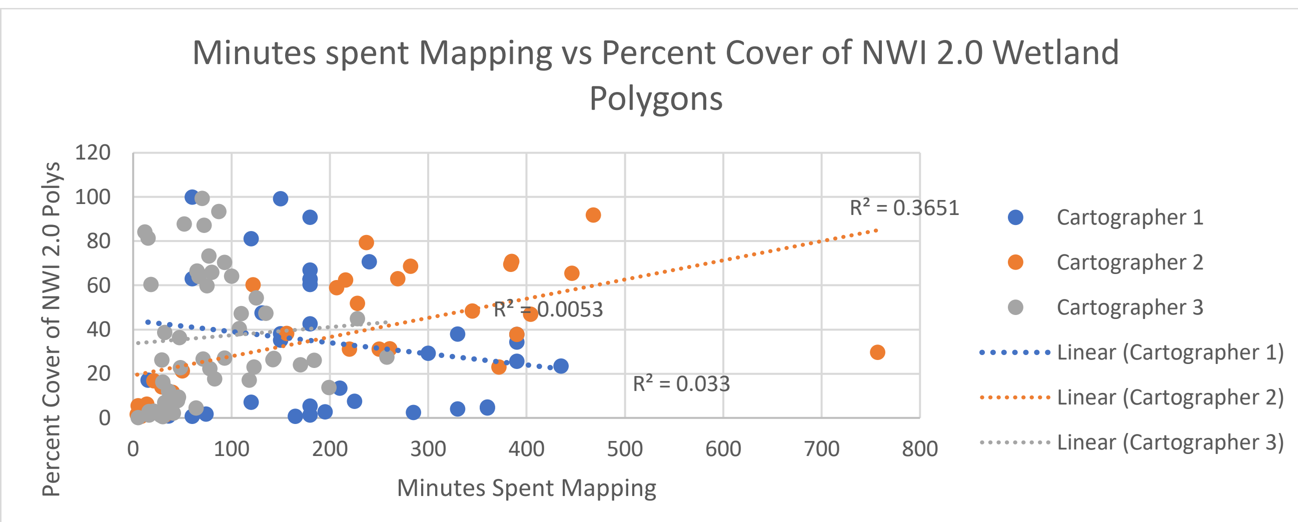
From each low, medium, and high category, 51 sections were drawn at random using the "=Random" function in Microsoft Excel. From these these 51 sections, the three authors were assigned at random 17 ordered sections. Each cartographer was responsible for completing GIS data production in at least 10 of these sections, working their way sequentially through their list of assigned sections for each density category. A few exceptions were noted to allow exclusion of sections if an area was surrounded by a single large lake polygon, landed in an area already mapped for a pilot watershed, or the section deviated more than 20% in terms of area from one square mile (640 acres), that section was dropped from the list and the next section on the list taken in numerical order to ensure bias was minimized.

Metrics of Performance - The total number of minutes needed to map each section was carefully logged on a time-tracking spreadsheet. To ensure accountability, each cartographer drafted surface water and wetland data for their sections using a geodatabase that enables time tracking of polygon feature creation and editing from start to finish by automatically populating two fields, "First Edit Time" and "Last Edit Time" for each feature created. Rest breaks of more than five minutes were subtracted from the total number of minutes in order to reduce error in the final data.

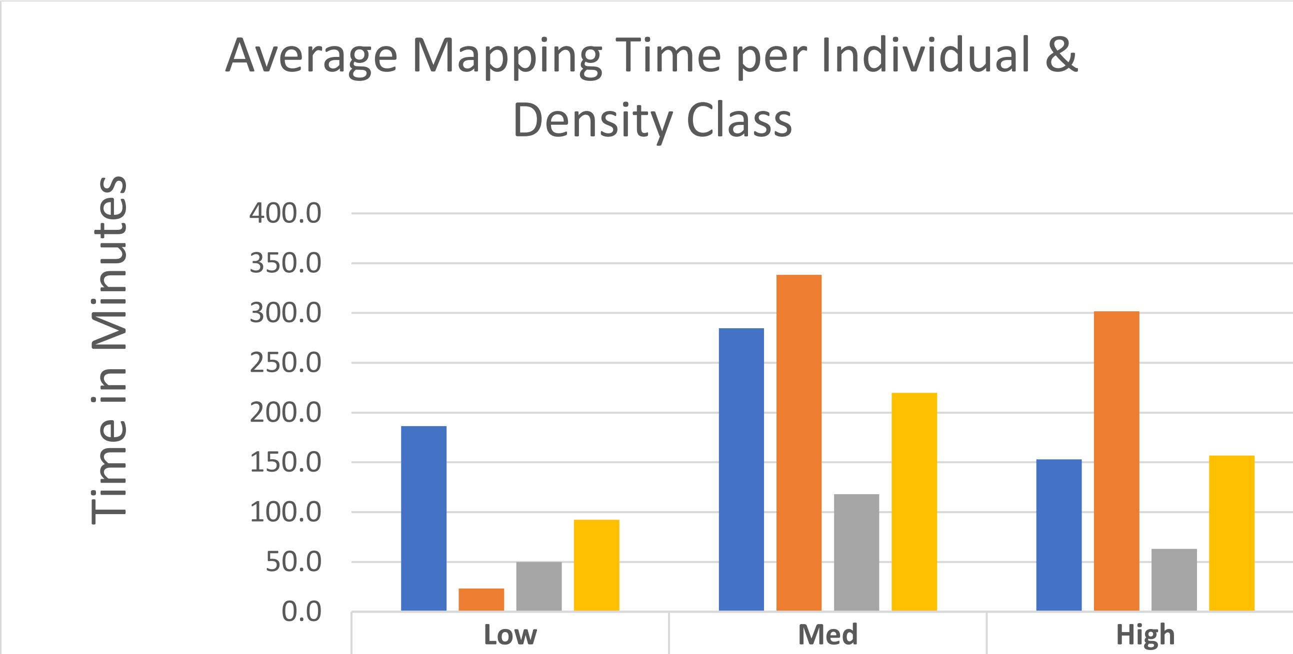
Analysis - Across 115 square miles of Wisconsin, three mappers worked independently to draft new maps according to the updated methods outlined in the Wetland Mapping S.O.P. (2019). The average amount of time taken to remap a PLSS Section was 154.1 minutes per square mile.

Across All Mappers	**Minutes**
Avg Time Spent on ALL SECTIONS by ALL CARTOGRAPHERS	154.1
Avg Time Spent per Low Section	92.3
Avg Time Spent per Medium Section	219.8
Avg Time Spent per High Section	157.0

Initial attempts at creating a regression line based on individual or combined data points showed poor correlation between percent cover of NWI 2.0 polygon coverage and minutes spent remapping a section. As a result, creating a formula that can be applied statewide based on aeral cover of NWI 2.0 polygons was ruled out.



A cruder but potentially more reliable approach involves combining time data across all mappers for each density strata to get a simple average.



	Low	Med	High
Cartographer 1	186.3	284.6	153.0
Cartographer 2	23.3	338.3	301.6
Cartographer 3	50.0	118.0	63.2
All Cartographer Avg	92.3	219.8	157.0

Results - If combined averages for each section are assumed to hold relatively steady for the entire state on account of sample sizes of at least 30 sections per category, and each density category is weighed proportionally, the percent wetland and surface water polygon cover above, we arrive at the following equation for estimating remapping time for the state:

$$(n_{\text{Zero Density Sections}} * 5\text{ min}) + (n_{\text{Low Density Sections}} * 92.3\text{ min}) + (n_{\text{Medium Density Sections}} * 219.8\text{ min}) + (n_{\text{Zero Density Sections}} * 157\text{ min}) = 7{,}705{,}909\text{ minutes}$$

This extrapolation suggests it will require 128,432 work hours or 64.2 person work-years of labor to redo all sections in the WWI to include more accurate wetlands and surface waters data with the WWI's current balance of cartographic talent.

Discussion - A highly confounding factor in this estimate of hours required to remap wetlands and surface waters according to methods outlined in the WWI Wetland Mapping S.O.P (2019) is the outsized role of individual cartographer efficiency due to the WWI's small sample size of three mappers. An extremely significant takeaway here is that the importance of a cartographer's ability to efficiently and skillfully apply mapping methods and techniques to the landscape *cannot be overstated.*

If the three cartographers who contributed to this report worked solo to remap the state, it would take Cartographer 1 almost 101 work-years, Cartographer 2 would take 66.2 years, and Cartographer 3 would take 34 years!

In all likelihood, the numbers presented above offer a high-end estimate which does not factor in improvements in cartographer skill level over time, efficiency gained through further refinements in methodology, and technological advances in GIS tools like AI-based image classification methods that are just beginning to reach the mainstream GIS world. However, for the foreseeable future, drafting wetland maps still requires a lot of work. Cumulatively, even the simplest watershed requires thousands of human mapping decisions to be made. More complex likely require hundreds of thousands of decisions and beyond.

Going forward, WWI staff are logging all time spent on new mapping projects in a project-specific excel spreadsheet. It is expected that newly mapped & tracked watersheds will improve the quality of data used for statewide feasibility projections. Further work also needs to be conducted to investigate improved linkages between time required to map an area and other GIS feature properties like polygon perimeter distance.

Above *– Leatherleaf (Chamaedaphne calyculata) shrubs colonizes along nurse logs in a PSS3/EM1Eg kettle wetland in Forest Co, WI. Most of the sedge and native grass dominated area is likely subject to seasonal inundation, while leatherleaf keeps its feet ever so slightly drier.*

Accuracy Assessments

Watershed 1 - Duck Creek (HUC ID = 070700031805) Adams County, WI

The Duck Cr watershed was among the first watersheds undertaken in the Pilot Project. As a result, it served heavily as a training watershed for learning how to apply NWI schema to Wisconsin wetlands. The cartographer, Christopher Smith, made at least three photographic trips to determining factors such as flow direction, wetland attribute classes, and hydro periods. Because of the initial learning curve around learning Cowardin Code definitions and appropriate mapping conventions, much could be corrected in this watershed, but it is likely to remain “as-is” to provide an example of the perils of zooming in too close while drafting polygons, which resulted in over-splitting of wetland types instead of lumping to represent small scale heterogeneity. Nonetheless, the mapping effort still represents an improvement over previous WWI data. Photographic days were generally partly cloudy or overcast, and cell phone reception was good to poor depending on the distance from the towers which impacted GPS receiver accuracy. Precipitation and water levels were high due to an exceptionally wet summer and early fall.

Much of Duck Creek can be characterized as former glacial lake bottom with many drained wetland flats in agricultural production. Drainage is extensive and excavated, straightened streams and rivers are common. Points were initially chosen where flow was undetermined, with additional points at places of opportunity, mostly where road grades intersect wetlands. The field verification was based on these initial points and further sites of opportunity.

Accuracy Assessmet Check Points for Duck Creek HUC-12 in Adams Co, WI

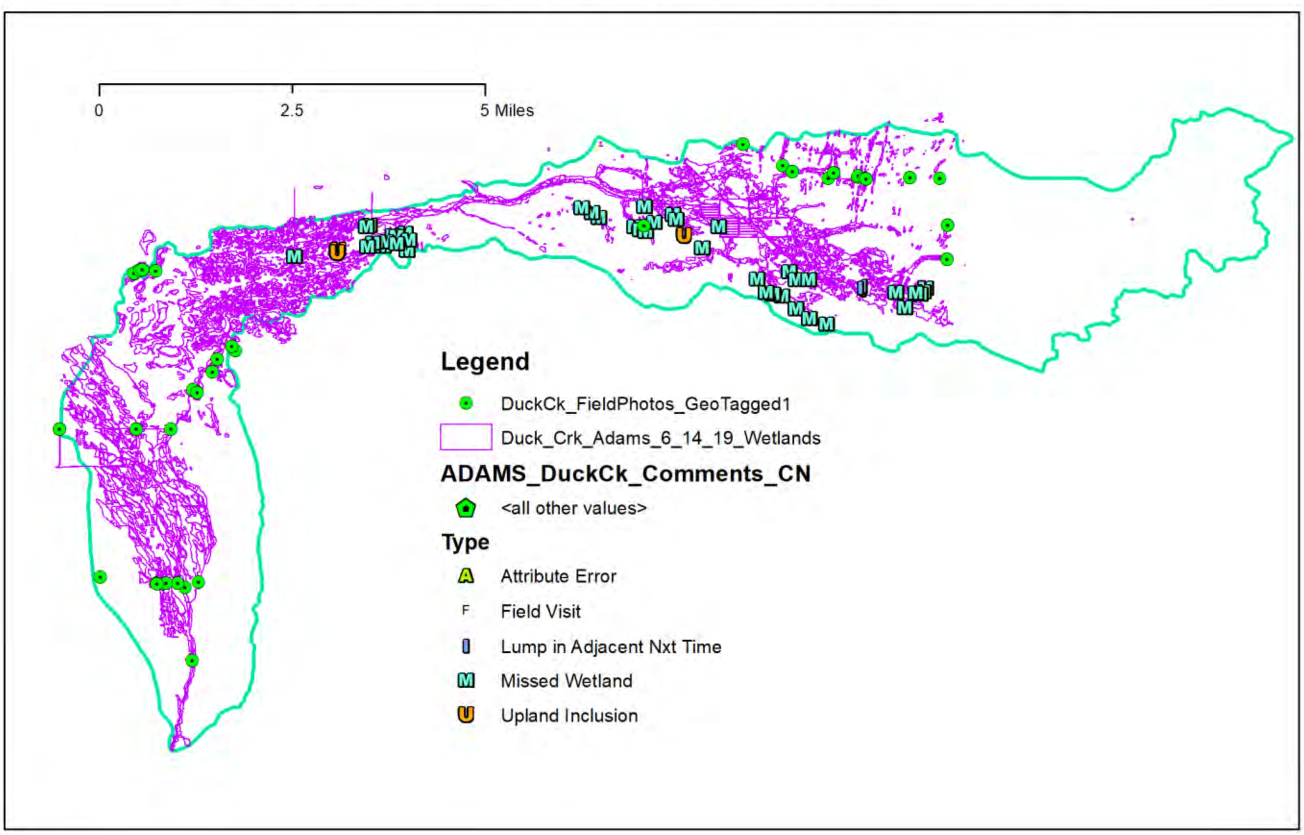


Image 1- Point 1, 11/18/2018

Image 2 – Point 116, 11/17/2018

Regime, Scheme and Overmap

This site is near the base of the watershed where the effect of the impoundment can be seen in lower reach. The stream which had water in it in the first field check, was dry in the second and flooded in the third.

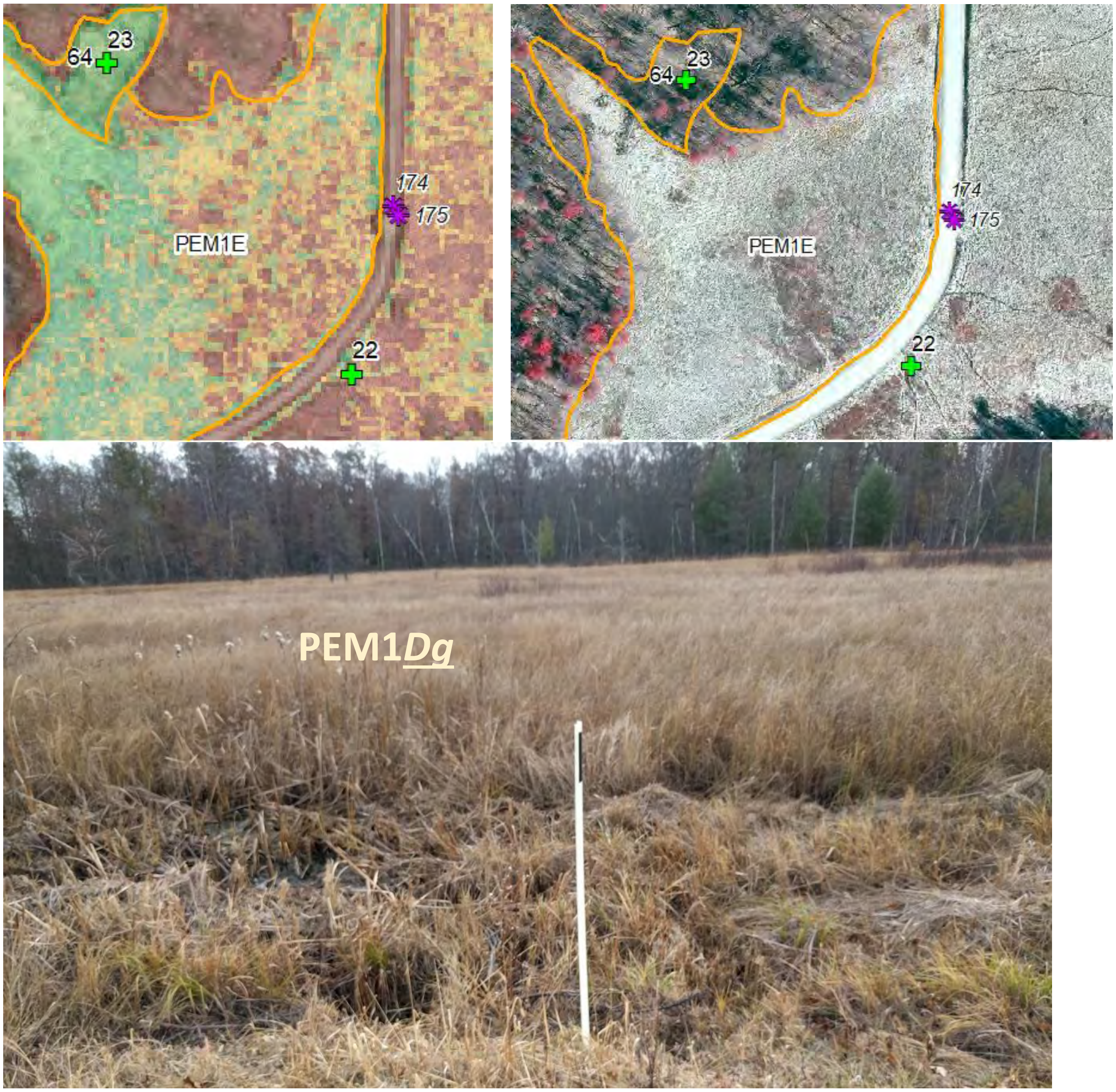
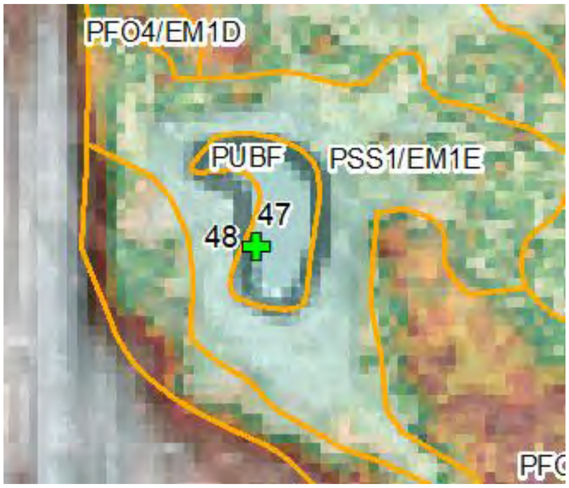


Image 1 – 22, 11/18/2018

PEM1E Confirmation

This polygon was found to be correctly identified as a PEM1, however the slight impounding effect produced by the road grade was not enough to cause seasonal standing water as required by the “E” hydrologic regime. Consistent saturation and flat topography visible on the LiDAR image also warrant the “g” organic soil special modifier. Minor inclusions of leatherleaf (SS3) were determined to not be significant enough for split class inclusion.



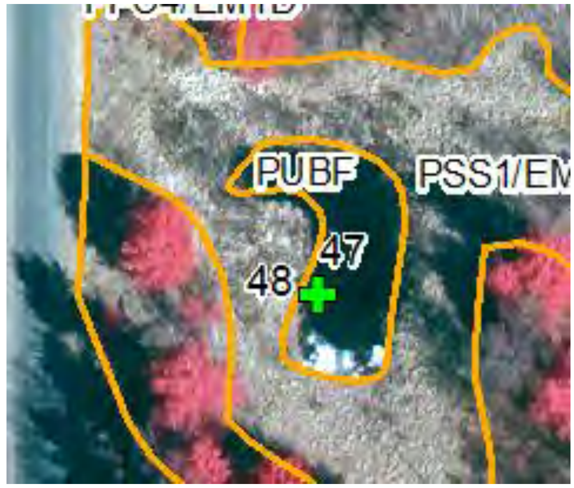


Image 1 – 48, 11/18/2020

Pond Regime Change, Confirmation of Open Water, and Confirmation of Emergent-Scrub Shrub Wetland

This site was originally labeled as an F Hydro Regime Code and lacked a modifier to reflect the excavated character. Excavation depth means this pond and situation within a continually saturated shrubby sedge meadow means the pond likely retains water in all but the driest years and as a result best fits the requirements of a “G” hydrologic regime. The Shrub/Emergent was correctly classified in terms of vegetation but was overly wet in terms of hydrology and reduced to a continuously saturated “D” water regime.

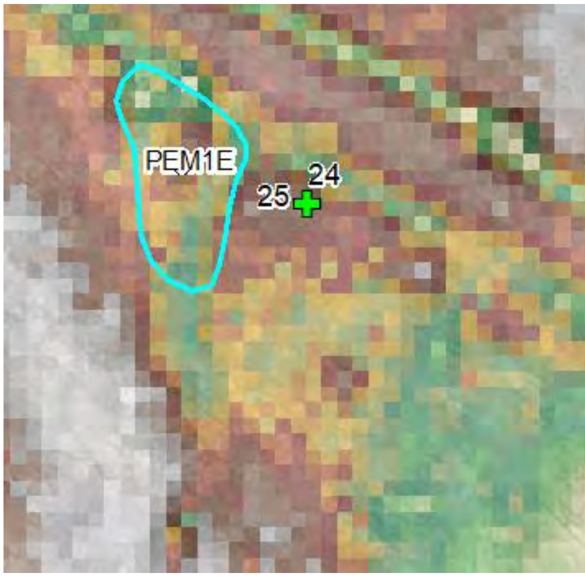


Image 1 – 25, 11/18/2020

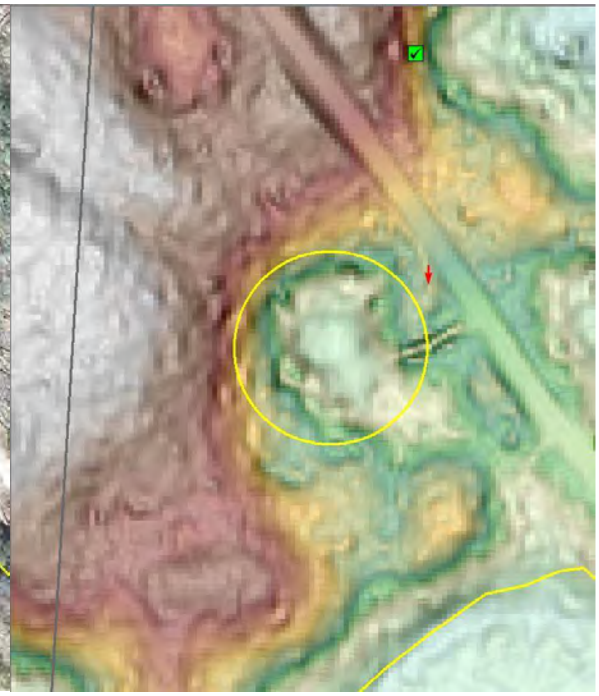
Missed Wetland

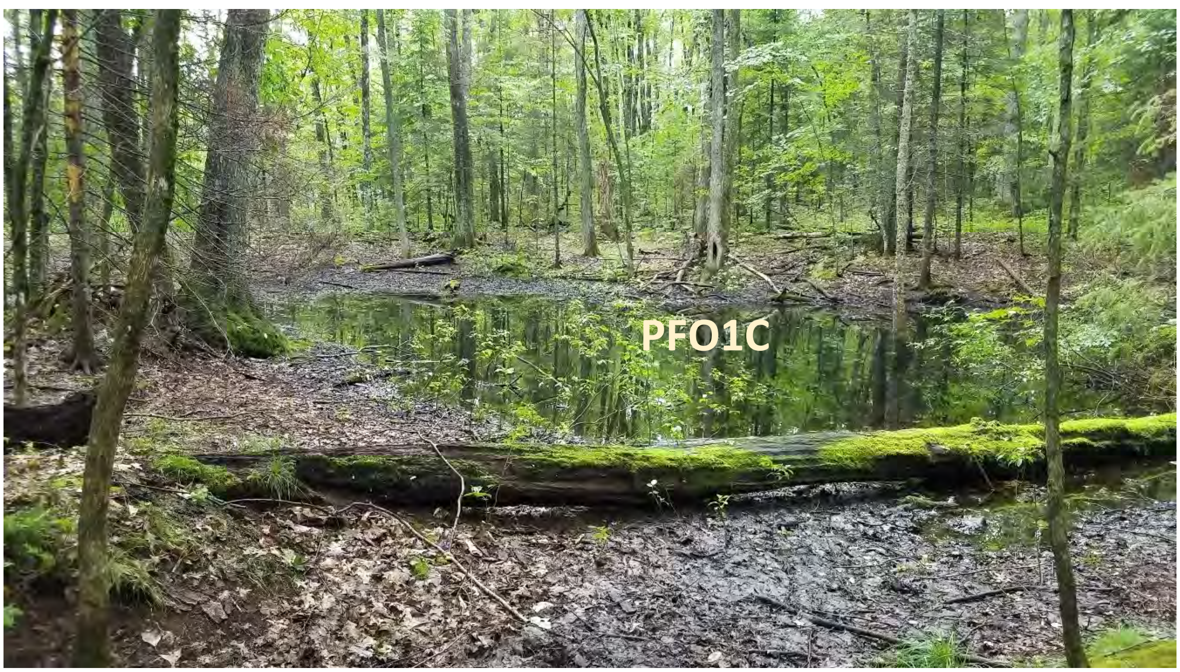
During field checks, many missed wetlands were encountered. There was little signature on LiDAR or imagery, but owing to the saturated conditions in 2018 and presence of a culvert, this wetland was identified and determined to be a PEM1E. In drier years, this small depression may not experience sustained inundation long enough to fit the requirements for an "E" hydrologic regime.

Watershed 2 – Flynn Lake (HUC ID = 040103020601) Bayfield County, WI

All information was collected on August 28, 2020. The sites visited were documented using the ESRI mobile apps Arc Explorer and Arc Collector installed on an android phone with leaf-off imagery and new draft wetland and surface waters pre-loaded. Due to heavy canopy cover, poor or no cell connection made GPS tracking difficult.

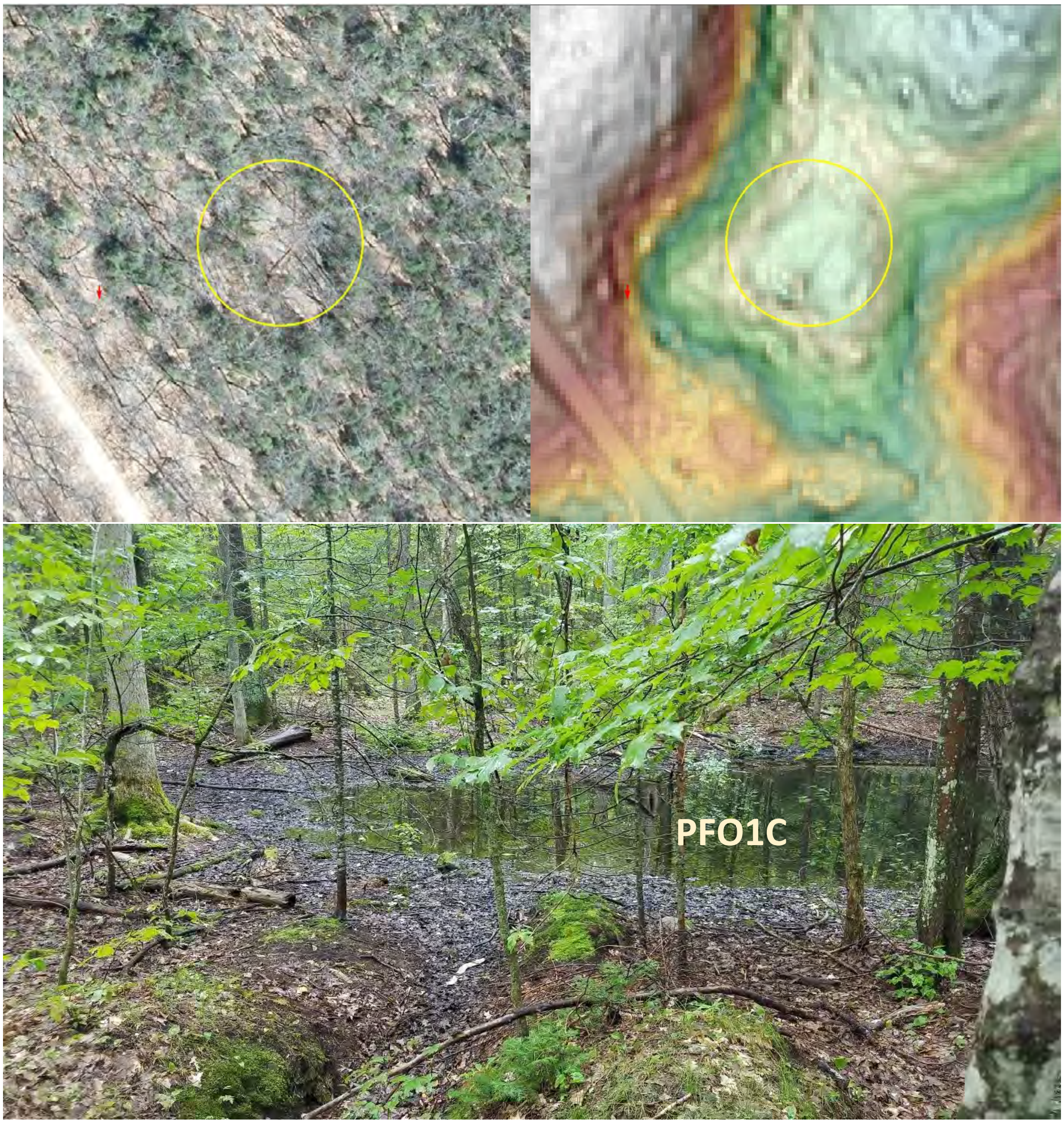
Missed wetland - Image on upper left shows 2015 leaf-off photography. This imagery lacked a definitive aerial signature indicating seasonal inundation, further complicated by tree branches and shadow. The LiDAR image on right shows a depression and possible wetland signature. The bottom image suggests a small PFO1A wetland.



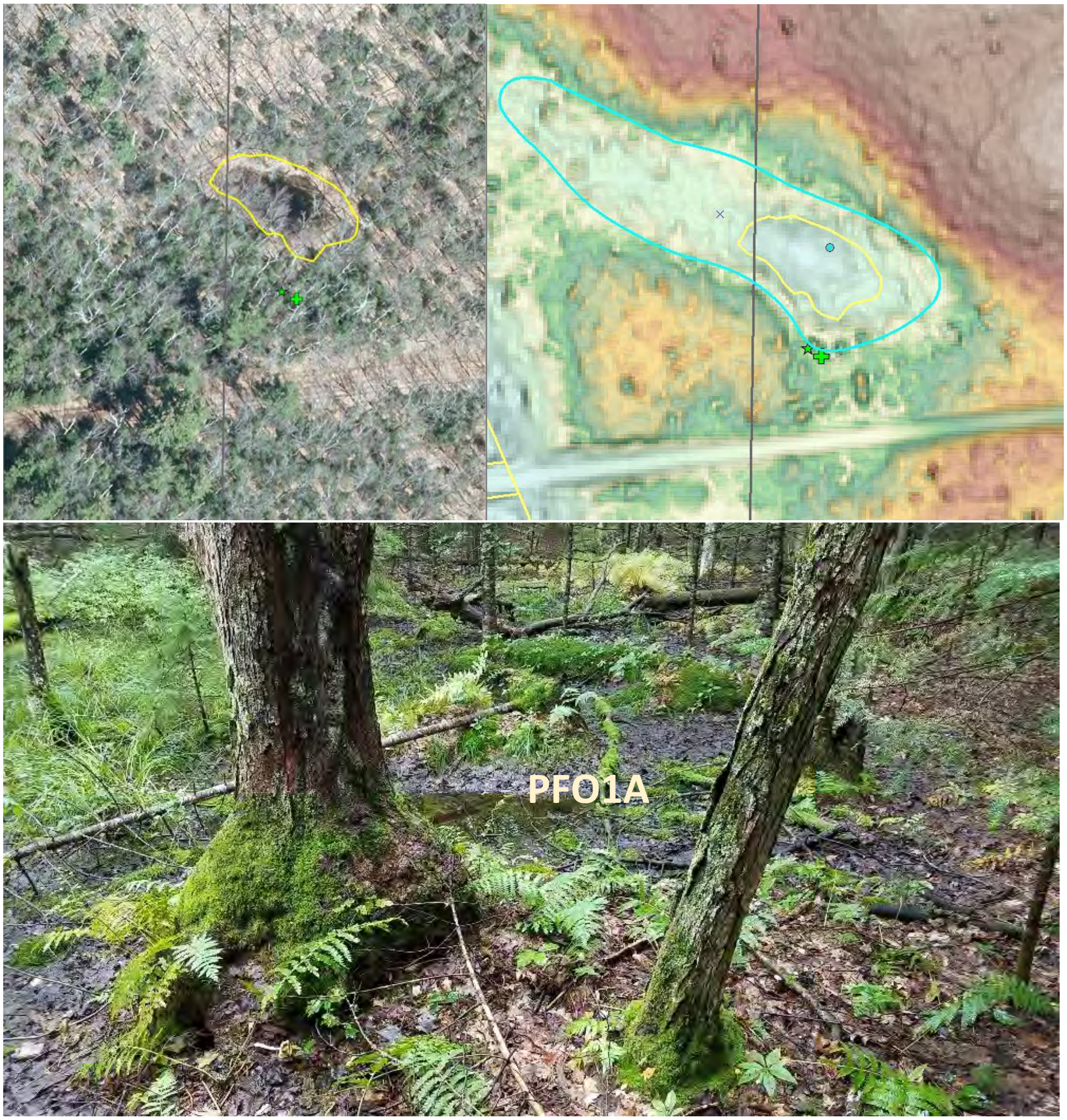


Missed wetland – The top left aerial photo shows no sign of inudation in spring, despite the notable kettle visible in the top right LiDAR image. Top Left: Again, leaf-off imagery is inconclusive. Top Right: LiDAR elevation/slope view shows depression and flow beneath the road.

Image of view towards southwest.



Missed wetland – The top left leaf-off aerial image shows no signs of wetland presence at the bottom of the kettle depression visible on the top-right LiDAR image. The bottom field photo confirmed wetland hydrology consistent with a “PFO1C” attribute.



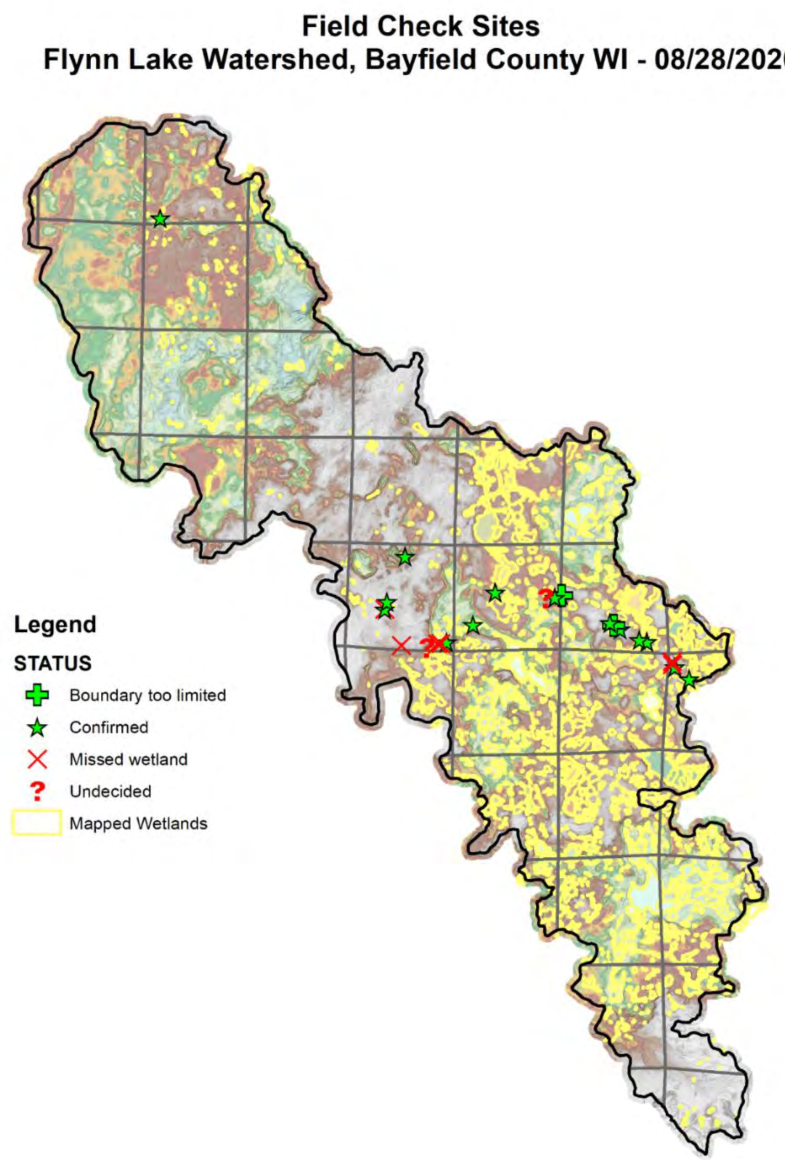
Undermapped wetland – On the top left image, water is seen ponding in spring 2015 corresponding with a kettle depression. The flat terrain surrounding this kettle on LiDAR suggests possible wetland fringing the ephemeral pond in wetter years, but leaf-off imagery lacks indicators of saturation. This field visit confirmed a larger wetland surrounding the open water. A larger boundary was added, as seen in the top right LiDAR view.

Undermapped wetland - This last site represents a wetland boundary drafted that looks to accurately grab the open water, but the line could be widened to include the “fringe” as seen in the photo above.

Conclusion: Much of the watershed was not field checked due to time constraints and accessibility limitations. Covid-19 also affected working as a team. After reviewing the limited accessible sites and seeing the landscape, the watershed would appear to be under-mapped and should be reviewed again to add new boundaries and enhance boundaries already drafted.

Even with a 1:2000 mapping scale and the available imagery, these locations highlight situations that are still beyond the limits of our ability to effectively capture a proper delineation with high reliability. Assumptions could be made based solely on the LiDAR data, but without quality ancillary data to back up the decision, avoidable error would be introduced.

Because it is not feasible to confirm the wetland status of each kettle bottom in the field, seasonally flooded basins remain under mapped in this watershed. A second watershed visit with true GPS gear would best help determine questionable sites where imagery is inconclusive, but LiDAR viewed topography and soil data say otherwise.



Watershed/Project Area 3 – Rat River 4 HUC-12's in Bayfield County, WI – Independent Review by US Forest Service Staff

Field verification review of wetlands within the Middle Rat River Watershed
Conducted by Chris Ester and Mark Farina on November 18, 2020 and Sara Sommer on November 23, 2020

Kmz file has points where field verification occurred (WWI_field_verification_all_2020_1209.kmz). Points identified as "field check" were prioritized for review (though, not all field check points were visited), as well as many of the newly delineated wetlands with easy access from roads. Points are labeled utilizing a general naming convention of good or bad. Most of the wetlands were good; surprisingly good! Many of the small isolated pocket wetlands were clearly delineated. On many, existing WWI wetlands, the spatial "shift" issues which were common and widespread were corrected by the new polygons. Locations where the WWI used to show wetland, but your view removed wetlands were also reviewed. Those sites were labeled as "Good no wetland" to confirm the removal.

To simplify some of the other findings they are lumped in categories listed below with more explanation:

> **Tentative/Questionable**- these sites would be good to revisit during the growing season. Some sites were in upland hardwood stands that were small pockets of poorly drained soils. Some may have met the hydric soil criteria but would be good to look at plants during growing condition to confirm wetland status. Maybe that is overkill, but it would help to calibrate these questionable sites.
>
> **Add Wetland/Missed/Wrong: Wetland Here**- a few sites were missed. One site had water standing and it may have been a low spot where water has accumulated. In general water levels were quite high during both field reviews. Again, would be good to confirm some of these locations during growing season to review herbs.
>
> **Wrong/Bad**- A general trend found was that some of the wetlands were delineated beyond the actual boundary. This was found in aspen stands adjacent to wetlands where the topography was flat. These sites had no distinct topo breaks to distinguish them from the adjacent wetlands. And these ended up being on moderately well drained soils and clearly not wetlands. In addition, some were in transition areas between wetlands that were identified as an old glacial drainageway. There were large boulders on the surface but the soils and what was left of plants did not indicate wetland presence. This may be difficult to identify on air photos and lidar due to low relief and balsam-aspen stand types. Will need to keep an eye out for these conditions in future areas. We believe that utilizing a soil layer will be helpful for determining wetland boundaries in these types of landscapes. A simple intersect of the pre-final new WWI polygons with certain moderately well drained and well-drained soil types would flag these areas for further review. Though, we are not sure if the mapping level will pick up some of those small isolated areas.

The two large over-mapped wetlands we found where soils would have helped identify as not wetland are:

- The wetland adjacent to Mexico Creek south of Indian Market Road in Section 36 of T35N, R15E.
- The wetland north and south of Kuffner Road in section 26 and 23 of T35N, R15E

In general, it was good to review these sites during leaf off but in some of the questionable areas it would be nice to review plants during the growing condition. Maybe an optimal time for field review is early or mid-May before leaf on but some of the herbs are emerging.

Response from Christopher Noll, WDNR

Areas south of Kuffner Road were trimmed significantly but didn't exclude every "no wetland" area on account of conflicts of topographic consistency with areas labeled as wetland. Will follow up with Sara to double check field notes and location.

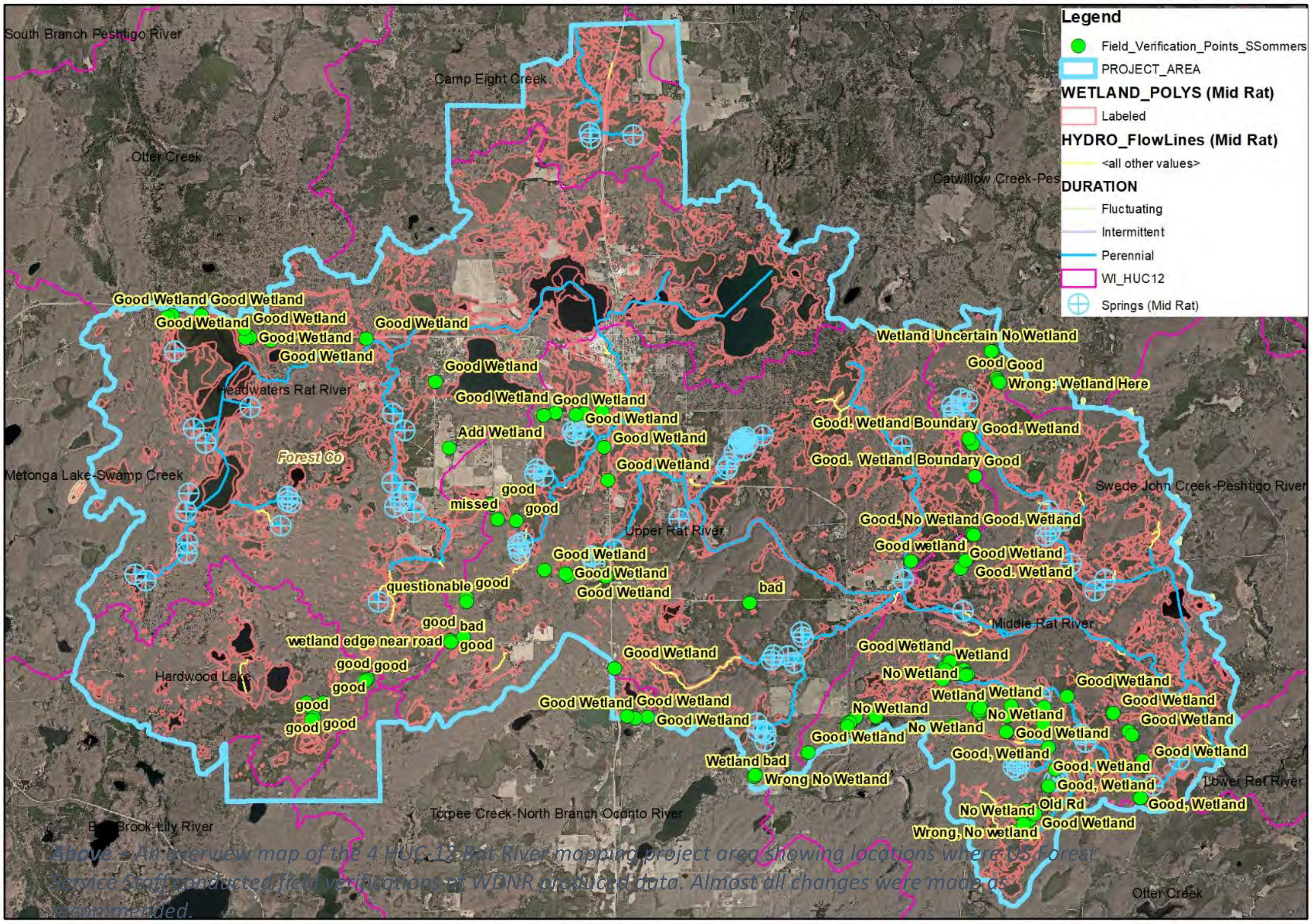
Thank you so much for getting into the Mexico Creek area. As you indicate above, seasonally saturated mineral soil swamps dominated by facultative species are among the hardest wetlands to map due to the frequent lack of topographic break. Double that difficulty when you must determine what is outwash from the ice-age vs existing wetland on a very subtly undulating outwash terrain. I recall it being one of the larger areas of uncertainty in the mapping area. I trimmed significant areas off.

Regarding soils and SSURGO data – guilty as charged for short-changing this data for making mapping decisions. I will try to reference it more in future areas. But two big reasons why inclusion and consideration of soil data is difficult for wetland mapping: First, we are mapping at roughly an order of magnitude closer scale than soils (1:2000 vs 1:15,0000-ish) and SSURGO data does not separate out lesser inclusions – many of which can be hydric and are mappable for WWI criteria & standards which creates a lot of gray area for less experienced staff. Second, we are using lidar, which was not available at the time of soil map creation. There is no way to map boundaries as tight as we are doing for wetlands on a wide scale without lidar, so my default is to assume SSURGO boundaries as "general guides" having a much wider area of uncertainty at the edge. This was the case with older WWI data too. Thus, I generally default to trusting what I can interpret from the most recent color imagery and lidar.

I do have confidence in larger areas of conflicting wetland & upland indications, and I think you've shown this well regarding higher areas surrounding Mexico Creek. Most of the soil within that polygon formed on an outwash plain which gave it a similar topography to what I see in seasonally saturated mineral soil swamps. Based on photo signatures and equivalent topographic positions, I think there are still some wetland inclusion in the Vansile Silt Loam polygons that I have left.

Thanks again and I look forward to mapping future Chequamegon Nicolet National Forest watersheds.

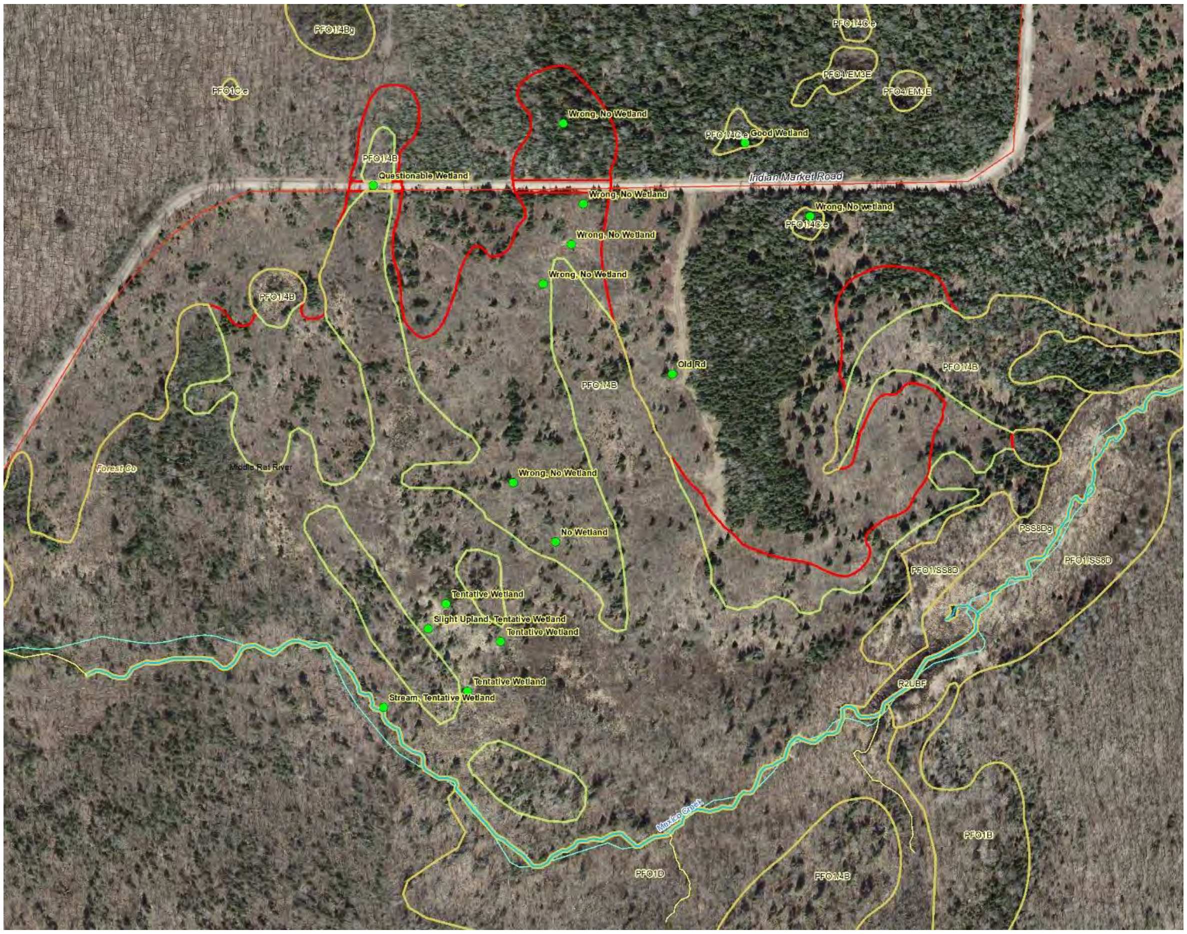
US Forest Service Accuracy Assessment of the Rat River Project Area

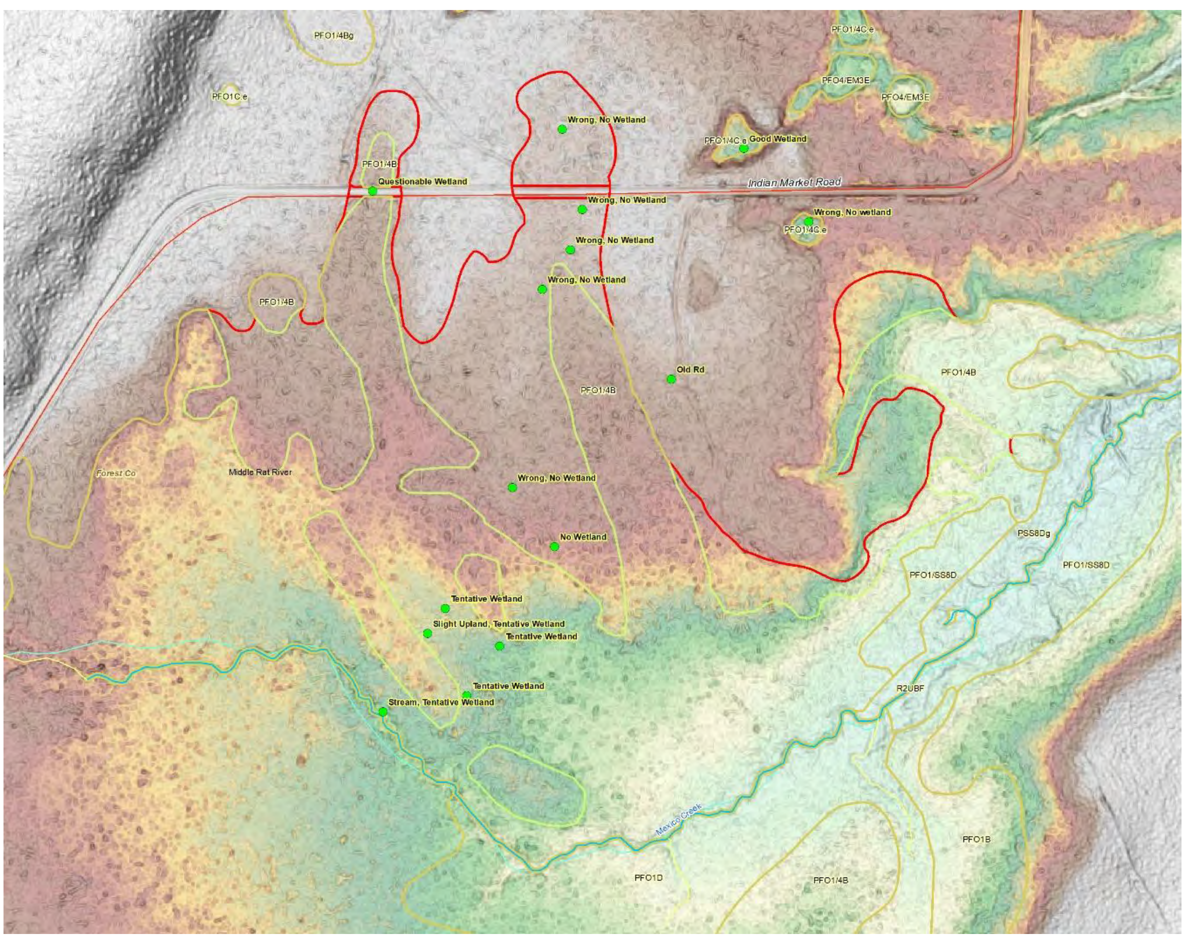


Above – An overview map of the 4 HUC 12 Rat River mapping project area showing locations where US Forest Service Staff conducted field verifications of WDNR produced data. Almost all changes were made as recommended.

Next Page Top – Detail aerial view (1:2300) of over-mapped wetland boundaries (red) surrounding Mexico Creek. There is little shift in photo signature between areas USFS staff identified as upland forest and the nearby wet swales, likely owing to dominance by facultative tree species like quaking aspen (Populus tremuloides). Remaining swamps were reduced in terms of hydrologic regime from a "D" to a "B" to reflect the likely shorter hydroperiod of mineral soil seepage slopes. Corrections were made to boundaries (green) for all points in this area.

Next Page Bottom – LiDAR data visualization of the same image as above showing the extremely subtle, undulating terrain at play.


PFO1/4Bg
PFO1/4C.e
PFO1C.e
PFO4/EM3E
PFO4/EM3E
Wrong, No Wetland
PFO1/4C.e
Good Wetland
PFO1/4B
Questionable Wetland
Indian Market Road
Wrong, No Wetland
Wrong, No wetland
PFO1/4C.e
Wrong, No Wetland
Wrong, No Wetland
PFO1/4B
Old Rd
PFO1/4B
PFO1/4B
Forest Co
Middle Rat River
Wrong, No Wetland
No Wetland
PSS8Dg
PFO1/SS8D
PFO1/SS8D
Tentative Wetland
Slight Upland, Tentative Wetland
Tentative Wetland
Tentative Wetland
Stream, Tentative Wetland
R2UBF
Mexico Creek
PFO1B
PFO1D
PFO1/4B


PFO1/4Bg
PFO1/4C.e
PFO1C.e
PFO4/EM3E
PFO4/EM3E
Wrong, No Wetland
PFO1/4C.e
Good Wetland
PFO1/4B
Questionable Wetland
Indian Market Road
Wrong, No Wetland
Wrong, No wetland
PFO1/4C.e
Wrong, No Wetland
Wrong, No Wetland
PFO1/4B
Old Rd
PFO1/4B
PFO1/4B
Forest Co
Middle Rat River
Wrong, No Wetland
No Wetland
PSS8Dg
PFO1/SS8D
PFO1/SS8D
Tentative Wetland
Slight Upland, Tentative Wetland
Tentative Wetland
Tentative Wetland
Stream, Tentative Wetland
R2UBF
Mexico Creek
PFO1B
PFO1D
PFO1/4B

Additional Documentation Produced with Funding from this Grant

- “Integrated Wetland and Hydrography Mapping in Select Sub-Watersheds of Wisconsin – A Pilot Project” authored by Stark (et al. 2019). This 116 page document produced under contract with Geospatial Services staff at St. Mary’s University provides a useful general purpose primer on mapping wetlands in addition to detailing several novel approaches for mapping hydrography.
- “WDNR Wisconsin Wetland Inventory (WWI) Map Production SOP, Draft 8/27/2020”. Also available by request from the authors of this report.

Other Noteworthy Developments and Deliverables

- Direct Image analysis Python Add-in Toolbar for semi-automatically digitizing high-contrast surface water features directly from imagery. Contact Christopher.noll@wisconsin.gov for more details.
- WWI/NWI Cowardin Shorthand Python Add-in Toolbar – allows NWI wetland attributes to be directly entered through a tool-bar while saving up to 40% of redundant keystrokes. “SS” is reduced to “S”, “EM” is reduced to “E”, and so forth. Slashes “/” are also automatically inserted into the final NWI attribute. Contact Christopher.noll@wisconsin.gov for more details.

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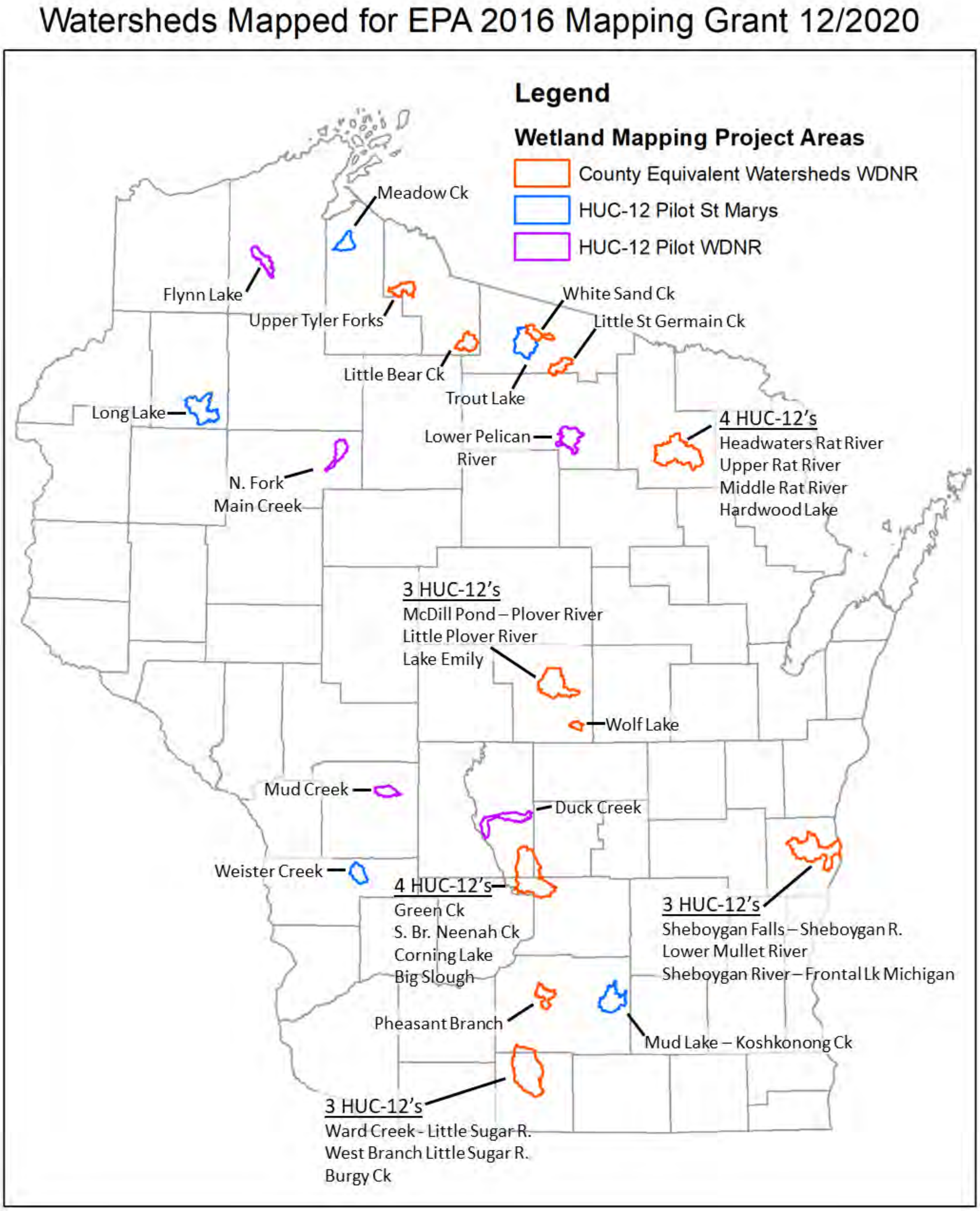
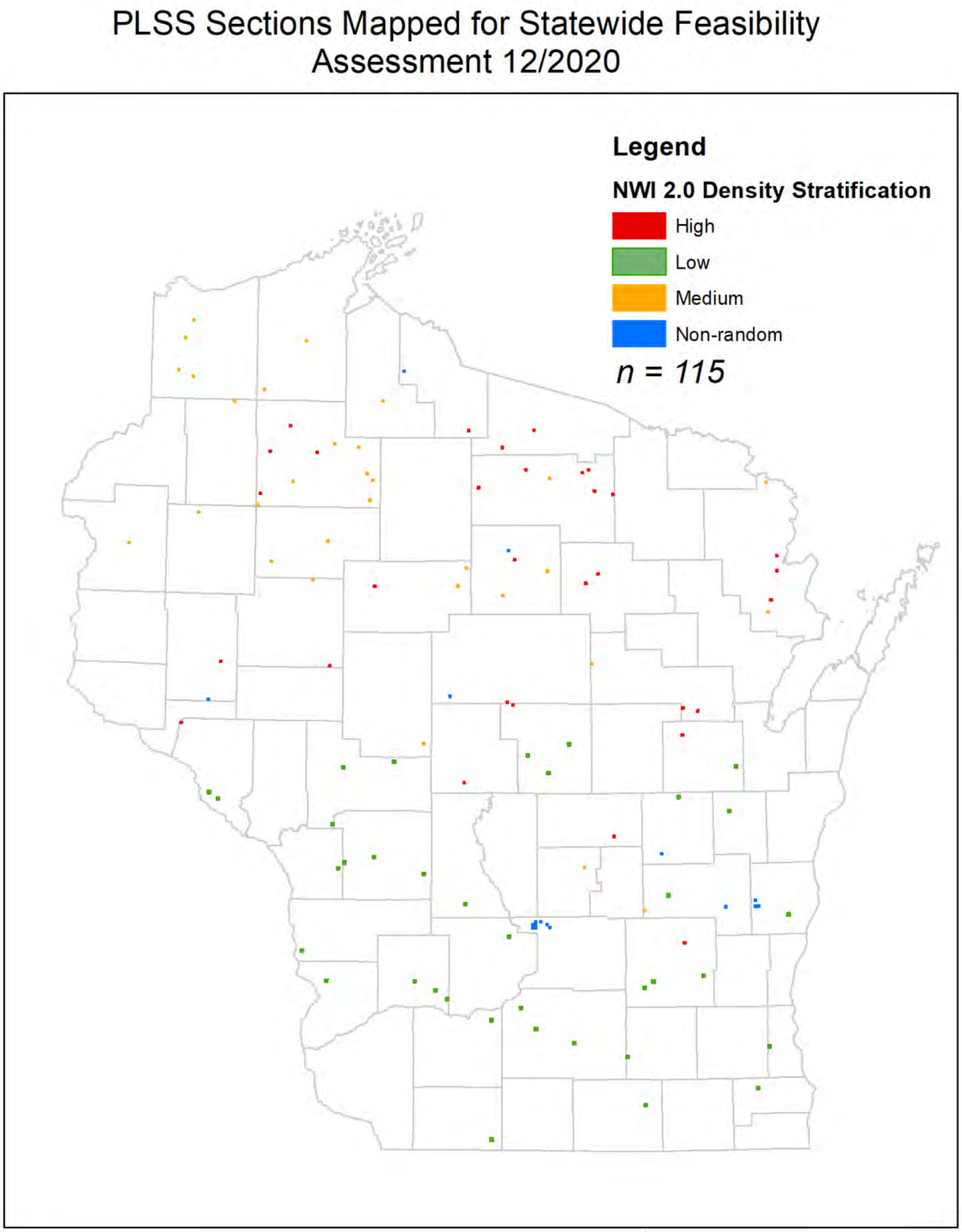
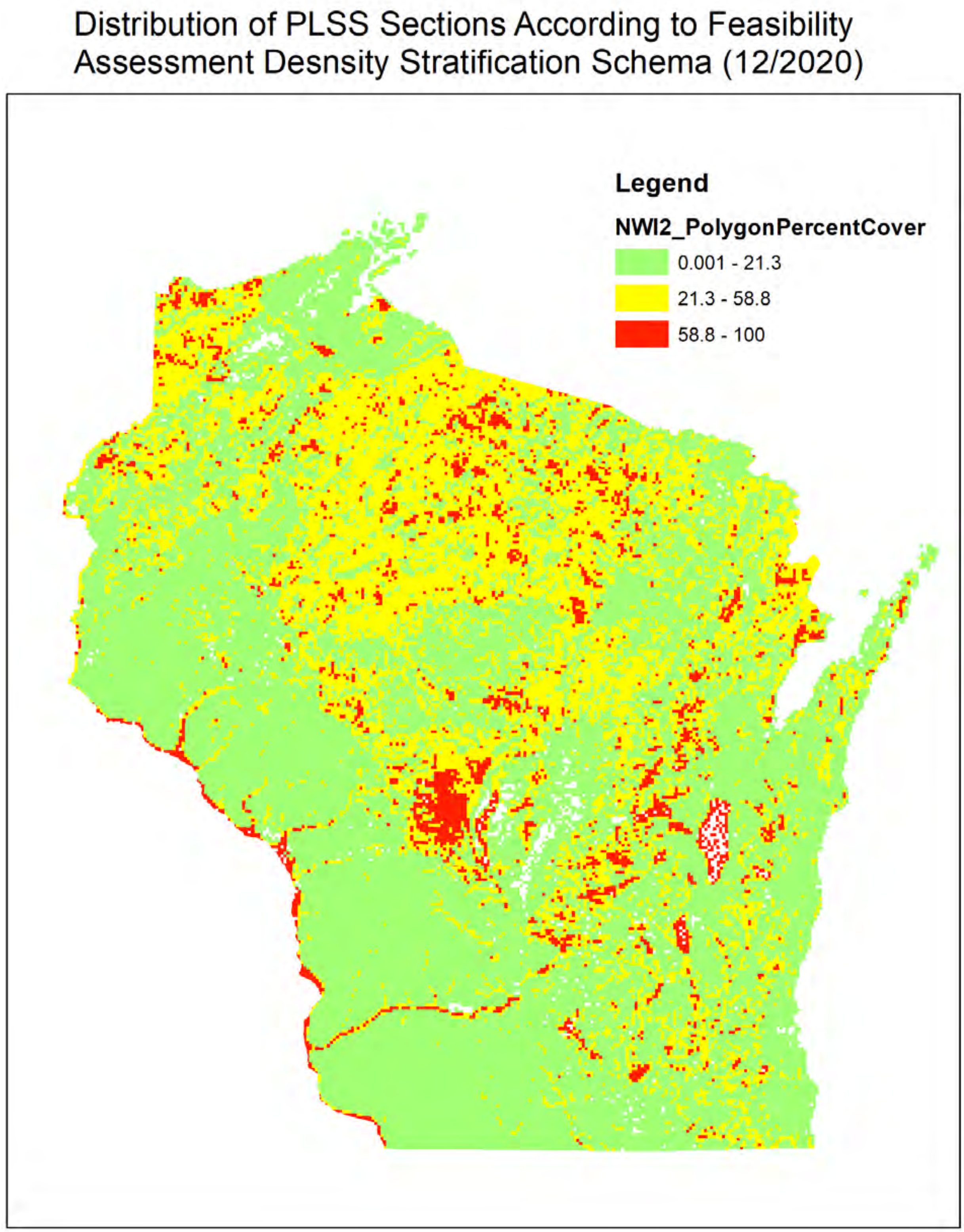
Appendix A:



Map 1 *– The distribution of thirty-three HUC-12 watersheds covering 561,023 acres were updated for the Mapping Pilot. Individual watershed attributes are described in Appendix C*



Map 2 *– Wetlands within ninety-nine randomly selected PLSS sections (63,458 acres, 641 acre average size) representing the full spectrum of wetland areal density were mapped while carefully tracking time in an effort to create an estimate of resources needed to remap the entire state using standards and procedures. An additional 16 PLSS sections covering 10,196 acres were also timed for feasibility purposes. Some of these sections were later included in full watershed mapping projects.*



Map 3 *– A color coded map showing the breakdown of PLSS Sections and corresponding desnsity of NWI 2.0 polygons. No color areas either indicate zero mapped wetland presence or areas of pure open water.*

Appendix B: Raw Feasibility Assessment Data Table

CARTO	DTRS	Minutes	Stratification	Acres	Shape_Area	NWI_2_PolygonPercentCover	Non_Random	NWI_2_PolygonTotalCover_sq_meters
CAL	4031418	60	Low	627.03993	2537540.6	0.651364	<Null>	16528.633
CAL	4140312	165	Low	629.57844	2547813.5	0.698737	<Null>	17802.504
CAL	2160511	36	Low	637.78925	2581041.5	0.883893	<Null>	22813.65
CAL	2100519	180	Low	679.178	2748535.9	1.314155	<Null>	36120.023
CAL	4120604	74	Low	631.33173	2554908.9	1.700523	<Null>	43446.804
CAL	4080706	285	Low	652.43088	2640294.1	2.471224	<Null>	65247.583
CAL	4070712	195	Low	635.02652	2569861.2	2.728882	<Null>	70128.481
CAL	4010516	330	Low	659.21679	2667755.7	4.027945	<Null>	107455.74
CAL	2190528	360	Low	635.39356	2571346.5	4.509425	<Null>	115952.95
CAL	4062107	360	Low	683.82919	2767358.5	4.936899	<Null>	136621.7
CAL	2220419	180	Low	656.32478	2656052.1	5.317049	<Null>	141223.58
CAL	4042021	120	Low	633.70663	2564519.7	7.07896	<Null>	181541.33
CAL	4061330	225	Low	629.22638	2546388.8	7.46468	<Null>	190079.79
CAL	4201607	210	Low	633.82352	2564992.8	13.433164	<Null>	344559.7
CAL	4101431	15	Low	596.10853	2412365.6	17.033462	<Null>	410909.37
CAL	4312034	435	Medium	645.46826	2612117.4	23.467723	<Null>	613004.47
CAL	4281130	390	Medium	617.09963	2497313.6	25.544251	<Null>	637920.05
CAL	2421102	300	Medium	649.27743	2627532.5	29.148331	<Null>	765881.87
CAL	2400423	390	Medium	592.59755	2398157.2	34.256434	<Null>	821523.15
CAL	2441328	150	Medium	635.75212	2572797.5	35.114136	<Null>	903415.63
CAL	4382022	390	Medium	620.39529	2510650.7	37.69399	<Null>	946364.41
CAL	4380816	330	Medium	608.77916	2463641.8	37.943157	<Null>	934783.5
CAL	4141419	150	Medium	642.87978	2601642.2	38.041544	<Null>	989704.84
CAL	4161011	180	Medium	639.37953	2587477.1	42.495079	<Null>	1099550.5
CAL	4230110	131	Medium	627.5588	2539640.3	47.406679	<Null>	1203959.1
CAL	4312011	180	High	643.33111	2603468.6	60.389653	<Null>	1572225.7
CAL	4241630	180	High	740.04455	2994854	62.65151	<Null>	1876321.3
CAL	4181216	180	High	640.47813	2591923	62.771043	<Null>	1626977.1
CAL	4410722	60	High	611.8362	2476013.2	62.953867	<Null>	1558746.1
CAL	4340633	180	High	642.13427	2598625.2	66.949469	<Null>	1739765.8
CAL	4210313	240	High	648.72082	2625280	70.633996	<Null>	1854340.2
CAL	2370908	120	High	605.66526	2451040.4	81.071587	<Null>	1987097.3
CAL	4251607	180	High	651.83295	2637874.4	90.809672	<Null>	2395445.1
CAL	4391034	150	High	672.61003	2721956.2	99.236244	<Null>	2701167.1

CAL	4121617	60	High	644.07281	2606470.2	99.887408	<Null>	2603535.5
CJS	4221919	8	Low	615.22005	2489707.2	0.682069	<Null>	16981.531
CJS	2201204	32	Low	761.52868	3081797.2	1.063202	<Null>	32765.73
CJS	4230734	4	Low	644.52837	2608313.8	1.515071	<Null>	39517.818
CJS	4191801	5	Low	646.44712	2616078.7	5.402646	<Null>	141337.48
CJS	4090224	14	Low	627.93806	2541175.2	6.150663	<Null>	156299.12
CJS	4101709	40	Low	649.16117	2627062	11.582711	<Null>	304285.01
CJS	2170431	29	Low	638.74734	2584918.8	13.986602	<Null>	361542.32
CJS	4151528	30	Low	643.29241	2603312	15.483908	<Null>	403094.43
CJS	4071031	21	Low	635.37551	2571273.5	16.707261	<Null>	429589.37
CJS	4101422	50	Low	650.24666	2631454.9	21.191388	<Null>	557641.8
CJS	2380305	372	Medium	670.55332	2713633	22.936343	<Null>	622408.18
CJS	2370931	757	Medium	598.28586	2421177	29.601851	<Null>	716713.2
CJS	4330820	250	Medium	629.94817	2549309.8	31.071371	<Null>	792105.5
CJS	2330901	220	Medium	640.28513	2591142	31.099913	<Null>	805842.9
CJS	2441415	261	Medium	638.89652	2585522.5	31.311972	<Null>	809578.07
CJS	2430231	390	Medium	629.4693	2547371.9	37.70177	<Null>	960404.27
CJS	2350531	156	Medium	670.69964	2714225.2	38.137166	<Null>	1035128.5
CJS	2461424	404	Medium	651.01567	2634567	46.867539	<Null>	1234756.7
CJS	2380719	345	Medium	605.47154	2450256.4	48.273643	<Null>	1182828
CJS	4320317	228	Medium	632.20707	2558451.3	51.872895	<Null>	1327142.7
CJS	2320314	207	High	638.75187	2584937.1	58.89739	<Null>	1522460.5
CJS	4342130	122	High	628.55891	2543687.7	60.206643	<Null>	1531468.9
CJS	4371001	216	High	685.92875	2775855.2	62.406848	<Null>	1732323.7
CJS	4381005	269	High	608.18467	2461236	62.950997	<Null>	1549372.6
CJS	2280532	446	High	638.51411	2583974.9	65.473512	<Null>	1691819.2
CJS	4410324	282	High	629.07086	2545759.4	68.582691	<Null>	1745950.3
CJS	4250602	384	High	630.21112	2550373.9	69.523807	<Null>	1773117
CJS	4331130	385	High	669.53109	2709496.2	70.801089	<Null>	1918352.8
CJS	2400633	237	High	611.84837	2476062.5	79.287502	<Null>	1963208.1
CJS	2241412	468	High	632.51118	2559681.9	91.85923	<Null>	2351304.1
CLN	4230911	5	Low	647.69192	2621116.2	0.061768	<Null>	1618.9995
CLN	2120735	30	Low	637.55007	2580073.6	0.506067	<Null>	13056.907
CLN	4090205	28	Low	634.72275	2568631.8	1.124026	<Null>	28872.095
CLN	4080528	16	Low	633.33156	2563001.9	1.268091	<Null>	32501.189
CLN	4100119	41	Low	648.15263	2622980.6	2.134213	<Null>	55979.999
CLN	4220835	40	Low	638.77809	2585043.2	2.689114	<Null>	69514.769
CLN	4130712	16	Low	628.95836	2545304.2	2.873717	Yes	73144.838
CLN	2261233	21	Low	638.36229	2583360.5	3.062183	Yes	79107.218
CLN	4160122	64	Low	633.6659	2564354.9	4.476307	<Null>	114788.39
CLN	4130723	32	Low	632.89238	2561224.6	6.984857	Yes	178897.87
CLN	2201213	45	Low	644.80937	2609450.9	7.785102	<Null>	203148.42
CLN	2170323	46	Low	632.63761	2560193.6	9.368007	<Null>	239839.12

CLN	4130724	36	Low	634.96614	2569616.8	12.179623	Yes	312969.63
CLN	2220212	199	Low	640.14754	2590585.2	13.743599	<Null>	356039.65
CLN	4130714	30	Low	642.79628	2601304.3	16.128363	Yes	419547.79
CLN	4142005	118	Low	651.29965	2635716.1	17.095857	Yes	450598.26
CLN	4142231	83	Low	673.67064	2726248.4	17.598196	<Null>	479770.52
CLN	2341712	78	Medium	632.15051	2558222.3	22.236067	<Null>	568848.02
CLN	4142016	48	Medium	628.59863	2543848.4	22.760675	Yes	578997.07
CLN	2370321	123	Medium	651.315	2635778.3	23.057212	<Null>	607737
CLN	4330314	170	Medium	634.88225	2569277.3	23.943127	<Null>	615165.34
CLN	2430916	184	Medium	641.84154	2597440.5	26.044113	<Null>	676480.34
CLN	4130713	29	Medium	647.99736	2622352.3	26.240445	Yes	688116.9
CLN	2440108	142	Medium	619.77634	2508145.9	26.322085	Yes	660196.3
CLN	2320605	71	Medium	574.53319	2325053.3	26.567952	<Null>	617719.05
CLN	2361314	143	Medium	642.08616	2598430.5	26.952113	<Null>	700331.93
CLN	2380315	93	Medium	629.50789	2547528	27.104761	<Null>	690501.38
CLN	2460723	258	Medium	645.28738	2611385.4	27.540305	<Null>	719183.51
CLN	4130815	47	Medium	645.23547	2611175.3	36.28938	Yes	947579.34
CLN	4130823	32	Medium	646.51361	2616347.8	38.655323	Yes	1011357.7
CLN	4141815	108	Medium	649.03984	2626571	40.312805	Yes	1058844.5
CLN	2471321	228	Medium	652.44589	2640354.8	44.849495	<Null>	1184185.8
CLN	2400516	110	Medium	650.4507	2632280.6	47.168049	<Null>	1241595.4
CLN	4320535	135	Medium	645.83981	2613621	47.390937	<Null>	1238619.5
CLN	4142017	125	Medium	662.79504	2682236.3	54.326454	Yes	1457163.9
CLN	2281130	75	High	625.72987	2532239	59.763253	<Null>	1513348.4
CLN	2410813	18	High	626.34589	2534731.9	60.389033	<Null>	1530700.1
CLN	4380433	67	High	635.84066	2573155.8	63.967453	<Null>	1645982.3
CLN	4340618	100	High	645.64564	2612835.2	64.166626	Yes	1676568.2
CLN	4332119	80	High	639.26677	2587020.8	65.817462	<Null>	1702711.4
CLN	4371112	65	High	696.30024	2817827.1	66.274918	<Null>	1867512.6
CLN	4130808	65	High	642.3024	2599305.6	66.50651	Yes	1728707.4
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CLN	2400935	77	High	640.50158	2592017.9	73.207916	<Null>	1897562.3
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CLN	4321009	52	High	705.15528	2853662.2	87.752827	<Null>	2504169.2
CLN	4260633	87	High	632.774	2560745.5	93.397425	<Null>	2391670.4
CLN	4260319	70	High	562.60278	2276772.7	99.278111	Yes	2260336.9

Appendix C: Mapped Watershed HUC-12 Attribute Information

AREASQKM	HUC12	NAME	Status 1/2021	Cartographer	US ACRES	Project_Name
85.56	40301010903	Lower Mullet River	Awaiting QA/QC	Calvin Lawrence	21142	WDNR County Equivalent
65.23	70900040403	Burgy Creek	Awaiting QA/QC	Christopher Smith	16118	WDNR County Equivalent
82.72	40302010203	S. Branch Neenah Creek	Awaiting QA/QC	Christopher Noll	20439	WDNR County Equivalent
59.76	40302010202	Green Creek	Awaiting QA/QC	Christopher Noll	14766	WDNR County Equivalent
71.1	40301011109	heboygan R.-Frontal Lk Michiga	Awaiting QA/QC	Calvin Lawrence	17569	WDNR County Equivalent
61.28	40301011108	City of Sheboygan Falls	Awaiting QA/QC	Calvin Lawrence	15142	WDNR County Equivalent
55.7	40103020201	Upper Tyler Forks	Awaiting QA/QC	Christopher Noll; Calvin Lawrence	13764	WDNR County Equivalent
50.3	70700010403	Little Saint Germain Creek	Awaiting QA/QC	Christopher Noll; Christopher Smith	12428	WDNR County Equivalent
61.83	70500020204	Bear River	Awaiting QA/QC	Christopher Noll; Calvin Lawrence	15278	WDNR County Equivalent
44.06	70500020101	White Sand Creek	Awaiting QA/QC	Christopher Noll	10878	WDNR County Equivalent
93.16	40302010204	Big Slough	Awaiting QA/QC	Christopher Noll	23019	WDNR County Equivalent
58.44	70900020603	Pheasant Branch	Awaiting QA/QC	Christopher Smith	14441	WDNR County Equivalent
42.99	70700031907	Corning Lake	Awaiting QA/QC	Christopher Noll	10622	WDNR County Equivalent
55.31	70700030303	Little Plover River	Awaiting QA/QC	Christopher Noll	13656	WDNR County Equivalent
25.54	40302021802	Lake Emily	Awaiting QA/QC	Christopher Noll	6306	WDNR County Equivalent
88.59	70900040401	W. Branch Little Sugar R.	Awaiting QA/QC	Christopher Smith	21892	WDNR County Equivalent
120.36	70900040402	Ward Ck-Little Sugar R.	Awaiting QA/QC	Christopher Smith	29743	WDNR County Equivalent
85.87	70700030104	McDill Pond-Plover R.	Awaiting QA/QC	Christopher Noll	21202	WDNR County Equivalent
16.62	40302021805	Wolf Lake	Awaiting QA/QC	Christopher Noll	4104	WDNR County Equivalent
81.96	40301050101	Headwaters Rat River	Awaiting QA/QC	Christopher Noll	20253	WDNR County Equivalent
69.77	40301050102	Upper Rat River	Awaiting QA/QC	Christopher Noll	17240	WDNR County Equivalent
53.25	40301050103	Middle Rat River	Awaiting QA/QC	Christopher Noll	13159	WDNR County Equivalent
16.88	40302020203	Hardwood Lake	Awaiting QA/QC	Christopher Noll	4170	WDNR County Equivalent
52.35	40103020610	Meadow Creek	Finished QA/QC	St. Mary's University	12937	Pilot St Marys
112.52	70500020105	Trout Lake	Finished QA/QC	St. Mary's University	27804	Pilot St Marys
135.75	70500070302	Long Lake	Finished QA/QC	St. Mary's University	33545	Pilot St Marys
111.16	70900020403	Mud Lake-Koshkonong Ck	Finished QA/QC	St. Mary's University	27468	Pilot St Marys
55.52	70700060304	Weister Creek	Finished QA/QC	St. Mary's University	13719	Pilot St Marys
44.85	70700031502	Mud Creek	Awaiting QA/QC	istopher Smith; Calvin Lawre	11083	Pilot WDNR
54.86	70500040302	North Fork Main creek	Finished QA/QC	Christopher Smith	13557	Pilot WDNR
91.68	70700010708	Lower Pelican River	Awaiting QA/QC	Christopher Noll	22655	Pilot WDNR
58.75	40103020601	Flynn Lake	Awaiting QA/QC	Calvin Lawrence	14517	Pilot WDNR
89.56	70700031805	Duck Creek	Awaiting QA/QC	Christopher Smith	22130.5	Pilot WDNR

WDNR Wisconsin Wetland Inventory (WWI) Map Production SOP

Draft: 8/27/2020

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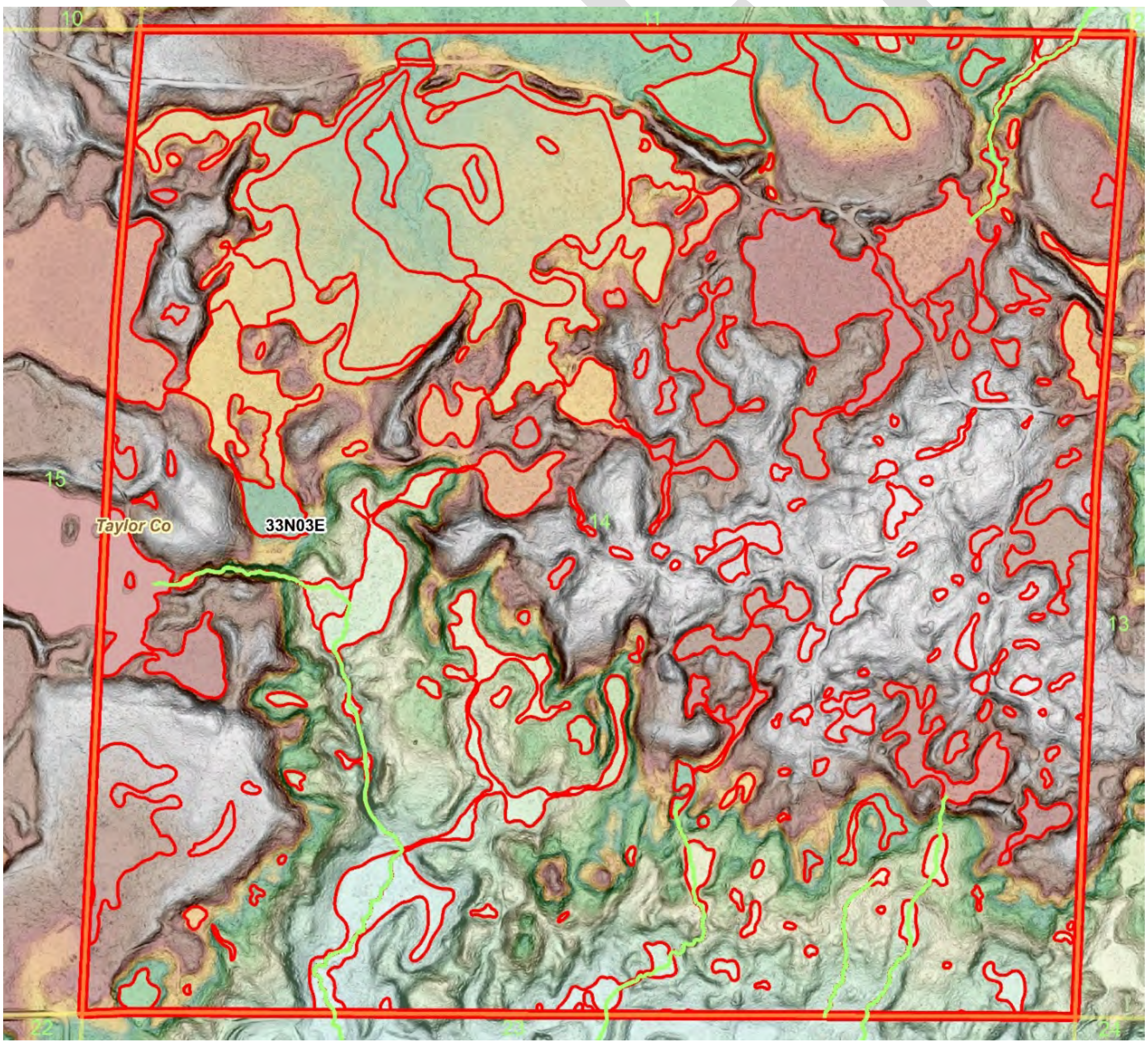
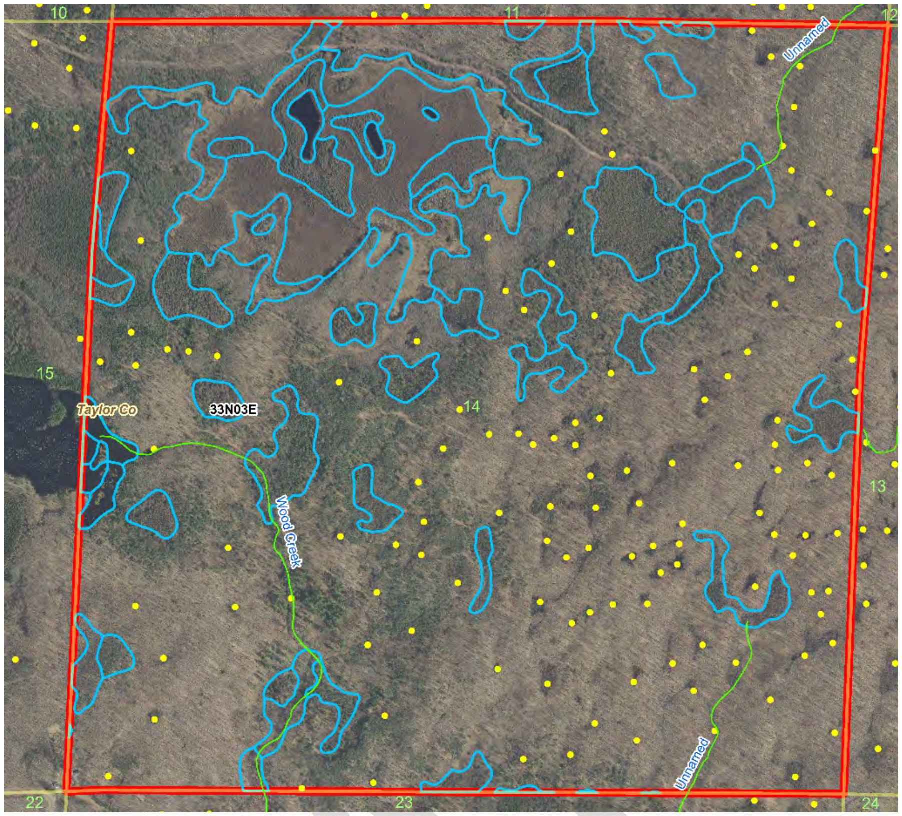
Calvin Lawrence calvin.lawrence@wisconsin.gov





This page *- Comparison of analog hard-copy data drafting (top) end-product with new lidar and high-res image-based product (bottom) within a 1 square mile section of Taylor Co (T33N 3E Sec 14). Expert staff required 2 hours and 50 minutes to remap this square mile, much longer than average. As a result, point symbols have been upgraded to accurate boundaries which, along with improved boundaries elsewhere, captured fifty-three additional acres (8.2% of the total section area) of wetland in addition to two added intermittent streams.*

Front Cover *– LiDAR visualization using semi-transparent color-stretched elevation overlaid with slope. This combination allows for viewing and interpretation of the landscape in unprecedented detail.*

Table of Contents

Introduction

The goal of the Wisconsin Wetland Inventory (WWI) Wetland Mapping SOP is to standardize and outline as much as practical the standards and steps used to draft new wetland and surface water map data from start to finish. As staff at WDNR, partner agencies, and the general public read this SOP, they can contact Calvin Lawrence (calvin.lawrence@wisconsin.gov), Digital Wisconsin Wetland Inventory Coordinator, with any comments and questions. A spreadsheet has been located along with this SOP for internal use to track needed updates.

Origins & History of Wisconsin Wetland Inventory

The Wisconsin State Legislature passed a law in 1978 (Ch. 374, Act of 1977) requiring the Department to map all wetlands in the state. The law also established a statutory definition of wetlands (Wis. Stats., s. 23.32(1)) with which to accomplish the mapping; "an area where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which has soils indicative of wet conditions."

Following an intensive, years-long multimillion dollar effort, initial mapping of the state's wetlands was completed in 1984. The 1984-85 Legislature session produced legislation requiring an update to the original Wisconsin Wetland Inventory (WWI) maps on a 10 year cycle. This updating was to be accomplished with newer aerial photography to improve the data layer and capture aeral change from the previous version. Updating wetland maps is necessary to keep pace with landscape change, improve accuracy, and contrubite to the various research, resource management, and regulatory programs needs within the Department and beyond. Since 1986 DNR has requested adequate staff and funding to update the WWI on a 10-year cycle. Doing this work in-house was determinted to more economical and efficient but, the DNR has been unsuccessful in obtaining permanent staff and funds to update the WWI on a 10-year cycle.

Various improvements in data standards have been implemented over the years. The first WWI maps were drafted on paper aerial photo prints with wetlands delineated using ink pens. These "hard copy" photos had to be "digitized" using combersome early GIS software, hardware, and techniques, had large minimum mapping units, and were not corrected for the horizontal error that results from local elevation changes. Subsuqent mapping standards still used hard-copy drafting techniques, but evolved to use finer-point pens, different color inks to facilitate data separation, and added orthorectification steps during digitization to improve horizontal accuracy and map smaller wetlands. The final two counties using this hard-copy ortrhorectified data standard were completed in 2016. This ended 24 years of updates that resulted in each county being remapped one to two times. Due to further budget cuts and the general obsolesence of film-based printing, this also marked the end of the methods used to map wetlands using infrared-sensitive black and white stereo-pair photos as well as the last couties where the WWI classification system was used to categorize and classify the wetland vegetation and hydrology.

In 2016, the WDNR was awrded an EPA Region 5 Wetland Program Development Grant to help develop improved, modernized methods that utilized existing photography and elevation data for the purpose of mapping wetlands and surface waters in a single digital workflow. Additional objectives include the use of the Cowardin Classification System for polygon attribution, the production of updated flow-network polylines for hydro mapping purposes, and all data produced according to the National Wetland Inventory standards outlined by the Federal Geographic Data Committee (2013). The WDNR contracted with Geospatial Services at St. Mary's University in Winona, MN to help develop methodology and train WDNR staff how to map wetlands according to NWI standards. The WDNR also performed independent research and development to create internal standards that go beyond the minimum requirements of the NWI (FGDC 2013) to address high-value Wisconsin-specific needs within the WDNR and state. While some minor elements of mapping convention have carried over from the early WWI methods, the procedures outlined in this document are the result of a years-long sifting and winnowing process that adapts elements of methodology delivered by St. Mary's Universityand combines it with the result of WDNR's research.

Definition of a Wetland for Mapping Purposes, Limits of Remotely Produced Maps, and Disclaimer

Conceptually, wetlands are places where the presence of saturated conditions, either on the surface or underground, is a predominant force shaping the physical factors and biotic community present. While many definitions of a wetland exist, the two relevant to discuss here represent the legal and mapping interpretations of what defines a wetland.

The U.S. Army Corps of Engineers Wetland Delineation Manual (1987) establishes the criteria an area must meet to be delineated as a wetland based on soils, vegetation, and hydrologic indicators by an on-the-ground wetland delineation professional. This is the standard used by the Clean Water Act Section 404 regulatory program which further divides wetlands into federal and non-federal categories.

Due to the reasons discussed below, remotely produced wetland maps cannot be used for jurisdictional decision making. The key concept to note in the ACOE's approach to wetland determination revolves around indicators that are observed "on-the-ground". Many indicators used in the ACOE Wetland Delineation Manual consist of fine surface and subsurface details that cannot be observed on even the best aerial images. As a result, remotely mapped wetlands represent a reconnaissance level survey standard that relies on primary indicators observable through aerial interpretation of vegetation signatures, surface hydrology, and topography to build a compelling case for the presence of wetlands. While this process results in a high-quality wetland map product that is suitable for many applications, remotely produced wetland maps still require a blanket disclaimer removing them from use in jurisdictional settings. Legal questions involving wetlands can only be resolved through a field delineation performed by a wetland delineation professional.

The principal focus and objective of the wetland inventory is to produce reliable reconnaissance-level wetland maps showing graphic representations of the type, size and location of wetlands in Wisconsin that are accurate when overlaid with a 1:2,000 (1 inch = 167 feet) base map. *They may be used as a reliable guide to wetland presence at a statewide level, but there is no attempt, in either the design or products of this inventory, to define the limits of jurisdiction of any federal, state, or local government or to establish the geographical scope of the regulatory programs of government agencies.*

The Wisconsin Wetland Inventory's definition of a "mappable" wetland is the same as the one used for the National Wetland Inventory as first defined by Lewis Cowardin and Francis Golet (1979) and later enshrined in many subsequent data standards guidance documents published by the Federal Geographic Data Committee (FGDC). The most recent FGDC guidance documents include the Wetland Mapping

Standard (2009) and [“Classification of Wetlands and Deepwater Habitats of the United States”] (Cowardin et al. 2013) – a.k.a. The Cowardin Classification System.

It is important to understand that remote Geographic Information System (GIS)-based mapping of wetlands, surface waters, and cover type relies heavily on human decisions based on the interpretation of one or more primary data sources and potentially several ancillary data sets. Further, each cartographer brings forth their own sets of strengths and weaknesses from their domain of knowledge and experience. Because wetland mapping is an interpretive process based around image and topographic-based cues set within a geologically diverse state, it is important to acknowledge that individual skill, training, and familiarity with Wisconsin’s landscape are very important components of producing accurate wetland maps. This still results in a somewhat variable interpretive process where one photo interpreter works within a set rules to arrive at, ideally, a boundary that ought to be very similar - but often not identical - to what another cartographer would produce.

Just as training a dog or building a house from a single set of written instructions with little prior experience would prove an extremely difficult, variable task with each new situation, it is not practical to outline a single start-to-finish sequence of tasks that works across the entire state. As a result, this SOP outlines the methods, data, standards, and constraints used to arrive at the photo-interpretive and topography-based decisions necessary to produce attributed wetland and surface water maps.

Data Production Standards and Overview

Project Boundary Determination

Until 2018, the WWI was mapped based on the Public Land Survey Township/Range land classification system (PLSS) due to computer processing limitations. Flight paths were flown based on county boundaries and final wetland maps were broken apart along the Towns/Ranges that made up the county. With the inclusion of hydrography in the mapping process, the WWI is moving away from county-based mapping to project boundaries based on Hydrologic Unit Code (HUC) watersheds. The smallest order of watershed division is the “HUC-12”, which typically forms the base unit of wetland mapping. Depending on the watershed boundary, each new mapping project may include more than one county and/or HUC-12 watershed. As of 2020, with full statewide LiDAR data coverage, smaller PLSS section-based project boundaries may be considered on a case-by-case basis to address special needs across the state.

Mapping Scale

The WWI produces maps with a nominal mapping scale of 1:2,000. Practically speaking, this means that when viewed with imagery at 1:2,000 scale, mapped boundaries should appear tight and precise. During the drafting process, it is often necessary to “zoom in” to examine imagery at a sub-1:2,000 scale, but most lines and attribute determinations are made with information discernable at 1:2,000.

Minimum Mapping Unit

There are no hard-exclusionary lower area thresholds for wetlands that can remotely detected and mapped. Per FGDC (2009) standards, the National Wetland Inventory Target Mapping Unit for the lower 48 states is 0.5 acres. The WWI aims to capture all remotely detectable wetlands down to 0.1 acres and may be smaller than 0.05 acres in the case of ephemeral ponds, excavated ponds, and pothole wetlands. At a certain size point, a wetland may be difficult to even see a at 1:1,000 scale or represent non-target wetland features like puddles in dirt roads.

That said, the WWI recognizes the need to maintain certain minimum units of subdivision from larger wetland complexes for the sake of production efficiency. In the same sense that a handful of trees do not make a forest, pockets of vegetation differing from a larger, surrounding wetland type are typically not subdivided unless they are at least 0.2 acres in size or represent a surface water feature.

Target Wetland Feature, Horizontal, and Attribute Accuracy

The WWI follows standards laid out by the FGDC (2009) Wetland Subcommittee for producer's accuracy for NWI data. Wetland feature accuracy refers to the percent of mapped features correctly identified as a wetland, which is 98% for the lower 48 states. For a wetland feature to meet horizontal accuracy standards, the mapped boundary should fall within 5 meters of the ground-truthed boundary. Finally, attribution accuracy should be at least 85% correct. These accuracy targets are verified in the QA/QC and field-checking process described in later sections.

Standard Coordinate System

The official Wisconsin DNR coordinate system is Wisconsin Transverse Mercator. All data layers inside the DNR's wetland geodatabase use this coordinate system. The Wisconsin Transverse Mercator projection uses meters as the X, Y units. Vertical units for elevation data may be U.S. Survey foot or meters. If it is unclear what units a LiDAR data layer uses, it is helpful to keep in mind the highest point in Wisconsin is Timms Hill at 1,951 ft/595 meters, and the lowest points are Lake Michigan at 577 ft/176 m and the Mississippi River in Grant Co at 593 ft/180 m). When working in ArcGIS, the following WKID (Well Known ID) projection file is to be used. To ensure consistent coordinate systems are used, the first layer added to a new MXD should be the "WWI_Polys" layer from the WWI template geodatabase.

"NAD_1983_HARN_Wisconsin_TM" - WKID: 3071 Authority: EPSG

Projection: Transverse Mercator
False Easting: 520000.0
False Northing: -4480000.0
Central Meridian: -90.0
Scale_Factor: 0.9996
Latitude_Of_Origin: 0.0
Linear Unit: **Meter (1.0)**
Geographic Coordinate System: GCS_North_American_1983_HARN
Angular Unit: Degree (0.0174532925199433)
Prime Meridian: Greenwich (0.0)
Datum: D_North_American_1983_HARN
  Spheroid: GRS_1980
  Semimajor Axis: 6378137.0
  Semiminor Axis: 6356752.314140356
  Inverse Flattening: 298.257222101
NAD_1983_HARN_Wisconsin_TM

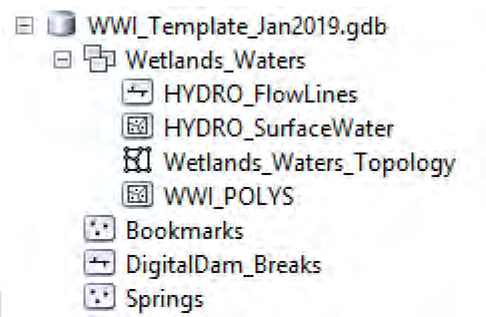
Vertical units for elevation data can be U.S. Survey foot or meters – however, meters are strongly encouraged. Check the metadata along with the linear units to make sure both are in meters.

Template Geodatabase for New Mapping Projects

A standardized template geodatabase exists on the DNR network (here) and an empty copy should be created in your working directory before for starting each new mapping project. All layers have edit tracking enabled to allow for transparency in the source and time of edits.

Standard Production Layers

The most important layers are contained within the "Wetlands_Waters" group layer.



HYDRO_FlowLines – This polyline layer contains three types of flow line – perennial, intermittent, and fluctuating - that are intended to become source data for 24k Hydro updates.

HYDRO_SurfaceWater – This polygon layer is a generalized subset of the WWI_POLYS layer that has been dissolved to the DNR 24k Hydro geodatabase standard. It is populated through the execution of a query.

"Wetlands_Waters_Topology" – This set of topology rules defines the allowable geographic constraints that features must fit within. The rules can be viewed by right clicking the topology layer and selecting properties.

"WWI_POLYS" – This is the primary and most important layer for drafting.

"Bookmarks" – These points are intended for simple cartographic notes and reminders which can be added in the attribute table. This layer is also useful for identifying possible field verification locations when used in combination with a parcel layer.

"DigitalDam_Breaks" – This layer is optional but encouraged for the creation of bridge, culvert, and wetland divide data that is being aggregated at the State Cartographers Office.

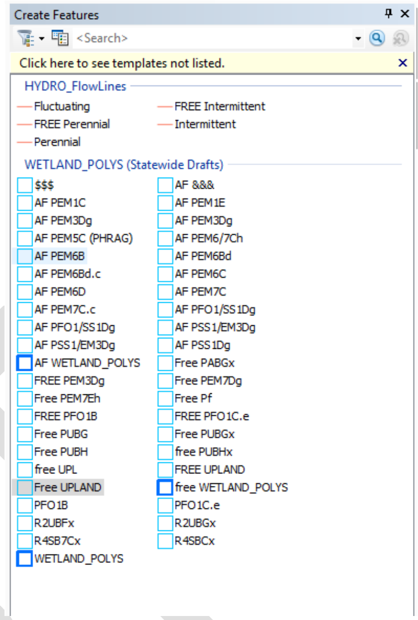
"Springs" – This layer is for capturing spring pool locations to supplement the Wisconsin Geologic and Natural History Survey's database.

"Point_Anaytics" – This layer is used to provide information to an experimental, semi-automated point-based wetland boundary analysis process that is in development.

Feature Editing Templates

Feature editing templates are highly useful tools for directly creating fully attributed polygon and polyline data. Templates can be created by simply right-clicking on an existing template and selecting “copy”. When creating new templates, there are three important considerations

1.) Properly assign the FULL WWI and NWI attributes.
2.) Select the most appropriate, commonly used drafting method (usually polygon, freehand, or auto-freehand).
3.) Rename the template as appropriate. If using freehand and auto-freehand drafting methods, prefacing your template name with AF (auto-free) and FREE (standard freehand) can be helpful to keep the editing window orderly.



Primary Data Overview

Primary Data and Secondary Data

For a given class of data, the most valuable and heavily used layers for basing mapping decisions are referred to as primary data layers. Examples of primary data include recent leaf-off tiff imagery and LiDAR-derived elevation products. Secondary data layers still possess valuable information but do not provide the cartographer with enough information or precision to base certain decisions or create accurate boundaries and largely plays a supporting role. Examples of secondary data include historic imagery, leaf-on imagery, DNR 24k Hydro flow network, SSURGO soil-based data products, and previous versions of the Wisconsin Wetland Inventory.

Primary TIFF Imagery

It is critical to use the best available imagery for the primary aerial image layer when delineating wetlands. In landscapes where wetlands lack clearly defined boundaries, such as those on mineral soils and/or seepage slopes, visual interpretation of wetland signatures from aerial photography is necessary to draft boundaries. The ideal primary aerial image layer is the most recent, highest resolution (6-12 inch) county-wide set of leaf-off uncompressed TIFF orthoimagery that can be sourced. Often, this image layer is supplied in the form of many small “tiles” which need to be mosaicked together through the creation of a raster catalog or using the “mosaic to new raster” tool in the ArcToolbox.

If uncompressed imagery is unavailable, then the highest-resolution compressed leaf-off imagery may be used. JPEG or MrSID are examples of compressed image file formats. Image compression algorithms use data-compression techniques to reduce file sizes and appear blurry or “blockified” at close viewing scales. As a result, they are not ideal for the cartographic decision making. Compressed images should not be used for mapping where uncompressed imagery from the same flight is available. If detailed leaf-off imagery less than 10 years old is unavailable for a given county, drafting of new wetlands maps should be discouraged except for high-priority needs.

Ideally, the primary aerial image should have been flown close to the same year as the LiDAR data during a period of normal precipitation, as this reduces inconsistencies that arise from changes on the landscape (e.g. widening of roads, construction of buildings, etc.). Uncompressed TIFF data is typically not hosted on the DNR network due to space constraints. Check the BTS data holdings intranet page to check for availability. Imagery can be requested from the DNR Bureau of Technology Services through Cherwell along with providing an external hard drive for data to be copied to. If necessary, contact the county land information officer. It should not be assumed that TIFF data is unavailable unless it is confirmed by either of these offices.

Mosaicking TIFF Images

TIFF images demand extra storage space and processing power. The files for a county are usually broken up into an unwieldy number of small chunks or "tiles". When you obtain new TIFF imagery, chances are good that individual tiles will need to be mosaicked together into a new TIFF image. Fortunately, the spatial properties of HUC watersheds and TIFF images can be leveraged to automate the process of mosaicking images together.
In order to accomplish this, four items are needed:

- Uncompressed tiff images with a consistent file structure
- An "image tile index" (or similarly named layer) containing an attribute column containing the image file name
- HUC 12 or HUC 10 polygon features
- An example python script to automate the mosaicking process is located at \\dnr.state.wi.us\programs\WT\Temp\WT_W4WETLANDS\Wetland_Hydro_Mapping\ --> "Watershed_MosaicGenerator_OneidaHuc10.py"

If any of the above items are not available, a TIFF mosaic image can be manually created using the "Create Mosaic Dataset" and the "Add To Mosaic Dataset" tools within the Data Management, Raster toolbox of ArcMap. Tutorials for how to use these tools are available within ArcGIS and searchable online. In any situation, original TIFF image tiles should **never** be deleted fter mosaicking.

Secondary Image Layers

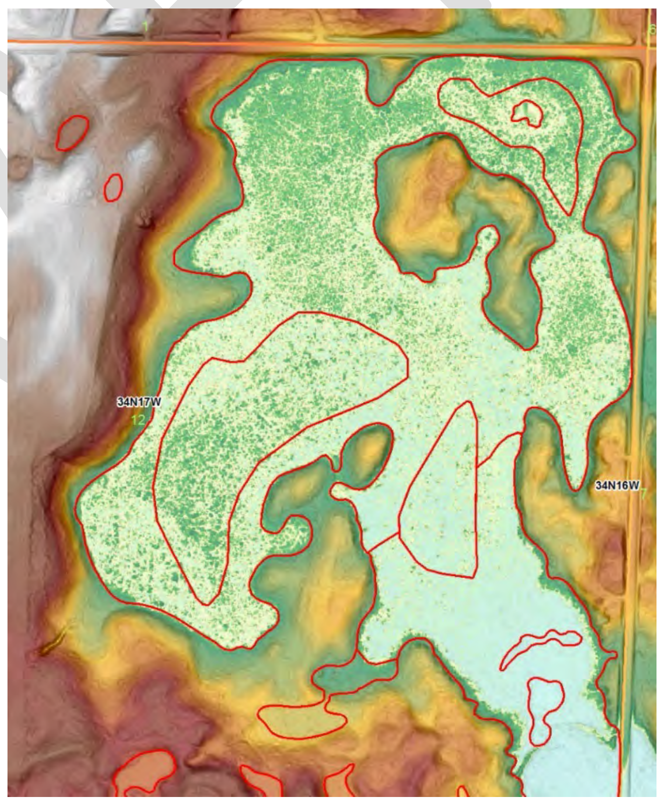
In addition to the primary aerial image layer, secondary image layers need to be assembled and organized. Functions of secondary image layers include observing vegetation during summer months, checking water levels across multiple years, and confirming the presence or absence of live trees, shrubs, and herbaceous vegetation. An ideal place to download and assemble supplementary imagery is on the following WDNR network folder: \\dnr\GIS\Airphoto_DOP\doplib\ or \\dnr.state.wi.us\gis\airphoto_DOP\doplib\

For better performance and stability in ArcMap, all relevant data from the network for the project area should be copied to a local folder before adding the layers to an ArcMap document. This is because every time ArcMap refreshes due to a display update, it must redraw all visible layers. Layers being pulled from the network will often take extra seconds to load and when multiplied by the tens or hundreds of thousands of screen refresh cycles, many extra hours of unproductive load time can be saved by taking a few minutes to copy data before starting. It is important to note any restrictions placed on an image layer by the locality that provided the data and be careful about distributing this data to unauthorized partners.

In addition to readily available imagery on the WDNR network, other sources of secondary imagery can be leveraged. These include, but are not limited to layers in the following list:

- Orthorectified Historic WWI grayscale imagery - Maintained by Calvin Lawrence and stored on external hard drives.
- Hard-copy WWI imagery – Requires Tracking Down on Roller-shelves and manual scanning.
- B |A |G Tool - Opens an internet browser window using Bing Maps, ArcGIS Online, or Google Maps. This is a python add-in toolbar that must be installed.
- Historic Aerial Imagery 1937-1940 - 600 DPI TIFF scans can be downloaded from the "WHAIF" website.
- USGS Earth Explorer – Hosts uncompressed NAIP Imagery and Volumes of historic scanned single-frame aerial images.
- ESRI World Imagery - Can be streamed from the internet by "Adding data from ArcGIS Online".

LiDAR Data



1 LiDAR raster with a histogram-equalized color ramp applied to emphasize flat wetland areas

LiDAR data products are the result of a rapidly improving technology that has expanded in the last 20 years from niche applications to a foundational landscape-scale dataset. Similar in principle to weather radar, LiDAR data is generated by flying a specialized instrument that sends millions of laser light pulses toward the Earth from an aircraft per second. By measuring the number of returns for each light pulse and the time it takes for each to occur, a 3-D model of the Earth's surface is generated. Once these signals are properly classified and converted into a Digital Elevation Model (DEM), a "bare earth" view of the ground surface is constructed which provides critical information for visual interpretation and computational detection of the topographic shifts that indicate wetland boundaries and hydrologic regimes. Often, this information cannot be reliably interpreted through imagery alone. As a result, most LiDAR DEM's produced since 2008 are considered a primary data layer for drafting wetland and surface water data. As of 2020, all Wisconsin counties have at least one set LiDAR data products. As a rapidly advancing technology, counties with older LiDAR data containing less information per square meter than newer flights. While coarser, even older layers with 1.5 m horizontal resolution are usable for drafting improved wetland maps.

LiDAR DEM ("Bare Earth" Digital Elevation Model)

There are two main options when it comes to importing LiDAR data for use in the wetland mapping process.

1. Use the contractor-delivered pre-processed BARE EARTH elevation raster (DEM).

2. Manually create your own bare earth raster using the raw LiDAR point cloud (.LAS extension) data files.

In most cases, the contractor-delivered DEM is good enough for basing decisions regarding wetland boundaries. It is important to note that these DEM products typically undergo a series of modifications which may create issues of which the cartographer should be aware. Notably, contractor delivered DEM's often have breaklines "burned" into the elevation data. Where this is most relevant is around surface water features, where the contractor or a county has used polygon features to enforce a hard "break" on the terrain in order to remove visually unpleasant elevation artifacts on water surfaces, cliff edges, and other places where a sharp change in elevation needs to be enforced. Frequently these breaklines have inaccuracies and/or were created from an outdated or unknown images source. In other cases, breaklines are apparently derived through an automated or semi-automated algorithm by the contractor where the same caveats apply.

In some instances, after initial review of the contractor-delivered pre-processed DEM, errors may be discovered in various aspects of the DEM. An example may be points that are improperly classified as ground. In this case, it may be necessary to re-create the DEM through a manual process using point-cloud (LAS) data. The process to do so is detailed in Appendix C(?).

Because LiDAR data collection flights are often contracted though the counties, data may be provided in county coordinate systems and non-metric horizontal and/or vertical units that needs to be projected to Wisconsin Transverse Mercator. This is discussed further under the "Official Coordinate System" section.

Potential future uses of LiDAR may evolve to include the use of first-return data to create more reliable estimates of vegetation cover classes like emergent, shrub, and forest as well as semi-automated boundary detection through terrain analysis.

A large collection of pre-made bare-earth Digital Elevation Models projected to WTM are available on the internal DNR network. It should be attempted to use these layers first before spending time on manual DEM creation. A few counties may require the creation of a DEM through mosaicking tiles or LAS classification. Additional data is listed on the Bureau of Technology Services data holding intranet page. Also, https://www.wisconsinview.org hosts LiDAR data with supplementary files that may not be held elsewhere. Lastly, contacting county land information offices may be necessary to obtain recently collected LiDAR data.

Slope vs. Hillshade

Slope and Hillshade layers are LiDAR-derived rasters that are used to add 3-D "pop" by providing visual context for changes in the slope of the terrain. Both tools are found in the ArcToolbox under "3D Analyst Tools à Raster Surface". While these layers share similarities, it is important to note a few key differences. Hillshades use a simulated sun angle to create areas of light and shadow on hills. Slope rasters, on the other hand, are unidirectional and represent slopes of an equal degree with the same shade of gray.

Because hillshade use a simulated sun to create areas of light and shadow, these tonal characters may be cast beyond areas of actual topographic shift and cannot relied upon to indicate the toe of a slope where uplands transition to wetland – a critically important area for delineating wetland extent. While cartographically pleasing, compared with the consistent unidirectional properties of a slope raster hillshades provide an inferior visualization of the actual land surface and should be avoided for use in boundary interpretation. Because of these issues, the WWI does not use hillshades for wetland data drafting. The following DEM visualization scheme provides more accurate information about the landscape when coupled with the slope raster.

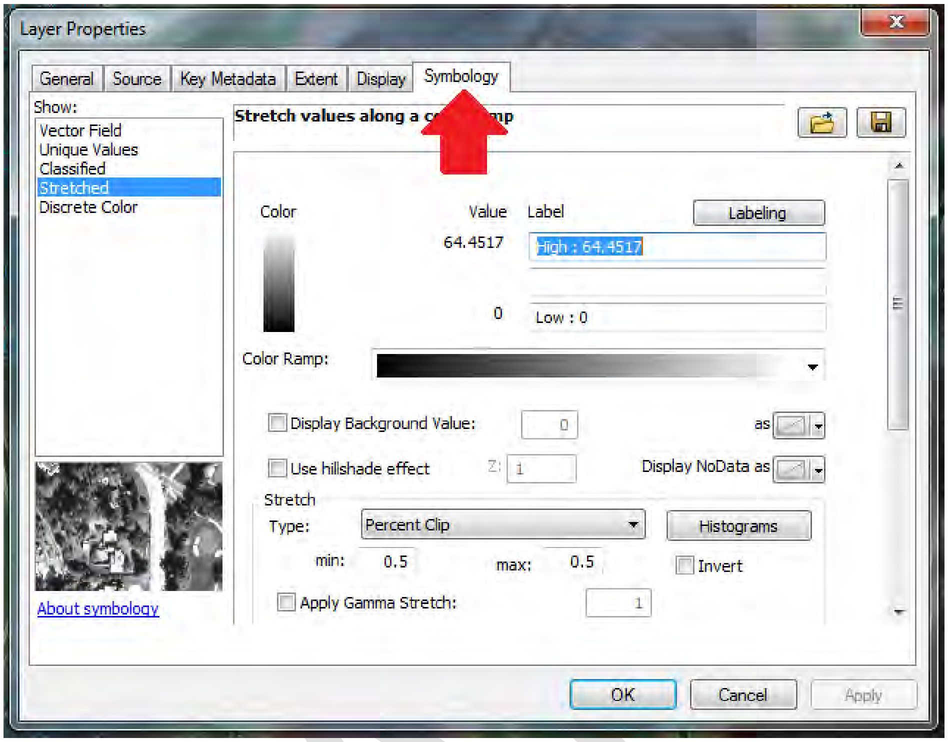
Visualization of Bare-earth LiDAR DEM and Slope Data

Preferably, your source elevation DEM should use meters as the vertical units. The slope raster should be placed *under* the bare earth Color-Stretched LiDAR DEM. Histogram Equalize is the stretch of choice for most of Wisconsin, especially where wetlands form large, flat or gently sloping lowlands, but it is not always the most useful stretch in every landscape. Low-relief landscapes in particular tend to be challenging and may require different stretches should be tried. Raster display statistics should **always** be maintained as "From Current Display Extent".

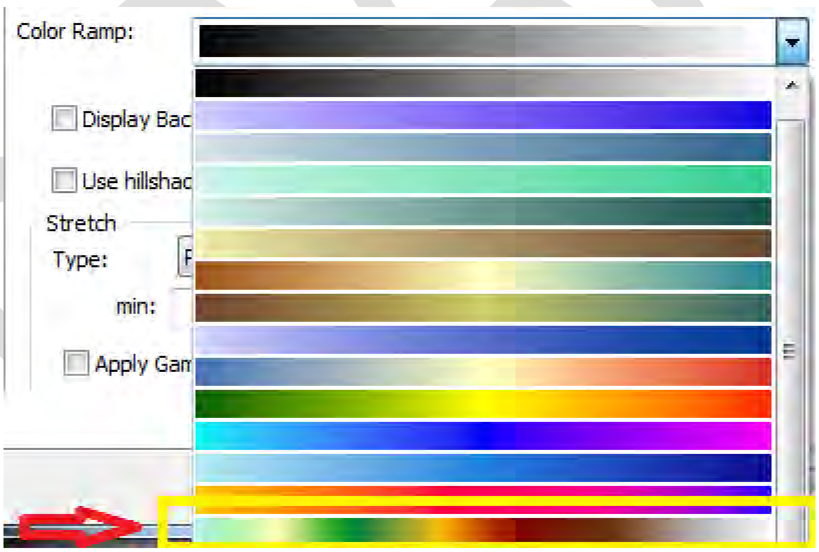
Steps for adding LiDAR images and properly applying a color ramp in ArcMap

1. **ADD THE LIDAR ELEVATION RASTER.** Click the "Add Data" button. Navigate to your raster, click "Add"
    a. In the table of contents, Right-click the newly added Lidar Elevation Tiff layer, then click "zoom to layer".
    b. In the table of contents, Right-click on your Lidar Elevation tiff, select "Properties" at the bottom of the menu. Within the properties box:

c. Click the “Symbology” Tab



d. Change the Color ramp from grayscale to multi-color. Click “Apply” (bottom right)

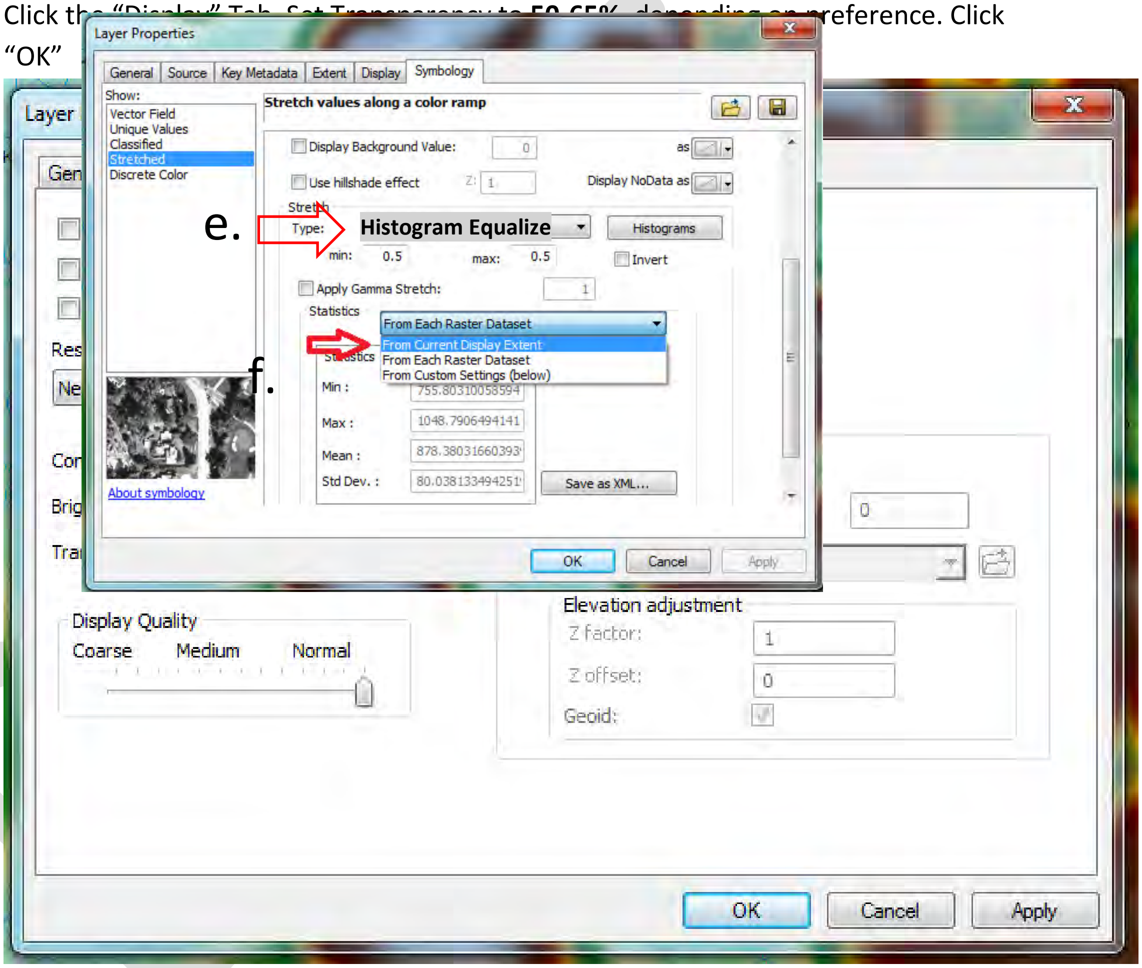


e. Change the Stretch Type to “**Histogram Equalize**”

Note: In landscapes where wetlands tend to form broad, flat lowlands that stand in contrast to more irregular uplands, generally the “**Histogram Equalize**" stretch is your best option. This stretch works well for much of the state. In landscapes with **very low relief and unclear distinctions between equally sloped uplands and wetlands** (areas of low drumlins in Rusk County are just one example), the histogram equalize stretch can create a misleading view of the landscape. In these cases, experiment with linear stretches like minimum-maximum and percent clip (vary the % clipped) to create something that makes visual sense. It is important, however, to maintain statistics using the "Current Display Extent".

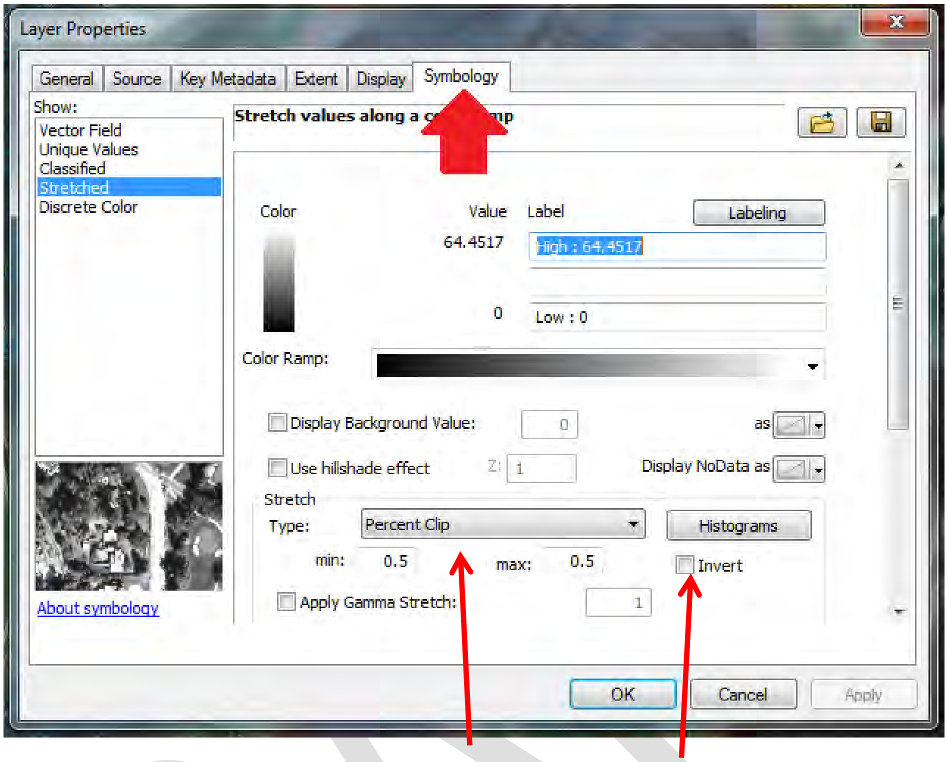
f. Scroll down until you see “Statistics”. Change to “From Current Display Extent”. Click Apply. This will re-stretch the image to the maximum color range within elevations displayed on screen.

g. Click the “Display” Tab. Set Transparency to 50-65% depending on preference. Click “OK”



2. **ADD THE SLOPE RASTER.**
   a. **If not already created, generate a slope raster using ArcToolbox “Spatial Analyst Tools -> “Surface” -> “Slope” Tool**
   b. Click the “add data” button, browse to your slope raster file location. Click “Add”
   c. In the table of contents, **click and hold** on “dane_slope1.tif” and **drag it below the LiDAR Tiff from the previous step.**

d. Right-click your slope raster in the table of contents and select “Properties”. Click the “Symbology” Tab.

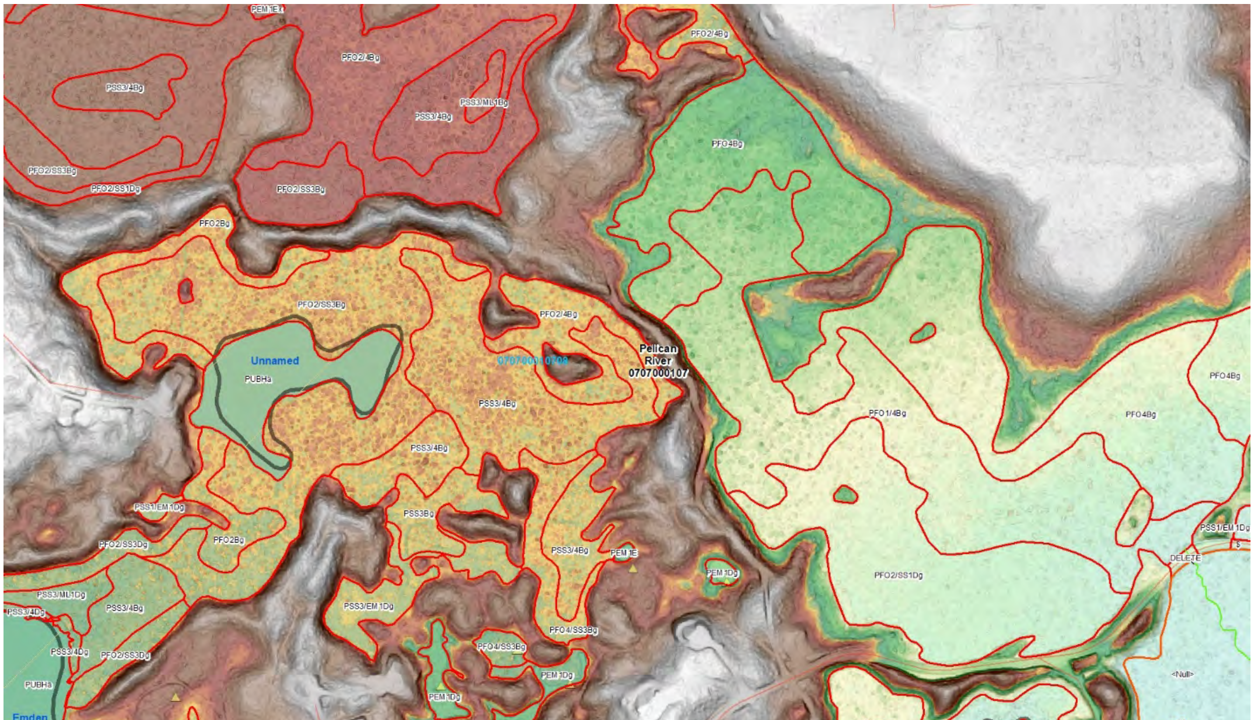


e. Change the stretch type to “Minimum-maximum”

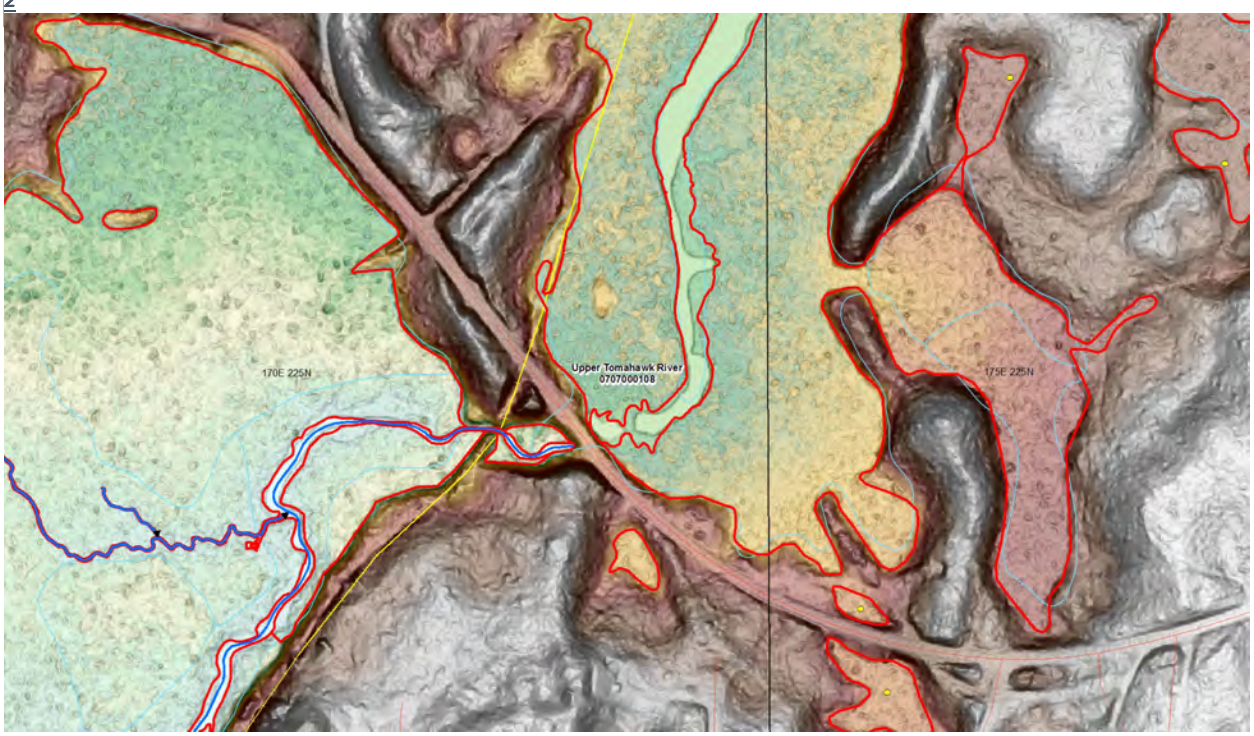
f. Click the “Invert” Checkbox and hit “apply”. STATISTICS SHOULD BE MAINTAINED AS “From Each Raster Dataset“.

g. Scroll around in your new map background! If happy with the results, **save your MXD.**

Comments: This arrangement of LiDAR data layers allows for both slope and elevation to be easily recognized. Pale greens and blues (think water) represents the low elevations, while brown and white (think snow-capped mountains) represent higher elevations. Gray-shaded areas indicate areas where the ground is sloped, with darker gray corresponding to steeper slopes. Because “Statistics are calculated from display extent”, ArcMap re-stretches the color ramp to take full advantage of the display capabilities to greatly exaggerate small changes in elevations when fully zoomed in. This allows us to see features like mounded peat domes in an otherwise almost-flat wetland complex quite clearly**, but it can also over-accentuate topographical features to create false upland/wetland signatures**, so judicious use is encouraged!



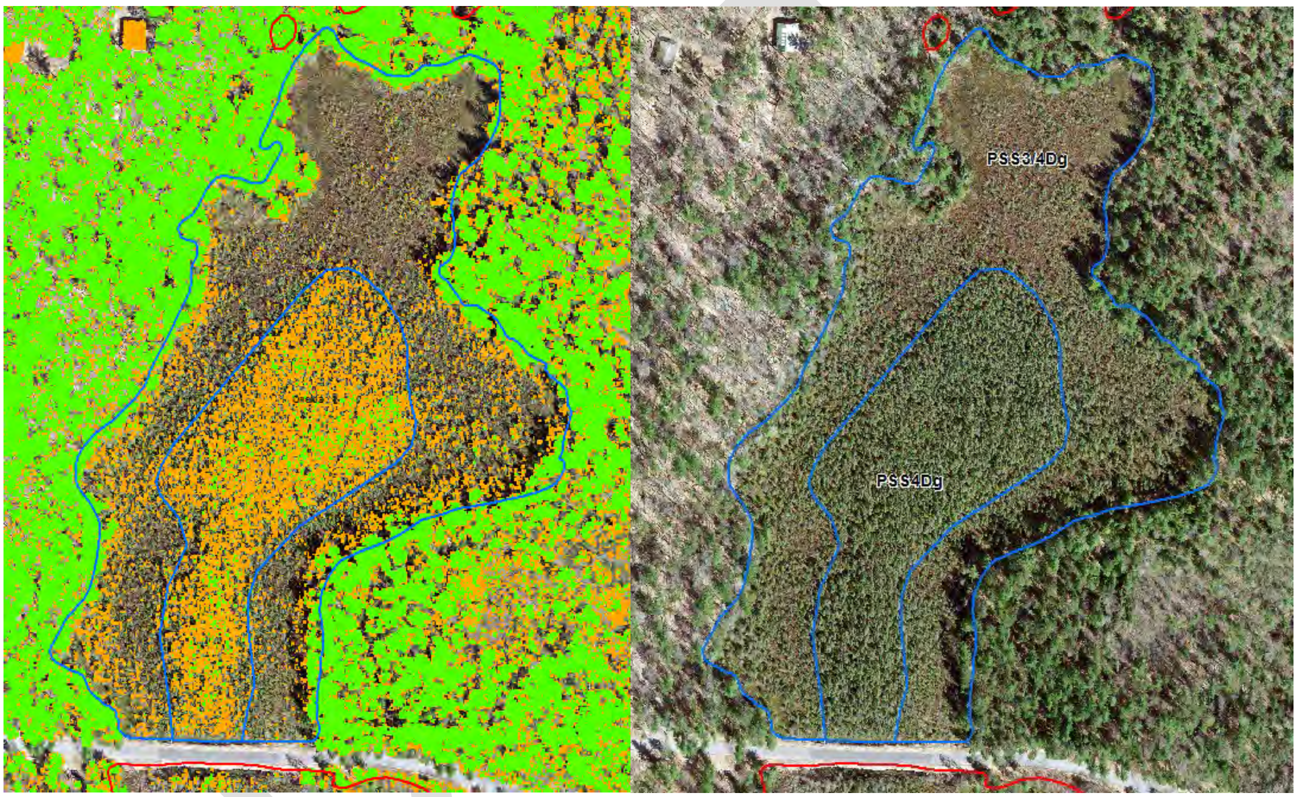
2



Resulting Slope + Histogram-equalized elevation overlay used for wetland outer boundary delineation in Oneida Co, WI

Digital Surface Models (DSM) and Canopy Height Models

Digital surface models use first return data to create a surface representation of the landscape that includes treetops, shrubs, buildings, and other non-ground features. Using raster math, a canopy height model is created by subtracting a bare earth DEM from a DSM. The resulting raster represents canopy height raster which can be reclassified according to a deciduous shrub height of 1.5 – 6m, and forested vegetation height of 6m or greater. Not all shrubs will meet a minimum height of 1.5 m, so accurate interpretation is needed to separate short-statured shrubs from emergent vegetation. In the example below, areas with vegetation less than 1.5 m tall contains stunted black spruce evergreens (SS4), broadleaf evergreen (Ericaceae family) shrubs (SS3), and minor, non-attributed components of emergent (EM3) vegetation. Despite these subtleties, canopy height rasters are especially valuable for separating short-statured forest from tall areas of shrub-scrub.



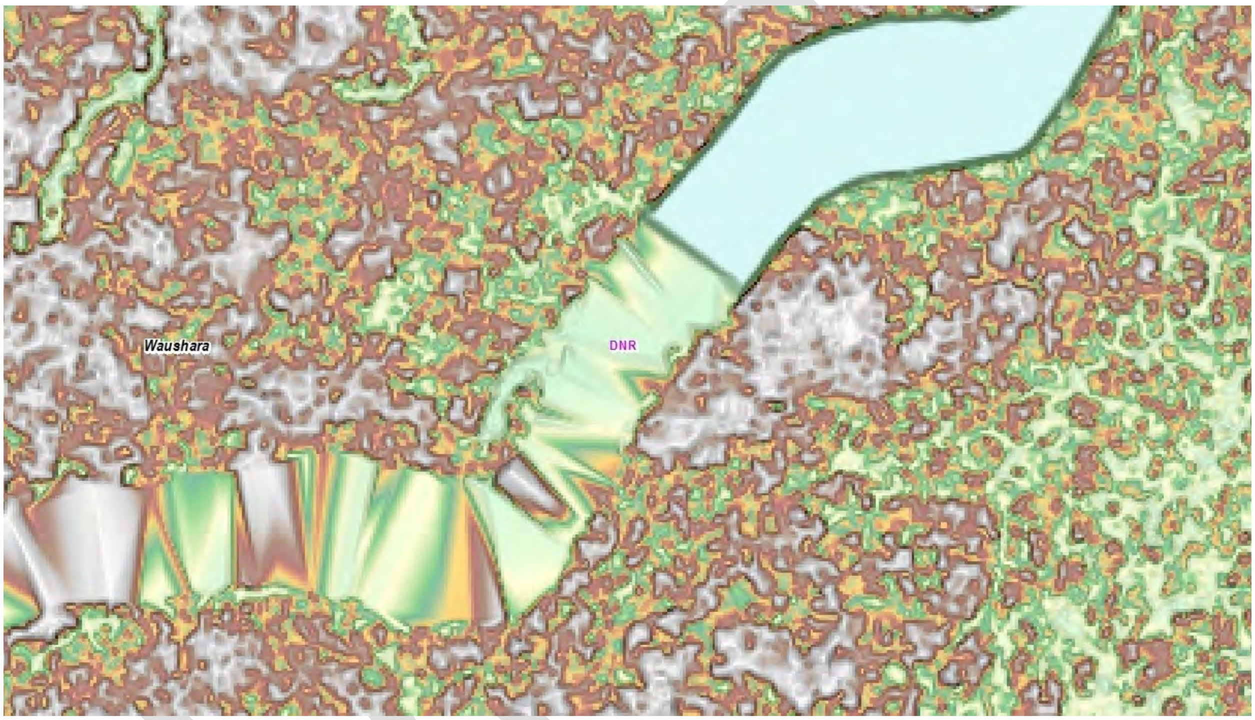
3 Visually estimating NWI tree height of 6+ meters can be a difficult task from imagery alone, especially in stunted muskegs where small spruce and tamarack appear similar to tree-size specimens. Left, a reclassified canopy height raster displays tree-height (6+ meters) areas in green, shrub-height (1.5 – 6 meters) areas in orange) vegetation, and emergent height areas (0 – 1.5 meters) as transparent over an open bog and muskeg wetland. Lidar data suggests that not enough black spruces are of NWI tree height to warrant assigning a forested subclass. Right, the resulting subdivision and classification, which was not obvious from the aerial image alone, overlays nicely with the aerial image.

Overview of Ancillary Vector Data

The layers below may be used for a small subset of cartographic decisions within a watershed or to increase data production efficiency but are not typically not required for dataset production.

LiDAR Breaklines

When LiDAR data packages are delivered, there is often "breakline" data included. These are vector features that have an elevation value embedded in the attribute table that are used for enforcing a smooth, visually pleasing surface in areas where return signals to the LiDAR sensor are weak and produce artifacts. A key area where breaklines are applied are over water features like lakes, rivers, streams and ponds where one would expect to see a smooth surface. In the image below, breakline elevation data for a river was burned into the NE corner but stops halfway through.



4 Screenshot shows the difference between breakline-enforced elevation (upper right portion of the river) and unedited lidar surface water artifacts (lower left portion of the river).

The origin of these features is often unknown, so it is often hard to say when or how these features were drafted. Regardless of the origin**, wherever these breakline features closely match the primary aerial image layer, they may be copied and pasted directly into the new wetland & surface water layer**. In the image pair below, a breakline is shown for a fluctuating pond. In this case, it may make sense to cut out an inner regularly inundated pond polygon and an outer regularly exposed emergent polygon.

5 Spring leaf-off view and summer color-infrared of the same kettle pond in different years overlaid with the corresponding breakline feature. In this case, the outer boundary may be used but the interior should be subdivided to an aquatic bed, flooded (PABF) polygon while the exterior ring should be labeled as an emergent – persistent seasonally flooded (PEM1E).

Breakline quality varies widely. The adoption of breakline features into the mapping layer requires examination of each feature during the mapping process. Those that do not meet FGDC standards for spatial accuracy or otherwise don't accurately represent the surface feature being mapped (such as breaklines created during flood conditions) should be rejected or deleted from your editing layer and re-drafted. Depending on overall quality, breaklines can be incorporated wholesale or added individually into a new mapping project. If a breakline polygon for a stream or river is copied into your editing geodatabase, a centerline for that polygon can be calculated efficiently using the DNR's AutoStream toolbar.

Current Wisconsin Wetlands Inventory (WWI)

Existing WWI data always needs to be available for viewing during the data creation process. This data was created using hard copy stereo-pair drafting methods at roughly 1:15,000 scale and is composed of polygons (mostly larger than ¼ acre) and point symbols for smaller wetlands. This layer is useful for checking approximate boundary accuracy, checking wetland attribution, and confirming the presence of larger wetlands.

DNR 24K Hydrography

The existing 1:24k DNR Hydro Geodatabase is a fundamental dataset for the DNR for mapping waterbodies and river centerlines. It is also outdated and, in many places, contains inaccurate flow paths. Regardless, this data is useful for getting a good idea of the placement of most streams in a watershed. Linework from WWI updates are currently slated to provide the raw data needed to update this geodatabase.

Hydric Soils (Network Layer: W11101.EN_WI_SOIL_HYDRIC_AR_SV)

This layer is based on the Natural Resources Conservation Service Soil Survey Geographic database (NRCS SSURGO soils database). It indicates the extent of soil polygons that are predominately hydric. It is worthwhile to note that the data in this layer can vary wildly in age and was typically drafted at a similar scale as the Wisconsin Wetland Inventory. As such, it should not be expected to possess a level of accuracy and detail to distinguish topographic features at 1:10,000 scale and larger ("zoomed in").

Public Lands (PAD CBI) and Parcels (SDEDNR.EN_PARCEL_AR_VAR)

Highlighting public lands within a watershed is useful for deciding where to perform field checks. Wetlands on public lands can be easily marked with point symbols indicating questions related to boundary decisions. Always confirm public ownership or receive written authorization from a private landowner before setting foot on a site.

Political Lines (PLSS, Counties, Cities, Roads)

These basic cartographic layers are used for overall orientation, determining where and how to obtain data, and for tracking progress. One of the more useful layers for tracking progress is the Public Land Survey System (PLSS) sections layer. Working within sections can be very useful for dividing a watershed into manageable chunks that can be mapped to completion with a high degree of confidence that the entire area was visually checked for wetland presence. Sections can also provide a measurable indicator of progress as one works through a watershed.

Hydrologic Units (10 & 12-digit HUC) The WWI has largely transitioned to creating project areas around on 10- and 12-digit watershed boundaries. As a result, the HUC-10 and HUC-12 watersheds should be a standard part of a map MXD. The statewide watershed layer can be found on the DNR network inside the following path here: Watershed GIS layers.

Though often imperfect, these watershed boundaries provide the most coherent watershed-based project area boundaries where flow networks are concerned.

Pro-tip: Do not keep this layer in an editing geodatabase. Inevitably, doing so will result in holes being clipped in the watershed during the editing process!

Springs

This layer contains known springs, sourced from the Wisconsin Geologic and Natural History Survey. The original springs point layer contains many features which no longer exist, so it is only to be used as a general guide.

Contours – (LiDAR Deliverable)

Contours can be useful for directly overlaying elevation data over imagery in a way that topographic cues can be interpreted. Due to the lumpy texture of bare-earth data, contours often consist of wobbly lines that are not cartographically pleasing and should generally not be used for boundary tracing purposes.

(*Note: ARCMAP often crashes when pushed beyond the limits of what source data can reliably support, such as creating a 2 ft layer from a 1 m DEM)*

Data Processing Techniques

Hydrographic Position Index or "HPI" Raster (Also described in "Appendix A")

The HPI was developed by the Minnesota DNR (Vaughn 2013) to aid in the interpretation of surface water flow and improve mapping for the state. It is particularly useful in areas of the state that have thick forest canopy obscuring a small stream channel.

In areas of Wisconsin where the terrain is highly dissected like the Driftless Area and parts of the Lake Superior Clay Plain, it is also sometimes possible to use reclassified HPI values and data processing techniques to isolate the centerline of a stream for accurate, semi-automated stream delineation. These methods are currently being refined as of 2020 and will be outlined in more detail in future versions of the wetland mapping SOP.

Vaughn, S.R., (2017). Hydrographic Position Index = Description and Symbolization. Technical Manuscript. MNIT at Minnesota Dept of Natural Resources – Ecological and Water Resources.

AG Conservation Planning Framework (ACPF) Tools

The Agricultural Conservation Planning Framework (ACPF) Toolbox software includes tools to process LiDAR-based digital elevation models for hydrologic analysis. These tools use the DEM to model surface water flow and direction in a watershed. These tools were extensively tested during the R&D phase of updated WWI methods and found to be of limited practical applicability in terms of generating cartographic-quality output. The success of the tool is entirely dependent on how well the flow impediments have been removed from a given DEM. Because DEMs are rarely hydro-enforced, the amount of work required to correct & surface obstacles during the hydro-conditioning process equals or exceeds the time it takes to simply digitize the final line. Even if hydro-conditioning steps are properly followed, the modeled stream flow outputs from ACPF are typically of poor cartographic quality. As a result, the main application for

ACPF for wetland mapping is to help inform the user of potential stream presence that is hidden under dense canopy cover. If found, these features will still be re-drafted in the final map.

Data Production Steps and Methods

Hydrography

Rivers, streams, lakes, ponds, and ditches are all part of the NWI 2.0 standard and need to be drafted if they convey water and are part of a wetland or wetland complex and meet the minimum definition of a wetland (not just ephemeral flow). Riverine features can be of Intermittent, Perennial, and Fluctuating water features are captured as part of the NWI process. Once captured, they can be copied out of the wetland layer and used for hydrography updates.

As mentioned earlier, many counties now have surface water breakline data included in their deliverables package from LiDAR contractors. This data should always be sought out and included in the drafting map so quality can be assessed. Where acceptable, breaklines can be directly copied into wetland maps and further processed into finished polygon data.

Hydro features, along with wetlands, are mapped at a scale of 1:2,000 or closer.

Mining Breaklines for Feature Data

Breakline products are the result of a semi or fully automated LiDAR processing. These features generally don't cover the smallest perennial stream, but they do capture larger streams, rivers, ponds and lakes. These features can be mined for outlines and centerlines to update the features in the current DNR 24k Hydro Layer.

1. Export all "lakes, ponds, and river" data from within the HUC12 you are working on into a new layer within your editing template geodatabase.
2. Start Editing.
3. Examine all captured streams, rivers, and drainage lake features. Breakline features can be copied without further modification if the **horizontal error meets the federal standard by being less than 5 meters compared to the image / boundary on the ground.**
4. Especially with riverine features, look for culverts, bridges, and other anomalies that are causing hydrologically connected water features to be represented as disconnected polygons.
    a. If two river polygons are disconnected because of a culvert, for instance, manually connect and merge the two polygons with a new feature that follows the path of the culvert as closely as possible.
5. When all riverine breakline polygons are properly connected, the "AutoStream" toolbar can be used to generate a centerline. The "Value" Attribute should be populated as "1". Click the "Poly to Raster" button, then click on the polygon you want to reclassify into a 1-bit raster
6. Use ArcScan to create a centerline within the output raster from step 5.
    a. Compression tolerance = 0.01
    b. Smoothing Weight = 3

7. If islands or multiple paths exist, pick the wider side to have the centerline follow. Try to avoid flow paths that cross islands. Very small islands (100 sq m or less) do not need to be digitized and are irrelevant for the purposes of centerline creation.
8. Abnormalities may occur where two line features meet and where ArcScan tries to create very short segments due to noise. These should be manually edited out by right clicking the line with the editor tool and selecting “edit vertices." Often, just selecting a few vertices at a time and deleting them will be enough to smooth out the line.
   a. TIP – It helps to assign a shortcut to the “Editor: Merge" function (“Ctrl + ALT + S"). Do this in the “Customize" menu in ArcMap

If breaklines do not exist or do not fit the quality criteria for inclusion in the WWI, a variety of manual and semi-automated processes can be used create a complete stream course.

Riverine Features

Criteria to consider for stream features vectorization:

- Drainage ditches are digitized if they meet the basic definition of a palustrine or riverine wetland system. They may or may not exist inside of a wetland feature.
- The current DNR 24K Hydrology geodatabase was sourced from data of varying ages and may be several decades old. Landscapes may have changed significantly in this time and no attempt should be made to re-create lines originally present in the geodatabase that no longer exist on the ground (i.e. - no banks or clear flow path observed). Caution and sound professional judgement must be used to avoid the propagation of error from old datasets to new datasets.
- If there is no evidence of intermittent or perennial surface water flow as evidenced by identifiable banks, or flow only occurs during heavy precipitation events, then it should be assumed to be ephemeral flow and not digitized as a wetland or intermittent stream. In most cases there will be no associated feature mapped in the 24K Hydro layer, however some ephemeral flow paths subject to erosion, like gullies in the Driftless Area, may be over-represented in 24K Hydro and should not be remapped unless they sustain intermittent flow for at least 1 week/yr after spring melt.
- Narrow stream polygons should be buffered a **minimum of 0.75 m** on each side of the polyline. Use the measuring tool to determine the appropriate buffer width.
- There is no NWI requirement to burn-in every intermittent stream on the landscape. Intermittent “R4” streams often are identifiable as ditches on the landscape until they empty into a larger wetland complex and the flow path disappears. Poorly defined flow paths should not be digitized as “R4” polygons cutting through wetland complexes. Instead, a “fluctuating” polyline may be used to connect the intermittent flow with the nearest connecting flow line. “R4” polygons should only be created where the is a defined flow path and/or they are not surrounded by an existing wetland

- A WWI Specific special modifier of “I” was created for channelized or “canalized” rivers that historically occupied a meandering channel. This stands in contrast to ditches that did not exist on the landscape prior to European colonization, which are identified as excavated “x” in their attribute. “I” generalizes to “x” in NWI classification.

Riverine Vectorization Methods

1. Heads-up Center **polyline** Vectorization + Polygon Buffer
    1. Manually digitize the center of the water feature from upstream to downstream using suitable recent image using the appropriate polyline editing template (Perennial, intermittent, or Fluctuating).

6 Above: Pink lines = 24k hydro, Red = new linework

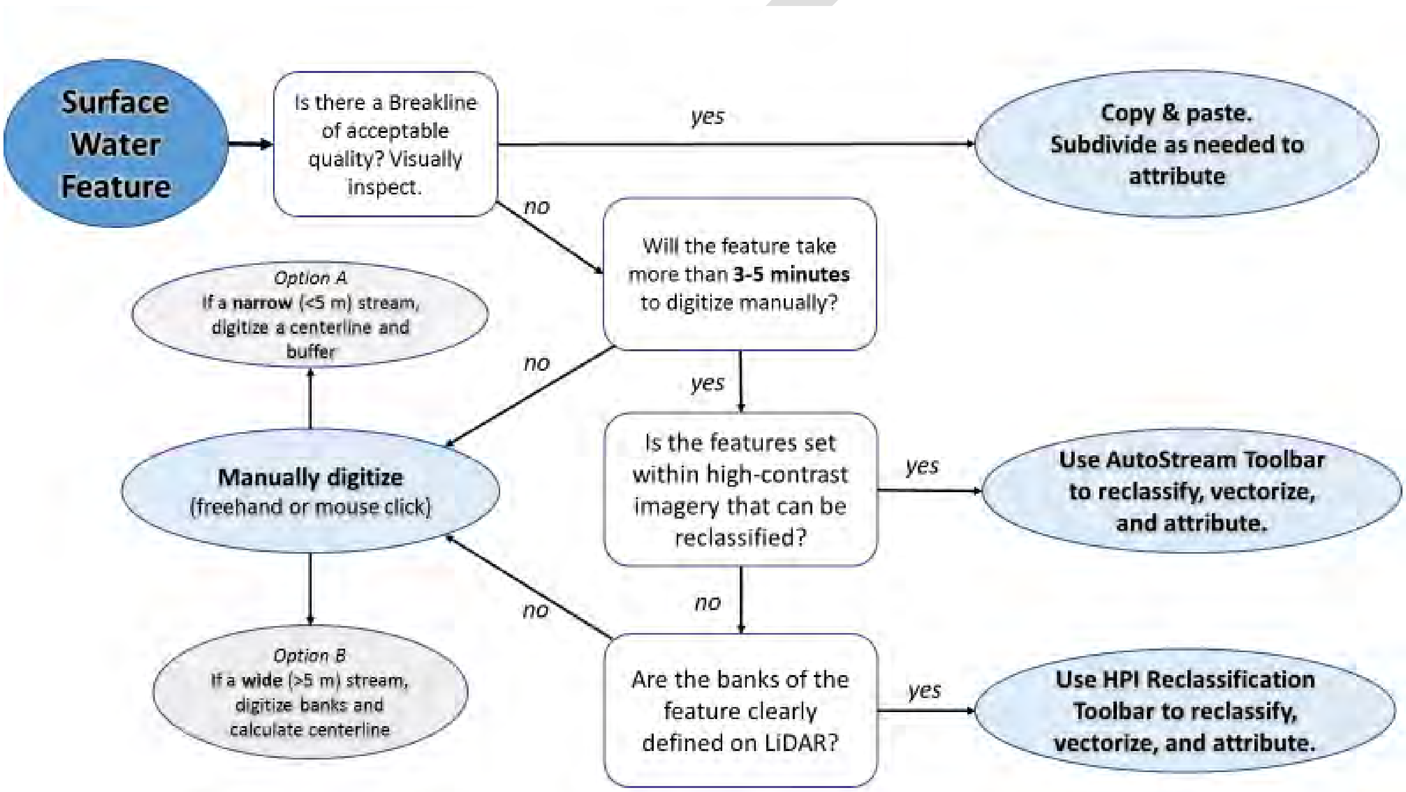
    2. Snap polylines to adjacent/intersecting polylines
    3. Buffer the polyline with a minimum 0.75-meter buffer width to create the Riverine polygon feature. If a riverine polygon template exists, you can buffer straight into an attributed polygon.

7 Finished centerline with polygon buffer

2. Heads-up **polygon** vectorization of Banks on **larger rivers**
    1. On larger, more complex rivers, the banks should be digitized in polygon form first
    2. Once the banks are digitized, a centerline can be created in two ways
        - Convert the polygon to a 1-bit raster using the "AutoStream" toolbar and create a centerline with ArcScan
        - Manually plot a general centerline through the finished polygon, snapping to any upstream/downstream polylines
3. Semi-Automated Image Processing - "AutoStream Toolbar" See “Appendix A”.
    1. Use when you have TIFF images and unobstructed views of the banks.

    2. This tool creates a reclassified 1-bit raster that can be vectorized into a polygon and centerline using ArcScan.
4. Semi-Automated HPI Processing Using ArcScan.
    1. See [HPI_HydroRasterProcess.docx]() or Appendix A of this document and follow the steps to map streams and conveyance features. This process works best in dissected landscapes like the Driftless Area where streams create incised banks. This approach is also useful in areas where dense forest cover obscures stream banks on aerial images.

8 Flowchart for deciding vectorization approach



Lacustrine

According to the NWI FGDC standard, lacustrine features must be at least 20 acres (80,000 square meters) in size, or more than 9 ft deep. A set of steps similar to drafting riverine feature drafting is used in the creation of lacustrine features.

In some cases, lakes and ponds can be captured directly from the image.

Special Criteria to consider for lake and pond feature vectorization:

- Drainage ditches are digitized if they meet the basic definition of a palustrine or riverine wetland system. They may or may not exist inside of a wetland feature.
- In northern counties, add the “a” acid special modifier if the pond/lake is mostly or entirely surrounded by bog and in an area known to have soft water.
- Flow lines must be manually digitized to connect any lake inlets and outlets.

Drafting Wetland Polygon Boundaries

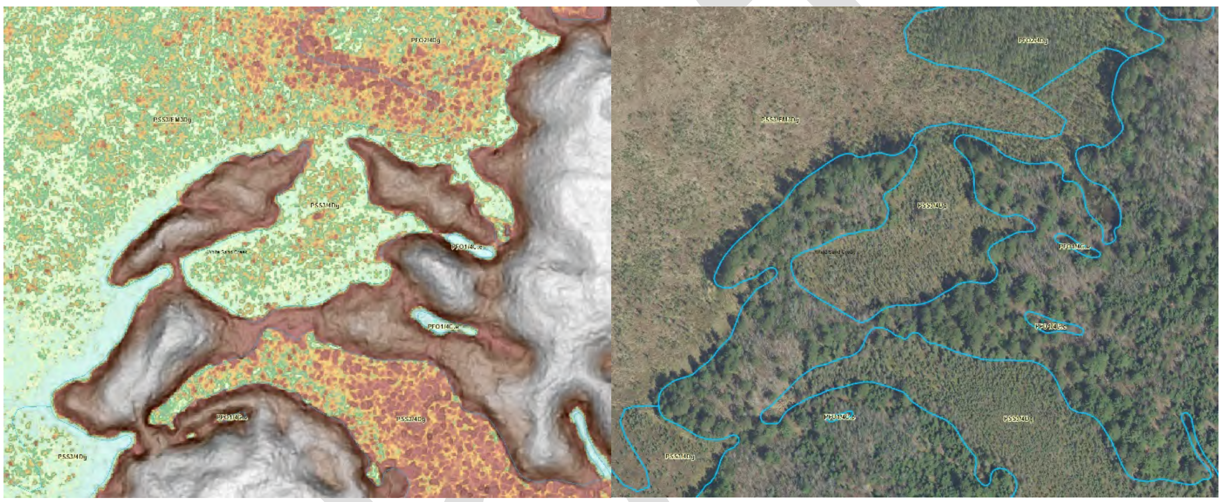
Wetland polygon boundaries require one or more pieces of visual evidence that can be used to identify primary indicators of surface hydrology. This can visual evidence from one or more aerial photos, LiDAR topographic signatures, or both.

The fundamentals of imagery interpretation rely on the interpretation of visual characters related to tone, size, shape, texture, patterning, association, and other cues. A more thorough treatment of these visual characters and on-screen methods is handled more thoroughly by the NWI National Standards and Support Team’s (2017) “Technical Procedures for Conducting Status and Trends of the Nations Wetlands” publication.

9 Seasonally saturated swamp bisected by a right of way shows characteristic signs of surface water mottling. In this case, the cut-over right of way can also help provide visual clues to the outer boundary of the wetland due to the higher contrast between grassy vegetation and wet pockets. Care must be taken to ensure tree shadows from small conifers are properly distinguished from surface water mottles.

With the statewide availability of LiDAR data, it is now possible to look at high-accuracy surface elevation data to find the toe-slope or “slope inflection point” on the landscape which marks the transition from upland mineral soils transition into organic or organic-rich hydric soils. The basic concepts establishing the use of this topographic transition zone to identify a wetland boundary line are outlined in Brinson’s “Hydrogeomorphic Classification for Wetlands” (1993). In simple terms, the slope inflection point is a narrow zone that can be identified by a flattening of the heterogeneous upland surface to a more uniform wetland seepage slope, typically between 0.3% - 2.5% grade, often comprised of organic hydric soils.

Where possible, WWI cartographers attempt to draw the outer boundary of a wetland first using a slope and elevation LiDAR data overlay viewed at 1:2,000 scale.



10 Left, the broad, flat areas of peatland stand in stark contrast to the uplands in the White Sand Creek Watershed when using Histogram-equalize + slope overlay visualization. This boundary is best drawn straight from the LiDAR image to avoid misinterpretation from tree shadow and overhang. Right, wetland boundaries are overlaid with a leaf-off aerial photo for attribute photointerpretation.

If the outer boundary of a wetland cannot be determined from lidar data, imagery is then used to look for primary indicators of wetland hydrology, namely evidence of surface water and shifts in the composition of dominant vegetation. Figure 9 shows an example of a seasonally saturated, mineral soil swamp that lacked a slope inflection point and had to be delineated on imagery.

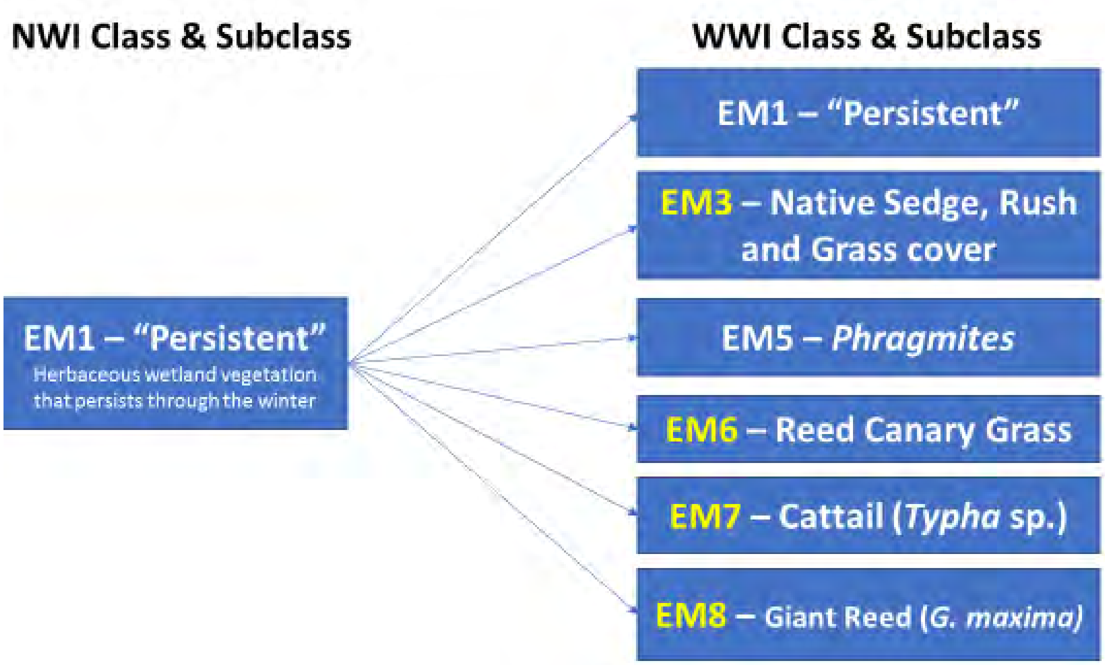
Wetland Polygon Subdivision and Attribution

All polygons, wetland or surface water, must be attributed. On larger wetlands with a diversity of vegetation cover types and/or hydrologic regimes, the wetland boundary polygon must be subdivided so that each area can be accurately represented. As noted previously in the data production standards, subdivision of larger wetland polygons into sub-units smaller than 0.2 acres is avoided to maintain data production efficiency in addition to the diminishing relevance of increasingly small subdivisions. Exceptions to this 0.2-acre threshold may be made for excavated ponds, adjacent areas of wetland fill, and upland islands surrounded by wetland.

Polygons are subdivided using the "Cut Polygon" Editor tool in ArcMap or drawn incrementally from the inside-out using autocomplete tools.

The WWI's standard attribution schema for all new wetland mapping is largely defined in the NWI's "Classification of Wetlands and Deepwater Habitats of the United States" (FGDC 2013), an updated version of the document originally published by Cowardin et. al 1979.

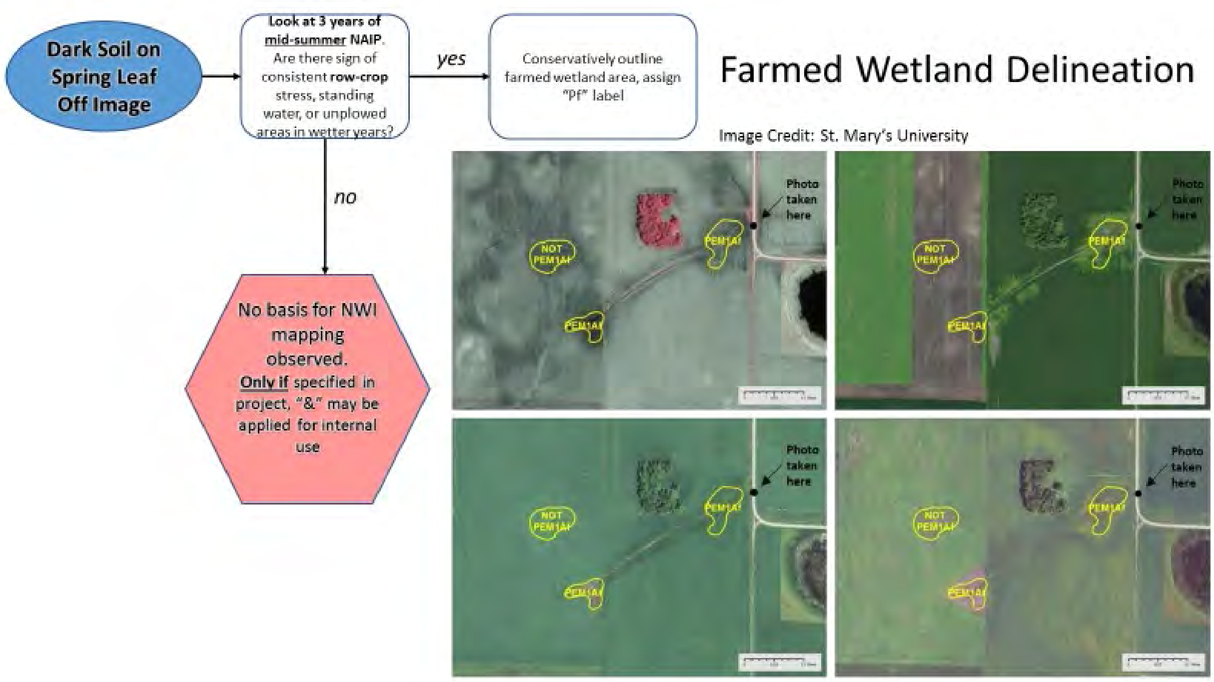
In addition to terms and conventions outlined by the FGDC (2013), the WWI is working to incorporate state-specific subclasses and special modifiers to add specificity to dominant vegetation cover types and land uses to add extra value to newly produced WWI data. These added classifications are defined in "Appendix B" and are designed to fit within the Cowardin framework. To ensure compatibility with base NWI Cowardin Classification, two attribute columns are maintained. "WWI_Attribute" is designated for WWI-specific attributes and a second, "ATTRIBUTE", for the generalized NWI polygon attributes. Often, WWI and NWI attributes are identical, but sometimes appear differently where certain subclasses and special modifiers are concerned. WWI-specific attributes are stripped from data submitted to the NWI in order to maintain compatibility with the national standard.

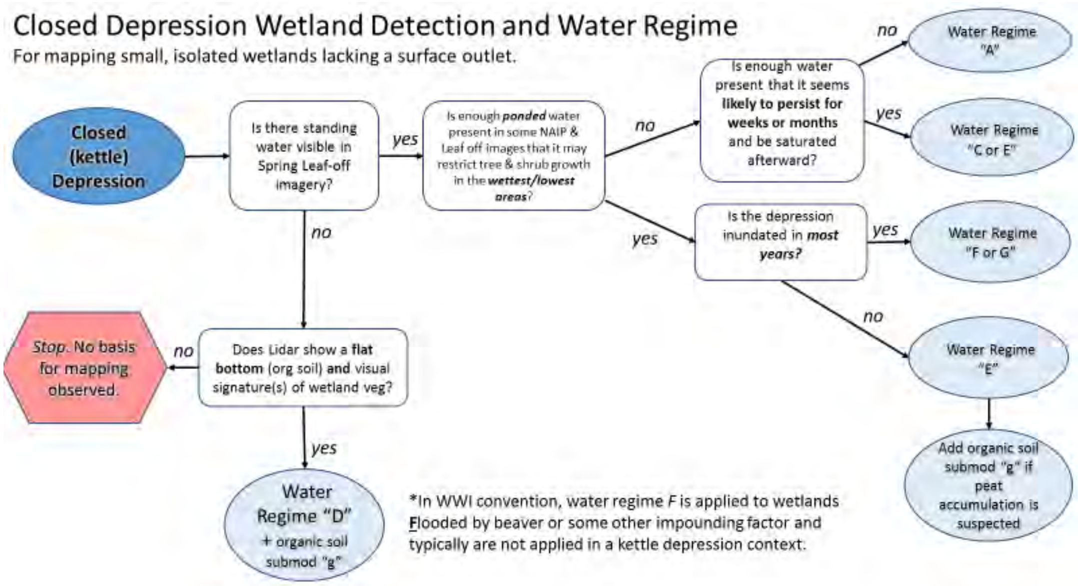


11 Wisconsin-specific breakout of the persistent emergent vegetation class and subclass (PEM1) to reflect the wide array of recognizable, dominant native and invasive vegetation cover types in Wisconsin. Note, Phragmites sp. *are included in NWI attribution*

12 Example of WWI breakout of emergent mapping units. Using standard NWI attribution, invasive cattail-dominated areas on the right side would receive the same attribute code as diverse sedge meadow on the left, despite being easily distinguished on aerial imagery and having drastically differing habitat value for plants and wildlife.

Finally, it is the intent of the WWI to develop methods and models to automatically assign Tiner LLWW codes to newly mapped wetlands. Amongst many aspects of wetland function that can be modeled with LLWW codes, they are important for identifying wetlands that may be considered Waters of the United States. As of 2020, this capability had been developed and applied to the original WWI classification system, but processes have not yet been updated make them function with new attribute codes and geodatabase schema.





QA/QC

Procedures used to ensure data quality and accuracy follow standards laid out by the National Wetland Inventory. NWI has produced data validation tools that are used by WWI staff

Tools and instructions can be viewed and downloaded from the following location: https://www.fws.gov/wetlands/Data/Verification-Tools.html

Additional procedures for ensuring the quality and validity of wetland data with WWI-specific attributes are in development and expected by the end of 2020.

Field Verification

It is important for a cartographer to have a detailed understand the landscape they are mapping. To this end, field verification of mapped wetlands should be done across each project area. A project area may include one or more HUC-12 watersheds. Field verification should include a documented set of check points where wetlands can be accessed and assessed on public lands.

In order to assist in finding public land to conduct field verification, a public lands layer and/or parcel dataset should be included in each working map document. As the cartographer makes decisions across a watershed, questionable areas can be identified and bookmarked with the “bookmarks” point layer included in the WWI Geodatabase Template.

Metadata

Each project area will include metadata that, at minimum, conforms with NWI and FGDC metadata standards. Work on WWI-specific metadata standards is ongoing and will continue to evolve and improve with time.

APPENDIX A: HPI Terrain Processing, Reclassification, and Vectorization

The steps outlined pertain to ArcMap 10.x, utilizing the ArcScan extension – not available in ArcGIS Pro

WWI Toolbox Method

Manual Processing Method

1. Create HPI using the bare earth DEM as the source input DEM. found in the WWI Toolbox (See Fig 14)

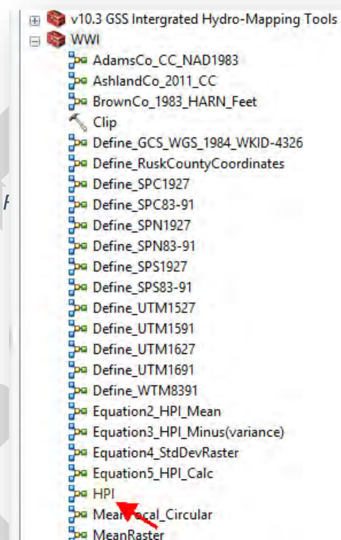


Figure 14

2. Color the HPI raster as found in the HPI documentation or use a preset Symbology layer (.lyr) file loaded from the Symbology menu.
3. You will need the highest resolution (TIFF image), Leaf-off image you can find as one of your base layers.
4. Duplicate (Copy and paste) your HPI raster from within your ArcMap session to get a second version. This will be the test raster you will use to find the indexed elevation values stored in the HPI raster that best represent the stream and hydro features you are trying to extract.
5. Rename this copied layer to **FocusedHPI**
6. Double click on **<VALUE>** from your **FocusedHPI** raster, Select **CLASSIFIED**, and change the classification to **2** classes.

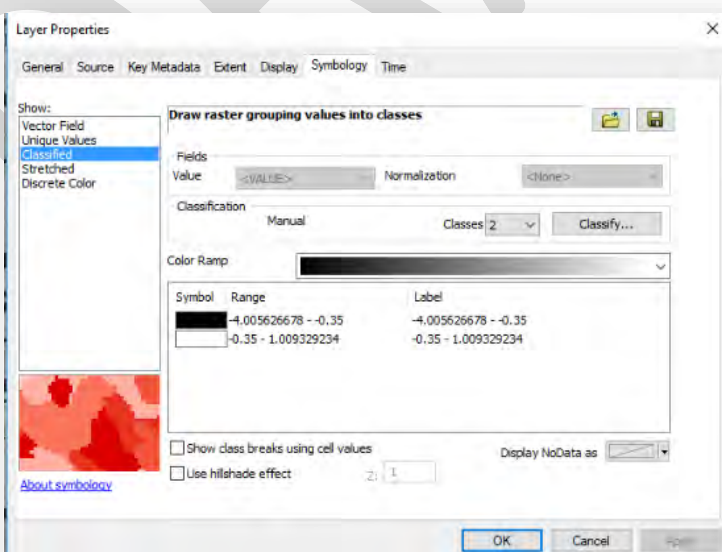


Figure 15 Focused HPI range

Slide your first class somewhere between -.6 and -.2 as a starting range. Turn the background to No Color and turn the pixels that cover the stream sections to a color that allows you to see the stream bounds amongst the colored pixels.

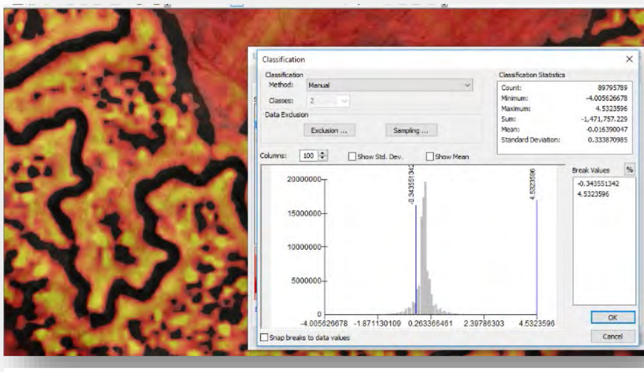


Figure 16

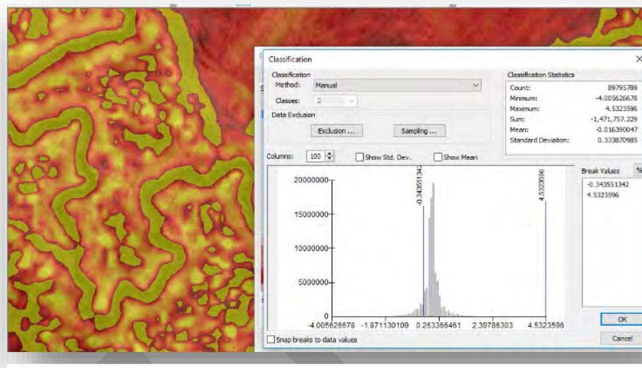


Figure 15

7. Once you have your 2 ranges, copy and paste them to notepad. You can easily do this by double-clicking on the <VALUE> of the raster again and copying the LABEL portion of the ranges and pasting inside the reclassify window. Copy each of them with the dash symbols. We will now extract only those pixels we want and create a new raster.
8. Find the *Reclassify* tool from the ArcToolbox (Found in Spatial Analyst & 3D Analyst, Reclass, Reclassify)
9. Copy and paste the range values you have in Notepad into the Reclassification tables as seen in figure 5. You may have to erase any populated values already in the table by selecting the rows and clicking on Delete Entries.

   Name the new raster **fhpiextract.tif**.

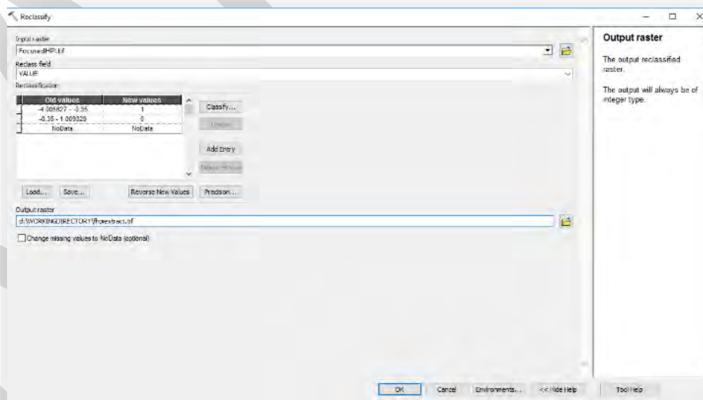


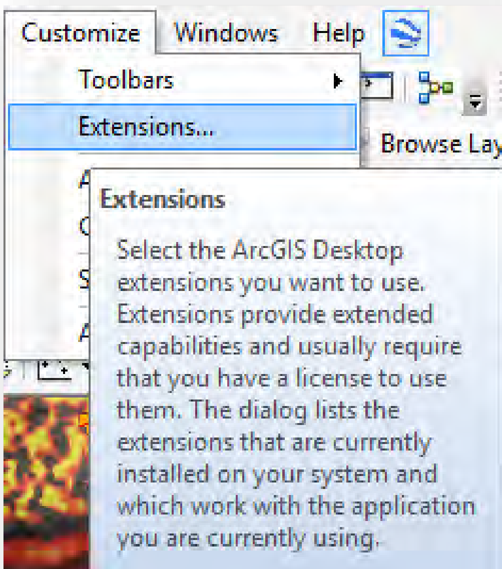
Figure 17 Reclassify to 0 and 1

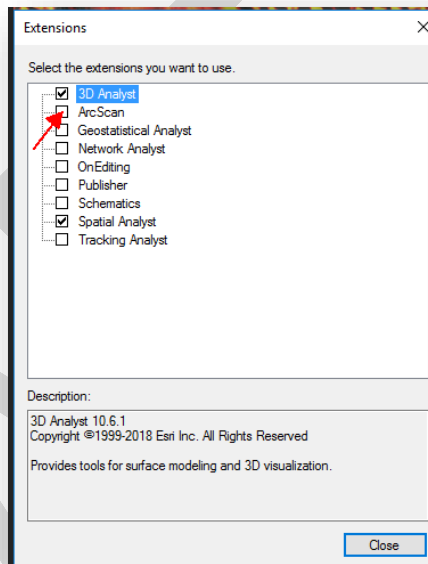
The next steps will involve probably the most important parts of this whole process.

- Our goal is to select only those raster pixels that make up the stream segments containing visible water and the not-so-visible water features but ARE CLEARLY defined on the fire-red HPI view.
- Our goal for the National Wetland Inventory is to create a polygon feature representing the Riverine environment for intermittent and perennial water features. This may include large ditches as well.
- You will be switching between the image and the HPI view at times.
- You may even want to make your **fhpiextract.tif** raster somewhat transparent if it helps you decipher what you need and don't need.
- You will be grabbing portions of stream raster segments that are disconnected from each other by tree overhang and road gaps, but if you "read" between the lines you can make out the stream course.

- IMPORTANT! You will be using some flavor of high resolution (3in, 6in, 12in) imagery along with your 1m-1.5m digital elevation model as represented by the HPI. THEY WILL NOT OVERLAY PIXEL BY PIXEL PERFECTLY.
- There may be discrepancies in the DEM vs Imagery due to lidar/image flight years. You will have to keep track of the information.
- You will have to stop and skip past farmed areas that have diverted or rerouted flow underground.
- We will not be able to capture everything.

10. Check to see if your ArcScan extension is turned on. Check the box if it is blank.

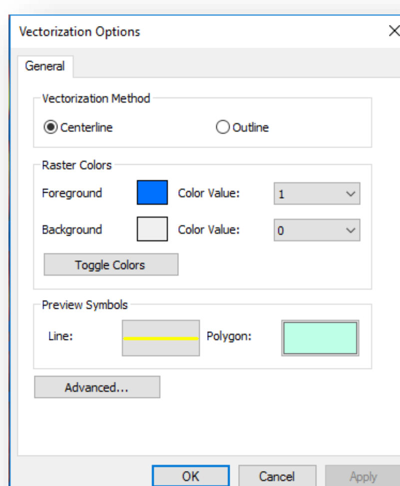




12. You should see the ArcScan toolbar now on your screen.

13. Start an edit session on either your Hydro flowlines or WWI Poly layers. This will activate your ArcScan toolbar. (Portions of the toolbar will no longer be greyed out.)
14. In the Raster dropdown box, make your **fhpiextract.tif** your raster to be edited within ArcScan. (See above.)

15. Click on **Vectorization** from the ArcScan toolbar, select **Options**. This opens up the choice menu to either vectorize the centerline of the raster or outline of your raster. We will choose centerline first. Click on **Centerline**.

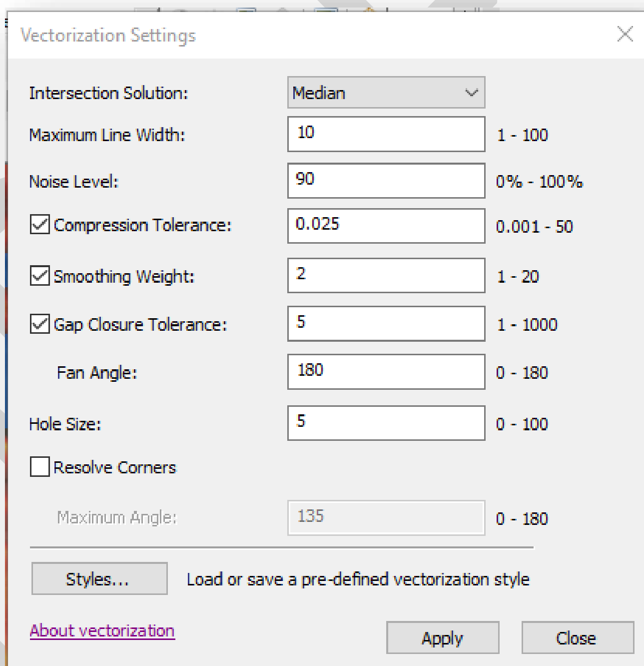


- Change your **Preview Symbol** for Line to a color and thickness that suits you.
- Adjust your foreground color of your **fhpiextract.tif** raster to a color that is pleasing to work with. Turn on 50% transparency for the raster - this allows the stream/water features to show through the raster pixels.
- Make your 0 values for your **fhpiextract.tif** raster No Color to allow the image/HPI layers to be visible.

River Centerline Generation from Raster

We will now use this new raster to locate all the connected and unconnected cells that make up the hydro segments. ArcScan will give you a preview of the centerline as you work your way up the watershed.

16. Zoom into an area of stream that you will be starting with. Do not be too far out as the next steps involve the software doing a great deal of processing to show you the stream centerlines for ALL the raster pixels that fit the vectorization settings.
17. Click on **Vectorization** from the ArcScan toolbar and select **Vectorization Settings.**

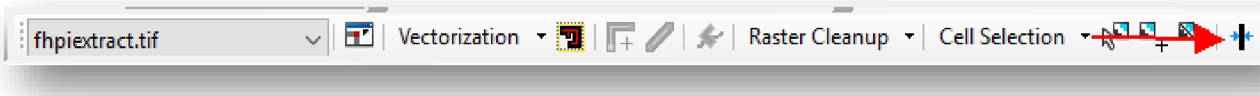


18. Change the settings to reflect the above numbers. Use as a guideline.

19. From the **Vectorization** menu, select **Show Preview** – from the Vectorization menu. This will activate the auto-trace preview for the raster and give you a preview.

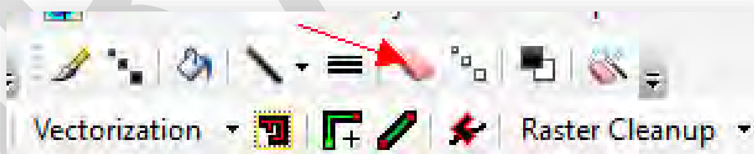
20. Set Maximum Line Width to about 5 above your average raster line width. If you have fatter parts that are ACTUAL streambed, you will have to make your Line Width setting wider.

    - You can use the Raster Width Tool to show you your width. Click on the **Raster Line Width** tool and Click on a portion of your raster and it will tell you the width.



21. Get yourself organized and work your way up the stream sections, going only as far as what fits the goal. Visible water, definite streambed, well defined intermittent flowpaths, drained areas and ditches.
22. When you come to a road crossing and the gap is too large for ArcScan to jump you can edit the raster:
    a. Select **Raster Cleanup**, slide down to ***Start Cleanup.***

    b. You can use the eraser to both erase and draw by switching between foreground/background. You don't need the paintbrush.
    c. Click on Eraser



    d. Click on proper sized eraser/draw width to use (insert image)

e. Click on foreground/background until you get the foreground. (You have to click on your raster to see which one you have. There's no other way to tell. You will either erase or paint – erase your added raster if it is noise with CTRL-Z)

f. CAREFULLY, paint the road gaps in or areas that were missed. Move fast.
g. If you make a mistake, click CTRL-Z to undo one step at a time.
h. If you have to erase pixels, click on the Foreground/background icon again.
i. SAVE YOUR RASTER EDITS, Click on **Raster Cleanup**, slide down to **Save**

j. Move up the stream and repeat your steps.
k. Let ArcScan's Show Preview jump the little gaps that may occur. If you see GLARING issues, fix accordingly.
l. Continue until the stream is no longer a visible intermittent and move to next stream channel.
m. SAVE YOUR RASTER EDITS, Click on Raster Cleanup, slide down to **Save**
n. Once you complete the centerline preview, it's time to do the Raster Outline process

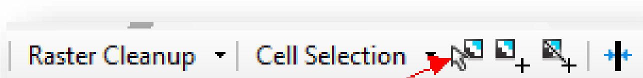
- ONLY use the Raster Cleanup Tool and Raster Painting Toolbar if the settings do not adhere to what you are trying to capture. Do not waste time.
- Fill in road gaps, walking bridges and anything else that forces ArcScan to stop.
- The Show Preview will change with any edits you make.

23. **Save your raster edits OFTEN, by Clicking on Raster Cleanup, Save.**

24. Work your way up the stream course as quickly as you can. DON'T FORGET TO SAVE your raster edits.

- TIP: use a line markup shapefile to make visible cross marks on those stream courses you have finished editing. When you zoom out to the watershed scale, you will not be able to see very well.

25. Turn off the **Show Preview** from ArcScan toolbar.
26. Move to your starting point for your watershed.
27. Click on **Select Connected Cells** tool from the ArcScan toolbar



28. With the mouse, grab ALL the cells that make up the water features, avoiding all noise (using the shift key to add to your selection).
    - You will find areas that you probably missed. Add them
    - The more breaks you have the more pieces of the puzzle you have to grab – That's ok.
29. **Save your selection, making sure you haven't dropped any by accident, by Clicking on Cell Selection, and sliding down to Save Selection As. Use a temporary filename for now.**

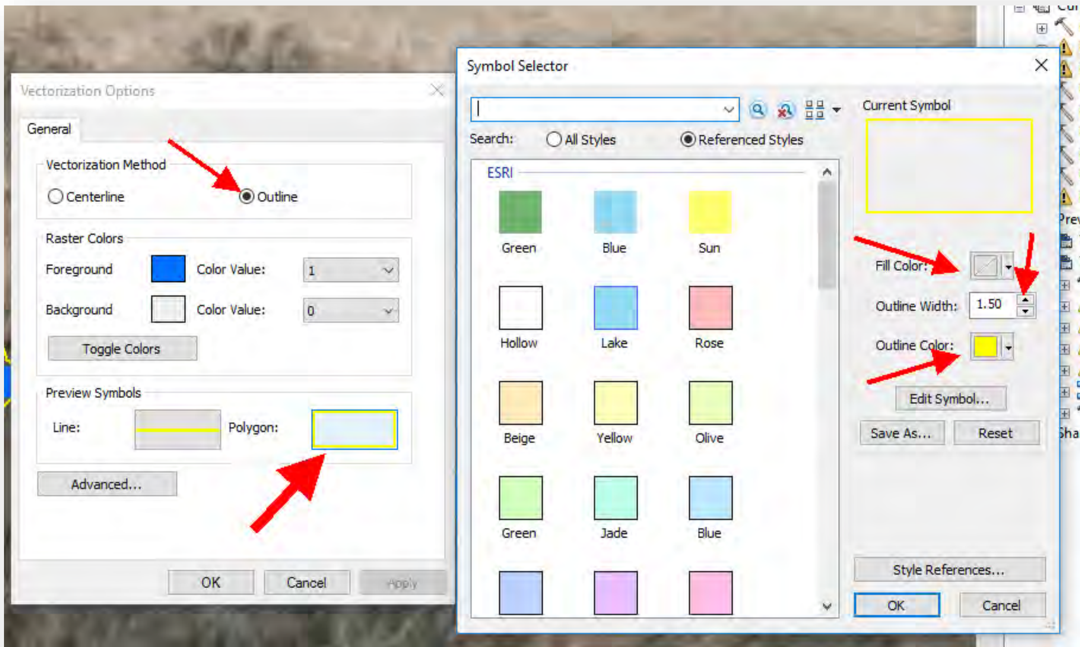
30. Save often
31. Once you have all the cells selected, save your connected cells to a new raster called **ConnectedCells.tif**

    - The new raster **ConnectedCells.tif** will most likely have the 0 and 1 cell values flipped. We will have to reclassify.

32. Reclassify **ConnectedCells.tif** raster, resetting 0 to 1 and 1 to 0., saving to a new raster **ConnectedReset.tif**
33. Turn off the unwanted noisy rasters from Table Of Contents and make sure your **ConnectedReset.tif** is now your ArcScan raster in the dropdown window.
34. Click on **Vectorization** and turn on **Show Preview** again. Look at the preview.
35. Follow each section from start to end up the stream/water features. If you are satisfied, let's move to the polygon outline process. This will capture the stream as a polygon to be part of the Riverine NWI layer. Zoom into beginning section of stream raster.

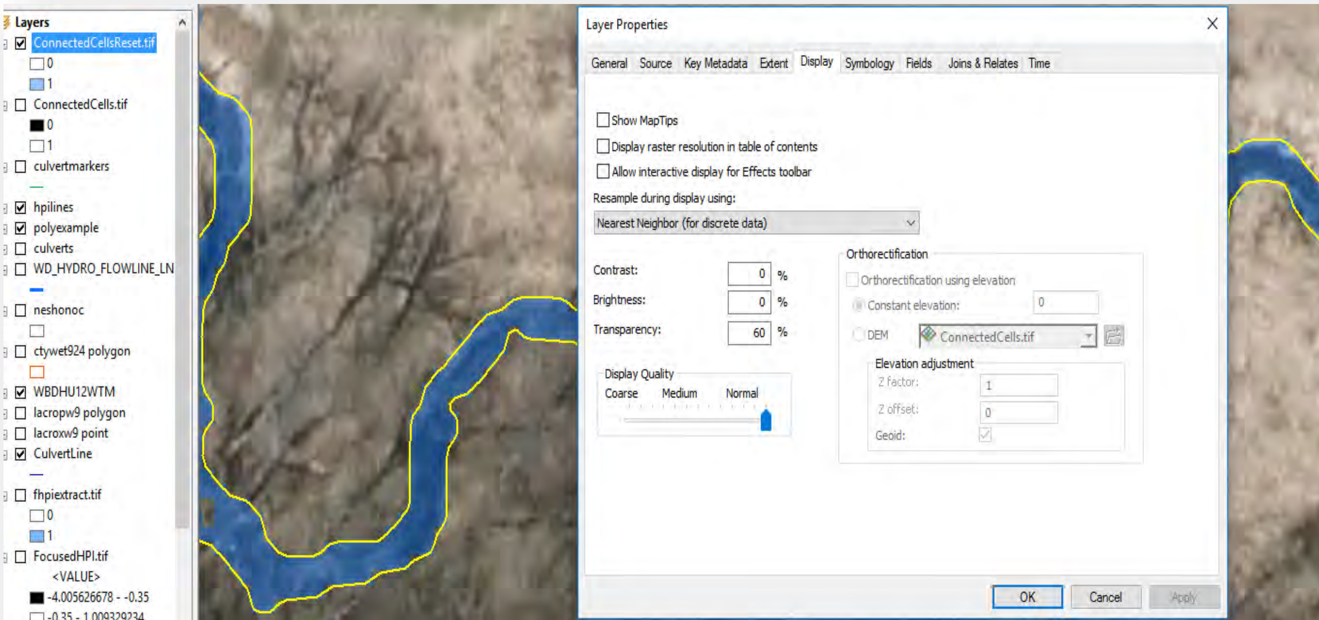
River Outline Generation from Raster

1. Select **Vectorization, Options**, Select the Outline button



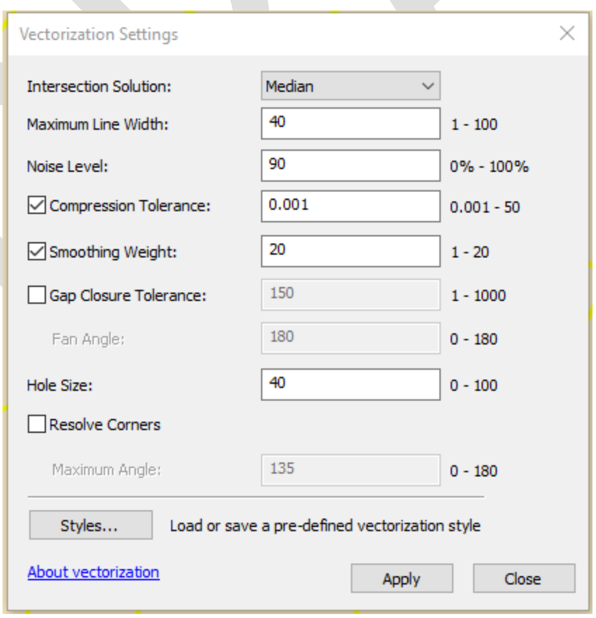
2. Under **Preview Symbols**, Click on **Polygon** color window
3. Change the Fill Color to No Color
4. Change the Outline Color to Yellow
5. Set the Outline Width to 1.5
6. Click Ok to close Symbol Selector window.

7. Change the display transparency for your **ConnectedReset.tif** raster.



This will allow you to see the stream feature underneath and guide your decisions in this outline process.

8. Select **Vectorization**, and **Show Preview**
9. Select **Vectorization**, **Vectorization Settings.** Use the below image as a guide.



10. When you edit the raster, you change the centerline for the flow, so do so carefully.

11. Move your way across the stream areas checking for areas that can either be fixed by adjusting the Vectorization options automatically, or with the Raster Cleanup process.

12. When you are done with the raster polygon editing, SAVE your ConnectedReset.tif raster.

13. Click on **Vectorization** and turn off **Show Preview**.

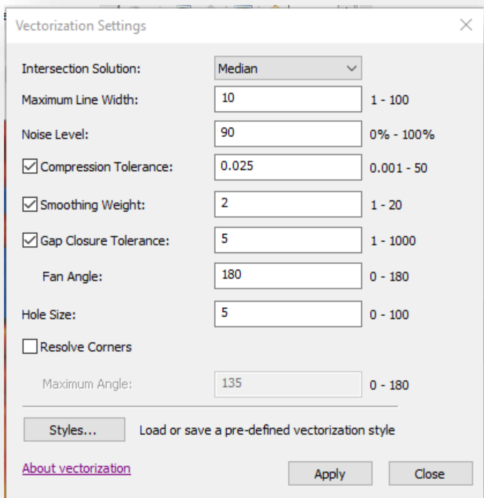
14. Click on **Vectorization** again and slide down to **Generate Features**. You will place the polygon feature into your WWI_POLY layer. If you know the stream segment being vectorized, you can assign the proper NWI template for the ATTRIBUTE field.

Now, let’s get the centerline for the new Hydro flow lines.

Raster Centerline

1. Click on **Vectorization** and slide down to **Options**.
2. Click on the **Centerline** button.

3. IMPORTANT! You must change the **Vectorization** settings from what they are currently set for the outline process back to what you had previously before generating the centerline features.



4. Click on **Vectorization** again and slide down to **Generate Features**. You will place the linear features into your HYDRO FlowLines layer. If you know the duration of stream segment being vectorized, you can assign the proper Perennial or Intermittent template for the ATTRIBUTE field.

Appendix B: Wisconsin-Specific Additions to NWI Attribution for Wetland and Waterbody Polygons Produced by the Wisconsin Wetland Inventory (WWI)

Christopher Noll, 7/13/2019

Introduction

From 1979 until 2017, the Wisconsin Wetland Inventory (WWI) produced wetland polygon and point data using hard copy photo drafting and digitization techniques. While drafting and digitization methods were refined and improved over time, the overall workflow and polygon attribution remained consistent as outlined in the Wisconsin Wetland Inventory Classification Guide (PUBL-WZ-WZ023, 1992).

With statewide coverage from orthorectified data recently completed, discontinuation of long-standing base materials (film-based B&W stereo pairs), and advances in state-of-the-art GIS data & availability, the time was ripe to consider major changes to the WWI to continue mapping while remaining relevant to agency and customer needs.

As part of the WDNR's FY2016 EPA Wetland Program Development Grant, funds were designated for a pilot mapping study (hereafter referred to as "the Pilot Study") to "design, test, and evaluate a process to map wetlands and surface waters in tandem from the same data surfaces, to produce a single Integrated Surface Waters and Wetlands GIS Layer." A primary goal of this project was to provide improved, modernized methods and a path forward for the Wisconsin Wetland Inventory (WWI).

During this overhaul process, a major area of consideration has been how to attribute polygons. In part because the WDNR's wetland mapping efforts preceded the NWI, Wisconsin created and maintained its own wetland classification system for decades even as 49 other states adopted the National Wetland Inventory (NWI) standards using the Cowardin Classification System (Cowardin et al. 1979). While the systems were roughly equivalent, they diverged in the WWI's relative lack of hydrologic modifiers versus the NWI's more numerous and descriptive modifiers.

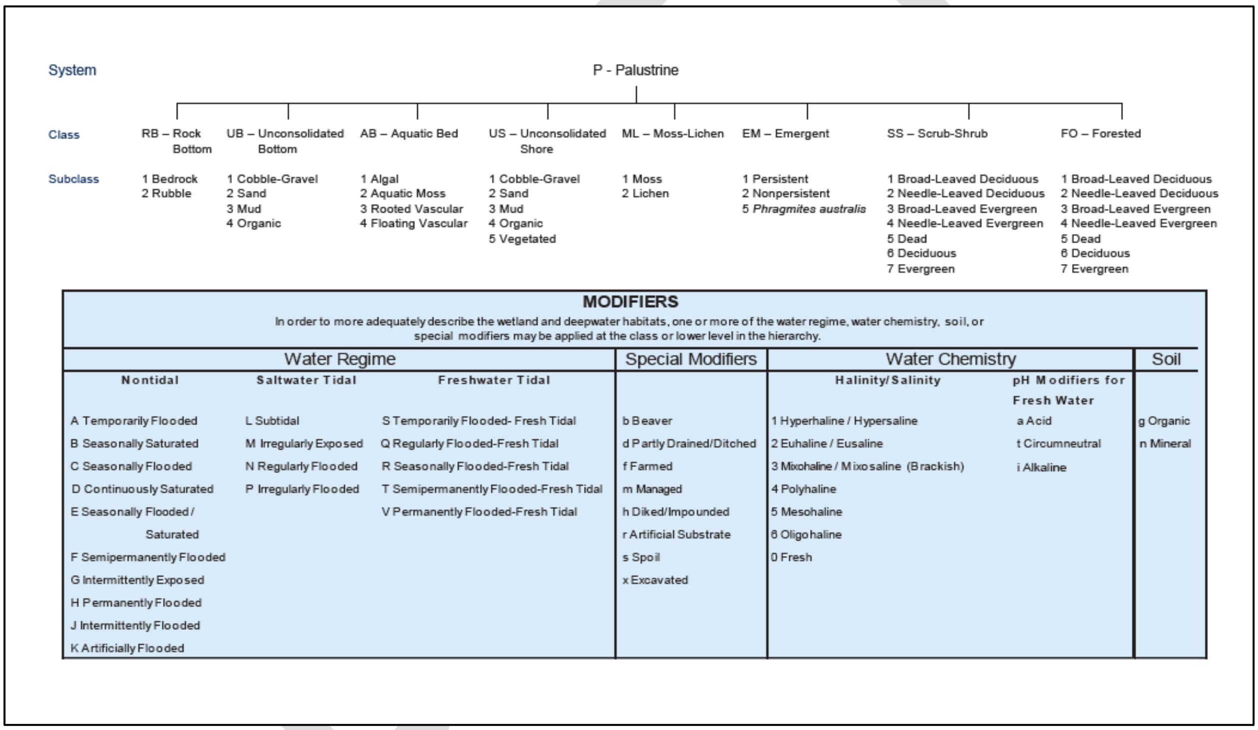
Since an objective of the Pilot Study was to create wetland maps that are fully compatible with NWI standards, by default the WWI needed to attribute wetland polygons using the Cowardin Classification System. This requirement created two possible scenarios for the attribution of wetland polygon data. The first, more complex scenario would require maintaining the WWI and Cowardin classification systems in parallel which would require significant expenditures in time and money to dual-attribute millions of polygons. The second scenario would require only using the Cowardin Classification and abandon WWI classification.

While the second scenario is preferable form a production standpoint, the WWI Classification System has decades of history and use across Wisconsin. As a result, the decision was made to proceed cautiously before abandoning the Wisconsin system. To get a sense of user opinions, in spring 2018 the WWI team surveyed stakeholders about how they interacted with wetland map data. This survey was distributed at the 2018 Wisconsin Wetland Association's Wetland Science Conference in Lake Geneva and at two Critical Methods workshops. Ninety-three responses were tallied. Of these results, only 2% of respondents thought switching to the Cowardin Classification System would have a negative impact. This overwhelming result provided the support to discontinue use of the WWI Classification System and adopt NWI standards as a base classification system. Additionally, 70% of users reported “frequently” or “occasionally” keying out wetcodes, confirming that classification tools are important and commonly referenced by users of wetland maps.

Enhancing Cowardin to suit Wisconsin’s Needs

The Cowardin Classification System has a hierarchical structure. The most general attribute code represents the *System*. Under this there may be a *Subsystem* if within Lacustrine or Riverine systems, followed by a *Class.* The *Class* describes a general type of land cover – such as forested, shrub, emergent, open water, etc. If applicable, each *Class* is modified by a *Subclass*, followed by a *Water Regime*, and optionally up to one *Special Modifier* to describe land use, soils, and water chemistry.

Sample Diagram - Classification of Wetlands and Deepwater Habitats of the United States, Cowardin *et al*. 1979



As of 2019, the amount of valuable, photo-interpretable detail that can be captured by wetland cartographers has greatly increased with LiDAR data and 6-12” imagery that easily supports 1:1,000 scale viewing. By resuming wetland and surface water mapping within the WDNR, exciting possibilities exist for capturing unprecedented detail about the landscape through photointerpretation and modeling. However, this data can only be captured if there is an efficient system and workflow for doing so. The Cowardin Classification System is nearly 40 years old. While robust, it was developed at a time of restrictive hard-copy methods, coarser imagery, and 1:20,000 mapping scales which limited what could be seen and captured. One way the WWI is seeking to increase the value of its mapping product is through the development of Wisconsin-specific attributes that fit within the Cowardin Classification System and expand its descriptive capabilities.

While it may seem contradictory to abandon a state-specific classification system in favor of a national standard only to re-add a suite of Wisconsin-specific attributes, there are several reasons why this approach makes sense:

1. Wisconsin-specific attributes recognize unique, high-value, local data needs that can be efficiently captured through a standardized mapping workflow. Careful consideration of attribute additions will hopefully increase the WWI's relevance and build support for increased output.
2. If Wisconsin-specific attributes are built *within* the existing Cowardin Classification System framework, there is no risk of incompatibility with NWI standards. For collaboration with the NWI, WWI GIS data can simply be dissolved (a GIS method of data generalization) into the NWI attribute to meet NWI standards.
3. Through Python scripting and custom GIS tool creation, the WWI team is capable of simultaneously dual-attributing wetland polygons with an "enhanced" WWI attribute and a generalized NWI-standard attribute. This minimizes the additional labor needed for creating polygons with enhanced attributes.

Some of the proposed classification additions in the following section may seem overly specific and detailed. However, the precedent for creating plant family and genus-specific subclasses was set by Cowardin (1979) with the inclusion of "broadleaf evergreen shrubs" and "needle leaved deciduous" trees/shrubs representing Heath Family (Ericaceae) and Tamarack (*Larix* sp.) respectively – at least in the upper Midwest. Cowardin classification relied on what was visible in 1970's era photography, and the attributes aim to push the boundaries of ecological descriptiveness further according to what can be interpreted from modern imagery and connected databases. Careful consideration and testing went into only adding new attributes that reliably categorized meaningful ecological data that could not be improvised through existing attributes.

Established and Proposed* Emergent Wetland Subclasses & Attribute Codes

Emergent Class "EM" Overview: "In this wetland Class, emergent plants—i.e., Erect, rooted, herbaceous hydrophytes, excluding mosses and lichens —are the tallest life form with at least 30% areal coverage. This vegetation is present for most of the growing season in most years. These wetlands are usually dominated by perennial plants" (FGDC 2013).

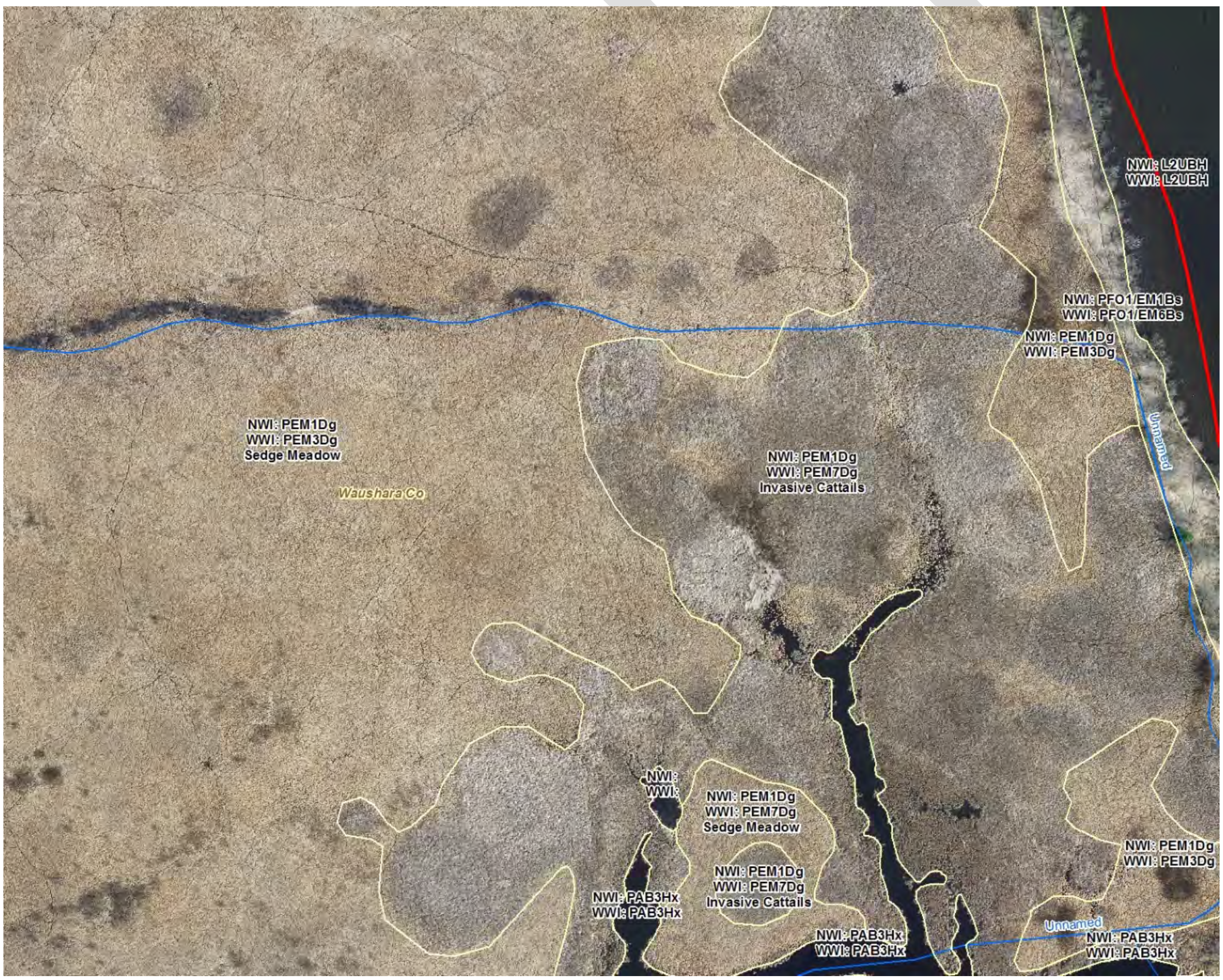
EM1 **NWI: Persistent** – "Persistent emergents are emergent hydrophytes whose stems and leaves are evident all year above the surface of the water, or above the soil surface if water is absent. Herbaceous wetland vegetation that persists through the winter and into the following growing season" (FGDC 2013)

WWI Refinement – This subclass shall be reserved for situations where no clear dominant emergent vegetation type can be determined. Situations where this may arise include very small wetlands, grazed pastures, early-successional regrowth after plowing, and disturbed wetlands with interspersed patches of dominant cover types.

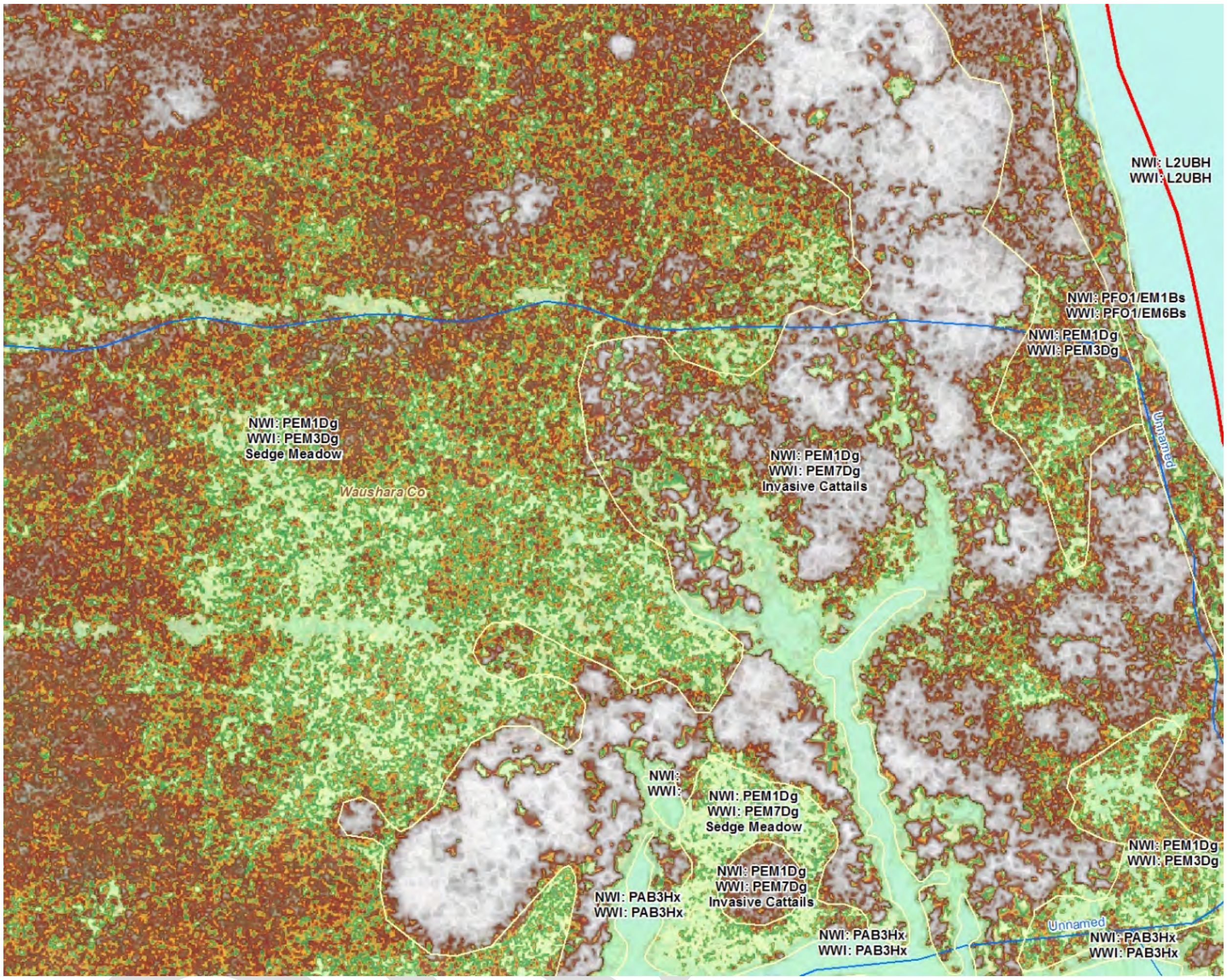
EM2 **NWI: Non-persistent** – "Nonpersistent emergents are emergent hydrophytes whose stems and leaves are evident above the water surface, or above the soil surface if surface water is absent, only during the growing season or shortly thereafter. During the dormant season, there is no obvious sign of emergent vegetation" (FGDC 2013).

EM3* **Cyperaceae Family and Native Grass** (WWI Specific)

WWI Definition – Northern and southern sedge meadows, calcareous fens, poor fens, wet mesic prairies are examples of classic natural community types that are dominated by sedges (Cyperaceae Family / *Carex* sp.) and native grasses. Less commonly, riverine wetlands may be dominated by bulrushes (*Bolboshenous* sp.). Collectively, these community types occupy hundreds of thousands of acres across Wisconsin and are often a significant indicator of wetland & water quality. In pure stands within emergent wetlands, sedges and bulrushes can be identified on leaf-off spring by observing fine-textured, straw or tan to light-brown winter-cured foliage. Depending on the community type, these wetlands may be dominated by one or more of the following species: *Carex lacustris, C. stricta, C. utriculata, C. trichocarpa, C. aquatilis*, *C. lasiocarpa, Scirpus* sp., *Schoenoplectus* sp., and *Bolboschoenus fluviatilis.* Pure stands of native grass are more challenging to discern but can be identified on leaf-off imagery by observing off-white foliage that is similar to Reed Canary (EM5), but differs by having a finer, less 'lumpy' texture due to its narrower leaves reflecting less light. This subclass generalizes to "EM1".



18 Invasive Cattail (EM7) expanding into native sedge meadow (EM3). Typha's grayish, fuzzy appearance contrasts with the more uniform beige sedge meadow, producing a "mold on cheese/bread" visual effect.



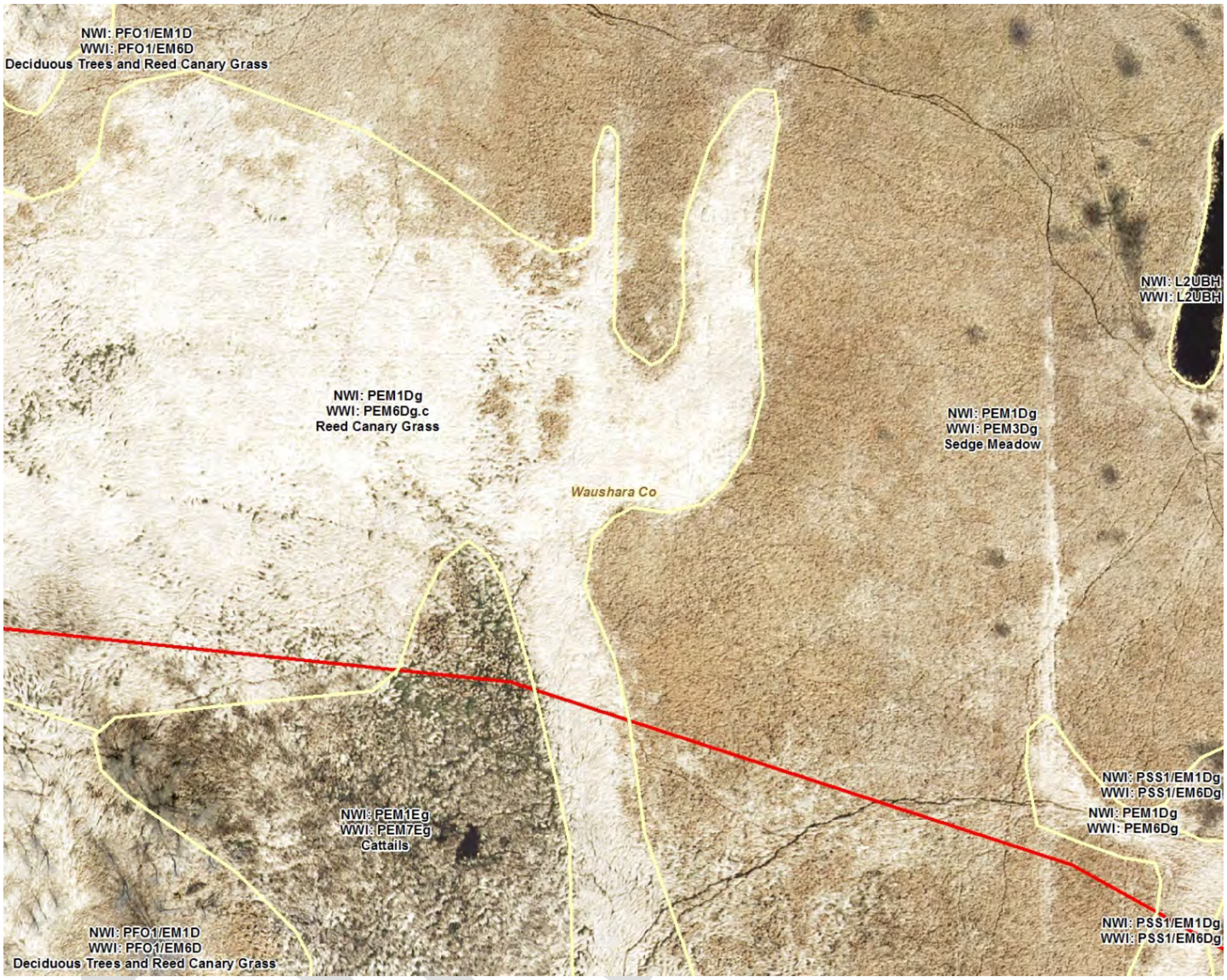
19. The same extent as the previous image showing stretched LiDAR data and the "false ground" signal created by dense, elevated invasive cattail litter

EM 4 Blank

EM5 NWI: Common Reed Grass, *Phragmites australis*

WWI Refinement – This NWI subclass should only apply to dense, tall, near-monotypic stands of non-native common reed grass (*Phragmities australis* subsp. *australis*). Stands of native common reed grass (*Phragmites australis* subsp. *americana*) rarely achieve more than 50% cover in a stand of sedges or cattail and are difficult to discern on even high-resolution aerial imagery.

EM6* WWI Proposed: Reed Canary, *Phalaris arundinacea* – *Phalaris arundinacea* is a prolific invasive species that covers hundreds of thousands of acres in Wisconsin (Bernthal and Hatch 2008) and a strong indicator of past or current disturbance. In the reed canary grass subclass, "EM6" polygons are assumed to have reed canary grass covering 50% or more of the upper most layers of foliage. Reed canary grass can be identified on leaf-off imagery by observing areas of bright white, coarse, and often 'lumpy' textured vegetation. The visual signature of sedges, if present, is overwhelmed by the high reflectance of reed canary grass. Reed canary will often be associated with 'partially drained', 'abandoned ag', and/or 'grazed' special modifiers and should not be split with other Emergent Subclasses. This subclass generalizes to "EM1".



20. Bright white Reed Canary Grass (EM6) winter foliage contrasts with tan Carex *foliage. A smaller polygon of cattail (EM7), possibly native as evidenced by a non-clonal appearance, is also visible.*

EM7* WWI Proposed: Invasive cattails, *Typha* species – Hybrid cattail (*T.* x *glauca*), along with the myriad back-crosses it forms with parent species narrow-leaf (*Typha angustifolia*) and broad-leaf (*T. latifolia*) cattail, frequently invade sedge (*Carex* sp.) and bulrush (*Schoenoplectus* sp.) dominated emergent wetlands to form dense stands of diminished functional and habitat value. In the invasive cattail mapping subclass, "EM7" polygons are assumed to be dominated by near-monotypic stands of hybrid or narrow-leaf cattail where the cover of current years' growth and standing dead vegetation exceeds 66%. At lower densities, as in the case when native cattails are interspersed with sedges, it is not practical to discern native vs invasive cattails aerially. Invasive cattails can be identified on leaf-off imagery by observing grayish, "fungal" or fuzzy-looking, circular patches of vegetation that increase in diameter from year to year until individual clones coalesce into a dense, near-monotypic stand. On LiDAR DEM's, these stands are often so dense that they create a false ground signal and appear as elevated circles within shorter-statured sedge and grass-dominated wetlands (see figure 18). Within a watershed, invasive cattails are commonly associated with nutrient inputs, road rights-of-way, impoundments, excavations, wetland fills, and hydrologic alteration from a pre-settlement regime. This subclass generalizes to "EM1" in NWI.

EM8* **WWI Proposed: Giant Reed Grass**, ***Glyceria maxima* –** *Glyceria maxima* is a recent invasive species that is rapidly expanding along drainage ditches, streams, and river corridors in southeast Wisconsin. Able to expand into and replace stands of reed canary grass (*Phalaris arundinacea*) and extend rhizomes that span across narrow streams and ditches, giant reed grass poses a serious threat to wetlands wherever it is found. Giant reed grass leaves often remain green throughout winter and can be identified on leaf-off or leaf-on imagery by observing patches of yellow-green (leaf-off) to bright emerald-green (leaf-on) grassy vegetation. In this subclass, "EM8" polygons are assumed to have *Glyceria maxima* covering 75% or more of the upper most layers of foliage. Already-mapped populations of this species will aid in photointerpretation. This subclass generalizes to "EM1" in NWI.

Established and Proposed* Scrub-Shrub Wetland Subclasses & Attribute Codes

Scrub-Shrub "SS" Class Overview "In Scrub-Shrub Wetlands, woody plants less than 6 m (20 ft) tall are the dominant life form—i.e., the tallest life form with at least 30 percent areal coverage" (FGDC 2013). This includes tree saplings in recently logged areas.

SS1 **NWI: Broad-leaved deciduous** – "In this Subclass, broad-leaved deciduous species have the greatest areal coverage within the shrub layer" (FGDC 2013). Any deciduous wetland shrub. Includes willows (*Salix* sp.), dogwoods (*Cornus* sp.), Alder (*Alnus* sp.), and several others.

SS2 **NWI: Needle-leaved Deciduous** – "In this Subclass, needle-leaved deciduous species have the greatest areal coverage within the shrub layer. Dominance Types include young or stunted tamarack and southern bald-cypress" (FGDC 2013). In Wisconsin, this subclass is limited to young or stunted tamarack trees (*Larix laricina*) less than 6 m tall.

SS3 **NWI: Broad-Leaved Evergreen** – "In the Palustrine System, the broadleaved evergreen species are typically found on organic soils. Northern representatives are labrador tea (*Ledum groenlandicum*), bog rosemary (*Andromeda polifolia L.*), bog laurel (*Kalmia polifolia*), and the semi-evergreen, leatherleaf (*Chamaedaphne calyculata*)" (FGDC 2013).

SS4 **NWI: Needle-leaved Evergreen** – "In this Subclass, needle-leaved evergreen species have the greatest areal coverage within the shrub layer. Examples of Dominance Types include young or stunted black spruce (*Picea mariana*) and pond pine (*Pinus serotina*)" (FGDC 2013).

SS5 **NWI: Dead** – "This Subclass includes stands of dead woody plants less than 6 m tall, regardless of their density, with less than 30 percent cover of living vegetation. If living vegetation equals or exceeds 30 percent in such stands, the Class and Subclass are based on the dominant life form of the living plants" (FGDC 2013).

SS6 **NWI: Deciduous** - *Not typically used, equivalent to SS1*.

SS7* ~~NWI: Evergreen~~ - *Redundant with "*SS4*", not used*

WWI Proposed Replacement: **Mixed needle-leaved evergreen & deciduous conifers** - In split-subclass shrub-dominated wetlands - especially muskegs - there are often significant proportions of both deciduous conifers (tamarack), evergreen conifers, and broadleaf evergreens present. This subclass improves descriptive accuracy by recognizing the co-dominance of stunted tamarack and evergreen conifers set within a matrix of broadleaf ericaceous shrubs or emergents. This subclass is used if estimated coverage of tamarack or needle-leaved conifers exceeds 10%, with a combined total of at least 30%. This subclass generalizes to "SS2" or "SS4" depending on which subclass appears to cover more basal area, however the default generalization is "SS4".

SS8* **WWI Proposed: Alder (or "Tag" Alder), *Alnus incana* –** *Alnus incana* occurs with increasingly frequency north of the tension zone, where large alder thickets form in association with minerotrophic hydrology. This subclass is used where alder (*Alnus incana*) is assumed to comprise at least 30% of the shrub layer. Alder may be co-dominant with other forest, shrub-scrub, or emergent subclasses, but should not be combined with "SS1" due to the unreliability of distinguishing mixed stands of alder and other deciduous shrubs. Reliable photointerpretation of this subclass requires high-quality uncompressed 6" leaf-off imagery where its characteristic dark bark and upright growth form can be seen. This subclass generalizes to "SS1".

SS9* **WWI Proposed: Buckthorn Thicket**, ***Rhamnus cathartica*** **and** ***Frangula alnus*** – Buckthorn thickets have only recently been recognized as a widespread, growing disturbance community. In this subclass, common buckthorn (*Rhamnus cathartica*) and glossy buckthorn (*Frangula alnus*) comprise at least 30% coverage of the shrub strata. Practically speaking, buckthorn needs to be present in higher percent covers to be photo interpretable. In dense thickets, there is often exposed, oxidizing muck from the lack of undergrowth, which combined with dark-barked shrubs creates a distinct aerial signature on leaf-off imagery. This subclass generalizes to "SS1".

Established and Proposed* Forested Wetland Subclasses & Attribute Codes

Forested "FO" Class overview "In Forested Wetlands, trees are the dominant life form—i.e., the tallest life form with at least 30 percent areal coverage. Trees are defined as woody plants at least 6 m (20 ft) in height" (FGDC 2013).

FO1 **NWI: Broad-leaved deciduous** – "In this Subclass, broad-leaved deciduous species have the greatest areal coverage in the tree layer. Broad-leaved Deciduous Forested Wetlands, which are represented throughout the United States, are most common in the South and East. Common Dominance Types include red maple, American elm (*Ulmus americana*), ashes (*Fraxinus pennsylvanica* and *F. nigra*), black gum (*Nyssa sylvatica*), tupelo gum (*N. aquatica*), swamp white oak (*Quercus bicolor*), overcup oak (*Q. lyrata*), and swamp chestnut oak (*Q. michauxii*). Wetlands in this Subclass generally occur on mineral soils or highly decomposed organic soils (FGDC 2013)."

FO2 **NWI: Needle Leaved Deciduous** – In this Subclass, needle-leaved deciduous species have the greatest areal coverage in the tree layer…Tamarack is characteristic of the Boreal Forest Region, where it occurs as a dominant on organic soils. Relatively few other species are included in this Subclass" (FGDC 2013)

FO3 **NWI: Broad-Leaved Evergreen** – *No broad-leaved evergreen trees grow in Wisconsin.*

FO4 NWI: Needle-leaved Evergreen – “In this Subclass, needle-leaved evergreen species have the greatest areal coverage in the tree layer. Black spruce, growing on nutrient-poor organic soils, represents a major dominant of the Needle-leaved Evergreen Subclass in the North. Eastern arborvitae (*Thuja occidentalis*) dominates northern wetlands on more nutrient rich sites” (FGDC 2013).

FO5 NWI: Dead – “This Subclass includes stands of dead woody plants at least 6 m tall, regardless of their density, with less than 30 percent cover of living vegetation. If living vegetation equals or exceeds 30 percent in such stands, the Class and Subclass are based on the dominant life form of the living plants. Dead Forested Wetlands usually are produced by a prolonged rise in the water level resulting from impoundment by humans or beavers” (FGDC 2013).

FO6 NWI: Deciduous (Standard NWI) - *Redundant with* FO1, *not used.*

FO7* NWI: ~~Evergreen~~ – *Redundant with “*FO4”, *not normally used*

WWI Proposed Replacement: Mixed needle-leaved evergreen & deciduous conifers

WWI Definition - In forested wetlands split between emergent or scrub-shrub classes, significant proportions of both deciduous conifers (tamarack) and evergreen conifers may be present. This subclass improves descriptive accuracy by recognizing the co-dominance of tamarack and evergreen conifers set within a matrix of broadleaf ericaceous shrubs or emergents. Use this subclass if estimated coverage of tamarack or needle-leaved conifers ranges from 30-70%, with individual proportions of at least 15%. This subclass generalizes to “FO2” or “FO4” depending on which subclass appears to cover more basal area. An additional attribute number is required to make this generalization.

FO8* WWI Proposed: White Cedar (*Thuja occidentalis*) – White Cedars, when present in well-developed stands with areal coverage above 30%, are indicators of ecologically distinct wetland communities fed by calcareous soils and/or groundwater. White cedars dominate a small fraction of Wisconsin’s total wetland area but provide habitat for many species of concern. This indication of conservation value and ecological distinctness merits separation from the black spruce and pine dominated communities that they would otherwise be lumped under which tend to form under acidic conditions. This subclass generalizes to “FO4”.X

Established and Proposed* Special Modifiers & Attribute Codes

All proposed WWI Special Modifiers are stored after a period in the attribute string and are stripped from the NWI attribute. A handful of proposed WWI modifiers are carry-overs from the WWI Classification System, while the remainder are new additions.

a Acid – Water pH <5.5. This special modifier should be used on lakes and ponds that are surrounded by sphagnum bogs, black spruce, and/or tamarack swamps.

b Beaver – “These wetlands have been created or modified by beaver (*Castor canadensis*). Dam building by beaver may increase the size of existing wetlands or create small impoundments that are easily identified on aerial imagery. Such flooding frequently creates Dead Forested or Dead

Scrub-Shrub Wetland initially, followed in a few years by Aquatic Bed and Emergent Wetland" (FGDC 2013).

c* **Abandoned Ag Land - WWI Definition** – Areas which appear to have been cultivated in the past, but which have since been abandoned from cultivation and have reverted to wetland vegetation.

d **Partially Drained/Ditched** – "A partly drained wetland has been altered hydrologically, but soil moisture is still sufficient to support hydrophytes. Drained areas that can no longer support hydrophytes are not considered wetland. This Modifier is also used to identify wetlands containing, or connected to, ditches. The Partly Drained/Ditched Modifier can be applied even if the ditches are too small to delineate. The Excavated Modifier should be used to identify ditches that are large enough to delineate as separate features; however, the Partly Drained/Ditched Modifier also should be applied to the wetland area affected by the ditching" (FGDC 2013).

e* **Ephemeral Pond - WWI Definition** – Applies to small, closed, seasonally-flooded depressional wetlands with standing water observed in one or more years of photography. Requires "C" Hydro modifier.

f **Farmed** – "Farmed wetlands occur where the soil surface has been mechanically or physically altered for production of crops, but where hydrophytes would become reestablished if the farming were discontinued. Farmed wetlands should be classified as Palustrine-Farmed. Cultivated cranberry bogs may be classified Palustrine-Farmed or Palustrine Scrub-Shrub Wetland-Farmed" (FGDC 2013).

g **Organic Soils** – "A soil is classified as an organic soil (Histosols) if more than half of the upper 80 cm (32 inches) of the soil is organic or if organic soil material of any thickness rests on rock or on fragmental material having interstices filled with organic matter" (Soil Survey Staff 1999).

h **Diked/Impounded** – "These wetlands have been created or modified by a man-made barrier or dam that obstructs the inflow or outflow of water" (FGDC 2013).

i* **Alkaline** – pH > 7.4. This special modifier should primarily be used on hard-water lakes where water chemistry data is known.

***WWI Refined Definition** – This modifier may also be applied to sedge ("EM3") and shrub-dominated communities where calcareous fens are known to exist. In this case, place the attribute after the NWI special modifier (most likely "g") in the "WWI" special modifier place.

j* **Reconstructed Wetland - WWI Definition –** Used to indicate areas where hydric conditions have been restored to previously fully-drained former wetlands.

k* **Restored Wetland – WWI Definition** – Used to indicate where previously extant, partially drained or fully impounded wetlands have been restored in a manner that re-approximates the pre-settlement hydrology under which they formed. This could apply to wetlands where ditch fills were performed, cultivated cranberry bogs are reclaimed, or dikes and water control structures are removed. This special modifier does not apply to areas than have been diked/impounded ("h") to create open water within formerly emergent wetlands, nor does it apply to artificial ("r") or Re-constructed ("j") wetlands.

l* **Channelized Streams and Rivers - WWI Definition** – Used to indicate streams and rivers that naturally existed on the landscape historically but were excavated and straightened by human activity. This modifier stands in contrast to excavated drainage ditches (“x”) which have no natural, historic analog.

m **Managed** – “This modifier is used to identify wetlands where water inputs are controlled to achieve a specific water regime or habitat type. Water control structures in combination with dikes and impoundments are common” (FGDC 2013).

n **Mineral Soil** – Any soil that falls below the organic content criterion outlined for organic soil, “g”.

o* **Artificial Wetland - WWI Definition** – Used to indicate wetlands which appear to be constructed/engineered in areas that lack wetland presence prior to 1991 and hydrophytic vegetation may be present as the result of human modification to the landscape. These wetlands are likely, but not guaranteed, to fall under the scope of Section 21 281.36(4n) in Act 183 exemption for “artificial wetlands”.

p* **Pastured/Grazed - WWI Definition** – Wetlands which are used for pasturing domesticated animals.

q* **Ruderal Vegetation - WWI Definition** – Wetlands dominated by one or more species of non-native plants which do not fit within any described subclass or where any one dominant exotic species subclass fails to reach 30% cover. May apply to vegetated classes within the palustrine or lacustrine systems. Dominant plant species in ruderal communities include non-native tree willows, boxelder, common buckthorn and glossy buckthorn, honeysuckle, giant ragweed, purple loosestrife, and stinging nettle. Ruderal wetlands tend to receive frequent disturbance from various sources and/or have experienced intense historic disturbance.

r **Artificial Substrate** – “This Modifier describes concrete-lined drainageways, as well as Rock Bottom, Unconsolidated Bottom, Rocky Shore and Unconsolidated Shore where the substrate material has been emplaced by humans. Jetties and breakwaters are examples of Artificial Rocky Shores” (FGDC 2013). Farmed cranberry is another common example of Artificial Substrate.

s **Spoil** – “The Spoil Modifier is used to describe wetlands where deposition of spoil material forms the primary substrate type. By definition, spoil is material that has been excavated and emplaced by humans. Ancillary data may be needed to accurately identify spoil in areas such as reclaimed strip mines that have become revegetated” (FGDC 2013).

t **Circumneutral** – pH 5.5-7.4. This special attribute is typically not applied except for very limited special applications where lake water chemistry data is known.

u* **Ridge and Swale Complex - WWI Definition** – “This landform occurs mainly along the Lake Michigan coast, where narrow beach ridges (strand lines) were formed parallel to the shore as the water in lake Michigan receded during post-glacial times. Depressions (swales) between the beach ridges contain wetland vegetation, but the ridge themselves are dry. This complex is used to indicate areas where the swales are too small to delineate individually.” This attribute also indicates a type of “Rare and high-quality wetland.”

v* **Vegetation Recently Removed - WWI Definition –** Used to indicate areas where the vegetation has been recently totally or partially removed by clearing, shearing, logging or other means.

w* **Floodplain Complex** - **WWI Definition** – This modifier describes the floodplains of rivers and streams which are composed of small areas of seasonally flooded wetlands, wet meanders scars, oxbow lakes, and or small inclusions of upland, all of which are too small to delineate individually.

x **Excavated** – "This Modifier is used to identify wetland basins or channels that were excavated by humans" (FGDC 2013). This modifier may apply to open water and aquatic bed classes as well as the emergent class where vegetation has grown over the excavated area.

y* **Glacial Lake Plain Complex** – **WWI Definition** – This modifier is reserved for complex, extremely difficult-to-map former glacial lake plains where estimated wetland coverage is greater than 75% and upland inclusions are less than 1/10th of an acre. In these cases, subtle topography makes delineation of wetlands and upland inclusions extremely challenging and impractical.

Proposed Non-wetland Standalone Special Modifiers & Attribute Codes

These modifiers are used to attribute non-wetland features that are created for maintaining spatial and hydrologic relationships between connected and formerly connected wetlands on the landscape.

$ **Filled Wetland - WWI Definition** – Used to indicate areas where wetlands were filled due to roadbuilding, building construction, or other human activities - historically or recently. These features will be dropped completely from NWI maps and may be retained for internal use.

& **Fully Drained Wetland** (special use only) - **WWI Definition** – Used to indicate areas of formerly hydric soils which are now fully drained as to no longer support hydric vegetation or qualify as a wetland under most commonly accepted definitions. While not practical for inclusion in routine statewide mapping, this symbol is reserved for special applications like watershed modeling, manual interpretation of potentially restorable wetlands, long-term trend assessment, and others where it may be important to account for the lost services and spatial relationships of fully drained wetlands within the landscape.

Appendix C: Strategy for Assessing the Feasibility of Producing a Statewide Combined Wetland and Surface Water GIS Layer

Christopher Noll, last updated 7/1/2020

Background: The WWI's FY2016 EPA Wetland Program Development Grant designated funds for a pilot mapping study to "design, test, and evaluate a process to map wetlands and surface waters in tandem from the same data surfaces, to produce a single Integrated Surface Waters and Wetlands GIS Layer." Part of the evaluation process required a feasibility assessment for resources required to remap the entire state.

Study Area

The study area encompasses all counties within Wisconsin that have usable (typically 2010 onward) lidar data.

Spatial Unit of Assessment

The base unit area of assessment consists of PLSS sections (generally consistent 1 sq mile squares). The target population was all PLSS sections within Wisconsin that intersect at least one wetland polygon from the current NWI 2.0 geodatabase. The choice was made to use NWI 2.0 over the current WWI dataset because it better approximates the intended final product by combining existing WWI polygons, points, and hydrography features into an all-polygon layer.

Sampling Strategy

Because Wetland density varies widely across Wisconsin's landscapes, and wetland-dense areas tend to take longer to map than drier areas, the whole spectrum from dry to wet needed to be accounted for to create accurate time and cost estimates. Because of this, we stratified our sample according to the following percent cover of wetland area to ensure even coverage along the density spectrum.

Low Density Sections = 0-21.3% wetland cover

Medium Density Sections = 21.4 – 58.8% wetland cover

High Density Sections = over 58.9% wetland Cover

To create these categories, PLSS Sections were intersected with NWI 2.0 wetland and surface water polygons, and for each section a percent cover was tabulated. Sections with 0% cover were excluded. The remaining sections on list were sorted by increasing percent cover, then divided equally into low, medium, or high.

From each low, medium, and high category, 51 sections were drawn at random. Of these 51 sections, three cartographers (Cal Lawrence, Chris Noll, and Chris Smith) were assigned 17 sections at random. Each cartographer was responsible for completing GIS data production in at least 10 of these sections. Each cartographer worked their way sequentially through the list of sections for each density category. If a section happened to be surrounded by a lake or deviated in area more than 10% from one square mile, that section was dropped and the next one on the list taken.

Metrics of Performance

Each cartographer drafted GIS data using a geodatabase that enabled time tracking of polygon feature creation and editing from start to finish by automatically populating two fields - “First Edit Time” and “Last Edit Time”- on each feature created. Additionally, time was manually tracked through an excel based spreadsheet recorded as total minutes. Each section started will be finished before moving on to the next one to ensure a consistent measure of time.

Preliminary Results

Several analyses using regression plots normalized to existing NWI 2.0 data will be ready by the time of the final grant delivery to create more accurate projections for the resources needed for remapping the state with integrated surface waters and wetlands. In the meantime, the following values can be used to summarize the results.

Across 113 square miles of Wisconsin and three mappers working independently to draft new maps using the updated methodology, the average amount of time taken to remap a PLSS Section was 114 minutes per square mile. The average wetland density of the re-mapped area was 36.4%.

If all variables held steady and were extrapolated to remapping the entire state (65,556 sq miles), roughly 124,556 hours of labor would be required to remap Wisconsin’s wetlands and surface waters. Assuming a rough figure of $45/hour total labor cost, this would bring the cost of the total effort to $5.6 million.

It must be noted that this is likely a high-end estimate which does not consider a number of confounding factors such as improvements in cartographer skill level over time, efficiency gained through further refinements in methodology, and technological advances in GIS tools like AI-based image classification that are just beginning to reach the GIS world. However, the data captured also did not account for productivity lost to essential tasks such as administrative tasks, obtaining data, running full QA/QC, and coordination & outreach with partners. A more in-depth analysis of the feasibility data will be included in the grant deliverables for the EPA in late fall of 2020.

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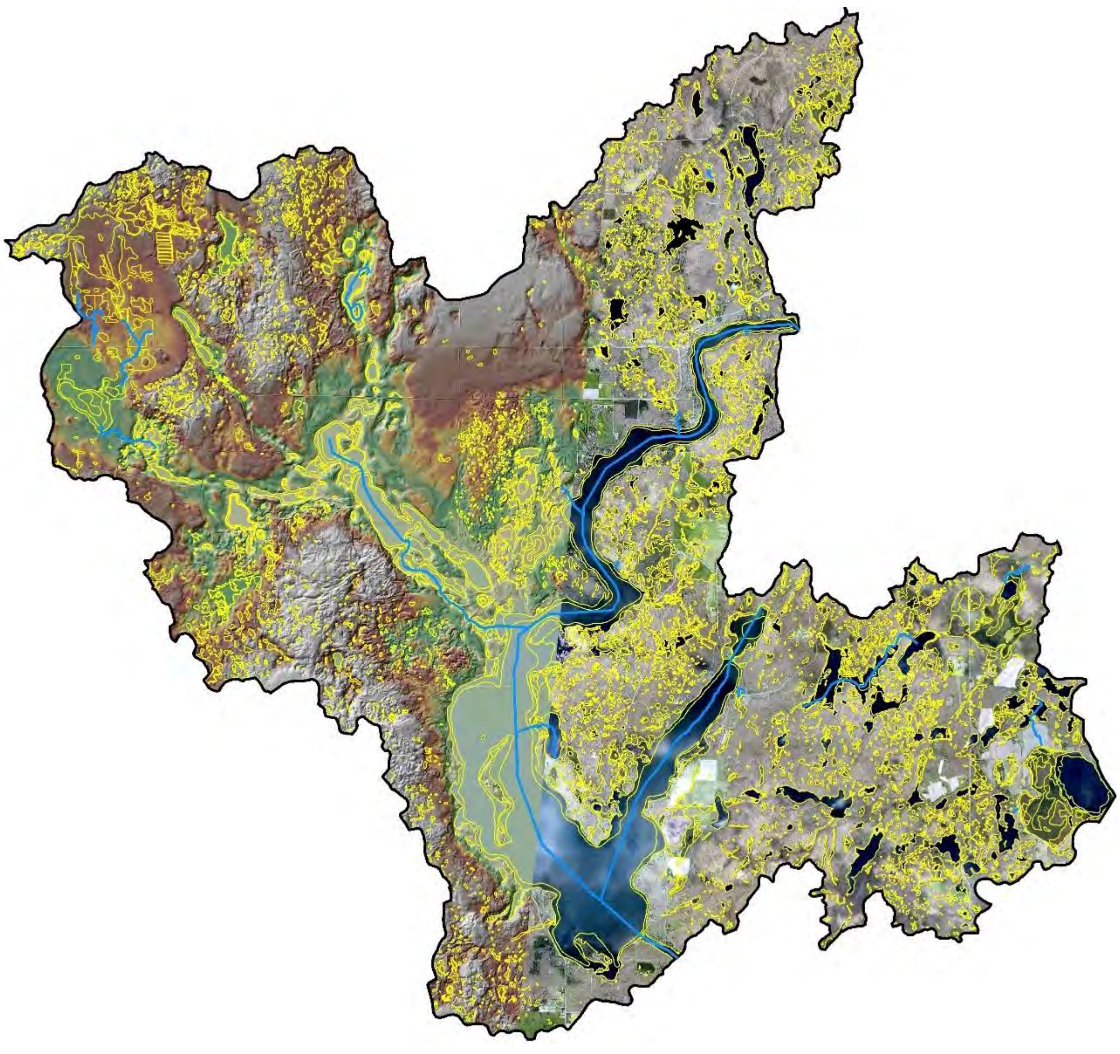
Integrated Wetland and Hydrography Mapping in Select Sub-Watersheds of Wisconsin

A Pilot Project



ON THE COVER
Map of the Long Lake watershed in Washburn County, Wisconsin. The map shows a comparison of the watersheds wetland and surface water feature as overlaid on a physical relief representation (left) and aerial imagery (right)
Map created by: Kevin Stark (GeoSpatial Services, Saint Mary's University of Minnesota)

Integrated Wetland and Hydrography Mapping in Select Sub-Watersheds of Wisconsin

A Pilot Study

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Acknowledgments

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List of Acronyms and Abbreviations

ACPF	Agricultural Conservation Planning Framework
CIR	Color Infrared
CTI	Compound Topographic Index
DEM	Digital Elevation Model
DRG	Digital Raster Graphic
FGDC	Federal Geographic Data Committee
FTP	File Transfer Protocol
GIS	Geographic Information System
GSS	Saint Mary’s University of Minnesota GeoSpatial Services
HARN	High Accuracy Reference Datum
HDEM	Hydro-enforced Digital Elevation Model
HGM	Hydrogeomorphic
HPI	Hydrographic Position Index
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
LLWW	Landscape Position, Landform, Water Flow Path, and Waterbody Type
MN DNR	Minnesota Department of Natural Resources
NAD	North American Datum
NAIP	National Agricultural Imagery Program
NHD	National Hydrography Dataset
NRCS	Natural Resources Conservation Service
NWI	National Wetlands Inventory
QA/QC	Quality Assurance and Quality Control
SPI	Stream Power Index
SSURGO	Soil Survey Geographic Database
TM	Transverse Mercator
TWI	Topographic Wetness Index
USFWS	U.S. Fish and Wildlife Service
WDNR	Wisconsin Department of Natural Resources
WEVM	Wisconsin Elevation Visualization Method
WWI	Wisconsin Wetland Inventory

1. Introduction

The Wisconsin Department of Natural Resources (WDNR) contracted with Saint Mary's University of Minnesota GeoSpatial Services (GSS) to design, test, and evaluate a process to map wetlands and surface waters in tandem from the same data sources, in an effort to produce a set of integrated surface waters and wetlands spatial data layers. This project piloted the process developed by GSS to create integrated surface water and wetland GIS (geographic information system) layers for a diversified group of watersheds located within the major hydrologic regions of Wisconsin. WDNR staff selected ten, demonstration, 12-digit HUC (hydrologic unit code) watersheds for pilot testing of the methodology (Table 1).

Table 1: Watersheds included in the pilot study

HUC 12 Name	HUC 12 Number	County	Mapping Responsibility
Duck Creek	70700031805	Adams	WDNR
Meadow Creek	40103020610	Ashland	GSS
Lower Duck Creek	40302040106	Brown	WDNR
Mud Lake-Koshkonong Creek	70900020403	Dane	GSS
Devils River	40301010202	Manitowoc	WDNR
Mud Creek	70700031502	Monroe	GSS / WDNR
N Fork Main Creek	70500040302	Rusk	WDNR
Wester Creek	70700060304	Vernon	GSS
Trout Lake	70500020105	Vilas	GSS
Long Lake-Middle Brill River	70500070302	Washburn	GSS

1.1 Project Background

Healthy waters are the backbone of Wisconsin's recreational economy and quality of life. Wisconsin's water programs are charged with maintaining the quantity and quality of wetlands, streams, and lakes for the long-term benefit of the people of the state. Anglers, hunters, boaters, farmers, landowners, realtors, loggers, utilities, the construction industry, residential and commercial developers, conservation organizations, and virtually all sectors of Wisconsin's economy depend on accurate and up-to-date maps of wetlands, lakes, and streams maintained and updated by the WDNR. It is critical that these maps be kept as current and accurate as possible to improve customer service to applicants for the many types of permits that involve wetlands and waterways, and to improve the performance of water-related conservation programs.

1.2 Project Design

With the advent of LiDAR (Light Detection and Ranging) data and new high resolution, digital aerial imagery, it is possible that all surface waters and wetlands can be mapped in tandem into an integrated GIS layer. The question is how to achieve this in a timely cost-effective manner. The objective of this pilot mapping project is;

- to design a methodology that will produce integrated GIS layers for wetlands and surface water features that adhere to Federal Geographic Data Committee (FGDC) standards for surface water and wetlands, and
- apply this methodology to 10 pilot Wisconsin watersheds (i.e., 12-digit HUC) in an effort to determine the feasibility and costs associated with deploying the method for the entire state.

A methodology for mapping wetlands and surface water as integrated GIS data layers was designed based on a process GSS has developed (and refined) for mapping wetland boundaries and applying attributes from aerial imagery, LiDAR, and other collateral GIS datasets. GSS worked collaboratively with WDNR staff to adapt this process to produce a suite of integrated wetland and surface water GIS datasets that adhere to FGDC spatial data standards, National Wetland Inventory (NWI) standards for wetlands and to National Hydrography Dataset (NHD) standards for streams. GSS and WDNR staff collaborated on the mapping of the wetlands and surface water features in pilot watersheds. GSS provided training materials to the WDNR and trained select WDNR staff on the wetland mapping process.

1.3 Project Deliverables

The primary deliverables of this project is this technical document, which provides a systematic methodology to create individual wetland and surface water GIS datasets that can provide a contiguous hydrologic GIS layer for the State of Wisconsin. Each section of this document provides the technical information and procedures required to create the wetlands and surface water GIS datasets.

The remaining pilot project deliverables are the GIS datasets that comprise the integrated wetland and surface water features: wetland polygon features, lakes/ponds polygon features, and stream segment polyline features.

2. Methodology

The technology for accessing and displaying map (geospatial) data has made incredible strides, but the accuracy and currency of basic water data - the current location and boundaries of wetlands, streams and lakes has not kept pace, with these advances. This disconnect has caused problems and delays with permitting and water management programs, frustrated planning efforts, and cost money to businesses and local governments alike. Many of these problems can be eliminated by locating wetlands, streams and lakes in the correct location and in the correct relationship to each other.

Wetlands mapped and attributed with the Cowardin classification used in NWI mapping, provides a base geospatial data layer from which open water features for lakes and rivers can be derived. The wetland codes provide a means for deriving separate, yet coincidental polygon and polyline data layers representing these open water features. The following sections provide a basic methodology for creating a NWI compatible wetlands GIS layer and the process for extracting a lakes/ponds and a streams/rivers GIS layer.

2.1 LiDAR Data Products

GSS derived several LiDAR products for use in this project. These products were part of the collateral data used in the wetland interpretation and delineation from a digital elevation model (DEM), including elevation contours, hillshade raster, hydrographic position index (HPI), and percent slope raster. A hydro-enforced DEM (HDEM) was produced for each watershed by the WDNR staff for use in the stream mapping process. Drainage and flow paths were derived by GSS from the HDEMs for use in adjusting or augmenting the stream centerlines derived from the wetland mapping. The LiDAR derivatives were created using the standard Surface and Hydrology Geoprocessing Tools in Esri ArcGIS 10.5.1 Desktop.

2.2 Wetland and Deepwater Habitat Mapping

2.2.1 Software and Data Management

Esri ArcGIS 10.5.1 Desktop 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 HUC 12 checkout in order to track the data production. The routing sheet was used to document the interpreter's checkout information including: task, hours, and polygons created. The Project Lead and Quality Assurance/Quality Control (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. All edits took place within one file geodatabase per HUC 12. 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 backup 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 backup and segregate the completed data.

The collateral data for this project resided in a dedicated file structure on a server. In addition to the LiDAR derived products, other ancillary datasets used in this project included: historic Wisconsin Wetlands Inventory (WWI) polygons and points, HUC 12 boundaries, leaf-on 2015 and 2013

National Agricultural Imagery Program (NAIP) imagery, Soil Survey Geographic Database (SSURGO) soil polygons, and topographic digital raster graphics (DRGs).

2.2.2 Data Production

Data production utilized on-screen digitizing methods to generate the wetland data. Delineation and classification using the FGDC Cowardin Classification system was the first stage and the most labor-intensive portion of data production. It occurred within six, HUC 12 sub-watersheds, including Long Lake – Washburn, Meadow Creek – Ashland, Mud Creek – Monroe, Mud Lake – Dane, Trout Lake – Vilas, and Wester Creek – Vernon. It included initial delineation and attribution by an editor and internal QA/QC by GSS staff and concluded with the finalization of wetland polygon boundaries. The second stage was assigning Landscape Position, Landform, Water Flow Path and Water Body (LLWW) attributes at the HUC 12 level. The third stage was the WDNR draft review phase. At this stage, the draft data was submitted via FTP (file transfer protocol) in a file geodatabase for review and feedback (external QA/QC). GSS incorporated WDNR's feedback and resubmitted for review in the final data delivery. The NWI Verification Tool was applied to the data and any errors were fixed. Upon successful completion of the NWI Verification Tools, the data was run through a list of finalization tasks to ensure data consistency.

2.2.2.1 On-Screen Photointerpretation Process

Delineation & Cowardin Classification

This project used an on-screen, heads-up, digitizing process with the use of Esri ArcGIS 10.5.1 software. This approach took 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 Wetlands and Deepwater Habitats Classification (Appendix A (Cowardin, et al. 1979)) lists all of the possible NWI attributes by system, subsystem, class, subclass, water regime, and special modifier.

1. The interpreter started by creating a new ArcMap map document, (Figure 1). 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 NAD 1983 HARN Wisconsin TM projection. Imagery and collateral data sources were added next and the end result was an ArcMap document similar to the example. 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 with acceptable guidelines; this created a unique editing environment to help optimize productivity.

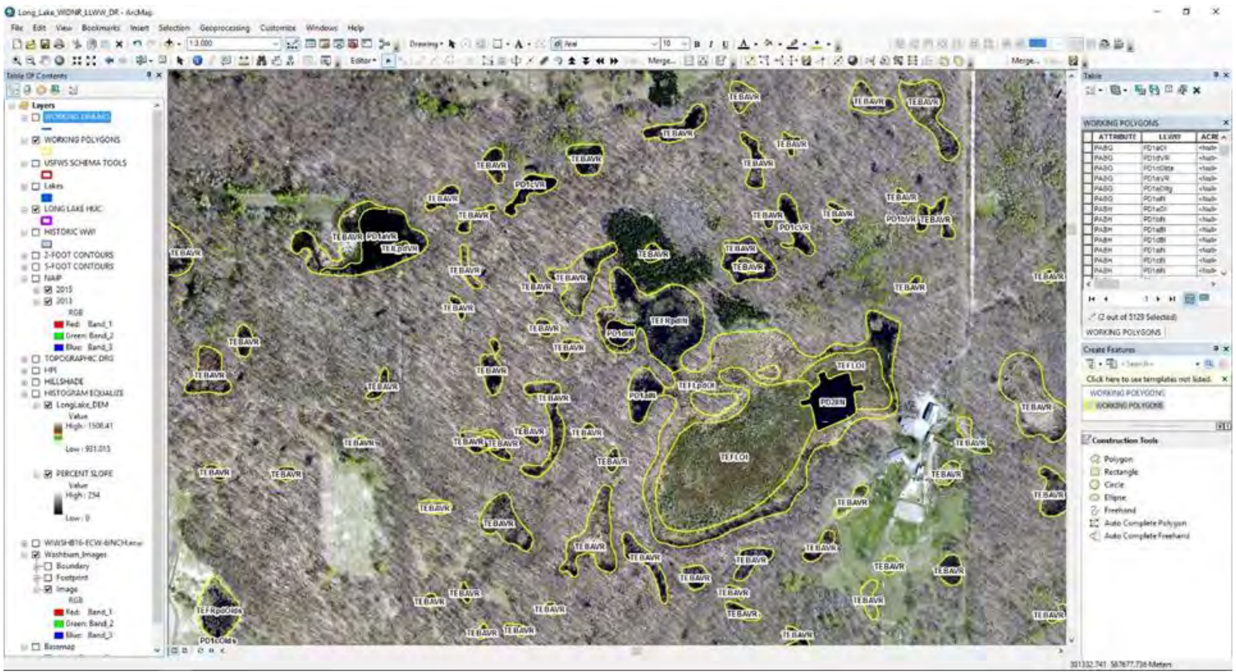

Figure 1. Example ArcMap working document for wetland mapping.

1. To clearly see wetland signatures, the edited wetland feature must be displayed as hollow polygon with a line color that contrasts with the underlying imagery. Polygon boundary thickness was set at a maximum one and one-half and attribute font size remained under ten in order not to obscure the wetland signature or boundary of the wetland feature. If Color infrared imagery (CIR) was available, then it was set to display the red band as band #4, the green band as band #1, and the blue band as band #2. This spectral enhancement 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. Long Lake – Washburn, Mud Creek – Monroe, and Mud Lake – Dane only had three bands available; red, green, and blue, no fourth-band CIR was used in the base imagery.
2. The entire extent of each of the six HUC 12 boundaries were examined for wetlands. This was accomplished through a "panning and zooming" technique where the interpreter started in the northwest corner of the assigned checkout at the mapping scale of ~1:3,000. This extent was examined for presence of wetlands based on the signatures and topographic indicators of wetlands; where wetlands were found, they were delineated as a polygon feature using the ArcMap Advanced Editing Tools. If a wetland signature was questionable, a review of additional collateral datasets were displayed and turned off until a determination wetland / upland was made. The imagery signatures in cooperation with collateral imagery and data provided information for the interpreter to then attribute a class and subclass of vegetation, water regime, and when present, a special modifier.
3. The first step in polygon production was creating the network of flowing streams, creeks, and rivers as linear features. These are narrow wetlands that have intermittent or upper and lower perennial flow, such as R4SBA, R4SBC, R3UBF, R3UBG, R3UBH, R2UBF, R2UBG, and

R2UBH. The R3 could potentially have the class RB (rock bottom) versus the UB (unconsolidated bottom). The R2 could potentially have the classes AB (aquatic bed) or EM2 (non-persistent emergent) versus the UB (unconsolidated bed). The standard in mapping original NWI systems of riverine was to only map the feature if it was greater than five-meters wide or if there was a double-lined blue polygon on the USGS, topographic DRG. With the advancements in high-resolution imagery and quality of collateral datasets such as LiDAR derived DEMs increasing, NWI 2.0 was developed to better represent smaller surface water features such as narrow creeks and streams. This process was often completed by "burning through" a hydrography dataset such as NHD linears. They were buffered to a consistent width and clipped through the NWI polygons.

4. In this heads-up delineation process, linears were created by digitizing on screen using the base imagery and LiDAR derived DEM raster images, (Figure 2). The benefit of this process is the location and width of the newly created line is substantially higher in accuracy and precision compared to the historic hydrography data meshed into an existing wetland polygon layer. The linears were digitized at a scale of 1:1,000, sometimes tighter, and were buffered to a measured distance of width, down to a buffered distance of one-half-meter or bank to bank. A half-meter buffer creates a one-meter bed or channel width, five times more precise than the previous standard of five-meters in historic NWI, (Figure 3).

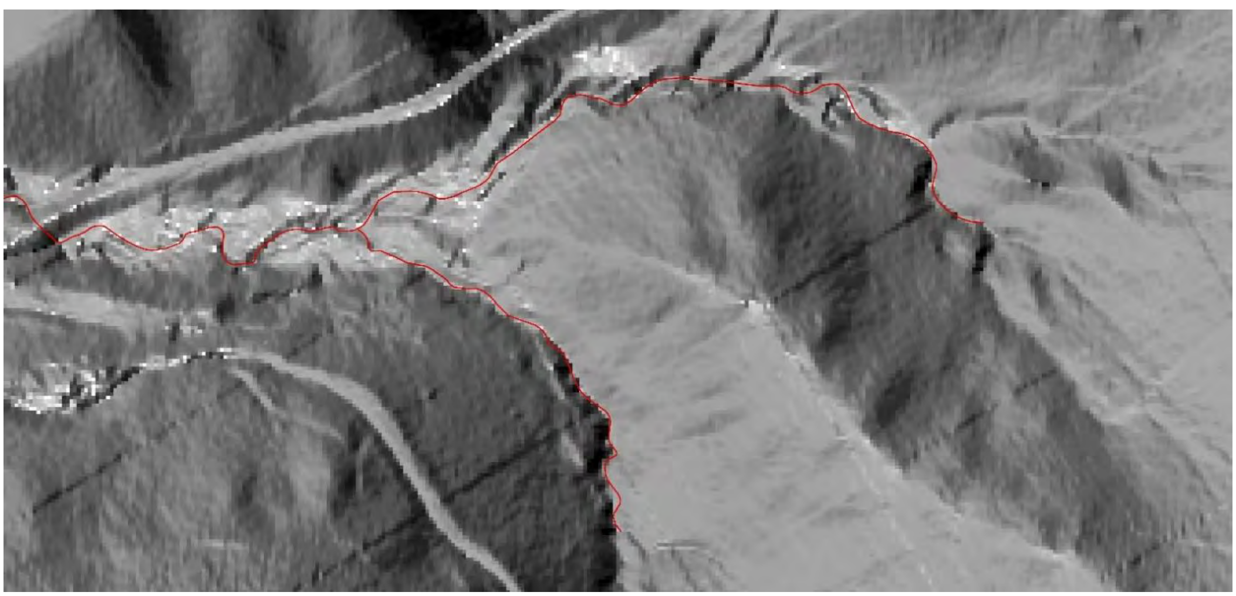

Figure 2. Linear bed, bank, and channel prior to buffering in Wester Creek, Vernon County – 1:1,000.

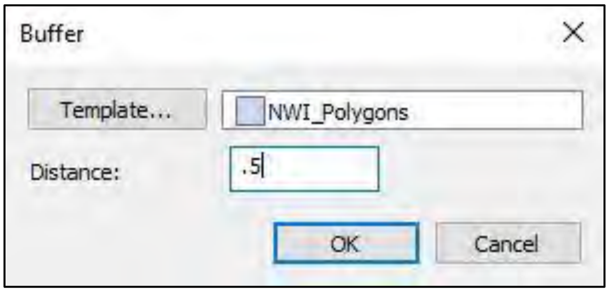

Figure 3. Editor Tool - Buffer Linear to Polygon.

5. After the linear was buffered and entered into the polygon dataset, polygons surrounding the buffered line were added. This was done through ArcMap Advanced Editing Tools. Polygons directly connected to the linear network were auto-complete freehanded to form a coincidental boundary with the adjacent flow network, (Figure 4). Stand alone polygons were created with the freehand polygon tool and additional tools such as: cut, reshape, clip, and merge were used represent the signatures on the imagery, as they most likely appeared on the terrain.

Figure 4. Buffered linears adjacent to auto-complete freehanded polygons in Wester Creek, Vernon County – 1:1,000.

6. Wetland classification utilized the Cowardin Classification system and occurred by directly editing the ATTRIBUTE field in the NWI_Polygons feature class attribute table (Figure 5). Wetland classes and water regimes were assigned as individual wetland polygons were delineated. After NWI attributes were entered, LLWW codes were entered into the appropriate field. Some LLWW codes have a one-to-one crosswalk with NWI, such as R4SBA and R4SBC are ST4TI. Those codes were populated by the use of the Field Calculator in the attribute table. Other LLWW attributes like lentic (LE), lotic stream (LS),

and lotic river (LR) are based on adjacency or proximity to lakes, streams, and rivers, and were attributed using spatial selections and coincidental boundaries. The remaining terrene (TE) and ponds (PD) attributes were attributed with the use of the base imagery, collateral datasets, and surrounding NWI polygons as interpretative input.

Table

WORKING POLYGONS

ATTRIBUTE	LLWW	ACRES	QAQC_CODE	WETLAND_TYPE	Shape_Length	OBJECTID *	Shape_Area	Shape *
PABH	PD1aIN	9.78657	<Null>	<Null>	2020.576349	9677	39409.179101	Polygon
PABH	PD1bIN	10.2476	<Null>	<Null>	2398.44279	9846	41265.990882	Polygon
PABH	PD1bIN	5.01085	<Null>	<Null>	1929.349816	9859	20178.027006	Polygon
PABH	PD1aIN	14.2090	<Null>	<Null>	3052.535428	9912	57217.784911	Polygon
PEM1/3B	TEBAOI	3.60102	<Null>	<Null>	634.916816	6097	14500.807098	Polygon
PEM1/3B	TEBAOI	7.74790	<Null>	<Null>	3264.622907	9941	31199.718275	Polygon
PEM1/SS1C	TEBAVR	0.40052	<Null>	<Null>	214.809768	4648	1612.84243	Polygon
PEM1/SS1E	LE1BABI	1.23129	<Null>	<Null>	420.547723	4352	4958.239086	Polygon
PEM1/SS3B	TEFLOIds	2.83124	<Null>	<Null>	587.13272	6301	11401.009763	Polygon
PEM1/SS4E	LE1BABI	0.39927	<Null>	<Null>	192.82274	4707	1607.822997	Polygon
PEM1A	TEBAVR	0.09700	<Null>	<Null>	70.767155	6982	390.622289	Polygon
PEM1A	TEBAVR	0.3069	<Null>	<Null>	163.319618	6984	1235.843936	Polygon
PEM1A	TEBAVR	0.23297	<Null>	<Null>	121.777564	6986	938.145911	Polygon
PEM1A	TEBAVR	2.14413	<Null>	<Null>	1499.097463	9850	8634.144038	Polygon
PEM1A	TEBAVR	0.39150	<Null>	<Null>	361.797443	10036	1576.533159	Polygon
PEM1Ad	TEFLOIdr	1.27803	<Null>	<Null>	378.875222	3882	5146.464309	Polygon
PEM1Af	TEFLOIhifg	1.17687	<Null>	<Null>	306.888713	3833	4739.089435	Polygon
PEM1Af	TEFLOIhi	0.36441	<Null>	<Null>	196.315037	4764	1467.463819	Polygon

0 (0 out of 5129 Selected)

WORKING POLYGONS

Figure 5. NWI_Polygons - feature class attribute table.

7. The interpreter was allowed to zoom in to a scale of 1:3,000 if necessary to make edits. Zooming adjustments were permitted at finer scales to allow the "WDNR Elevation Visualization Method" (WEVM) grouping to refresh. After all the wetlands in the 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. Any delineation along the edge is overlapped by approximately 200 meters to allow complete coverage of the sub-watershed and could be clipped to the boundary or incorporated into an edgematch process after delivery. 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.

Finalization Tasks

The finalization tasks were a vital step in making sure the data being produced met the project standards and remained consistent throughout the duration of the pilot project. The objective of this procedure was to eliminate as many errors and issues as possible before the data was sent for delivery. This helped QA/QC focus their efforts on more difficult tasks rather than spending time on easily addressed issues. After completing photo-interpretation and classification edits, the HUC 12 assignment was finalized by performing the following steps:

1. All NWI_Polygons features (edited, wetland feature class) were selected and exploded to split any multi-part features into separate polygons. This was repeated multiple times until there were no multi-part features to explode and the feature count remained stable.
2. The NWI_Polygons attribute table was sorted on the *ATTRIBUTE* field in ascending order to locate null and blank entries. A null or blank entry in the attribute field could occur for a number of reasons. The interpreter may have neglected to assign a classification code to the wetland feature or removed the attribute and failed to enter a new code in. It also occurred when a “ghost” polygon was 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 without geometry were deleted.
3. The NWI_Polygons attribute table was then sorted on the *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 one-tenth of an acre (~400 square meters) should 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 a quarter-acre (~1,000 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 1:5,000 and easily delineated at a scale of 1:3,000 could be retained (i.e., PUBF ponds). Isolated polygons of 400 square meters in size and polygons internal to wetland complex of 1,000 square meters are known as minimum mapping units, (MMU).
4. A check for erroneous attributes was conducted by using “Select by Attribute” on the *ATTRIBUTE* field of the NWI_Polygons 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 opened (Figure 6), “ATTRIBUTE” was selected in the field list, then “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 invalid attribution errors included: 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), (Figure 6). Erroneous attributes were directly edited in the table to fix errors, and may have required looking back to the imagery for verification.

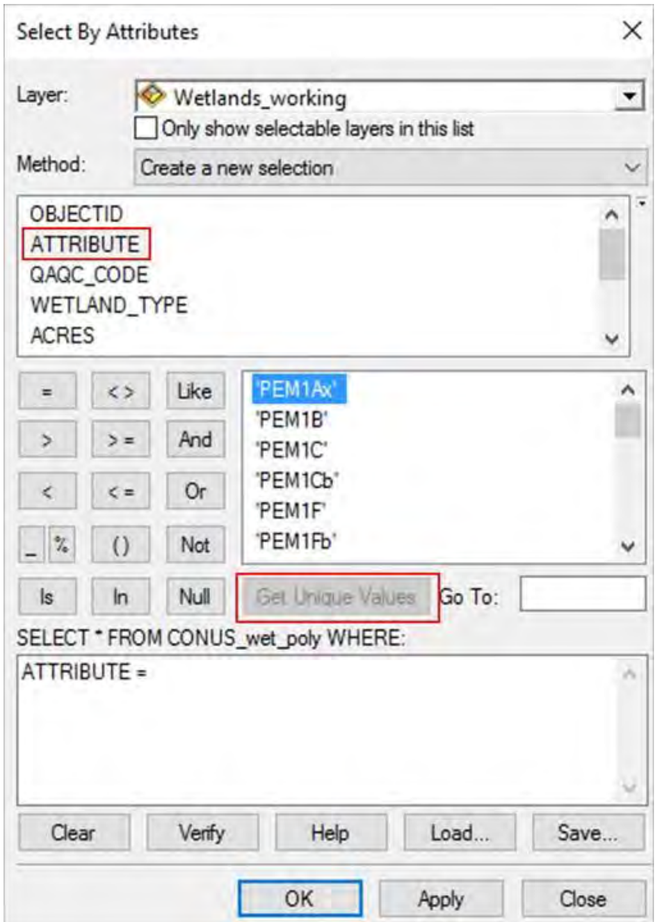

Figure 6. Select by Attribute graphical user interface.

5. Topology was used to look for geometry issues and at this point, the only rules applied by the interpreter was a cluster tolerance set to 0.001 meters and "must not overlap." 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.

2.2.2.2 Quality Assurance/Quality Control (QA/QC)

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. 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 with the working wetlands file geodatabase and symbology and display were changed to the preference of the reviewer.
2. Using the new QA/QC map document, the entire checkout was scanned at a scale of 1:5,000 using the "pan and zoom" technique to guarantee the entirety of the checkout was reviewed. QA/QC verified that the data met the standards described above (section 2.2.2.1), checking the following:
    - Accurate delineations – The wetlands boundaries were correct in size and location based on signatures and supporting collateral data. No wetlands were omitted. No uplands were included as wetland polygons.
    - Correct Cowardin Classifications – Attribute values matched photo signatures based on imagery and supporting collateral data. All attributes are valid. There are no nulls, ghosts, and split classes are applied appropriately.
    - Line work – Smooth polygons 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.
    - General accuracy and consistency – The data was delineated and classified accurately with similar signatures mapped consistently across the checkout; decisions conform to NWI 2.0, LLWW 3.0 and FGDC standards.
3. When issues were identified, QA/QC used "Bookmarks" stored in a .dat file to locate errors and display solutions and proper delineation and attribution in order to provide feedback. Not all errors were necessarily identified, but enough were highlighted to illustrate any patterns of errors present in the data. 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 a few isolated errors that were not part of a systematic pattern, and the data was nearly considered complete, QA/QC may have performed the revisions rather than returning it to the interpreter.
4. The checkout was completed 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 cluster tolerance along with "must not overlap". 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 was free of topological errors.

5. The final step in the QA/QC process was running the data through the USFWS Wetlands Data Verification Toolset. A copy of the HUC12 wetland data was moved to the hard drive and polygon features were loaded into the Wetlands_Database_Schema.gdb file geodatabase. The NWI_QAQC_Tool.tbx ModelBuilder Toolset was run and outputs were exported and used to locate issues on the working database. This tool checks for the following issues: same adjacent wetlands, incorrect wetland codes, lake and pond sizes, overlapping wetlands, sliver uplands, and sliver wetlands. The tool also contains a field reset option, a wetland type calculator, and QAQC summary report. Complete instructions for installing and running the tools as utilizing the outputs create are located at Appendix C.
6. A backup copy was created and stored in a different location from the working and QA/QC data. The data were then considered complete in regards to delineation and FGDC classification.

2.2.3 Wetland Mapping Classification Systems

GIS technology has allowed wetland mapping to advance from hard copy maps drawn directly on Mylar film to large, searchable geodatabases able to satisfy any number of queries. Wetlands are typically mapped using on-screen digitizing methods by highly trained image interpreters. Aerial imagery serves as a base map and is combined with collateral data such as soils, topographic, hydrologic, and land cover information. This information allows a skilled image interpreter to make informed wetland mapping and classification determinations. The use of a GIS geodatabase structure provides the advantage of being able to assign any number of attributes (and any number of classification systems) to characterize wetland features. How various wetland attributes are assigned is dependent on the particular classification system in use. In the case of this wetland mapping and classification pilot, two classification systems are relevant. These are the Wetlands and Deepwater Habitats Classification, (Cowardin, et al. 1979) and the Dichotomous Keys and Mapping Codes for Wetland Landscape Position, Landform, Water Flow Path, and Waterbody Type Descriptors (Tiner 2014).

2.2.3.1 NWI – National Wetland Inventory

The U. S. Fish and Wildlife Service (USFWS) agency is responsible for the development of the NWI, an ongoing national program. The National Wetlands Classification System (Wetlands and Deepwater Habitats Classification, Cowardin et al., 1979) was adopted in 1996 by the NWI program and is used for wetland mapping across the country for conservation purposes. Any partner providing mapping services for the NWI must also adhere to the NWI Data Collection Requirements and Procedures for Mapping Wetland, Deepwater and Related Habitats for the United States implemented in 2009. This program satisfies the federal standard for wetland mapping and classification (FGDC, 2009).

A wetland is defined by the NWI Program as “land supporting hydrophytic plant communities, land with hydric soils, or land where the water table is at or near the surface for part of the year.” If these conditions are met the area can be identified as a wetland. The Wetlands and Deepwater Habitats Classification (Cowardin, et al. 1979) separates wetlands into large Systems, and further divides these Systems again into Subsystems, Classes, Subclasses, Water Regimes and Modifiers.

Alphanumeric codes representing the classification of each wetland mapped are assigned and stored into the geodatabase. This information provides descriptions about the wetland; the water, plant communities, alterations by humans or wildlife, and surface hydrology.

Refer to Appendix A for a hierarchical view and list the codes and descriptions of this system.

With the use of current and high resolution aerial photography, the presence of hydrophytic vegetation becomes a dominant factor in identifying and classifying wetlands. Collateral data is also used to aid in classification and normally consists of soils, topographic, and land cover data. Soil data, for example, provides information on the location of hydric soils while topographic data provides insight into surface hydrology. Collateral data is important especially when mapping semi-arid regions such as those found in the project area of New Mexico.

The Wetlands and Deepwater Habitats Classification used for the NWI describes wetland characteristics in a hierarchal order including:

- System
- Subsystem (with the exception of the Palustrine System)
- Class
- Subclass (only required for Forested, Scrub-Shrub, and Emergent Classes)
- Water Regime
- Special Modifiers (only required where applicable).

The wetland classification is written in an alphanumeric code and is expressed left to right in the following sequence: *System-Subsystem-Class-Subclass-Water-Regime-Special Modifier.*

The classification index first defines wetlands in the broadest sense by identifying their **System** with a single uppercase alphabetic (letter) code. There are five Systems including *M (*Marine), *E (*Estuarine), *L* (Lacustrine), *R (*Riverine), and *P* (Palustrine). Of these, only the latter three apply to the project study areas in Wisconsin (the first two refer to coastal and offshore saltwater environments).

The *R* (Riverine System) (Figure 7) includes deepwater habitats and mostly non-vegetated wetlands contained in natural or artificial channels periodically or continuously containing flowing water or which form a connecting link between the two bodies of standing water. Three out of five of the **Subsystems** from the *R* (Riverine) System are found in Wisconsin. These include *R2* (Lower Perennial), *R3* (Upper Perennial), and *R4* (Intermittent). Examples include rivers, streams, creeks, washes, and drainage ditches.

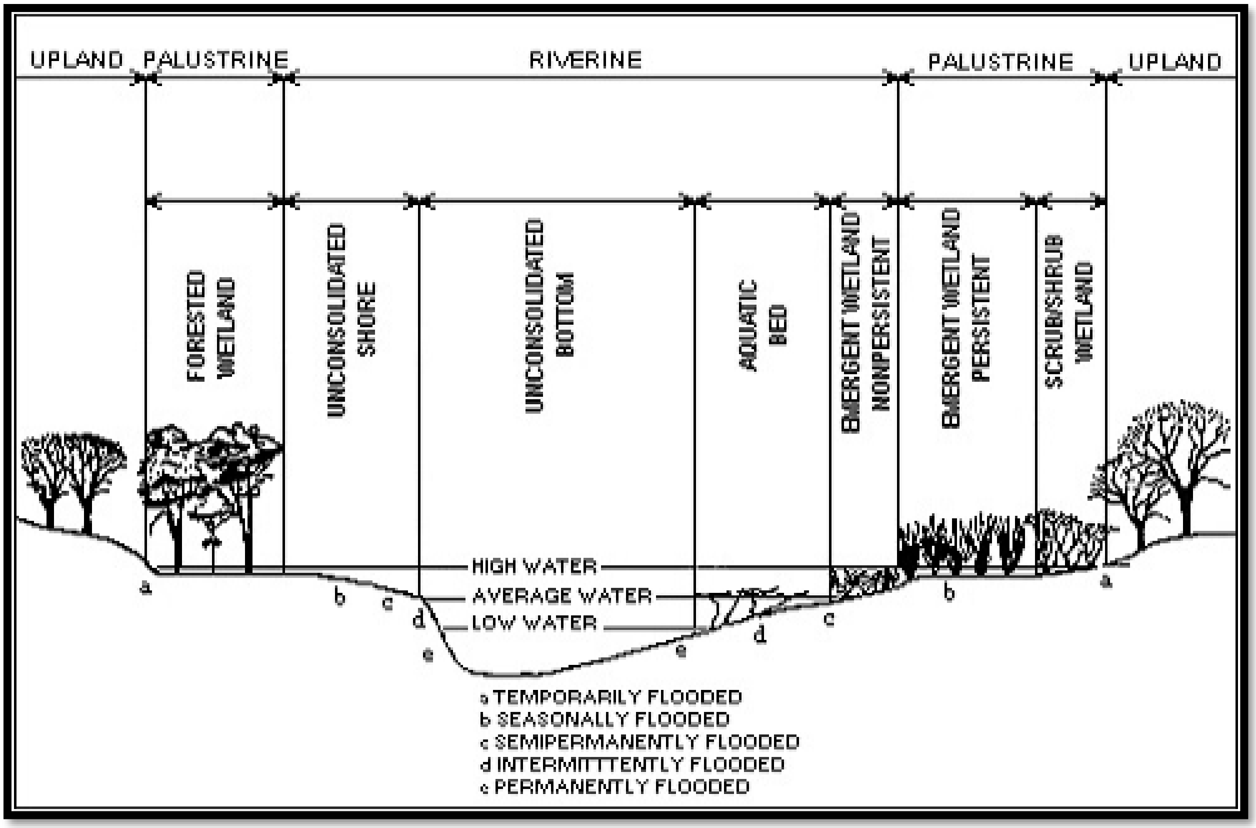

Figure 7. NWI Wetlands & Deepwater Habitats Classification - Riverine schema (Cowardin, et al. 1979).

The *L* (Lacustrine System) (Figure 8), includes wetlands and deepwater habitats defined by all of the following characteristics; deep water situated in a topographic depression or a dammed river channel, area of wetland lacking trees, shrubs, or persistent emergents, emergent mosses or lichens with greater than 30 percent aerial coverage; wetland area exceeding 20 acres; or total wetland area less than 8 hectares and deeper than 6.6 meters at low water. There are two **Subsystems** in the Lacustrine System; *L1* (Limnetic) and *L2* (Littoral). Wetland examples include: open water lakes, wild rice marshes, large beaches, and dammed reservoirs.

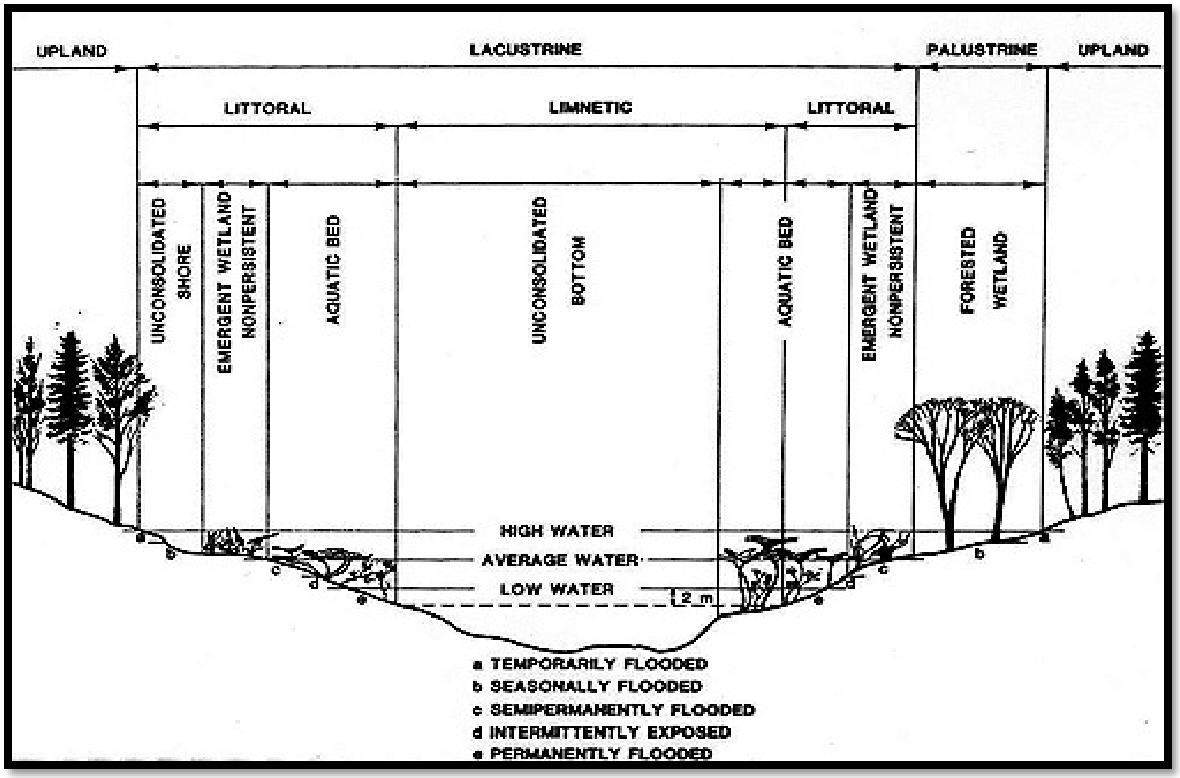

Figure 8. Wetlands and Deepwater Habitats Classification - Lacustrine schema (Cowardin, et al. 1979).

The *P* (Palustrine System) (Figure 9) includes all non-tidal wetlands dominated by trees, shrubs, emergents, mosses or lichens, and all wetlands that occur in tidal areas where salinity due to ocean-derived salt is below 0.5 ppt. An estimated 95 percent of all wetlands in the U.S. are freshwater, palustrine wetlands, and will predominate in most wetland mapping efforts. There are no Subsystems in the *(P)* Palustrine System. Examples of Palustrine wetlands found in Wisconsin include: marshes, swamps, shoreline fringe, bogs, fens, and ponds.

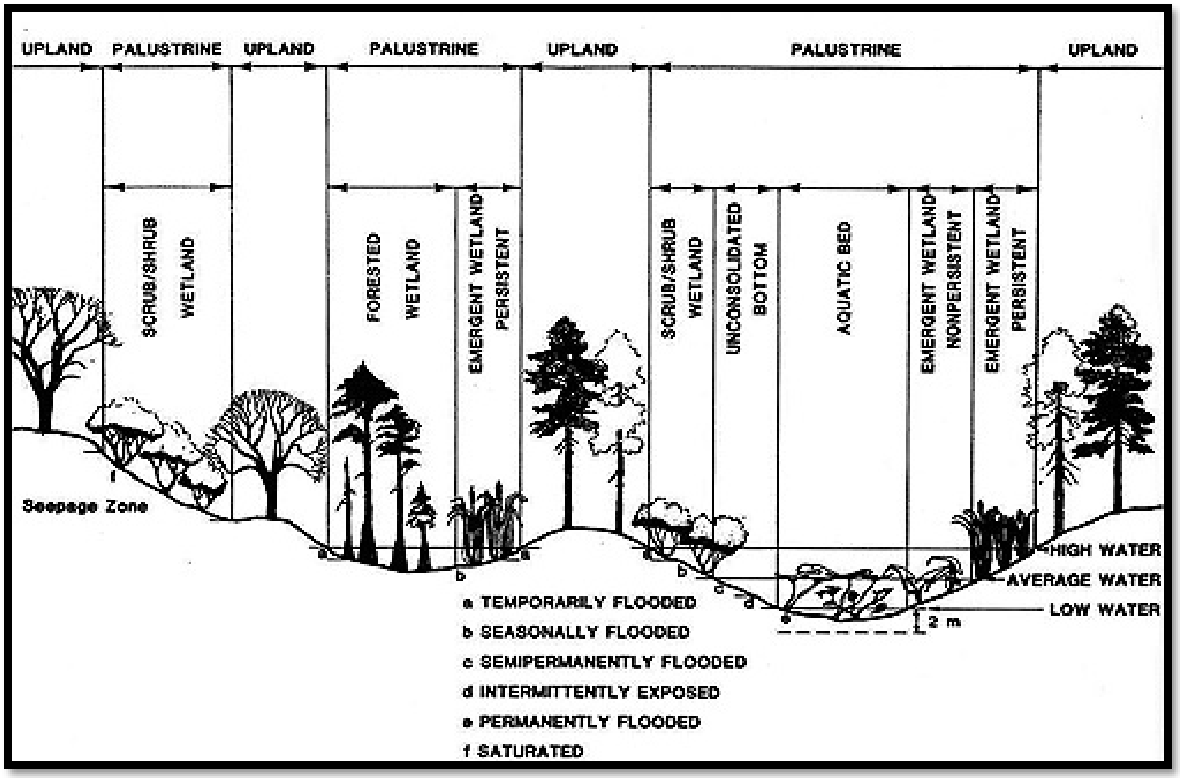

Figure 9**.** Wetlands and Deepwater Habitats Classification - Palustrine schema (Cowardin, et al. 1979).

After the System and Subsystem are classified, a **Class** is assigned which is denoted by a two-letter uppercase letter code referring to the dominant vegetation or substrate type. Examples of Classes include *UB* (Unconsolidated Bottom, *AB* (Aquatic Bed), and *FO* (Forested).

The **Subclass,** while similar to a Subsystem, refers to a more specific type within the wetland *Class* and is coded with a single number. For example, the code *FO1* refers to broad-leaved deciduous forest while *FO4* refers to needle-leaved evergreen forest. It is also possible to have dual Classes assigned; these are separated and notated in the alphanumeric code with a forward slash "/".

The meaning of a Subsystem code is dependent upon the particular System to which it is being applied. Similarly, the meaning of the Subclass is dependent on the Class to which it is being applied. Often times a wetland code is not classified to the Subclass level. In this case, there is no number representing a Subclass after the Class code itself.

There are several **Modifiers** in the classification system that may be applied to a wetland classification at the Class (or lower level) in the hierarchy. Modifiers include Water Regime, Special Modifiers, Water Chemistry, and Soil. Within these Modifiers are additional codes that describe the wetland in more detail. The Water Regime Modifier is sometimes referred to as the "hydrologic" Modifier. It consists of a single uppercase letter and encodes hydrologic information such as flooding frequency. The Water Regime Modifier is only applied during the growing season, because flooding during the dormant season does not significantly affect the vegetation that is present. The *B*

(Saturated) Water Regime is often used to classify hydric soils. Other Water Regimes include, in order of ascending wetness, *A* (Temporarily Flooded), *B* (Seasonally Saturated), *C* (Seasonally Flooded), *D* (Continually Saturated), *E* (Seasonally Flooded/Saturated), *F* (Semi-permanently Flooded), *G* (Intermittently Exposed), *H* (Permanently Flooded), *J* (Intermittently Flooded), and *K* (Artificially Flooded).

The Modifiers-Special Modifiers are notated as a single lower case letter. This code characterizes very specific physical conditions within a wetland including *b* (Beaver), *d* (Partly Drained/Ditched), *f* (Farmed), *h* (Diked/Impounded), *r* (Artificial), *s* (Spoils) or *x* (Excavated). The *x* (Excavated) and *h* (Diked/Impounded) codes from the Modifiers-Special Modifiers are most commonly applied because their presence is usually interpretable from aerial imagery.

The Modifiers-Water Chemistry indicate pH modifiers for fresh water. An example of the Water Chemistry modifier applied to the project area included the *(i)* alkaline code.

The Modifiers-Soil identify the presence of either *g* (organic) or *m* (mineral) soil conditions in a wetland.

A common characteristic of NWI classification data is that not all special modifiers are regularly used and that the lack of a special modifier does not necessarily mean that a particular condition does not exist in that wetland. This is especially true of Modifiers-Water Chemistry and Modifiers-Soil codes where interpretive limitations exist. These modifiers are difficult to infer using imagery and DEM products. They require the use of extensive field verification and additional collateral data, and therefore are often not included.

As aerial imagery resolution improves and the availability of digital collateral data increases, the application of Modifiers in wetland mapping projects is increasing. It is also possible to have more than one special modifier attached to a wetland.

<u>2.2.3.2 LLWW – Landscape Position, Landform, Water Flow Path and Water Body Classification System</u>

The applicability of NWI data for planning and decision support, especially related to wetland functional assessment, can be enhanced through the addition of hydrogeomorphic (HGM) descriptors to the wetland geodatabase. In recognition of this fact, the U.S. Fish and Wildlife Service has developed a HGM classification system that is complimentary to the national wetlands classification system (Cowardin, et al. 1979) and describes abiotic and landscape features such as Landscape Position (L), Landform (L), Water Flow Path (W) and Waterbody (W) or LLWW. This classification system is sometimes called 'NWI Plus' because of its relationship to the National Wetlands Inventory, however, for clarity in this report it is referenced as "LLWW."

LLWW is not based on vegetation as indicators, but instead classifies wetlands and water bodies with the area's landscape position and hydrologic characteristics, which are more permanent on the earth's surface. In a similar manner to the Wetlands and Deepwater Habitats Classification (Cowardin, et al. 1979), the LLWW system uses alphanumeric codes to describe wetland characteristics. The LLWW classification makes a distinction between wetlands and water bodies. Wetlands are vegetated, while water bodies are deepwater habitats. The coding syntax can actually take two slightly different forms depending on whether the feature is being classified as a wetland or a water body. Vegetated wetlands, such as marshes, wet meadows, and non-vegetated substrates that are periodically exposed (for example mud flats), are first classified using the wetland Landscape Position and Landform codes identified below. The LLWW code (noted here in italics and underlined) is expressed *Landscape Position, Landform, Water Flow Path, Modifier(s).*

In the LLWW system *Landscape Position* is denoted as an uppercase two letter code, describes whether the wetland is associated with a lake, river, or surrounded by uplands. There are also classifications for marine and coastal areas that do not apply in the case of the Wisconsin HUC12 boundary areas pertaining to this report. Wetlands associated with lakes are defined as *LE* (Lentic). Wetlands associated with flowing water are classified as *LS* (Lotic stream) or *LR* (Lotic River), depending upon their size. Wetlands that are surrounded by upland as part of an isolated basin are classified as *TE* (Terrene). In LLWW, the Landscape Position can be more specifically classified using a hierarchal combination of lowercase letters and numbers similar to the subsystem or subclass in the NWI classification system. The modifying codes are dependent on the Landscape Position code to which they are being applied.

The second portion of the LLWW code is *Landform*. This code is made up of two uppercase letters, which can be classified more specifically with the addition of codes consisting of two lower case letters. Landform refers to the geomorphic structure on or in which the wetland resides. While both coastal and inland Landforms are defined in LLWW, only inland Landforms are present in the study area. Landform codes include *SL* (Slope), *FR* (Fringe), *FP* (Floodplain), *BA* (Basin), and *FL* (Flat). Further classification of each Landform code may occur by adding an additional lowercase two-letter code. For example, a *FR* (Fringe) wetland associated with a *pd* (Pond) would be coded as *FRpd*. Lowercase codes only apply to specific Landform types, and although there is not any repetition in codes between the Landforms, the Dichotomous Keys and Mapping Codes for Wetland Landscape Position, Landform, Water Flow Path, and Waterbody Type Descriptors (Tiner, 2014) should be consulted so that valid codes are accurately applied.

There are also *Water Flow Path* and *Other Modifier* codes within the LLWW schema. Since these are the same for both wetland and water bodies, the Waterbody Type coding schema will be addressed first.

In LLWW, the *Waterbody Type* consists of an uppercase two-letter code. There are six water body types, two coastal and four inland. Four inland waterbody types are present in the study areas of this pilot, including: *LK* (lake), *RV* (River), *PD* (Pond), and *ST* (Stream). Additional codes consisting of a number followed by a lowercase letter may be added to further specify the wetland's characteristics. For example, woodland ponds surrounded by uplands are often common in watersheds and might be classified as *PD1c* (Pond, natural, woodland-dryland). When a wetland feature is classified as a Waterbody Type there is no Landform code applied; the wetland is considered to be its own Landform.

The next component of the code is *Water Flow Path*, which applies to both wetlands and water bodies as defined by LLWW. Water Flow Path refers to how and if the feature is part of the surface hydrology network. Common codes for Water Flow Path include TH (Throughflow), IN (Inflow), and OU (Outflow). Wetlands that are not connected to the surface hydrology network are classified as *VR* (*Vertical Flow).* Most of the Water Flow Path codes are the same for both wetlands and Waterbody Types but there are some small differences. As a result, reference materials need to be consulted to ensure that appropriate codes are consistently applied. It should be emphasized that the LLWW classification can only consider surface hydrology. Subsurface hydrologic connectivity is not considered because these characteristics cannot be assessed through image interpretation. Refer to Appendix B for the primary codes and descriptions of this classification system and for an example diagram.

Finally, the LLWW code includes *Other Modifiers*. These modifier codes consist of two lower case letters. Other Modifiers are used to encode very specific conditions, and more than one modifier may be used. Common examples are *fv* (floating vegetation on the surface) or the *hw* (headwater) modifier. Again, there are some differences in which modifiers can be applied to wetlands versus those applied to Waterbody Types.

LLWW codes can vary in length from 5 characters up to 14 or more characters depending on how many modifiers are applied. Examples of LLWW codes (for both linear and polygon wetland features) classified in the Jemez Mountains study area are provided below.

For additional LLWW information refer to "Dichotomous Keys and Mapping Codes for Wetland Landscape Position, Landform, Water Flow Path, and Waterbody Type Descriptors" (Tiner 2014).

2.2.3.3 LLWW – Summary of Wetland Rules and Standards

1. Wetlands are classified in both the NWI 2.0 and LLWW 3.0 Systems with use of historical WWI as guidance for attribution of NWI class and subclass codes.
2. Deep Water Habitat was classified as L1UBH, L2UBG or H, R2UBF, G or H, and R3UBG or H. These areas were "Non-wetland gaps" in the WWI System and did not exist as polygons in the historic wetland data.
3. WWI "Human Influence" Special Modifiers and their NWI equivalents, found in project area, include the following; Drained "d", Farmed "f", Excavated "x" Impounded or diked "h", have been applied to wetland codes where applicable.
4. The following WWI special modifiers, found within the project area, do not have equivalent codes in the NWI System; Grazed "g", Mats "m", Vegetation recently removed "v", and Muskrat activity "z". WWI special modifiers are not applied on the NWI classification system.
5. The following NWI Special Modifiers, found within the project areas, do not have equivalent codes in the WWI System; Beaver "b", and Impounded "h".
6. Dual attributes were separated by a slash after the subclass code, (e.g. PSS3/FO2B) to distinguish a 51% - 75% dominant broad-leaved evergreen (bog laurel) understory with a 26% - 49% cover of needle-leaved deciduous (tamarack). Dual attributes or "mixed classes" were not mapped under one-quarter of cover. In those cases, only the dominant plant type is

listed as the NWI code or the portion of vegetation that is less dominant is cut out from the larger polygon.

7. Mixed classes in the WWI Systems are separated by a slash (T3/S3K) by dominance, the same method as NWI.
8. The WWI has four Water Regime classifications. The NWI has seven Water Regime classifications. The NWI final product will appear more detailed than the WWI finalized database as high-resolution imagery and multiple LiDAR derived DEM products allow for higher precision polygon boundaries and classification.
9. Polygons that crossed roads in the WWI database have stopped short of the shoulder of the road and pick up on the other side in the NWI database even where culverts were present, unless that polygon is of the Riverine system; flowing streams, creeks, and rivers are delineated across the road.
10. Polygons broken by roads have been designated as fragmented (fg) in the LLWW code.
11. Sewage lagoons and other man-made disposal pits were excluded from the WWI database. These areas will be included in the NWI database as PUBKx and PD3VR in LLWW attribution.
12. No explicit MMU was determined prior to the pilot mapping exercise. The quality of the high resolution imagery coupled with the large number of LiDAR derived DEM products allowed for an average minimum mapping unit is one-eighth of an acre for individually delineated polygons and one-quarter of an acre for polygons inside larger wetland complexes and was used as a loose guideline in order to maintain consistency.
13. Non-wetland lakes surrounded by wetland are classified as "DEEP WATER LAKE"- DWL in the WWI Classification System were attributed as L1UBH or L2UBH in NWI Classification.
14. Non-wetland open water in channels were lumped in as upland in the WWI, but will be classified as rivers or streams in the NWI. Attributes included R2UBF, R2UBG, R2UBH, R3UBF, R3UBG, R3UBH, R4SBC, and R4SBA.
15. The Federal Geographic Data Committee (FGDC) standard for LLWW coding was applied after all polygon boundaries, in a given sub-watershed, were created and NWI attributes entered.
16. Coding is subject to revision pending guidance from WDNR and USFWS.

2.2.4 NWI, WWI, LLWW Attribution Signature Descriptions

To help further illustrate the coding for the Wetlands and Deepwater Habitats Classification, (Cowardin, et al. 1979), the following codes for various wetlands found in the project area are provided as examples:

2.2.4.1 Lakes and Ponds

L1UBH - (Lacustrine, Limnetic, Permanently Flooded)
DWL - (Deep Water Lake)
LK1aVR – (Natural Lake, Vertical Flow)

Signature: Black or very dark blue smooth and uniform texture, (Figure 10).
Collateral: Open water deeper than 7’ on DRG or other ancillary datasets. Cumulative area of the waterbody L1 and L2 must be 20 acres or larger, (Figure 11).

Figure 10. Limnetic (L1) and Littoral (L2) boundaries with sandy beach in Trout Lake, Vilas County - 1:3,000.

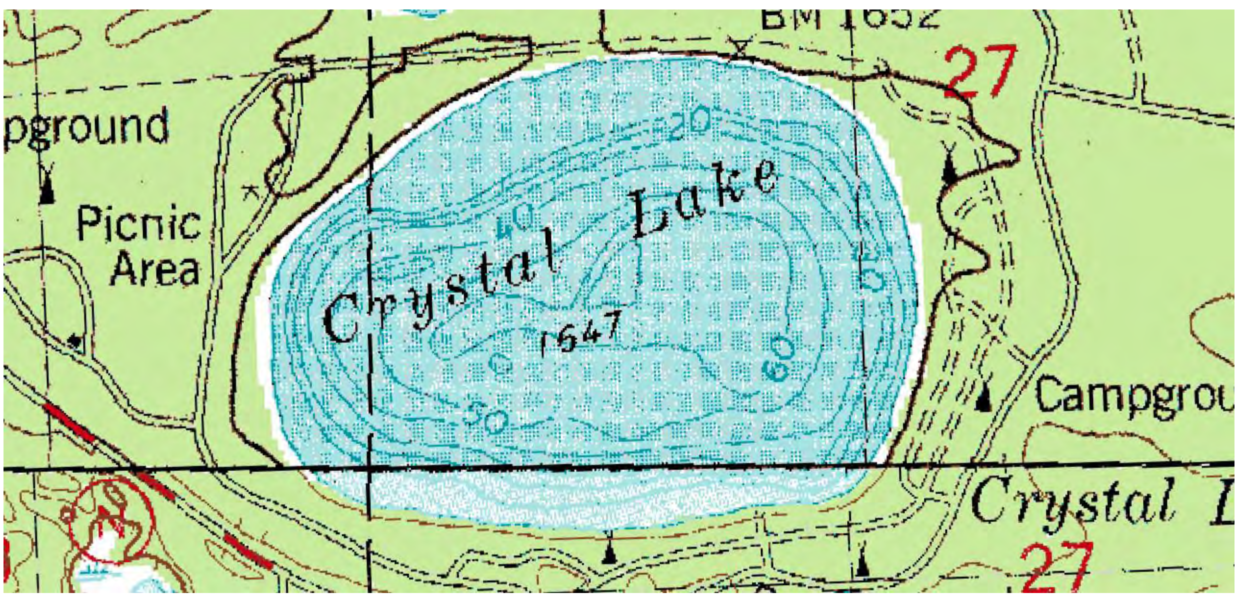

Figure 11. DRG with bathymetry contours in Trout Lake, Vilas County - 1:3,000.

L2UBH - (Lacustrine, Littoral, Permanently Flooded)
W0L - (Water, Subclass unknown, Standing water, Lake)
LK1aVR – (Natural Lake, Vertical Flow)
Signature: Very dark blue to nearly black, smooth and uniform texture, (Figure 10). Often the perimeter of L2 appears lighter in color or paler in tone that the L1 polygon because the bottom is closer to sunlight.
Collateral: These areas will be delineated near locations of seven-foot bathymetry contours or soundings on DRGs and other collateral open water sources from the USGS or WDNR, (Figure 11).

L2USA - (Lacustrine, Littoral, Unconsolidated Shore, Temporarily Flooded)
F2K - (Flats / Vegetated, Sand, Wet Soil)
LE1FLBI – (Lentic, Flat, Vertical Flow)
Signature: White to light beige in color, very smooth and uniform texture, (Figure 10).
Collateral: Occasionally sandy beaches and have a speckled polygon on the DRG.

PUBG - (Palustrine, Unconsolidated Bottom, Intermittently Exposed)
PUBH - (Palustrine, Unconsolidated Bottom, Permanently Flooded)
PD1VR – (Natural Pond, Vertical Flow)
W0H - (Water, Subclass unknown, Standing water, Palustrine)
Signature: Dark color, flat photographic texture, open water signature on both spring or summer imagery regardless of CIR or true-color, (Figure 12).
Collateral: Light blue open water indicator on DRG.

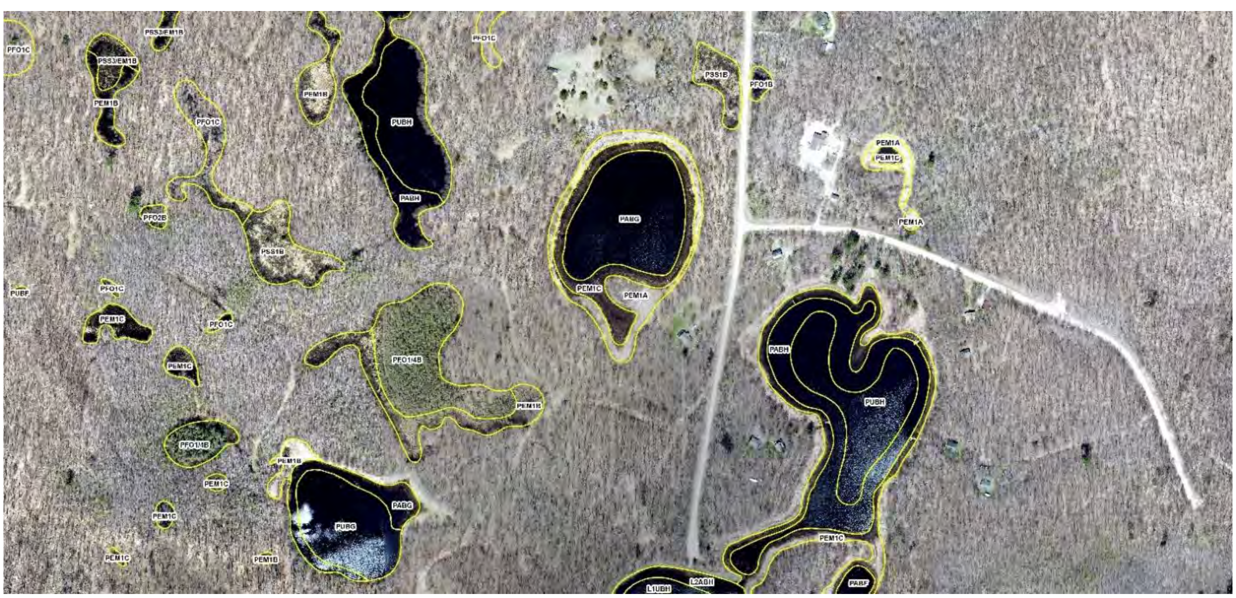

Figure 12. Open water ponds in spring, leaf-off, true-color imagery in Long Lake, Washburn County - 1:3,000.

PABG - (Palustrine, Aquatic Bed, Rooted Vascular, Intermittently Exposed)
PABH - (Palustrine, Aquatic Bed, Rooted Vascular, Permanently Flooded)
A3H - (Water, Rooted floating, Standing water, Palustrine)
PD1VR – (Natural Pond, Vertical Flow)
Signature: Dark color, flat photographic texture, open water signature on both spring imagery regardless of CIR or true-color, (Figure 12).
Collateral: Summer, true-color imagery, such as NAIP, shows a very smooth textured signature, lime to neon green in color, (Figure 13).

Figure 13. Ponds with aquatic bed formation in summer, peak vegetation, true-color NAIP imagery in Long Lake, Washburn County - 1:3,000.

<u>2.2.4.2 Floodplain and Rivers</u>
PFO1A - (Palustrine, Forested, Broad-leaved deciduous, Temporarily Flooded)
T3K - (Forested, Broad-leaved deciduous, Wet soil, Palustrine)
LR1FPflTH – (Lotic River, Floodplain Flat, Throughflow)
Signature: Medium brown to gray signature, dense tree crowns – narrow spikes and hatches, (Figure 14).
Collateral: Adjacent to or at minimum close proximity to a river and commonly found associated with alluvial soils but not with collateral marsh symbols.

Figure 14. Temporarily flooded forested floodplain in Wester Creek, Vernon County - 1:3,000.

PFO1E - (Palustrine, Forested, Broad-leaved deciduous, Seasonally Flooded / Saturated)
T3K - (Forested, Broad-leaved deciduous, Wet soil, Palustrine)
LR1FPbaTH – (Lotic River, Floodplain Basin, Throughflow)
Signature: Medium brown to gray signature, rough but uniform in texture; dense tree crowns, (Figure 15).
Collateral: Commonly found not associated with marsh symbols on DRG and adjacent to or at minimum close proximity to a river.

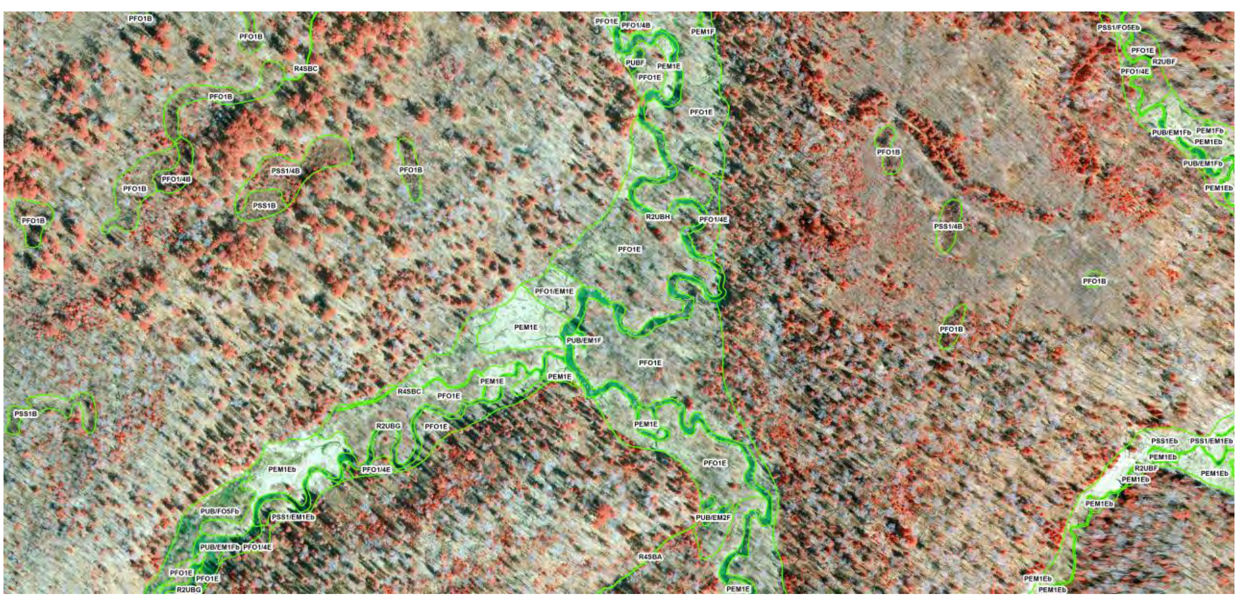

Figure 15. Seasonally flooded/saturated forested floodplain in Meadow Creek, Ashland County - 1:2,000.

R2UBHx - (Riverine, Lower Perennial, Unconsolidated Bottom, Permanently Flooded, Excavated)
No mapping of lower perennial rivers in WWI.
RV1TH – (Perennial River, Throughflow)
Signature: Black to dark blue color, flat and uniform texture; most often narrow and long in shape, (Figure 16).
Collateral: Double lined, medium blue polygon on DRG. Very clear channel indicated on LiDAR products. Unless excavated, perennial rivers tend to deposit sand bars and meander.

Figure 16. Excavated perennial river with floodplain in Mud Lake, Dane County - 1:3,000.

R4SBA - (Riverine, Intermittent, Stream Bed, Temporarily Flooded)
No mapping of intermittent streams in WWI.
ST4TI – (Intermittent Stream, Throughflow Intermittent)
Signature: Narrow, dark gray to brown color with rough texture forming a connected network. Often covered by tree canopy and rarely seen containing water, (Figure 17).
Collateral: DEM products such as the HPI help guide an interpreter when the signature is below the forest canopy, (Figure 18).

R4SBCx - (Riverine, Intermittent, Stream Bed, Seasonally Flooded, Excavated)
No mapping of intermittent streams in WWI.
ST4TIch – (Intermittent Stream, Throughflow Intermittent, Channelized)
Image signature: Narrow and straight, dark gray to brown color with rough texture forming a connected network. Often covered by tree canopy and rarely seen containing water, (Figure 17).
Collateral: DEM products such as the HPI help guide an interpreter when the signature is below the forest canopy, (Figure 18).

Figure 17. Intermittently flowing streams in Wester Creek, Vernon County - 1:3,000.

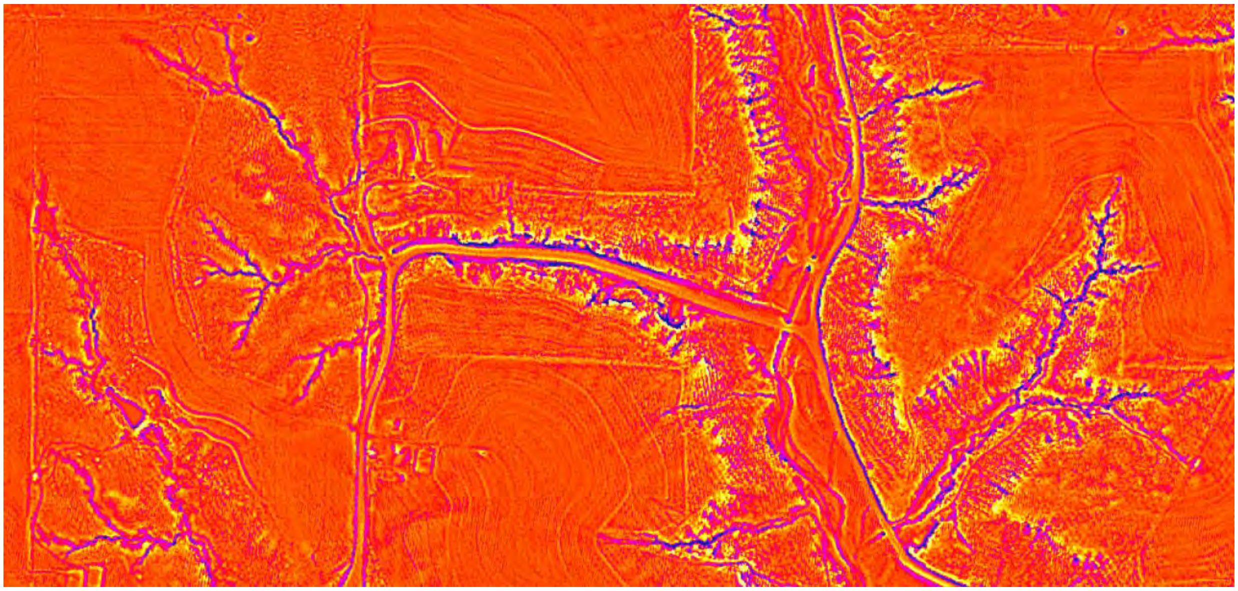

Figure 18. Bright pink and blue indicate narrow streams on HPI below tree canopy in Wester Creek, Vernon County - 1:3,000.

<u>2.2.4.3 Terrene Basins</u>

PEM1A - (Palustrine, Emergent, Persistent, Temporarily Flooded)

E2K - (Emergent, Narrow-leaved persistent, Wet soil, Palustrine)

TEFLVR – (Lotic River, Floodplain Flat, Throughflow)

Signature: White to very light gray, generally a smooth uniform texture in flat-open areas. Frequently associated with very poorly drained soils, (Figure 19).

Figure 19. PEM1A basin in Mud Lake, Dane County - 1:5,000.

PEM1C - (Palustrine, Emergent, Persistent, Seasonally Flooded)
E2K - (Emergent, Narrow-leaved persistent, Wet soil, Palustrine)
TEFLVR – (Terrene, Basin, Vertical Flow)
Signature: Whitish to varying shades of gray, somewhat smooth and mostly uniform texture in depressions and in wetland drainage patterns. Frequently associated with marsh symbols and very poorly drained soils, (Figure 20).

PEM1F - (Palustrine, Emergent, Persistent, Semi-permanently Flooded)
E2H - (Emergent, Narrow-leaved persistent, Standing water, Palustrine)
TEFLVR – (Terrene, Basin, Vertical Flow)
Signature: Light gray to dark gray color often speckled with dark black open water. Texture is often very rough and not uniform, (Figure 20).

Figure 20. PEM1C and PEM1F basins in Mud Lake, Dane County - 1:5,000.

<u>2.2.4.4 Saturated Wetlands</u>

PEM1B - (Palustrine, Emergent, Persistent, Seasonally Saturated)
E2K - (Emergent, Narrow-leaved persistent, Wet soil, Palustrine)
TESLOI – (Terrene, Sloped, Intermittent Outflow)
Signature: Whitish to varying shades of gray, somewhat smooth but uniform texture sometimes crackled appearance, (Figure 21).
Collateral: Found in flat-open areas with moderate to high slope. Frequently associated with very poorly drained soils. Several DEM products such as a hillshade with five-foot contours (Figure 22), and WEVM (Figure 23), were view to interpret the level of slope and intermittent outflow.

Figure 21. Seasonally saturated sloped wetlands on spring, leaf-off, true-color imagery in Mud Creek, Monroe County - 1:3,000.

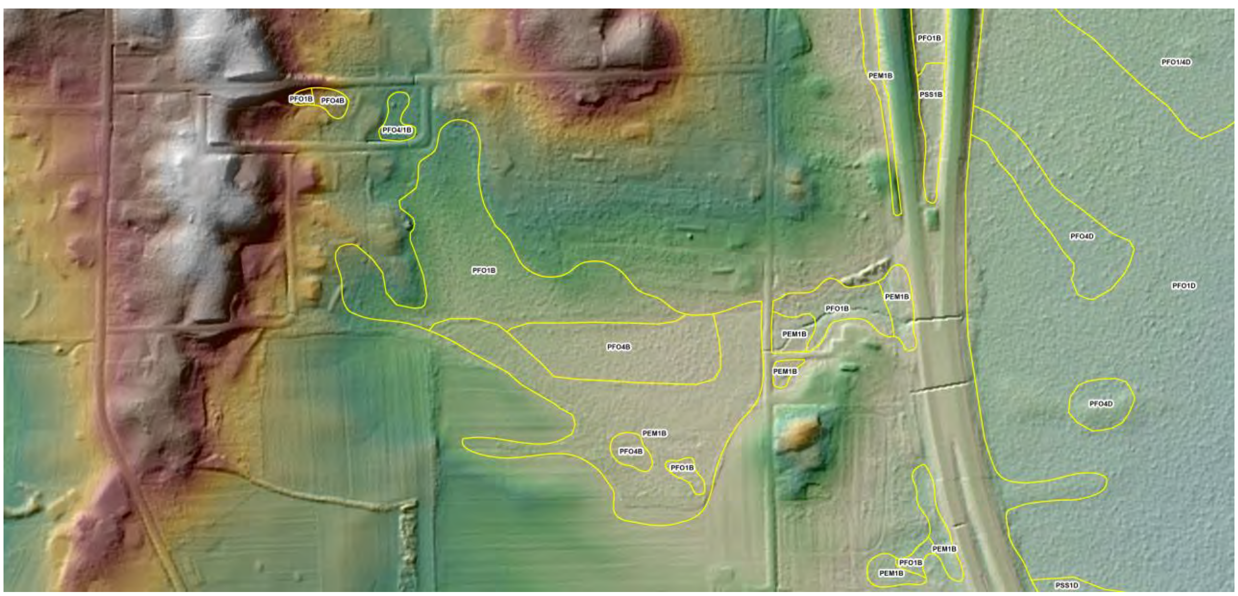

Figure 22. Seasonally saturated sloped wetlands on the WEVM data (i.e., a semi-transparent elevation color ramp over a black and white percent slope raster) in Mud Creek, Monroe County - 1:3,000.

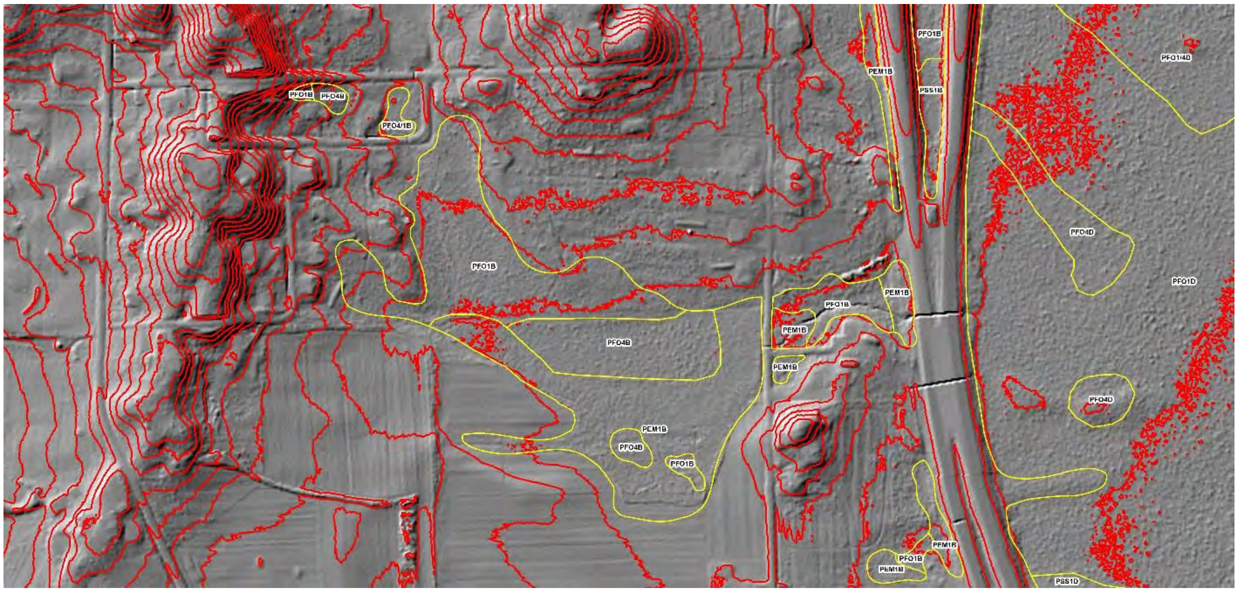

Figure 23. Seasonally saturated sloped wetlands on exaggerated hillshade and five-foot contours in Mud Creek, Monroe County - 1:3,000.

PFO1B - (Palustrine, Forested, Broad-leaved deciduous, Seasonally Saturated)
T3K - (Forested, Broad-leaved deciduous, Wet soil, Palustrine)
TESLOI – (Terrene, Sloped, Intermittent Outflow)
Signature: Dark grey signature, dense tree crowns, commonly found not associated with collateral marsh symbols or very poorly drained soils, (Figure 21).
Collateral: Found in flat-open areas with moderate to high slope. Frequently associated with very poorly drained soils. Several DEM products such as a hillshade with five-foot contours (Figure 22), and WEVM (i.e., a semi-transparent elevation color ramp over a black and white percent slope raster) (Figure 23), were view to interpret the level of slope and intermittent outflow.

PFO4B - (Palustrine, Forested, Needle-leaved evergreen, Seasonally Saturated)
T5K - (Forested, Needle-leaved evergreen, Wet soil, Palustrine)
TESLOI – (Terrene, Sloped, Intermittent Outflow)
Signature: Commonly black spruce and can be Northern white cedar or Eastern hemlock. Dark rough texture signatures in wetland drainage patterns with swamp symbols and/or very poorly drained soils, (Figure 21).
Collateral: Found in flat-open areas with moderate to high slope. Frequently associated with very poorly drained soils. Several DEM products such as a hillshade with five-foot contours (Figure 22), and WEVM data (i.e., a semi-transparent elevation color ramp over a black and white percent slope raster) (Figure 23), were view to interpret the level of slope and intermittent outflow.

PFO2D - (Palustrine, Forested, Needle-leaved deciduous, Continuously Saturated)
T2K - (Forested, Needle-leaved deciduous, Wet soil, Palustrine)
TEFLOI – (Terrene, Flat, Outflow Intermittent)

Signature: Tamarack trees, associated with dark grey puffy bulbs with light red shading appearing on edges, (Figure 24)
Collateral: Located in wetland drainage patterns frequently with swamp symbols and very poorly drained soils, with T2K found in WWI, (Figure 24).

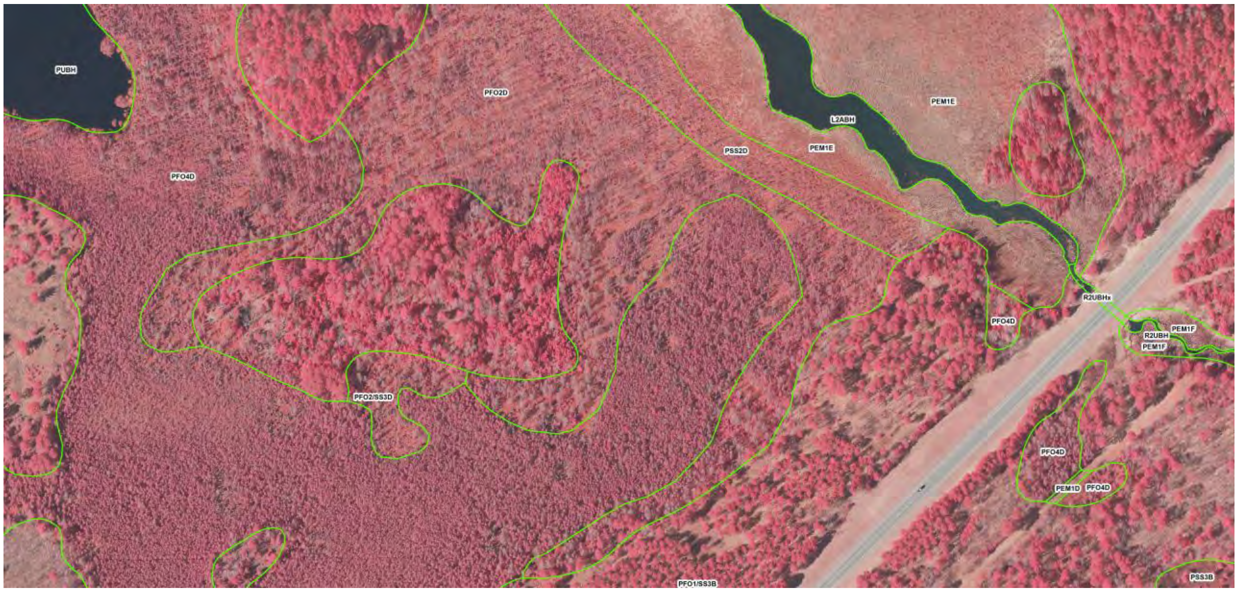

Figure 24. Continuously saturated bog with needle-leaved NWI polygons in Trout Lake, Vilas County - 1:3,000.

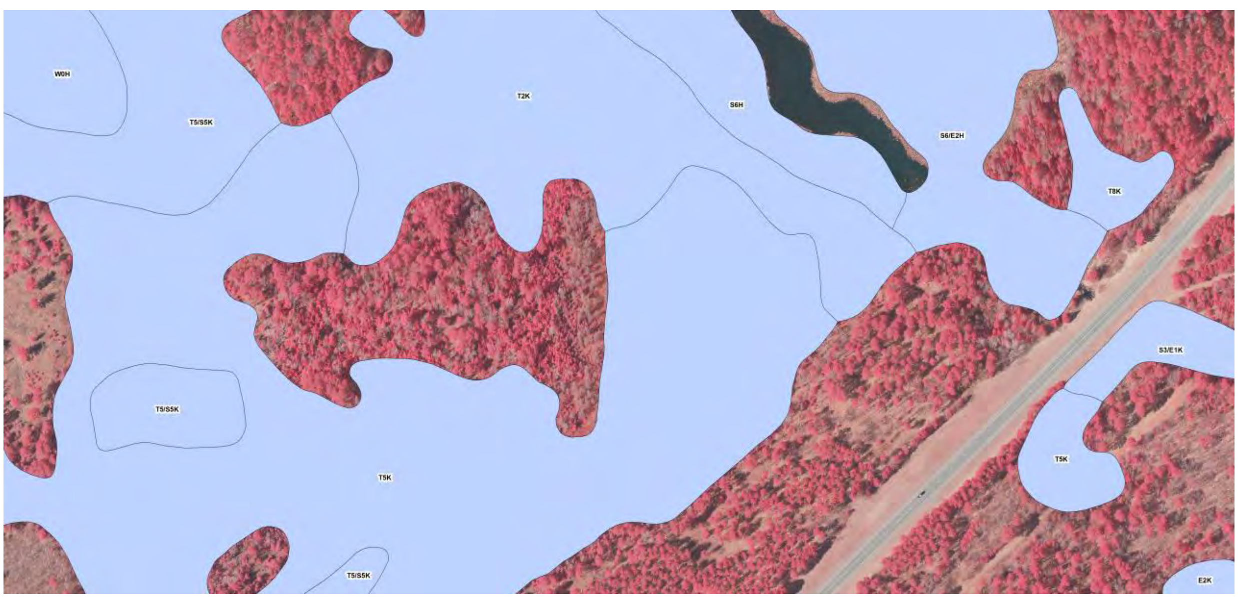

Figure 25. Continuously saturated bog with needle-leaved WWI polygons in Trout Lake, Vilas County - 1:3,000.

PFO4D - (Palustrine, Forested, Needle-leaved evergreen, Continuously Saturated)
T5K - (Forested, Needle-leaved evergreen, Wet soil, Palustrine)

TEFLOI – (Terrene, Flat, Outflow Intermittent)
Signature: Usually black spruce, dark red bulbs or puffy cloud-like texture of forested signatures, (Figure 24).
Collateral: Located in wetland drainage patterns frequently with swamp symbols and very poorly drained soils, usually mapped as T5K in WWI, (Figure 25).

PSS3D - (Palustrine, Scrub/Shrub, Broad-leaved evergreen, Continuously Saturated)
S6K - (Shrub, Broad-leaved evergreen, Wet soil, Palustrine)
TEFLOI – (Terrene, Flat, Outflow Intermittent)
Signature: Species include bog laurel and leatherleaf which has a distinct salmon pink color and very smooth and uniform texture, (Figure 23).

Figure 26. Broad-leaved evergreen, continuously saturated bog in Trout Lake, Vilas County - 1:3,000.

<u>2.2.4.5 Special Modifiers</u>
PEM1Af - (Palustrine, Emergent, Persistent, Temporarily Flooded, Farmed)
E2Kf - (Emergent, Narrow-leaved persistent, Wet soil, Palustrine, Farmed)
TEFLOIdrhi – (Lotic River, Floodplain Flat, Throughflow)
Signature: Whitish or light gray somewhat smooth texture with plow lines running through, associated with crop production. Found in flat-open areas often with drain tile or drainage ditching, (Figure 27).

Pf - (Palustrine, Farmed)
No mapping of farmed wetlands with vegetation fully removed in WWI.
TEFLOIdrhi – (Lotic River, Floodplain Flat, Throughflow)
Signature: Black to dark gray in color, with smooth uniform texture. Sometimes plow lines were seen running through, other occurrences had standing water or mucky soil at the surface, (Figure 27).

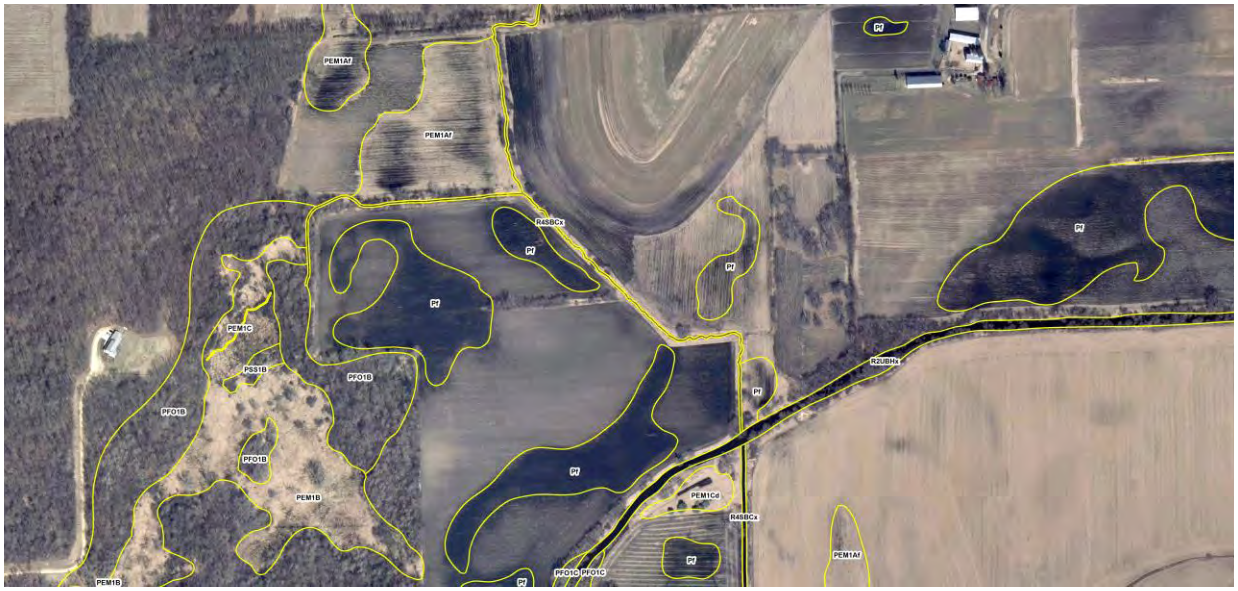

Figure 27. Farmed wetlands in Mud Lake, Dane County - 1:3,000.

PSS3Kx - (Palustrine, Scrub/Shrub, Broad-leaved evergreen, Artificially Flooded, Excavated)
S6Kc - (Shrub, Broad-leaved evergreen, Wet soil, Palustrine Constructed Cranberry Bog)
TEBAVTAcr – (Terrene, Basin, Vertical Flow / Artificial Throughflow, Constructed Cranberry Bog) (Figure 28).
Signature: The spring imagery revealed polygonal, open water – black or very dark gray color and a smooth and uniform texture because the bog was flooded the previous fall, (Figure 29).
Collateral: The late summer true-color NAIP photography indicates a light green and smooth uniform texture with vegetation and polygonal in shape, (Figure 30).


Figure 28. Vertical flow complex with artificial throughflow applied to all cranberry bogs and excavated water sources in Mud Creek, Monroe County - 1:5,000.

Figure 29. Artificially flooded cranberry bogs in spring in Mud Creek, Monroe County - 1:3,000.

Figure 30. Artificially flooded cranberry bogs in summer in Mud Creek, Monroe County - 1:3,000.

PEM1Eb - (Palustrine, Emergent, Persistent, Seasonally Flooded / Saturated, Beaver)
E2K - (Emergent, Narrow-leaved persistent, Wet soil, Palustrine)
LS4BATI – (Lotic Stream Intermittent, Basin, Throughflow Intermittent)
Signature: Whitish to varying shades of gray, smooth and uniform texture in depressions and in wetland drainage patterns. Often found in adjacent to dammed beaver ponds (PUBFb or PUBGb) and streams (R2UBG or R4SBC), (Figure 31).
Collateral: Frequently associated with marsh symbols and very poorly drained soils.

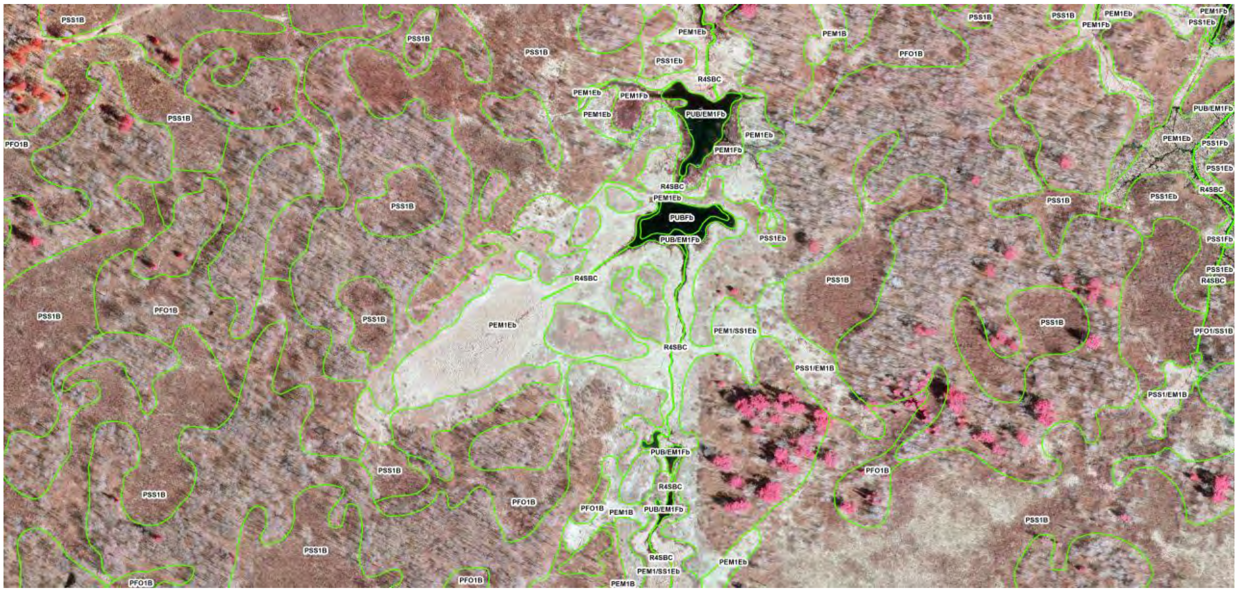

Figure 31. Beaver meadow and flooded beaver ponds in Meadow Creek, Ashland County - 1:3,000.

PUBFh - (Palustrine, Unconsolidated Bottom, Semi-Permanently Flooded, Impounded)
W0H - (Water, Subclass unknown, Standing water, Palustrine)
PD2a1TI – (Pond, Agriculture Cropland, Throughflow Intermittent)
Signature: Black to dark color, flat photographic texture, open water signature. Flat side facing downhill and often found with inlet stream or polygon and/or stream exiting, (Figure 32).
Collateral: Open water on DRG.

Figure 32. Impounded open water ponds in Wester Creek, Vernon County - 1:3,000.

2.2.4.6 Upland

U - Upland

Signature: Upland varies greatly across the landscape of Wisconsin. Below were a small sample of upland indicators that were found in this mapping pilot.

Upland deciduous forest - Signature is made up of brown and grey slashes and cross-hatches with a light understory in leaf-off, spring CIR imagery. The texture is semi-rough but uniform, (Figure 33).

Figure 33. Upland deciduous forest in Wester Creek, Vernon County - 1:3,000.

Upland evergreen forest - Signature is made up of dark red to magenta bulbs with an understory that does not shine through in leaf-off, spring CIR imagery. The texture is very rough but uniform, (Figure 34).

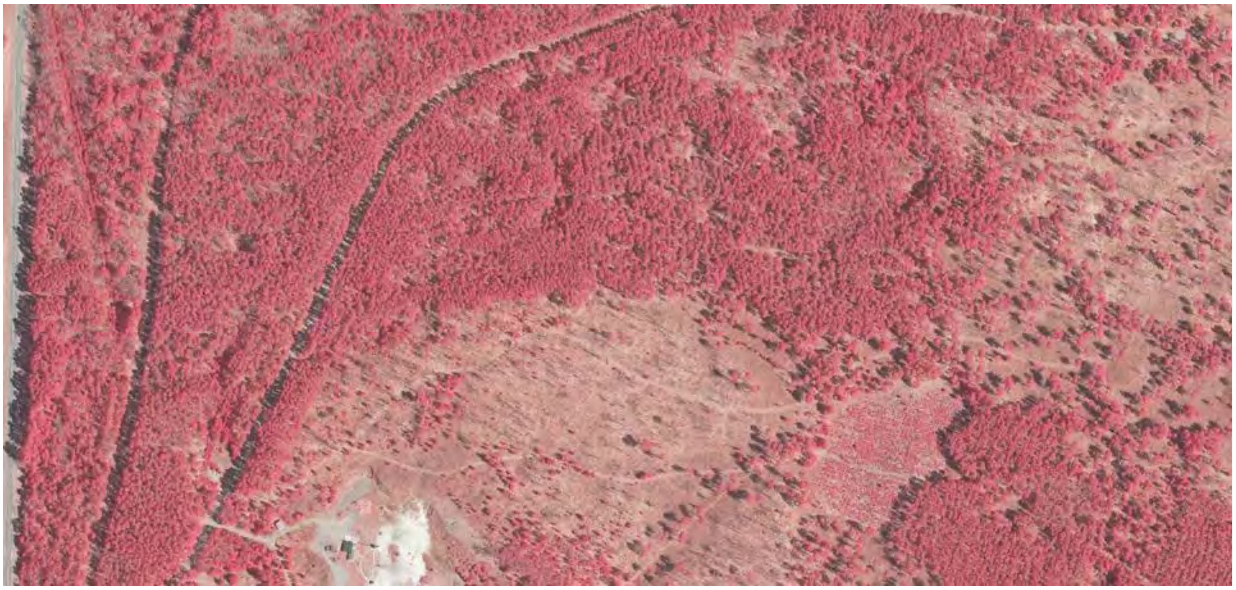

Figure 34. Upland evergreen forest in Trout Lake, Vilas County - 1:3,000.

Highly sloped uplands – Portions of land that are most often natural forests, pasture and rangeland, or open fields were corroborated as upland through the use of LiDAR derived DEM products, such as dark black or bright white of the hillshade DEM or contours packed tightly together, (Figure 35).

Figure 35. Highly sloped upland in Wester Creek, Vernon County - 1:3,000.

Upland agriculture - Signature in leaf-off, spring, true-color imagery varies based on the timing of the crops. If the vegetation was not growing and the bare earth is exposed from fresh tilling or after harvesting, the colors will be grey, brown or almost black from fresh ground breaking, (Figure 36). When crops are growing and not yet harvested in this imagery or leaf-on, summer true-color imagery, the color will be a pale green in the early growing season and bright or dark green at the end of the growing season. In CIR, the greens would have been red. Regardless of the type of imagery and presence of crops, there were visible plow lines and clear rows where the vegetation grows and combines and harvesting trucks drive between. The texture is most always very uniform and smooth.

Upland development – The presence of human constructed buildings, utilities, transportation routes, and industry indicated no natural wetlands present, (Figure 36). Concrete roads and highways appear white to light grey, smooth, straight-line and uniform. Asphalt parking lots are also smooth and uniform in texture but are dark grey to black in color. Yards and houses of rural residences or suburban subdivision are geometric with straight segments separating them and turf grass will green up earlier than natural vegetation or cropland.

Figure 36. Upland development and agriculture in Mud Lake, Dane County - 1:3,000.

2.2.5 Utilizing Additional Collateral Datasets

2.2.5.1 LiDAR DEM Products

The two primary DEM (LiDAR derived) products used as collateral data for this mapping initiative were the hillshade and the WEVM symbology. The hillshade was created with sun angle Azimuth of Northwest, 270 degrees and a vertical exaggeration of four. When displayed in an ArcMap session, high slope areas facing toward the sun (northwest) appear white to very light gray and high slopes that are shadowed by hill or cliff top appear black to very dark gray, (Figure 37). The medium gray tones in-between all have high potential for the presence of a wetland. Very smooth textured polygon shapes indicate the presence of open water. Natural vegetation (uniform rough texture) was differentiated from cropland (uniform but smooth textured lines). The hillshade DEM was not to be delineated directly from; although both the LiDAR data and the base imagery were collected coincidentally, there were noticeable inconsistencies with the two datasets “matching up” in positional appearance. The base imagery was always consulted before delineating wetland boundaries. The primary imagery was spring, leaf-off, CIR or true-color and was high resolution, twelve inch pixels or smaller. The base imagery was always used as the primary data interpretation source, and the presence of water, hydrophyte, or substrate class was required for the delineation of a wetland polygon.

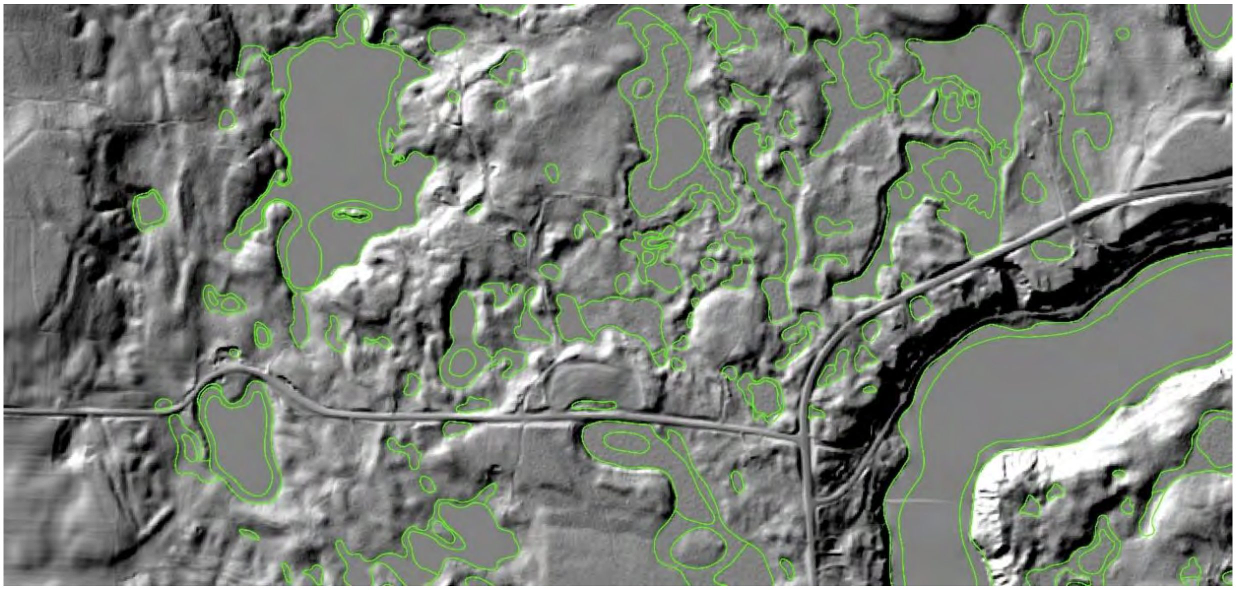

Figure 37. Hillshade DEM in Long Lake, Washburn County - 1:10,000.

The color ramped elevation model display was a combination of the traditional DEM with a stretch set to “histogram equalize” and a transparency over a percent slope raster, (Figure 38). The display was set to adjust on-the-fly as interpreter moved across this landscape. This allowed for the elevation display to continually set the palest green as the lowest point, moving into green, yellow, orange, red, and white always set at the highest points. If this setting was not used the highest point of the raster would always be white and lowest as pale green, and may skew the editor’s interpretation of the landscape. This meant that in an area where there was less variance in elevation or slope, the display of color was closely the same shade and it made great difficulty in pulling out basins, floodplains, and other depressions from the surrounding upland. As with the hillshade DEM, the histogram equalize display was not to be delineated on directly, and the base imagery was always used as the primary dataset for interpretation and delineation.

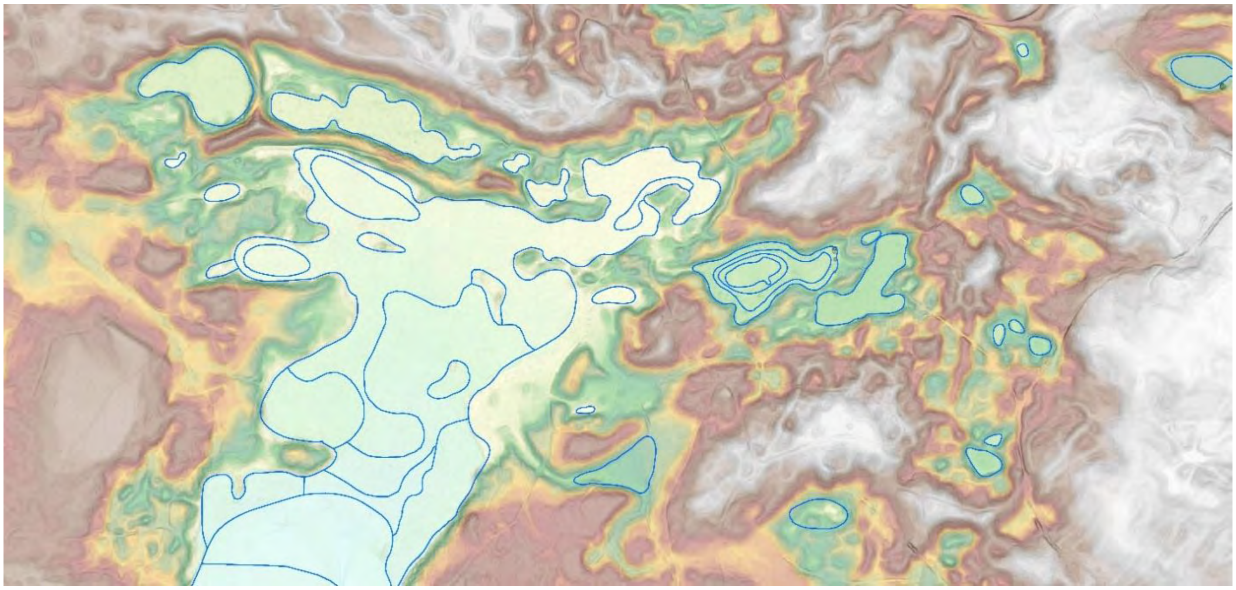

Figure 38. Color-ramped DEM in Trout Lake, Vilas County at 1:10,000.

2.2.5.2 Leaf-on, True-color, Summer NAIP Aerial Imagery

In addition to the spring, leaf-off CIR, multiple years of true-color NAIP imagery were available online through download from the NRCS NAIP download site. 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 did 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. NAIP imagery was taken later in the year (September), aquatic bed wetlands appeared in the imagery and thus were easily differentiated from open water. Multiple years of NAIP imagery were available from NRCS; 2015 and 2013, the most recent years of summer imagery, were also used to confirm the presence of a wetland, check for accurate delineation of a wetland to upland boundaries, and verify the class of vegetation interpreted.

2.2.5.3 Historic WWI Data

Wetland data from the historic WWI dataset range in years from 2006 to 2013 for the six, sub-watersheds completed by GSS. The data was originally interpreted on air photo imagery with stereoscopes and drawn on Mylar sheets with radio pens, (Figure 39). Polygons were drawn in red with green labels while points were depicted by blue symbols. The point symbols indicated the following four types of small wetlands: square – excavated pond, triangle – impounded pond, marsh symbol – wetland less than two acres, and letter S – natural spring. Note that NWI does not contain wetland points, however, the points from WWI data were used to indicate areas where small NWI polygons could be delineated. The hard copy images with illustrated points and polygons were scanned and orthorectified. The wetland boundaries, points, and attributes were converted from hard copy drawings to raster and finally vector data. The converted raster polygons were cleaned and built in ArcScan to produce vector polygons. Finally the points and polygons were attributed, further revised, and reviewed using ArcMap.

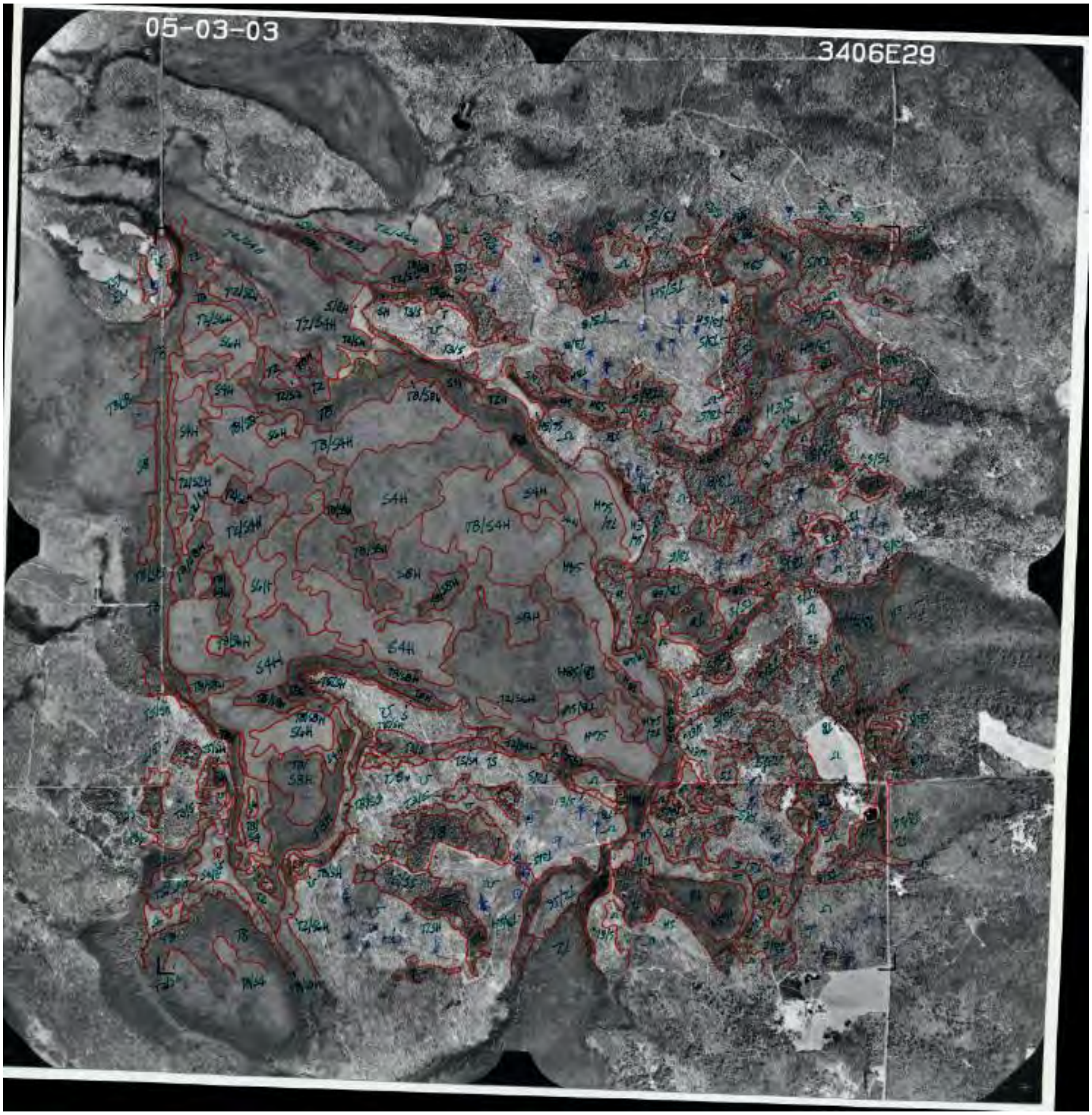

Figure 39. WWI polygons and attributes drawn on Mylar Overlay on black and white infrared imagery.

The WWI polygons provided valuable information for the vegetative types of wetlands in those six sub-watersheds. Vegetation class and subclass was directly correlated from WWI to NWI, however there was not a connection between palustrine water regimes between the two classification systems. The S4/E2K circle, equates to PSS3/EM1 and a water regime of B, D, or E, (Figure 40). The EM2 seemed to have been taken over by more PSS3 and PFO4, (Figure 41). However, both S4 and PSS3 indicate a broad-leaf evergreen shrub bog such as leatherleaf or bog laurel. The T8K in the Southeast indicates a catch-all attribute in the WWI meaning “needle-leaf”, (Figure 40). This may indicate that the original interpreter was unsure if the vegetation was deciduous or evergreen needle-leaves. In this case, it was probably an indication of a mixture of tamarack and black spruce, PFO2/4D, (Figure 41).

The level of correlation between WWI and NWI in this pilot hinged on the amount and magnitude of human influenced modifications to the landscape and how accurately the historic WWI was mapped.

Figure 40. Continuously saturated bog with evergreen WWI polygons in Trout Lake, Vilas County - 1:3,000.

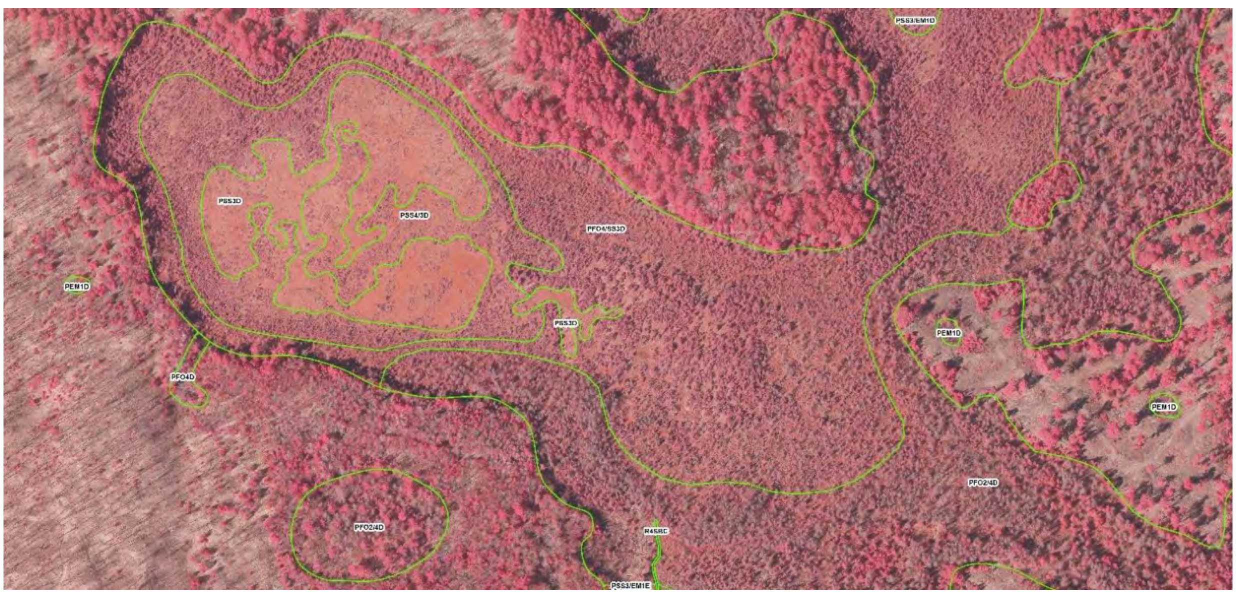

Figure 41. Continuously saturated bog with evergreen NWI polygons in Trout Lake, Vilas County - 1:3,000.

<u>2.2.5.4 U.S. Geological Survey (USGS) Topographic Maps (Digital Raster Graphic [DRG])</u>

The USGS 1:24,000 scale topographic map series, also known as a DRG, are used to verify the presence of hydrologic indicators through wetland symbology (i.e., brown contours with hash marks indicating basins of temporarily or seasonally flooded vegetated wetlands, marsh symbols for the possible presence of temporarily, seasonally, or semi-permanent flooded vegetated wetlands, dashed blue lines for intermittent streams, and double-lined blue for perennial rivers). DRGs have bathymetry lines and soundings on lakes to determine limnetic (L1) and littoral (L2) boundaries at the seven-foot mark. They are also 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 interpretation, landscape-scale terrain analysis. For this pilot project, two-foot and ten-foot contours derived from LiDAR were the primary source for elevation analysis, while the DRGs were secondary.

2.2.5.5 Soil Survey Geographic Database

Poorly drained and very poorly drained soils from SSURGO were selected and exported from the soil dataset. They were symbolized with a solid polygon color. This layer was used to indicate generalized wetland to upland separations in a sub-watershed and possible outer boundaries of wetland complexes, (Figure 42).

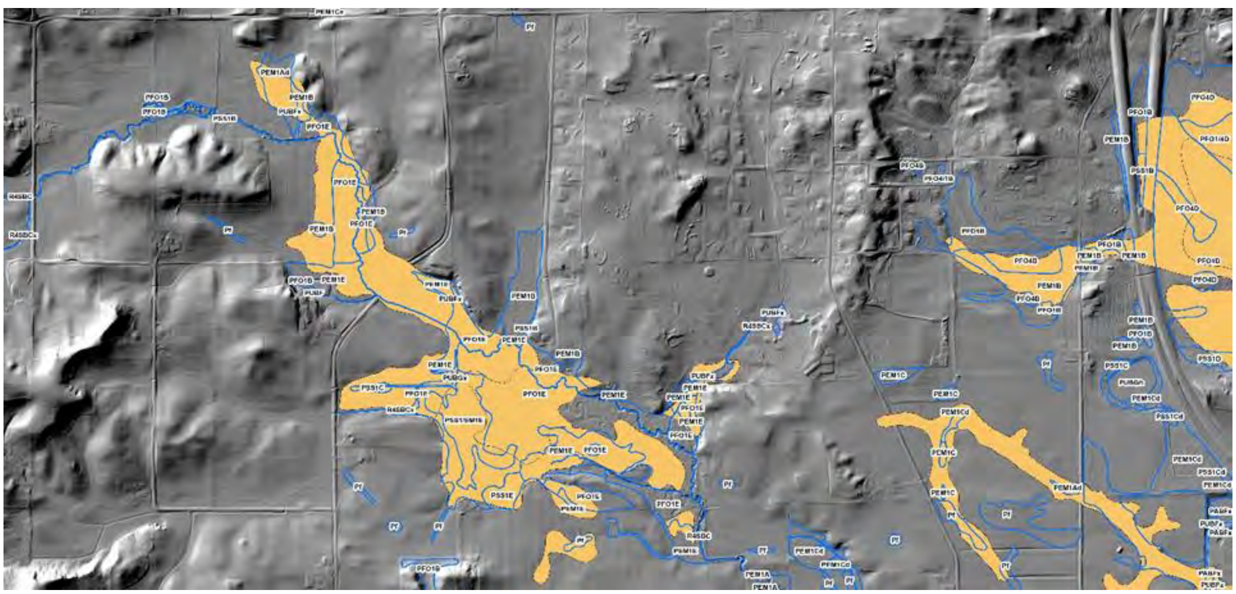

Figure 42. Poorly drained and very poorly drained soils with NWI polygons overlaid on hillshade DEM in Mud Creek, Monroe County - 1:3,000.

2.3. Identifying Surface Water Features from the Wetland Mapping

Surface water features for the purposes of this project are waterbodies and riverine systems. They are the “deepwater” habitats in the Cowardin classification. Waterbodies are classified as lacustrine (L) and streams and rivers as classified as riverine (R). The LLWW classification system for wetlands also provides codes for these deepwater habitats. In LLWW, the *Landform* code of LE (lentic) or a *Waterbody* code of LK (lake) or PD (pond) are applied to waterbodies. Wetlands that represent streams and rivers have either a *Landform* code of LR (lotic river) or LS (lotic stream) or a *Waterbody* code of ST (stream) or RV (river).

2.3.1. Creating a Lakes/Ponds Feature Class

The following process describes how the combination of the Cowardin and LLWW codes can be used to extract a polygon layer representing lakes and ponds from the wetland mapping.

Step 1: Query out all wetland polygons that represent pond and lake habitat. For the most accurate results, the queries should be done using a combination of the NWI Cowardin classification and the Tiner LLWW classification. The NWI query (ATTRIBUTE LIKE '%L%UB%' or ATTRIBUTE LIKE '%P%UB%') identifies all potential surface water bodies and the LLWW portion of the query ensures that the selection only returns actual surface water features. The same results could be returned by using only the LLWW query

- Select Where
  - (LLWW LIKE '%LK%' Or LLWW LIKE '%PD%' Or LLWW LIKE '%LE%') AND (ATTRIBUTE LIKE '%L%UB%' or ATTRIBUTE LIKE '%P%UB%')

Step 2: Export selection to new feature class in "Scratch" workspace

- Output Feature Class: Lakes_Ponds_SELECT

Step 3: Run the DISSOLVE tool

- Tool parameter settings
  - Input Feature Class: Lakes_Ponds_SELECT
  - Output Workspace: Scratch
  - Output Feature Class: Lakes_Ponds_Dissolve

Step 4: Run the MULIPART TO SINGLE PART tool

- Tool parameter settings
  - Input Feature Class: Lakes_Ponds_Dissolve
  - Output Workspace: Surface_Water Feature Datasaet
  - Output Feature Class: Lakes_Ponds

2.3.2. Creating a 24K Compatible Stream Feature Class

In surface water mapping, such as that conducted to produce the NHD 24K flowlines dataset, streams are mapped as a single-line (centerline) streams or double-line (edge of banks) streams. Centerlines are traditionally mapped as polylines, while the double-line streams are mapped as polygons, based on a stream width threshold that determines where centerlines give way to double-lines. Network connectivity in the streams data model is maintained by artificial path centerlines through double-line streams.

2.3.2.1. Extracting a Stream Centerline Feature Class

As detailed earlier, the Cowardin and LLWW wetland classifications provide a means to identify deepwater habitats in the wetland mapping. The following documentation outlines the process for delineating 24K compatible flowline dataset from the wetland mapping using existing GIS hydro-analysis tools. For the purposes of this assessment, compatibility will be defined as meeting the same standards as defined for the current 24K stream GIS layer maintained by the WDNR.

The process for deriving stream centerlines from the wetland mapping can be completed in either ArcGIS Desktop or ArcGIS Pro. With the exception of **Step 5**, the process is the same regardless of which ArcGIS product is being used. Instructions for **Step 5** are provided for both ArcGIS Desktop and ArcGIS Pro.

Step 1: Query out all wetland polygons that represent rivers and stream habitat. Queries can be done using either the NWI Cowardin classification or the Tiner LLWW classification. Select river and stream polygons from NWI mapping using the LLWW or NWI codes

- Select Where
  - (LLWW LIKE '%LR%' Or LLWW LIKE '%LS%' Or LLWW LIKE '%ST%' Or LLWW LIKE '%RV%') AND (ATTRIBUTE LIKE '%R%')

Step 2: Check the output of the selection and add/subtract additional wetland polygons as necessary to ensure the entire wetted channel is included for each stream/river segment.

Step 3: Export selection to new feature class in "Scratch" workspace

- Output Feature Class: Streams_Rivers_SELECT

Step 4: Run the DISSOLVE tool

- Tool parameter settings
  - Input Feature Class: Streams_Rivers_SELECT
  - Output Workspace: Scratch
  - Output Feature Class: Streams_Rivers_Dissolve

Step 5: Create initial stream polyline feature class

If using ArcGIS Desktop

- Run the FEATURE TO LINE tool
  - Tool parameter settings
    - Input Features: Streams_Rivers_Dissolve
    - Output Workspace: Scratch
    - Output Feature Class: Streams_Rivers_Dissolve_Line
- Prep for editing lines for conversion to centerlines
  - Start editing session and select all lines, merge, then explode

- Clip the ends of each polyline as shown in Figure 43.

Figure 43. Basic process for “clipping” the ends of wetland polygons. Select the feature (Left image), Use the SPLIT LINE tool to clip the end segments (Middle image), then select and delete the unwanted end portion. The result of the edit should resemble the image on the right.

- Run the COLLAPSE DUAL LINES TO SINGLE LINE tool
    - Tool parameter settings (Figure 44)
        - Input Feature: Edited Streams_Rivers_Dissolve_Line
        - Output Workspace: Scratch
        - Output Feature: Centerline
        - Maximum Width: 100 m
    - In some cases, the polylines need to be adjusted to ensure the accurate positioning of stream centerlines. Figure 43 shows typical situations where the streamlines need to be reshaped.
    - Repeat process as necessary to generate the most accurate centerline. In cases where one of the double polylines does not have an end vertex at a position parallel and perpendicular to its paired line, the resultant centerline will need to be manually edited. In most instances, this happens when the centerline connects to a wetland polygon representing a lake or a pond.

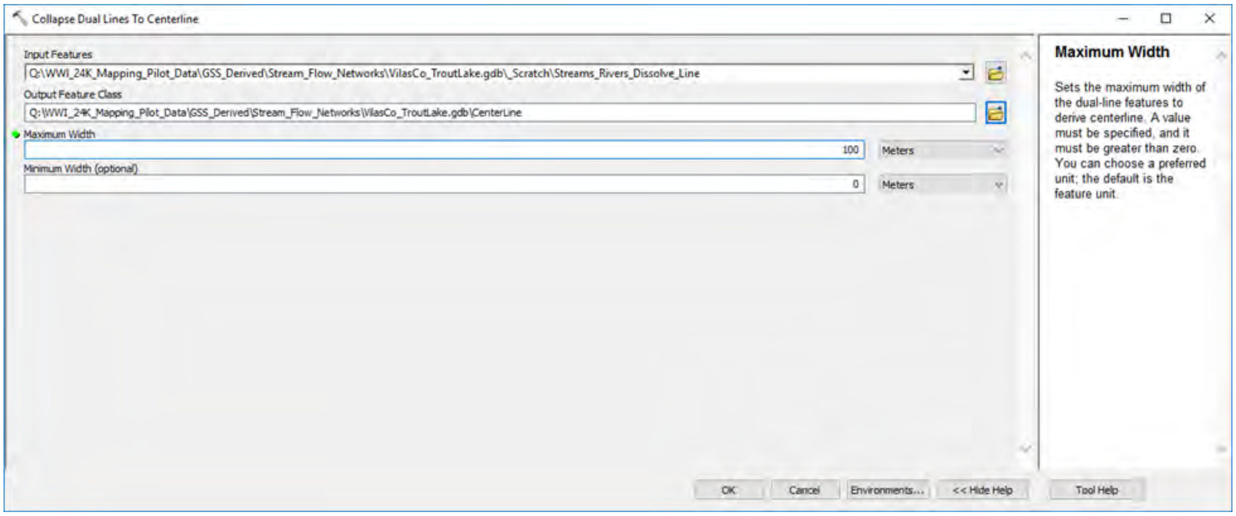

Figure 44. The user interface of the Collapse Dual Lines to Single Line tool

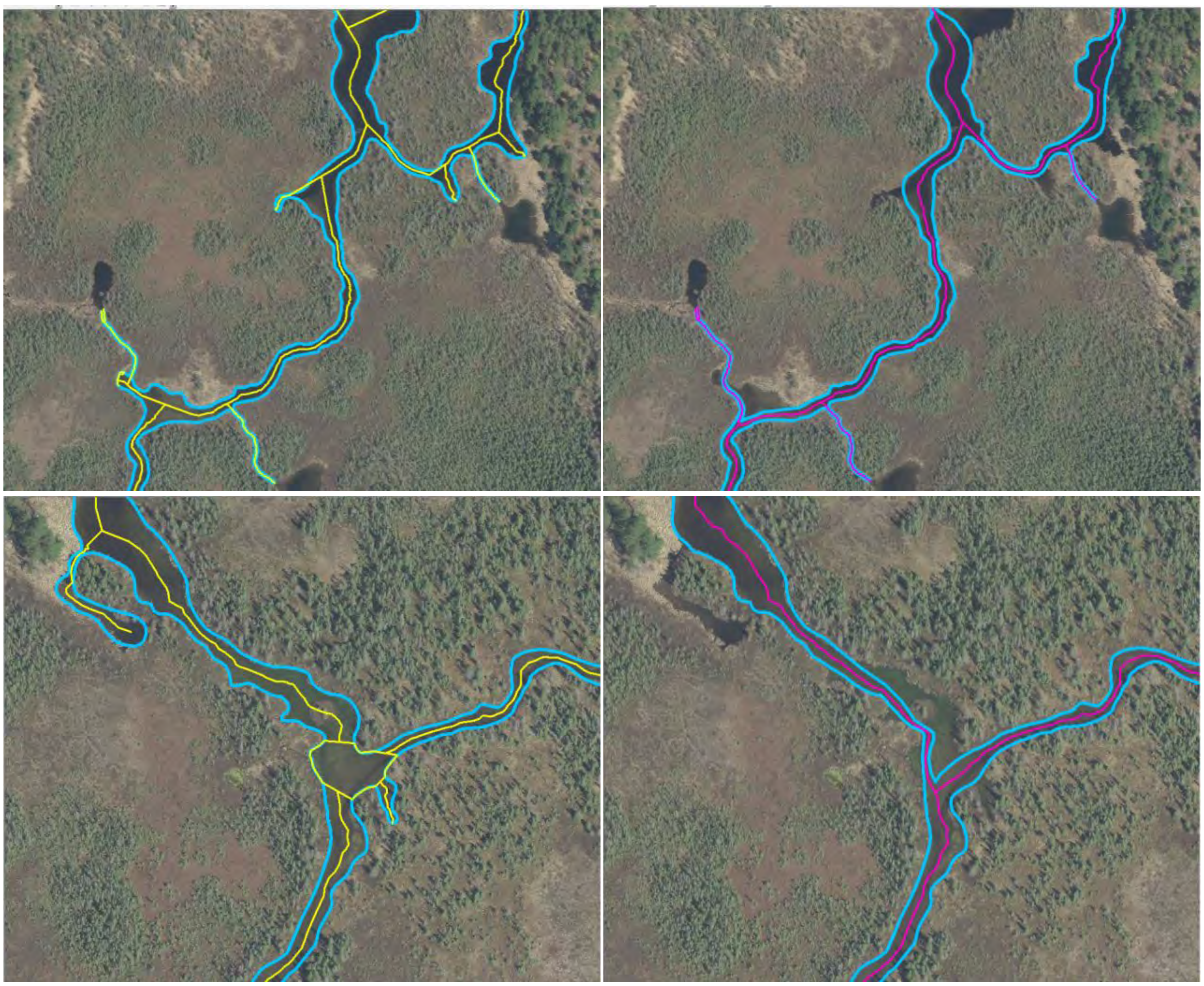

Figure 45. The top and bottom right images show the output of the Collapse Dual Lines to Single Line tool without any adjustments to the initial wetland map unit geometry. The images on the left show how the wetland boundaries were reshaped, resulting in a better fitting centerline. No changes were made to the

final wetland boundary data, edits were made on the select wetland boundaries exported for the purpose of creating the centerlines.

If using ArcGIS Pro

- Run the POLYGON TO CENTERLINE tool
  - Tool parameter settings (Figure 46)
    - Input Feature: Streams_Rivers_Dissolve
    - Output Workspace: Scratch
    - Output Feature: Centerline

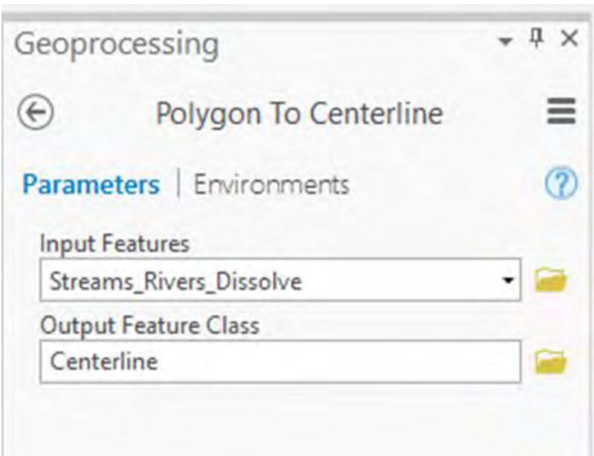

Figure 46. The user interface of the Polygon to Centerline tool

Continue Using Either ArcGIS Desktop or ArcGIS Pro

Step 6: Use the ERASE tool to remove any overshoots that have been created during the automated centerline process. This will delete any segments of the centerlines that cross into "lakes or ponds" and will snap the end of the line to the edge of the "lake" polygons.

- Tool parameter settings
  - Input Features: Centerline
  - Erase Features: Dissolved lakes layer. See creation of lake layer process below.
  - Output Location: Scratch
  - Output Feature Class: Centerlines_temp

Step 7: Check the direction of flow in all resultant centerlines and make adjustments as needed. This is done during an "Edit" session, select the segment in question, click on the *Edit Vertex* button, hover over one of the vertices, right-click the mouse and select *Flip* (Figure 47).

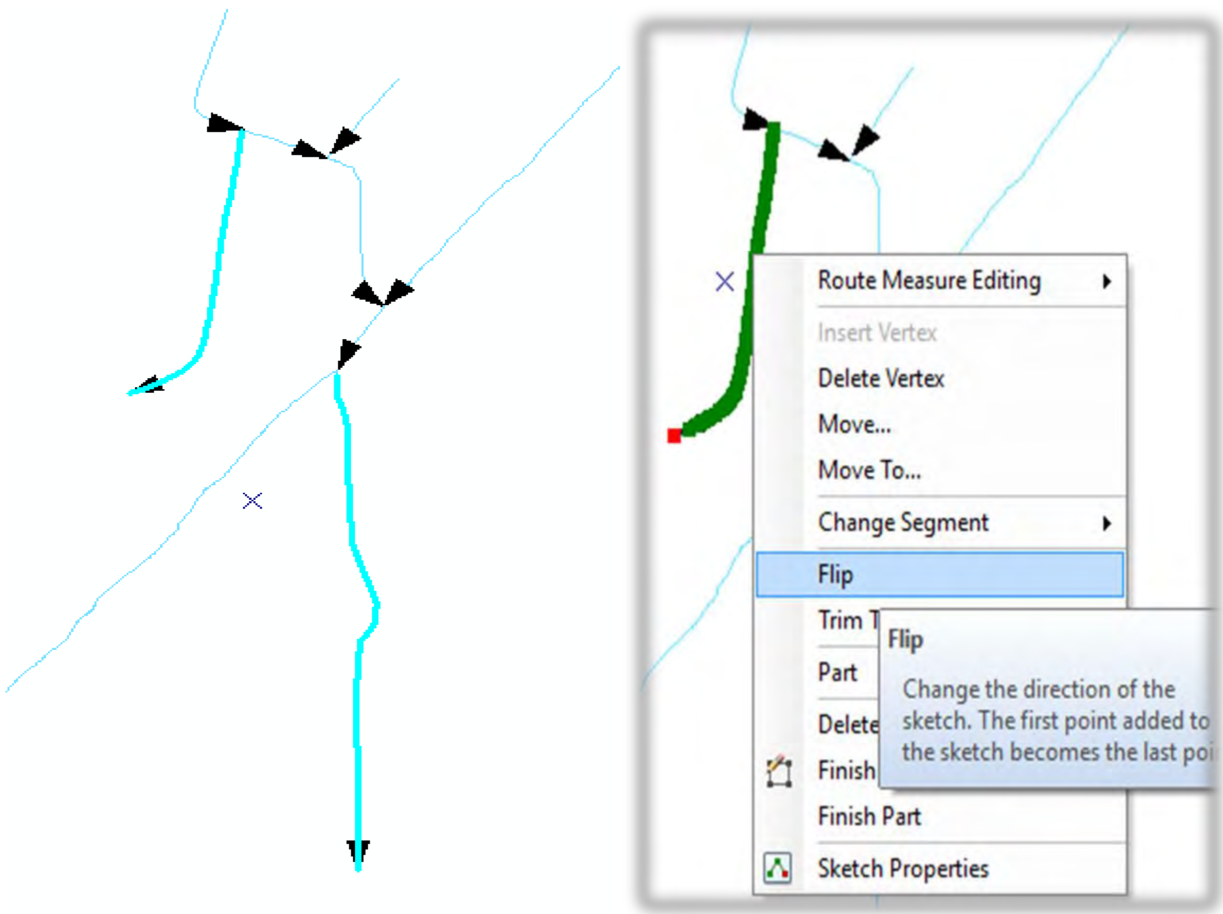

Figure 47. Screen-shot of the process to “flip” the direction of flow for stream segments.

Step 8: Use the IDENTITY tool to bring in the data from the wetland polygons so that the new single line streams can be attributed with *Flow Type*.

- Tool parameter settings (Figure 48)
  - Input Features: Centerlines_temp
  - Identity Features: NWI layer
  - Output Feature Class: Centerlines_identity in the S*cratch Feature Dataset*.

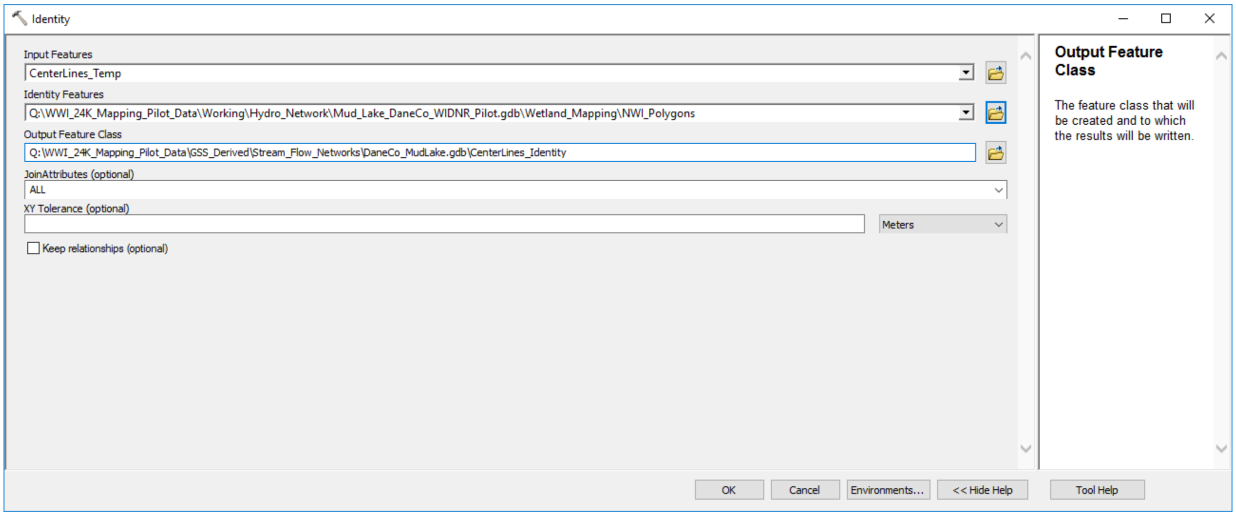

Figure 48. The user interface of the Identity tool.

Step 9: Add HYDROCODE field to centerline dataset

- Tool parameter settings
    - Name: HYDROCODE
    - Type: Text

Step 10: Populate the HYDROCODE attribute. The process described below is completed using ArcGIS Desktop.

- Using the Select by Attribute tool
    - SELECT Where ATTRIBUTE LIKE '%R4%'
        - Use the field calculator to attribute the HYDROCODE field as “Intermittent”
    - Create a new selections Where ATTRIBUTE LIKE '%R2%' OR ATTRIBUTE LIKE '%R3%'
        - Use the field calculator to attribute the HYDROCODE field as “Perennial”
- For the same reasons as mentioned above, some of the stream, in particular those that were added above will need to be manually reviewed and attributed accordingly.
- Existing WDNR 24K Hydro lines should be used as final determiner of whether the segment is perennial or intermittent.

Step 11: DISSOLVE the Centerlines_identity layer by HYDRCODE to eliminate small segments created by Identity tool or centerlines process.

- Tool parameter settings
    - Input Features: Centerlines_identity
    - Output Feature Class: Stream_Centerlines
    - Dissolve field: HYDROCODE

Step 12: Make the Stream_Centerlines feature class editable and *Explode* to turn the multipart features to single part. Some "clean-up" of this output may need to be required. Carefully review the results of the *Explode* function and edit the resultant stream layer as needed.

2.3.2.2. Processing Stream Centerlines to a Stream Single-line Feature Class

The stream centerline feature class derived using the process described in this document may be not be continuous across the watershed. Gaps within the linear network may be present (Figure 49). These errors of omission are a direct result of the derivation of the stream linears from the wetland dataset. The most common reason for a gap or missing segment in the network is due to lakes and ponds (Figure 50). Gaps in the network are also commonly due to a wetland not being classified as a riverine habitat due to the strict attribution rules of the NWI data standard and/or the resolution of the imagery used in the wetland boundary interpretation (Figure 51). In rare cases, the gap in the network or a missing segment may be due to no wetland being mapped due to the resolution of the imagery and collateral data.

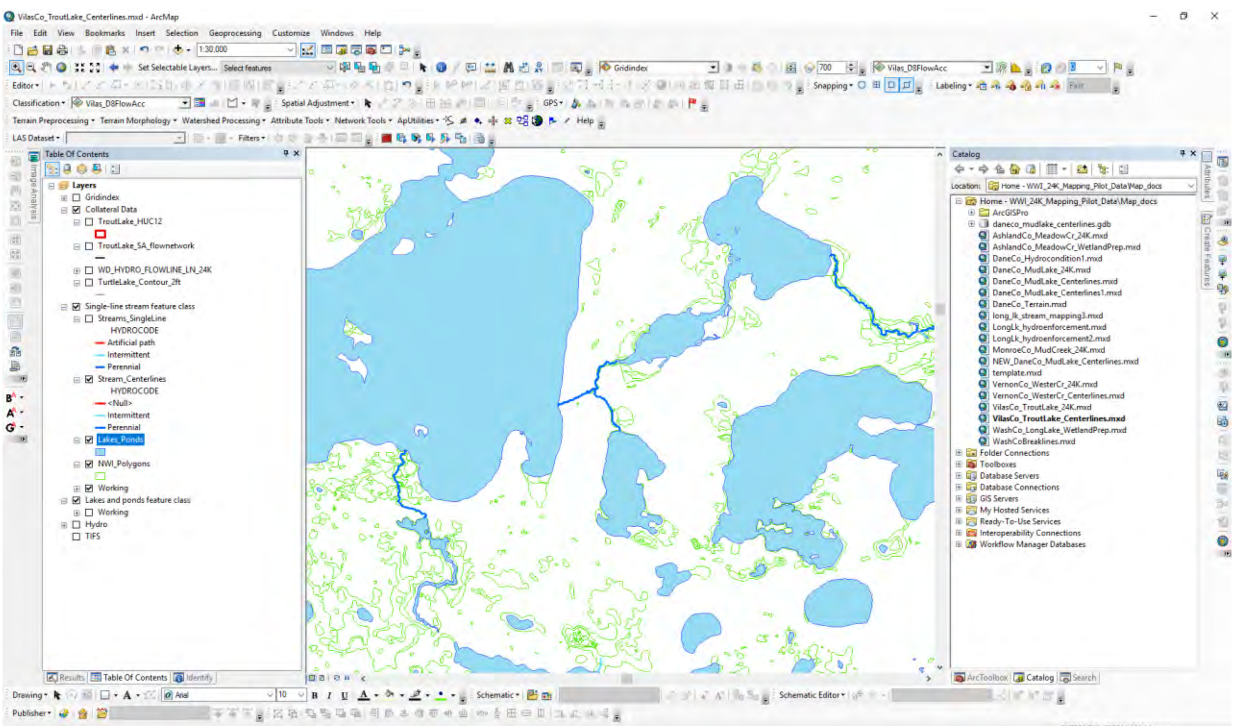

Figure 49. Example of a stream network (dark blue) with gaps. The green polygons are wetland boundaries, light blue are lakes or ponds.

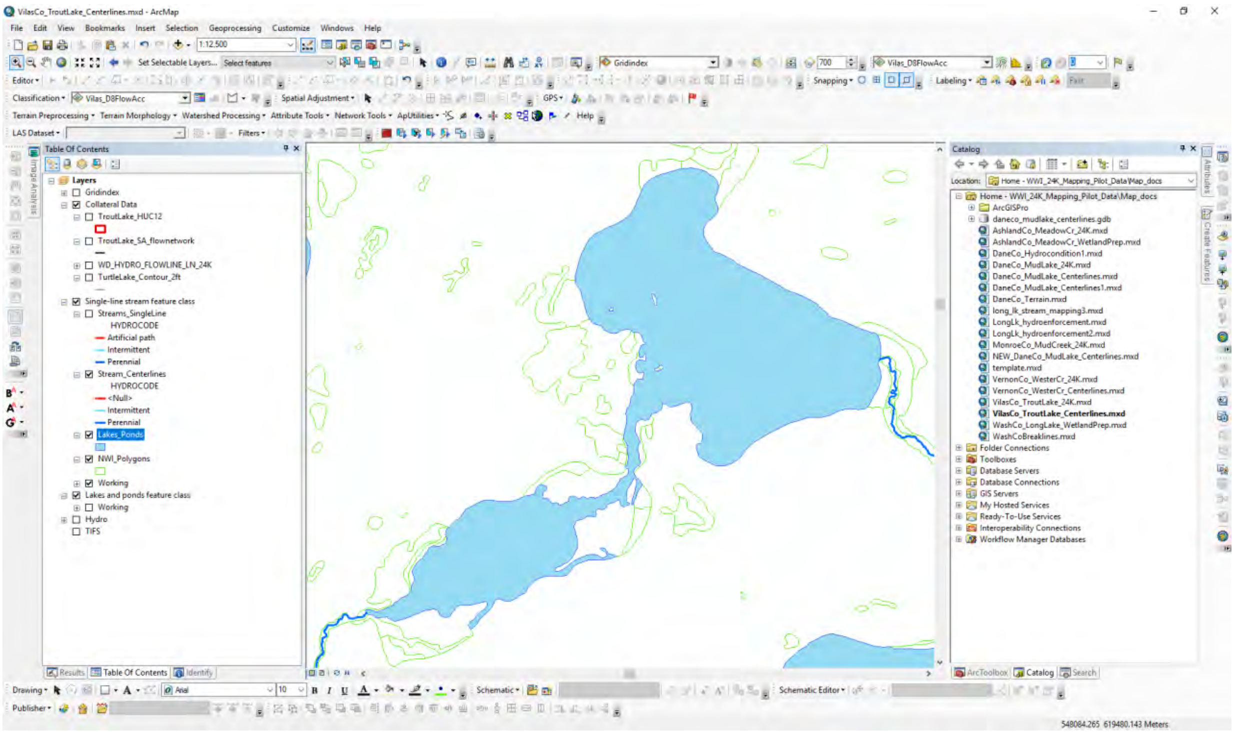

Figure 50. Example of a stream network (dark blue) with gaps due to lakes. The green polygons are wetland boundaries, light blue are lakes or ponds.

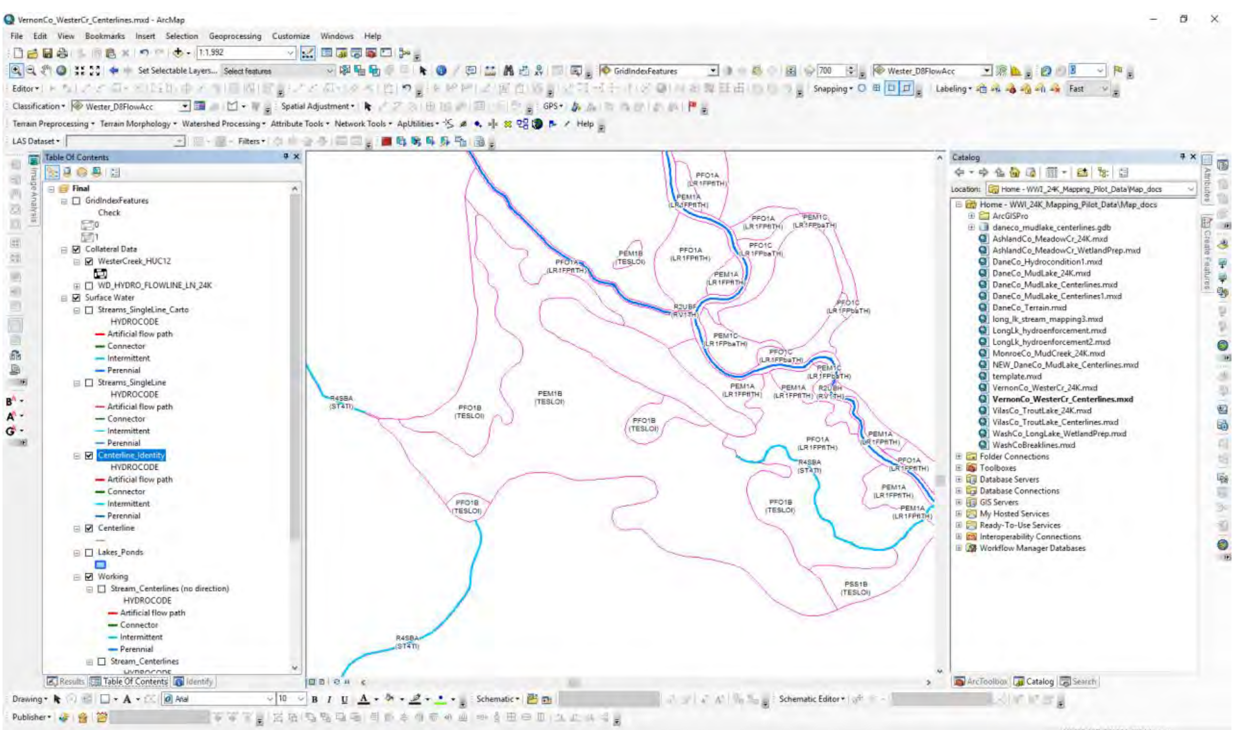

Figure 51. Example of a stream network (light blue = intermittent, dark blue = perennial) with gaps due to non-riverine wetlands. The violet polygons are wetland boundaries.

These missing segments can be “filled-in” by manually digitizing new line segments across these gaps using the existing wetland boundaries, wetland classification codes, the aerial imagery, the existing WDNR 24K flowlines and other datasets derived from the LIDAR as guides. The wetland classification codes for the *Water Flow Path* in the LLWW classification can be used to determine whether the new flowline should be classified as perennial or intermittent flow. These codes are provided in Table 2. In the event there is a corresponding flowline from the current WDNR 24K flowline, can provide/verify the flow type. In some instances, a stream segment is not present, due to limitations of the mapping scale (1:3,000) a wetland polygon could not be discerned by the mapping protocol. In these cases from new lines need to be digitized using the imagery, LiDAR derivatives, and the existing WDNR 24K flowline to aid in the interpretation of the flowline location. Digitizing of these new flowlines does not have the mapping scale restriction present in the wetland digitizing protocol. Attribution of the flow type is determined mainly by the existing WNDR 24K flowline dataset or by the downstream connecting stream segment.

Table 2. Water Flow Path codes from LLWW classification and the associated flow type.

LLWW Water Flow Path Code	Flow Type
OU	Outflow-perennial
OI	Outflow-intermittent
TH	Throughflow (considered perennial)
TI	Throughflow-intermittent

A number of datasets can be derived from the LiDAR data for use as guides to stream centerline development. The hillshade and slope raster is used in the wetland digitizing, as well as contour lines are also relevant for digitizing stream segments. Additional raster datasets derived from the LiDAR can provide a visually representation of channelized flow and drainage pathways. The Topographic Wetness Index (TWI), also known as the Compound Topographic Index (CTI) incorporates the upslope contribution area (flow accumulation raster) and a slope raster in geometric function equations. In the resultant raster surface, the higher CTI values represent drainage depressions. When symbolized, the drainage pattern becomes visible. Similarly, a Stream Power Index (SPI) can be derived from the flow accumulation and slope raster using nearly the exact process as used to derive the CTI. The difference is in the calculation of the CTI, the flow accumulation is divided by the slope and in the SPI, the flow accumulation values are multiplied by the slope. Appendix E1 and Appendix E2 provide a process model and equations for deriving each of these products.

Both the CTI and the SPI require a flow accumulation raster as an input. The flow accumulation raster in one of the products derived as part of the process of deriving a drainage network from a DEM. While this can be a lengthy process and requires the ability to interpret locations of water flow paths across an elevation surface, the resultant drainage network could also be used to guide the digitizing of the stream reaches to fill in the gaps in the stream network. This process results in a polyline feature class that can guide the digitizing process.

The HPI was developed by the Minnesota Department of Natural Resources (MN DNR) to aid in the accurate identification, digitizing, and extraction of hydrologic features from a DEM (Vaughn 2017).

A graphical representation of a geoprocessing model based on the process developed by Vaughn (2017) for creating a HPI raster shown in Figure 52. Using specific symbolization and display settings the HPI relies on warm yellow and red hues, trending to black, to produce a visual effect that discerns high elevations from low elevations. In the HPI, yellow indicates locations with higher elevations than surrounding cells and black indicated locations of lower elevation. Concentrated areas of black cells form linear patterns that can be interpreted as streams or water flow paths (Figure 53).

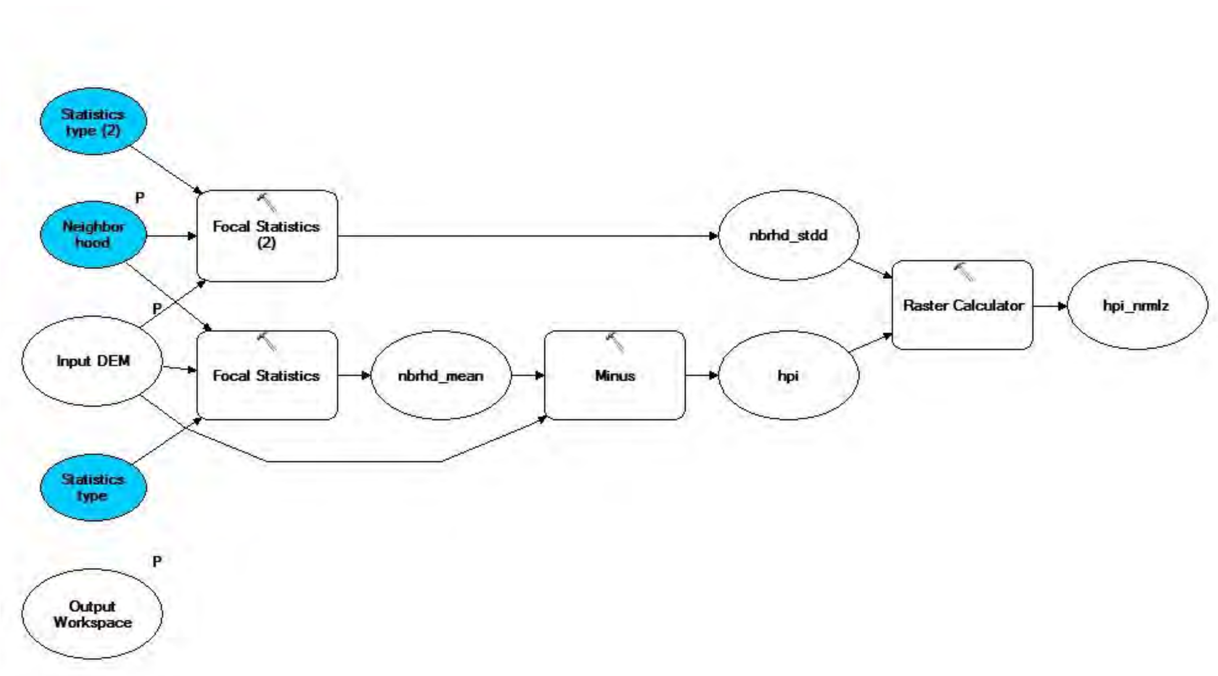

Figure 52. ArcGIS ModelBuilder diagram showing the development of a HPI raster.

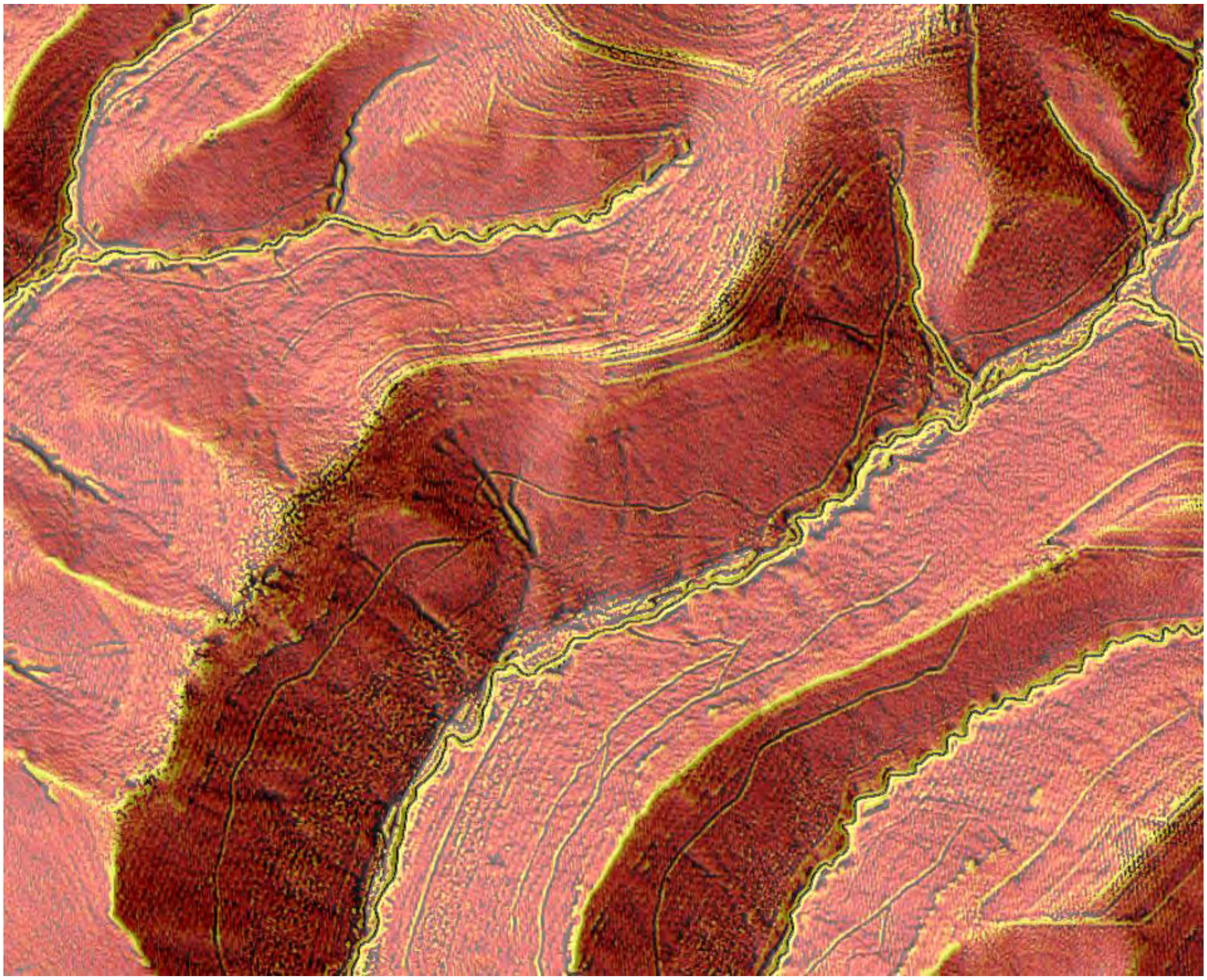

Figure 53. A HPI raster symbolized with the “fire” color ramp. Areas of high elevations trend towards yellow and areas of lower elevations trend towards black.

The following paragraphs provide examples of the common gaps and omissions and reasons why they are present in the derived linear stream network. Each example also provides a solution of how to digitize the missing segment(s). Regardless of the collateral data used aid in the digitizing of the new segments, once completed, they should be merged with the relevant existing segments to create the stream reach segmented by nodes at each confluence network structure that is required for linear flow networks.

Gaps Due to Lakes or Ponds

The most common gaps in the stream network occur where stream centerlines end at a lake inlet point (Figure 50). In these cases, an “artificial path” needs to be manually digitized connecting the lake inlet to the lake outlet (Figure 54). This artificial path does not need to be centered within the polygon, rather it should approximate a straight-line crossing of the waterbody while remaining within the wetland polygon boundaries.

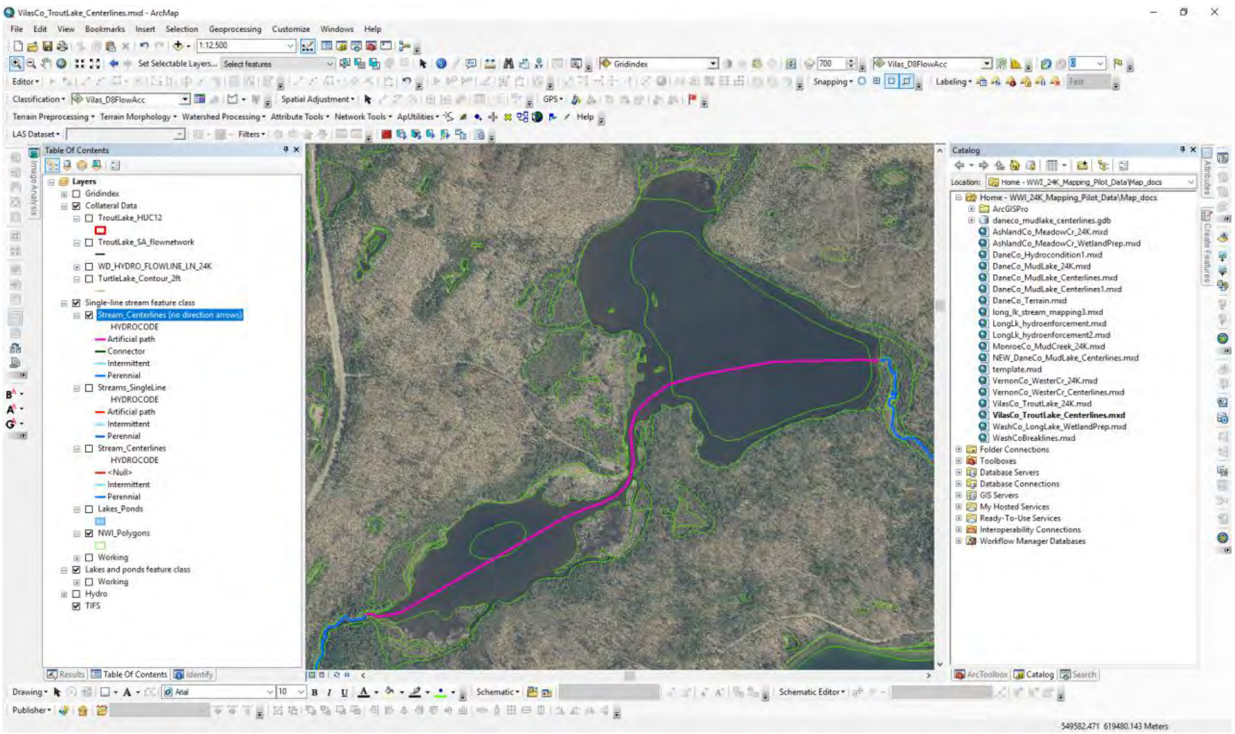

Figure 54. Example of how an artificial path (purple) is used to reconnect a gap in the stream network (dark blue) due to lakes. The green polygons are wetland boundaries, light blue are lakes or ponds.

<u>Gaps Due to Non-riverine Wetlands</u>

In the first example, for a short segment of the intermittent stream a discernable channel could not be identified in the imagery or the collateral data. NWI rules dictate that this must be attributed as a palustrine wetland and in this case a two different palustrine types, (Figure 55). In Figure 56, it can be seen how the Flowpath feature class was used as a guide to digitize in the connecting segment. Note that the new stream segment did not exactly mimic the derived flow path as that would have caused the segment to cross-over the wetland boundary in order to maintain the coincidence of the wetland/surface water datasets.

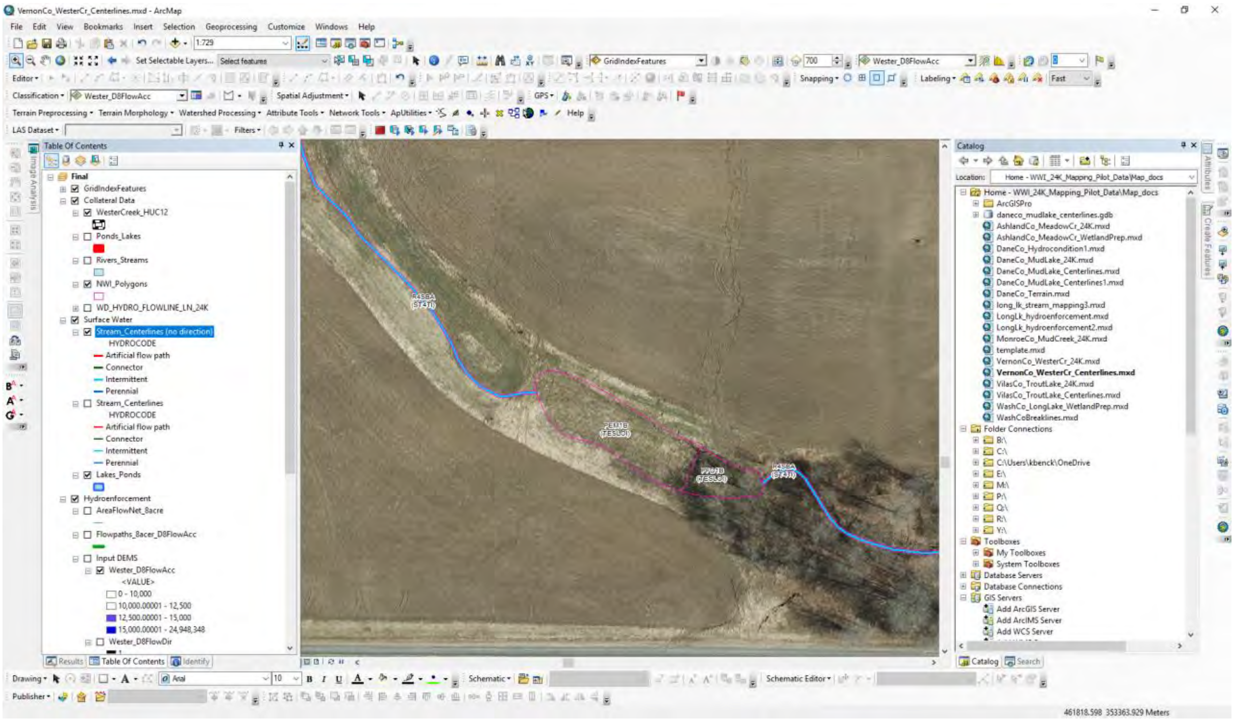

Figure 55. Gap in stream centerline network due to no discernable channel.

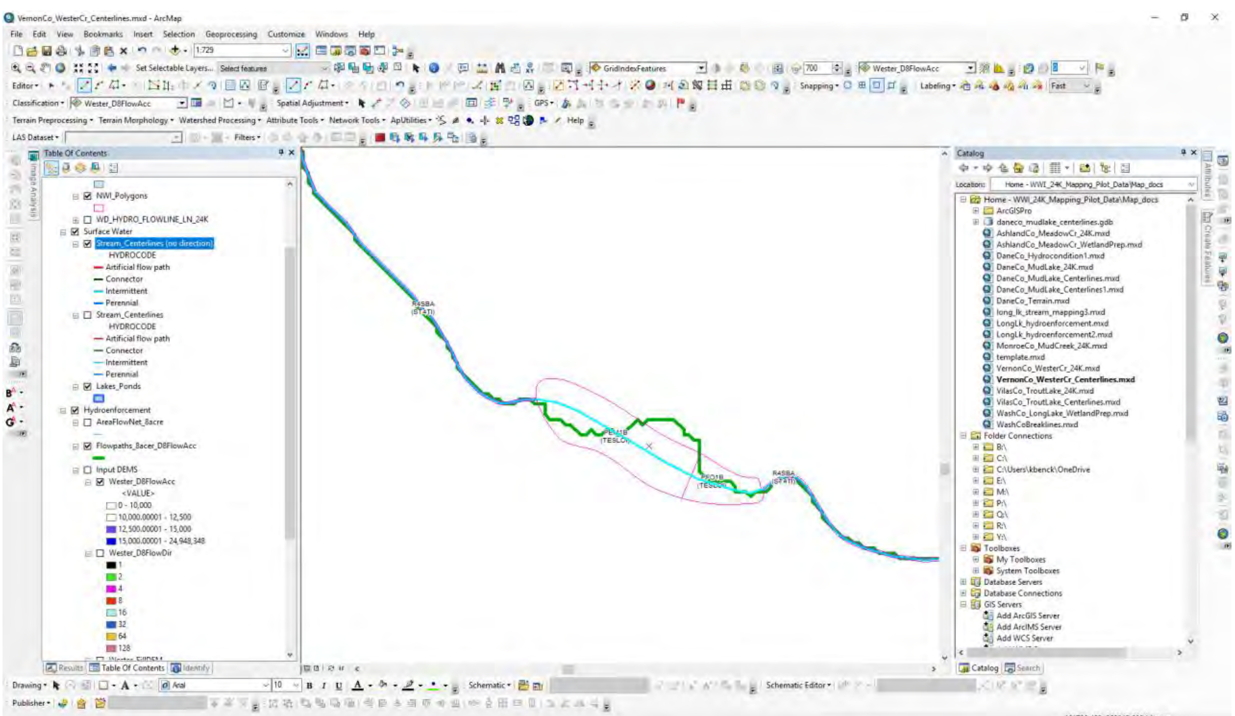

Figure 56. Location of new stream centerline based on wetland polygons and flow network derived from LiDAR.

In some cases, the gaps in the Stream_Centerlines feature class are occur where two or more stream segments come together (Figure 57). In this circumstance multiple segments need to be digitized, one for each branch to their confluence, and then another segment that runs from the confluence to connect the outflow segment (Figure 58).

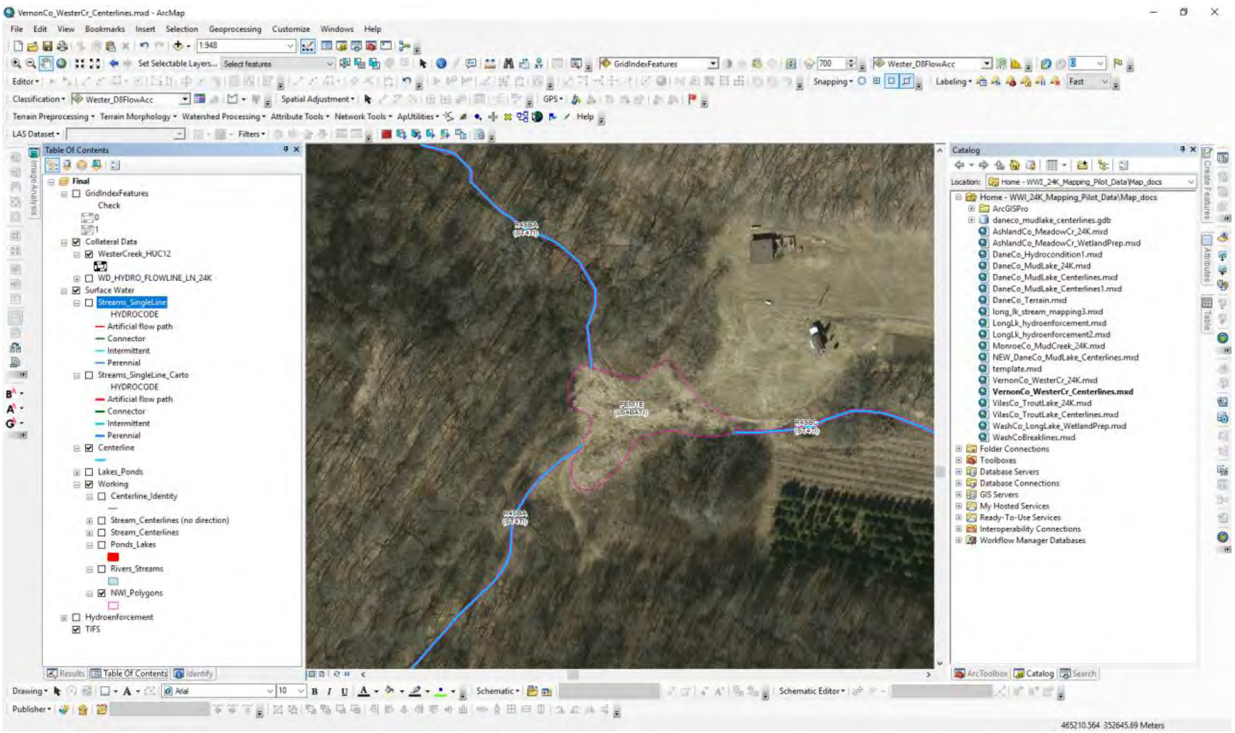

Figure 57. Gap in stream centerline network at the confluence of two intermittent streams with no visible channel.

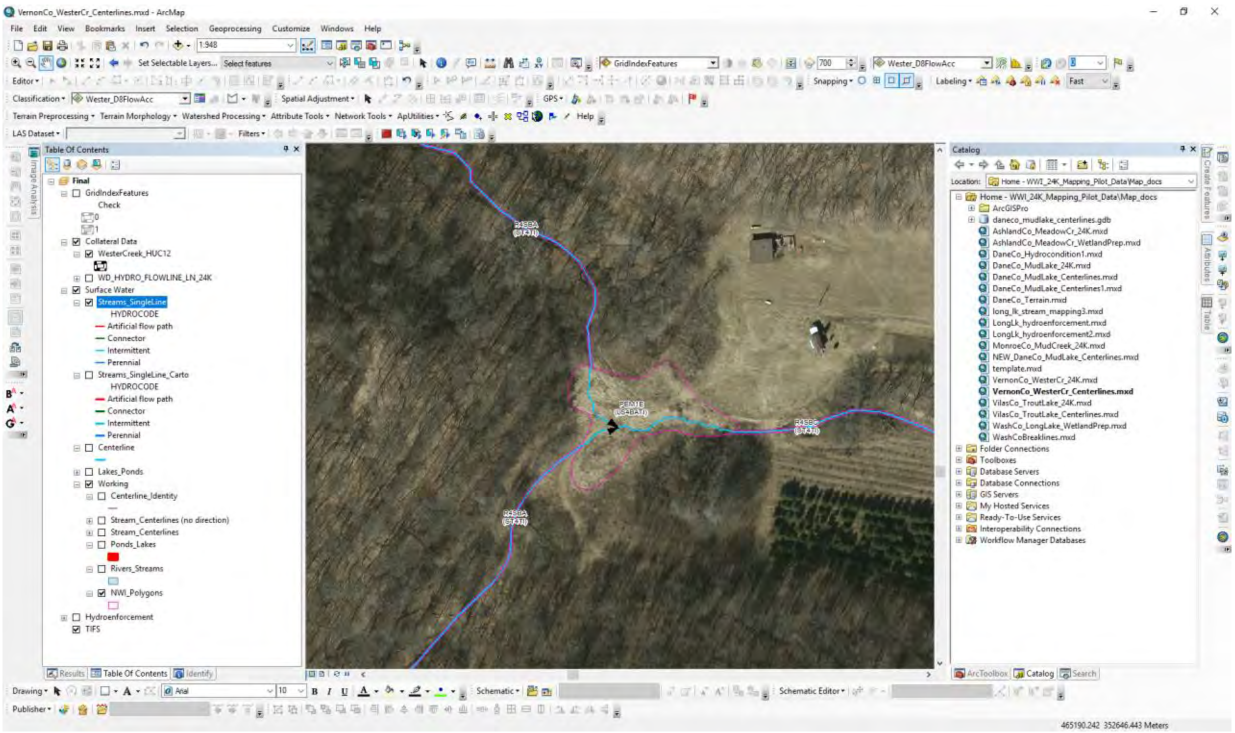

Figure 58. Location of 3 new stream centerlines based on wetland polygon and flow network derived from LiDAR.

Another case scenario occurs in locations where there are relatively large areas where intermittent[1] stream segments are disjointed by one or more large wetland polygons. This situation again occurs due to the strict attribution rules of the NWI codes or due to "lumping" of signatures during the wetland boundary digitizing process. For example, the wetlands are not coded in NWI or LLWW as intermittent as no visible channel or bank in present in the imagery or the collateral data used in the interpretation of wetland boundaries (Figure 59). Figure 60 shows this same location with the HPI raster. Notice a linear path can be discerned in the area of the missing stream segment. Figure 61 shows where a new intermittent linear segment has been digitized to close the gap and maintain the integrity of the network.

[1] Disjointed intermittent streams make up the vast majority of these cases; however, perennial stream segments can also exhibit these types of gaps due to "lumping" procedures during the boundary identification and attribution process.

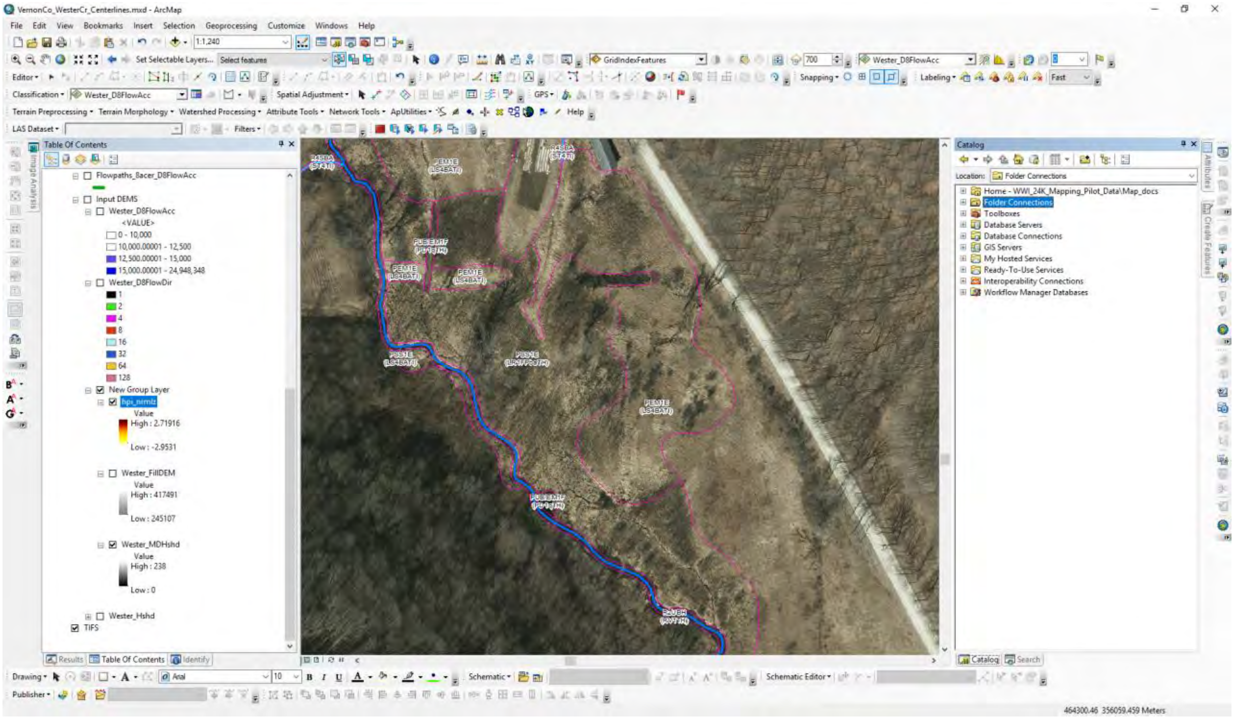

Figure 59. Gap in stream network due to “lumping” of signatures.

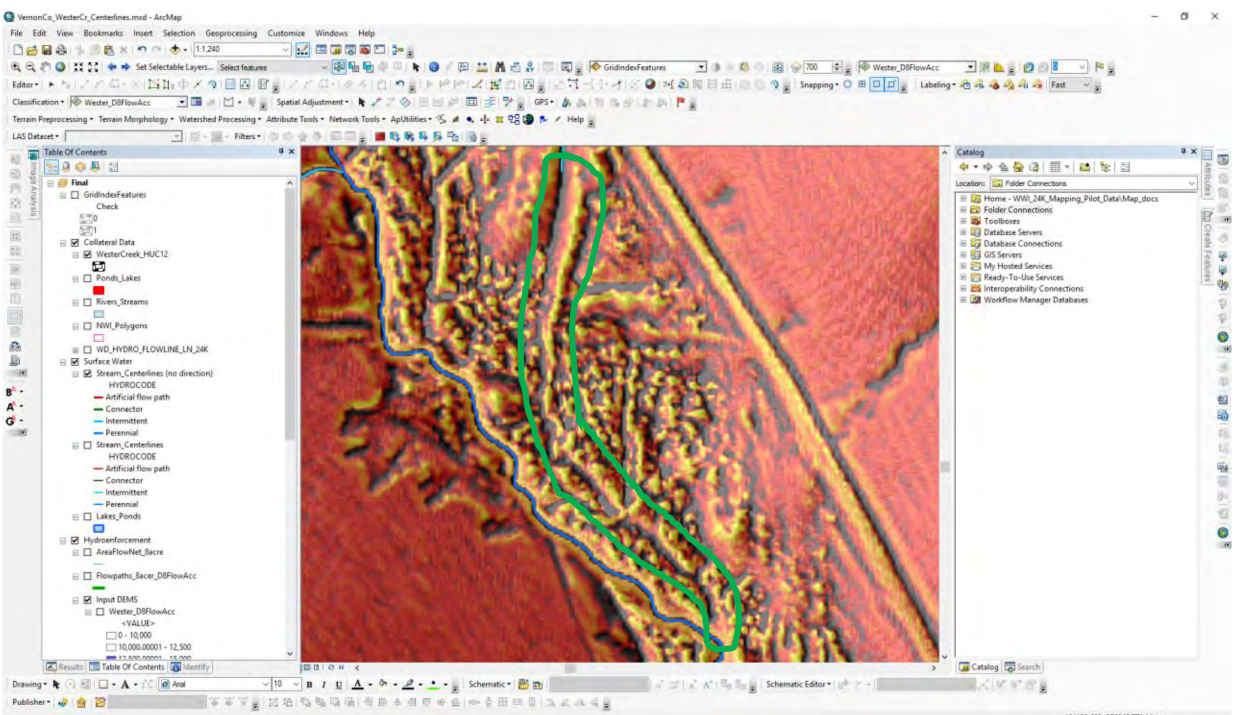

Figure 60. HPI layer for the area in question. The flow path in the HPI is circled by the green line.

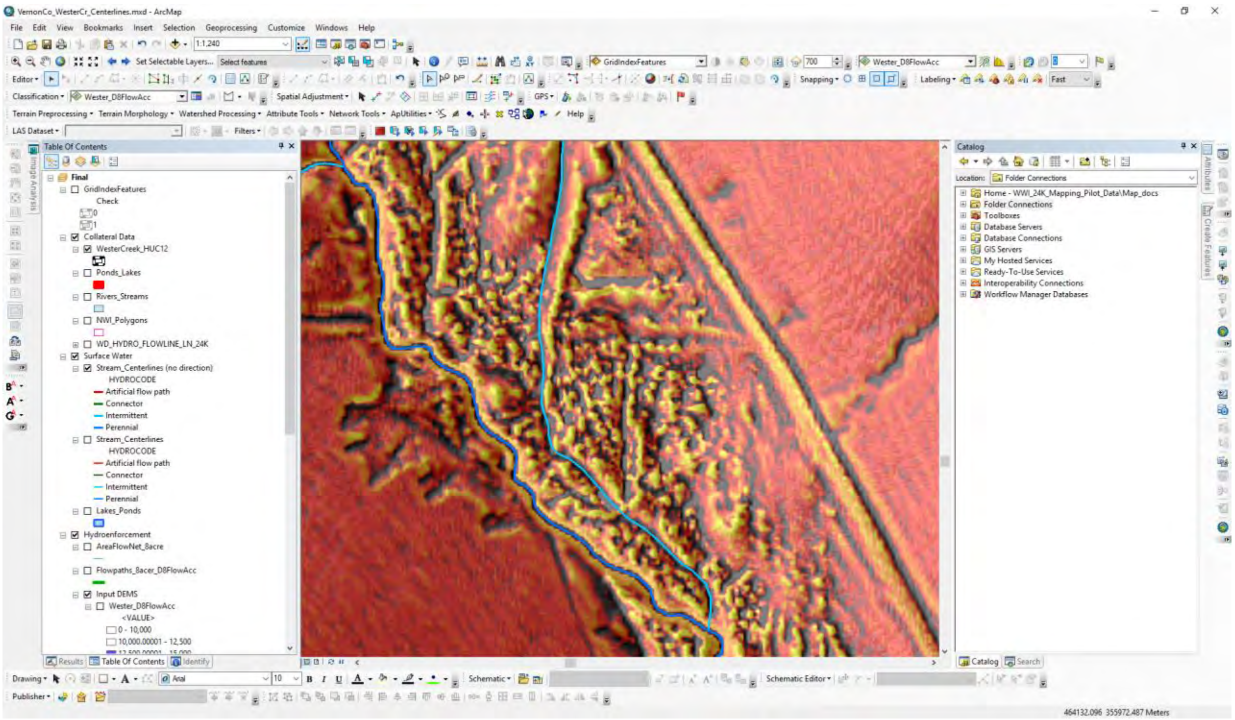

Figure 61. New stream centerline digitized based on interpretaion of the HPI layer.

Finalizing the Stream Centerline Feature Class

Once all gaps in the stream network have been addressed, the updated Stream_Centerline feature class should be exported to a new feature class (i.e. Stream_SingleLine feature class). The updated Stream_Centerline feature class should be retained in the event there is a need to produce a hydro-enforced DEM (HDEM) for additional hydrologic analysis. For cartographic purposes, a smooth-line version of the Stream_SingleLine feature class can also be generated using the Smooth Line tool.

2.3.3. Creating a Double-line Streams Feature Class

Double-line stream segments are streams that have a sufficient wetted width to be represented by a polygon instead of the stream centerline. For the purposes of this pilot project, the sufficient wetted width criteria of the NHD 24K dataset was used. This threshold value for switching from a single line respresentation of a stream to a double line (i.e., polygon) is 20 meters. In the completion of this pilot study, no stream or river met the minimum wetted width criteria, as a result there is no double-line stream feature class in the project deliverables. However, a process that could be used to determine wetted width qualification and development of a double-line feature class is provided below.

Steps can be taken to review the average polygon width of riverine wetland polygons to determine if the qualify for representation as a double-line stream. As noted earlier, a minimum average width threshold of 20 meters is required. Calculate the average polygon widths of the NWI map units selected as streams under the Step 1 of the *Extracting a Stream Centerline Feature Class* process.

Step 1: ADD FIELD

- Tool parameter settings
    - Name: Avg_Width
    - Type: Double

Step 2: CALCULATE FIELD

- Tool parameter settings (Figure 62)
    - Input Table: Streams_Rivers_SELECT
    - Field Name: Avg_Width
    - Expression: ([Shape_Area] / [Shape_Length]) * 4[2]

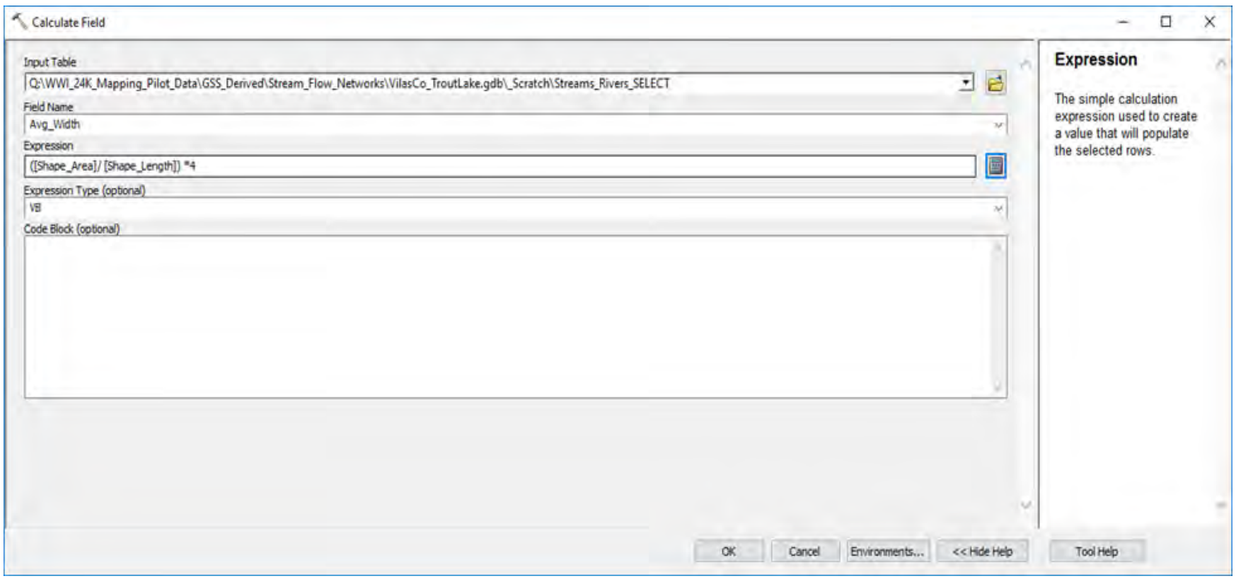

Figure 62. The user interface of the Identity tool.

Step 3: Use the results in the Avg_Width field to identify which, if any of the polygons should be exported to a Stream_DoubleLine feature class. The average width values that are calculated are in the units of the feature classes.

- The minimum width threshold used by the National Hydrography Dataset in determining when to create the double-line stream segments is when the average width is 20 meters. The threshold to use is at the discretion of the WDNR. For the purposes of this pilot study, the 20 meters threshold is used.

[2] https://gis.stackexchange.com/questions/20279/calculating-average-width-of-polygon/181801#181801

3. Application of the Methodology

3.1 Data Issues

3.1.1 LiDAR and Imagery Alignment

Initially, stream centerlines were derived through the hydro-enforcement of the LiDAR DEM using the ACPF or Esri Spatial Analysis tools. These centerlines were intended for use as the basis for creating linear wetland features. These linear features would be converted to wetland polygons through a buffering and reshaping process. In the initial phases of the wetland mapping, it became apparent that the imagery was offline, (shifted) as compared to the LiDAR as there were issues with the stream centerlines matching with the location of streams in the imagery. This misalignment could create a situation where the resultant wetland data produced from the aerial imagery (and supported by additional collateral datasets) is not topologically nor cartographically consistent with data derivatives, such as stream centerlines, of the LiDAR data.

3.1.2 Coordinate System of LiDAR Point Cloud Data

In the initial development of collateral data, datasets derived from the Lidar point cloud where not spatially consistent in their location as other data for the same watershed. The spatial extent of data derived from the LiDAR point cloud was not coincidental with other data collected from various sources for a watershed. Upon examination of the LiDAR point cloud data, it was found that the data had been delivered in a "custom" coordinate system that was not recognizable by the Esri software employed in the data analysis and data derivation for the project. Since the Esri software did not recognize the coordinate system, it could not be drawn in the proper location in reference to other data. Figure 63 shows how the Esri software interpreted the location of the LiDAR point cloud (red grid pattern) in relation to the DEM for the project watershed in Washburn County. The normal process to fix this misalignment is to reproject the data to the correct coordinate system. In this case, this process would not work, as the LiDAR point cloud cannot be reprojected. In addition, due to the "custom" nature of the point cloud coordinate system, the data derived from the point cloud could not be reprojected accurately.

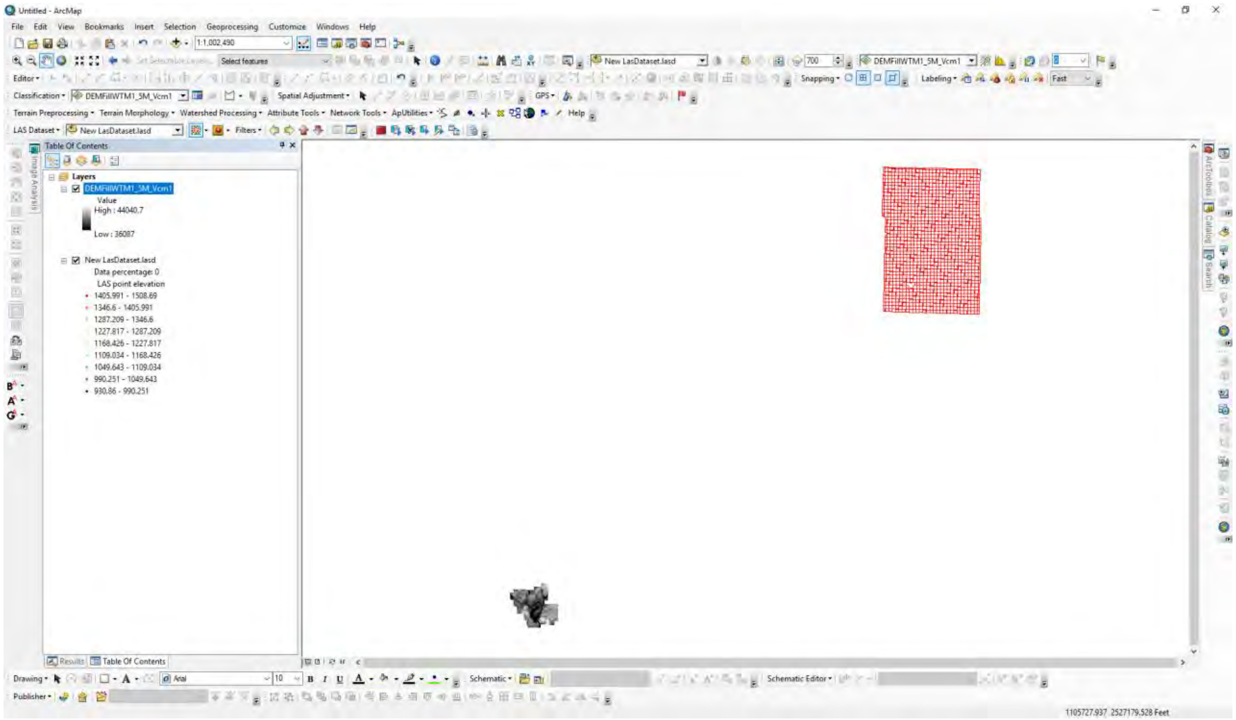

Figure 63. How ArcMap interprets the location of the LiDAR point cloud and DEM for the Washburn County project area. The point cloud location is represented by the red grid pattern in the upper right and the actual location of the Long Lake watershed in Washburn County is the gray area to the lower left.

Further investigation into the “custom” projection of the point cloud dataset revealed a simple solution to this problem. Table 3 shows the settings for the Lidar point clouds “custom” coordinate system (on the left) and the settings for the accepted well-known identifier (WKID) for Washburn County, Wisconsin. The only difference in the settings is the False Easting and False Northing. These two points are used by the software as a (0,0) location. This allows the software to create spatially coincidental representations of data, regardless of the data’s inherent coordinate system.

Table 3. Comparison of custom coordinate system settings of the LiDAR point cloud and the accepted WKID for Washburn County, Wisconsin

NAD_1983_2011_WISCRS_Washburn_Feet	NAD_1983_2011_WISCRS_Washburn_Feet
Authority: Custom	WKID: 7640 Authority: EPSG
Projection: Lambert_Conformal_Conic	Projection: Lambert_Conformal_Conic
False_Easting: 234086.8681737364	False_Easting: 768000.0
False_Northing: 188358.6059436119	False_Northing: 617973.193
Central_Meridian: -91.7833333333333	Central_Meridian: -91.78333333333333
Standard_Parallel_1: 45.9612198333333	Standard_Parallel_1: 45.96121983333334
Scale_Factor: 1.0000475376	Scale_Factor: 1.0000475376
Latitude_Of_Origin: 45.9612198333333	Latitude_Of_Origin: 45.96121983333334
Linear Unit: Foot_US (0.3048006096012192)	Linear Unit: Foot_US (0.3048006096012192)
Geographic Coordinate System: GCS_NAD_1983_2011	Geographic Coordinate System: GCS_NAD_1983_2011
Angular Unit: Degree (0.0174532925199433)	Angular Unit: Degree (0.0174532925199433)
Prime Meridian: Greenwich (0.0)	Prime Meridian: Greenwich (0.0)
Datum: D_NAD_1983_2011	Datum: D_NAD_1983_2011
Spheroid: GRS_1980	Spheroid: GRS_1980
Semimajor Axis: 6378137.0	Semimajor Axis: 6378137.0
Semiminor Axis: 6356752.314140356	Semiminor Axis: 6356752.314140356
Inverse Flattening: 298.257222101	Inverse Flattening: 298.257222101

Since this was the only difference in the two coordinate systems, a simple edit of the “Spatial Reference” of the derived raster data fixed the misalignment problem. This fix is easily accomplished using the ArcCatalog interface of ArcGIS Desktop. The spatial reference of a raster can be edited by opening the raster’s “Properties” dialog and scroll to the “Spatial Reference” section. Simple select the “Edit” button and navigate to the proper coordinate system and select it (Figure 64. Process for editing the Spatial Reference for a raster dataset. The raster’s “Properties” window in on the left and the “Spatial Reference” properties window is on the left.). Once this change is made, the raster and all derivatives of that raster will be in the proper coordinate system.

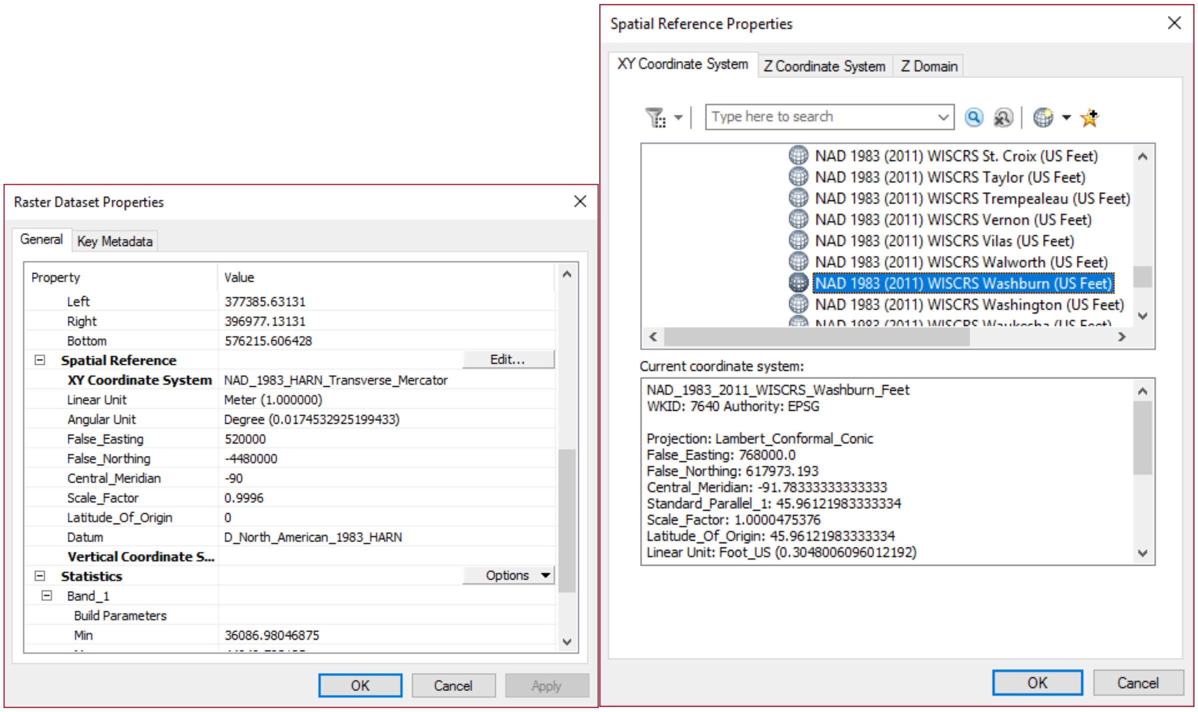

Figure 64. Process for editing the Spatial Reference for a raster dataset. The raster's "Properties" window in on the left and the "Spatial Reference" properties window is on the left.

3.1.3 LiDAR Hydro-enforcement Issues

The initial scope of work for this project called for the hydro-enforcement of the LiDAR DEM. This process was intended to produce an elevation surface that accurately represented the flow of water across a watershed landscape. The intent was to use this HDEM to create a set of linear stream features that would be used in the wetland mapping as the basis for delineating riverine polygons. This process involves the identification and removal of potential "digital dams" that may exist in the bare earth DEM. Digital dams are artifacts in the elevation surface that act as impediments to the natural flow of water across the DEM surface. Digital dams are most commonly bridge decks and culverts, but due to the large-scale resolution of the LiDAR data (small grid cell size) even overhanging vegetation can be represented in the data as a digital dam. To repair the natural flow across the surface, these digital dams need to be removed. There are a number of geoprocessing tools that can be used to accomplish this task. For the purposes of this project a protocol using a combination of Esri geoprocessing tools and The Agricultural Conservation Planning Framework (ACPF) Toolbox v 2.2 (https://acpf4watersheds.org/toolbox/) was implemented[3]. This toolbox provides a number of python scripts for hydrologic flow assessments that package several Esri hydrologic geoprocessing tools into a simplified user interface. The ACPF tools do require the installation of the TauDEM suite of tools (http://hydrology.usu.edu/taudem/taudem5/).

The hydro-enforcement of the LiDAR DEM was ultimately abandoned for two reasons. As detailed above, the LiDAR and the aerial imagery where not completely in alignment, however the primary

[3] Version 3.o of the ACPF tool was released after the hydro-enforcement portion of the project was completed.

reason was the inconsistencies and irregularities in the LiDAR DEM's provided to the WDNR by its contractor. In general, the identification and removal of digital dams is a relatively straightforward process. LiDAR derivatives can be generated that identify locations impediments to flow and generalized flow paths. Breaklines are digitized across the impediments connecting the generalized flow paths. Geoprocessing tools take the breakline feature class and "burn" the connecting paths into the elevation model. The resultant raster dataset can be used to generate the flow direction and flow accumulation models required to create a linear flow network. Despite repeated attempts at hydro-enforcement, the resultant flow networks did not represent the actual flow across the watersheds to the degree of accuracy required for inputs to the wetland mapping. Upon review of the bare earth DEM and raw LiDAR datasets that were provided by the contractor, inaccuracies and irregularities were found in these products that were preventing the accurate portrayal of flow across the watersheds. These inaccuracies and irregularities included; water body locations that had not been hydro-flattened, "trenching" along lake shorelines (Figure 65) and along stream routes (Figure 66), and random locations where linear segments appeared to have been "burned" into the surface.

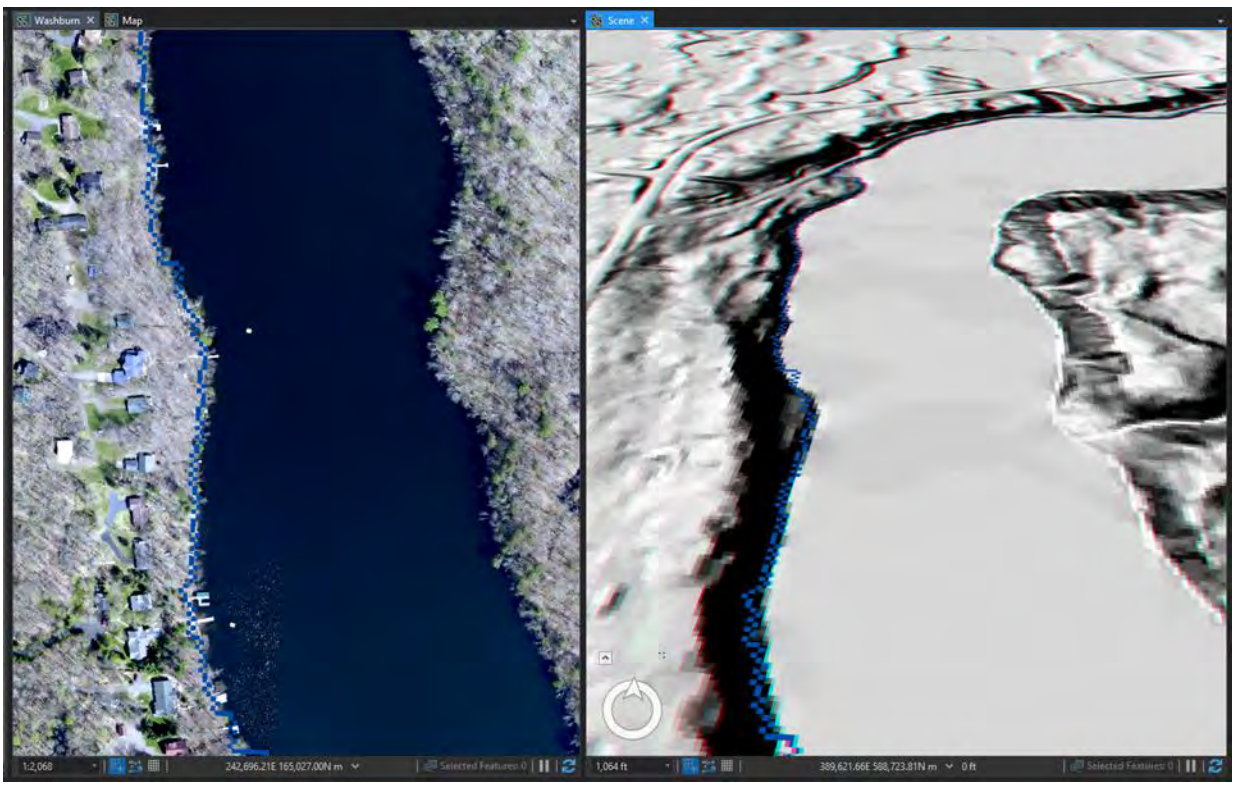

Figure 65. Example of trenching along lake boundaries in the Long Lake watershed in Washburn County. The image on the left is the aerial with the blue line representing the flow path derived from the LiDAR DEM. On the right is a 3-D representation of the same location showing how the flow path (blue line) runs along the lakeshore.

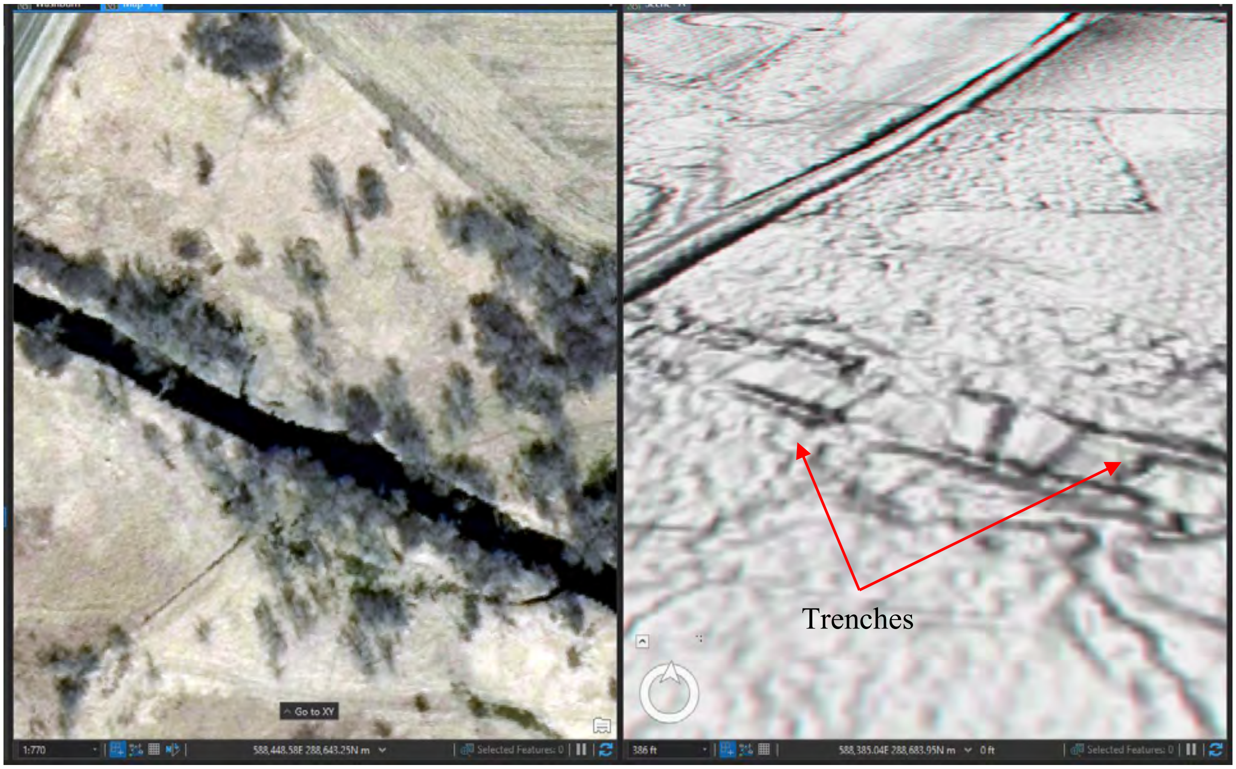

Figure 66. Example of "trenching" found along stream edges. The aerial image on the right shows the location of a stream. The three-dimensional representation of the elevation model on the left depicts the same location and the trenches on either side of the stream are clearly visible.

Due to the existence of these irregularities and inaccuracies, an accurate set of linear stream features could not be generated as a starting point for mapping stream linears according to the NWI mapping protocol. Instead, all stream wetland polygons were first mapped as a linear feature, buffered and reshaped to match the signatures from the collateral data and imagery using the process described in Section 2.2 above.

3.2 Data Caveats

3.2.1 Stream Single-line Network

The stream network generated from the wetland mapping is not intended to replace the existing 24K hydro-flowline dataset for Wisconsin. The purpose of this pilot project was to determine if a flowline network (comparable to the 24K network) could be derived that was coincidental to the wetland and deep-water habitat mapping. The proposed method of extracting the stream network from the wetland mapping was to extract all the wetland polygons identified as intermittent (R4) or perennial (R2 or R3) using the Cowardin classification. Geoprocessing tools were then used to derive a centerline for these polygons. Due to the constraints of the mapping standards and classification attribution rules required for wetland data to be included in the national NWI data repository, the resultant centerlines had gaps. In an effort to eliminate these gaps, classification codes representing intermittent and perennial streams from the LLWW classification were added (rivers (RV), streams (ST), lotic river (LR), and lotic stream (LS). This addition did close some of the gaps in the centerlines, but some still remained. These remaining gaps were locations where the stream polygons could not be isolated from the surrounding habitat due to the mapping standards required by the NWI. In the majority of cases, the stream ran through a larger wetland polygon, but in some cases, the stream was not digitized as a wetland habitat, or the stream coincided with a polygon(s) border. Section 2.3.2 above outlines the process that was developed to address these identified issues.

The "mapping" of the existing 24K segments to their counterparts in the wetland derived stream centerlines and the conflation of attributes was not undertaken as part of this project. The final product of the single-line stream network was attributed with only the type of flow present. Perennial or intermittent flow was taken directly from the wetland NWI classifications. In an effort to more closely replicate the attributes in the existing 24K dataset, in cases where a stream was included in a larger wetland polygon, centerline locations where derived based on interpretation of collateral datasets. These collateral datasets where a shaded relief symbolization of the DEM and a HPI. These datasets were draped over a hillshade model to provide a faux three-dimensional surface. A synthetic flow network derived from a flow accumulation model using a flow threshold of 0.5 acres was also utilized. Table 4 outlines the flow type categories that were ultimately used to attribute the flow type field (HYDROCODE attribute).

Table 4. Flow types used in the stream single-line mapping.

HYDROCODE	Definition
Perennial	Wetland polygon attributed as a perennial stream (NWI = R2 or R3)
Intermittent	Wetland polygon attributed as an intermittent stream (NWI = R4 and/or Waterflow Path = TI or OI)
Wetland connector - Perennial	Stream not digitized as unique polygon, but as part of larger wetland polygon Path of flow was digitized based on collateral data. Flow type was determined by wetlands waterflow attribute (TH)
Wetland connector - Intermittent	Stream not digitized as unique polygon, but as part of larger wetland polygon Path of flow was digitized based on collateral data. Flow type was determined by wetlands waterflow attribute (TI or OI)
Flow path - Perennial	Stream not digitized as part of wetland mapping. Determination of perennial was based on existing 24K mapping or the connecting digitized wetlands attributes
Flow path - Intermittent	Stream not digitized as part of wetland mapping. Determination of intermittent was based on existing 24K mapping or the connecting digitized wetlands attributes

3.3 Recommended Adaptions to the Methodology and Other Considerations

3.3.1 Imagery Resolution, Scale, and Minimum Mapping Units

Ideally, a wetland mapping project would use the same spring, leaf-off, primary image collection for the entire area intended to be delineated and classified. Spring, leaf-off, imagery is ideal in wetland identification for a number of reasons:

1. High flood stage of rivers and maximum capacity of wetland basins and depressions show outer boundary of wetland to upland. This is captured after the snow pack has melted and spring rain events have begun.

2. Deciduous trees and shrubs have not yet produced leaves, allowing interpreters to determine deciduous versus evergreen classification. The lack of a deciduous canopy also allows classification of ground vegetation underneath the canopy.

3. The presence of dead emergent vegetation compacted by the winter's snow pack allows classification of persistent emergent versus the non-persistent vegetation that will appear later in the summer, NAIP imagery.

Unfortunately, image acquisition in this pilot project was not consistent; the following imagery types and resolutions were used in the six, HUC12 subwatersheds: Ashland, Meadow Creek – six-inch, CIR, Dane, Mud Lake – eighteen-inch, true-color, Monroe, Mud Creek – six-inch, true-color, Vernon, Wester Creek – twelve-inch, CIR, Vilas, Trout Lake – six-inch, CIR, and Washburn, Long Lake – six-inch, true-color.

When embarking upon the scoping portion of a project the methodology is usually agreed upon before production of work. However, in a pilot project such as this, there is room for some experimentation in order to find a better suited methodology and produce the highest quality results, such was the case in determining a MMU. In the past GSS and its clients have agreed upon a MMU of one-half acre internal to wetland complexes and one-quarter acre for small isolated polygons when delineating off of NAIP – one-meter resolution, true-color, leaf-on imagery. For this pilot, all of the image resolutions were eighteen-inch, twelve-inch, or six-inch, which allow for mapping at a much tighter scale and the delineation and classification of much smaller wetlands.

The primary factor to consider in mapping wetlands with a small MMU is the efficiency at which production can be supported by the budget in order to complete the effort. Imagery with a one-meter (39-inch) resolution is nearly seven times courser than six-inch resolution. This allows an interpreter to zoom in to a much tighter scale to both see a wetland signature for classification and identify the outer boundary of the feature. Substantially more isolated polygons are created as well as more polygons are differentiated from the surrounding wetlands in large wetland complexes, which in turn increases the total time for production of wetland features, QA/QC review, and finalization tasks and tools. Ultimately, the cost to delineate polygons is directly influenced by the time spent zooming in and out, panning across a study area, refreshing collateral data, delineating polygons, and attributing the wetland. The smaller the MMU, the tighter the scale an interpreter needs to zoom in and out, which increases number of polygons will be produced and precision of boundaries; all of which will increase the time and cost of production.

3.3.2 Bare-Earth DEM Algorithm - Ashland

In our professional opinion, the bare-earth DEM developed from LiDAR did not provide the precision to detect the micro-topography that often determines wetland polygon extents in much of the clay plain of the Meadow Creek, Ashland County subwatershed. We recommend that the interpreter use vegetation signatures more heavily than what the LiDAR DEM indicates. The bare-earth DEM for this area appears "lumpy" and suspect that there was some issue in the algorithm used to strip off the first-return points that hit dense vegetation during the LiDAR point collection.

3.2.3 LiDAR and Imagery

Due to the potential for alignment issues between the LiDAR DEM (and its derivatives) and the base imagery, as well as other collateral data used, it is not recommended that LiDAR derivatives be used as the primary source in determining topographic locations of wetland boundaries. Digitizing wetland features from LiDAR products on some polygons and the base imagery on others introduces errors into the positional accuracy of the data. In all cases, it is encouraged to delineate features directly from the primary imagery (spring, leaf-off, high-resolution, preferably CIR imagery). These boundaries can then be adjusted and/or reshaped based on interpretation of the LiDAR derivatives and other collateral data.

The goal of the project was to develop a methodology that could be used to create wetland and surface water datasets that are both topographically and cartographically consistent. To ensure this it is recommended that the surface water dataset be derived from the wetland features. In the same manner as in the wetland mapping, the resultant stream features can then be adjusted and/or reshaped based on the interpretation of the LiDAR HDEM and LiDAR derived flow patterns.

3.2.4 Shallow surface ditches in the red clay plain

In the Meadow Creek Subwatershed of Ashland County, shallow surface ditches are common in the perennial forage, (hay or native grass mixes) agricultural fields. These ditched hay fields are common across agricultural fields in the Lake Superior Basin's red clay plain. The ditches are in place to reduce ponding; they convey water during spring snow melt and during rainfall events. Since the fields are often managed to provide perennial forage, (either cutting hay from them or pasturing livestock on them) and not typically cultivated and planted with annual crops, the ditches often have a high percentage of hydrophytes in them. If the ditches are left alone long enough (i.e., not maintained by mowing and occasional scraping) they will become colonized by vegetation, most of which is hydrophitic.

Some of these shallow ditches in the Meadow Creek Sub-watershed were mapped using the buffered linear process, (see page 5). These ditches are narrow, usually under one-meter in width, and often can be seen in the high-resolution aerial photography as having a subtle emergent wetland vegetation signature, (Figure 67). The deeper and wider excavated channels appear as a pale green in the color ramped elevation raster, (Figure 68). For this project, they were classified as excavated, intermittent-flowing, riverine features, (R4SBAx). However, there is question as to if these should be mapped at all considering the significant additional time it might take to do thoroughly and get every ditch and how exactly to consistently map them when they leave the farm fields and enter roadsides and into more natural flow paths in forested areas. There is also a question of how they be classified as in the National Wetland Inventory. Based on field work in other clay plain areas of Douglas County, Wisconsin, most of these narrow agricultural ditches are acting as ephemeral conveyances of water and wetland vegetation signatures can be detected if available aerial photography is of high enough resolution. They develop hydrophytes because there is frequently enough water in these clay dominated soils that allows water to drain downslope but water does very little infiltration. There are also exceptions to the nature of the flow within these in-field ditches. For example, there are cases in Douglas County were the ditch is coincident with an intermittent stream according to existing WI

24K Hydro data, where the ditch (intermittent stream) occurs in the middle of a hay field with several feeder ditches coming into it. Therefore, in these cases, the shallow ditches may actually be conveying significant volumes of water and flow may be at least intermittent.

Figure 67. Shallow surface ditches visible in CIR imagery of a hay field in the Meadow Creek Subwatershed, Ashland County - 1;2,000.

Figure 68. Shallow surface ditches visible in color ramped elevation model of a hay field in the Meadow Creek Subwatershed, Ashland County - 1;2,000.

Ephemeral riverine features are often not mapped as part of typical NWI mapping and classification in most Midwestern states. How these shallow surface ditches that are prevalent across agricultural lands in the red clay plain are to be handled in future mapping efforts will require some thoughtful consideration. As opposed to mapped as riverine features, they might also be considered as excavated palustrine features (e.g., PEM1Ax) because they spend a large part of the season not conveying water, but support hydrophytes. Field testing in this area was not part of this pilot project so these classification mapping conventions were not fully determined. Since their shape was long and narrow and they were created to move water off the field, it was determined that these had enough flow, and were best represented as riverine – R4SBAx. Field verification would also help to determine if the water mostly stayed stagnant in the channel or flowed continuously into a larger wetland channel or complex.

4. Future Adaptations/Data Needs

4.1 Hydro-enforcement of the DEM

If the issues raised above about the inconsistences and inaccuracies in the LiDAR data are addressed, a HDEM could be generated for use in hydrologic analysis based on the derived stream single-line feature class. A synthetic flow network could be derived from the bare earth DEM using the standard process of identifying and filling sinks, and creating a flow direction and flow accumulation model from the filled DEM. A synthetic flow network could then be derived using an initiation threshold for the watershed. This resultant flow network could be compared to the single-line network to identify and derive a digital dam breakline dataset. This could then be used to create a HDEM using the ACPF tools or some other equivalent geoprocessing model.

4.2 Future Uses of Lidar

A number of collateral datasets instrumental to the wetland mapping process and the derivation of surface water features were derived from the LiDAR bare earth DEM available for each project watershed. In addition to the bare earth DEM, other collateral datasets can be derived from the LiDAR point cloud data that could inform the delineation of and attribution of the wetland mapping. The “first return” points from the point cloud can be used to create DEMs that represent average vegetation height and canopy cover, (Esri 2017).

Feature extraction techniques have the potential to provide datasets that can inform the mapping and attribution or provide initial polygon or polyline map units. Geomorphic features (channel heads and channel networks) can be extracted and channel morphometric analysis could provide both initial map units and assist in attribution (Passalacqua, Belmont and Goufoula-Georgiou 2012). This process and the traditional method of delineating surface water features from a LiDAR DEM. Surface water features can also be derived from the LiDAR point cloud data. Methodologies for extracting stream channel flow paths (Anderson and Ames 2011) and open water polygons from the LiDAR point cloud can be used to produce initial mapping (Worstall, et al. 2014).

The process developed by Worstall et al. (2014) was tested during this project for the accuracy of providing initial open water polygons for use in the wetland mapping. This methodology was developed to create breakline data for use in the hydro-conditioning of a LiDAR DEM for use in hydrologic analysis. In the collection of the LiDAR data, LiDAR pulses are normally absorbed by water, resulting in voids or low intensity returns in the LiDAR point cloud (Worstall, et al. 2014). Data analysis techniques can be used to identify and evaluate these locations as water bodies that can be converted to polygon features. The methodology was followed to create polygon features representing lakes, ponds, streams and rivers for each of the 6 watersheds in the pilot project. The results of the testing were mixed, in some watersheds the process resulted in lake and wetland polygons that were extremely accurate (Figure 69). In other watersheds, the method was extremely ineffective (Figure 70). Analysis of the resultant polygons and LiDAR point cloud showed that 2 factors were instrumental in the accuracy of the water body polygons, the point spacing of the point cloud and clarity of the water. Due to this, the polygons created where not used as starting points for the wetland mapping. In the watersheds with the larger point spacing, voids and low intensity return levels in the point cloud extended inland from the actual locations of water. This resulted in polygons that overestimated the locations of open water and would require extensive editing to fix. In Ashland County, the situation was different. Due to the geography of the landscape and the timing of the LiDAR collection, all waterbodies exhibited quite a bit of turbidity, resulting in the reflection of the LiDAR pulse by the water instead of absorbing the pulse (Figure 70).

Figure 69. Open water polygons derived from the LiDAR point cloud dataset for the Mud Creek watershed in Monroe County. The image on the left is the aerial photo and the image on the right has the open water polygons overlaying the aerial photo.

Figure 70. Open water polygons derived from the LiDAR point cloud dataset for the Meadow Creek watershed in Ashland County. The image on the left is the aerial photo and the image on the right has the open water polygons overlaying the aerial photo.

Literature Cited

Anderson, Danny L., and Daniel P. Ames. 2011. "A method for extracting stream channel flow paths form LiDAR point cloud data." *Journal of Spatial Hydrology* 11 (1).

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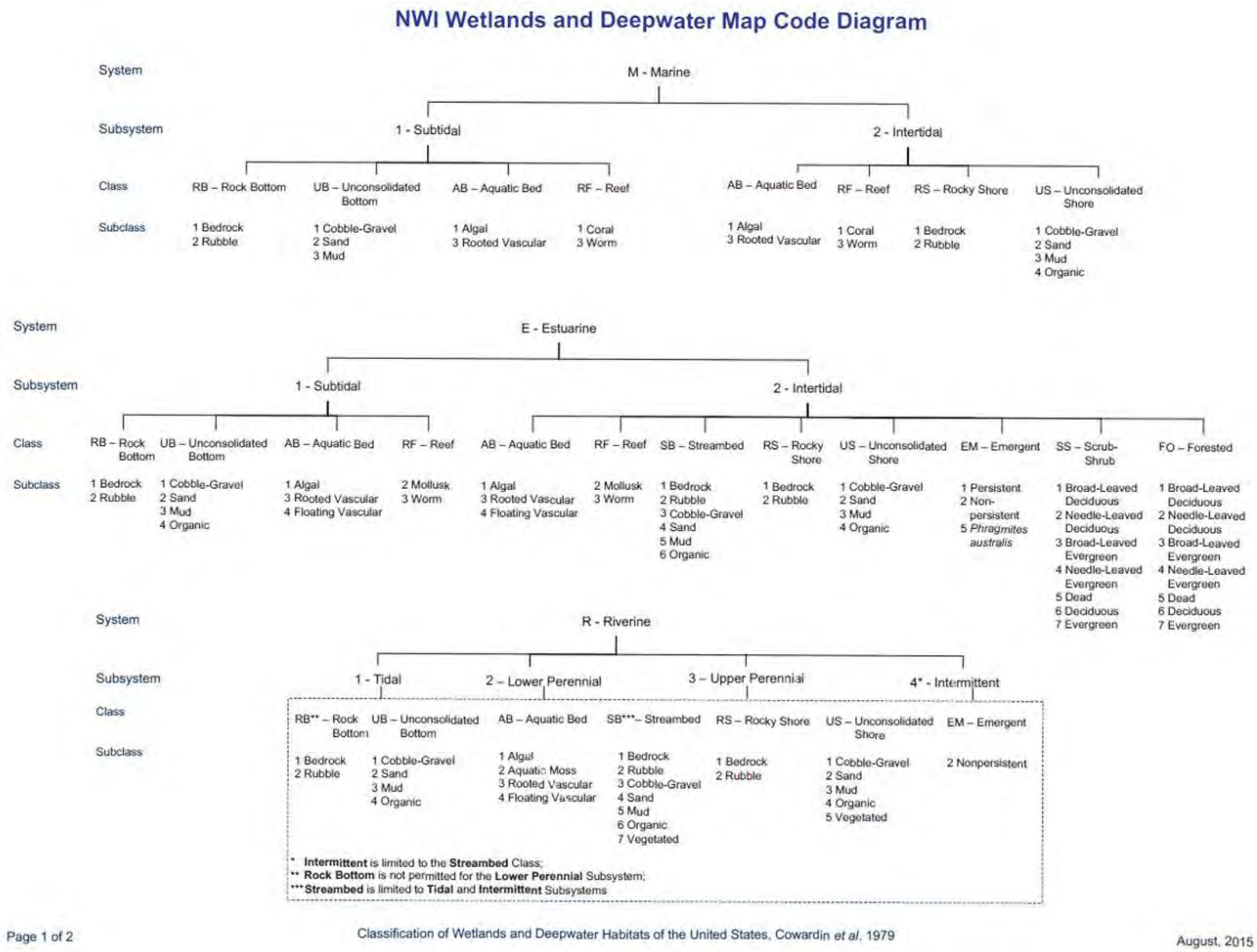
Appendix A. Wetlands and Deepwater Habitats Classification



NWI Wetlands and Deepwater Map Code Diagram

System: L - Lacustrine

Subsystem: 1 - Limnetic

Class	RB – Rock Bottom	UB – Unconsolidated Bottom	AB – Aquatic Bed
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular

Subsystem: 2 - Littoral

Class	RB – Rock Bottom	UB – Unconsolidated Bottom	AB – Aquatic Bed	RS – Rocky Shore	US – Unconsolidated Shore	EM – Emergent
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic 5 Vegetated	2 Nonpersistent

System: P - Palustrine

Class	RB – Rock Bottom	UB – Unconsolidated Bottom	AB – Aquatic Bed	US – Unconsolidated Shore	ML – Moss-Lichen	EM – Emergent	SS – Scrub-Shrub	FO – Forested
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic 5 Vegetated	1 Moss 2 Lichen	1 Persistent 2 Nonpersistent 5 *Phragmites australis*	1 Broad-Leaved Deciduous 2 Needle-Leaved Deciduous 3 Broad-Leaved Evergreen 4 Needle-Leaved Evergreen 5 Dead 6 Deciduous 7 Evergreen	1 Broad-Leaved Deciduous 2 Needle-Leaved Deciduous 3 Broad-Leaved Evergreen 4 Needle-Leaved Evergreen 5 Dead 6 Deciduous 7 Evergreen

MODIFIERS

In order to more adequately describe the wetland and deepwater habitats, one or more of the water regime, water chemistry, soil, or special modifiers may be applied at the class or lower level in the hierarchy.

Water Regime			Special Modifiers	Water Chemistry		Soil
Nontidal	**Saltwater Tidal**	**Freshwater Tidal**		**Halinity/Salinity**	**pH Modifiers for Fresh Water**	
A Temporarily Flooded	L Subtidal	S Temporarily Flooded-Fresh Tidal	b Beaver	1 Hyperhaline / Hypersaline	a Acid	g Organic
B Seasonally Saturated	M Irregularly Exposed	Q Regularly Flooded-Fresh Tidal	d Partly Drained/Ditched	2 Euhaline / Eusaline	t Circumneutral	n Mineral
C Seasonally Flooded	N Regularly Flooded	R Seasonally Flooded-Fresh Tidal	f Farmed	3 Mixohaline / Mixosaline (Brackish)	i Alkaline	
D Continuously Saturated	P Irregularly Flooded	T Semipermanently Flooded-Fresh Tidal	m Managed	4 Polyhaline		
E Seasonally Flooded / Saturated		V Permanently Flooded-Fresh Tidal	h Diked/Impounded	5 Mesohaline		
F Semipermanently Flooded			r Artificial Substrate	6 Oligohaline		
G Intermittently Exposed			s Spoil	0 Fresh		
H Permanently Flooded			x Excavated			
J Intermittently Flooded						
K Artificially Flooded						

Appendix B. Common LLWW Descriptors, Codes, and Definitions

LLWW Attribute	Code	Definition
Landscape Position		
Lentic	LE	Wetlands associated with a lake basin or the relatively flat plain adjacent. (Lacustrine)
Lotic River	LR	Wetland that is within the banks or periodically flooded by a river. (Riverine)
Lotic Stream	LS	Wetland that is within the banks or periodically flooded by a stream. (Riverine)
Terrene	TE	Wetland or wetland complex that is surrounded by upland. It is not found within a floodplain or lake basin. It is not affected by lake, river, or stream flow processes. (Palustrine)
Landform		
Basin	BA	Wetlands that occur in a distinct depression.
Flat	FL	Wetlands that occur on relatively level ground surface.
Floodplain	FP	Wetlands that occur within an active flood zone of a river or stream.
Fringe	FR	Wetlands that occur in the shallow water zone of a permanent water body.
Interfluve	IF	Region of wetlands between two rivers, in the same drainage system.
Island	IL	A wetland or complex of wetlands that are completely surrounded by water.
Slope	SL	Wetlands occurring on a gradient of five-percent or greater.
Waterflow Path		
Bidirectional	BI	Wetlands adjacent to lakes that are subject to the rise and fall of its water level. There is no influence from rivers or streams to the lake or surrounding wetlands.
Inflow	IN	Wetlands found in sinks receiving water from streams, rivers, or other surface source. These wetlands lack surface water outflow.
Outflow	OU	Water flows out from the wetland or complex naturally, but there is no source of water inflow.
Outflow Artificial	OA	Water flows out from this wetland or complex via drainage ditches or underground tiles.
Outflow Intermittent	OI	Outflow occurs from this wetland or complex at intervals, not continuously, and lacks inflow source.
Throughflow	TH	Water flows naturally into and out of these wetlands. They are often adjacent to rivers and streams.
Throughflow Artificial	TA	Water flows into and out of these wetlands and complexes via drainage ditches.
Throughflow Intermittent	TI	Water flows into and out of at intervals, not continuously and is associated with intermittent streams.
Vertical Flow	VR	Water may move in and out via groundwater seepage, it may also enter by precipitation and surface flow, or exit by evaporation.
Waterbody Type		
Lake	LK	A body of water within a large lacustrine basin, much smaller than lakes. (Lacustrine)
Pond	PD	Open water, sand, or mud depressions much smaller than lakes. Ponds may be broken down into subclasses of natural, damned, excavated, beaver, or other. They can be further broken down by modifier to agriculture, commercial, industrial, aesthetic, or recreational. (Palustrine)

LLWW Attribute	Code	Definition
Waterbody Type (cont.)		
River	RV	A flowing watercourse that empties into a larger water body such as a lake, sea, ocean or other river. It must be a polygon feature on a U.S. Geological survey or National Wetland Inventory map. (Riverine)
Stream	ST	A flowing watercourse that empties into a larger water body such as a river, lake, or other stream. They are narrower, shorter, and carry less volume of water than rivers. Streams and rivers are broken into low, middle, and high gradients, intermittent or dammed. (Riverine)
Special Modifiers		
Barren	br	Wetlands lacking vegetation such as beaches, sand bars, and mud flats.
Beaver	bv	Wetlands that include area upstream flooded by beaver dams.
Channelized	ch	Stream or river that is dug wider or deeper to alter the general flow of a watercourse.
Cranberry bog	cr	Excavated shrub wetland constructed for cranberry production.
Drainage divide	dd	Wetlands found on watershed boundary that typically have outflow.
Diverted	dv	Wetlands where the course or direction of surface flow is altered.
Fragmented	fg	Wetlands broken from complexes due to railroads, roads, or utilities.
Floating Mat	frn	Carpet of vegetated material supported on water's surface - sphagnum moss.
Floating vegetation	fv	Duckweed, water hyacinth, or water lilies.
Leveed	lv	Wetlands altered by an artificially constructed dike or embankment.
Headwater	hw	Water source for wetlands and complexes downstream and includes wetlands along first and second order streams and intermittent streams upslope.
Lake island	li	Wetland connected to upland island that is completely surrounded by open water or lake.
Partly drained	pd	Wetland with majority of water removed - farmed wetland.
Pond island	pi	Wetland connected to upland island that is completely surrounded by open water of pond.
River island	ri	Wetland connected to upland island that is completely surrounded by open water of river.
Human influenced	hi	Significantly degraded by human activities and often changes the function or level of function.
Spring-fed	sf	Wetlands where ground water reaches the surface to produce a seep or fen.
Subsurface flow	ss	Wetlands affected by the movement of water beneath the earth's surface..
Submerged vegetation	sv	Watercress, hydrilla, and water milfoil.
Surface water	sd	Wetlands that receive their water from runoff and flooding.

Appendix C. U.S. Fish and Wildlife Service Verification Tool

U.S. Fish & Wildlife Service
National Wetlands Inventory
National Standards and Support Team

Wetlands Data Verification Toolset

Installation Instructions and User Information

ESRI ArcMap Version 10.3.1

June 2016

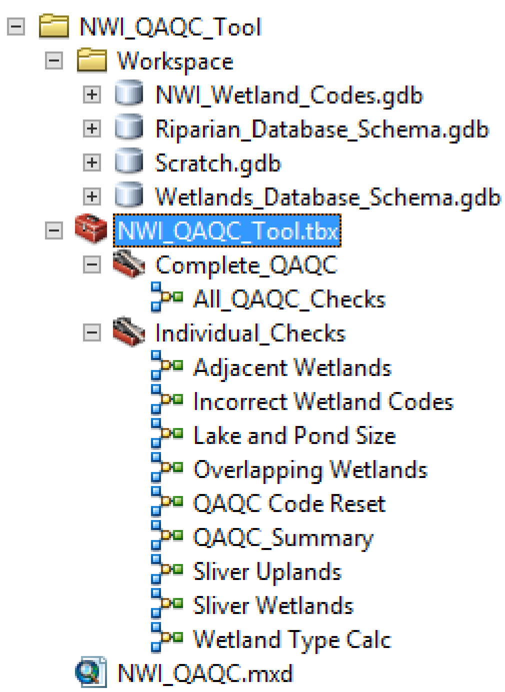
Mitchell T. Bergeson
U.S. Fish and Wildlife Service
Division of Ecological Services
Branch of Geospatial Mapping and Technical Support
National Standards and Support Team

Introduction

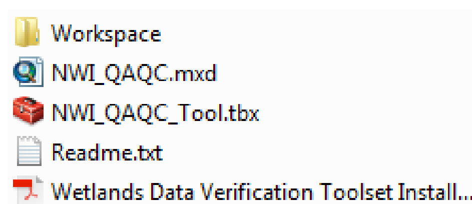
The Wetlands Data Verification Toolset is designed to automate the quality control functions necessary to ensure data in the Wetlands geodatabase is accurate. It has been designed to address geospatial errors, digital anomalies, and logic checks. The tool should be run multiple times by photo interpreters while mapping wetlands and as an interim and final quality control step. This toolset was created using Environmental Systems Research Institute's (ESRI) ModelBuilder, is compatible with ESRI's ArcDesktop 10.3.1 software suite, only works on File Geodatabases, and replaces previous custom Wetlands Verification Tools.

Getting Started

The Verification Toolset and associated files are stored in an 'NWI_QAQC_Tool' folder. This folder can be stored in any location on your machine and contains:



NWI_QAQC_Tool view
in ArcCatalog.



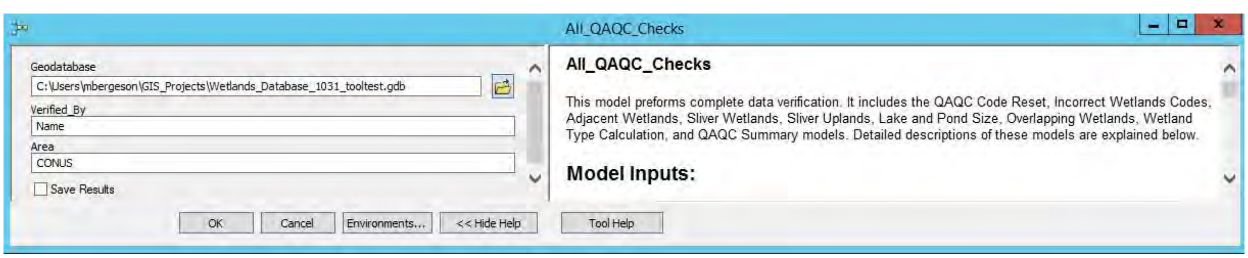
NWI_QAQC_Tool view
In Windows Explorer.

The Readme.txt provides a general description of the contents and purpose of the folder. The Wetlands Data Verification Toolset Installation and User Information document provides descriptions and procedures on the use of the verification models. The Workspace folder is used for writing intermediate data from the models and contains a file geodatabase named Scratch.gdb that is required for the models to run correctly. This folder also contains a file geodatabase of wetland codes and an example file geodatabase of the wetlands and riparian database schema. The NWI_QAQC_Tool.tbx is the ArcToolbox that contains the Wetlands QAQC models and the NWI_QAQC.mxd can be used to cartographically view errors.

Running the models

This toolset was designed to work on File Geodatabases extracted from the FWS Wetlands Database and will only work on data with that schema. In particular, it requires the feature class CONUS_wet_poly in a CONUS_wetlands feature dataset, and CONUS_wet_projects in a CONUS_projects feature dataset (substitute AK, HI, PRVI or PacTrust for CONUS in other mapping areas). The CONUS_wet_projects feature class must contain a polygon that completely covers the area where wetland mapping was conducted. This project polygon should represent the exact extent of the area that wetland mapping was conducted. A sample File Geodatabase is provided with this tool in the Workspace folder. This sample file geodatabase can be copied and loaded with wetlands data or used as a reference to build file geodatabases with the correct schema. Use of this toolbox on other data formats or schemas is not recommended and will likely fail.

To run any of the QAQC models, simply navigate to the NWI_QAQC_Tool toolbox in ArcCatalog, which is in the NWI_QAQC_Tool folder, open the toolbox, open either the Complete_QAQC toolset or the Individual_Checks toolset and double-click on any of the models. A window will appear, similar to the one below, which will allow the user to select input data and provides a description of the tool on the right pane, if the Show Help >> button is selected. Click the browse button next to the Geodatabase text box and browse to the Wetlands file geodatabase you want to conduct verification on (or drag and drop), identify the mapping area you are working in, and then press 'Ok'. Some models also require the entry of your name in the 'Verified_By' text box and provide a check box which allows you to save the results. Each verification check can be run individually to address specific types of errors by using the models in the Individual_Checks Toolset or all the verification checks can be run at once using the All_QAQC_Checks model. Note: Because the Overlapping Wetlands and the All_QAQC_Checks use the topology layer, schema lock errors will occur if the data is in ArcMap when those models are run, unless you run those models from the Catalog window in that ArcMap session. All other individual models can be run when the data is in an ArcMap session from the standard ArcCatalog interface.



Example of a model user interface.

Modifications and Use Recommendations

This toolset was created using Environmental Systems Research Institute's (ESRI) ModelBuilder, is compatible with ESRI's ArcDesktop 10.3.1 software suite, only works on File Geodatabases, and replaces previous custom Wetlands Verification Tools. To improve performance of this toolset it is recommended that the tool and data are stored on the same computer. Modifications to this 10.3.1 tool include: the most recent, expanded and up to date wetland code list from June 2016, the addition of quad boundaries to improve the performance of the Upland Slivers tool, the use of ESRI topology to improve performance of identifying Overlapping Wetlands, and the insertion of a compact geodatabase and repair geometry functions before every tool is run to reduce the occurrence of lost data after an edit session due to an ESRI bug. This ESRI bug has not been resolved in 10.3.1 or earlier versions so be sure to make backup copies on the data often and check polygon counts before and after edit sessions and running models. When loss of data is observed, exporting and reloading the data from that feature class has shown to force the geodatabase to read the missing features and they reappear.

Explanations of the Verification Models

All QAQC Checks

This model performs complete data verification. It includes the QAQC Code Reset, Incorrect Wetland Codes, Adjacent Wetlands, Sliver Wetlands, Sliver Uplands, Lake and Pond Size, Overlapping Wetlands, Wetland Type Calculation, and QAQC Summary models. Detailed descriptions of these models are explained below. Check the 'Save Results' box to permanently save date stamped summary tables to your file geodatabase. The tool was designed to be run multiple times by photo interpreters while doing update work and in the process over writes the summary tables every time the tool is run. To pass the summary results and comments about the errors up the line to the next reviewer check this box to save a copy of the summary tables to your geodatabase.

QAQC Code Reset

This model calculates the QAQC_Code = 'NNNNNN'. This erases all recorded errors in the dataset and properly attributes the field for use by all other models.

Incorrect Wetland Codes

This model identifies wetland polygons with incorrect wetland codes, or null or blank values in the 'attribute' field. A bad attribute summary table is created and stored with your wetlands file geodatabase. Changes character 1 of QAQC_Code = 'C' if wetland code is bad.

Adjacent Wetlands

This model identifies wetland polygons that are adjacent to other wetland polygons with the same 'attribute' and changes the second character of QAQC_Code = 'A'.

Sliver Wetlands

This model identifies wetland polygons less than 0.01 acres and changes the third character of QAQC_Code = 'S'. These wetland features fall below the minimum mapping standard for wetlands and should be reviewed. Actual wetland features flagged as sliver wetlands can be justified as correct in the comments field of the QAQC_Summary table. These comments will only be saved if the 'Save Results' box is checked prior to running the All_QAQC_Checks model.

Sliver Uplands

Identifies upland islands or holes in wetlands that are less than 0.01 acres. These may be actual upland features but are identified as errors as they are typically errors in wetland mapping. The model changes the fourth character of QAQC_Code = 'U', in all wetland polygons adjacent to the upland sliver. The sliver upland polygons are stored as a new feature class 'Sliver Uplands' in your wetlands file geodatabase to assist in locating these small geographic features for review. This tool requires that a 'CONUS_wet_projects' has a feature(s) that defines the wetland mapping project and completely covers all features in the 'CONUS_wet_poly' feature class. NOTE: This tool is a computationally intensive process and may fail on extremely large geographic areas. To remedy this possible failure, quads that intersect the project polygon are used in this tool. Recognize that this may identify false sliver uplands along the interior quad lines within your project. These false sliver uplands can be deleted from the sliver upland feature class and comments can be added to the QAQC_Summary table to note these false errors.

Lake and Pond Size

This model identifies Lakes that are less than 20 acres in size and Ponds that are greater or equal to 20 acres in size. It changes the fifth character of QAQC_Code = 'L' for small lakes or 'P' for large ponds. These may or may not be errors and can be justified based on water depth of the identified waterbody or small lake portions on the edge of the mapping project area. Comments can be added to the 'comments' field of the QAQC_Summary table for those wetland features flagged that are valid based on depth requirements outlined in the wetlands mapping standards.

Overlapping Wetlands

This model identifies overlapping wetland polygons and changes the sixth character of QAQC_Code = 'O'. The overlapping portions of these polygons are stored in wetlands file geodatabase as an 'Overlapping_poly' feature class to assist in locating these features. It is also important to note that utilization of smoothing, buffering, and other functions that produce Bayesian curves along coincident wetland polygon boundaries may result in very small overlapping areas that may not be identified by this tool.

Wetland Type Calculation

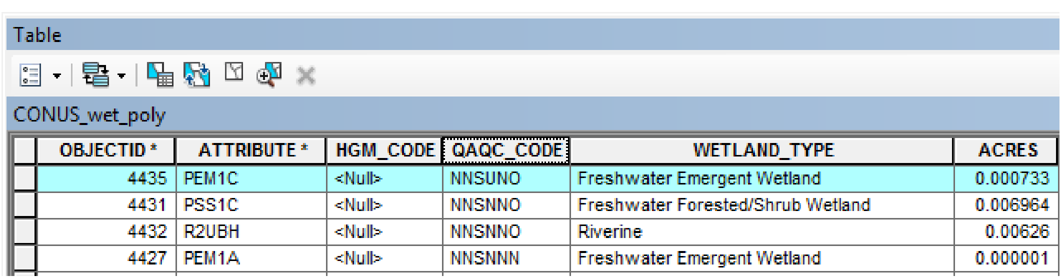
This model calculates the 'wetland_type' field based on the wetland code in the 'attribute' field. The 'wetland_type' field provides a general description of the wetland and is used in the cartographic representation of the different wetland types on the Wetlands Mapper.

QAQC Summary

This model summarizes the QAQC_CODE field into a 'QAQC_Summary' table in your wetlands file geodatabase. It also describes each error type and records who conducted the verification and when the verification was run. Comments can be added to the 'comments' field of the QAQC_Summary table to justify specific types of errors. These comments will only be saved if the 'Save Results' box is checked prior to running the All_QAQC_Checks model.

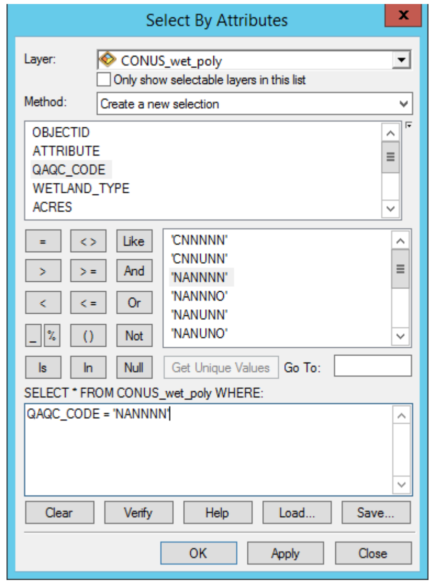
Reviewing Verification Errors

To find specific instances of an error in ArcMap sort the attribute table by QAQC_CODE and double-click the gray box associated with a given record on the far left side of the table. This will zoom the ArcMap display to that polygon.

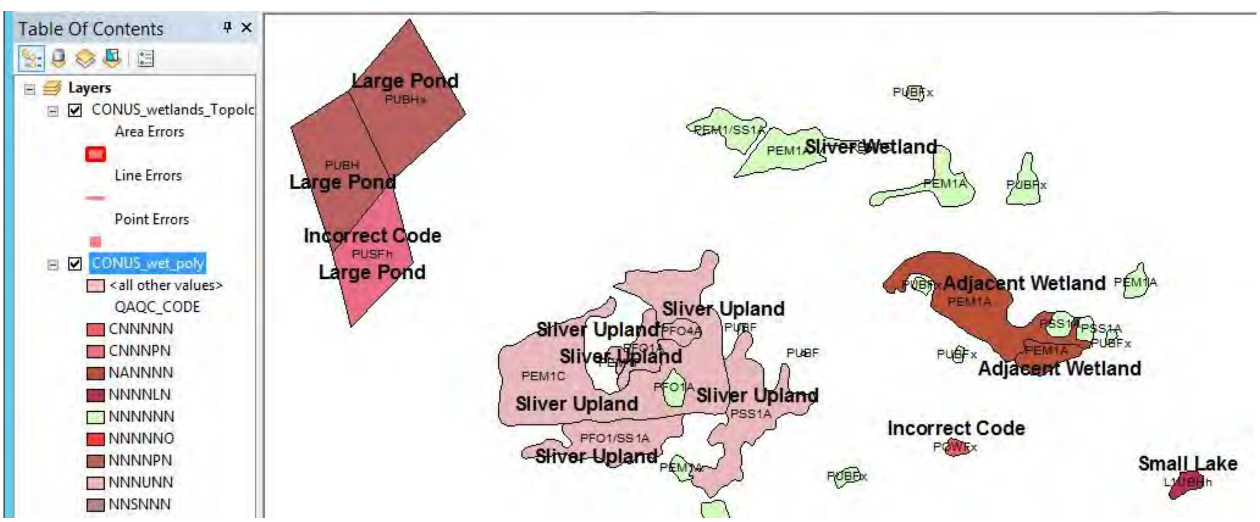


OBJECTID *	ATTRIBUTE *	HGM_CODE	QAQC_CODE	WETLAND_TYPE	ACRES
4435	PEM1C	<Null>	NNSUNO	Freshwater Emergent Wetland	0.000733
4431	PSS1C	<Null>	NNSNNO	Freshwater Forested/Shrub Wetland	0.006964
4432	R2UBH	<Null>	NNSNNO	Riverine	0.00626
4427	PEM1A	<Null>	NNSNNN	Freshwater Emergent Wetland	0.000001

The 'Select by Attribute' function in ArcMap can also be used to select all records of a defined QAQC_CODE value. Example below:



To cartographically view the errors, create symbology rules on the CONUS_wet_poly feature class using the QAQC_CODE field. (e.g. QAQC_CODE = 'NNNNNN' symbolize green, all other values symbolize in shades of red). Or use the NWI_QAQC.mxd found in the NWI_QAQC_Tool folder. This map document color codes and labels errors.



Example of
NWI_QAQC.mxd

For further information, assistance or questions contact: Wetlands_Team@fws.gov

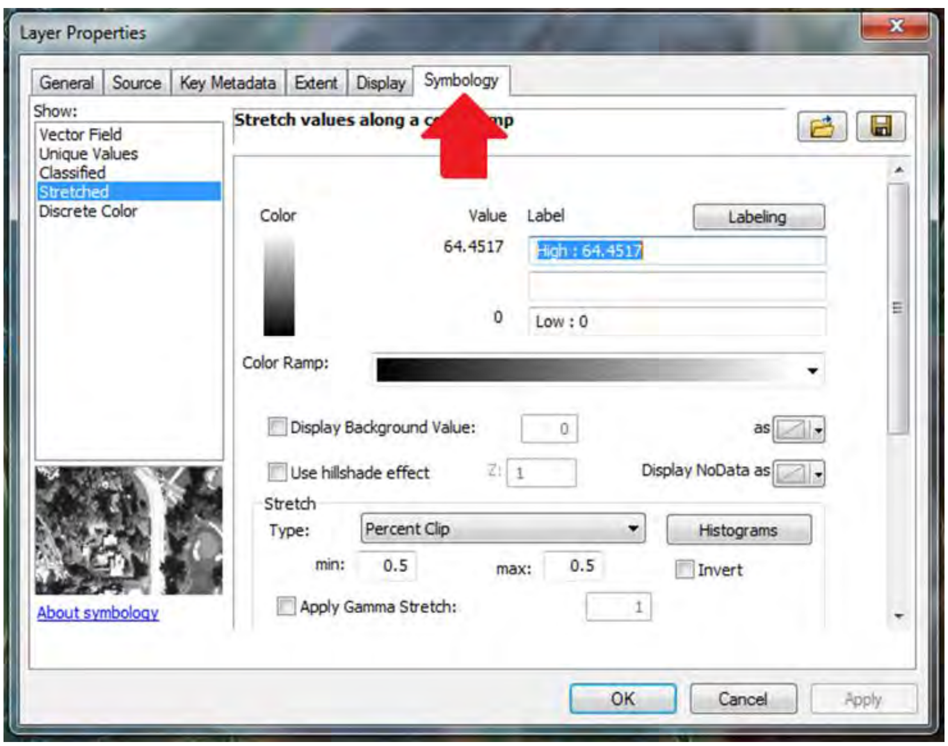
Appendix D. Wisconsin Elevation Visualization Method

The following process was developed by the WI DNR's Christopher Noll to better represent relative elevation values in the six HUC12 subwatersheds.

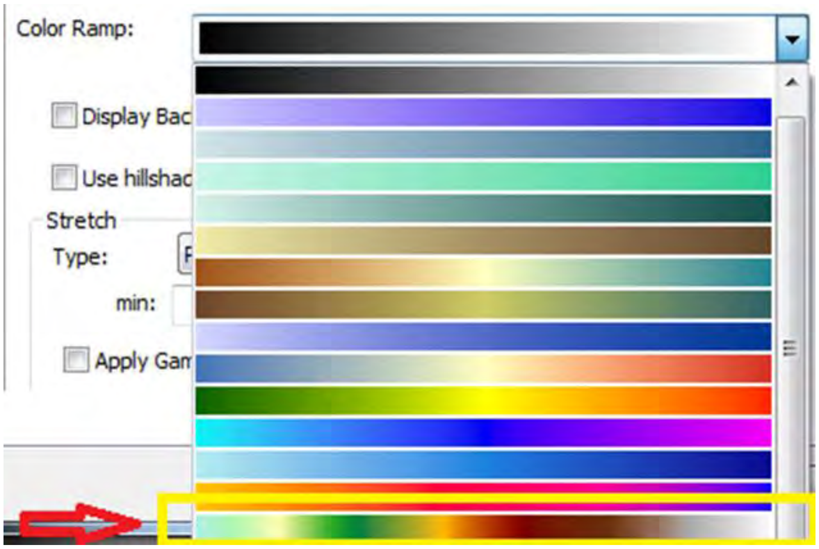
Steps for adding LiDAR images and properly applying a color ramp in ArcMap (pers comp. Chris Noll, Wisconsin Wetland Inventory Production/Wetland Biologist, WDNR, 11 January 2019).

Within an open ArcMap (.mxd) document…*

1. **ADD THE LIDAR ELEVATION RASTER.** Click the "Add Data" button. Navigate to your raster, click "Add"
   - a In the table of contents, Right-click the newly added "LidarElevation.tif" layer, then click "zoom to layer".
   - b In the table of contents, Right-click "LidarElevation.tif", select "Properties" at the bottom of the menu. Within the properties box:
     - i) Click the "Symbology" Tab

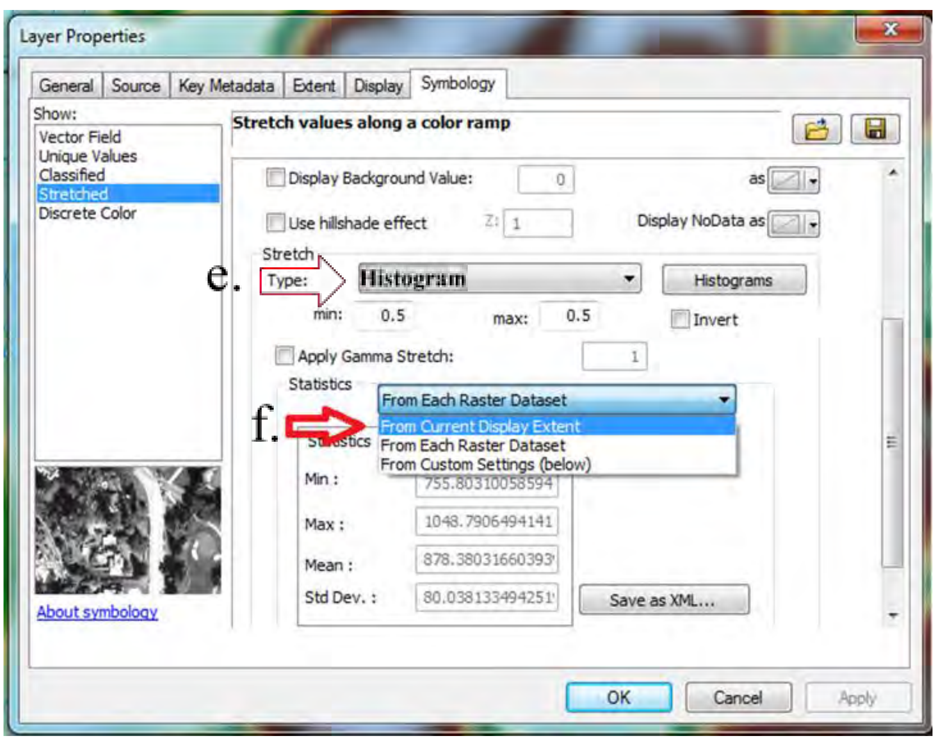


   - c Change the Color ramp from grayscale to multi-color. Click "Apply" on the bottom right.

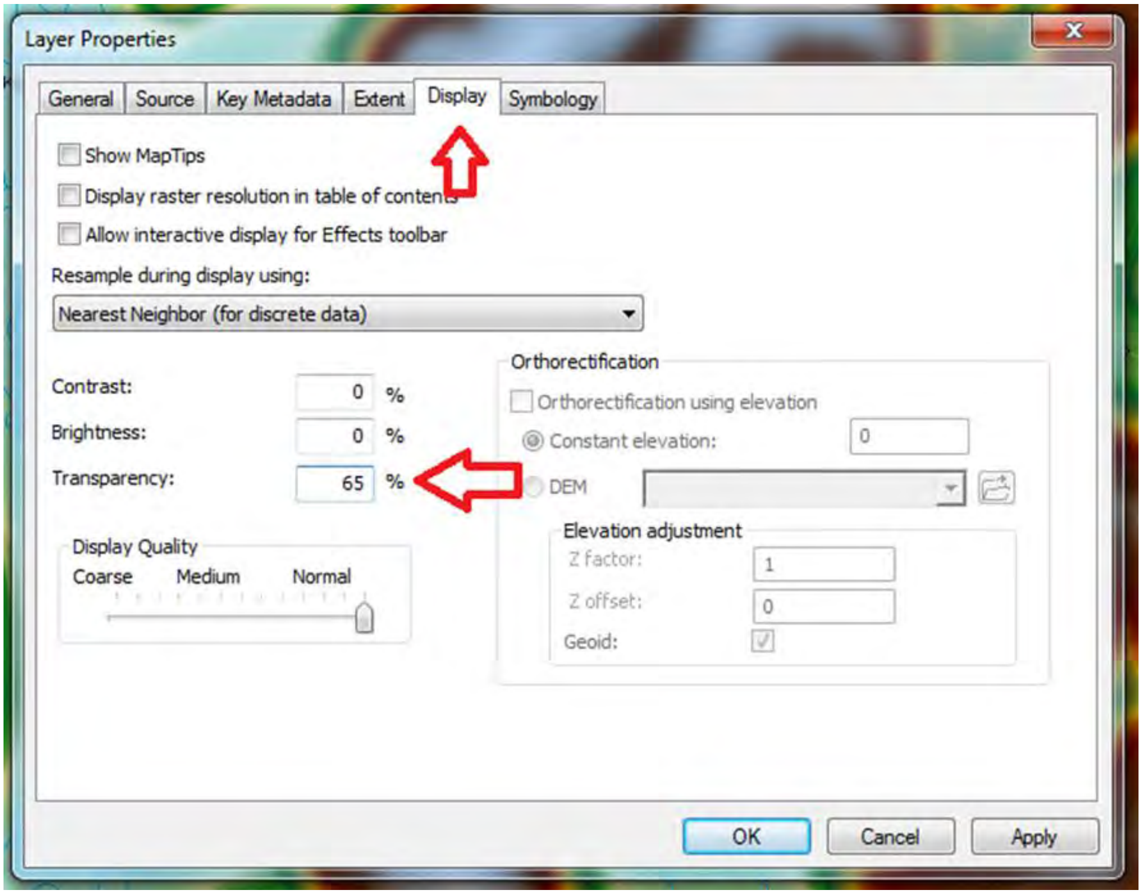


d Change the Stretch Type to "**<u>Histogram Equalize</u>**"

e Scroll down until you see "Statistics". Change to "From Current Display Extent". Click Apply. This will re-stretch the image to the maximum color range within elevations displayed on screen.



f Click the "Display" Tab, Set Transparency to 65%. Click "OK"



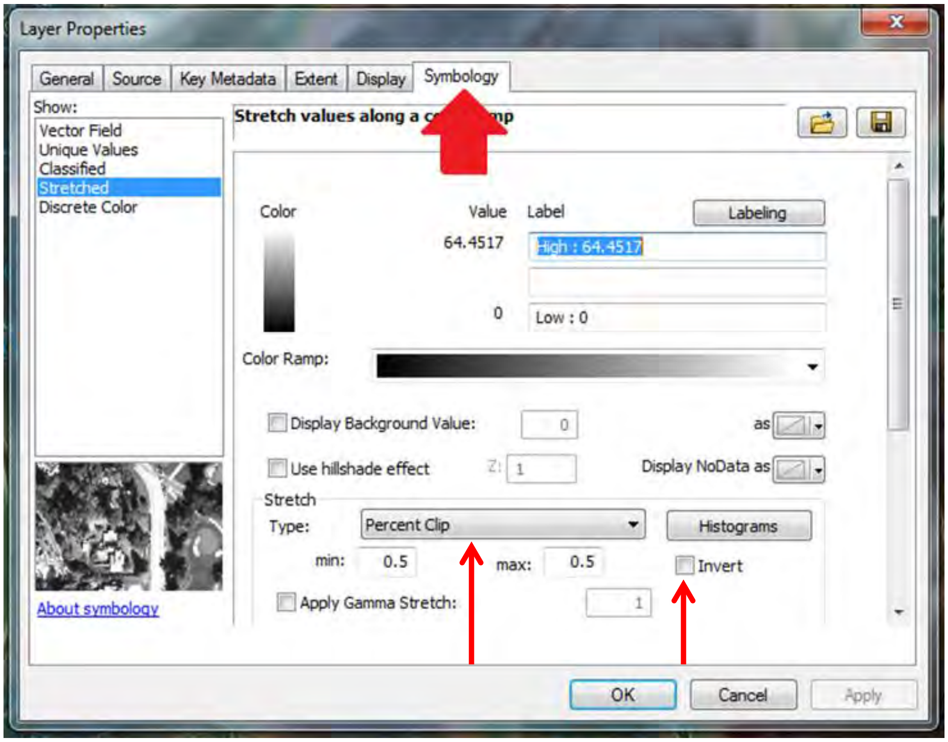
2. **ADD THE SLOPE RASTER.**

   a **If not already created, generate a slope raster using ArcToolbox "Spatial Analyst Tools -> "Surface" -> "Slope" Tool**

   b Click the "add data" button, browse to your slope raster file location. Click "Add"

   c In the table of contents, **click and hold** on "dane_slope1.tif" and **<u>drag it below the LiDAR tiff from the previous step.</u>**

   d Right-click "dane_slope1.tif" and select "Properties". Click the "Symbology" Tab.



e Change the stretch type to “Minimum-maximum”

f Click the “Invert” Checkbox and hit “apply”.

g Scroll around in your new map background! If happy with the results, **save your MXD.**

Notes: This arrangement of LiDAR data layers allows for both slope and elevation to be easily recognized. Pale greens and blues (think water) represents the low elevations, while brown and white (think snow-capped mountains) represent higher elevations. Gray-shaded areas indicate areas where the ground is sloped, with darker gray corresponding to steeper slopes. Because “Statistics are calculated from display extent”, ArcMap re-stretches the color ramp to take full advantage of the display capabilities to greatly exaggerate small changes in elevations when fully zoomed in. This allows us to see features like mounded peat domes in an otherwise almost-flat wetland complex quite clearly, but it can also over-accentuate topographical features to create false upland/wetland signatures, so judicious use is encouraged!

Appendix E. Raster Geoprocessing Models and Equations

Appendix E1. Contour Topographic Index

The compound topographic index is often referred to as the steady state wetness index. It is and it is defined as: CTI = ln (*As* / tan*B*) where *As* is the specific catchment area expressed as m^2 per unit width orthogonal to the flow direction and *B* is the slope angle. This basic equation can be reproduced using ArcGIS ModelBuilder (Figure E1). In this model, the Flow Accumulation raster represent *As* and a Slope (degrees) raster represents *B*.

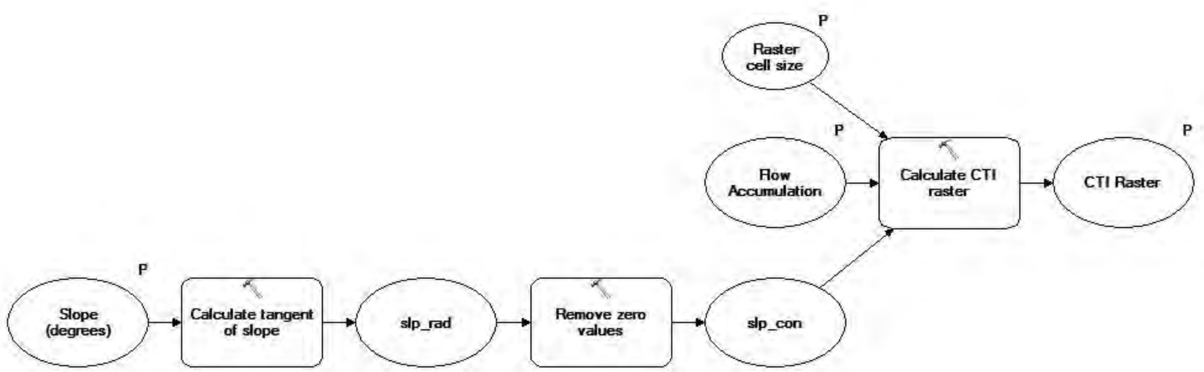


Figure E1. Graphical representation of the process used to create a CTI.

Within the model, the following processes contain the equations that are used to derive the CTI raster from the two raster inputs;

Calculate tangent of slope: Tan(("%Slope (degrees)%" * 1.570796) / 90)

Remove zero values: Con("%slp_rad%"==0,0.0001,"%slp_rad%")

Calculate CTI raster: Ln((("%Flow Accumulation%" + 1) *(%Raster cell size% * %Raster cell size%)) / "%slp_con%")

Appendix E2. Stream Power Index

The stream power index is normally used to describe potential flow erosion at any given point in a watershed. However, due to the fact the SPI is identifying flow paths it is also relevant as an indicator or channelized flow. It is and it is defined as: CTI = ln (*As* * tan*B*) where *As* is the specific catchment area expressed as m^2 per unit width orthogonal to the flow direction and *B* is the slope angle. This basic equation can be reproduced using ArcGIS ModelBuilder (Figure E2). In this model, the Flow Accumulation raster represent *As* and a Slope (degrees) raster represents *B*.

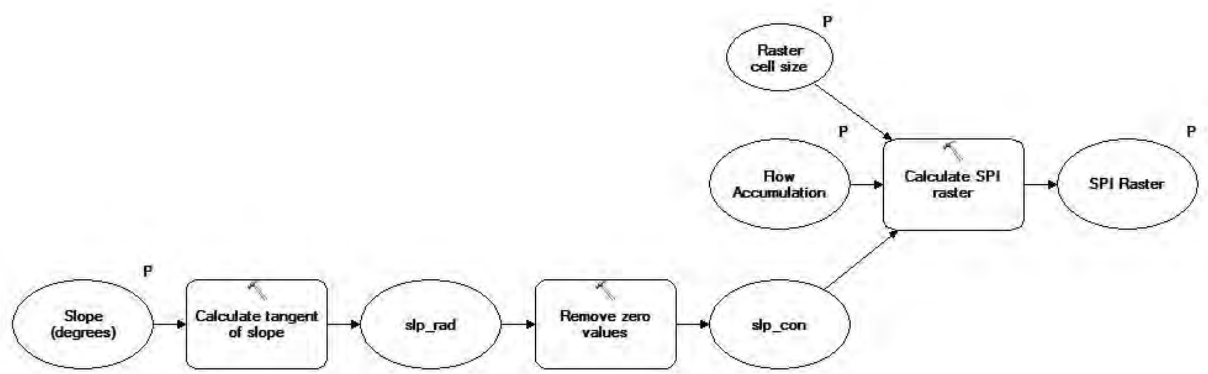


Figure E2. Graphical representation of the process used to create a SPI.

Within the model, the following processes contain the equations that are used to derive the CTI raster from the two raster inputs;

Calculate tangent of slope: Tan(("%Slope (degrees)%" * 1.570796) / 90)

Remove zero values: Con("%slp_rad%"==0,0.0001,"%slp_rad%")

Calculate SPI raster: Ln((("%Flow Accumulation%" + 1) *(%Raster cell size% * %Raster cell size%)) * "%slp_con%")

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