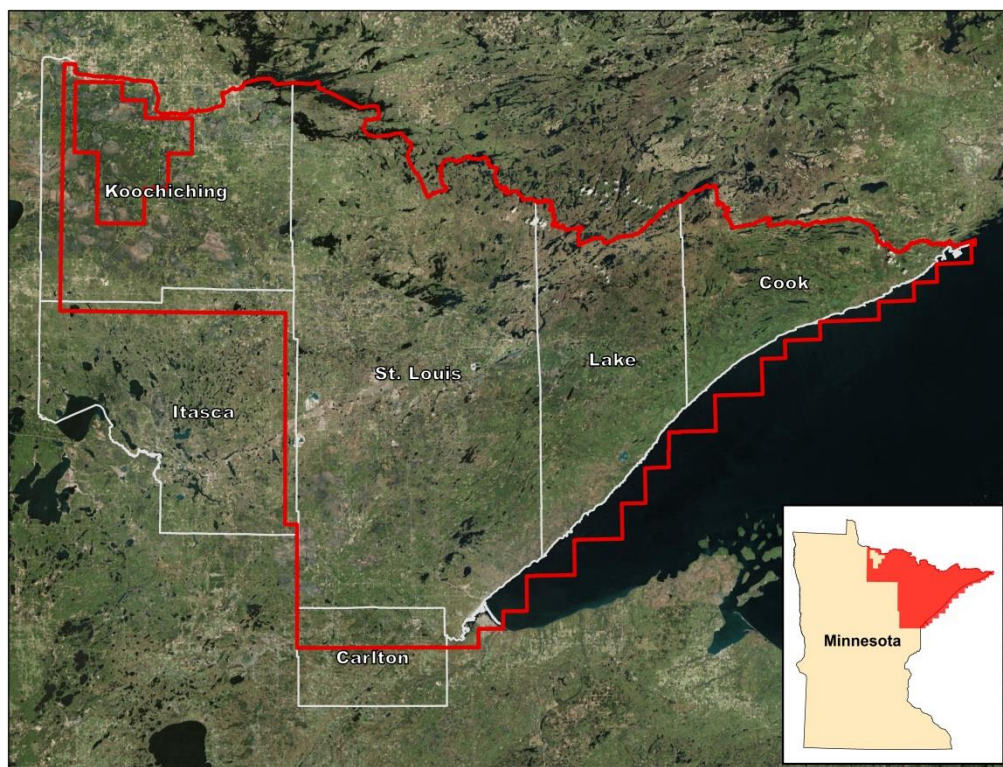


Updating the National Wetland Inventory in Northeast Minnesota

Technical Documentation

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Prepared by:

Robb D. Macleod, Robert S. Paige and Alek J. Kreiger
1220 Eisenhower Place
Ann Arbor, MI 48108-3281
USA



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Additional funding and support was supplied by the U.S. Fish and Wildlife Service.



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For additional information about the project, reports, or maps, please contact: Ducks Unlimited, Inc., Great Lakes/Atlantic Regional Office, 1220 Eisenhower Place, Ann Arbor, MI 48108, (734)-623-2000.

3.0 Introduction

3.1 Project overview

The Minnesota Department of Natural Resources (MDNR) has taken the lead in coordinating a multi-agency effort to update and enhance the National Wetland Inventory (NWI) for Minnesota. Wetland inventories are an essential tool for effective wetland management, protection, and restoration. Such inventories provide baseline information for assessing the effectiveness of wetland policies and management actions. These data are used at all levels of government, as well as by private industry and non-profit organizations for wetland regulation and management, land use and conservation planning, environmental impact assessment, and natural resource inventories. The NWI is the only spatially comprehensive wetland inventory for Minnesota. Yet, there are issues with the original NWI data for Minnesota. First and foremost, the data are about 25 to 30 years out of date. Second, various limitations in the original technology, methodology, and source data resulted in an under representation of very small wetlands, drier-end wetlands, and forested wetlands. This Minnesota NWI update will be completed piecemeal by dividing the state of Minnesota into multiple project areas.

3.2 Project area

The project area for this iteration of the NWI update consists of approximately 14,330 square miles and intersects parts of six counties in northeastern Minnesota including: Itasca, Koochiching, St. Louis, Carlton, Lake, and Cook Counties (Figure 1) and will be hereafter referred to as the northeast Minnesota project area or simply, the northeast project area.

3.3 Project organization

Ducks Unlimited (DU) and the Minnesota Department of Natural Resource's Resource Assessment Office (RA) partnered to perform the NWI update for the northeast project area. DU had primary responsibility for developing the final updated NWI and RA had primary responsibility for the LiDAR and DEM processing as well as assisting with the field data collection.

Updating the NWI utilized a hierarchal organizational structure (Fig. 2) that incorporated multiple levels of iterative review and opportunities for cross-organizational feedback. DU employed up to four GIS Interns to work on photo interpretation and classification of wetlands. A lead image analyst supervised the photo interpretation and had primary responsibility for the quality assurance/quality control process as well as incorporating the updated NWI into a seamless database. A database administrator and programmer employed by DU was responsible for custom tool development, including the simplified plant community classification and Hydro-Geomorphic (HGM) classification and any web based management and information sharing tools. DU worked with a private contractor and experienced image analyst to develop automated image segmentation methods. All of DU staff reported to a project manager who coordinated and oversaw all project activity. The DU project manager worked closely with staff from the Minnesota DNR RA and communicated directly with the Minnesota DNR Wetlands Monitoring Coordinator, who reported to the Technical Advisory Committee. The Technical Advisory Committee includes personnel from the Minnesota DNR, the United States Fish and Wildlife Service, and the University of Minnesota and oversaw the completion of the NWI update for the state of Minnesota.

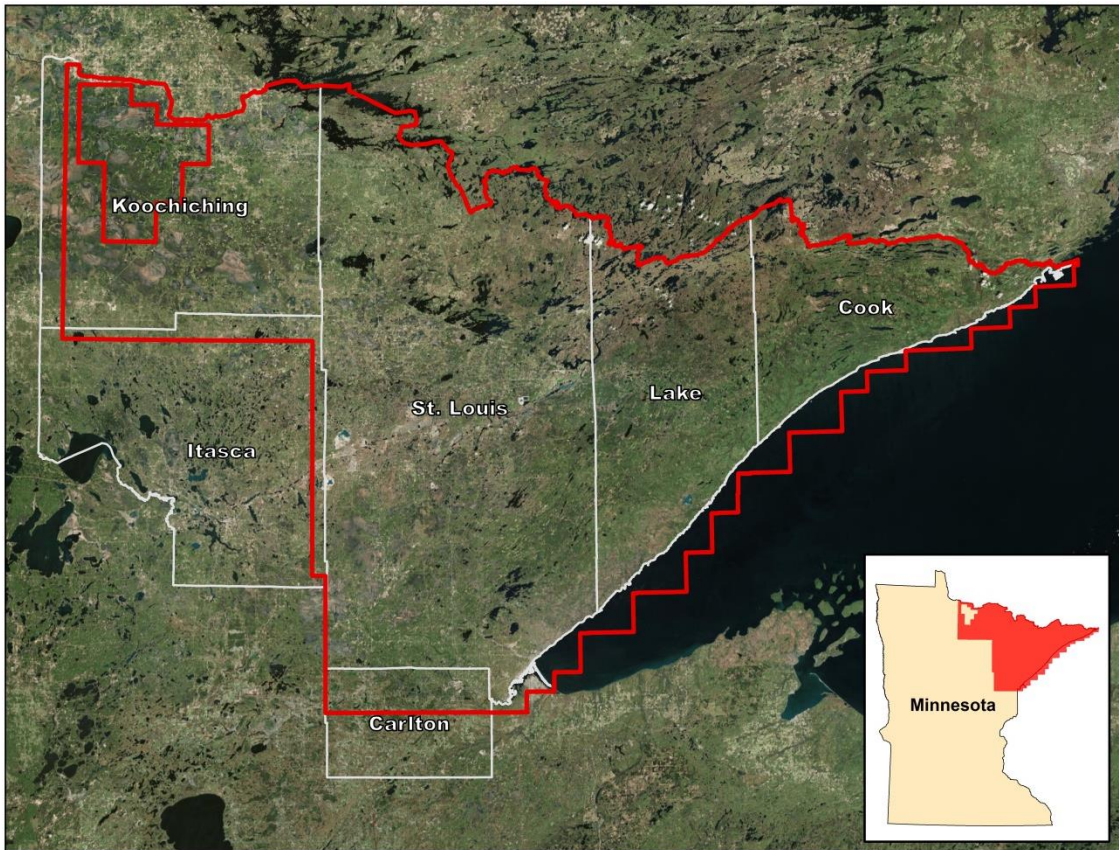


Figure 1: Map of the northeast Minnesota project area.

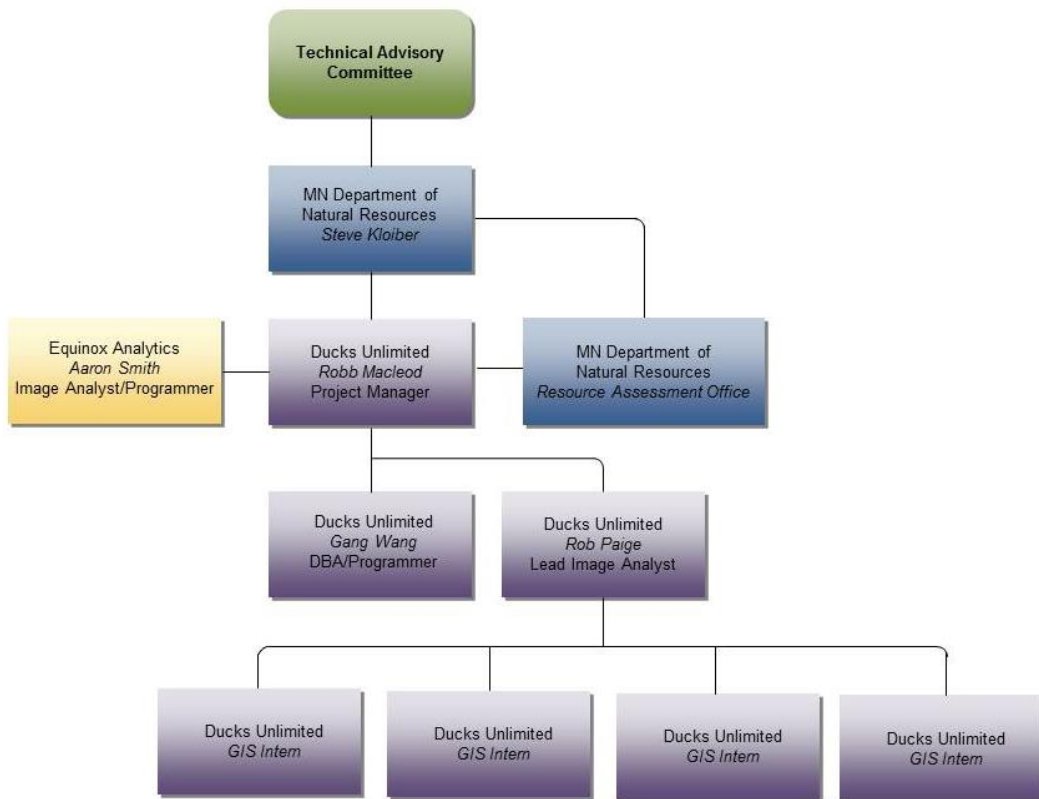


Figure 2: Organizational structure for the northeast Minnesota NWI update project.

4.0 Data

4.1 Projection

The NWI update for the northeast project area in Minnesota used the UTM projection, Zone 15N and the NAD83 datum with linear unit meters. All data layers used this spatial reference. The final products were also projected to Albers Equal Area Conic Projection, NAD83 to conform to the spatial reference set by the U.S. Fish and Wildlife for NWI data.

4.2 Primary data layers

The primary data layers for this project were the layers used in the image segmentation and/or the photo interpretation process.

4.2.1 Seamless updated NWI

A seamless NWI geodatabase was created for the East-central project area and includes the Koochiching and Duluth project areas. This same geodatabase was utilized to incorporate the final updated NWI for the Northeast project area.

4.2.2 Spring aerial photos

The primary image data set for the NWI update was the 2009 4-band, digital ortho quarter quads, spring leaf-off aerial imagery (<http://www.mngeo.state.mn.us/chouse/airphoto/nemn09.html>) (Fig. 3). The imagery was acquired from the State and covers the entire Northeast MN Project Area. Cook, Lake, and St. Louis Counties as well as a portion of Carlton County were flown with a spatial resolution of 0.5 meter. Koochiching County and portions of Itasca, St. Louis, and Carlton Counties were flown with a spatial resolution of 0.3 meter. This means the NWI update for the northeast project area should be considered current to the year 2009.

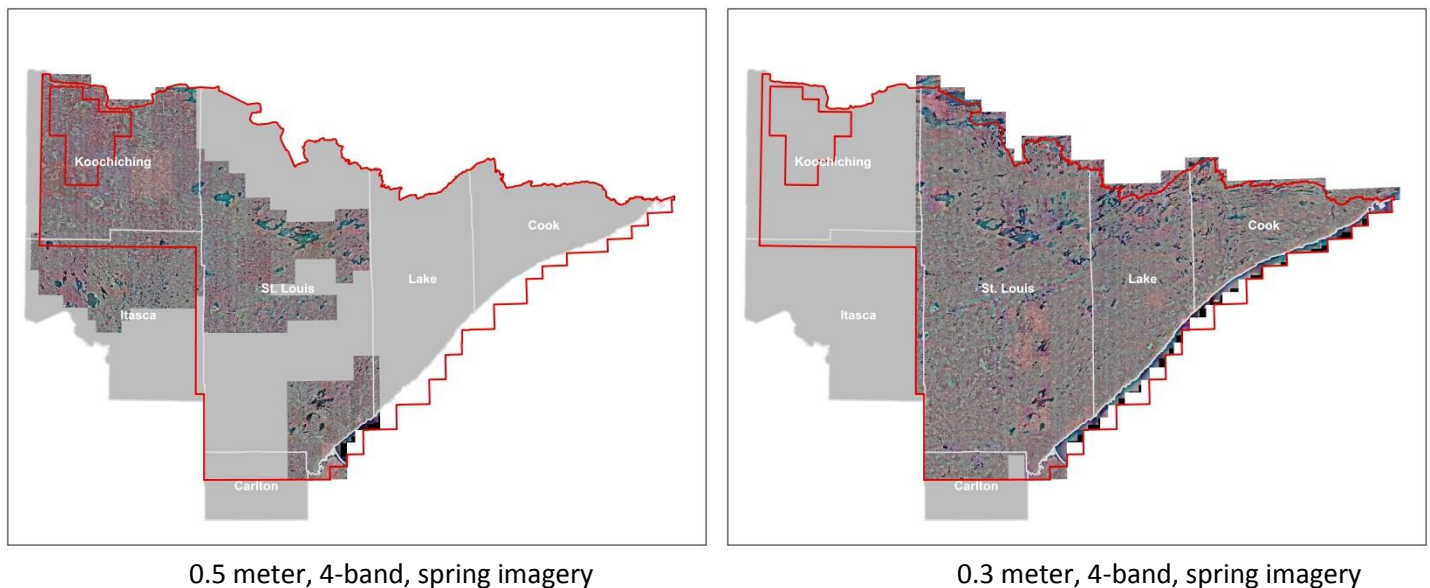


Figure 3. The spring aerial imagery for the northeast project area.

4.2.3 Summer aerial photos

State-wide summer aerial photos have been flown by the Farm Service Agency (FSA) National Agriculture Imagery Program (NAIP) in 2008, 2009, and 2010. The 2008 imagery is 4-band, ortho-rectified imagery, while the 2009 and 2010 imagery is natural color (3-band), ortho-rectified imagery. (<http://www.mngeo.state.mn.us/chouse/airphoto/fsa.html>)

4.2.4 LiDAR data

LiDAR (Light Detection and Ranging) is an active remote sensing technology that operates on the power of laser light to detect and measure surface features on the earth. This data is particularly valuable for representing the topographical variation across a landscape. LiDAR data is available for the entire northeast project area at a spatial resolution of 3 meters.

4.2.5 Lake bathymetry (DEM)

This layer does not include bathymetric information for all lakes in the northeast project area, but was used where available for the semi-automated delineation of the limnetic and littoral subsystem boundary within the lacustrine system of the Cowardin classification system as part of the segmentation process described in section 7.6. The bathymetric data is available from the Minnesota Geospatial Commons at <https://gisdata.mn.gov/dataset/water-lake-bathymetry>.

4.3 Ancillary data layers

The ancillary data layers were used for creating the training data for the wetlands probability layer and for assisting with the photo interpretation.

4.3.1 Fall peak color aerial photos

The MN DNR has flown fall peak color aerial photos (3-band natural color) that covers the entire project area (Fig. 4) and assisted in interpreting forested wetlands and determining water regime.

4.3.2 SSURGO soils data

The Natural Resources Conservation Service (NRCS) produces soils maps in GIS format (Soil Survey Geographic Database [SSURGO]) from the original soil survey maps. These maps can be very useful in identifying wetlands using various combinations of attributes contained within the SSURGO database. The SSURGO database was available for the entire northeast Minnesota project area. Additional information can be found and data can be downloaded at <http://websoilsurvey.sc.egov.usda.gov>.

4.3.3 Native Plant Communities

The Minnesota County Biological Survey collects information on high-quality, native plant communities. The Minnesota County Biological Survey locates higher quality native plant communities using aerial photo interpretation followed by field survey of selected sites. The native plant communities dataset can be downloaded in GIS format from the Minnesota Geospatial Commons at <https://gisdata.mn.gov/dataset/biota-dnr-native-plant-comm>.

4.3.4 MNDNR Forest Stand Inventory

The Minnesota DNR Foresters aggregate spatially explicit information on forest stands that occur on state-owned property. The resulting dataset provides a description of each distinct stand including main cover type and physiographic category, and are often field verified. The forest stand inventory dataset can be downloaded in GIS format from the Minnesota Geospatial Commons at <https://gisdata.mn.gov/dataset/biota-dnr-forest-stand-inventory>.



Figure 4. The fall aerial imagery that intersects the northeast project area.

4.3.5 USGS 1:24,000 DRG

The topographic maps from the USGS are made available as digital raster graphics (DRG) and were used to assist in the classification process.

4.3.6 U.S. Fish and Wildlife Service National Wetland Inventory

The FWS administers a seamless version of the original NWI as part of the National Map in an ArcSDE master geodatabase format. The importance of the original NWI should not be overlooked when making classification decisions. While the base imagery for the original NWI was not ideal for detailed wetland classification, it was accomplished with experienced photo interpreters using stereo pairs. This information can provide valuable historic information regarding the hydrologic regimes, classes and boundaries that can be used to inform the current classification process as long as the interpreter understands the limitations of the dataset.

4.3.7 Wetland restoration sites

Ducks Unlimited has a point file for all of its wetland restoration projects. This layer can be helpful in identifying newly created wetlands and determining wetland class.

5.0 Cowardin Classification System guidance for Minnesota

The primary classification system used for the National Wetland Inventory (NWI) was described by Cowardin et al. (1979). All wetland classification definitions for the update of the Minnesota NWI follow Cowardin et al. (1979) and Dahl et al. (2009) unless otherwise noted below. The following section describes the valid codes and descriptions of the Cowardin classification system as applied to the NWI update for the northeast project area. A full list of valid codes is provided in Table 1. For examples of the NWI classes and how they were interpreted, please see the Photo Interpretation Guide for the Minnesota NWI Update (Ducks Unlimited 2016).

Table 1: Valid codes for NWI update of Minnesota

System	Subsystem	Class	Subclass	Water Regime	Special Modifier
L	L1	UB		H, K	h, x
L	L2	UB		F, H, K	b, d, h, x
		AB		F, H, K	b, d, h, x
		EM	2	F, H, K	b, d, h, x
		US		A, C, K	b, d, h, x
		RS		A, C, K	b, d, h, x
		RB		F, H, K	b, d, h, x
P		UB		F, H, K	b, d, h, x
		AB		F, H, K	b, d, h, x
		EM	1	A, B, C, F, K	b, d, f, h, x, q
		EM	2	C, F, H, K	b, d, h, x,
		FO	1, 2, 4	A, B, C, F, K	b, d, h, x, q
		SS	1, 2, 3, 4	A, B, C, F, K	b, d, h, x, q
		US		A, C, K	b, d, h, x
		RB		F, H, K	b, d, h, x
		ML		B	d, q
R	R2	UB		H	h, x
		AB		H	h, x
		US		A, C	h, x
		EM	2	F, H	h, x
		RS		A, C	h, x
		RB		H	h, x
R	R3	UB		F, H	h, x
		US		A, C	h, x
		RS		A, C	h, x
		RB		F, H	h, x
R	R4	SB		A, C	h, x

5.1 Cowardin classes

The Cowardin classification system is a hierarchical system developed to standardize the classification of wetlands and deepwater habitats of the United States. At the highest level are five systems: marine, estuarine, riverine, lacustrine, and palustrine. Only three of these systems are relevant to the inland wetlands found in Minnesota: riverine, lacustrine, and palustrine. Santos and Gauster (1993) included a list of valid Cowardin wetland types for Minnesota in their regional user's guide to the National Wetland Inventory Maps.

Within the riverine and lacustrine systems, there are subsystems. Minnesota has lower perennial rivers, upper perennial rivers, and intermittent streams for riverine subsystems. There are no tidal riverine systems. There are also two lacustrine subsystems, limnetic and littoral. The palustrine system has no subsystems. Within each of these systems and subsystems there are several classes that are defined either on the dominant vegetation (e.g. scrub-shrub and forested) or the dominant substrate (e.g. unconsolidated bottom). Additional details of the classification system including the definition of each system, subsystem, class, and subclass can be found in Cowardin et al. (1979) and Dahl et al. (2009).

Valid classes for the remaining systems and subsystems were derived from Cowardin et al. (1979). These wetland classes are listed in Table 2.

General guidance followed for wetland classes:

- All wetland polygons would be classified to the Cowardin class level.
- Estuarine and marine systems and the tidal riverine system would not be used.
- Use of subclasses would be limited to emergent, scrub-shrub, and forested wetlands and must be identified for these classes (section 5.2).
- Only the systems, subsystems, and classes listed in Table 2 should be used for the NWI update.
- Mixed classes would be allowed as specified by Dahl et al. (2009), but should be minimized (section 5.1.1).

Table 2: Valid classes for NWI update of Minnesota

System	Subsystem	Class	Code	
Lacustrine	Limnetic	Unconsolidated Bottom	L1UB	
	Littoral	Rock Bottom	L2RB	
		Unconsolidated Bottom	L2UB	
		Aquatic Bed	L2AB	
		Rocky Shore	L2RS	
		Unconsolidated Shore	L2US	
		Emergent	L2EM	
Palustrine		Rock Bottom	PRB	
		Unconsolidated Bottom	PUB	
		Aquatic Bed	PAB	
		Unconsolidated Shore	PUS	
		Moss-Lichen	PML	
		Emergent	PEM	
		Scrub-Shrub	PSS	
		Forested	PFO	
Riverine	Lower Perennial	Rock Bottom	R2RB	
		Unconsolidated Bottom	R2UB	
		Aquatic Bed	R2AB	
		Rocky Shore	R2RS	
		Unconsolidated Shore	R2US	
		Emergent	R2EM	
	Upper Perennial	Rock Bottom	R3RB	
		Unconsolidated Bottom	R3UB	
		Rocky Shore	R3RS	
		Unconsolidated Shore	R3US	
	Intermittent		Streambed	R4SB

5.1.1 Mixed classes

Mixed classes were avoided wherever possible (i.e. areas of homogenous classes were delineated as separate polygons). In cases where the classes were interspersed without clear spatial definition of the classes, the mixed classes were limited to: FO/SS, FO/EM, SS/EM, UB/SS, and AB/SS with no reciprocals.

5.2 Wetland subclass

The historical application of the Cowardin subclasses in the Minnesota NWI is inconsistent with current guidance. Some historical subclasses such as subclass 5 for palustrine emergent wetlands were used in Minnesota, but have been abandoned in recent guidance or re-purposed (Dahl et al. 2009). In addition, many of the subclasses are difficult to reliably determine using remote sensing data. For this reason, the federal wetlands mapping standard (FGDC 2009) only requires subclasses for the emergent, scrub-shrub, and forested classes.

General guidance followed for subclasses:

- Subclasses would only be used for scrub-shrub, forested, and emergent wetland classes and must be identified for these classes.
- Whenever possible, the most specific subclass, such as broad-leaved deciduous (PFO1) would be used instead of the more generic subclasses, such as deciduous (PFO6).
- There are no broad leaved evergreen tree species in Minnesota, so that subclass (PFO3) would not be used. However, there are broad-leaved evergreen shrub species (PSS3).
- Based on discussions of the technical advisory committee, sub-class 5 (dead) for both scrub-shrub wetlands and forested wetlands should be avoided. Wetlands would be classified based on the dominant (>30% cover) living life form or substrate.
- Valid subclasses for the Minnesota NWI are in Table 6.
- Mixed subclasses on forested and scrub-shrub classes would be avoided if possible (section 5.2.1)

Table 3: Subclasses for the NWI update of Minnesota

Class	Subclass
Emergent	1-Persistent 2-Nonpersistent
Scrub-Shrub	1-Broad-leaved deciduous 2-Needle-leaved deciduous 3-Broad-leaved evergreen 4-Needle-leaved evergreen 6-Deciduous* 7-Evergreen*
Forested	1-Broad-leaved deciduous 2-Needle-leaved deciduous 4-Needle-leaved evergreen 6-Deciduous* 7-Evergreen*

* The more specific subclasses were used whenever possible.

5.2.1 Mixed subclasses

Mixed subclasses on forested and scrub-shrub were avoided wherever possible (i.e. areas of homogenous subclasses were delineated as separate polygons). In cases where the classes were interspersed without clear spatial definition of the subclasses, the mixed classes were limited to: 1/2, 1/3, 1/4, 2/4 and 3/4 with no reciprocals.

5.3 Water regime modifier

To fully describe wetlands and deepwater habitats, one must apply certain modifiers at the class level or lower. The water regime modifier describes the hydrologic characteristics of the wetland including the frequency and duration of inundated or saturated conditions. Because detailed hydrologic records are seldom available, the assignment of water regime modifiers relies on interpretation of water levels from images taken at various times as well as interpretation based on the plant communities.

There are some differences in water regime definitions between various guidance documents (Cowardin et al. 1979; Santos and Gauster 1993; Dahl et al. 2009). The Minnesota NWI update uses the water regimes A, B, C, F, H, and K as defined by Dahl et al. (2009). There are no tidal or sub-tidal water regimes. The Minnesota NWI update does not use the E water regime (seasonally flooded – saturated) due to its potential overlap with the C water regime. The Intermittently Flooded (J) water regime is generally considered to only occur in the western United States. This water regime is also excluded from the Minnesota NWI update. In addition, due to the difficulty in determining the difference between Intermittently Exposed (G) and Permanently Flooded (H) with limited temporal data, the G water regime is not used.

Given limited temporal data (typically only one spring image, one fall image, and a summer image from each of a few relatively recent years), it is difficult to classify water regime on the basis of water observation alone. Therefore, it was important to make inferences based on plant community, landscape position, and other factors. Fortunately, Cowardin et al. (1979) simplifies this task somewhat by restricting the water regimes for each class to only a few possibilities. In addition, water regimes are further restricted somewhat by regional wetland characteristics. For example, Cowardin allows for forested wetlands to have all water regimes except sub-tidal regimes. However, Minnesota does not have any tree species that can tolerate permanent or semi-permanent flooding (like Cypress). This is further supported by the statistics for water regimes in the original NWI for Minnesota.

General guidance followed for water regime:

- Water regime modifiers would be applied to all wetland polygons.
- Only the A, B, C, F, H, and K water regimes as defined by Dahl et al. (2009) would be used in Minnesota.
- The (E) water regime from Dahl et al. (2009) would not be used. Instead, it would be incorporated into the (C) water regime.
- Due to the potential difficulty of reliably separating F, G, and H water regimes without long-term hydrologic records, the G water regime would not be used. Instead wetlands with more permanent water regimes would be classified as either semi-permanently flooded (F) or permanently flooded (H).
- The (J) water regime would not be used.
- Water regimes for each valid Cowardin class are listed in Table 4, with most-likely water regimes indicated by the abbreviation “ML”.

Table 4: Water regime modifiers for the NWI update of Minnesota

Cowardin Class	Water Regime					
	A	B	C	F	H	K
L1UB					ML	P
L2UB				P	ML	P
L2AB				P	ML	P
L2EM				P	ML	P
L2US	ML		P			P
L2RS	ML		P			P
L2RB				P	ML	P
PUB				P	ML	P
PAB				P	ML	P
PEM	P	P	ML	P	P	P
PFO	P	ML	ML	P		P
PSS	P	ML	ML	P		P
PUS	ML		P			P
PRB				P	ML	P
PML		ML				
R2UB					ML	
R2AB					ML	
R2US	ML		P			
R2EM				ML	P	
R2RS	ML		P			
R2RB					ML	
R3UB				P	ML	
R3US	ML		P			
R3RS	ML		P			
R3RB				P	ML	
R4SB	ML		P			

* The most-likely water regimes are indicated by “ML”. Possible, but not-likely, water regimes are indicated by “P”.

5.4 Special modifier

Special modifiers were used extensively in the original NWI and are used in the NWI update for Minnesota (Table 5). The most commonly used special modifier in the original NWI for Minnesota was the (d) modifier for partly drained or ditched. Many of Minnesota's wetlands are partly drained or ditched and this characteristic is readily interpretable from most aerial imagery. The application of special modifiers for beaver impacts and excavated wetlands were also frequently used. As with the partly drained wetlands, these characteristics are often readily identifiable from aerial photos.

Little used modifiers include the modifiers for farmed, artificial substrate, and spoils. The farmed modifier was infrequently used at least in part due to policy decisions not to map most farmed wetlands in the original NWI for Minnesota. The current policy is to map these farmed wetlands, where they exist, and so the f modifier was used in the NWI update for the northeast project area. The typical farmed wetland in Minnesota is usually a depression that is wet in the spring and it shows signs of cultivation. It may be cropped during the summer, but crop stress is often evident. Please see the Photo Interpretation Guide for the Minnesota NWI Update for examples of identifying farmed wetlands. Based on discussions with the technical advisory committee, the spoils modifier (s) would not be used in the NWI update for Minnesota. In addition, the artificial modifier (r) would not be used in the NWI update for Minnesota. Wastewater ponds are coded as PUBKh.

A new modifier was proposed specifically for the Minnesota NWI update. Wetlands that have peatland (bog/fen) signatures (typical vegetation may include Sphagnum, Leatherleaf, Sedges, Black Spruce, and Tamarack) are assigned the (q) modifier. Peatlands are readily identifiable from color-infrared imagery (Hop et al. 2000).

General guidance followed for special modifiers:

- Special modifiers would be applied using the definitions provided by Dahl et al. (2009), except that the special modifier for spoils (s) and artificial (r) would not be used.
- Farmed wetlands would be identified whenever possible using the guidance in the Photo Interpretation Guide.
- An additional special modifier was added and applied to indicate peatlands (based on the presence of Sphagnum peat mat or other peatland indicators).
- Wastewater stabilization ponds would be coded PUBKh.

Table 5: Valid special modifiers for the NWI update of Minnesota

Special Modifiers
Beaver (b)
Partly drained/ditched (d)
Farmed (f)
Diked/impounded (h)
Peatland (q)
Excavated (x)

5.5 Water chemistry modifier issues

The water chemistry modifiers were virtually ignored in the original NWI for Minnesota. Only four polygons were associated with water chemistry modifiers. Certain peatlands identified with the special modifier (q) are likely to be acidic, but pH cannot be reliably determined from remote sensing data. Therefore, water chemistry modifiers are not applied to wetland classification codes for the NWI update for Minnesota.

5.6 Soil modifier issues

The original NWI did make some use of the soils modifiers, but their use was inconsistent. The most reliable mapped information on soils in Minnesota is from the USDA Soil Survey Geographic (SSURGO) Data. Application of soil modifiers in the absence of additional field work would be no better than simply relying on SSURGO. Therefore, soil modifiers are not applied to wetland classification codes for the NWI update for Minnesota.

6.0 Field verification

The field verification would serve three purposes: 1) to train the interpreters through on-the-ground experience, 2) as site based photos for inclusion in the photo interpretation guide, and 3) to provide quality assurance data for review. The field verification occurred at three different times: fall 2013, spring 2014, and fall 2014. Staff from DU assisted the RA staff with the field verification in the fall of 2013 so they can gain on-the-ground experience with the wetlands in northeastern MN. The RA staff was responsible for the field work in the spring of 2014 and fall of 2014.

The original NWI was used to identify wetland types to field visit for the fall of 2013. A stratified sample of the wetland types was selected based on accessibility and efficiency. The field verification crew was provided with a laptop and the wetland polygon location. The crew recorded the MN NWI class, subclass, water regime and special modifiers for the site along with a general description and took a digital photograph of the site. The field-verified information was compared to the original NWI classification and sites with discrepancies were further examined. A determination of the proper code was made by a consensus of the image interpreters. In cases of confusion, the MN DNR and FWS NWI coordinator were consulted. The field verification in the spring of 2014 and fall of 2014 was performed by the MN DNR Resource Assessment staff. DU provided the RA staff locations of wetlands that were difficult to determine from the photo interpretation process or unique classes that can be added to the photo interpretation guide.

7.0 Data processing

7.1 Spring aerial photos

The Minnesota NWI update for the northeast project area conducted by Ducks Unlimited and the MN DNR Resource Assessment group utilized two resolutions of imagery (30cm and 50cm pixel resolution) for image interpretation and segmentation for the purpose of wetland delineation and labeling for incorporation into the updated NWI database. After considerable difficulty in identifying a set of image segmentation parameters that would produce comparable results in both image resolutions, a solution was proposed which entailed resampling (coarsening) the 30cm resolution data to the same spatial resolution as the 50cm data available for the majority of the project area. The 30cm imagery was retained and used for photo-interpretation tasks but for the purposes of automated image analysis the resampled data allowed for a single unified set of processing algorithms to be applied across the entire project area.

In order to ensure the resampling step would not compromise the quality of the final database a small evaluation was developed to test alternative resampling methods with respect to the image segmentation process. The resampling evaluation yielded visual and segmentation results similar to the imagery acquired and delivered at 50cm resolution (50cm base). Therefore, the 30cm data was resampled to 50cm for the purposes of image segmentation for this project.

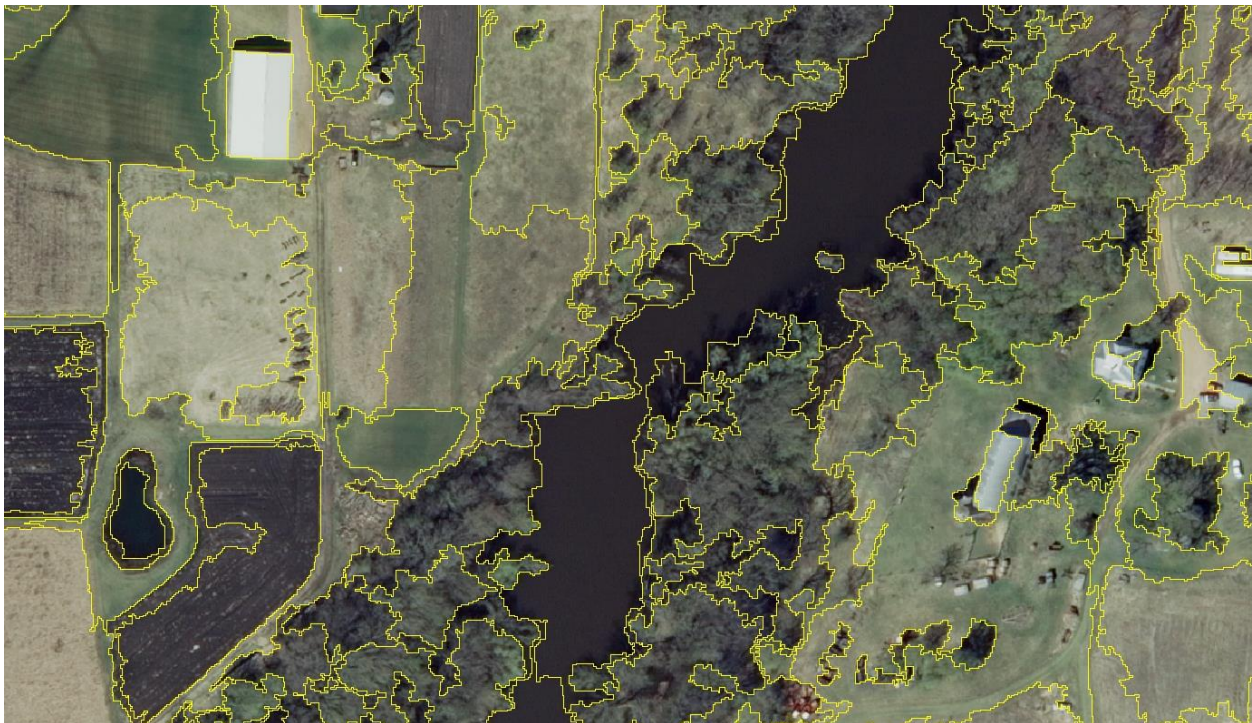


Figure 5. Segmentation based on data resampled to 50cm resolution displayed over the original unaltered 30cm imagery at a scale of 1:1000.

7.2 LiDAR/DEM processing

Several topographic metrics or indices were derived from the LiDAR data. These derived metrics and indices provide a greater ability to discriminate wetland from upland than the DEMs alone. These derivatives are described in the following sections and were produced and provided to DU by the RA staff.

7.2.1 Slope

Slope represents the rate of change of the elevation for each digital elevation model (DEM) cell. Slope is normally output into degree or percent rise. However, the compound topographic index (CTI, as described below) has better results with the slope expressed in radians. Therefore, the slope was calculated in degrees and converted to radians. Areas with low slope (flat areas) are more likely to be wetlands than areas with high slope.

7.2.2 Topographic Position Index (TPI)

TPI values provide a simple and powerful means to classify the landscape into morphological classes (Jenness 2005 and Tagil and Jenness 2008). TPI is a simplification of the Landscape Position Index described by Fels and Zobel (1995) and developed by Weiss (2001).

TPI for each cell is calculated by subtracting the mean elevation of its neighborhood from its own elevation value. A positive value indicates the pixel is higher than its neighbors, while a negative value indicates it is lower. This simple classification is a useful means of mapping topographic depressions. Groups of pixels with negative TPI scores represent such depressions, and are possible wetland locations.

A Digital Elevation Model (DEM) is the only data required to calculate TPI. An ArcGIS Model Builder was used to create the TPI (Fig. 9). Selecting appropriate neighborhood settings is an important part of the process. Selecting too small of a neighborhood will result in very fine resolution which is not adequate for detecting topographic depressions over large areas. For this project, the neighborhood setting of 240 meter circle radius was used. The focal statistics neighborhood settings were specified as a circle with radius 240, and statistics type as mean. The output of this process is a mean elevation raster. The minus tool subtracts the mean elevation raster from the original DEM. The final result is the TPI raster.

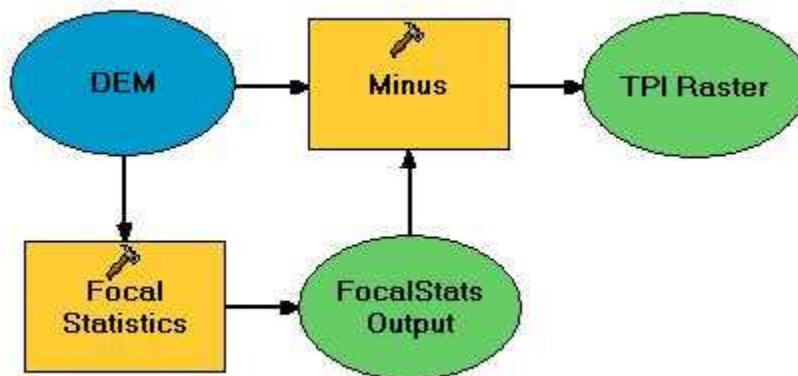


Figure 6. The ArcGIS Model Builder for calculating the TPI.

7.2.3 Compound Topographic Index (CTI)

The Compound Topographic Index (CTI) is a function of both the slope and the upstream contributing area. CTI can be calculated as:

$$CTI = \ln (A_s / (\tan(\beta))),$$

where A_s = contributing area and β is the slope expressed in radians. Slope and flow direction were calculated using the TauDEM tool (Tarboton 2003). Flow direction was calculated using the D-Infinity (D-inf) algorithm. Flow direction was then used to derive the contributing drainage area, also using TauDEM. The slope grid and contributing area were then plugged in the equation for CTI.

Prior to calculating the CTI topographic depressions (sinks) were removed to generate a "sinkless" DEM. A python script was written to batch process the CTI.

7.2.4 Average elevation of first returns

The LiDAR datasets include elevation information (in meters above sea level) for various classes of returns. Returns are classified by time intervals (i.e. the length of time between the moment a light pulse is emitted from the sensor and the moment the same light pulse – or portions of that pulse – is received by the sensor after reflecting off the earth's surface). LiDAR information is stored as geographically-explicit points in a LAS file and the ArcGIS LAS to Raster tool is used to extract information from the LAS files while converting the data to raster format. The average elevation of the first returns was derived from the LiDAR dataset by filtering the LAS file for the appropriate return class(es) and using a binning interpolation method that assigns output cell values with the average elevation value of points within a cell and filling voids (i.e. cells that do not contain any LAS points) by assigning those cells as No Data. The average elevation of first returns was used to distinguish differences in vegetation height in order to classify scrub-shrub and forested wetlands.

7.2.5 Average intensity of bare earth returns

LiDAR datasets also include information on the intensity, or strength, of the signal that is received by the sensor. Intensity is known to be correlated with surface moisture where signal strength is diminished when the signal interacts with water. A portion of returns are classified as bare earth, or ground returns, and represent the longest time interval between light pulse emission and reception. The average intensity of bare earth returns was produced using the ArcGIS LAS to Raster tool to filter the LAS datasets for ground returns and using a binning interpolation method to assign output cell values with the average intensity value of all points within a cell and using the No Data void fill method.

7.4 Layerstack

The input to the eCognition (Trimble 2010) segmentation process (described in section 8.2) is a tiff layerstack and the raw spring 2009 aerial imagery. The processes for creating the tiff layer stack are summarized in Fig. 7. These processes largely relied on python scripting to ensure consistency and efficiency in the processing steps. The DEM and the LiDAR DEM derivatives were processed for each of the 94 buffered watershed boundaries (described in section 8.1). These products were then mosaicked and clipped to the northeast project area boundary, and became input rasters for the layerstacks. The LAS rasters were created from the filtered LAS datasets that intersected each of the 94 watersheds (original extent is the quarter quarter-quad LAS tiles), mosaicked and then clipped to the northeast project area boundary to produce 80 watershed rasters. (This means that the LiDAR derivatives from the DEM were clipped and processed for the full extent of all the original 94 buffered watersheds.) A DEM No Data mask was created for each watershed and used to define the area of interest (AOI) as part of the image segmentation process. Each final tiff layerstack consisted of the following layers:

- 1) DEM
- 2) DEM No Data Mask
- 3) Slope
- 4) TPI
- 5) CTI
- 6) Average Elevation of 1st Returns
- 7) Average Intensity of Bare Earth Returns

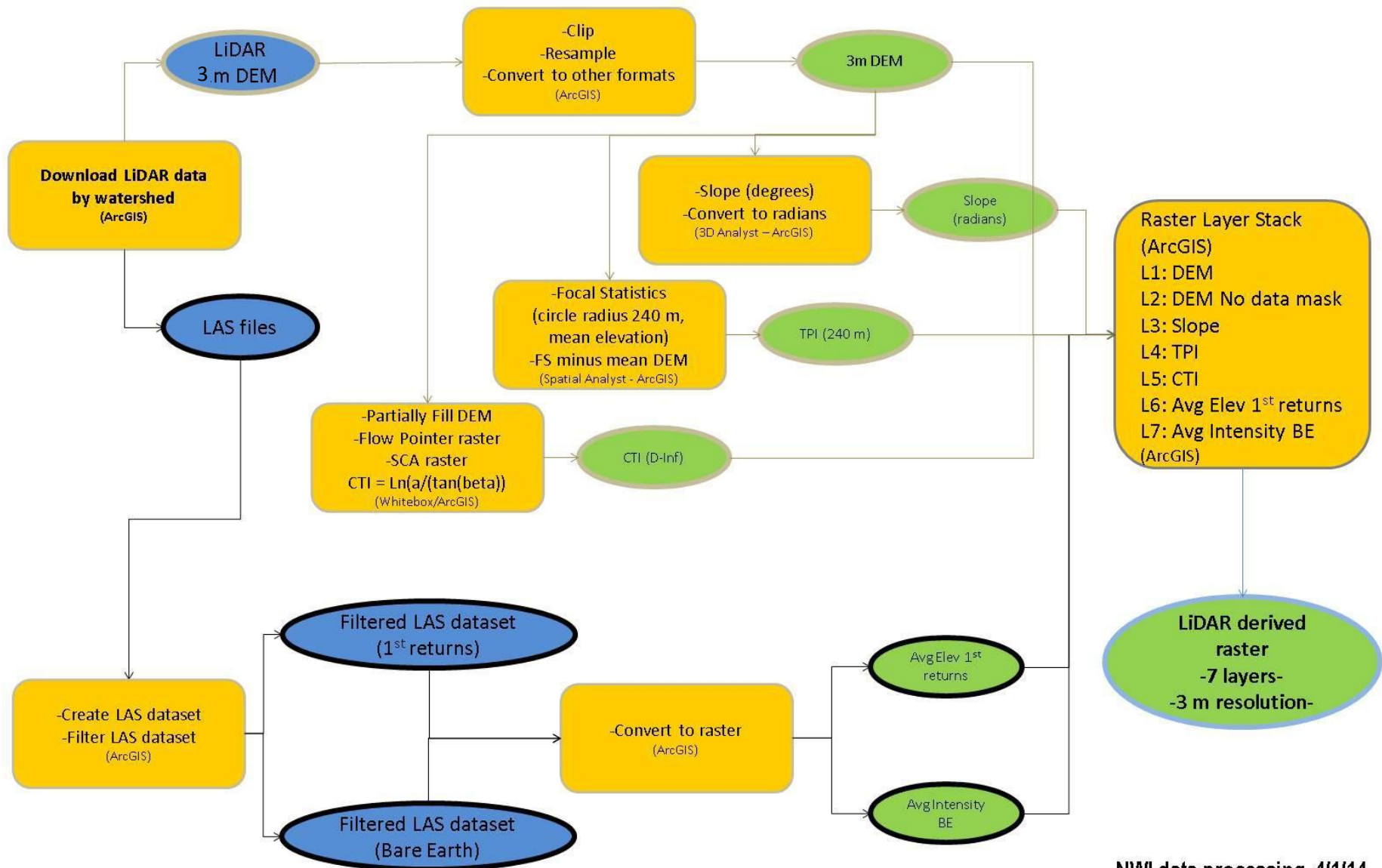
7.5 SSURGO analysis

An ordinal map based on the predominant soil water regime (SSURGO soil map derivative) will be used as ancillary data in the NWI update for northeast Minnesota. The variables included in the analysis to create the soil water regime map are those most likely to be related to wetland water regime (i.e. drainage class, flood frequency for April, pond frequency for April, and pond frequency for August). The drainage class, April flood frequency, April pond frequency, and August pond frequency fields are concatenated and the results sorted on the concatenated field. The resulting table includes water regime classes for all soil components. Map units may contain more than one component. Therefore, the data must be summarized to the map unit level. The water regime field is used as an indicator of wetness intensity from 0 to 8 with higher numbers indicating wetter, more permanent water regimes (Table 6). This water regime index is used as a guide in the classification and photo interpretation process as the SSURGO soils data does not take into account anthropogenic changes such as tile draining.

7.6 Limnetic and littoral subsystem delineation

The lake bathymetry data (DEM) were utilized in an iterative semi-automated process to create limnetic (L1) and littoral (L2) features for each lake in the project area. The rasterized data of the DEM was converted to polygon features where any cell with a depth value of 8.2021 ft. (2.5 m) or greater is classified as L1 and any cell with a depth value less than 8.2021 ft. is classified as L2.

Since the bathymetric data available could not be used to delineate an accurate boundary for lake shorelines, only the L1 features and those L2 features that are contained within L1 features (that may represent shallow areas surrounding islands, for example) were selected from the results of the aforementioned process. These selected L1 and L2 features were then “burned” into the segments produced via the eCognition image segmentation process. Shoreline boundaries were delineated as part of the eCognition segmentation process. Littoral zones that occupy the area between the L1 features and the lake shoreline were manually classified as such. For any lakes that were not included in the available bathymetry datasets the USGS digital topographic maps were consulted and a L1/L2 boundary was approximated manually.



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Figure 7. Method for creating the Layerstack for input into the segmentation process.

Table 6. SSURGO water regime values

Water Regime	Description	Values for Concatenated Field
0	All excessively drained, somewhat excessively drained, and well drained soils as well as udorthents, udipsamments, pits, and gravel. This water regime level also includes moderately well drained soils and somewhat poorly drained soils that do not flood.	Null-Null-Null-Null (Pits, Udipsamments); Excessively drained-None-None-None; Moderately well drained-None-None-None; Null-None-None-None; Somewhat excessively drained-None-None-None; Somewhat excessively drained-Rare-None-None; Somewhat poorly drained-None-None-None; Well drained-None-None-None
1	This water regime level includes moderately well drained soils and somewhat poorly drained soils that do flood at least rarely. (floodplain formations) This is similar to Cowardin's temporarily flooded "A" water regime.	Moderately well drained-Occasional-None-None; Moderately well drained-Rare-None-None; Somewhat poorly drained-Frequent-None-None; Somewhat poorly drained-Occasional-None-None
2	Poorly drained and very poorly drained soils that neither flood nor pond. This is similar to Cowardin's saturated "B" water regime.	Poorly drained-None-None-None; Very poorly drained-None-None-None
3	Poorly drained soils that occasionally flood during spring (almost all floodplain formations). Similar to Cowardin's "A" or "C" water regime depending on the length of flooding.	Poorly drained-Occasional-None-None
4	Very poorly drained soils with frequent spring flooding, but no ponding (almost all floodplain formations). Similar to Cowardin's seasonal "C" water regime.	Very poorly drained-Frequent-None-None
5	Very poorly drained soils with frequent spring flooding and spring ponding (almost all floodplain formations). Similar to Cowardin's seasonal "C" water regime.	Very poorly drained-Frequent-Frequent-None
6	Very poorly drained soils with no flooding, but that do have spring ponding (almost all depressional formations). Similar to Cowardin's seasonal "C" water regime.	Very poorly drained-None-Frequent-None
7	Very poorly drained soils with ponding throughout most, if not all the year (marsh). Similar to Cowardin's "F" or "G" water regime.	Very poorly drained-None-Frequent-Frequent
8	Map units designated as water (non-soil). Similar to "H" WR	Null-Null-Null-Null (Water)

8.0 NWI classification process

The NWI classification process for northeast Minnesota consists of two basic steps: 1) creation of image segments (polygons), and 3) manual photo interpretation and classification of the image segments. A detailed description of each of the steps is described in the sections below and outlined below.

The layerstack (described in previous section) and the 2009 spring 4-band imagery was input into eCognition software to create the image segments.

The goal of the image segmentation process was to have the photo interpretation team spend the vast majority of their time interpreting wetland classes that are difficult to classify instead of digitizing boundaries. The gain in efficiency allowed the photo interpreters to spend more time on difficult classes and focus on increasing classification accuracy. The intent was to allocate most of the delineation effort to making minor edits to existing polygons rather than on manually creating a new polygon for each wetland feature, which serves as an enhancement to the more traditional photo interpretation of the imagery of heads-up digitizing.

Each of the segments were viewed, edited (e.g. merged with neighboring segments of the same class or cut to exclude an area), and assigned a final NWI classification based on the previously described imagery and data (see sections 4 and 7). This process was performed and repeated on a section-by-section basis according to a USGS HUC 10 watershed tiling scheme (described in section 8.1). Once a watershed was completed, the segments were dissolved based on NWI attribute and run through an iterative quality control process that checks for overlaps, gaps and approved NWI codes.

The draft version of the NWI classification for the watershed was sent to the MN DNR for review. Once the review was completed, the watershed was merged into a seamless state-wide layer. The final NWI layer for the northeast project area was projected to Albers equal area projection for delivery to the U.S. Fish and Wildlife Service.

8.1 USGS HUC 10 watershed tiling scheme

The northeast Minnesota project area was divided into sections by intersecting the project area with the USGS HUC 10 watershed GIS data layer (available for download from the USDA Geospatial Data Gateway at <https://gdg.sc.egov.usda.gov>). This divided the project area into digestible pieces for segmentation and interpretation. Additionally, this division allowed for a means by which to track progress towards project completion. Watershed boundaries were used to divide the project area under the assumption that wetlands would be unlikely to occur on the boundary of a watershed, which would make incorporation into the seamless NWI data layer more efficient. The NWI update process described in the following sections (and progress tracking of the process) was performed on a watershed-by-watershed basis until the entire project area was completed. Ninety-four HUC 10 watersheds intersect the northeast project area. In preparation for the segmentation process, a 30 meter buffer was created for each watershed boundary. The buffered watersheds were aggregated and clipped to the northeast project area boundary, resulting in a total of 80 watersheds in the final tiling scheme (Fig. 8).

8.2 Segmentation

The spring 2009 4-band imagery and layerstack files were imported into eCognition software (Trimble 2010) to create the image segmentation files. The eCognition processing rule-set performs over 250 separate operations designed to reduce the amount of manual editing required from the photo interpreters. These operations include:

1. Initial multi-resolution image segmentation
2. Sub-processes to manage edge matching between adjacent tiles
3. Hierarchical image object aggregation by spectral, topographic, and classification based characteristics
4. Basic classification of image objects based on spectral and topographic parameters
5. Smoothing of all image object boundaries (vertices no closer than 10 feet)
6. Elimination of image objects smaller than the MMU (1/20th of an acre)
7. Export of a final shapefile for each tile

Improvements to the ruleset and process development were conducted by creating prototype segmentations for the photo-interpretation team to review. Suggestions and requests to improve the properties of the segmentation were made by the photo interpretation team and incorporated into subsequent versions of the segmentation process. The ultimate goal was to develop eCognition based segmentation and feature extraction processes (Fig. 9) that support and complement the work done by the photo interpretation team rather than to try to replace human photo-interpretation entirely.

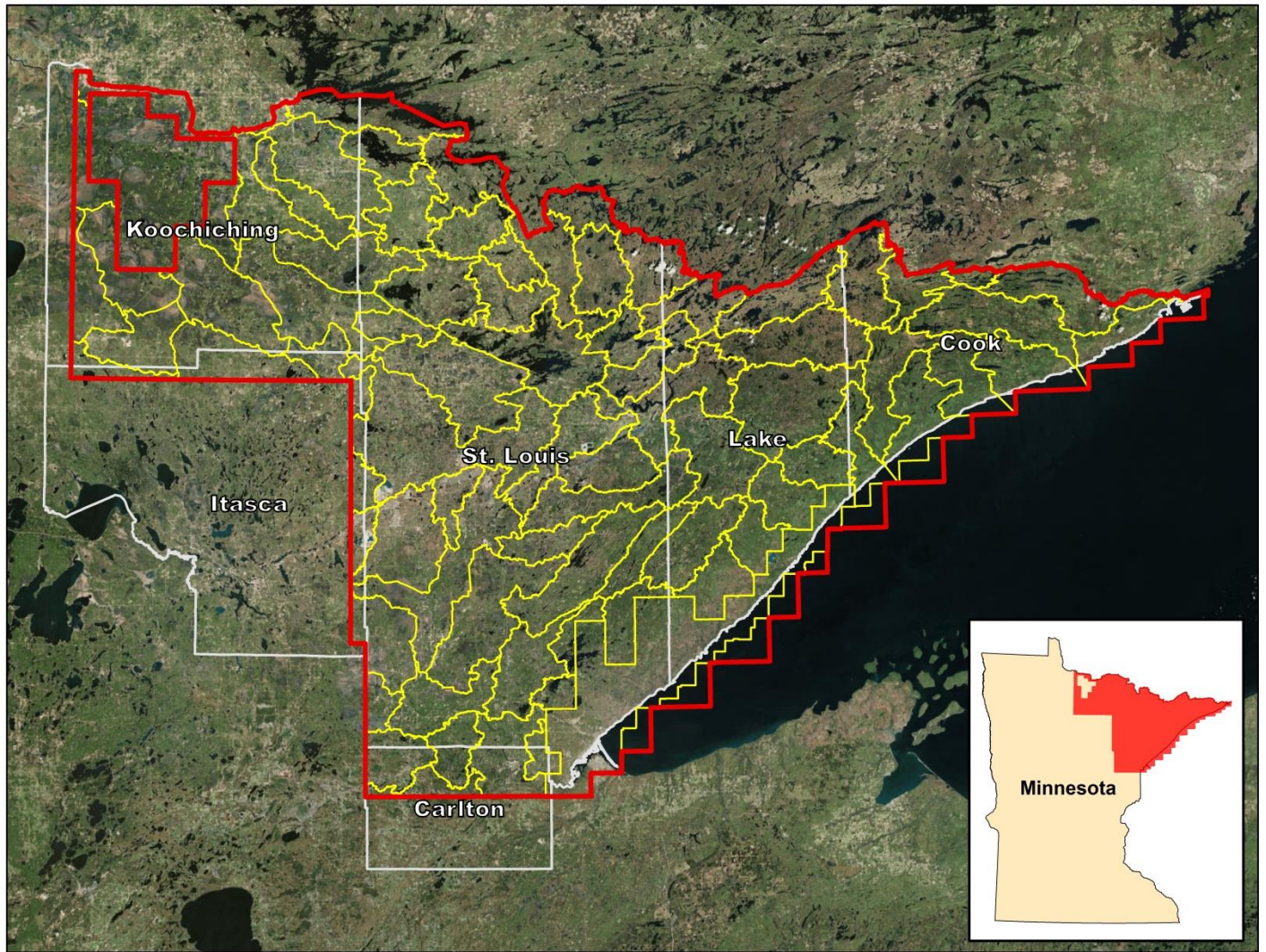


Figure 8. The HUC 10 watershed tiling scheme (yellow) used to divide the northeast Minnesota project area.

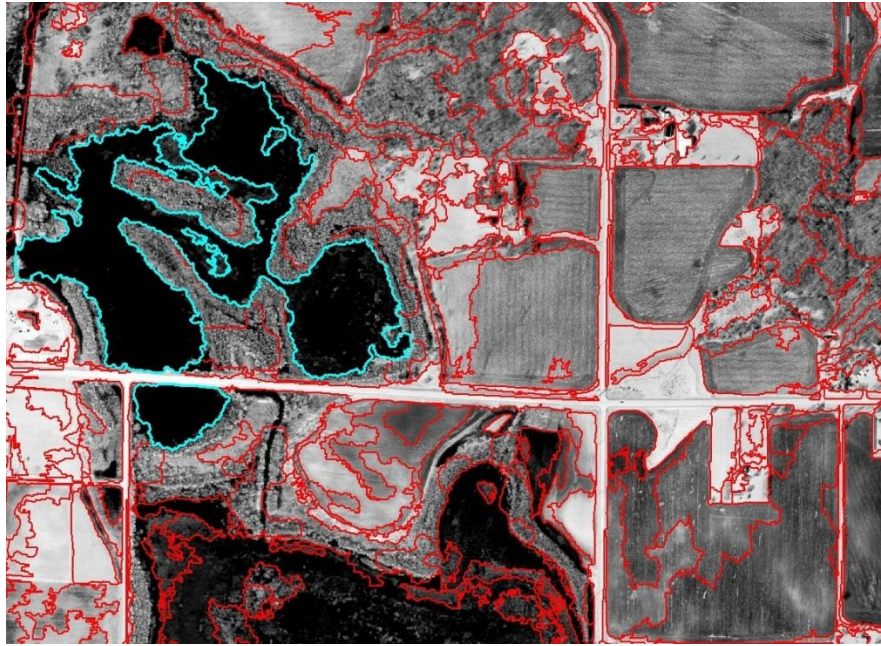


Figure 9. The unedited image segmentation results (red) with two wetland polygons selected (blue) displayed over the IR band of the primary 50cm resolution CIR imagery.

We considered the image segmentation effort to be successful when we reached a point where it took less time for an interpreter to edit an eCognition segmentation-derived shapefile for a watershed than it would have taken for that interpreter to manually digitize all of the features in that watershed. Most of the delineation was based on making minor edits to existing polygons rather than on manually creating new polygons for each feature. All subsequent segmentation process development efforts were directed toward improving the efficiency of the overall workflow in order to further reduce the amount of time required to complete the inventory update.

An online tracking system was implemented where the photo-interpretation team could request processing of specific watersheds or suggest improvements to the segmentation process. Overall efficiency was also improved by optimizing the ruleset for efficient batch processing using the production oriented functions provided by eCognition Server software (Trimble 2010). Additional fields (attribute, comments, field verified) were added to the image segment attribute table to assist in the photo interpretation process.

8.3 Photo interpretation

A detailed list of steps for the photo interpretation process is listed in Appendix A.

8.3.1 Photo interpretation guide

A photo interpretation guide has been created to assist interpreters and help standardize NWI update methodology. This guide includes a brief description of the wetland class and is followed by a representative photo taken during the field verification process, as well as aerial imagery for spring and summer in CIR and natural color. These images will help the interpreter identify wetland types by viewing ground photos paired with aerial photos for the same wetland type.

8.3.2 Photo interpretation process

The photo interpreters viewed the segments over the spring 2010 imagery to identify wetland segments. The photo interpreters used the spring imagery, professional knowledge, photointerpretation guide, as well as the summer imagery to assign the NWI code. Additional data layers (e.g. USGS DRG, SSURGO soils, DEM and other LiDAR-derived products) were also available to assist with the NWI classification. Adjacent segments of the same class were merged. Segments that have multiple wetland classes or combine wetland and upland classes were cut into separate polygons to conform to the NWI class boundary. Each watershed of the USGS HUC 10 tiling scheme was interpreted systematically until the entire area had been completed. Additional details for the photo interpretation process are provided in Appendix A.

8.3.3 Quality assurance and quality control

Quality control and quality assurance (QA/QC) programs were written to automatically check for topological (e.g. gaps and overlaps) as well as spatial accuracy and attribute errors within the classification after the photo interpretation process had been completed. Once a watershed was completed, the interpreter executes the QA/QC program and corrects any identified errors before moving on to another watershed. After successful execution of the QA/QC process by the interpreter, a second interpreter inspected the wetland classification to ensure consistency and accuracy of the wetland classification between individual interpreters. After the second review, the NWI QA/QC lead analyst reviewed the overall classification for the watershed and executed a second series of automated QA/QC procedures provided by the USFWS.

The draft version of the NWI classification for the watershed was then sent to the Minnesota Department of Natural Resources for review. Errors found through the DNR review process were addressed prior to final production. Additional information on the DNR QA/QC review can be found in the Quality Assurance Project Plan for the National Wetland Inventory of Minnesota (DNR 2010).

Once the review was completed, the watershed was merged into a seamless state-wide layer. Final accuracy of the NWI update for the northeast project area was assessed by the Minnesota Department of Natural Resources.

8.3.4 Merge with seamless layer

After completion of the QA/QC of a watershed, the data was merged into a seamless NWI layer for the northeast project area.

8.3.5 Final product generation

Before final product generation, the photo interpreted segments were generalized to “smooth” the polygons so they look more natural for the end user. This smoothing process was accomplished by removing unnecessary vertices, thus reducing the storage requirements and improving the overall efficiency of the data. The final product was delivered in an Albers Equal Area projection for conformance to the FWS standard as well as the Universal Transverse Mercator projection to conform to the Minnesota standard for geospatial data.

9.0 Simplified Plant Community Classification system

In addition to the Cowardin classification system, the NWI update for Minnesota includes the addition of a simplified plant community classification (SPCC) based on the classification of Eggers and Reed (1997). The 15 plant community classes from Eggers and Reed were re-grouped into nine simplified plant community classes with one additional class for non-vegetated aquatic communities (e.g. substrate types for certain systems/sub-systems including unconsolidated bottom, rock bottom, rocky shore, unconsolidated shore, and streambed). This simplification of the Eggers and Reed classification system was designed to provide information on wetland plant communities to the end users of the updated NWI within the bounds of what was currently possible to achieve with reasonable accuracy with remote sensing data. The simplified plant community classes are summarized in Table 7.

9.1 Combining classes

Plant community classes described by Eggers and Reed (1997) were combined to create the simplified plant community classification system for the Minnesota NWI update. These groupings are as follows:

- 1) The Sedge Meadow, Fresh Wet Meadow, Wet to Wet-Mesic Prairie, and the herbaceous form of the Calcareous Fen classes were combined into a single simplified Inland Wet Meadow class.
- 2) The various bog types and subtypes of Eggers and Reed were combined into a single simplified Peatland class.
- 3) The Shrub-Carr, Alder Thicket, and the shrub form of the Calcareous Fen classes were combined into a single simplified Shrub Wetland class.

Table 7: Simplified plant community classes

	Modified Plant Community Class	Eggers and Reed Plant Community Class
1	Seasonally Flooded Basin	Seasonally Flooded Basins - 16B
2	Wet Meadow	Sedge Meadow - 13A Fresh (Wet) Meadows - 15B Wet to Wet-Mesic Prairies - 15A Calcareous Fens (Herbaceous Type) - 14A
3	Shallow Marsh	Shallow Marshes - 13B
4	Deep Marsh	Deep Marshes - 12B
5	Shallow Open Water Community	Shallow Open Water Communities -16A
6	Peatland	Open Bog (Herbaceous Type) - 10A Open Bog (Shrub Type) - 7A Coniferous Bogs - 4A
7	Shrub Wetland	Shrub-Carrs - 8B Alder Thickets - 8A Calcareous Fens (Shrub Type) - 7B
8	Hardwood Wetland	Hardwood Swamps - 3B Floodplain Forests - 3A
9	Coniferous Swamps	Coniferous Swamps - 4B
10	Non-Vegetated Aquatic Community	NA

9.2 Classification cross-walk to Cowardin

Implementing this simplified plant community class was primarily a process of re-coding from the Cowardin classification system including wetland classes, subclasses, water regime modifiers, and special modifiers to the simplified plant community class. The applicability of the cross-walk between the Cowardin classification system and the simplified plant community classification system requires special attention to how the Cowardin codes were applied. This cross-walk is summarized in Table 8 and described by the following steps:

- 1) Split the Cowardin palustrine emergent class (PEM) across four simplified plant community classes based on water regime: Seasonally Flooded Basins (PEMA), Inland Wet Meadow (PEMB), Shallow Marshes (PEMC & PEMF), and Deep Marshes (PEMH).
- 2) There is some potential for class confusion between simplified Inland Wet Meadow class and the Seasonally Flooded Basin class. Particular attention is required during the photo-interpretation of the temporarily flooded (A) water regime for the PEM class to ensure proper class separation. The Eggers and Reed classification key states that Seasonally Flooded Basins are often cultivated or dominated by annuals such as smartweed and wild millet. Wetlands with photo-signatures indicating dominant plant communities are obligate wetland species (such as Typha) should not be classified as PEMA.
- 3) Split the Cowardin PAB class across Deep Marshes (PABF) and Shallow Open Water Communities (PABH) based on water regime.
- 4) Split the Cowardin forested wetland class (PFO) into Coniferous Wetland (PFO2 & PFO4) and Hardwood Wetland (PFO1) plant community classes based on sub-class with the exception of the coniferous wetlands that should be placed in the peatland class (see rule 5).
- 5) The peatland community class crosses the PEM, PSS, and PFO Cowardin classes. Additional interpretation beyond what is typically required for the NWI is needed to effectively separate the peatland community class. Wetlands that have photo-signatures that indicate closed canopy black spruce stands, sphagnum-moss/leather-leaf, sphagnum/sedge, sphagnum/tamarack, or possessing other peatland indicators such as the characteristic open water moat will be assigned a new special modifier (q) that will then be used to complete the cross-walk for the simplified peatland community class.

NOTE: This peatland community class is most closely related the Eggers and Reed bog classes, but the relationship is not expected to be perfect. According to Eggers and Reed, bogs have the following plant characteristics:

- *Tamarack (PFO2) and/or black spruce (PFO4) are dominant; growing on a continuous sphagnum moss mat and acid, peat soils*
- *Shrubs are ericaceous and evergreen (PSS3, PSS4) growing on a sphagnum moss mat layer; peat soils are acidic*
- *Sphagnum moss mat on acid peat soils; leatherleaf, pitcher plants, certain sedges, and other herbaceous species (PEM) tolerant of low nutrient conditions may be present*

The presence of a sphagnum moss mat and ericaceous shrubs can usually be photo-interpreted. In some cases, the tree canopy can be too dense to view the underlying layers. However, depending upon the characteristics of the tree canopy, the presence of a sphagnum mat can be inferred. The Native Plant Community Classification System refers to some wetlands with extensive sphagnum coverage as poor fens. Eggers and Reed do not make this distinction. These poor fens are difficult to separate from bogs without detailed field studies. In fact, fens and bogs may occur within the same wetland complex.

Table 8: Cross-walk from Cowardin to simplified plant community class

System	Subsystem	Class	Subclass	Water Regime	Code	Modifier	Plant Community Class
Lacustrine	Limnetic	Rock Bottom		H	L1RBH		Non-Vegetated Aquatic Community
		Unconsolidated Bottom		H	L1UBH		Non-Vegetated Aquatic Community
		Aquatic Bed		H	L1ABH		Shallow Open Water Community
	Littoral	Rock Bottom		F	L2RBF		Non-Vegetated Wetland
				H	L2RBH		
		Unconsolidated Bottom		F	L2UBF		Shallow Open Water Community
				H	L2UBH		
		Aquatic Bed		F	L2ABF		Shallow Open Water Community
				H	L2ABH		
		Rocky Shore		A	L2RSA		
			C	L2RSC			
	Unconsolidated Shore		A	L2USA		Non-Vegetated Aquatic Community	
			C	L2USC			
Emergent	2-Nonpersistent	F	L2EM2F		Shallow Open Water Community		
		H	L2EM2H				
Riverine	Lower Perennial	Rock Bottom		F	R2RBF		Non-Vegetated Aquatic Community
				H	R2RBH		
		Unconsolidated Bottom		F	R2UBF		Non-Vegetated Aquatic Community
				H	R2UBH		
		Aquatic Bed		F	R2ABF		Shallow Open Water Community
				H	R2ABH		
		Rocky Shore		A	R2RSA		
			C	R2RSC			
	Unconsolidated Shore		A	R2USA		Non-Vegetated Aquatic Community	
			C	R2USC			
	Emergent	2-Nonpersistent	F	R2EM2F		Shallow Open Water Community	
			H	R2EM2H			
	Upper Perennial	Rock Bottom		F	R3RBF		Non-Vegetated Aquatic Community
				H	R3RBH		
		Unconsolidated Bottom		F	R3UBF		Non-Vegetated Aquatic Community
				H	R3UBH		
		Aquatic Bed		F	R3ABF		Shallow Open Water Community
				H	R3ABH		
		Rocky Shore		A	R3RSA		
				C	R3RSC		
Unconsolidated Shore			A	R3USA		Non-Vegetated Aquatic Community	
			C	R3USC			
Intermittent	Streambed		A	R4SBA			
			C	R4SBC			

**Table 8: Cross-walk from Cowardin to simplified plant community type
(continued)**

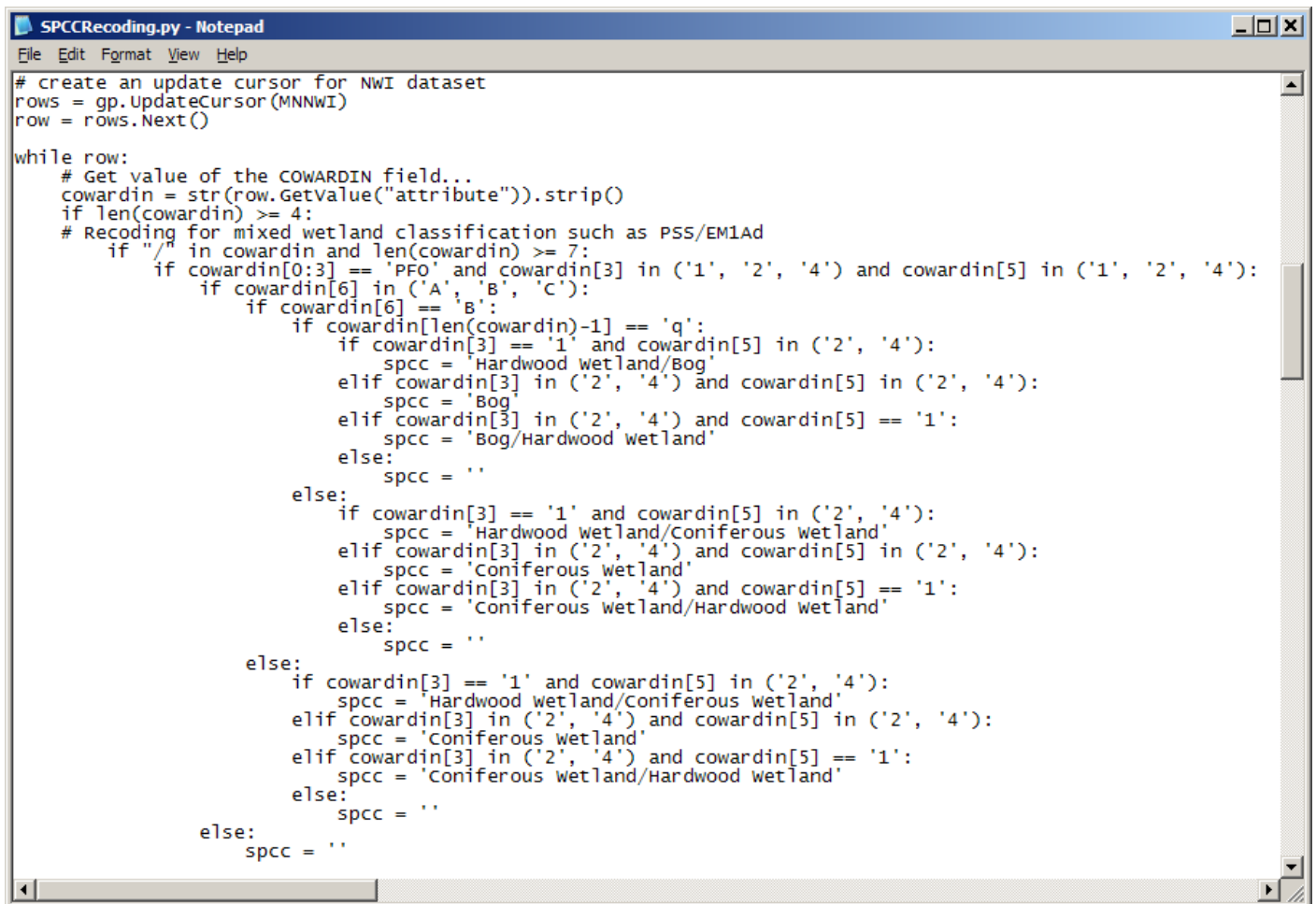
System	Subsystem	Class	Subclass	Water Regime	Code	Modifier	Plant Community Class	
Palustrine	Palustrine	Rock Bottom		F	PRBF		Non-Vegetated Aquatic Community	
				H	PRBH			
		Unconsolidated Bottom		F	PUBF		Shallow Open Water Community	
				H	PUBH			
		Aquatic Bed	F	PABF		Deep Marsh		
		Unconsolidated Shore	H	PABH		Shallow Open Water Community		
			A	PUSA				
		Moss-Lichen	C	PUSC		Non-Vegetated Aquatic Community		
			B	PMLB	q		Peatland	
		Emergent	1-Persistent	A	PEM1A		Seasonally Flooded Basin	
				B	PEM1B	not q	Wet Meadow	
			C	PEM1C	q	Peatland		
			F	PEM1F		Shallow Marsh		
		2-Nonpersistent	F	PEM2F		Deep Marsh		
			H	PEM2H				
		1-Broad-leaved deciduous		A	PSS1A		Shrub Wetland	
				B	PSS1B			
				C	PSS1C			
				A	PSS2A			Shrub Wetland
		2-Needle-leaved deciduous		B	PSS2B	not q	Shrub Wetland	
				C	PSS2C	q	Peatland	
				C	PSS2C		Shrub Wetland	
		3-Broad-leaved evergreen	B	PSS3B	q	Peatland		
		4-Needle-leaved evergreen		A	PSS4A		Shrub Wetland	
				B	PSS4B	not q	Shrub Wetland	
				C	PSS4B	q	Peatland	
				C	PSS4C		Shrub Wetland	
		1-Broad-leaved deciduous		A	PFO1A		Hardwood Wetland	
				B	PFO1B			
				C	PFO1C			
			2-Needle-leaved deciduous		A	PFO2A		Coniferous Wetland
					B	PFO2B	not q	Coniferous Wetland
					C	PFO2C	q	Peatland
			4-Needle-leaved evergreen		A	PFO4A		Coniferous Wetland
					B	PFO4B	not q	Coniferous Wetland
					C	PFO4B	q	Peatland
					C	PFO4C		Coniferous Wetland

Water regimes shaded blue are the most likely regime for the associated Cowardin class

9.3 Data processing for SPCC

Geoprocessing functionalities within ArcGIS were utilized to generate a script to populate the SPCC based on the NWI code (Fig. 10). There were no additional input data, hardware and software required. The script can be run under any ArcGIS desktop environment. The following lists the general steps of developing, testing, deploying, and distributing the script.

- 1) Write the python script in Notebook and saved it into a .py file.
- 2) Test the script and check the field to see if it's correctly populated.
- 3) Import into ArcToolbox as an arctool with a user-friendly interface.



```
# create an update cursor for NWI dataset
rows = gp.UpdateCursor(MNNWI)
row = rows.Next()

while row:
    # Get value of the COWARDIN field...
    cowardin = str(row.GetValue("attribute")).strip()
    if len(cowardin) >= 4:
        # Recoding for mixed wetland classification such as PSS/EM1Ad
        if "/" in cowardin and len(cowardin) >= 7:
            if cowardin[0:3] == 'PFO' and cowardin[3] in ('1', '2', '4') and cowardin[5] in ('1', '2', '4'):
                if cowardin[6] in ('A', 'B', 'C'):
                    if cowardin[6] == 'B':
                        if cowardin[len(cowardin)-1] == 'q':
                            if cowardin[3] == '1' and cowardin[5] in ('2', '4'):
                                spcc = 'Hardwood wetland/Bog'
                            elif cowardin[3] in ('2', '4') and cowardin[5] in ('2', '4'):
                                spcc = 'Bog'
                            elif cowardin[3] in ('2', '4') and cowardin[5] == '1':
                                spcc = 'Bog/Hardwood wetland'
                            else:
                                spcc = ''
                        else:
                            if cowardin[3] == '1' and cowardin[5] in ('2', '4'):
                                spcc = 'Hardwood wetland/Coniferous wetland'
                            elif cowardin[3] in ('2', '4') and cowardin[5] in ('2', '4'):
                                spcc = 'Coniferous wetland'
                            elif cowardin[3] in ('2', '4') and cowardin[5] == '1':
                                spcc = 'Coniferous wetland/Hardwood wetland'
                            else:
                                spcc = ''
                    else:
                        if cowardin[3] == '1' and cowardin[5] in ('2', '4'):
                            spcc = 'Hardwood wetland/Coniferous wetland'
                        elif cowardin[3] in ('2', '4') and cowardin[5] in ('2', '4'):
                            spcc = 'Coniferous wetland'
                        elif cowardin[3] in ('2', '4') and cowardin[5] == '1':
                            spcc = 'Coniferous wetland/Hardwood wetland'
                        else:
                            spcc = ''
                else:
                    spcc = ''
            else:
                spcc = ''
        else:
            spcc = ''
```

Figure 10. An example of part of the SPCC code.

10.0 Simplified key for hydro-geomorphic classification

10.1 HGM Classification Overview

A simplified Hydro-Geomorphic (HGM) Classification was created for the updated NWI for Minnesota based on the rules listed in this section (see Fig. 11-15). A geoprocessing script was created to automate the simplified HGM classification for the northeast project area. Every polygon in the NWI data layer has an HGM attribute for landscape position, landform/waterbody, and water flow path. The allowable classes are provided in Table 9.

10.2 Data Requirements and Layer Generation

The required data layers to perform the HGM classification on the updated NWI are:

- 1) Northeast MN NWI layer with valid NWI codes
- 2) MN DNR streams data
- 3) Slope layer generated from DEM (raster format)
- 4) Public Water Inventory (PWI) Basin Delineations
- 5) Landscape position mask (described below)

The following six attribute fields are required to be added to the updated NWI layer:

- 1) Landscape
- 2) Landform
- 3) Water flow
- 4) Secondary water flow
- 5) HGM Name
- 6) HGM Code

Table 9: Allowable HGM classes for the Minnesota NWI update

Landscape Position	Landform/Waterbody	Water Flow Path
Lentic Lotic River Lotic Stream Terrene	Island Fringe Floodplain Basin Flat Slope Peatland	Inflow Outflow Throughflow Bi-directional Non-tidal Vertical flow
	Lake Lake Floodplain River Pond Pond Floodplain	

10.2.1 Derived data layers

Two additional layers were developed from the MN DNR stream data. The first layer is a flooding stream layer that is used later to define the extent of the lotic landscape component. The flooding stream layer was created by deleting all of the drainage ditches, connectors and small streams from the stream layer. Small headwater streams and artificial channels were generally found not to have developed flood inundation areas. A visual review of the flooding stream layer was conducted and any stream without a visible floodplain was deleted.

The second layer is a stream layer for the water flow path analysis. All streams were used and visually reviewed for accuracy. The visual review of the stream layer digitized any stream that did not completely connect with a lake or any missed stream that would affect the water flow path analysis.

A landscape position mask was created in order to identify the landscape position component of the HGM class. The mask consists of identifying the lentic and lotic landscape positions and the remaining areas were considered terrene. The lentic and lotic landscape position were created from the ordinary high water mark delineation of lakes from the Minnesota Department of Natural Resource's Public Water Inventory (PWI) basin layer and the flooding streams layer as described below.

To identify the lentic landscape position, a lentic layer was derived from the PWI. The PWI basin layer contains both wetlands and open water bodies delineated to the ordinary high water mark. A spatial selection was done between the PWI layer and all lacustrine wetlands within the NWI. A reverse selection was performed to identify any feature within the PWI that was not associated with a lacustrine wetland within the NWI. These features were reviewed for accuracy and deleted. The remaining PWI basins were then used to create a lentic landscape position feature class.

To identify the lotic landscape position, a riparian area layer was derived from the flooding stream layer and the DEM. A slope grid was first calculated on the DEM layer, which was used to create a fractional slope grid (rise over run). The fractional slope grid was used in conjunction with the stream floodplain layer to run a cost-distance analysis, where the flooding stream layer was the source feature and the fractional slope was used as the cost. The results from this analysis provided an approximation of the height above the nearest stream. A threshold classification approach was used to select a height above the nearest stream that corresponds to the extent of the riparian area (Table 10). This threshold was selected based on visual inspection of the DEM, aerial photos and FEMA floodplain delineation, where available.

A landscape position classification layer was made by combining the lentic and lotic layers. Lentic features were given priority over lotic features when they overlapped. Any areas within the project boundary not covered by either lotic or lentic features were assigned to a terrene class. A final inspection of the lotic feature class was performed to remove any small polygons surrounding the lentic features.

In order to assign slope wetlands to the Landform type, a two percent slope layer was created using the DEM. A percent slope grid was calculated from the DEM and all areas greater than two percent slope were identified. Any cell with a value of two percent slope or less was reclassified with a value of 1. Any cell with a value of greater than two percent was reclassified to a value of 2.

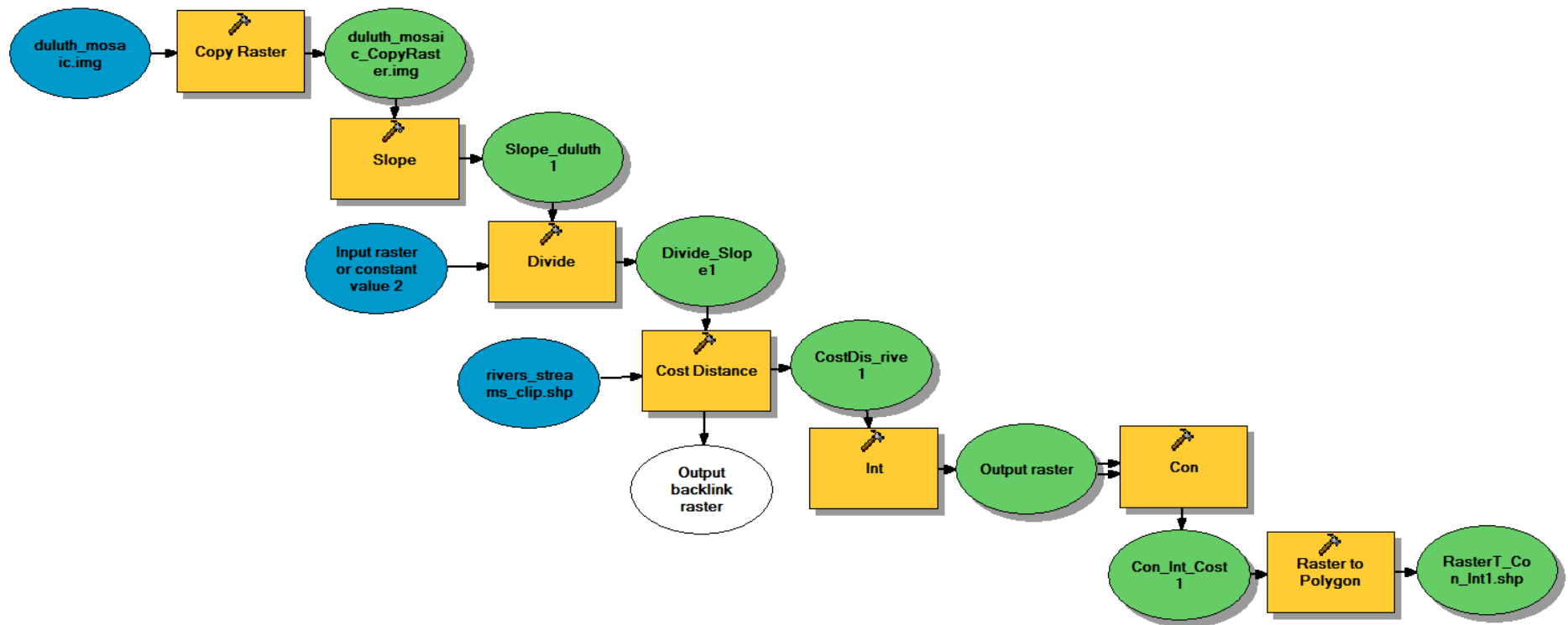


Figure 11. A ModelBuilder Model of the HAS Processing Steps.

Table 10: Steps to Perform a Height Above Stream Analysis

- 1) Extract the desired stream/river features for the project area from a stream GIS data layer such as DNR 24K Streams or the National Hydrography Dataset (NHD) for your desired project area (e.g. Analysis Tools>Extract>Clip).
- 2) Extract, clip, or mosaic the DEM as needed to match your project extent (e.g. Spatial Analyst Tools>Extraction>Extract by Rectangle).
- 3) Use the “Copy Raster” tool to set 0 values to Null (Data Management>Raster>Raster Dataset>Copy Raster).
- 4) Calculate the slope grid from the DEM selecting the output to be expressed as percent slope not degrees (Spatial Analyst>Surface>Slope). Make sure that the vertical and horizontal units are the same, or use a conversion factor to make the units the same.
- 5) Use raster calculator to convert the percent slope to fractional slope (rise/run) by dividing by 100 (Spatial Analyst Tools>Map Algebra>Raster Calculator).
- 6) Run a cost-distance analysis (Spatial Analyst Tools>Distance>Cost Distance). The source data is the selected stream/river features extracted in step three. The cost raster is the fractional slope grid created in step six.
- 7) In order to convert the raster to polygons and manipulate the features (dissolve, select, etc.), first convert the raster values to integer (Spatial Analyst Tools>Math>Int).
- 8) To remove values more than a certain height above the stream, use a con statement (Spatial Analyst Tools>Conditional>Con). The input raster is the integer raster created in step 10, the expression is the SQL expression to select only the values you want in the output (e.g., VALUE <= 3), the input true raster is the same as the input raster, and the input false raster should be left blank. This means that if a pixel is less than or equal to 3 (meters above stream), the output includes that pixel, but if the value is 4 or greater the output does not include that pixel.
- 9) Convert the raster layer to polygon features (Conversion Tools>From Raster>Raster to Polygon).

10.3 HGM Classification Process

The model inputs are: 1) NWI layer with the following fields: landscape, landform, water flow, secondary water flow, HGM_Name, and HGM_Code; 2) landscape position mask; 3) two percent slope layer; 4) stream water flow layer; and 5) lentic layer.

The model is composed of six primary steps: 1) assignment of landscape position, 2) assignment of landform classes within the lentic landscape position, 3) assignment of landform classes within the lotic landscape position, 4) assignment of landform classes within the terrene landscape position, 5) assignment of water flow path, and 6) quality control review and assignment of secondary waterfowl path (Fig. 12).

The landscape position mask was used to assign the lentic, lotic and terrene landscape positions to all of the NWI wetlands. A majority rule was used for wetlands intersecting multiple landscape positions within the mask. The lotic position was further sub-divided by using the NWI riverine class (15 feet wide and larger) and assigning those wetlands a lotic river position with any remaining lotic positions being assigned lotic stream. Defining the landscape position restricts the potential landform classes that can be assigned to any given wetland. For example, lentic and lotic landscape positions cannot have slope landforms.

Wetlands within the lentic position were classified into landform types fringe, basin or flat based on NWI water regime. Wetlands with a semi-permanently flooded (F) water regime were assigned the fringe landform type. Wetlands with a seasonally flooded (C) water regime were assigned a basin landform type and any remaining lentic wetlands were assigned the flat landform type.

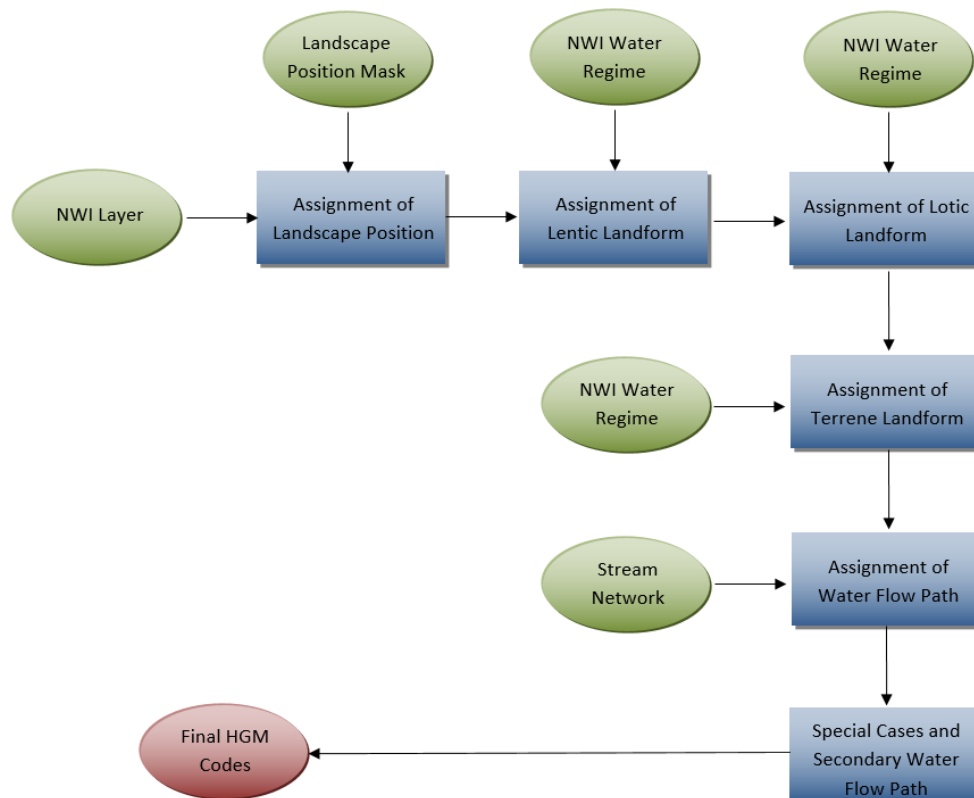


Figure 12. HGM classification flow chart.

Wetlands within the lotic position were classified into landform types fringe, floodplain, or reclassified into the terrene landscape position. Wetlands with an unconsolidated shore class or semi-permanently flooded (F) water regime were assigned the fringe landform type. Wetlands with a temporarily flooded (A) or seasonally flooded (C) water regime were assigned the floodplain landform type. All wetlands within the lotic position with a saturated (B) water regime were reclassified to the terrene landscape position. The saturated water regime was characteristic of bog wetlands which are mostly associated with the terrene landscape position.

Wetlands within the terrene position were classified into landform types of fringe, basin, flat or slope based on the water regime or two percent slope layer. Wetlands with a semi-permanently flooded (F) water regime were assigned the fringe landform type. Wetlands with a seasonally flooded (C) water regime were assigned the basin landform type and wetlands with a temporarily flooded (A) water regime were assigned the flat landform type. Wetlands with a slope greater than two percent were assigned the slope landform type (these wetlands should also generally have a saturated (B) water regime).

The water flow path was assigned by determining the location of the wetland in relation to the stream layer. If the stream layer ended at the wetlands, it was assigned an inflow water flow path. If the stream layer started at the wetland or if the wetland was adjacent to a riverine wetland it was assigned an outflow water flow path. If the stream flowed through the wetland, it was assigned a through flow water flow path. All wetlands without stream connection were assigned the vertical flow water flow path. All riverine wetlands were assigned a through flow water flow path.

Finally, the classification process includes a step to address some situations that were not addressed by the above steps. Any wetland that was surrounded by open water or aquatic bed was assigned the island landform type. Peatlands identified through photo-interpretation and assigned the special modifier “q” were also assigned the peatland landform type. Any lacustrine open water wetland was assigned the lake landform type and any palustrine open water wetland was assigned the pond landform type. Any riverine open water wetland was assigned the river landform type. Any slope wetland was assigned an outflow water flow path. Any fringe landform type with either a lentic or terrene landscape position was assigned a bi-directional water flow path and any wetland with a peatland modifier was assigned a terrene landscape position and vertical flow water flow path.

Table 11. HGM description crosswalk to HGM codes.

Landscape Position		Landform/Waterbody		Water Flow Path	
NAME	CODE	NAME	CODE	NAME	CODE
Lentic	LE	Island	IL	Inflow	IN
Lotic River	LR	Fringe	FR	Outflow	OU
Lotic Stream	LS	Floodplain	FP	Throughflow	TH
Terrene	TE	Basin	BA	Bi-directional Non-tidal	BI
		Flat	FL	Isolated	IS
		Slope	SL		
		Lake	LK		
		River	RV		
		Pond	PD		

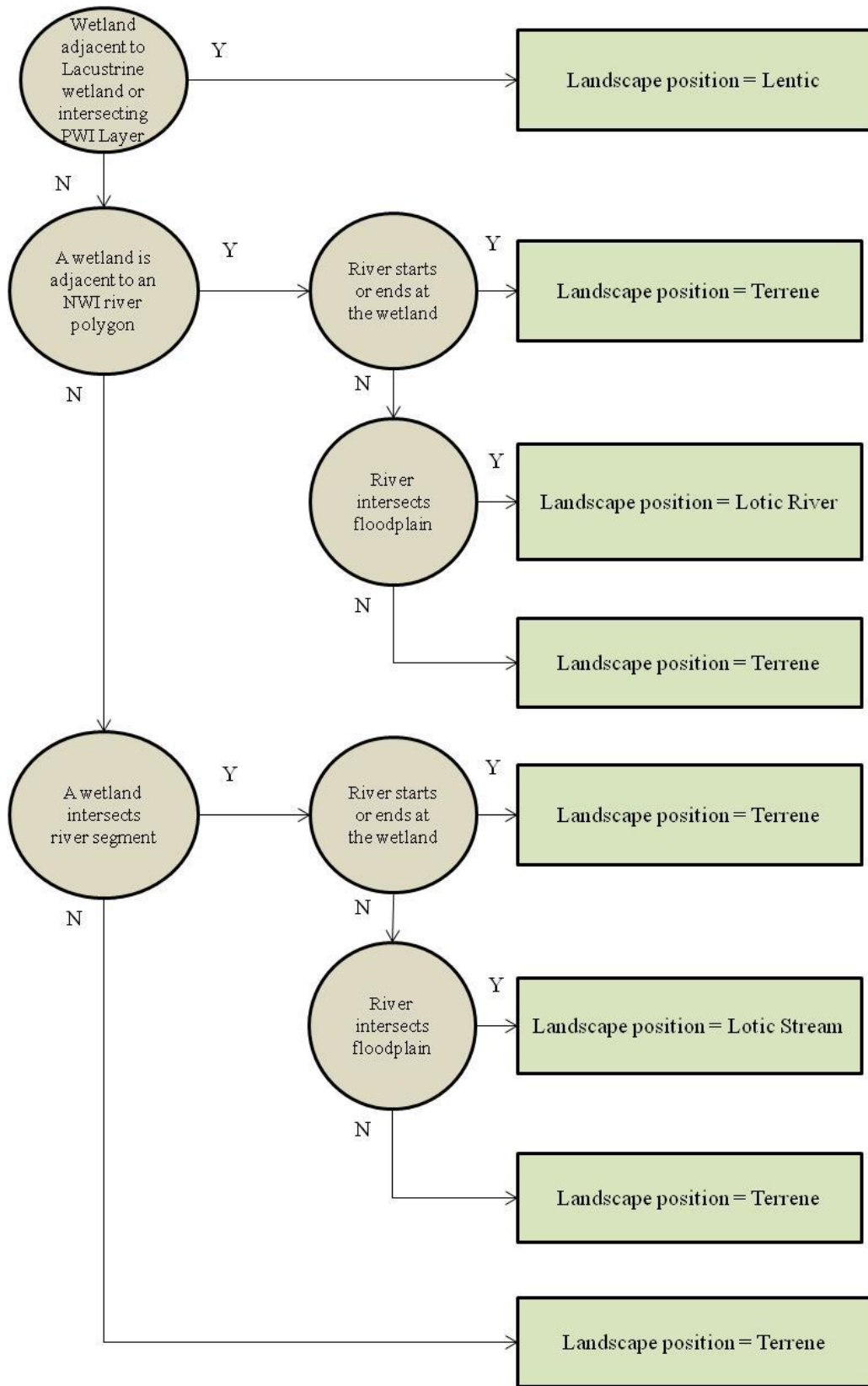


Figure 13. Landscape Position Decision Tree.

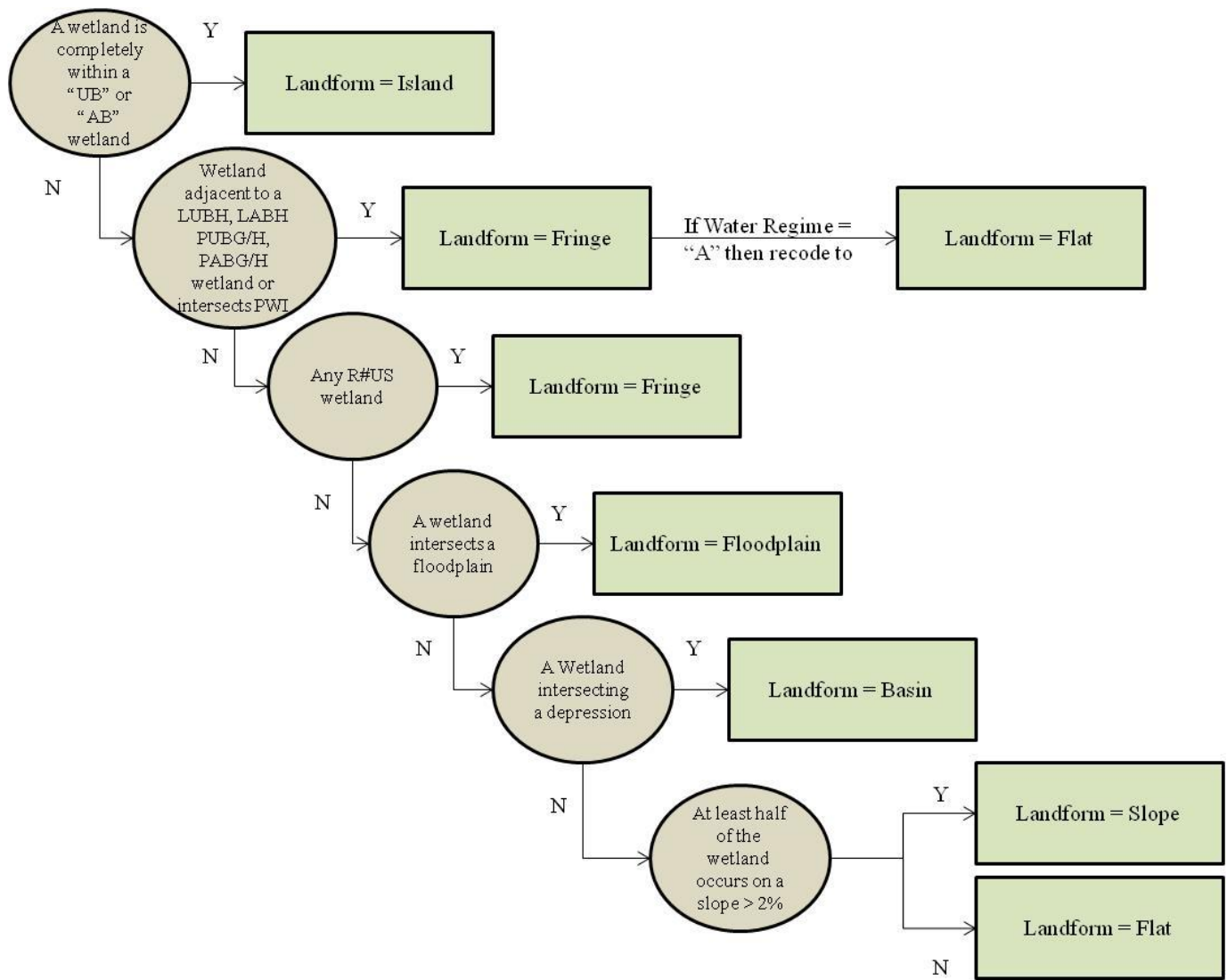


Figure 14. Landform Decision Tree.

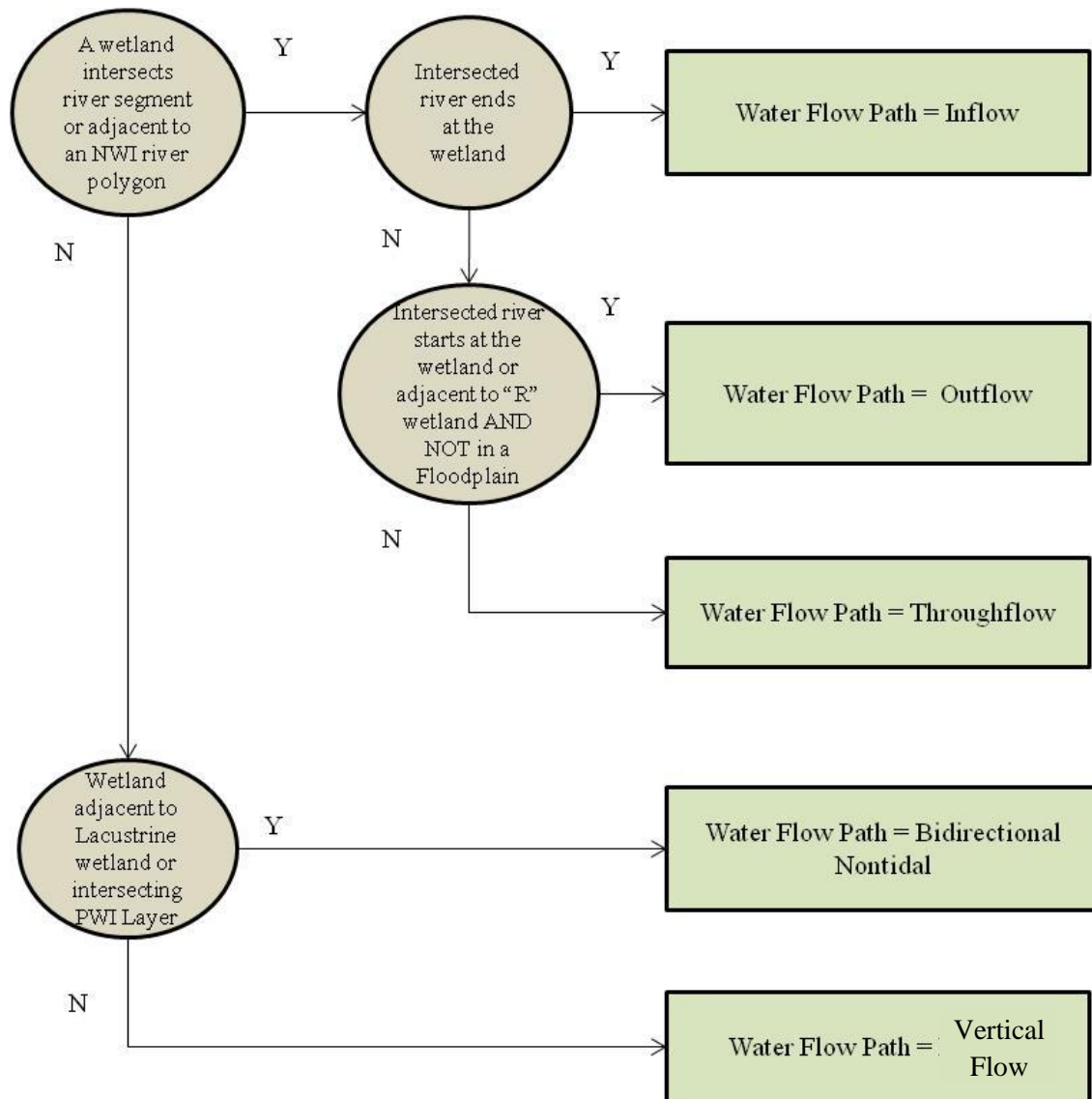


Figure 15. Water Flow Path Decision Tree.

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Appendix A: Photo Interpretation Process

1. Data layers are fed into eCognition segmentation software at GPRO (Great Plains Regional Office)

- a. DEM
- b. DEM NoData Mask
- c. Slope
- d. TPI
- e. CTI
- f. Average Elevation of 1st Returns
- g. Average Intensity of Bare Earth Returns
- h. Spring 2010 aerial imagery

2. eCognition exports to GLARO

- a. segment polygon shapefile
 - i. named *quadname_polys* (q3131ne_polys)
 1. W:\GreatLakes_NWI_Update\MN\EcognitionOutput\polys
 2. Fields
 - a. Class_name
 - b. ACRES
 3. To be loaded into MN_NWI Feature Dataset

3. Import Script

- a. Input – all polygon shapefiles in W:\GreatLakes_NWI_Update\MN\EcognitionOutput\polys
- b. Backs up shapefiles to external hard drive (\\GLARO_SDE\Backup\NWI_Backup\MN\RawSegmentShapefiles)
- c. Repairs Geometry
- d. Adds fields
 - i. ATTRIBUTE (Text 20)
 - ii. COMMENTS (Text 255)
 - iii. FIELD_VER (Text 1)
 - iv. QAQC_CODE (Text 5)
- e. Loads polygon shapefiles into File Geodatabase
 - i. W:\GreatLakes_NWI_Update\MN\ActiveDatabase\MN_NWI_2010.gdb
 - ii. MN_NWI feature dataset
 - iii. Individual Feature Classes named *quadname_polys* (q3131ne_polys)
- f. Deletes shapefiles from W:\GreatLakes_NWI_Update\MN\EcognitionOutput\polys once they have been backed up to external hard drive and added to file geodatabase.
- g. Copies feature classes from W:\GreatLakes_NWI_Update\MN\ActiveDatabase\MN_NWI_2010.gdb to

4. Before starting the 1st watershed

- a. Use ArcCatalog to copy W:\GreatLakes_NWI_Update\MN\ActiveDatabase\MN_NWI_2010.gdb to local machine (D:\Working\NWI)
- b. Copy W:\GreatLakes_NWI_Update\MN\ActiveDatabase\MN_NWI.mxd to local machine (D:\Working\NWI)
- c. Install MN NWI QA/QC toolbox: V:\Installs\GIS Misc\NWI\QAQC Toolbox\MN_WI
- d. Load Find Multipart Polygon script to ArcMap button - V:\Installs\GIS Misc\ArcMap_Scripts_Tools\Find_Multipart_Polygons
- e. Map B:\GLARO_SDE\Backup\Nwi_Backup\MN\PostPhotoInterpSegments – select reconnect at logon

5. Pre-Photo Interpretation

- a. Using ArcCatalog, copy the watershed for editing from W:\GreatLakes_NWI_Update\MN\ActiveDatabase\MN_NWI_2010.gdb and paste it into D:\Working\NWI\MN\MN_NWI_2010.gdb in the MN_NWI feature dataset
- b. Indicate on map and tracking sheet which watershed you checked out. This is very important to make sure two people are not working on the same watershed.
- c. Still in Catalog, right-click on the MN_NWI feature dataset on your computer and go to New and then Topology
 - i. Use the default name and cluster tolerance
 - ii. Select the newly added feature dataset
 - iii. Use the default rank
 - iv. Click Add Rule
 1. Add Must Not Overlap
 2. Add Must Not Have Gaps
 - v. Finish
 - vi. Topology does not need to be validated at this time

6. The Map Document

- a. Add feature dataset to D:\Working\NWI\MN\MN_NWI.mxd
 - i. Or change the data source to save the symbology from a previous watershed
- b. Reference grid – a simple polygon fishnet to help keep track of what has/has not been done
- c. Original NWI – this layer can be used for reference, but many codes and boundaries are suspect.
- d. SSURGO Soils – another reference layer displayed by suggested water regime
- e. Topo – USGS 1:24k topographic map.
- f. Bing Maps – Aerial
- g. CIR_2010 – 2010 Raster\MN_1FT_2010 and/or MN_HALFMETER_2010 displayed 4,2,3)
- h. TrueColor_2010 Raster\MN_1FT_2010 and/or MN_HALFMETER_2010 displayed 1,2,3)
- i. 2009 NAIP
 - i. A group of county level .sid images. Can be expanded to turn different counties on/off or to move them up/down in drawing order
- j. MN_NAIP_2008

7. Photo Interpretation

- a. Start editing NWI watershed segment layer
- b. Merge/cut/classify polygons
 - i. Make sure to look at all imagery and the topo
 - ii. Check auxiliary data if unsure
 - iii. Fill in attribute for all wetland polygons
 - iv. If unsure, mark field verified field as “N”
 - v. Leave comments if there are questions
 - vi. We need to classify upland examples, but do not spent a lot of time on this step
 - vii. Save edits often
 - viii. Keep track of your progress on the map with graphics
 - ix. Save the map document on occasion
 - x. At least 1/day backup the feature dataset to W:\GreatLakes_NWI_Update\Data Backup

8. QA/QC own watershed

- a. When photo interpretation on a watershed is complete, run the MN NWI QAQC toolbox tools from ArcToolbox or the Command Prompt
 - i. All Attributes must be valid
 - ii. Search and classify any NULL attributes
 - iii. Double-check questionable attributes
 1. Usually mixed classes like AB/UB or EM/UB
 - iv. No sliver polygons (under 0.05 acres)
 1. Merge these with neighboring polygon
 - v. No PUBs over 20 acres
 1. Open water over 20 acres should be a Lake (L1 or L2)
- b. Add the Topology (say no to adding layers involved in the topology since it is already added)
 - i. Start editing segment polygon layer
 - ii. Run the validate topology for entire layer
 - iii. Open the error inspector and search on all rules, for entire extent.
 - iv. The Must Not have Gaps rule will flag all of the outside polygons – they are ok and can be ignored or marked as exceptions.
 - v. All other overlaps and gaps need to be corrected
 1. For gaps, use the create feature fix to make a new polygon
 - i. Check to see if it should be merged with a neighbor
 2. For overlaps, use the merge fix to merge the overlap with one of the neighboring polygons.
 3. Save edits
- c. Re-run the sliver test from the QA/QC toolbox
- d. Save edits/stop editing
- e. Copy with ArcCatalog into W:\GreatLakes_NWI_Update\ReadyforQAQC_MN_NWI_2010
- f. Copy watershed segment layer into
B:\GLARO_SDE\Backup\Nwi_Backup\MN\PostPhotoInterpSegements
- g. Fill out QAQC Status.xls on W:\GreatLakes_NWI_Update\Finished Geodatabases
 - i. Watershed name
 - ii. State abbreviation
 - iii. Interpreter name
 - iv. Date in MM/DD/YYYY format that watershed was completed
 - v. Copied to backup – put Y to indicate the edited watershed segment layer was copied from local hard drive to
B:\GLARO_SDE\Backup\Nwi_Backup\MN\PostPhotoInterpSegements
 - vi. Save and close .xls
- h. Use ArcCatalog to delete watershed segment feature class from D:\Working\NWI\MN\MN_NWI_2010.gdb\MN_NWI

9. QA/QC another interpreter's watershed segments

- a. Copy segment data from W:\GreatLakes_NWI_Update\ReadyforQAQC_MN_NWI_2010 to local machine.
- b. Perform visual inspection
- c. Rerun steps 8a through 8e
- d. Copy with ArcCatalog into W:\GreatLakes_NWI_Update\Finished_MN_NWI_2010
- e. Fill out QAQC Status.xls on W:\GreatLakes_NWI_Update\Finished Geodatabases
- f. Copy watershed segment layer into B:\GLARO_SDE\Backup\Nwi_Backup\MN\PostPhotoInterpSegements rename with "postqaqc" at end.

10. Analyst QA/QC

- a. Fill out QAQC Status.xls on W:\GreatLakes_NWI_Update\Finished Geodatabases
- b. Copy and delete from W:\GreatLakes_NWI_Update\MN\Finished_MN_NWI_2010.gdb
- c. Check attributes and investigate any uncommon codes
- d. Perform visual inspection on watershed
- e. Select all "U" codes and merge
 - i. Select all unattributed polygons
 - ii. Calculate ATTRIBUTE field with "U"
 - iii. Select by attribute all "U" codes
 - iv. Merge all "U" segments
 - v. Select **ALL** segments and explode multipart features
 - vi. Calculate acreage and visually check all polygons under .05 acres
- f. Run tool to check for adjacent features with the same attribute
- g. Validate and run topology (gaps and overlaps) and fix any errors

Continued on next page...

- h. Append classified segment data to Reference Data
 - i. Select watershed segments by attribute
 - 1. "ATTRIBUTE" <> "U"
 - ii. Join selected table with W:\GreatLakes_NWI_Update\Codes\NWI_Code_LookupTable.dbf and export attributed records to .dbf
 - 1. FULL_CODE (All Valid codes)
 - 2. Class
 - 3. Subclass
 - 4. WATER_REG
 - 5. Modifier
 - 6. Wetland
 - iii. Append exported .dbf to
W:\GreatLakes_NWI_Update\MN\RandomForest\Reference_Data\Reference_Data.dbf
- i. Export all wetland segments to database to be sent to MNDNR for review
- j. Export all segments to B:\GLARO_SDE\Backup\Nwi_Backup\MN\Finished
- k. Append individual watershed segment feature class into seamless dataset for entire project area: vector.glarogis. MN_NWI_2010
- l. Run QA/QC tool box tools for MN
 - i. All Attributes must be valid
 - ii. No sliver polygons under 0.01 acres
 - iii. No PUBs over 20 acres
 - iv. No L1UBs/L2UBs under 20 acres
- m. Validate and run topology (gaps and overlaps) and fix any errors
- n. When complete
 - i. Dissolve W:\GreatLakes_NWI_Update\MN\State_Level_NWI\MN_State_NWI_2010.gdb
 - 1. Dissolve Field: ATTRIBUTE
 - 2. Uncheck Create multipart features
 - ii. Convert result to coverage
 - iii. Run GENERATE <in cov> <out cov> 4 BendSimplify errorcheck
 - iv. Delete uplands and non-attributed polygons