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Modeling Pre-Settlement Wetlands in Northern Minnesota

Johnathon T. Salfer
Minnesota State University, Mankato

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By

Johnathon T. Salfer

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Dr. Fei Yuan

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Abstract

Modern land use has dramatically altered the native landscape across much of Minnesota and the United States. "Manifest Destiny" has ingrained the idea in American society that wetlands and related lands of "low value" need to be tamed and made profitable. In many places, wetlands have been drained and removed so that agriculture can take over. In recent years, people have begun to see the unintended consequences of this method, and importance is now being given to natural wetlands through various government projects and programs.

Using National Wetlands Inventory (NWI) data, Drainage Index (DI) values calculated from Soil Survey Geographic Database (SSURGO) data, and areas of low anthropogenic disturbance, this study investigates correlations between mapped soils and mapped wetlands. The main objective is to estimate the amount of wetland area that has been lost and suggest the likelihood of what type of wetland was present. The results reveal a good correlation with Max DI values and NWI wetland types when the Max DI values were greater than 75, meaning that it is sufficient enough to use soil data as representations for past wetlands based on the mapping techniques used in this study. Initial results suggest this process can be applied iteratively at a regional level for more accurate measurements in future studies.

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1 Introduction

1.1 Background and Objectives

Wetlands are both a powerful resource for water quality improvement and a great obstacle for people looking to traverse the land or use it for productive means. During the settlement era, many wetlands were drained and replaced with agricultural farms. Over time, perceptions of these wetlands have changed as people have learned more about the presence, composition, and benefits these wetlands provide. Modern efforts have made great advances in mapping wetlands across the United States (U.S.) today. The National Wetlands Inventory (NWI), National Hydrography Dataset (NHD), Department of Natural Resources (DNR), and other agencies provide comprehensive databases of modern wetlands.

However, current inventories of Minnesota's wetlands are incomplete pictures of pre-settlement wetlands. Since these pre-settlement wetlands can no longer be observed, they must be inferred. Soils data give perhaps the best indication of previous land cover based on the length of time required for soil development. The University of Minnesota (UMN) developed an estimation of pre-settlement wetlands (Figure 1.1) in addition to available wetlands for bioenergy purposes (Figure 1.2) in 1981. Based on these two maps, the UMN estimated that 53% of Minnesota's wetlands have been lost. However, no method was provided aside from a selection of soil types shown by the legend. The UMN is unable to produce documentation regarding the decisions made to justify those areas as pre-settlement wetlands.

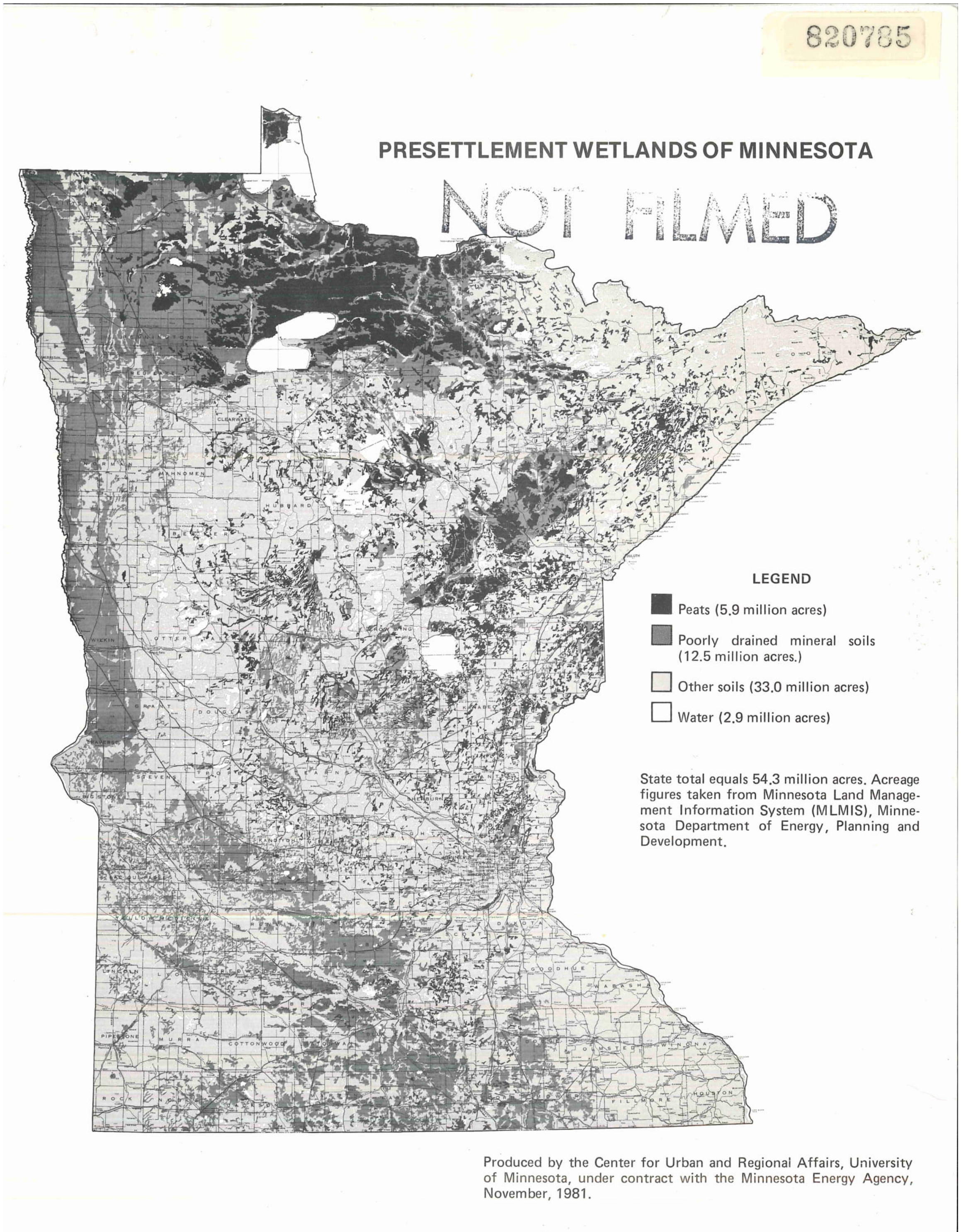


Figure 1.1 Estimated pre-settlement wetland coverage across Minnesota (UMN, 1981)

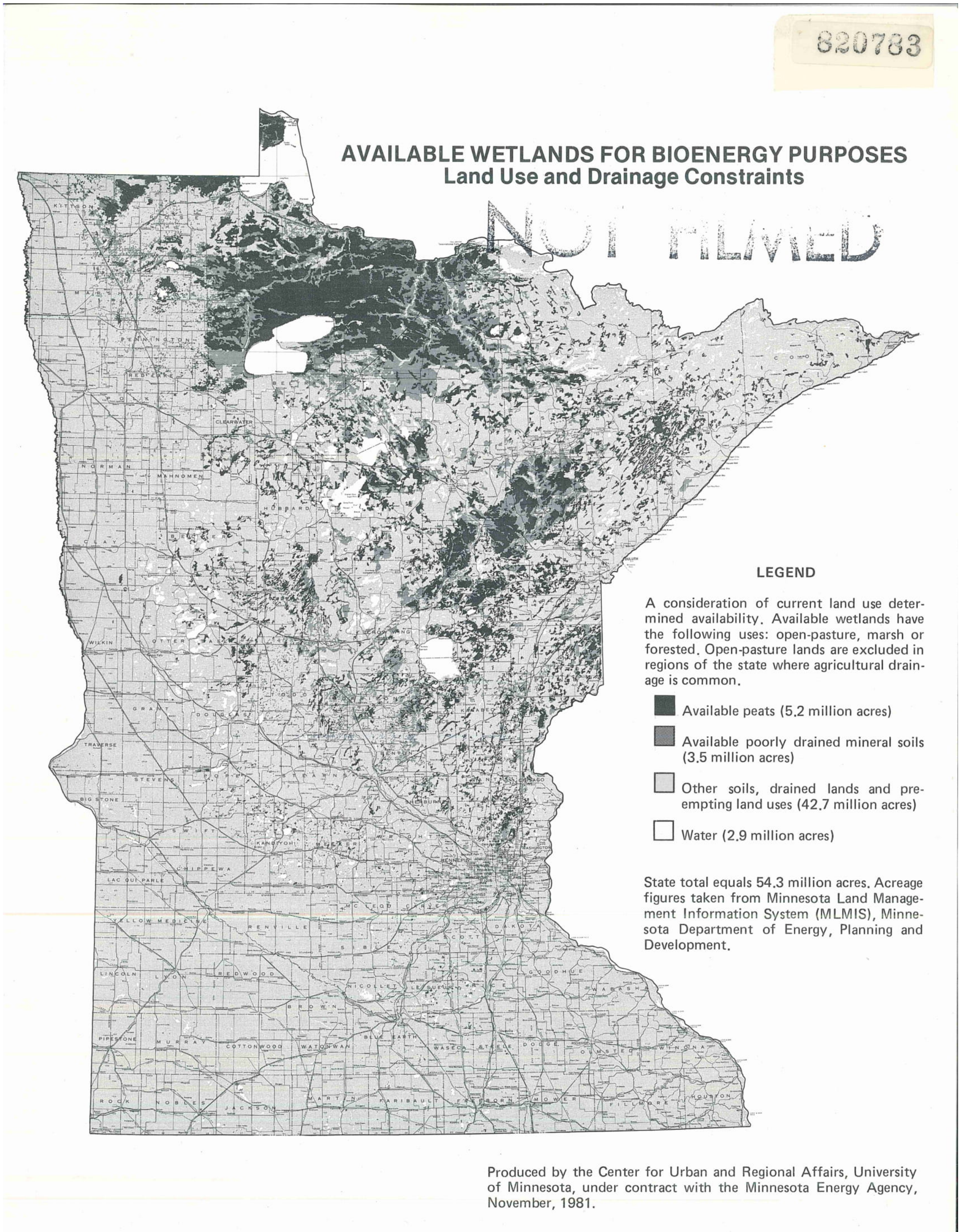


Figure 1.2 Wetland coverage by 1980 after severe drainage (UMN 1981)

The Minnesota Legislative Reference Library, which holds the documents for the now-defunct Minnesota Energy Agency, also received other documents regarding the Peatland project, but they could not offer any information regarding the decisions made for the creation of Figure 1.1 (Mundale and Nelson 1981a, 1981b; Aiken and Wilson 1982). Despite the seemingly arbitrary origin of the pre-settlement area estimation, this figure of 53% wetland loss is still used to convey the amount of wetlands that have been lost over Minnesota's history (State of Minnesota 1998; Tiner 1984; BWSR 1982).

To solve the problem above, this research focuses on the following objectives:

1. Review American sentiment and perception of wetlands over time
2. Review existing models and data of pre-settlement wetland coverage
3. Test a new methodology for comparison with existing methods of modeling pre-settlement wetlands in Minnesota

Using a combination of current datasets and a few common-sense data processing rules, a reasonable estimation of pre-settlement wetlands can be achieved. This will help determine if the often cited UMN paper is a good estimate of wetland loss since 1780. This paper is organized as follows. This chapter introduces MnModel in addition to aforementioned background and objectives of this research. The next chapter reviews relevant prior research on wetlands, soil attributes, and pre-settlement wetland modeling. Chapter 3 presents a method for using simplified soil data (Drainage Index) with wetland data to find regional correlations and extrapolate those findings across other soils. Chapter 4 evaluates the method. Conclusions and future study are provided in the final chapter.

1.2 What is a Model?

A Model for purposes of this research is "an abstraction of reality." Since, in reality, pre-settlement wetlands have been drained and no longer exist for observation, we must draw an abstraction of reality and estimate the total wetlands that prevailed before settlement. Models can make use of logical expressions, mathematical equations, categorical variables, and certain criteria in an effort to simulate a process, predict an outcome, or characterize some phenomena. This research intends to simulate a process, in which the existence of wetlands recorded in soil variables can be reconstructed by matching existing wetlands with existing soil variables.

Existing models are divided into different types. Hammer (1993) defined two important models: a descriptive model and an explanatory model. Descriptive models are theoretical constructs that mirror the behavior or results of an observed phenomenon. It is a "Black Box" process that only requires the correct stimuli, or inputs. The process of converting this data into information is unknown, or the process is not well defined. In comparison, an explanatory model is one that mirrors the behavior of a phenomenon and the processes that produce or cause the observed behaviors. The process of converting data into information is planned and thought out to the point that the results are replicable should others chose to follow the model. Due to their nature, descriptive models are only used to find relationships between inputs and outputs and to discover potential processes that can be applied to an explanatory model. In other words, the goal of a descriptive model is to produce an explanatory model.

Models in ArcGIS are defined as "… workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input." (ESRI 2017).

This research uses the Model Builder in ArcGIS to visually represent how associations between soil data and relatively untouched wetlands are made. This is an explanatory part of the modeling process, which should allow other researchers to apply this methodology to their own geographic areas of interest.

1.3 MnModel Phases 1 and 2

MnModel is a Geographic Information System (GIS) based statistical predictive model created for the entire state of Minnesota to predict the potential for finding Native American sites. This model is a cost-saving measure that can be used by the Department of Transportation (DOT) to reduce the cost of site assessments if used effectively. For example, if the place has a low probability of finding a site, a less intensive examination can be done. In comparison, if an area has a high potential to find a site, it can be surveyed before the start of construction and planning so that disturbance of previously unknown sites does not happen. The MnModel project started in 1995 and has four main phases to it (Minnesota Department of Transportation 2018). Phase 1 was from 1995 to 1996 and consisted of basic data collection and prototype model development. This phase focused on probabilistic surveys and logistic regression. Phase 2 was from 1996 to 1997 and was the formal model development portion. More archeological data was added to the GIS database, and regions were created for modeling purposes. These first two phases were the conceptual framework behind the bigger project. Phases 3 and 4 are discussed in more detail following this section.

1.3.1 MnModel Phase 3

Phase 3 was the model refinement and implementation segment from 1997 to 1999. Regions were recreated in phase 3 to better fit with the Ecological Classification System (ECS). The state was divided into 20 regions based on resources present (see Figure 1.3). Additional variables were created to feed into the phase 3 predictive model, bringing the total number up to 44 environmental variables.

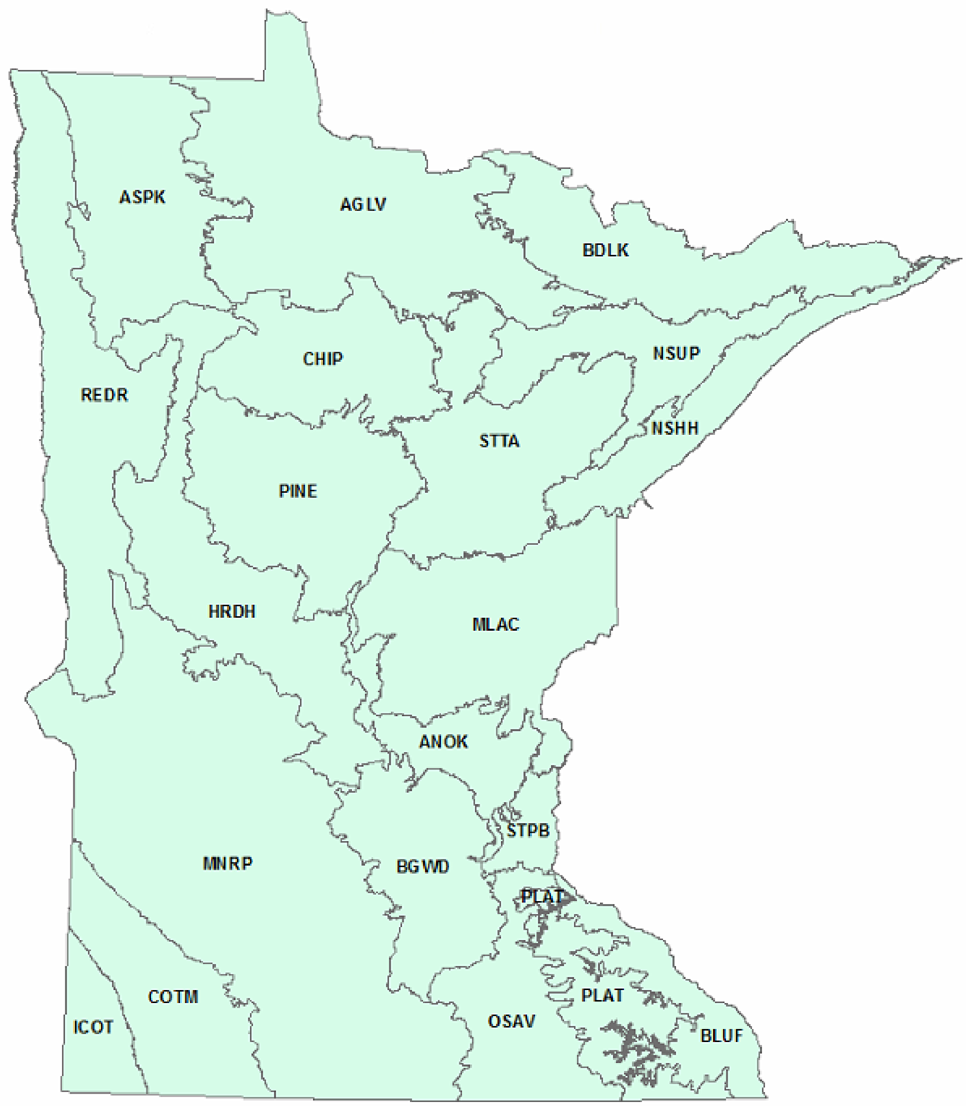


Figure 1.3 Twenty regions of the MnModel project

The predictive model was used in conjunction with a Survey Bias model. This is important because sites are sought out based on an archeologist's intuition and research. Known sites have attributes that the model recognizes and weighs with importance. Because researchers tend to find their own correlations between environmental variables and the likelihood of finding sites, there are biases in the data and the correlations between inputs and expected results. This raises the question, "Are non-site areas empty because area attributes are undesirable, or because no surveys have been done to test a model of perceived behavior?" There is a large "unknown" area of site bias. Ideally, more surveys would be done in those unknown areas to develop a better bell curve of surveys to feed the model. Phase 3 has produced a site probability map along with a survey bias map, but these were developed using the data available at the time.

1.3.2 MnModel Phase 4

The goal of phase 4 is to incorporate higher resolution data and more accurate data to the final probability map. It also aims to supplement unknown areas with more data to reduce survey bias. Site points have been converted into polygons to cover more area, but many polygons are arbitrarily defined. Occasionally, site polygons cover large square areas, going down steep hillslopes where sites do not actually reside. These "site locations" would thus train MnModel incorrectly regarding favored living areas of Native Americans. Redefining the boundaries of the sites will help the model, but this will be done at a later time. Archeological, Terrain, Landscape, Hydrography, and Vegetation data are used in Phase 4.

The MnModel phase 4 project has a hydrographic model that wants to use locations of pre-settlement wetlands to help predict where Native American sites might be located. The final outcome of this project is a statewide raster dataset that predicts the probability of finding Native American sites and artifacts. Working for the MnModel project and looking for ways that the project might be improved has been the inspiration for this research. The current methodology for the hydrographic model is not optimized due to manual subjectivity, lack of automated procedures, and drifting methodology.

1.3.3 Hydrographic Model

The Hydrographic model (HYDMOD) consisted of some manual steps that were very exploratory in nature due to the way available data was used. This portion of the project suffered from issues of inappropriate data usage, individual subjectivity, and ill-defined methodology.

First, the ALLMODWAT layer, which is a union of several datasets listed below, was created.

- National Wetlands Inventory (NWI) wetlands
- Native Plant Communities (NPC)
- National Hydrography Dataset (NHD) water body data
- Department of Natural Resources (DNR) Hydrography Data
- Soil Survey Geographic (SSURGO) Data.

The process to create the ALLMODWAT layer began with 2013 NWI data. Attribute data was reclassified to be consistent with *Minnesota's Native Vegetation: A Key to Natural Communities, Version 1.5* (Aaseng et al. 1993). This data source was considered authoritative, but incomplete, as there were many large bodies of water that NWI did not map. DNR 2015 Water & Wetlands data as well as NHD data were added to the NWI data using a UNION function in ArcMap. The UNION function in ArcMap takes two layers and combines the two. Any overlapping pieces are given new FIDs and added to the table as a separate polygon unit. Figure 1.4 shows how this is done.

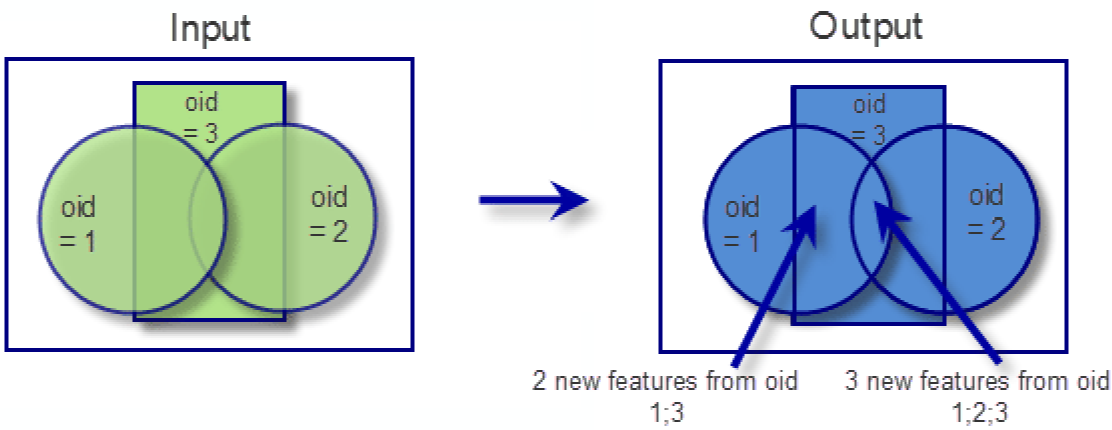


Figure 1.4 UNION operation in ArcMap 10.5 (ESRI 2017)

Useful fields from SSURGO data were also identified, so another UNION operation was performed. Lastly, as NPC data was found to contain wetlands not mapped by other data sources, a final UNION was performed. The subsequent UNION operations preserved all of the fields from each dataset, but it also substantially increased the total number of polygons. This method of creating a layer has led to the unfortunate creation of several slivers, otherwise known as small, unwanted polygons resulting from the polygon layer intersection of the UNION operation. Every unique combination of data is kept, regardless of the size of the polygon created. One way to remedy this type of conflict would be to unify the classification standards between agencies using a kind of one-to-many dictionary of classification codes for each agency's classification standards. A Python dictionary uses key-value pairs to associate two elements. Making a dictionary for each classification system, assigning many complex values to one simplistic value, and creating a new field that combines all classification systems' new values would solve much of the sliver problem, though it is too late in the project to implement this. After the Minnesota State University, Mankato (MSUM) team is finished recoding these polygons manually, they will be quality-assessed by MNDOT.

Subjectivity of polygon classification is another substantial problem. Instead of performing data-driven operations for creating a consistent and reproducible ALLMODWAT layer, MNDOT has instead chosen to keep the current ALLMODWAT layer and have MSUM learn to recognize different kinds of wetlands from aerial photos and interpret nearby data to make decisions on a "best-guess" classification system. There are some decision flowcharts to help with classification, but available aerial photos do not give the required resolution necessary to decide what class and type of wetland is present. Figure 1.5 shows an image of a typical polygon a user would need to examine and determine what class and type of wetland is present. In heavily engineered landscapes, it becomes very difficult to determine what kind of wetland a person might call a parcel of land that used to be a wetland. All fields are stored as string, so user fatigue and lack of attention might easily result in mistyped information and result in errors of the final dataset.

ICOT POLYGON ID 32918

Polygon to classify:

Source: DNR

Class: INTERMITTENT WATER

MSU field choices:

HYD_SYS_MSU	CLASS_MSU	TYPE_MSU	SOURCE_MSU	CLASS_CONF_MSU	ALT_TYPE_MSU
PALUSTRINE	EMERGENT MARSH	MARSH	NWI	5	0
LACUSTRINE	AQUATIC LAKE COMMUNI	LAKE BED	NWI	5	0
PALUSTRINE	INTERMITTENT WATER	INTERMITTENT WATER	DNR	2	1

Reasons: Not water, DNR, clearly urban land or farm field. AKT_TYPE was suggested as Farmed. Gave confidence of 4 (edited) because soils are very poorly drained, and it is DNR.

Figure 1.5 An example of subjectivity in manually classifying polygons.

In addition to the difficulty of selecting from a number of specific wetland types, mapping at such a resolution may be unnecessary for an archeological model. Reports from Spanish missionaries show that Ojibwa and Dakota people have words for different wetland classes, but not to the resolution of wetland types we are mapping (Whelan 1992). More importance was given to individual plants than entire ecosystems. If the same is true for other tribes, mapping at this resolution of vegetation identification may be excessive for the final model. A review of Native vocabulary should be carried out.

Lastly, the evolving nature of this project has held back its progress. The hydrographic model is currently a descriptive model. The data and the idea for a model of pre-settlement waterbodies is present, but how that data will be processed from modern day data inputs to output of pre-settlement information is yet unknown. There is still some disconnection between what exactly the output should be. Due to the temporal extent of this dataset, manually reclassifying data can be difficult at times. Polygons may represent features that have been recently created due to needs of modern society. This includes things like ditches that control modern agriculture, rivers digitized within the last few years that represent a controlled river instead of a free-flowing river during pre-settlement years, reservoirs that may have pushed back old shorelines and submerged site locations, and so on. This is part of the reason why manual inspection of the data is labeled as important, but this also lends to very difficult decision making at times. The evolving methodology has also created instances where discoveries about the methodology were inconsiderate of important information, and due to these revelations, datasets would need to be retrofitted to reflect this new information, or previously completed work would be discarded and restarted under the new methodology, resulting in some wasted hours of work.

2 Literature Review

2.1 What is a wetland?

According to the U.S. Department of the Interior, Fish and Wildlife Service (USFWS), wetlands are:

"… lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. The single feature that most wetlands share is soil or substrate that is at least periodically saturated with or covered by water. The water creates severe physiological problems for all plants and animals except those that are adapted for life in water or in saturated soil." - (Cowardin et al. 1979)

Wetlands get their name from the fact that saturation is the dominate factor in soil development, plant growth, and animal species competition. The 'land' is naturally 'wet'. These wetlands can be found everywhere between well-drained upland areas and permanently flooded deep-water habitats. Due to the continuum existence of these wetlands, there are many different types, such as marshes, swamps, and bogs. This can make delineating wetlands difficult (Tiner 1984). Figure 2.1 gives a good illustration of why delineation can be difficult. Notice the fluctuation of the water levels, and the seepage zones where saturation is dominate but not immdiately obvious.

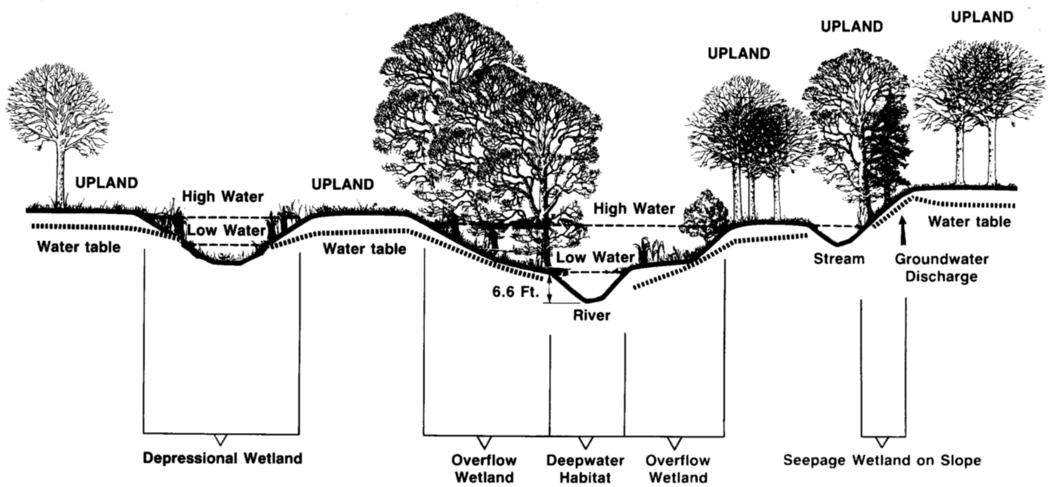


Figure 2.1 Wetlands, deep water habitats, and uplands (Tiner 1984)

Several other definitions have been proposed for wetlands from the corps of engineers in 1977, the Swampbuster program of 1990, and the Committee on Characterization of Wetlands of 1995, but the most current definition of wetlands comes from National Wetlands Inventory. This definition is based on the old USFWS definition, but now addresses wetlands from a functional standpoint.

"Wetlands provide a multitude of ecological, economic and social benefits. They provide habitat for fish, wildlife and plants - many of which have a commercial or recreational value - recharge groundwater, reduce flooding, provide clean drinking water, offer food and fiber, and support cultural and recreational activities." - (U.S. Fish and Wildlife Services 2018)

2.2 Soil and plant-life qualities of wetlands

The NWI uses wetland classification codes based heavily upon the work done by Cowardin et al. (1979). This system uses a hierarchal classification method, including systems, subsystems, down to classes, sub classes, and dominance types. In general, the NWI classifies 5 types of wetlands:

"(1) areas with hydrophytes and hydric soils, such as those commonly known as marshes, swamps, and bogs; (2) areas without hydrophytes but with hydric soils—for example, flats where drastic fluctuation in water level, wave action, turbidity, or high concentration of salts may prevent the growth of hydrophytes; (3) areas with hydrophytes but nonhydric soils, such as margins of impoundments or excavations where hydrophytes have become established but hydric soils have not yet developed; (4) areas without soils but with hydrophytes such as the seaweed-covered portion of rocky shores; and (5) wetlands without soil and without hydrophytes, such as gravel beaches or rocky shores without vegetation." - (Cowardin et al. 1979)

Hydrophytes are defined as, "any plant living in water or on a substrate that is at least periodically anaerobic due to excess water" (Tiner 1991). These are important indicators of wetland extents, especially for those mapping wetland areas. Any kind of plant that is able to survive in an environment that is often flooded and deficient in oxygen as a result of water content can be called a hydrophyte. Tiner stresses another point made by Cardwin et al., that while hydrophytes are important for delineating wetland, they are not the sole criteria for wetland identification, as many hydrophytes can exist outside of wetland areas.

According to a list of potential hydrophytes, there are 7,662 potential hydrophyte species (Tiner 2006). Of these 7,662 species, 317 wetland plants among fifteen plant communities are identified as common for the Minnesota and Wisconsin region (Eggers and Reed 2011). Since these hydrophytes exist in a continuum of wetness, there are certain descriptors to attribute hydrophytes with likelihood of wetland correlation. Lichvar et al. (2012) gave a revised list of 5 different indicators and their meanings. Table 2.1 shows what these indicators are. These attributes are necessary to help assess the likelihood of wetland presence.

Table 2.1 Wetland indicator status ratings based on ecolocial descriptions.

Indicator status (abbreviation)	**Ecological description (Lichvar and Minkin 2008)**
Obligate (OBL)	Almost always is a hydrophyte, rarely in uplands
Facultative Wetland (FACW)	Usually is a hydrophyte but occasionally found in uplands
Facultative (FAC)	Commonly occurs as either a hydrophyte or nonhyrdophyte
Facultative Uplands (FACU)	Ocassionally is a hydrophyte, but usually occurs in uplands
Upland (UPL)	Rarely is a hydrophyte, almost always in uplands

Beyond hydrophytes, hydric soils are particularly important to wetland identification, but as noted by the presence of hydrophytes, it is not entirely necessary. After all, soils is “the collection of natural bodies in the earth's surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors.” (Farm Service Agency 2011).

Moreover, the FAS defines hydric soil as soil that “in its undrained condition, is saturated, flooded, or ponded long enough during the growing season to develop an anaerobic condition that supports the growth and regeneration of hydrophytic vegetation.” Climate, living organisms, landscape position or topography, parent material, and time all play crucial roles in hydric soil development. For example, a colder climate area that receives more water than it sheds can have low respiration-rate microbes that would develop hydric soil at very fast rate. Drained hydric soils that cannot support hydrophytes due to change in water regime are not considered wetlands by NWI standards, but again, they can be very useful for identifying historic wetlands (Cowardin et al. 1979).

2.2.1 Natural Soil Drainage Index

The University of Michigan developed a calculated soils product called the Natural Soil Drainage Index that measures the long-term soil wetness (Schaetzl et al. 2009). It uses SSURGO data and computed values, rather than other products that incorporate lots of data to make a new map / data layer entirely. This product reduces frustration in using the nominal variables by allowing their use in quantifiable applications. This essentially reduces the complexity of soil data into an easy to visualize, ordinal scale that shows the amount of water that soils contain and make available to plants under normal conditions. The scale ranges from 0 to 99 with 0 being bedrock, and 99 being open water.

To calculate a Drainage Index (DI) number, the Soil Moisture Regime and the Natural Soil Drainage Class are determined. Specific combinations are given different base DI values. Then, once those values are assigned, other columns, such as Texture, Shallowness to the bedrock, high organic matter, and so on, are combined for attributes that either add to or subtract from that initial value. Finally, slope values can be applied to modify DI values further, giving the best representation of long time soils wetness possible.

2.3 Wetland Perspectives over Time

Many wetlands of old have been destroyed and removed to make way for other land uses. Since America was settled by Europeans who lived in heavily engineered landscapes, many of them were unfamiliar with what a wetland actually was. Wetlands had no inherent value to Europeans, as they have long been lost or reshaped. These attitudes were brought over to America, where wetlands were seen for their resources and harvested almost immediately. While wetlands were recognized for their economic value, the inherent value of wetlands for wildlife, hydrology management, and biodiversity was not known to early Americans. Even today, this revelation is fairly recent.

In 1630, Puritans colonists arrived in North America as part of the Massachusetts Bay Company. Governor John Winthrop helped organized the group, and through their religious values, promised that their lives in the new world will "be as a city upon the hill" (Brick 1981). This moral image of landscape was projected onto the physical landscape, and this view helped shape their view of the land. Coastal marshes were harvested for their useful resources. The cordgrass made excellent material for thatch roofing, and abundant waterfowl were a staple source of food. The city on hill they established was Boston.

Swamps, on the other hand, were not readily accepted or integrated into people's lives. Since forested wetlands have been removed from England for quite some time, English-speaking settlers had no real word to describe the swamps they encountered. "Dismal" is one word they often used to describe such lands (Saltonstall 1913). In some aspects, swamps were consider evil, the same way that Indians were seen as sinful (Bradford 1952). Their familiarity with the swamp landscape lead colonists to believe that the swamps themselves were evil. In addition to the association with Native Americans, once malaria was introduced to the U.S., it spread, and swamps were filled with it. People living near swamps would be stricken with this disease without fully understanding it. The ‘miasma’, or poisonous air ‘generated’ by the swamps and other wetlands quickly gave communities a reason to mobilize and begin removing wetlands.

While this was one of the original views of swamps, others soon found that the timber and the land itself could be very profitable. In 1764, George Washington had obtained a charter for a new company he called “Adventurers for draining the great Dismal Swamp” (P. C. Stewart 1981). This swamp was located in Virginia. He and five other investors knew the timber would be profitable, but they also sought the money that would come from farmlands after the trees had been cleared. This helped spark the government’s larger interest in wetland extents and resources.

In 1812, the General Land Office was established with the goal of surveying and platting the nation as it grew westward. Wetlands were a terrible hindrance to their progress. Surveyors were instructed to meander around water bodies and wetlands of sufficient magnitude, rather than to go through them (L. O. Stewart 1935). This lead to some interesting delineations across county lines where lines do not match up due to summer and winter variations in wetland water content.

In 1850, several states had successfully applied for wetland grants through the federal government so that, “the proceeds of said lands shall be applied, exclusively, as far as necessary, to the purpose of reclaiming said lands by means of levees and drains” (United States 1850). The prospects that malarial swamps could be made healthy, agriculture would proliferate, and that adjacent locations of drained wetlands would increase in value was very promising. Original definitions of identified wetlands relaxed, and the responsibility of identifying prime land for drainage was handed over to citizens who lived within each state.

Even in 1915, wetlands were still being viewed as prime location for agriculture to take over. Ben Palmer, a political scientist at the UMN, had this to say about wetlands:

"When we consider that these wetlands are so vast in extent, that they are unproductive and an economic waste, and that they are in many states so productive of malaria diseases as to constitute a serious and ever-present menace to the lives and health of people, the importance of the problem of land drainage in the United States is apparent." - (Palmer 1915)

For years, the government has subsidized and encouraged the drainage of wetlands for agriculture under this impression of profitability. Drainage efforts led to much higher crop yields since the soil now had less water over all. This lengthened the growing seasons, lowers the water table, warms the under soil more quickly, allows plant roots to grow deeper, and aerates the soil. The draining activities pictured in Figure 2.2 were common across much of southern Minnesota.

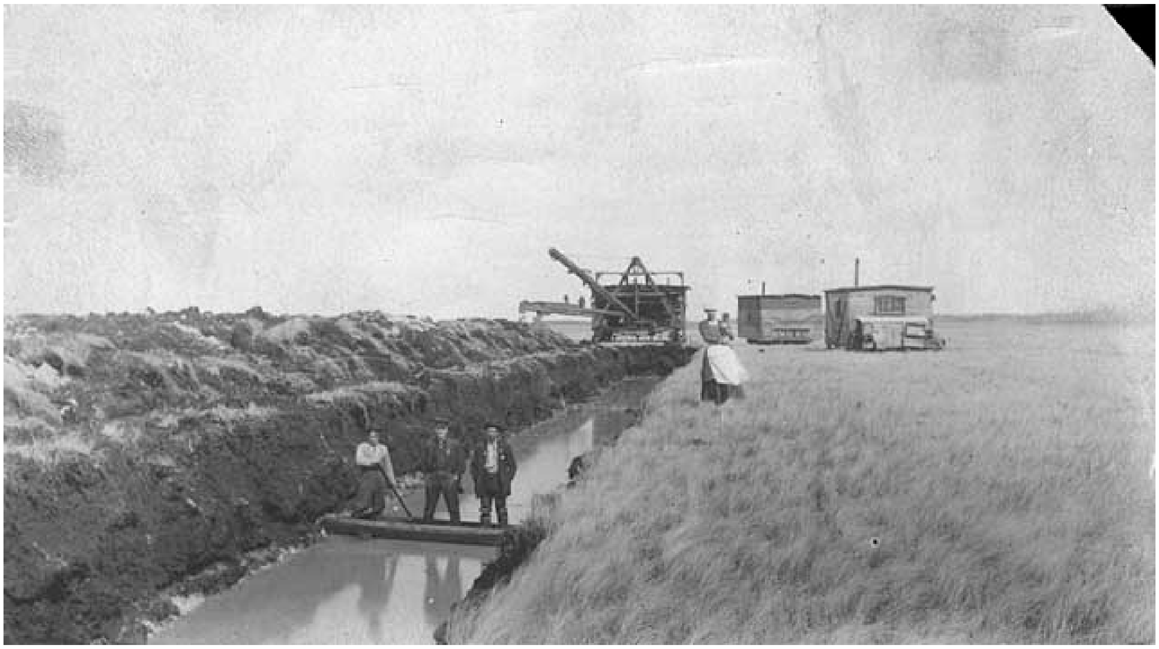


Figure 2.2 Digging Ditch on Joseph Dostal farm, Beltrami County, 1915.
Source: Collections Online of Minnesota Historical Society.

While wet prairies have been mostly removed from Minnesota, the northern bogs are still mostly intact. Some attempts to harvest peat have been made, and looking at aerial imagery, drainage attempts were clearly undertaken. As later reported, when trying to drain peat bogs, “these deposits shrink and subside after drainage, and when they are dried out excessively, they are a serious fire hazard. In some cases shrinkage lowers the peat surface nearly to the outlet level and further drainage by gravity becomes impossible” (Haswell 1937). This information came too late, as drainage efforts that started in 1905 had already ended by 1929.

The drainage efforts ended in disaster. As soon as 1910, fires started breaking out across much of Beltrami county and lasted until 1918 (Ahrens 1987). Farming was impossible due to the acidic nature of bogs, even if recently burned areas provided some temporarily nutrients. In 1929, the Minnesota legislature realized that their passage of the Volstad act in 1908 was largely responsible for pressuring many northern counties to dig drainage ditches that led them to financial ruin. Shortly thereafter, the Red Lake Game Preserve was created, "to protect and propagate wild life, to prevent forest fires, to develop forests, and for the preservation and development of rare and distinctive species of flora native in such areas".

These sorts of revelations were necessary in shifting the thinking of the American people and their perspectives of wetland areas. Years later, President George H.W. Bush would go on to address Ducks Unlimited about an idea he helped champion called 'No net loss' regarding wetlands in America.

"I want to ask you today what the generations to follow will say of us 40 years from now. It could be they'll report the loss of many million acres more, the extinction of species, the disappearance of wilderness and wildlife; or they could report something else. They could report that sometime around 1989 things began to change and that we began to hold on to our parks and refuges and that we protected our species and that in that year the seeds of a new policy about our valuable wetlands were sown, a policy summed up in three simple words: 'No net loss.'" – President George H.W. Bush (USGPO 1990)

Similarly, other government entities were rapidly realizing the true cost associated with the previous removal of wetlands. "Wetland acreage has diminished to the point where environmental, and even socioeconomic benefits (groundwater supply and water quality, shoreline erosion, floodwater storage and trapping of sediments, and climatic changes) are now seriously threatened." - (Dahl 1990)

From a growing consensus at the end of the 20th century that wetland loss was now more harmful to America than it was beneficial, it became increasingly difficult to drain remaining wetlands. Across America, the goal of 'No net loss' meant that farmers and other land owners hoping to increase drainage in the area needed to consult with the federal Natural Resources Conservation Service, the Agricultural Stabilization and Conservation Service, and the Environmental Protection Agency. Any drainage that flows out to public water ways required the discharge to meet water quality standards set by the U.S. Army Corps of Engineers (USACE). At the state level, Minnesota residents required further approval from the Department of Conservation, the Game and Fish Division, the Division of Forestry, the Land and Minerals Division, and the Minnesota Outdoor Recreation Resources Commission.

Today, the government is now very much in support of preserving, and in some cases expanding, wetlands. Ralph Tiner, a professor at the University of Massachusetts and NWI director of over 35 years, had this to say about current attitudes:

"The coterminous U.S. has lost more than 50% of its wetlands since colonial times. Today, wetlands are highly valued for many functions including temporary storage of surface water, streamflow maintenance, nutrient transformation, sediment retention, shoreline stabilization, and provision of fish and wildlife habitat. Government agencies and other organizations are actively developing plans to help protect, conserve, and restore wetlands in watersheds." - (Tiner 2005)

For example, the Clean Water Act regulates most dredging and filling activities in wetlands, the Minnesota Wetland Conservation Act of 1991 mandates a 'No net loss' policy, and several programs (e.g., Swampbuster, Reinvest In Minnesota (RIM), Flood

Risk Reduction Program, and wetland Reserve Program) have spawned to promote wetland restoration in agriculture area (State of Minnesota 1998). Today, these threats are recognized, and a new buffer law has gone into effect for Minnesota to mitigate damage to streams and water ways. Figure 2.3 shows the current extent of waterways in Minnesota and the required buffer sizes. All agricultural drainage ditch activities now require a 16.5-foot buffer.

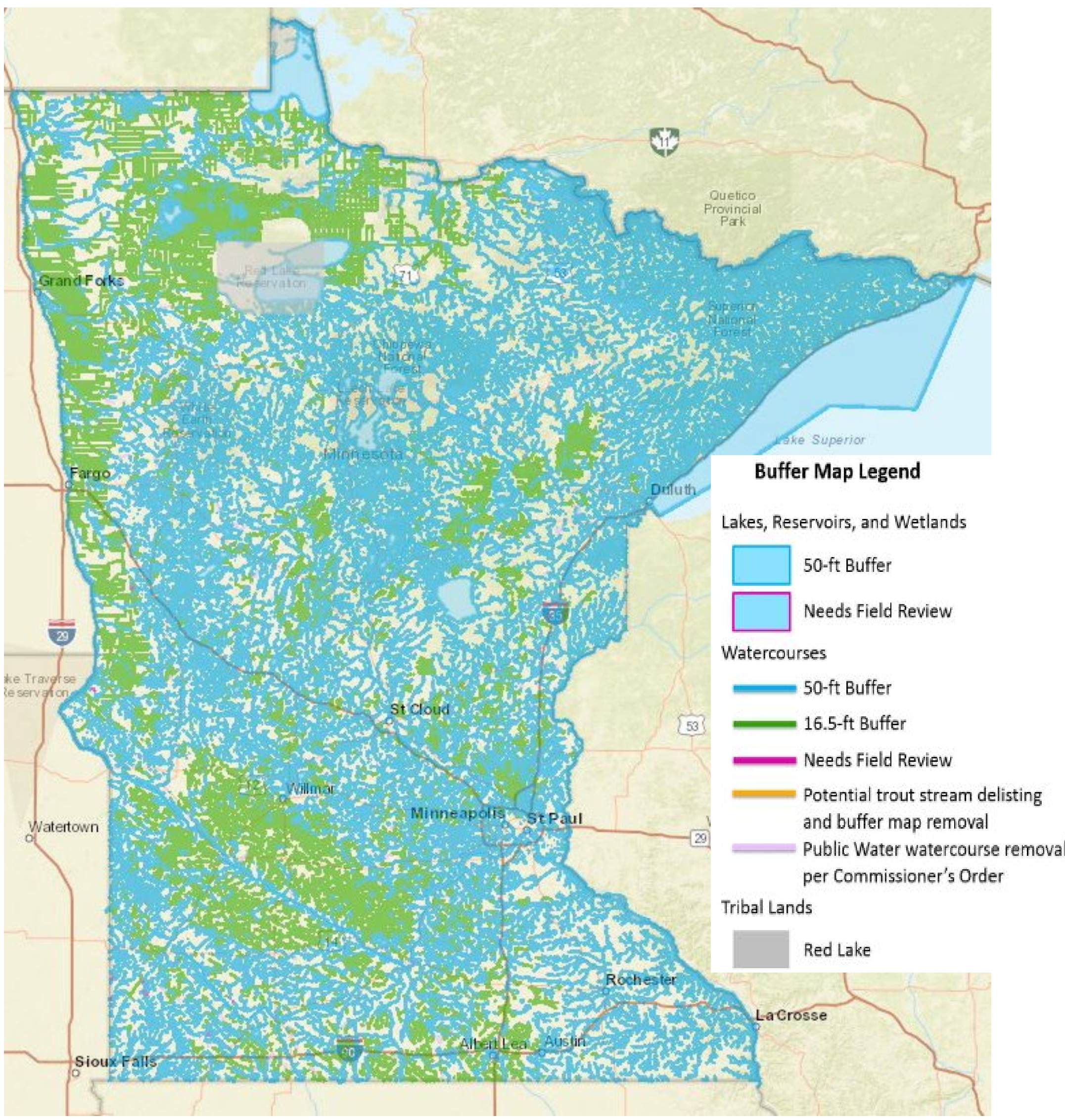


Figure 2.3 2018 buffers to stream areas (Department of Natural Resources 2018)

As evident by the extent of this map, heavy drainage activities are still pervasive across the state of Minnesota, relict from early years. Now that national sentiments have shifted to focus on wetlands, more work must be done to identify these wetlands so restoration projects can be effectively undertaken.

2.4 What attempts have been made to model pre-contact wetlands?

To fulfil a request from Congress, U.S. Fish and Wildlife Service employee Thomas Dahl put together a report called "Wetland Losses in the United States" (Dahl 1990). The goal of this report was to estimate the total number of wetland acres as of 1780's and the 1980's then calculate the percentage of loss of wetlands in each state during this 200-year timespan. Dahl identified 4 different studies that used their own methods of estimating wetlands acreage for 1780. See table 2.2 for a concise overview of these studies. The first study looked at land that was already drained and added that total to land they deemed suitable for drainage (Roe and Ayres 1954). The second used only soils data and the suborder of 'Aquic' to estimate wetlands (U.S. Department of Agriculture 1975). The third was based upon land drainage in the 50's combined with all inventoried wetlands from the U.S. Fish and Wildlife Services wetland study (U.S. Department of Agriculture 1989). The fourth study was based on U.S. Department of Agriculture (USDA) agriculture drainage trends.

Table 2.2 Original Wetland Acreage Estimates

Estimate Authors	**Millions of Acres**
Roe and Ayers, 1954	215
Aquic suborder soils (hydric) Soil Taxonomy, 1975	211
USDA Economic Research Service	217
USDA Ecnomic Research Service, 1987 (agricultural drainage plus remaining wetlands	213
Dahl, 1990	221

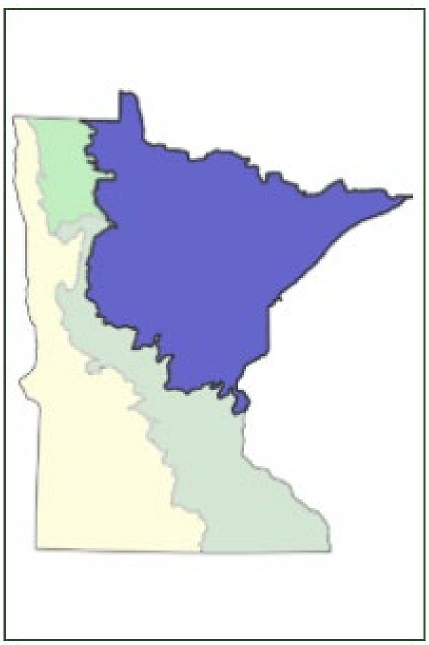
Interesting to note is three of these studies focus on drained land acreage as an estimation of pre-settlement wetland. While this research does not directly use known tracts of drained land, the idea behind training wetland data is to avoid drained agriculture land by selecting relatively untouched tracts of land.

More recently, Tiner (2005) has tried assessing cumulative loss of wetlands in the Nanticoke river watershed using NWI data. He also used hydric soils as his primary indicator of pre-settlement wetlands. Comparisons were made between the two datasets, and pre-settlement wetlands were given certain high-level NWI classifications. Tiner made it clear that his methods only provided an approximation and not an exact replication of pre-settlement conditions.

3 Methodology

3.1 Study Area

The study site for this research is the Laurentian Mixed Forest Providence (LMFP) as defined by the Ecological Classification System (ECS). See Figure 3.1. The LMFP region has large tracts of untouched land, making the correlation portion of the model much easier to train. Unfortunately, the arrowhead region of the state (named for its triangular appearance reminiscent of the tip of an arrow) has not been mapped for soils, so there are some areas missing where the model cannot be trained.



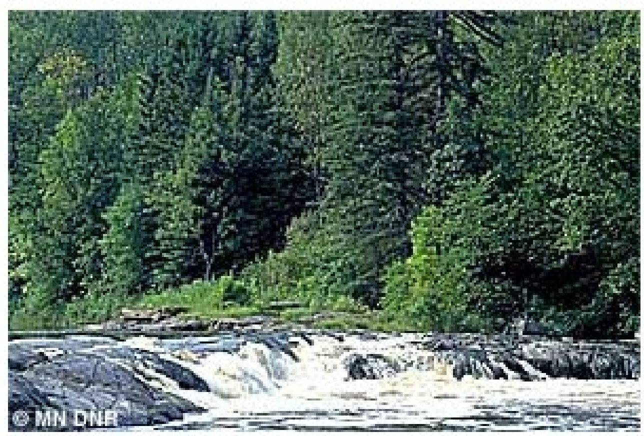


Figure 3.1 Laurentian Mixed Forest Province (the cobalt color) and example image

The LMFP covers approximately 23 million acres (9.3 million ha) of Minnesota. Swamps and Bogs are common in the region. Yearly precipitation ranges from 21 inches to 32 inches traveling west to east across the providence. Conifer forests are prevalent.

3.2 Dataset Selection, Preprocessing, and Rationale

The objective of this research is to model where pre-settlement wetlands were located, and perhaps what types of wetland have been lost. Beyond simply listing soils as wetland, this project is interested in determining the likelihood that these areas are wetlands, and how one might infer types of wetland based on soil properties. While the resolution of soils data is good and there is a good correlation with hydric type soils and pre-settlement wetlands, soils take time to develop, and it is possible for wetlands to have existed on non-wetland soils. This research aims to correlate wetland datasets with soils data and look for trends.

3.2.1 Rationale

Using the Drainage Index scale, variation in soil wetness becomes easily identifiable. Figure 3.2 shows an example of Minnesota soils using the Drainage Index.

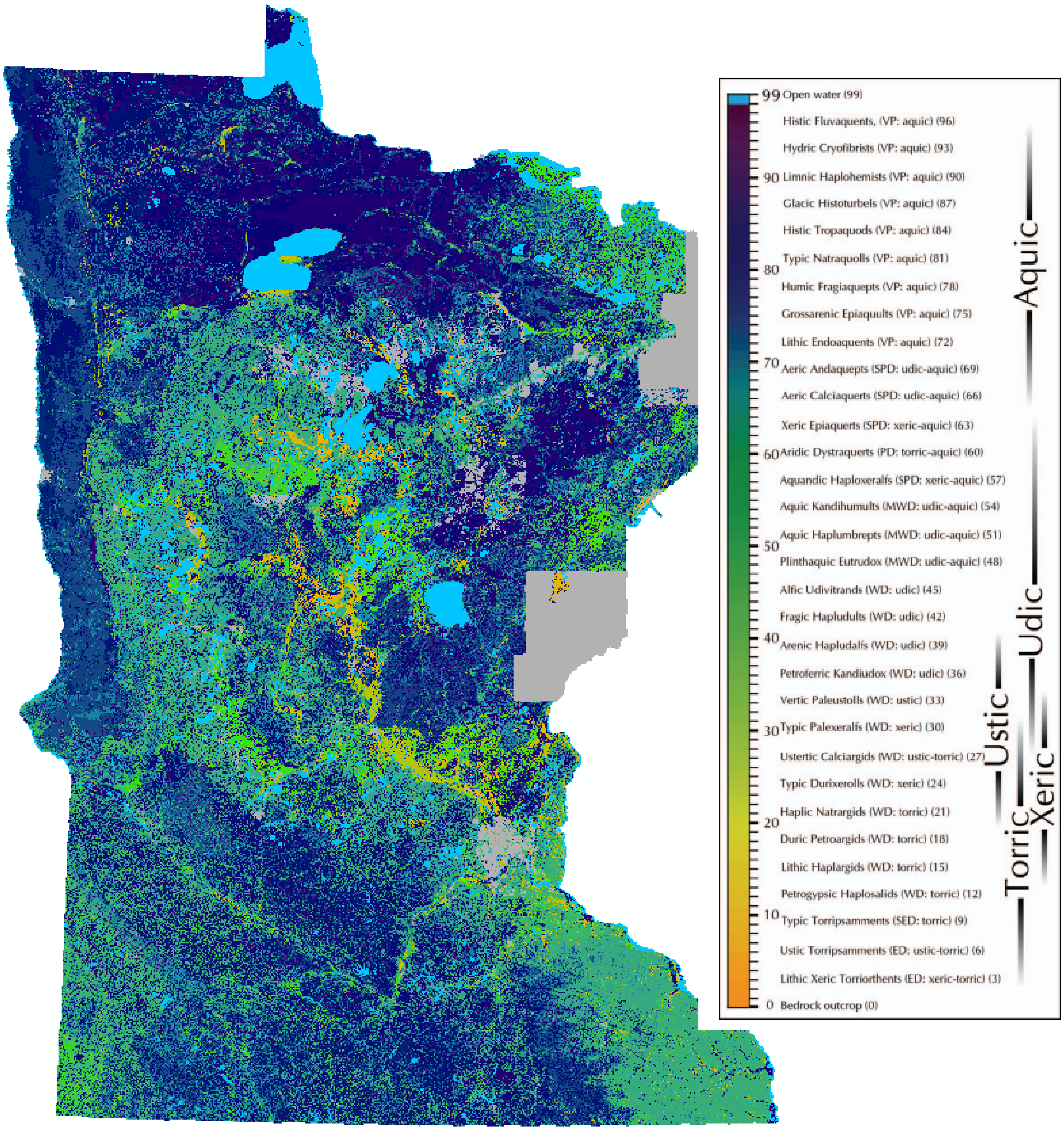


Figure 3.2 Drainage Index legend and Minnesota DI values

By overlaying wetland data with soil data, one can immediately identify spatial trends in the data. Specifically, much of the ‘purple’ and ‘blue’ map areas have been hidden under the pastel pink-orange wetland color. In areas where blue is still present, agriculture can be easily identified. Figure 3.3 shows this relationship between high DI and wetlands.

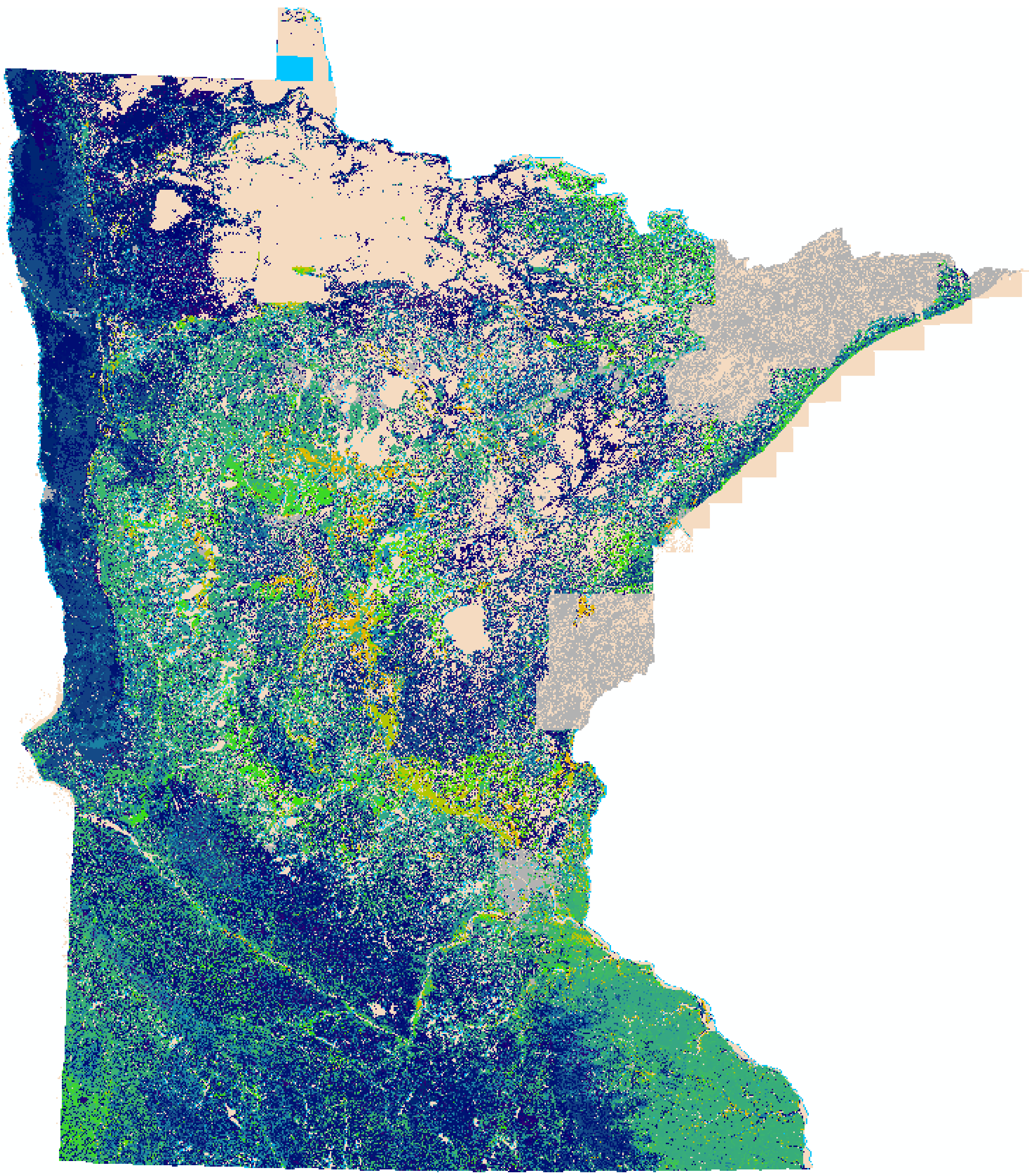


Figure 3.3 Drainage Index with NWI wetland polygons overlain

Since the purpose of this model is to correctly correlate wetlands to drainage index values, selecting undisturbed locations is very important. Heavily engineered landscapes give poor representation and poor training samples of natural areas. Figure 3.4 shows a picture of Swan Lake in Nicollet County. Notice the algae blooms and the Emergent Marsh land due to local farm run off. The purple color indicates algae ridden areas and a classification code of “EM” for Emergent is given. Pink is closer to what should be expected of an undisturbed area in this region, or “UB” for Unconsolidated Bottom.

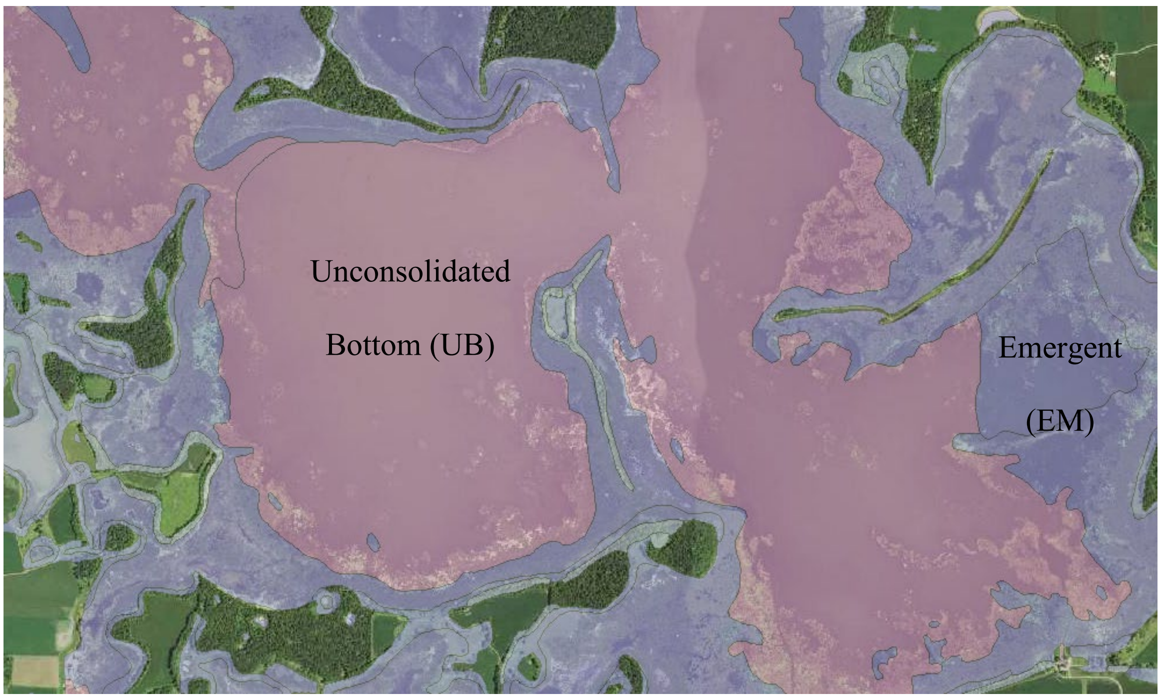


Figure 3.4 Eutrophication classifications of Swan Lake.

Figure 3.5 shows how these layers would be classified using the Drainage Index values. Notice how much light blue is visible over the EM layer. This would be incorrectly classified due to local farm activity, hence why undisturbed areas must be located.

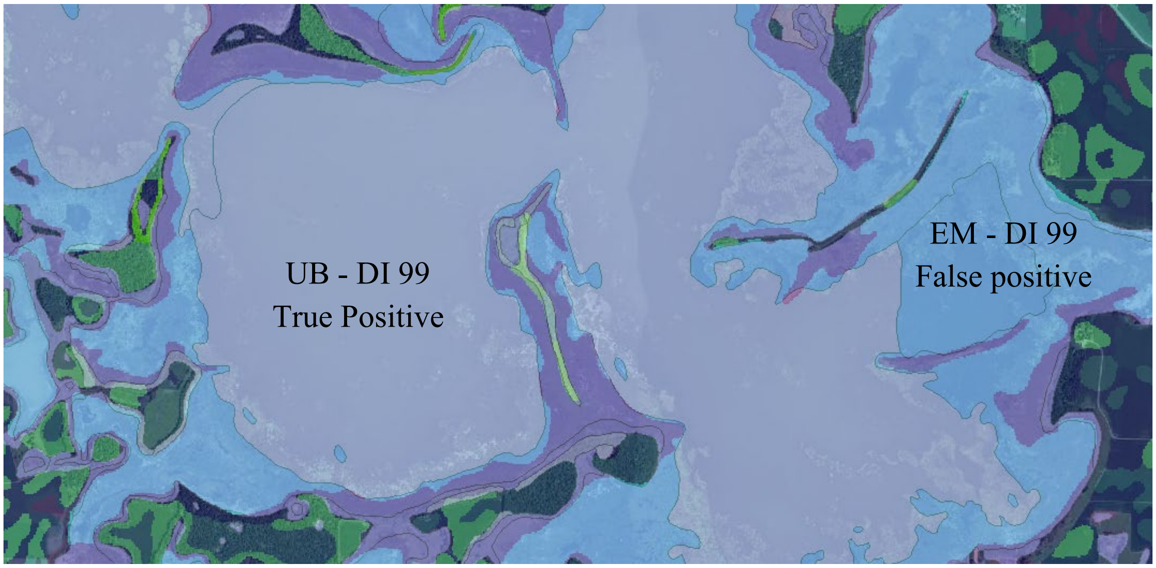


Figure 3.5 Drainage Index values over False Positive wetland type EM

Just as important as avoiding false positive results, false negatives must also be avoided. False negative areas are places where soil properties and drainage indicate wetlands were present in the past, but current data show no presence of wetlands. Figure 3.6 shows farmland north of Swan Lake among very high drainage values, indicating that wetlands have likely been destroyed to increase cropland.

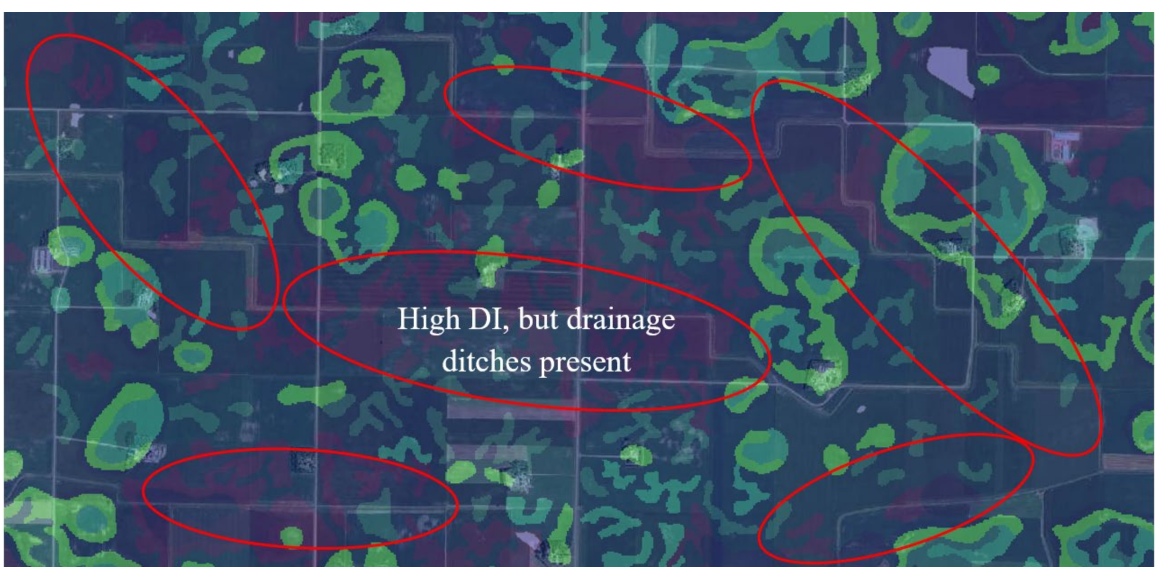


Figure 3.6 Drainage Index values over False Negative drained "non-wetlands"

In an effort to avoid these types of errors, the study is being trained in the LMFP since over 80% of the wetlands are remaining, as described by Figure 3.7.

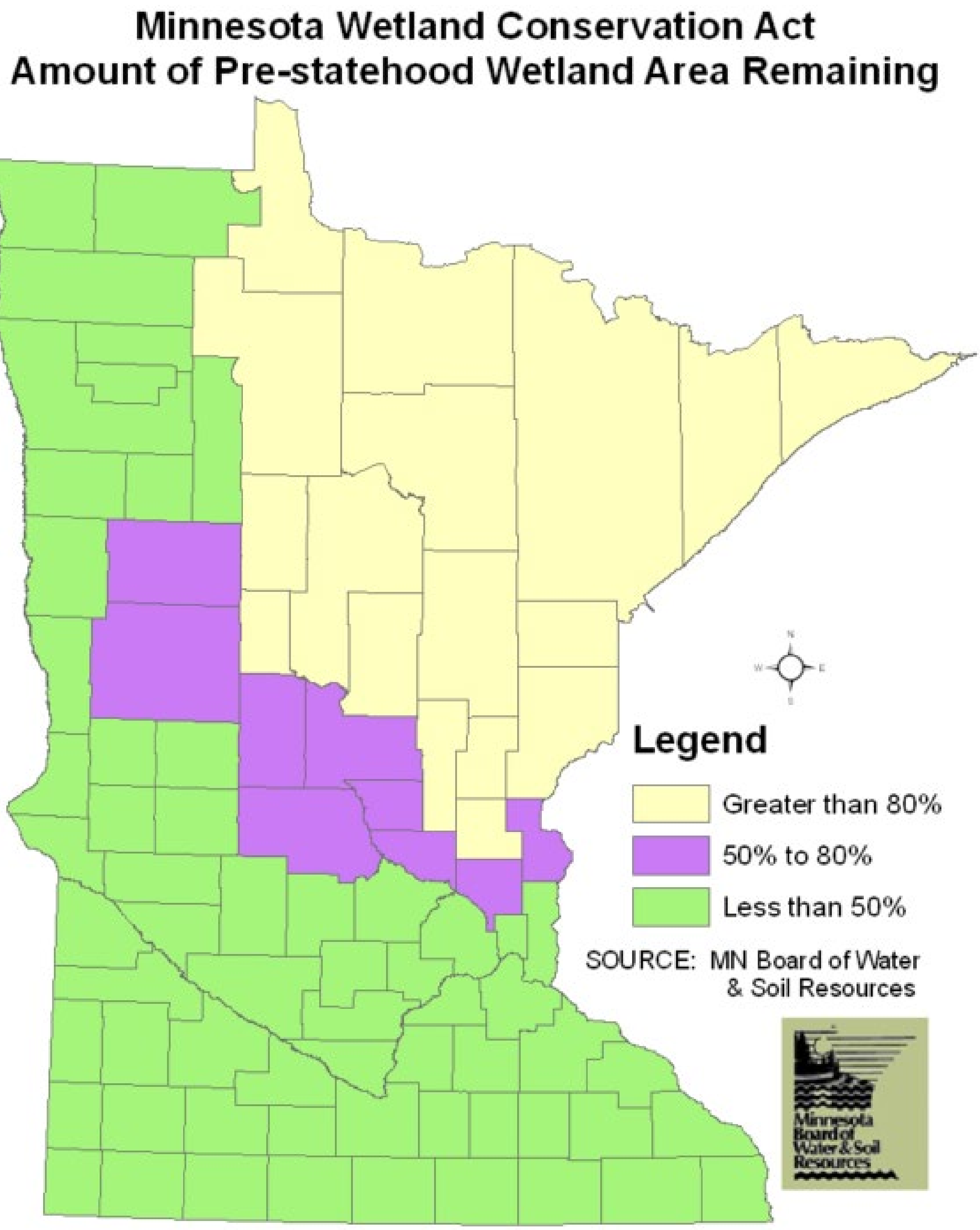


Figure 3.7 Wetland Conservation Act historic wetland area (Gernes and Norris 2006)

While some drainage activities were carried out on the peatlands, activities have stopped since then. The LMFP gives the best likelihood of avoiding bad training data, but there is also a significant portion of soils data missing for training. See Figure 3.8 for the availability of SSURGO data.

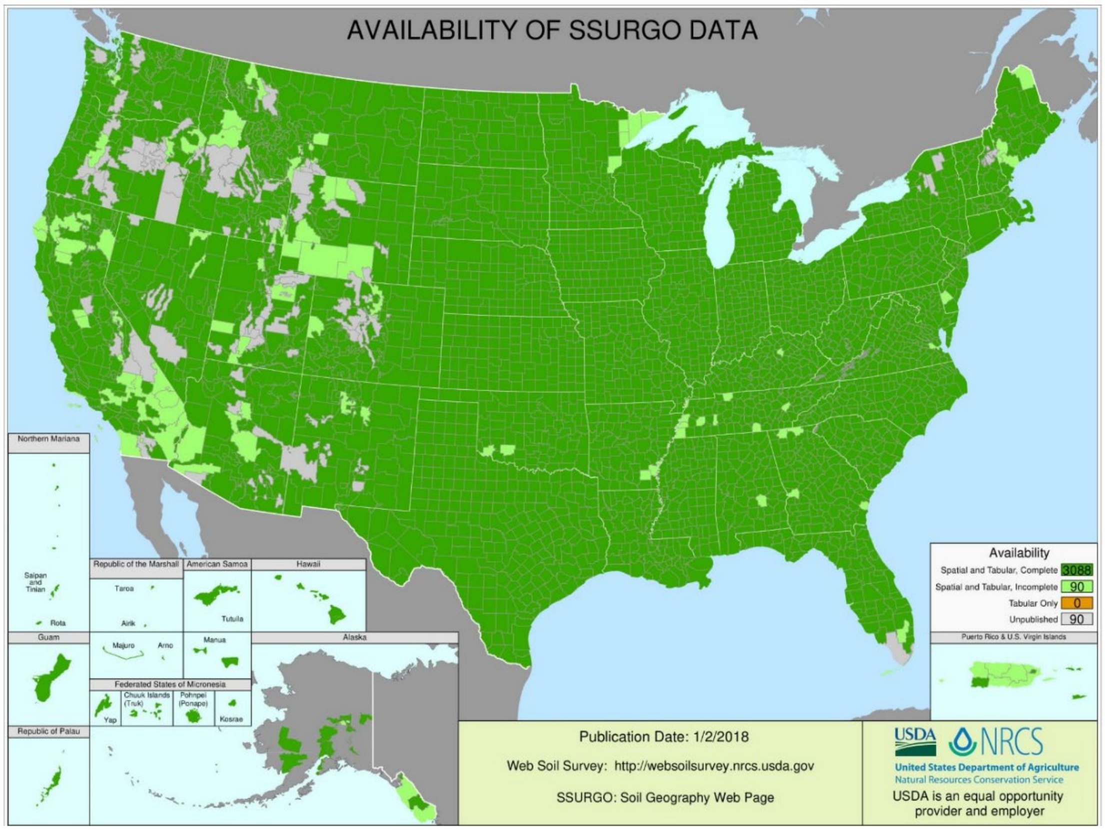


Figure 3.8 Availability of SSURGO data (USDA and NRCS 2018)

As show by the map, five counties are missing some or all soils data in the upper right corner of the state. This presents a small problem, but nothing overly disruptive.

3.2.2 Boundary Datasets

The following datasets were used to delineate areas of significance. The first five ones were used as training locations that will be discussed in the methodology. The Ecological Sections of Minnesota was useful for determining similar regions so that findings for the area were not severely impacted by regional changes in climate or geomorphic processes. See Figure 3.9 for a graphical example of these datasets.

1) State Forest Statutory Boundaries and Management Units:
   https://gisdata.mn.gov/dataset/bdry-state-forest
2) Scientific and Natural Area Units:
   https://gisdata.mn.gov/dataset/bdry-scientific-and-nat-areas
3) Publicly Accessible State Wildlife Management Areas :
   https://gisdata.mn.gov/dataset/bdry-dnr-wildlife-mgmt-areas-pub
4) State Parks, Recreation Areas, and Waysides:
   https://gisdata.mn.gov/dataset/bdry-dnr-lrs-prk
5) US National Forest Areas: National Cadastral Data:
   https://data.fs.usda.gov/geodata/edw/datasets.php?dsetCategory=boundaries
6) Ecological Sections of Minnesota:
   https://gisdata.mn.gov/dataset/geos-ecological-class-system

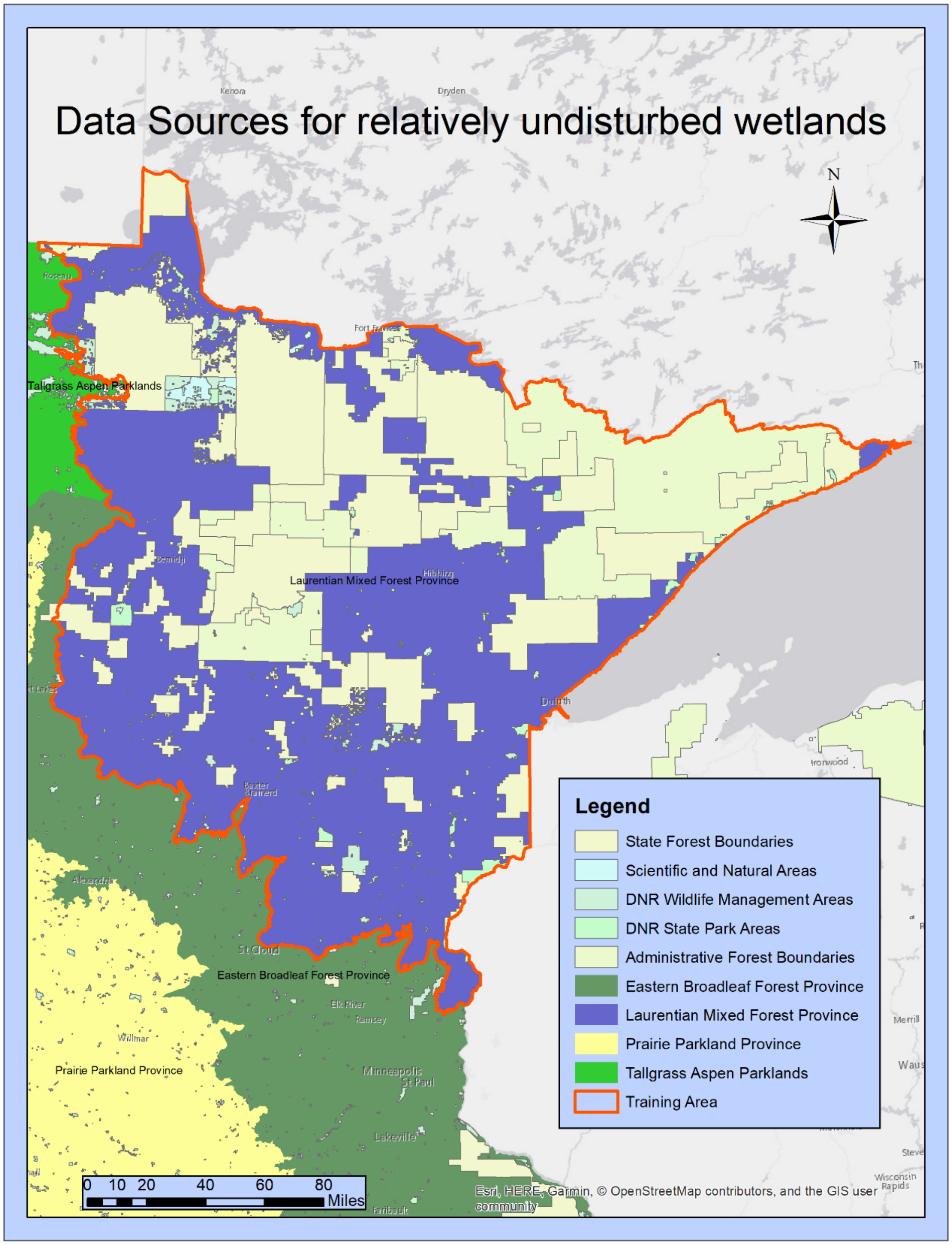


Figure 3.9 Data sources used for this model

These data sources were inspected and determined to consist of relatively untouched areas (example: State Forest Areas have been established to "protect watersheds", the Scientific and Natural Areas have been recognized to protect "undisturbed natural states" of lands and waters for important research purposes, and State Parks are designated for "natural, historic, or other resource" reasons.). Using these data sources, it will be possible to accurately correlate wetlands to drainage values so that we can more reasonably suggest probable wetland area and types for certain drainage index values.

3.3 Wetland Training data

To test this methodology, NWI 1980-86 data was downloaded from the Minnesota Geospatial Commons at https://gisdata.mn.gov/dataset/water-nat-wetlands-inventory, though any wetland dataset can be used. It all depends on what type of training data or classification system the user wants to test.

NWI data is based on the wetland classification scheme devised by Cowardin et al. (1979) for the USFWS. Three types of ecosystems present in Minnesota are Lacustrine, Palustrine, and Riverine. These correspond to lakes, wetlands, and rivers respectively. The 1986 data lists eight main classes for palustrine environments. See Figures 3.10 - 3.11 for the complete list. Of the eight, the three most important are Shrub-Scrub, Emergent, and Forested, as these relate closest to the more commonly known names of bog, marsh, and swamp.

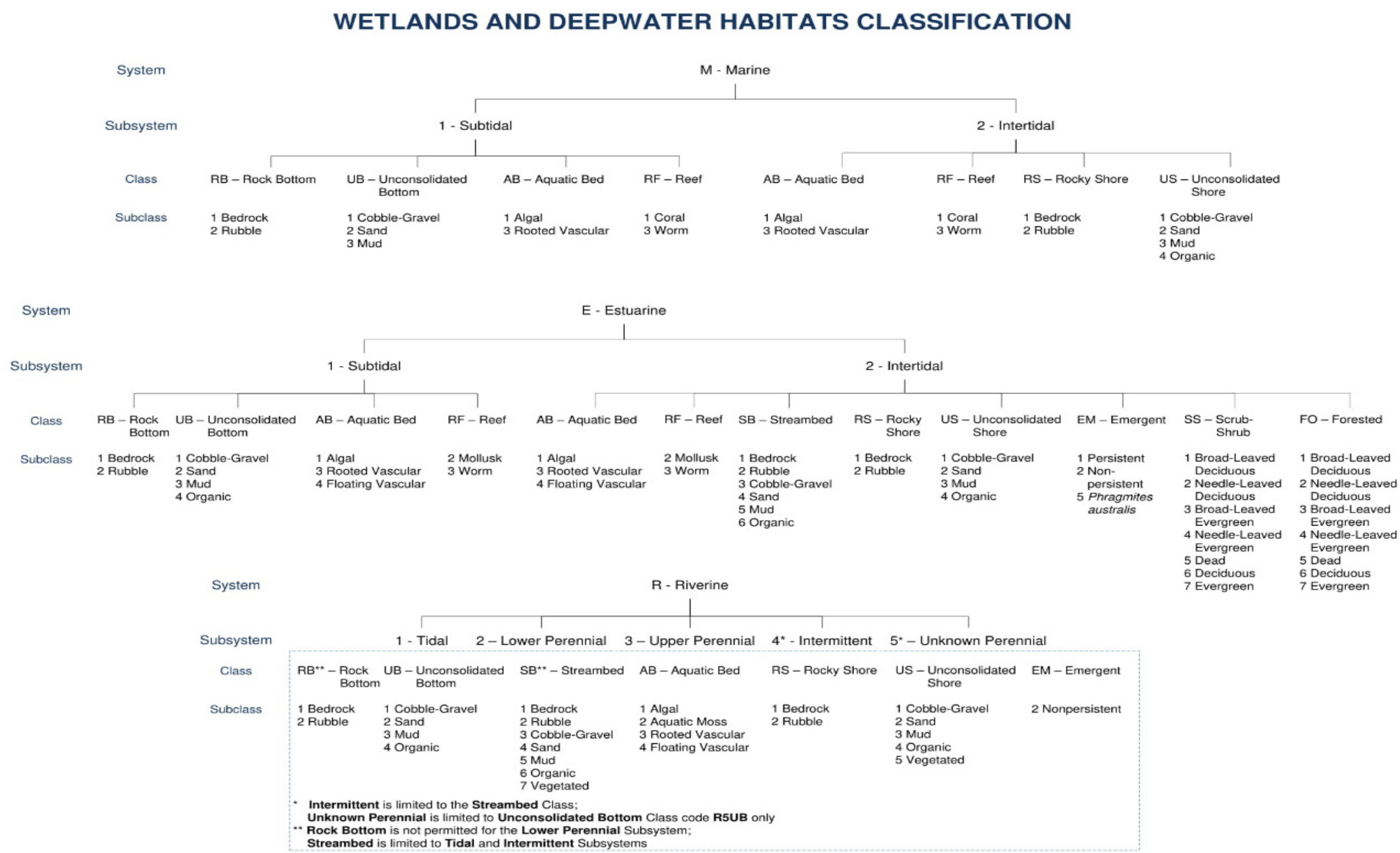
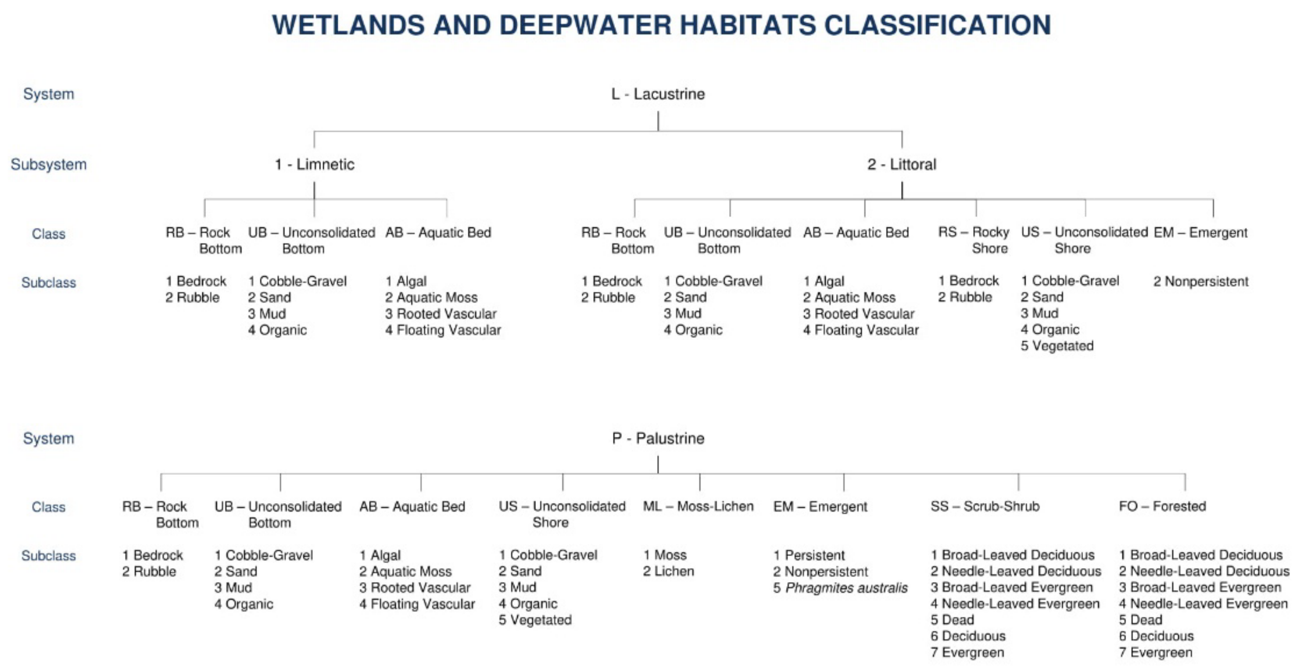


Figure 3.10 NWI classifications of coastal and riverine environments (NWI 2011)



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. The farmed modifier may also be applied to the ecological system.

Water Regime			Special Modifiers	Water Chemistry			Soil
Nontidal	**Saltwater Tidal**	**Freshwater Tidal**		**Coastal Halinity**	**Inland Salinity**	**pH Modifiers for all Fresh Water**	
A Temporarily Flooded	L Subtidal	S Temporarily Flooded-Tidal	b Beaver	1 Hyperhaline	7 Hypersaline	a Acid	g Organic
B Saturated	M Irregularly Exposed	R Seasonally Flooded-Tidal	d Partly Drained/Ditched	2 Euhaline	8 Eusaline	t Circumneutral	n Mineral
C Seasonally Flooded	N Regularly Flooded	T Semipermanently Flooded-Tidal	f Farmed	3 Mixohaline (Brackish)	9 Mixosaline	i Alkaline	
E Seasonally Flooded/ Saturated	P Irregularly Flooded	V Permanently Flooded-Tidal	h Diked/Impounded	4 Polyhaline	0 Fresh		
F Semipermanently Flooded			r Artificial	5 Mesohaline			
G Intermittently Exposed			s Spoil	6 Oligohaline			
H Permanently Flooded			x Excavated	0 Fresh			
J Intermittently Flooded							
K Artificially Flooded							

Figure 3.11 NWI classifications for Lacustrine and Palustrine environments (NWI 2011)

Using these observations, soils that indicate high probability of certain wetlands can be modeled. Using the Soil Survey Geographic Database (SSURGO) and calculated product (Drainage Index), the NWI 1980-86 dataset will be matched with the soils data. Based on the matches between classification types and DI values, confidence intervals can be made to model what kinds of wetlands would be likely in a particular region.

3.4 Preprocessing – Northern Natural Area Extent

The aim of this research is to correlate undisturbed soils with undisturbed wetlands and wetland types. To complete this task, the first step is to model this process. This research identified mostly undisturbed wetland areas, merged the extent of their boundaries into one, limited the training area to the Laurentian Mixed Forest province, dissolved all of these numerous polygons into one feature, and removed training areas where soil is not present. This part of the model created training areas of soil values so that any wetland dataset or classification system can be correlated to this base data. It is important to note that union is not needed for this portion of the model because the fields of each polygon feature are irrelevant; only the area extent of each polygon is necessary to preserve. Figure 3.12 is the final product of this model using ArcGIS Model Builder. See Appendix A for a modified script that allows anyone to easily use this methodology.

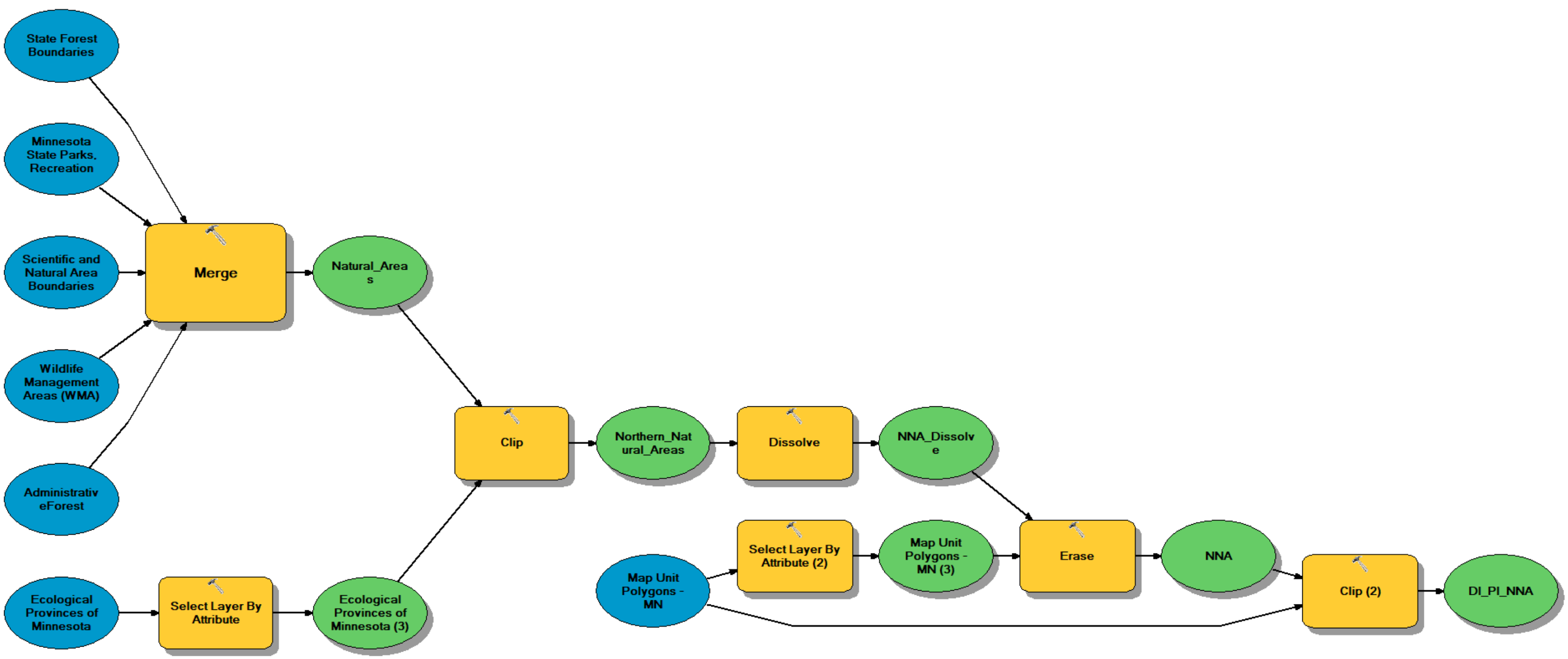


Figure 3.12 The preprocessing workflow to identify wetland training areas

The next step is to clip the chosen wetland data to the same extent as the soils data. Once complete, a single union operation can be done with the soils and the wetland to give a single feature class with both wetland and valid soil data classifications. The final remaining step is to join the drainage index tables to the soil tables. Advanced instructions on how to do this can be found at https://foresthealth.fs.usda.gov/soils/MoreInfo, but this as simple as selecting a DI product and joining the MUKEY fields from each table. For this research, the Max component was chosen to measure the ceiling values for the DI with their percentage of map unit covered. At this point, various measurements can be taken. In the modified Appendix script, the wetland clipping and union operation is done for the user. The preferred DI table is to be joined manually after the union finishes processing.

This model can be best summarized in the pseudocode below:

- `Identify training regions for a desired study area`
- `Merge all training areas into one feature class`
- `Select Ecological Region`
- `Clip training data to within your Ecological region`
- `Dissolve training data to a single polygon`
- `Select NULL and zero values in Soil data`
- `Erase training areas using selected soil data`
- `Clip Soil data using final training area`
- `Clip Wetland data using final training area`
- `Union Soil to Wetland data`
- `Join Drainage Index Table to Soil-Wetland-Union feature class`

4 Results and Discussion

4.1 Wetlands with Drainage Index values

The visual trend observed in the spatial data is also presented in the numerical representation of the data. Figure 4.1 shows a strong concentration of wetlands in high drainage index values, confirming the visual spatial trend identified in the datasets, especially in values 87, 90, 95, and 99. Favorable conditions are seen in values 75 and up, whereas below 75, wetlands are less and less likely to be present.

Figure 4.1 The results of combining soil and wetland data

4.2 Leave One Out Cross Validation

To validate the integrity of this model, Leave One Out Cross Validation (LOOCV) was used. Instead of taking random samples, however, this research used samples of varying size base upon subsections of the ECS Laurentian Mixed Forest province. Splitting things this way allows for testing areas that might have some important regional characteristics that will show up more immediately in the data. If regional differences are apparent and there are no errors in the training data locations, then we know that results modelled for one region cannot be assumed for other regions, ensuring that the methodology must be refined to properly predict different regions. Figure 4.2 shows some possible diversity likely to be found in each of these distinct regions.

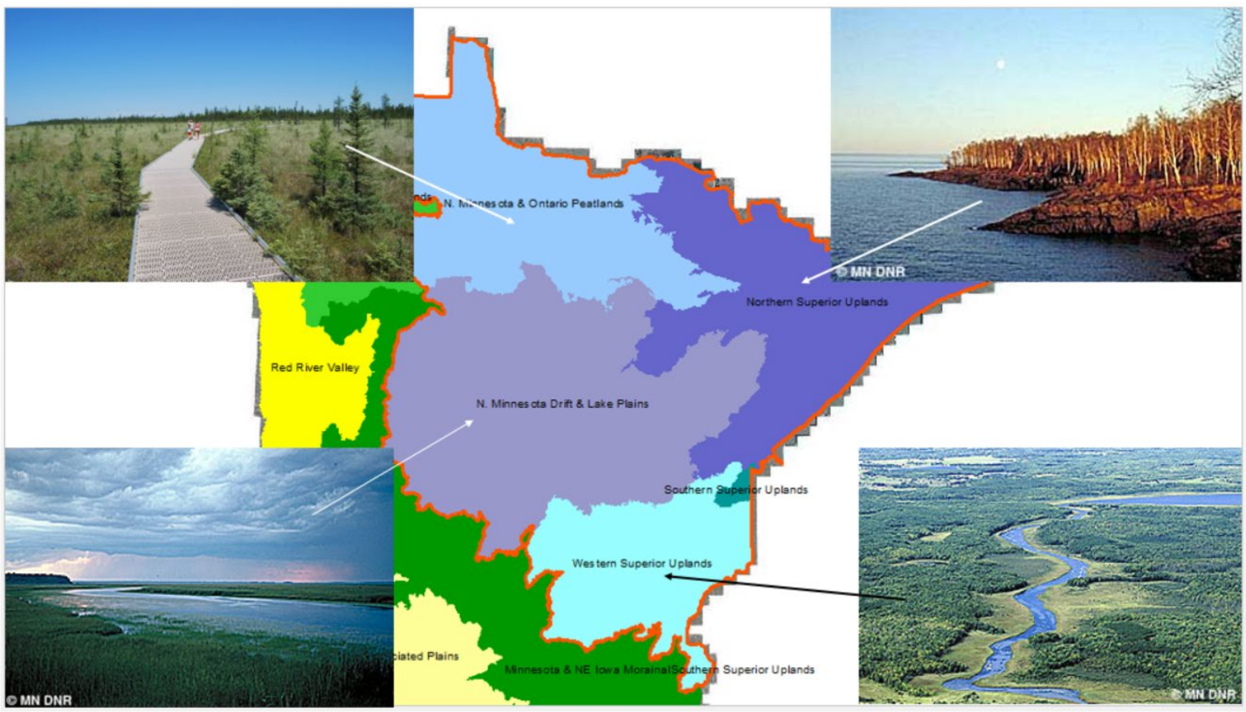


Figure 4.2 Subdivisions of the Laurentian Mixed Forest Province used for LOOCV

The four regions were called PEAT, PLAINS, NORTH, and WEST. Based on how the data was divided, PEAT had 50% of the total area, PLAINS accounted for 35.1% of the total area, NORTH was 11.6%, and WEST was 3.2%. The imbalance in LOOCV unit size illuminated some regional variation and training data issues. West was expected to have the largest variance because it contributed the least to the average values. Tables 4.1-4.3 show drainage indexes of 99, 90, and 87 respectively and how each sub-region deviates from the mean values.

Table 4.1 Drainage Index values and Wetland type of DI 99

DI 99		Ecological Section			
Wetland Class	NORTH	PEAT	PLAINS	WEST	Total
Non-Wetland	3.00%	10.98%	1.18%	4.38%	2.87%
AB - Aquatic Bed	0.03%	0.03%	0.03%	NULL	0.03%
EM - Emergent	3.26%	2.55%	4.29%	13.66%	3.95%
FO - Forested	0.97%	0.49%	0.16%	0.89%	0.35%
RB - Rock Bottom	0.00%	0.01%	NULL	NULL	0.00%
RS - Rocky Shore	0.01%	NULL	NULL	NULL	0.00%
SS - Shrub-Scrub	1.92%	0.42%	0.53%	1.61%	0.76%
UB - Unconsolidated Bottom	90.79%	84.92%	93.81%	79.43%	91.94%
US - Unconsolidated Shore	0.01%	0.60%	0.01%	0.04%	0.09%

For DI of 99, there is an overwhelming correlation with Unconsolidated Bottom values. This is expected, as Unconsolidated Bottom is closest to deep water habitats, or where one end of the wetland continuum ends. There is a large non-wetland section in the Peatlands, and this is either because some misclassification was done, or a decision was made that the lake was too deep in that area to warrant the UB classification. This gives the large non-wetland correlation of 10.98%. The Western Superior Uplands region has a large Emergent Marsh component to it, but it also has the largest human population and largest agricultural component to it as well. Some of the streams have become sediment loaded and cannot properly transport material anymore, so marshes emerge.

Table 4.2 Drainage Index values and Wetland type of DI 90

DI 90		Ecological Section			
Wetland Class	NORTH	PEAT	PLAINS	WEST	Total
Non-Wetland	14.10%	1.10%	11.47%	9.04%	6.51%
EM - Emergent	1.83%	5.49%	13.83%	27.15%	8.69%
FO - Forsted	65.82%	46.51%	47.98%	31.90%	48.80%
SS - Shrub-Scrub	17.78%	46.83%	25.80%	31.48%	35.58%
UB - Unconsolidated Bottom	0.48%	0.06%	0.92%	0.43%	0.42%

Again, the trend with Emergent marshes shows up in the Western Superior Uplands. The Northern Superior Uplands shows an interesting favoritism of Forested wetlands over Shrub-Scrub wetlands. This may be in part due to the glacially scoured bedrock common in the area. Fire-dependent forests are also a prevailing feature of the region. The Peatlands show more favoritism to Shrub-Scrub than Forested wetlands, but there is an abundance of Bogs in that area, which would fall under Shrub-Scrub. There is simply too much water for large conifers to handle, so obligate and facultative wetland vegetation prevails. The DI value of 90 should be inspected as to how exactly it is being calculated. There may be some important soil variables that are controlling the growth of forests and shrubs. If so, it will be easier to make the distinction between forested and shrub-scrub wetlands based on those key variables.

Table 4.3 Drainage Index values and Wetland type of DI 87

DI 87		Ecological Section			
Wetland Class	NORTH	PEAT	PLAINS	WEST	Total
Non-Wetland	25.60%	2.51%	21.62%	15.34%	7.13%
EM - Emergent	3.88%	7.68%	15.68%	40.08%	9.27%
FO - Forested	52.08%	54.65%	29.56%	17.85%	50.05%
SS - Shrub-Scrub	17.75%	35.06%	32.03%	25.30%	33.23%
UB - Unconsolidated Bottom	0.0068	0.0011	0.011	0.0143	0.0032

As the drainage index lowers, the wetland types become more diverse and prone to change. Emergent Marsh makes up a sizeable 40% of all wetland area in the Western Superior Uplands now. More research into the training area is needed to determine what percent of this contribution is human led and which percentage is natural. Making this distinction will help determine if model results can be extrapolated to this region, or if this region needs to be modelled by itself. There are large portions of non-wetland areas in many of these regions, which will be covered in the discussion.

4.3 Discussion

This research makes an attempt at examining wetland correlation with quantified soil values. Examining the results of the training data, there are certainly some errors present in the training set. False positives and false negatives are present in different ways. The draining work in the peat bogs area encroaches on part of our training data and is easily identifiable (Figure 4.3). Red outlines indicated areas of high DI value, but no wetland classification type. Because, historically, peat draining did not take place for very long, and because areas were selected where ditching and draining should be low, this type of human disturbance error accounts for only a minor portion of oddities in correlation. As stated in the methodology, over 80% of pre-statehood wetlands remain in the chosen study area, keeping the probability of this type of error low. A more significant portion of non-wetland correlation is in areas where the soils are very diverse and patterned throughout the land. This leads to slivers along soil transition zones where NWI and SSURGO mapping techniques differ based on year and time of year. See Figure 4.4 for an example. This kind of error increases as soil complexity increases.

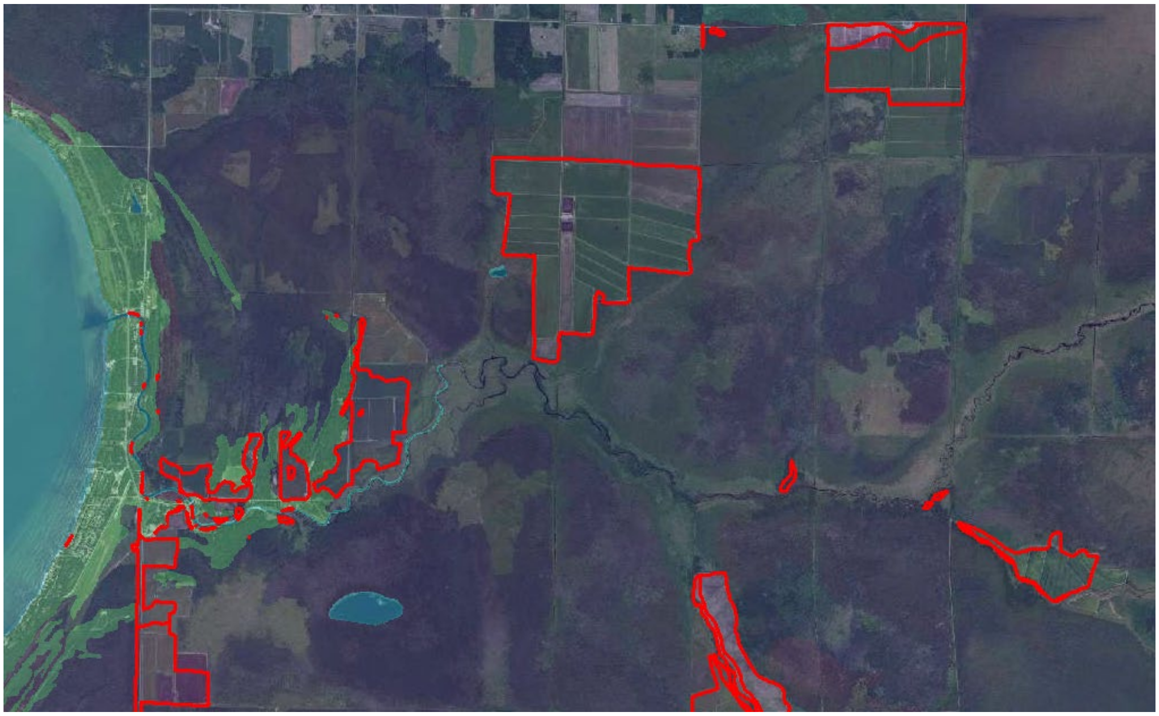


Figure 4.3 False Positive training data missing definite wetland-soil correlation

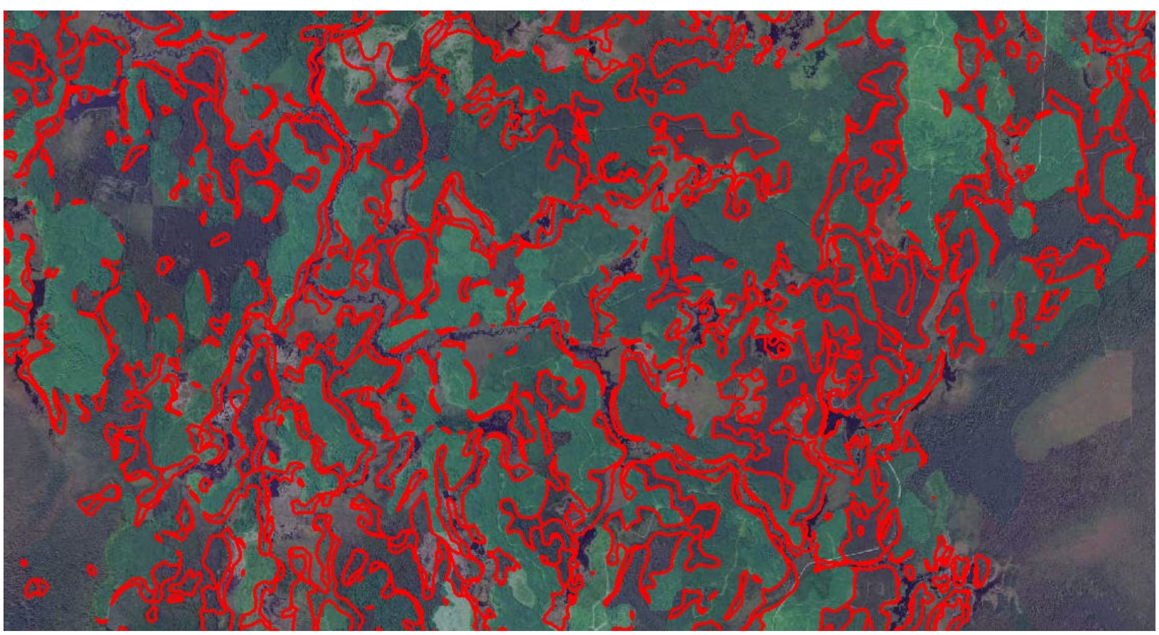


Figure 4.4 Slivers and thin channels of high DI with no wetland correlation

In addition, NWI does not always map riparian zones, also known as transitional habitats along a water course. Riparian zones are often in very high DI value regions due to the way groundwater moves. Seepage wetlands are very common. Since riparian mapping started much later in NWI's lifetime, riparian mapping is available mostly for western states, but not Midwestern or Eastern states. This lends to a high degree of misclassification of high DI zones as non-wetland areas. See Figure 4.5 for an example of unmapped riparian zones. These are the major false positive results of the training data.

False negatives, or areas where wetlands are mapped but the DI of soils do not inherently support a wetland classification are less of an issue, but still present. Figure 4.6 shows this relationship. The extent of the area is the same as Figure 4.4, the issue of slivers at the edges of "non-wetland soils" is again present. Compared to these slivers, there are few instances where wetlands are defined entirely within a low value DI polygon, indicating a good correlation with higher DI values.

Lastly, a small source of error comes from the soil survey quality between counties. Not all people recording soil data were necessarily in agreement on how to classify certain soil types, so there is some variation across county lines in places. Luckily, many of this study's selected areas did not encounter large areas of disagreeable soil values or DI values.

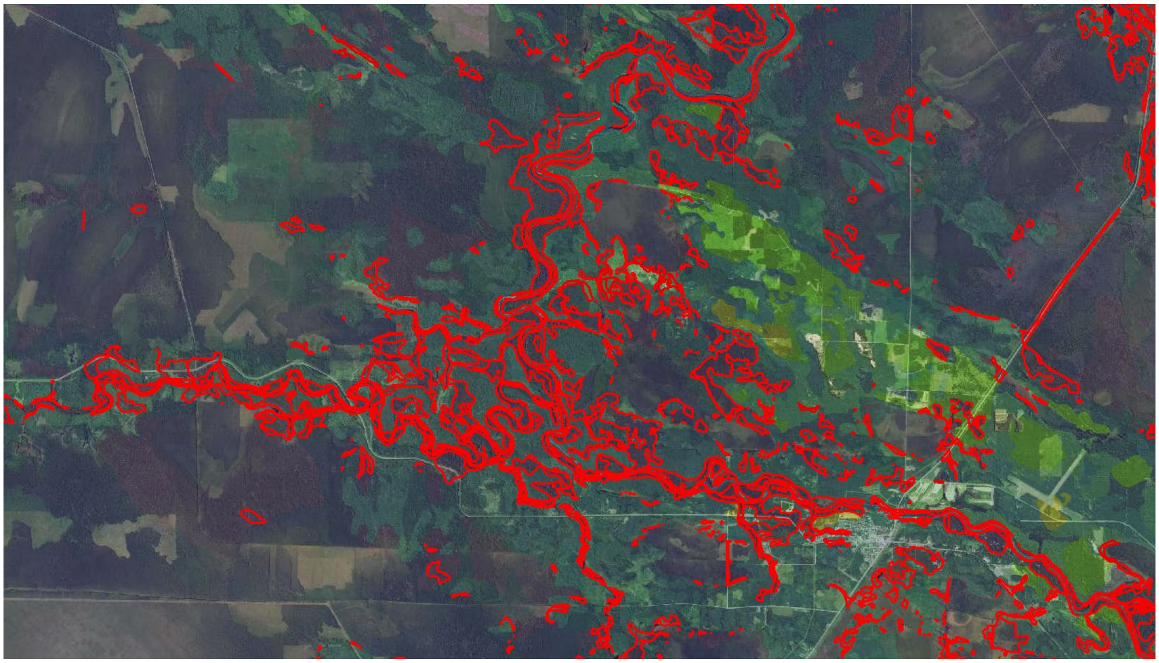


Figure 4.5 False Positive correlation from lack of NWI riparian mapping

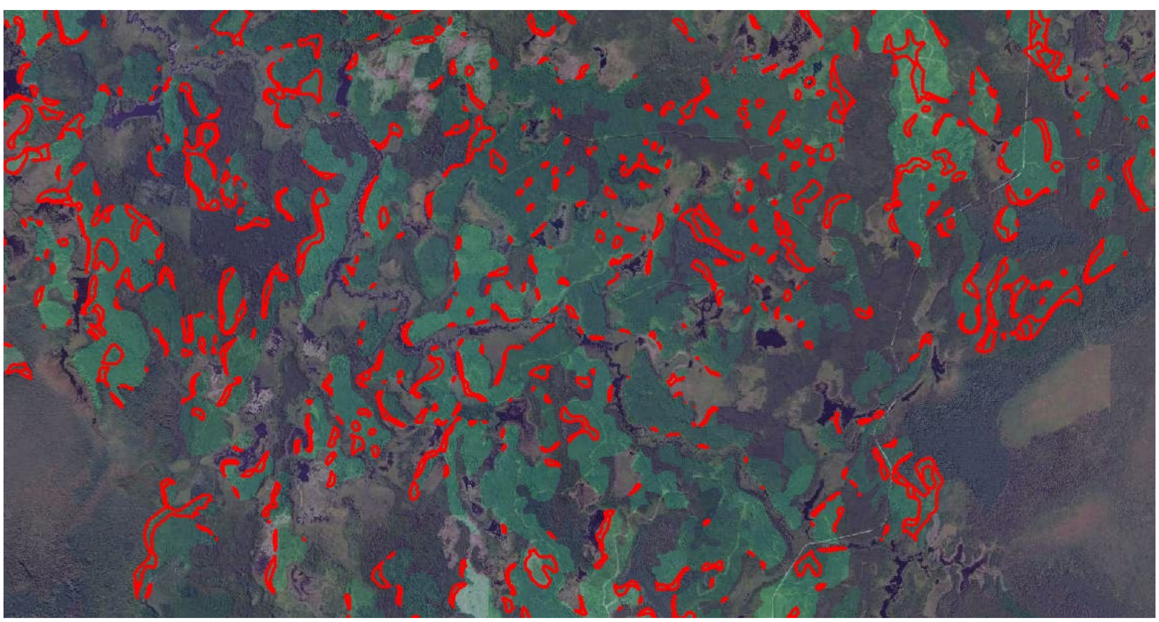


Figure 4.6 False Negative where NWI resolution supports wetlands but soils does not

4.3.1 Estimating Wetlands for the State of Minnesota

While the data was only trained in the LMFP area, and regional variations do seem to have an effect on training the data, we can still give an approximate estimate of pre-settlement wetlands for the entire State of Minnesota. By representing each DI value by percent of wetland type and non-wetland, a rough estimate of total wetland area in Minnesota can be calculated. Figure 4.7 shows the occupancy percent of each NWI wetland class based on DI value.

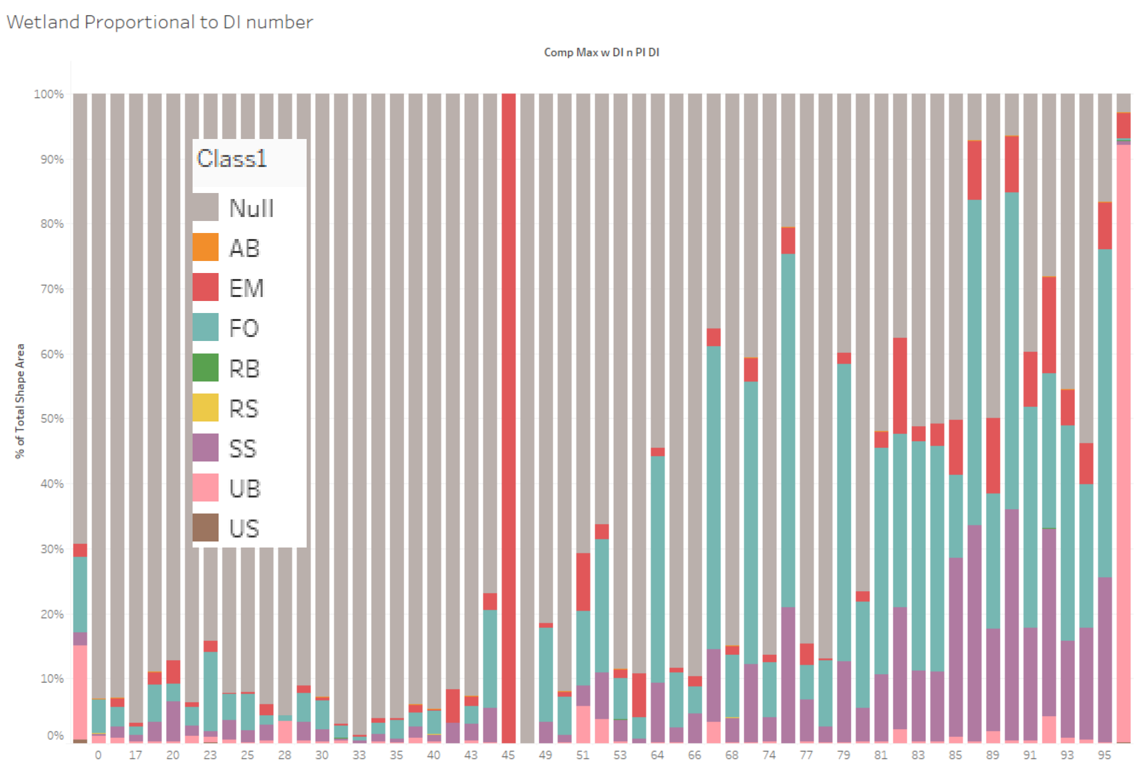


Figure 4.7 Percent likelihood of wetland based on DI

The total area represented by the gSSURGO 2018 database is 218,585.4 square kilometers. Reassigning oddities (see DI 45) and Null DI values (like 26, 36, 47, etc.) as completely non-wetland areas, the total state area of non-wetland comes to 129,741.1 sq km, and total wetland area comes out to 88,844.2 sq km. See calculations in Appendix B.

This means that historically, 40.6% of the state used to be wetland area. By contrast, the NWI 1980-86 training data used for this only covers about 53,405.2 sq km, or 24.4% of the state area. This is a sharp reduction in wetland area. The University of Minnesota (1981) has calculated pre-settlement wetlands at around 18.4 million Acres, which equates to roughly 74,452.2 sq km, or 34.1% of the state. This study shows it is possible the UMN has underestimated wetland loss since they were only targeting poorly drained mineral soils, whereas soils must first develop under wetland conditions to achieve that form. Moreover, hydric soils are very complex in nature, and they are hard to properly classify in all conditions. The Farm Service Agency (2011) claims, "When a soil fails to exhibit a hydric soil indictor, but meets the hydric soil definition, the FSA Procedures refer to this as a false negative. For hydric soils, false negative are not uncommon," meaning that it is very easy to underrepresent the total amount of hydric soils present in a landscape. This reinforces the idea that false negatives in the training data may actually be valid wetlands.

5 Conclusions and Future Research

5.1 Conclusions

Through preliminary analysis, this research has shown that the Drainage Index is more than capable of supporting estimations of pre-settlement wetlands. The MnModel phase 4 hydrographic model discussed in this research could certainly benefit from the use of Drainage Index values. The DI product could help automate procedures and reduce manual error while helping document the project and its reproducibility.

Wetland definitions have changed over time, along with public opinion of wetlands. Definitions have changed from purely descriptive texts, to quantitative text based on the presence of hydrophytes and certain soil types, and to include functions of wetlands in addition to measurable components. Wetlands were once viewed as dismal places meant to be reclaimed and made profitable through drainage efforts, but this is no longer the case today. Government regulations have slowed the demolition of wetland acreage now that wetland functions are understood to be essential to the growth and maintenance of wildlife species and groundwater control. In some instances, incentives have helped restore lost wetlands. Knowing the importance of wetlands has encouraged many others to attempt modeling pre-settlement wetlands. Many of these studies rely on known areas of drainage activities across the nation.

With proper training location selection, this model can draw important wetland correlations for large ecological areas. The training areas used for informing the model should be representative of the ecological area a user wishes to model, as there can be significant variation between regions, and applying the results of one region to another may not be entirely viable if modeling classes or types of wetlands. Processing and vetting of undisturbed areas should be carried out thoroughly so that incorrect correlations are not made. Knowing the strengths and weaknesses of the selected wetlands data is also important when accounting for false positives and false negatives. Slivers will be present when combining polygon datasets.

This methodology compares favorably with the University of Minnesota's 1981 estimate of pre-settlement wetland and suggest that their estimate may be under-estimating the number and coverage of Minnesota's wetlands.

5.2 Future Research

To improve upon the foundations of this work, future research should iteratively run this method. After the first completion, datasets should be inspected for possible false positive and false negative areas so the user can determine if those areas should stay in the training data or be removed. In addition, modeling one ecoregion at a time should yield the most honest representation of that area given that the sample size for the region is not too low. For areas where a DI value has no training data, some method of averaging wetland presence in the two nearest DI values may be viable. Where soils data is not available, it should be acceptable to simply treat that null value as any other DI value, given that manual inspection of the area proves that there is no falsity in the correlation. In the future, these suggestions would greatly improve upon the integrity of this method for offering accurate pre-settlement wetland estimations.

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7 Appendix

Appendix A

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# DIY_Training_Data.py
# Created on: 2018-07-16 11:19:09.00000
#   (generated by ArcGIS/ModelBuilder)
# Modified by: Johnathon Thomas Salfer
# Usage: DIY_Training_Data <Undisturbed_Areas__Merged_>
# <Eco_Region__ECS_boundary_> <Wetland_Data> <SSURGO_Data>
# Description:
# This script is a modified version of the model found in Figure
# 3.12. This script assumes the user has merged all of their desired
# training datasets into one shapefile, removed all fields, and
# selected a single eco-region. Depending on the size of your soil,
# wetland, and state area, this may take a while to run. Minnesota
# (86K miles) takes about 20 minutes to complete. Once complete,
# simply join the DI table to the MUKEY in the Soil_Wetland_Union
# feature class to begin your analysis. When adding this script to a
# toolbox, check the box for "store relative path names".
# Also remember to set the 5 required parameters:
# 0-Workspace 1-Undisturbed, 2-ECS_Region, 3-Wetland, 4-Soil
# ---------------------------------------------------------------------------

# Set the necessary product code
# import arcinfo

# Import arcpy module
import arcpy
from arcpy import env
env.workspace = arcpy.GetParameterAsText(0)

# Script arguments
# (You may also run this outside of ArcMap by specifying your paths
for each Script Argument)
# This is where you place your merged feature class of undisturbed
areas
Undisturbed_Areas__Merged_ = arcpy.GetParameterAsText(1)

# This is where you place your selected ECS region
Eco_Region__ECS_boundary_ = arcpy.GetParameterAsText(2)

# This is where you place your wetland training data
Wetland_Data = arcpy.GetParameterAsText(3)

# This is where you place your state soil data
SSURGO_Data = arcpy.GetParameterAsText(4)
```

```
# Local variables:
Expression = "MUSYM = 'NOTCOM'"

# Process: Clip
# Limit training areas to ECS region
arcpy.Clip_analysis(Undisturbed_Areas__Merged_,
Eco_Region__ECS_boundary_, "Natural_Areas", "")

# Process: Dissolve
# Reduce training area polygons from many to 1 to save on processing
time
arcpy.Dissolve_management("Natural_Areas", "Natural_Area", "", "",
"MULTI_PART", "DISSOLVE_LINES")

# Process: Select
# Find NULL Soil values
arcpy.Select_analysis(SSURGO_Data, "No_Soils_Data", Expression)

# Process: Erase
# Remove areas with NULL soil values from Training data
arcpy.Erase_analysis("Natural_Area", "No_Soils_Data",
"Natural_Area_with_Soil_Records", "")

# Process: Clip (2)
# Fit Soil data to training area
arcpy.Clip_analysis(SSURGO_Data, "Natural_Area_with_Soil_Records",
"Soil_Training_Area", "")

# Process: Clip (3)
# Fit Wetland data to training area
arcpy.Clip_analysis(Wetland_Data, "Natural_Area_with_Soil_Records",
"Wetland_Training_Area", "")

# Process: Union
# Combine Soil and Wetland data into one feature class
arcpy.Union_analysis(["Soil_Training_Area",
"Wetland_Training_Area"], "Soil_Wetland_Union", "ALL", "", "GAPS")
```

Appendix B

Non Wetland calculations		*note: 100% means DI was not trained	
DI Value	Count (10 sqm)	% of Non-Wetland	Non-Wetland area (10 sqm)
-1	143230270	69.36%	99342103.64
0	23904394	93.06%	22244425.18
12	312580	100.00%	312580.00
14	24170967	92.96%	22469143.29
17	2422438	96.82%	2345395.38
18	368927	100.00%	368927.00
19	4281576	88.96%	3809014.39
20	1400700	87.18%	1221066.76
21	16644996	93.63%	15585290.81
22	2881136	100.00%	2881136.00
23	777399	84.19%	654498.27
24	153178	92.19%	141217.62
25	855918	92.08%	788133.50
26	148856	100.00%	148856.00
27	764251	93.94%	717944.66
28	477276	95.74%	456921.23
29	22275607	91.11%	20296398.77
30	8048406	92.87%	7474736.10
31	8916733	100.00%	8916733.00
32	20701446	96.99%	20078531.64
33	5885763	98.65%	5806165.38
34	10233895	96.10%	9834639.54
35	3148500	96.15%	3027153.04
36	1057441	100.00%	1057441.00
37	17098	100.00%	17098.00
38	34924	100.00%	34924.00
39	8240074	93.98%	7744297.99
40	56628187	94.66%	53602199.02
41	59795093	100.00%	59795093.00
42	85099611	91.71%	78041299.45
43	142926566	92.72%	132516144.34
44	105465134	76.92%	81125532.89
45	11904524	100.00%	11904524.00
46	87150	100.00%	87150.00
47	6813406	100.00%	6813406.00

DI Value	Count (10 sqm)	% of Non-Wetland	Non-Wetland area (10 sqm)
48	1330402	100%	1330402.00
49	8647262	81.49%	7046287.54
50	25341807	91.94%	23300242.31
51	71330814	70.75%	50467837.66
52	24306849	66.26%	16105600.53
53	81355117	88.52%	72015403.83
54	23856764	89.23%	21286480.58
55	586958	100.00%	586958.00
57	43201	100.00%	43201.00
59	2372	100.00%	2372.00
64	5496146	54.58%	2999635.09
65	11397095	88.34%	10067636.90
66	44456596	89.61%	39835460.73
67	84716392	36.19%	30657601.59
68	57514844	84.90%	48832709.68
69	34309271	40.59%	13926596.30
73	51016	100.00%	51016.00
74	114304	86.38%	98739.34
75	7287767	20.51%	1495024.69
77	2616425	84.63%	2214251.92
78	19552710	86.90%	16991371.33
79	14954225	39.96%	5975218.71
80	2277035	76.65%	1745246.85
81	165781570	51.96%	86140890.71
82	92300079	37.65%	34747306.31
83	61970111	51.21%	31732920.81
84	52083181	50.77%	26441261.76
85	1782696	50.17%	894364.08
87	95185018	7.13%	6782578.65
88	4442623	100.00%	4442623.00
89	3822582	50.01%	1911489.16
90	163530076	6.51%	10637939.94
91	25710498	39.69%	10204159.79
92	22963962	28.14%	6462009.90
93	41884607	45.49%	19052765.62
94	7708448	53.85%	4150716.39
95	29832946	16.67%	4974351.39
97	100208	100.00%	100208.00
99	115134972	2.87%	3304817.96
	Total Non-Wetland Area in Minnesota:		1300715819
			130,071.6 square kilomenters