WETLANDS OF CAMP GRAFTON SOUTH

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ABSTRACT

The Clean Water Act provided the basis for subsequent federal and state level wetland policies. Wetland regulations have significant implications for how wetland managers implement wetland restoration, creation, and enhancement projects and maintaining current wetland extents across the United States. Wetland classifications and inventories are key tools for wetland scientist and managers by providing information about the status and trends of wetlands. This information includes wetland extent, wetland health, wetland types, and wetland functions. Providing current or updated wetland inventories and classifications would help federal and state agencies implement accurate wetland regulations while providing managers information relevant to wetland restoration, creation, and enhancement. Recent research and development into geographic information systems has provided methods and tools to accurately map wetland boundaries. Hydrologic and classification tools utilize digital elevation maps (DEM) and aerial imagery to identify and map wetland boundaries. This study introduces a model for mapping wetland boundaries.

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CHAPTER 1. WETLAND LAW AND POLICY

Introduction

The importance of water within the United States is the result of many factors; among those include population growth, urban sprawl, agriculture, and changes in the climate. These factors have led to a surge of awareness towards the importance in protecting the nation's waterbodies. As a result, the United States began a jurisdictional roller-coaster towards water protection with the passing of the Federal Water Pollution Control Act. Amended in 1972, the Federal Water Pollution Control Act was renamed to the more commonly known Clean Water Act (CWA). While the CWA protected the navigable water within the United States, controversy arose over the interpretation of what is considered a navigable water following the Supreme Court decisions of SWANCC and Rapano's. The basis of the controversy was which waters that are not truly navigable (e.g. wetlands, temporary streams) are protected under the CWA. Isolated wetlands, especially the prairie pothole wetlands, sandhill depressional wetlands, and Rainwater Basin wetlands were among this discussion of isolated wetlands due to the significant importance these regions have on wildlife and local societies. This led to the most significant of these interpretations, termed "waters of the United States." The basis of this paper is how the "waters of the United States" has developed over the past 45 years through recodifications resulting from Supreme Court decisions, executive orders, and peer-reviewed science.

Section 404, Clean Water Act of 1972

The Clean Water Act was amended to restore and maintain the chemical, physical, and biological integrity of the nation's waters (33 U.S.C. 1251 et. Seq). Section 404 of the CWA breaks down specific limitations to polluting waters within the United States. "Section 404 restricts discharge of dredge and fill materials into the waters of the United States without permits issued by the U.S. Army Corps of Engineers (USACE) (33 U.S.C. 1344)”. Examples of some activities that would be regulated by section 404 include construction of dams, levees, and highways as well as many mining projects. It is important to note that these projects fall under Section 404 and need permitting if the process impacts the nations waterbodies. Those activities that are exempt from Section 404 include common farming practices and maintenance of serviceable structures. The only stipulation to these exemptions include the cases in which the activity involves new construction that alters or impacts navigable waters. “These activities require a permit issued by the USACE commonly known as the recapture provision (Andrew Cherry, personal communication).” The CWA gives the USACE and the Environmental Protection Agency (EPA) enforcement authority for Section 404 violators. At the local level and generally small operations, enforcement is by the USACE, while larger projects, repeat offenders, and violators forwarded by the USACE are enforced by the EPA.

1986 Regulatory Definition of “Waters of the United States”

Section 404 of the CWA failed to protect large amounts of wetlands, especially those wetlands that are isolated and defined as “completely surrounded by upland” (Tiner 2003). These wetlands are often characterized as temporary or seasonally flooded and regularly dry up throughout the growing season. Isolated wetlands are mainly found in areas where the main land use is agriculture. Historically, farmers and ranchers typically drain or excavate these wetlands, greatly altering them. These activities are allowed due to the exemptions for normal farming and ranching activities as well as the lack of a definition to navigable waters. To address this issue, President Jimmy Carter issued Executive Order No. 11990 on May 24, 1977 to protect wetlands nationwide.

Executive Order No. 11990 has a series of sections set in place to avoid the short-term and long-term impacts on wetlands that occur from destruction and construction projects. "Section 1 states that agencies shall take action to minimize the destruction, loss, and degradation of wetlands while providing protection to wetland values. Section 2 limits any agency's involvement in projects that may harm wetlands. Section 3 indicates that any authorization requests submitted to the Office of Management and Budget must indicate if the project involves wetlands so to abide by this executive order. Section 5 states that all agencies must consider all effects a project may have on the survival and quality of wetlands. Section 6 indicated that all agencies must manipulate current procedures so that it applies to this executive order. Section 8 indicates that projects before 1977 fiscal year do not apply to this executive order and all agencies must apply this order by October 1, 1977. This executive order set the stage for the next 40 years of interpretation of what was covered under Section 404 of the CWA (42 FR 26961)."

After May 24th, 1977, the term navigable waters failed to encompass some of the most valuable and sensitive wetlands in the United States. Navigable waters were then replaced by the term "Waters of the United States (WOTUS)". Any water body that is defined under WOTUS is federally protected under the CWA. This can be thought of as the base-line of water protection nationwide regardless of State law. The first codification presented by the EPA was published in 1986. "The EPA's definition of WOTUS included all waters subject to interstate/foreign commerce, waters subject to the oceans tide, all interstate waters including interstate wetlands, all lakes, rivers, streams, mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds that would impact interstate or foreign commerce, all impoundment waters, all tributary waters, and all territorial seas (40 CFR 230.3)." The 1986 regulatory definition of WOTUS, as broken down by seven circumstances left many questions about what was termed “adjacent wetlands.” As addressed in the legal documents, section seven under this definition states:

> “wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs 1-6 of this section; waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition) are not WOTUS (40 CFR 230.3).”

Interpreting this section can be confusing, especially to those that are impacted by this specific definition. This can be interpreted in two separate ways. At first glance, this section seems to list out those waters that are not considered WOTUS, including adjacent wetlands. This could also be interpreted as those adjacent wetlands that identify with the previous six sections would be considered WOTUS. It was clear that there needed to be more specific interpretations of WOTUS. These interpretations would come from the Supreme Court during two court cases that would shape the path of WOTUS.

Migratory Bird Rule

The Migratory Bird Treaty Act was established in 1918 protecting migratory birds under the authority of the United States Fish and Wildlife Service (USFWS). The specific regulations under this rule are as follows:

> “Establishment of a Federal prohibition, unless permitted by regulations, to "pursue, hunt, take, capture, kill, attempt to take, capture or kill, possess, offer for sale, sell, offer to purchase, purchase, deliver for shipment, ship, cause to be shipped, deliver for transportation, transport, cause to be transported, carry, or

> cause to be carried by any means whatever, receive for shipment, transportation or carriage, or export, at any time, or in any manner, any migratory bird, included in the terms of this Convention . . . for the protection of migratory birds . . . or any part, nest, or egg of any such bird."” (16 U.S.C. 703-712)

Based on the definition laid out in the CWA, the USACE and the Environmental Protection Agencies adopted what was called the Migratory Bird Rule, which gave protection to non-navigable waters such as isolated wetlands through their habitat uses by migratory birds. The Migratory Bird Rule also established these protections for migratory birds that cross state lines. This rule was overturned by the Supreme Court in a 2001 ruling of Solid Waste Agency of Northern Cook County v. United States Army Corps of Engineers.

SWANCC v. U.S. Army Corps of Engineers

Solid Waste Agency of Northern Cook County (SWANCC) v. United States Army Corp of Engineers in 2001 became a major court case decided by the Supreme Court dealing with the protection of wetlands. The solid waste agency applied for permits for the disposal of some non-hazardous waste on a site. The Corp of Engineers first determination was no permit was required due to the lack of wetlands located on the site. After a re-evaluation, the USACE determined the site was used as habitat for migratory birds thus falling under WOTUS via the Migratory Bird Rule. The Supreme Court ruled in favor of SWANCC stating, “the use of “isolated” non-navigable ponds by migratory birds was not by itself sufficient for federal regulatory authority under the CWA (531 U.S. 159).”

Rapanos v. United States

Another critical court decision that shaped the interpretation of WOTUS is from, Rapanos v. United States (2006). After wetlands were backfilled by Rapanos, the USACE and

EPA filed a law-suit against Rapanos arguing that the agencies have authority over wetlands that are adjacent to WOTUS. The Supreme Court had to determine what was considered adjacent. The wetlands that were backfilled were as much as 20 miles from any navigable water. The ruling by the Supreme Court was a split decision but ultimately the court found that Rapanos was in violation of the CWA (547 U.S. 715). There were two significant interpretations that came out of this court case. Justice Scalia's opinion and interpretation of WOTUS is as follows, "relatively permanent, standing or continuously flowing bodies of water that are connected to traditional navigable waters as well as wetlands with a continuous surface connection to such water bodies (547 U.S. 715)." The other opinion was from Justice Kennedy in which he stated that a body of water or wetland must have a "significant nexus" to a navigable water in order for it to be considered a water of the United States. Further guidance explaining the new term significant nexus was given by Justice Kennedy, "a wetland has a significant nexus to a navigable water if the wetland either alone or in combination with similarly situated wetlands in the region significantly affect the chemical, physical, and biological integrity of other covered waters more readily understood as navigable (547 U.S. 715)." The term "significant nexus" was used by the Obama Administration in the recodification of WOTUS in 2015.

Clean Water Rule: Definition of "Waters of the United States"

The Clean Water Rule was a combination of court decisions (SWANCC and Rapanos), federal agencies experience, prior WOTUS codifications, and the latest scientific research to interpret the scope of WOTUS. As stated in the legal document, the goal of the clean water rule was "to ensure the protection of the nation's public health and aquatic resources while increasing the CWA's program predictability and consistency by clarifying the scope of "WOTUS" protected under the Act (80 FR 37054-37127)." The Clean Water Rule lays out eight categories that are defined under WOTUS, each one of the eight categories are labeled either jurisdictional, non-jurisdictional, or case-specific analysis situations.

The agencies found the following waters to be jurisdictional under the WOTUS in all cases: "traditional navigable waters, interstate waters, territorial waters, and impoundments of jurisdictional waters (80 FR 37054-37127)." The least conventional waters that have been determined by scientific research to be jurisdictional by rule include tributaries and adjacent wetlands.

The term "adjacent" has come up in many instances previously discussed in this paper, though those situations lacked an interpretation of what constitutes as adjacent. The clean water rule defines adjacent as "bordering, contiguous, or neighboring while including those waters that are separated from other WOTUS by some constructed barrier (80 FR 37054-37127)." There are three instances in which a body of water is considered "Adjacent":

1. "Waters located within 100 feet of the ordinary high-water mark of those waters under the WOTUS definition."
2. "Waters located within the 100-year floodplain and are within 1500 feet of the ordinary high-water mark of those waters under the WOTUS definition."
3. "Waters located within 1500 feet of the high tide line of those waters under WOTUS definition and/or waters within 1500 feet of the ordinary high-water mark of the Great Lakes (80 FR 37054-37127)."

The agencies define examples that are considered "adjacent waters." These include wetlands, ponds, oxbows, impoundments, and other similar waters. Those wetlands or waterbodies outside of the three criteria listed above are subject to a case-specific analysis to determine if the feature is considered to have a significant nexus to the Nation's waterbodies.

Until proven to have a significant nexus, those waters would not be considered protected as a water of the United States.

The agencies found five specific regions that are of great importance and would be considered to have a significant nexus through a case-specific analysis. These regions include prairie potholes, Carolina and Delmarva Bays, pocosins, western vernal pools in California, and Texas coastal prairie wetlands (80 FR 37054-37127). All exclusions to the clean water rule include previously converted cropland, waste treatment systems, ditches with ephemeral flow that are located outside of a tributary or excavated boundary, or ditches with intermittent flow that are located outside of a tributary or excavated boundary (80 FR 37054-37127).

Waters of the United States: Recodification of Pre-existing Rules

Following the proposal of the Clean Water Rule, thirty-one states requested a judicial review into the legal authority of the proposed rule. Eventually these legal actions lead to the Supreme Court of Appeals for the Sixth Circuit temporarily suspending the Clean Water Rule until further court action. The Supreme Court granted the suspension provided by the Sixth Circuit. On January 28, 2017 President Trump issued an executive order titled, "Restoring the Rule of Law, Federalism, and Economic Growth by Reviewing the "WOTUS Rule" (82 FR 34899-34909)." The executive order requests the agencies to issue a proposed rule that rescinds the Clean Water Rule that was proposed in 2015. The new proposed rule must be consistent with section one which states, "it is in the Nation's interest to protect the Nation's navigable waters from pollution, while promoting economic growth, limiting regulatory uncertainty, and showing concern for Congress and states under the Constitution (82 FR 34899-34909)." The executive order also orders the agencies to interpret the new proposed rule in consistency with the opinion of Justice Scalia from the 2006 court case Rapanos v. United States. Until the agencies propose a new rule, the interpretations from the 1986 WOTUS rule will continue to be the agencies guidelines.

The Swampbuster Provision

Another noteworthy policy protecting wetlands included the Sampbuster provision under the Farm Bill of 1985 (Food Security Act). Regulated by the Natural Resources Conservation Service, Swampbuster provided wetland protection from agricultural practices through the withholding of United States Department of Agriculture (USDA) program benefits such federal crop insurance and crop loans (Glaser 1986). The Swampbuster provision applies to any person that plants an agricultural commodity on a wetland that has been converted after December 23, 1985 or converts an existing wetland for use in agriculture production after November 28, 1990 (Glaser 1986). Those wetlands that have been converted to agricultural crop production prior to the cut-off date (December 23, 1985) are exempt from the Swampbuster provision.

State Wetland Law

State laws that protect wetlands are extensions of federal policy. The federal policy acts as a baseline wetland protection policy required for each state. State run programs and laws such as the Minnesota's Public Water Work Permit Program of 1937 and the Minnesota Wetlands Conservation Act of 1991 further wetland protection beyond Federal regulations. The Public Water Work Permit Program, run by the Minnesota Department of Natural Resources (MNDNR), requires a permit for any work that could impact the course, current, or cross section of public waters. The Minnesota Wetland Conservation Act of 1991 aimed at a no net loss of Minnesota wetlands. Approval for activities that drain, fill, or excavate any Minnesota wetland must be obtained by the local government.

North Dakota, South Dakota, Nebraska, and Iowa are among some of the states that have no state laws or regulations protecting wetlands. These states fall under Federal jurisdiction, meaning any federal policy or regulation that pertains to wetlands will become the state law. For example, the passing of Clean Water Rule in 2015 resulted in the protection of many "isolated" wetlands in North Dakota. The recodification of "WOTUS" would revert this rule and result in many of these "isolated" wetlands not being covered under Federal regulations and thus not required by State to be protected.

The Term "Isolated" Wetlands

The term "isolated" in reference to wetlands was brought to the forefront by the court cases SWANCC and Rapanos. As mentioned, SWANCC resulted in the protection of isolated and non-navigable waters being dropped in cases where the sole protection was based on the "Migratory Bird Rule" (Leibowitz 2003, Nadeau and Leibowitz 2003, Mushet et al. 2015). The SWANCC ruling also included that these "isolated" waterbodies were protected by the CWA if such waterbodies had a "significant nexus" to a navigable water (Downing et al. 2003). Rapanos v. United States ruled that "isolated" waterbodies are protected if it is found to have a "significant nexus" to a traditional navigable water. Justice Kennedy provided the interpretation of "significant nexus" (specified earlier), something that was not clarified under the SWANCC ruling. Between the interpretations of SWANCC and Rapanos, there was a push to research "isolated" wetlands and clarify the term "isolated" in order to bridge the gap between scientists and regulators. The following sections will overview the different definition of "isolated" wetlands as well as the research that challenged the term "isolated" in response to the SWANCC decision.

Definitions and Interpretation

Traditionally, seasonal wetlands received very little jurisdictional protection due to the high variability in wetness from year to year (Gibbons 2003). At its initial state, isolated wetlands were described as depressional wetlands entirely surrounded by upland (Tiner 2003). The National Research Council termed isolated wetlands as a wetland not adjacent to another body of water (NRC 1995). Likens et al. (2000) deems the term “isolated” as not precise as it suggests that these wetlands lack a surface outlet, yet most scientists regard the term “isolated” as a matter of degree. Leibowitz (2003) described this as being along an isolation-connectivity continuum where the degree of isolation has implication of the functionalities of that wetland. Tiner (2003) states that isolated wetlands can be connected by subsurface and groundwater flow as well as by spillovers. Snodgrass et al. (1996) defined an isolated wetland as being unconnected from other waterbodies during average surface-water levels. Due to the lack of an accepted definition for “isolated wetlands,” Tiner (2003) called for the use of the term “geographically isolated wetland” to replace the uncertainties of the term “isolated”. Geographically isolated wetland is defined as a wetland surrounded by upland, thus describing the location of the wetland on the landscape (Tiner 2003). This description is based solely on characteristics of the landscape not that the wetland is “isolated” (Mushet et al. 2015). To better understand the need for a cross-disciplinary definition of these complex wetlands, research must be reviewed to determine the connectivity to “traditional” navigable waters.

Isolated Wetland Connectivity

Following the SWANCC decision, scientific research has shown the complexity in the connectivity of “isolated wetlands” or “geographic isolated wetlands” (Gibbons 2003; Leibowitz 2003; Winter and LaBaugh 2003; Marton et al. 2015; Mushet et al. 2015; Cohen et al. 2016).

Connectivity research is valuable to regulators that review wetlands with a “significant nexus” and which wetlands fall under CWA jurisdictions. Research has shown “isolated wetland” connectivity to jurisdictional water via ecological, hydrological, biogeochemical, and terrestrial habitat (Gibbons 2003; Leibowitz 2003; Winter and LaBaugh 2003; Marton et al. 2015; Mushet et al. 2015; Cohen et al. 2016). The following subsections will overview each topic and how the SWANCC decision would impact such processes.

Ecological

Ecological processes in science are loosely thought of as everything within an ecosystem is connected to each other (Tiner 2003). Thus wetlands, isolated or not are all connected through abiotic and biotic processes as well as having interconnected habitats. For example, the structure of these complex wetland systems has shown to maintain large populations northern leopard frogs (*Lithobates pipiens)* with high levels of genetic diversity (Mushet et al. 2013). Maintaining perennial wetland plant species have been linked to the presence of complex isolated wetlands. Composition of plant populations were impacted by distance between wetlands and size of surrounding wetlands (O’Connell et al. 2013). Following SWANCC, these complex systems may receive greater loss due to human activities (eg. Agriculture) having impacts of plant structures and northern leopard frog populations.

Hydrological

Hydrological connections have been the basis for regulators in determining which wetlands are covered by the CWA. Recent research discusses hydrological connections other than surface-water connections (Leibowitz 2003; Tiner 2003; Winter and LaBaugh 2003; Mushet et al. 2015). Sub-surface flow and groundwater flow are present between isolated wetlands (Leibowitz 2003; Tiner 2003; Mushet et al. 2015). These connections are based on the substrate, with water traveling multiple kilometers/year through gravel and can take up to a year for water to travel one meter in clayey substrate (Winter and LaBaugh 2003). Climate also impacts the connectivity of isolated wetlands. High precipitation years could raise the water level and spill over the wetland edge running off into other bodies of water (Winter and LaBaugh 2003). Hydrological connections are difficult to define due to variability in wet and dry periods as well as below ground flow making it difficult for regulators to identify a "significant nexus". Furthering research in identifying hydrological connections will help drive protection of these isolated wetlands.

Biogeochemical

The chemical connectivity between "isolated" and navigable waters is viewed as the chemical processes interacting within hydrologic and biotic processes (Mushet et al. 2015). Research has shown the transport and retention of nutrients is the result of the interaction between biogeochemical and hydrological processes providing services such as carbon sequestration, removal of nitrogen, storage of phosphorus, and nutrient retention (Leibowitz and Nadeau 2003; Marton et al. 2015). Marton et al. (2015) discussed how "isolated wetlands" biogeochemical processes such as retaining pollutants occur at similar rates to navigable waters. This research suggests that "isolated wetlands" contribute to the quality of downstream navigable waters and provide services to society such that they should be jurisdictionally protected.

Terrestrial Habitat

Looking at larger scales, terrestrial habitat and adjacent "isolated wetlands" interact and provide connectivity between other water bodies. Gibbons (2003) discussed the biotic and abiotic process are interconnected between terrestrial habitat and "isolated wetlands." Though terrestrial habitats are not specifically looked at when determining wetland connectivity, many vertebrate and avian species rely on these habitats for breeding and nesting habitat (Gibbons 2003; Leibowitz and Nadeau 2003). Terrestrial habitat provide emigration during drought years as well as hibernation habitat and available forage for many species. Gibbons (2003) states that understanding how biodiversity is impacted by the terrestrial and wetlands interaction could provide regulators enough information as to improve wetland protection.

Important Isolated Wetlands

The 2015 WOTUS ruling provided five waters that have been found to have a "significant nexus," these include prairie potholes, Carolina and Delmarva bays, pocosins, western vernal pools in California, and Texas coastal prairie wetlands (80 FR 37054-37127). Discussing the characteristics of different types of "isolated wetlands" within the Midwest could promote jurisdictional protection of these "isolated wetlands" under the CWA. This section will discuss the characteristics of the Sandhill's and Rainwater Basin of Nebraska and the Prairie Potholes of the Upper Midwest.

Sandhills Wetlands

The Sandhills region is located over much of Nebraska with just over 500 thousand hectares of wetlands, 60 percent of which are estimated to be "isolated wetlands (LeGrange 2001). This semi-arid region receives less than 400 millimeters of precipitation and is characterized by windswept depressional wetands (Frankforter 1996; Tiner 2003). The wetlands in the eastern part of the region are hydrologically connected by ground water and surface outlets, while the western part has minimal surface outlets but is still connected through ground water flow (Tiner 2003). The Sandhill wetlands are threatened by cattle grazing through wetland ditching and altered hydrology for irrigation. Loss of Sandhill wetlands would lead to loss in spring staging areas, breeding areas, and habitat for endangered species and migratory waterfowl (Gersib 1991; Tiner 2003).

Rainwater Basin Wetlands

The semi-arid/subhumid Rainwater Basin region is located in south-central and south-east Nebraska (Gersib 1991; Tiner 2003). With annual precipitation rates lower than evapotranspiration rates and clay-like substrate preventing groundwater recharge it is estimated that 90 percent of the regions wetlands are “isolated wetlands” (Tiner 2003). These “isolated wetlands” depend on precipitation and surface runoff as the source of hydrology. Millions of waterfowl depend on these wetlands for spring migrations as well as providing habitat and forage (Gersib et al. 1990; Gersib et al. 1992; Tiner 2003). Other services that could be lost for lack of judicial protection include wildlife habitat, flood water storage, and retention of nutrients and sedimentation (Gersib et al. 1989; Tiner 2003).

Prairie Pothole Wetlands

The Prairie Pothole Region is the largest of the three regions discussed in this section. Montana, North Dakota, South Dakota, Minnesota, Iowa, and parts of Canada represent the Prairie Pothole Region. Wetland loss from 1850 through the 1980s ranged from 32% loss in South Dakota to near total loss (90%) in Iowa (Dahl 2014). Status and trends documentation in the Prairie Pothole Region indicates that from 1997 to 2009 wetland loss occurred at a rate of 2,510 hectares (6,200 acres) per year. Wetland loss is significantly linked to agricultural growth in which wetlands were drained to provide fertile crop-land (Johnston 2013, Dahl 2014). The Prairie Pothole Region is also the only region in this section that was included in the 2015 WOTUS ruling as having a “significant nexus” (80 FR 37054-37127). This region is characterized by depressional wetlands that receive all of their water from precipitation, runoff, and snowmelt (Berkas 1996; Tiner 2003). These wetlands usually lack surface water outlets as a result of seasonally drying. During wet years these depressions fill up with water and occasionally spillover resulting in temporary surface water connections to other waterbodies (Leibowitz and Vining 2003; Tiner 2003). Recent research has shown groundwater connections to prairie potholes as well as subsurface from topographically high pothole wetlands into topographically low potholes, lakes, rivers, and streams (Winter 1989; Tiner 2003; Mushet et al. 2015). The Prairie Pothole Region on average produces half of North America's waterfowl due to the complex landscape of large and small depressions that allow waterfowl to spread out and reduce vulnerability to predation and disease (Kantrud et al. 1989; Tiner 2003). Continued loss of these wetlands would significantly reduce the successful breeding of waterfowl and migration of many bird species.

Conclusion

The United States grasped the importance of the Nation's waters with the passing of the CWA. The CWA has significant power to change how the Nation's waterbodies are managed, but this also comes at a cost to many people. It is the agencies duty to draw a line between which waters are truly considered "WOTUS" and which waters are not. The struggle to find that line was described above through interpretations of WOTUS resulting in three proposed codifications, two important Supreme Court decisions, and two executive orders. Today the struggle over WOTUS remains and that line that will promote economic growth while also protecting the nation's waters from destruction and degradation has yet to be decided.

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CHAPTER 2. WETLAND CLASSIFICATION AND INVENTORIES

Introduction

The role of wetland classifications and inventories are to provide the tools and framework needed to categorize wetlands (Schempf 1992, Finlayson and van der Valk 1995, Mitsch and Gosselink 2015, Braddock and Hennessey 2018). Classifications can categorize wetlands at a national level (Cowardin et al. 1979, Brinson 1993, Smith et al. 1995) or at the regional level (Stewart and Kantrud 1971, Euliss et al. 2004). Both levels of classification provide important tools that drive wetland conservation, wetland research, and wetland management. These classifications categorize wetlands using different wetland attributes such as landscape position, hydrologic regimes, habitat, landuse, vegetation structures, hydrodynamics, hydrologic flow, and climatic variations (Stewart and Kantrud 1971, Cowardin et al. 1979, Brinson 1993, Smith et al. 1995, Euliss et al. 2004). The differences within each classification do not conflict with each other, rather incorporating components of each classification system can significantly improve the detail and accuracy of classifying wetlands within the United States. Providing federal, state, and local agencies the most accurate classifications is important for promoting wetland conservation and can help aid in the development of wetland projects. This paper will discuss the history of wetland classifications and inventories, including detailed descriptions of the wetland classifications used in practice today. The detailed discussion into defining wetlands, classification systems, and inventories will provide context into understanding the importance of wetland classifications and wetland inventories.

Wetland Classification and Inventories

Defining Wetlands

Defining what constitutes as a wetland is the first fundamental step in producing a wetland classification (Schempf 1992, Cowardin and Golet 1995). It sets standards for data collection in the field as well as the basis for the establishment of policy and management. Maltby (1986) defined a wetland as an ecosystem that formed and whose processes and characteristics have been driven and dominated by water; a wetland is a location that has been wet long enough to produce water-adapted vegetation and other organisms. A more well-known definition of a wetland and used by the United States Fish and Wildlife Service (USFWS) is "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water" (Cowardin et al. 1979). Some of the issues that arise from attempting to define wetlands concisely include, moisture gradients throughout the landscape are continuous and the diversity of wetlands throughout the United States cannot be covered in one concise definition (Cowardin and Golet 1995). These difficulties were also acknowledged by the USFWS in there is no single definition that can cover such diversity of wetlands and the boundary of upland and wetland lies along a continuum (Cowardin et al. 1979, Schempf 1992). It is commonly seen in wetland classifications covering the entirety of the United States adopt a wetland definition or produce criteria that must be met in the field to be defined as a wetland. This is seen in the Cowardin Classification (Cowardin et al. 1979) that was adopted by the USFWS. It is also common to deal with definition inconsistencies by developing regional wetland classifications such as seen in Stewart and Kantrud's (1971) glaciated prairie classification.

Wetland Value and Functions

The functions and values provided by wetlands have driven the creation of wetland classifications and inventories in order to promote conservation and protection of the remaining wetland resources within the United States (Cowardin and Golet 1995, Finlayson and van der Valk 1995, Euliss et al. 2004, Braddock and Hennessey 2018). Early values and conservation efforts with wetlands dealt with habitat for fish and wildlife especially migratory birds and waterfowl. Research in recent decades have defined functions and values of wetlands dealing primarily with water quality and quantity (Braddock and Hennessey 2018). Three major functions and values provided by Braddock (2018) include water quality, flood attenuation/storm control, and ground water support. Wetlands are known as the kidneys of the landscape due to their natural filtering of nutrients from the water (Braddock and Hennessey 2018). Due to their position in the landscape wetlands are naturally nutrient sinks, in other words wetlands absorb/adsorb nutrients. Recent research has shown that wetlands are often diverse in their absorption and adsorption of nutrients (Kent 1994, Mitsch and Gosselink 2015, Braddock and Hennessey 2018). Absorbing/adsorbing nutrients is dependent on hydrology, season, position on the landscape, soil, and temperature (Braddock and Hennessey 2018). Some wetlands are net importers of nutrients, while other wetlands are net producers of nutrients (Kent 1994, Mitsch and Gosselink 2015, Braddock and Hennessey 2018). This can vary from year to year, with one year a wetland acting as a sink for nutrients then the next year that same wetland can release nutrients. Wetlands provide value through reduction of flood/storm water impacts in which wetlands absorb large amounts of water during storm/flood events slowly releasing water following the completion of the event (Braddock and Hennessey 2018). Wetlands are capable of holding up to 14 million liters/hectare (1.5 million gallons/acre) of water (USEPA N.d., Braddock and Hennessey 2018). Positioning of a wetland on the landscape is the driving force of flood attenuation such that isolated wetlands serve little toward flood storage but rather serve as storage from runoff (U.S. Army Corps of Engineers 1998, Braddock and Hennessey 2018). The hydrology of a wetland is not restricted to surface water but is also given value through its interaction with ground water. Wetlands either recharge the groundwater or receive water from the groundwater. This function is valuable for sustaining and protecting wetlands that recharge the groundwater supply (Mitsch and Gosselink 2015, Braddock and Hennessey 2018). Wetland classification systems and inventories provide ways of assessing wetlands partially based on the function and values discussed, and therefore aid in implementation of management and conservation plans, conducting research, and protecting fish and wildlife habitat (Schempf 1992, Braddock and Hennessey 2018).

Defining Classifications and Inventories

Understanding the differences between classifications and inventories is important, but it is also important to understand how classifications and inventories interact/intertwine with each other. A wetland classification is the categorizing of wetlands based on different characteristics such as hydrology or vegetation (EPA 1991, Schempf 1992). While a wetland inventory is simply the collection of wetland data and information (Schempf 1992). Wetland classifications are the first step in developing a wetland inventory and are often adopted as the main data collection protocols (Finlayson and van der Valk 1995). An example of this is the USFWS adoption of the Cowardin Classification System for the development of the National Wetland Inventory (NWI) (Cowardin and Golet 1995, Finlayson and van der Valk 1995), and the Cowardin Classification System connections to the NWI significantly impacts management of the nation’s wetland resources (Cowardin and Golet 1995).

Early Wetland Classifications

Circular 39 "Wetlands of the United States"

Circular 39 was the first classification system in the United States used for the development of a NWI (Schempf 1992, Mitsch and Gosselink 2015, Braddock and Hennessey 2018). The governmental document name Circular 39 was adopted by the USFWS in 1956 and follows the classification protocols laid out in the publication, "Wetlands of the United States" (Martin et al. 1953, Shaw and Fredine 1956). This classification aided in determining distribution, extent, and quality of wetlands and the value these wetlands had for wildlife habitat (Schempf 1992, EPA 2002, Mitsch and Gosselink 2015). The different wetland types were classified based on water depth, water permanence, water chemistry, vegetative life forms, and dominant plant species (Schempf 1992). The basis of this classification system was to protect wetland habitat in order to maintain healthy waterfowl populations (Schempf 1992, Braddock and Hennessey 2018). The downfall of this focus was the bias towards more inundated and large wetlands commonly known as waterfowl habitat resulting in the failure to include smaller isolated wetlands, fens, and spring seeps within the bounds of the classification (Braddock and Hennessey 2018). Regardless of the drawbacks, Circular 39 became the standard classification used by both state and federal agencies and served as the basis for federal regulations concerning the protection of wetlands (Stegman 1976, Schempf 1992). The classification is still used today by some wetland managers due to its simplistic parameters compared to modern era wetland classification systems (Mitsch and Gosselink 2015).

Stewart and Kantrud 1971

Following the wetland classification by Martin et al. (1953) and Shaw and Fredine (1956) "Wetlands of the United States," Stewart and Kantrud (1971) developed a wetland classification for the Prairie Pothole Region (PPR). The creation of “Classification of Natural Ponds and Lakes in the Glaciated Prairie Region” by Stewart and Kantrud (1971) was to classify more precisely the seasonal, regional, and local variations of wetlands within the PPR. Stewart and Kantrud (1971) recognized wetland characteristics that influenced waterfowl and wildlife the most. These characteristics included water permanence, water depth, water chemistry, and land use. Variations between these characteristics are followed by distinct changes in a wetlands vegetation community and the wetland’s vegetation cover. These distinct changes are the basis of this classification system. Within this classification system Stewart and Kantrud (1971) describe the different vegetation zones, the phases of these zones, plant species composition, and water salinities. Each of these characteristics determine what a certain wetland type is present at a site. The breakdown of these characteristics and the overall classification of wetland types will be described in the following sections.

There are seven vegetation zones described within this classification system, each of which are present within the glaciated prairie. These zones include wetland-low prairie, wet meadow, shallow-marsh, deep-marsh, permanent-open water, intermittent-alkali, and fen (Figure 2.1) (Stewart and Kantrud 1971). The wetland-low prairie is characterized by ephemeral surface water in the spring due to rapid porous soil. The low prairie can be the only vegetation zone present often known as an ephemeral wetland, or it can be present as the outer-most band of vegetation usually representing the upland boundary of the wetland. The wet-meadow zone is similar to the low prairie hydrology in which water seepage through the soil is relatively quick; however, surface water is present for a few weeks post-snow melt. Wet-meadow wetlands are normally characterized by emergent plant species. In wetlands with open water or deep marsh phases the wet meadow is often the outermost band or smaller-sized wetlands could be dominated by wet-meadow vegetation. The shallow-marsh zone is the central area of wetlands that have surface water presence most of the summer but dry up in late summer. In large wetlands with more permanent hydrology this vegetative zone is classified as being present between the wet meadow and deep-marsh zones. The deep-marsh zone is characterized by emergent vegetation and the band of vegetation that borders open water areas of wetlands. This vegetation zone is the central zone when there is a lack of open water present in a wetland. The permanent-open-water zone can have shallow or deep-water depths which drives the presence of submerged vegetation. The water permanence as well as the depth of water have shown to prevent the establishment of emergent vegetation. If this zone is present in a wetland it represents the central most part with other vegetation zones bordering the outer parts of the wetland. The succession of zones will naturally occur going from the deep-marsh that borders open-water, down to shallow-marsh, wet meadow, and finally the low-prairie/upland. The following two vegetation zones are known for the presence of alkalinity. The intermittent-alkali zone has saline water in which the salts present include sulfates and chlorides. Due to the high amounts of salts within the intermittent-alkali zone, emergent vegetation is not present. In a wetland where the intermittent-alkali zone is the central most zone, the wetland lacks a deep-marsh zone going straight into a shallow-marsh zone following the natural succession after that. The final vegetative zone within this classification is the fen zone or also mentioned as the alkaline bog. Some of the main characteristic of the fen zone include the lack of surface water with the soil being saturated by alkaline ground-water. Fen zones are mostly present in isolated pockets around ponds and lakes but can be present as the central most zone. Stewart and Kantrud (1971) break down the vegetation zones further into phases of each vegetation zone and how changes in water salinity impact species composition (Stewart and Kantrud 1971).

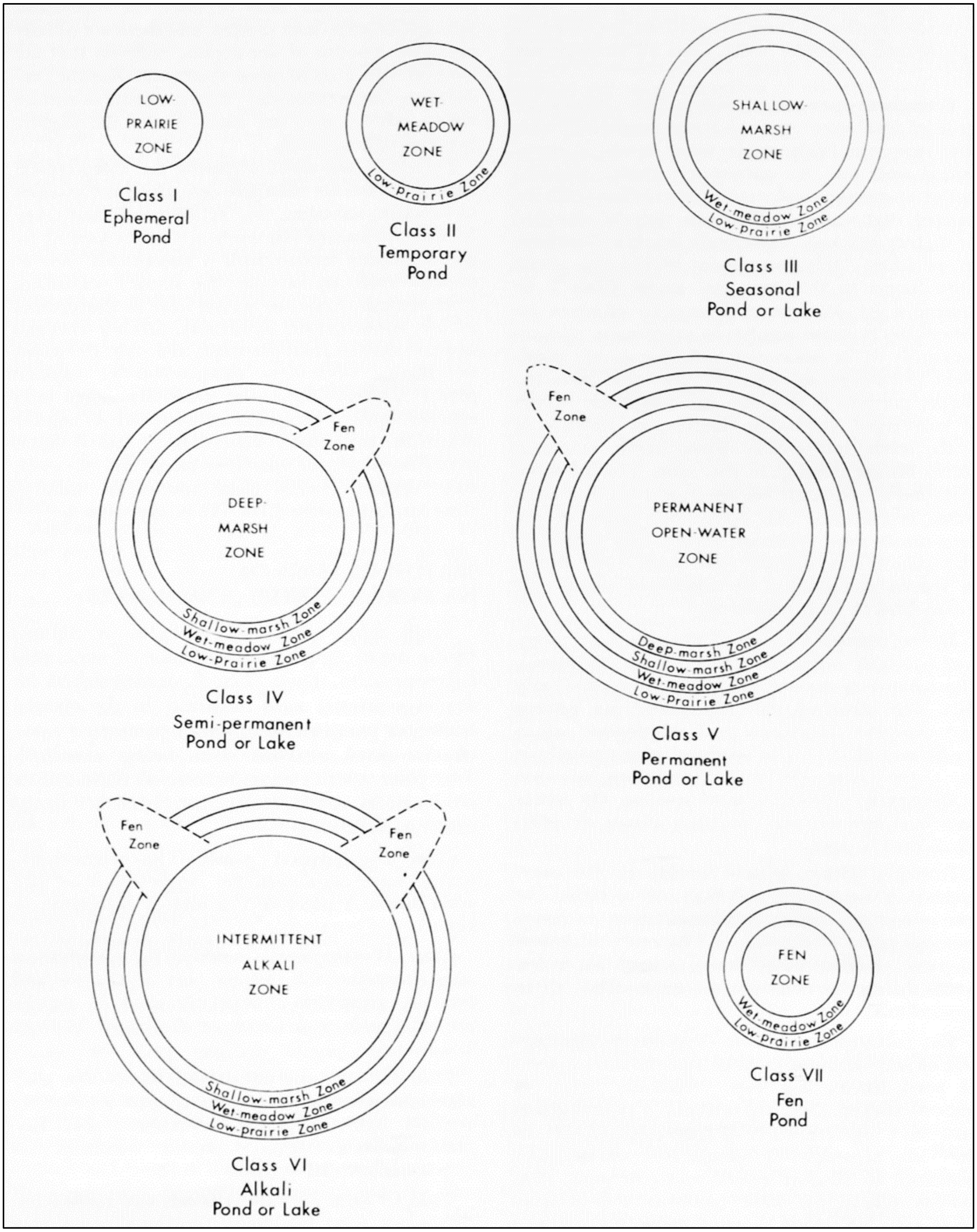

Figure 2.1. Stewart and Kantrud's (1971) wetland types and the correlating vegetation zones illustrated in "Classification of Natural Ponds and Lakes in the Glaciated Prairie Region."

There are multiple vegetation phases that can occur within a wetland and going from one phase to the next is dependent upon water level fluctuations and land use (Stewart and Kantrud 1971). These vegetation phases include normal emergent, open-water, drawdown bare-soil, and natural drawdown emergent. Under undisturbed land use practices the phase cycle a wetland goes through is as follows: emergent, open-water, drawdown bare-soil, and drawdown emergent. The normal emergent phase is the growth of wetland species that extend above the surface of the water or above the bottom soil. The cases where there is no emergent vegetation present above the water surface are known as the open-water phase. This phase can also be characterized by the presence of only submerged vegetation. During dry periods or through seasonal succession the open-water phase turns into a drawdown bare-soil phase once all the water recedes and a mudflat develops. Once the water recedes and mudflats are established, the wetland transfers into a natural drawdown emergent phase. During this phase emergent vegetation germinate and establish upon the mudflats. With more fluctuations in water level and/or season change the cycle will return to normal emergent and open-water phases. Upon disturbance or changes in land use such as cultivation a wetlands regular phase cycle is changed and the plant communities there are significantly different (Stewart and Kantrud 1971). Following cultivation, the wetland goes through the open-water phase and drawdown bare-soil phase. The disturbed wetland now goes through two different phases known as cropland drawdown and cropland tillage. The cropland drawdown phase is characterized by drawdown vegetation that is dominated by annual weeds and grasses. The cropland tillage phase are the tilled bottoms that lack the presence of vegetation or the wetland is dominated by annual field weeds. Each of these phases are characterized by changes in vegetation communities, but Stewart and Kantrud (1971) also noted changes in vegetative communities within each phase due to different levels of salinity within the wetland.

Common water fluctuations within prairie pothole wetlands make it difficult to classify salinity of wetlands based solely on water rather vegetation structures can indicate levels of salinity of a wetland (Stewart and Kantrud 1971). The changes in salinity within a wetland are caused by many factors such as extremely wet years, extreme drought years, position on the landscape, grazing, mowing, and burning. The changes in salinity are classified as fresh, slightly brackish, moderately brackish, brackish, subsaline, and saline. Going from more temporary wetlands into more permanent wetlands results in an increase in salinity or brackishness of the wetland (Stewart and Kantrud 1971). Having the knowledge of which plants occur in which phase, a researcher may determine whether a wetland is fresh water or brackish water.

Compiling the vegetation zones, phases, and salinity Stewart and Kantrud (1971) were able to distinguish between different wetland types. The classification system begins with the major class of the wetland which is either ephemeral ponds, temporary ponds, seasonal ponds and lakes, semi-permanent ponds and lakes, permanent ponds and lakes, alkali ponds and lakes, and fen (alkaline bog) ponds. The distinctions between each wetland type is determined by the presence of vegetation zones and which zone occurs in the central part of the wetland. The wetland type is then broken down by the changes in salinity and ultimately changes in vegetation communities. These subclasses include fresh, slightly brackish, moderately brackish, brackish, and subsaline. Each wetland type was found to have a more prevalent subclass such that temporary ponds were found to be fresh or slightly brackish which was different than permanent wetland types that were not found to be fresh but only different intensities of brackishness. The classification is broken down one last time by the difference in emergent vegetation cover types.

There are four cover types following a gradient of type one being mostly emergent vegetation and very little open water and type four being mostly open water with very little emergent vegetation (Stewart and Kantrud 1971). This classification is an example of the precision that can be developed in a regional wetland classification. The following sections will cover classifications and inventories used in practice today throughout the United States.

Classifications and Inventories in Practice

Cowardin Classification

Cowardin et al. (1979) "The Classification of Deepwater Habitats of the United Sates" has been adopted by the USFWS and many other state and local agencies as the main classification system used for wetland management and research (Schempf 1992, Cowardin and Golet 1995, EPA 2002, Braddock and Hennessey 2018). The USFWS developed this classification as to create uniformity of wetland concepts and terminology throughout the United States (Cowardin and Golet 1995). The Cowardin system's basis for identifying a wetland is determined by three attributes: presence and predominantly hydrophytes, predominantly undrained hydric soils, saturated soil or covered with surface water during the growing season (Cowardin et al. 1979, Schempf 1992, Cowardin and Golet 1995, Mitsch and Gosselink 2015).

The Cowardin System is a hierarchical system that follows the breakdown of systems, subsystems, classes, subclasses, and dominance types which incorporates landscape position, hydrologic regime, and habitat (Figures 2.2, 2.3, 2.4) (Cowardin et al. 1979, Schempf 1992, Cowardin and Golet 1995, EPA 2002, Mitsch and Gosselink 2015, Braddock and Hennessey 2018). The system utilizes hydrological, geomorphological, physical, chemical, and biological indicators to describe a wetland (Cowardin and Golet 1995, Mitsch and Gosselink 2015). The system categories include marine, estuarine, riverine, lacustrine, and palustrine (Cowardin et al.

1979). Each system is broken up into subsystems with the exception of palustrine. These subsystems are based on hydrologic considerations such as water depth and water permanence (Cowardin and Golet 1995). Marine and estuarine are broken down into subtidal and intertidal, lacustrine is broken down into limnetic and littoral, and riverine is broken down into tidal, lower perennial, upper perennial, and intermittent (Cowardin et al. 1979). Further breakdown of the classification system is known as classes and subclasses in which classes are either the vegetative structure present or the substrate present (Cowardin and Golet 1995, Mitsch and Gosselink 2015). Wetlands with 30 percent or more of vegetative cover will use the vegetative classes and wetlands otherwise will use substrate classes (Mitsch and Gosselink 2015). Classes defined for vegetative structure include aquatic bed, emergent wetland, scrub-shrub wetland, forested wetland, and moss-lichen wetland (Cowardin et al. 1979, Cowardin and Golet 1995). The substrate classes include rock bottom, unconsolidated shore, rocky shore, streambed, and reef. Subclasses simply go further in depth to the types of vegetation (persistent emergent, deciduous, evergreens) and types of substrate (bedrock, organic, mud, cobble-gravel) present within the wetland (Cowardin et al. 1979, Cowardin and Golet 1995). Dominance type is the lowest level of the Cowardin System and describes the dominant species present at the wetland.

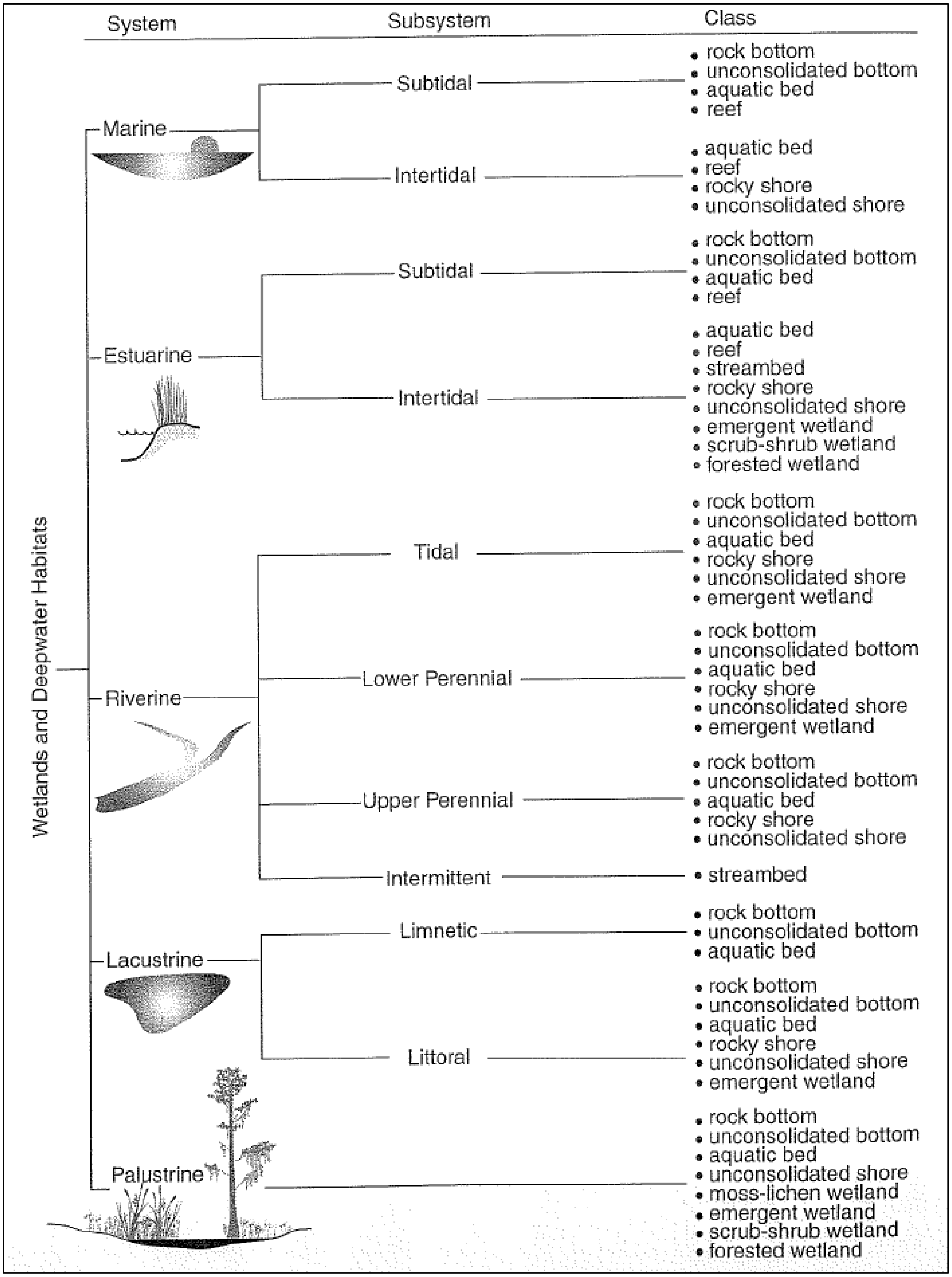

Figure 2.2. The hierarchal breakdown of the Cowardin Classification System with system, subsystem, classes (from Cowardin et al. 1979).

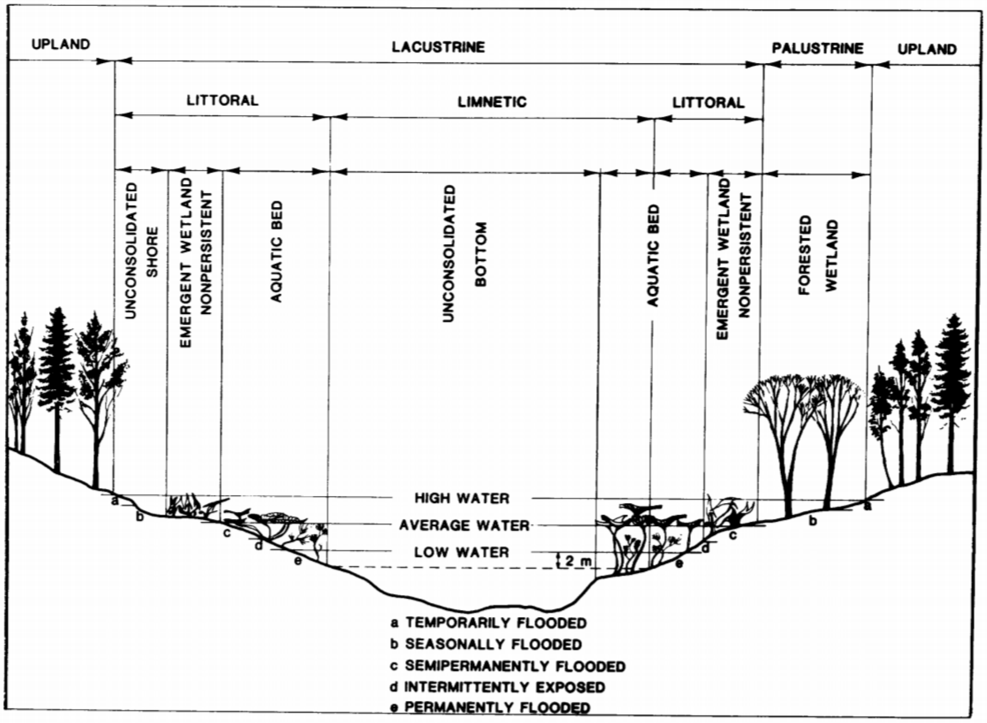

Figure 2.3. Visualization of the Lacustrine system of the Cowardin Classification System with a breakdown in the subsystems and classes (from Cowardin et al. 1979).

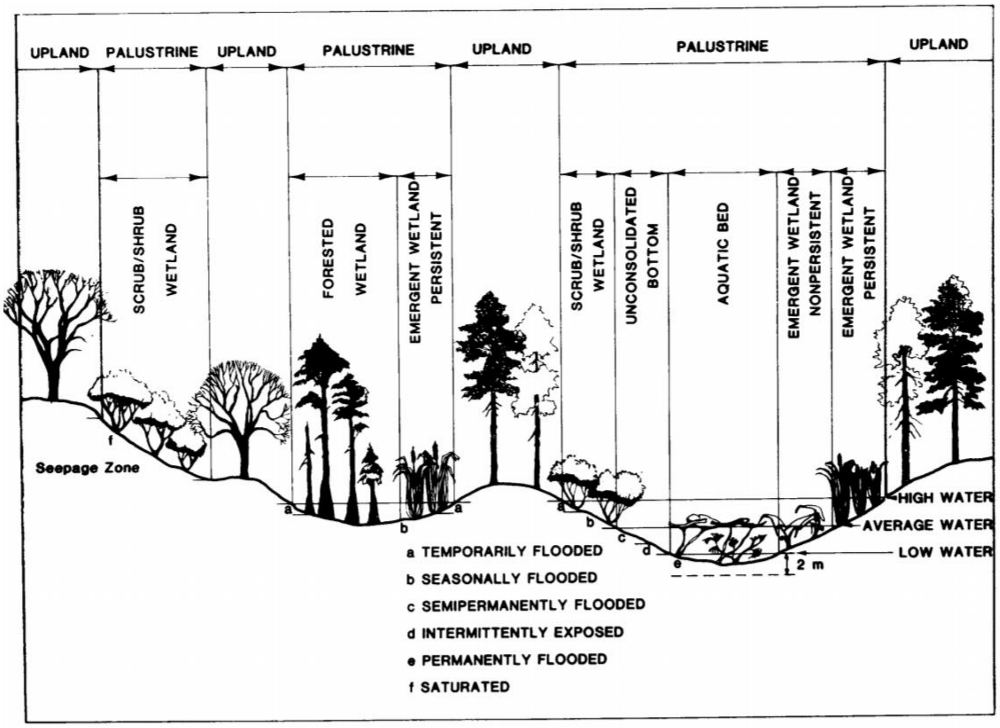

Figure 2.4. Breakdown of the Palustrine systems of the Corwardin Classification System. These wetlands are also represented by landscape location (from Cowardin et al. 1979).

The final component to the Cowardin System and one of the most important components in distinguishing one wetland from another on the landscape are the modifiers (Mitsch and Gosselink 2015). Modifiers describe the water regime, soil, and salinity of the wetland. Water regime indicators describe the frequency and duration of inundation (Cowardin and Golet 1995). For example, nontidal modifiers include permanently flooded, intermittently exposed, semi-permanently flooded, seasonally flooded, temporary flooded, intermittently flooded, and artificially flooded (Cowardin et al. 1979, Cowardin and Golet 1995). Soil modifiers are only for unconsolidated substrate that supports emergent vegetation. These modifiers include mineral soils and organic soils. Finally, there are special modifiers to describe any wetland that has been disturbed. Some of these special indicators include excavated, impounded, diked, farmed, and artificial (Cowardin et al. 1979, Cowardin and Golet 1995).

There are many strengths to the Cowardin System but there are also some limitations. Both of these were described in Cowardin and Golet (1995) and Schempf (1992). In the development of the Cowardin Classification System, Cowardin and Golet (1995) described some of the problems and setbacks encountered. These setbacks included the development of a wetland definition, definition of classification taxa, lack of data to support the classification system, and the limitations (Cowardin and Golet 1995). Shempf (1992) indicated that the classification lacked sufficient detail into the classification categories and lacked sufficient data to support such a project. Schempf (1992) also indicated that the hierarchy lacks details in specific vegetation community overstory, which restricts the distinction of habitat and community structures. Other limitations to the classification system included several indicators of how a specific wetland functions. These include wetland gradients, basin size, water source and transport, the interaction of open water with vegetation, land use, and landscape position and conditions compare to neighboring/regional wetlands (Dethier 1990; 1992, Adamus 1992, Schempf 1992). The strengths of the Cowardin Classification System is that is can be used within multiple levels, it is the basis for the NWI, and the structure allows high levels of accuracy and detail in areas where data is readily available (Schempf 1992).

National Wetland Inventory

The NWI is the product and reason for the creation of the Cowardin Classification System (Cowardin et al. 1979, Cowardin and Golet 1995, Finlayson and van der Valk 1995, Mitsch and Gosselink 2015). The NWI is the inventory of all wetlands and deepwater habitats that occur in the United States. The Cowardin Classification System is integrated into the NWI through mapping units and attributes (Schempf 1992, Mitsch and Gosselink 2015). The NWI project was carried out by the USFWS. Mapping each wetland was done by the interpretation of aerial photography and color-infrared imagery at resolution scales between 1:60,000 and 1:130,000 (Wilen and Pywell 1981, Tiner and Wilen 1983, Mitsch and Gosselink 2015). Interpretations of imagery are then field verified where funding is provided.

Regardless of accuracy rates the NWI provides data needed in driving conservation efforts (Finlayson and van der Valk 1995). The inventory can be used to identify wetland conservation priorities, monitor the status of the United States' wetlands, provide awareness of wetland management issues, and improve the exchange of information while allowing comparisons of wetlands between regions (Finlayson and van der Valk 1995). Today the NWI is publically available through the USFWS website and is known as the "Wetland Mapper" tool (http://fwsprimary.wim.usgs.gov/wetalnds/apps/wetlands-mapper/) (Mitsch and Gosselink 2015). This will aid in local and regional efforts to monitor and map wetland habitats.

Hydrogeomorphic Classification

The Hydrogeomorphic (HGM) Classification Method was created to assess the changes in the functionality of a wetland ecosystem in which restoration, creation, and enhancement projects are proposed or underway (Brinson et al. 1997, NRCS 2008). The classification itself recognizes the inputs and output of water within a wetland drive the functionality and habitat (NRCS 2008). This distinguishes itself from the Cowardin, which primarily was created for wetland inventories and wildlife habitat conservation. The Cowardin System will provide you with what the wetland looks like, while the HGM approach provides you with how that wetland functions (NRCS 2008). Following the development of the HGM approach, there are three components that the method utilizes: geomorphic setting, water source and transport, and hydrodynamics (Table 2.1) (Schempf 1992, Brinson 1993, Smith et al. 1995, EPA 2002, NRCS 2008, Mitsch and Gosselink 2015, Braddock and Hennessey 2018). Geomorphic setting is the topographic location a wetland is on the landscape. The water source and transport include hydrology components such as precipitation, surface and subsurface flow, and ground water flow. The hydrodynamics refers to the direction and strength of the water flow (Schempf 1992, Brinson 1993, Smith et al. 1995, EPA 2002, NRCS 2008, Mitsch and Gosselink 2015, Braddock and Hennessey 2018). These three components are interrelated with each other in which geomorphic setting determines a wetlands hydrodynamics, water source, and water transport (Braddock and Hennessey 2018). Multiple water sources can occur within one wetland (Brinson 1993, Smith et al. 1995, Mitsch and Gosselink 2015, Braddock and Hennessey 2018).

Brinson (1993) and Smith et al. (1995) broke the wetland types into seven categories including riverine, depressional, slope, mineral soil flats, organic soil flats, estuarine fringe, and lacustrine fringe. These wetland types describe the location of the wetland on the landscape

(Brinson 1993, Smith et al. 1995, NRCS 2008). The riverine wetland type occurs within the riparian areas of rivers and streams. The water source for riverine wetlands are from channel overflow and/or subsurface seepage (Brinson 1993, Smith et al. 1995, NRCS 2008). The next wetland types are depressional wetlands, which are defined as topographic lowlands that receive water from precipitation, ground water discharge, and surface/subsurface runoff (Brinson 1993, Smith et al. 1995, NRCS 2008). The primary hydrodynamics include seasonal vertical fluctuations in hydrology usually due to evapotranspiration, ground water recharge, and possible surface outlets. Slope wetlands are characterized by seeps, springs, and fens that develop on landscape slopes and gradients while receiving hydrology from ground water discharge (NRCS 2008, Braddock and Hennessey 2018). Other water sources include precipitation and water runoff from the surrounding upland. Hydrodynamics for slope wetlands are one-way flow down-slope and these wetlands lose water through evapotranspiration and subsurface/surface runoff. Mineral soil flats are distinguished from depressional and slope wetlands by the lack of ground water discharge, only receiving water from precipitation (Brinson 1993, Smith et al. 1995, NRCS 2008). Mineral soil flats are mainly characterized by vertical hydrological fluctuations. These wetlands lose water to evapotranspiration, surface overflow, and seepage to the ground water. The only characteristic that differs between mineral soil flats and the organic soil flat is the accumulation of organic peat material seen in organic soil flats (Brinson 1993, Smith et al. 1995, NRCS 2008). Finally, lacustrine fringe wetland types occur on the fringe of lakes in which the wetlands hydrology is driven by the water table of the lake. Lacustrine fringe wetlands also take in water through precipitation and ground water discharge. The loss of water within this wetland type is driven by the water fluctuations in the adjacent lake (Brinson 1993, Smith et al. 1995, NRCS 2008). Estuarine fringe are wetlands that are greatly influenced by the water level of the ocean. Water sources include the tidal currents, precipitation, and ground water discharge. The water flow in this system is bidirectional meaning during high tides or high-water levels the estuarine wetland fringe receives water while during periods of low tide and drier climate the fringe loses water to the estuarine system (Brinson 1993, Smith et al. 1995, NRCS 2008).

Table 2.1. The three components (geomorphic setting, water source, hydrodynamics) of the Hydrogeomorphic classification of Brinson (1993) are described and examples are given (from Brinson 1993 and Mitsch and Gosselink 2015).

CORE COMPONENTS	***DESCRIPTION***	***EXAMPLE***
Geomorphic Setting	Topographic location of a wetland in the surrounding landscape	
Depressional	Wetlands in depressions that typically receive most moisture from precipitation; found in dry and moist climates	Kettles, potholes, vernal pools, Carolina bays, groundwater slope wetlands
Extensive peatlands	Peat substrate isolates wetland from mineral substrate; peat dominates movement and storage of water and chemicals	Blanket bogs, tussock tundra
Riverine	Linear stripes in landscape; subject predominantly to unidirectional surface flow	Estuarine tidal wetlands, lacustrine fringes subject to winds, waves, and seiches
Water Source	Relative importance of three main sources of water to a wetland	
Precipitation	Wetlands dominated by precipitation as the primary water source; water levels may be variable because of evapotranspiration	Ombrotrophic bogs, pocosins
Groundwater discharge	Primary water source from regional or perched mineral groundwater sources	Fens, groundwater slope wetlands
Surface inflow	Water source dominated by surface inflow	Alluvial swamps, tidal wetlands, montane streamside wetlands
Hydrodynamics	Motion of water and its capacity to do work	
Vertical fluctuation	Vertical fluctuation of the water table resulting from evapotranspiration and replacement by precipitation or groundwater discharge	Usually depressional wetlands, bogs (annual), prairie potholes (multilayer)
Unidirectional flow	Unidirectional surface or near-surface flow; velocity corresponds to gradient	Usually riverine wetlands
Bidirectional flow	Occurrence in wetlands dominated by tidal and wind-generated water-level fluctuations	Usually riverine wetlands

In further dissection of the HGM approach, subclasses can provide information about the hydrologic inputs and outputs, water source, and hydrodynamics (Brinson 1993, Smith et al. 1995, NRCS 2008). This can be seen in the previous sections descriptions of each wetland type. Other descriptive subclasses that are useful include if a wetland is a flow-through, recharge, or discharge wetland. Ponded, flooded, saturated, and open water would describe the hydrological interactions within a wetland. Wetlands under the HGM approach can include one phase of subclasses such as depression, or it can include more detailed description with multiple phases such as depression, flow-through, and ground water influenced (NRCS 2008). Brinson (1993) recognized that wetlands are not just dependent on geomorphic settings and hydrology for functionality, it was recommended that biotic components be included as modifiers into the classification system. The NRCS (2008) recommends that the modifiers in Cowardin Classification (1979) would provide the HGM approach with further descriptions of wetlands.

Braddock (2018) and Mitsch and Gosselink (2015) discussed the potential strengths to wetland knowledge when integrating the Cowardin Classification System with the HGM approach. Some of these strengths include, “the ability to analyze potential impacts, assess cumulative impacts, assess the alternatives analysis, develop avoidance and minimization measures, and evaluate proposed mitigation measures of wetland projects” (Braddock and Hennessey 2018). This integration would significantly improve the conservation of wetlands through proper understanding of landscape positioning and how each wetland functions by itself and within the ecosystem.

Wetland Continuum

The Cowardin Classification in conjunction with the NWI was used to monitor changes in wetland area and to determine the status of individual wetland types (Cowardin et al. 1979, Euliss et al. 2004). The HGM approach integrated geomorphic setting, water source, and hydrodynamics to classify wetland functions and location on the landscape (Brinson 1993, Smith et al. 1995, Euliss et al. 2004). These classifications failed to integrate climatic variations and the temporal variations in geomorphic settings both of which significantly impact the biological structures of a wetland (Euliss et al. 2004). The wetland continuum concept was created on the basis that wetland processes are determined by both spatial and temporal continuums. Climatic variations can significantly change the structure and process of wetlands through trickle down effects. For example, changes in precipitation would alter both timing and amount of water inputs into a wetland, which impacts water depth, water solute concentrations, temperature of water, and drawdown phases. These abiotic changes ultimately determine the plant, vertebrate, and invertebrate communities present at that time in the wetland. The wetland continuum concept examined how a wetlands biological community are driven by hydrologic inputs and climatic changes. Placing wetlands along this continuum would result in dynamic classification of wetlands where changes in climate and hydrologic inputs could result in a change of a wetlands classification. The dynamic feature of this concept differs from traditional classifications that are static in which a wetland is classified by one moment in time. The intent of the wetland continuum is not to replace past wetland classifications, but rather act as a complimentary piece to these classifications as to increase the accuracy and detail of wetland classifications (Euliss et al. 2004).

The wetland continuum places wetlands on axes that are represented by ground water and atmospheric water. The x-axis represents the ground water interaction where the wetland is placed on a continuum between a recharge wetland and discharge wetland (Euliss et al. 2004). A recharge wetland is known as a wetland that loses water to the ground water while a discharge wetland receives water from ground water reserves. Wetlands that fall between a discharge and recharge wetland are known as flow-through wetlands having both incoming and outgoing water. The y-axis represents the atmospheric variations which is driven by temperature and precipitation. One end of the continuum is represented by extreme drought conditions and the other end represents extreme wet conditions. The biological expression of a wetland can be determined when interpreting both axis simultaneously (Figure 2.5). Determination of the biological community can be determined at any given time. Euliss et al. (2004) stated that short and long climatic variations could temporarily change the abiotic environment driving changes in biological communities (Euliss et al. 2004).

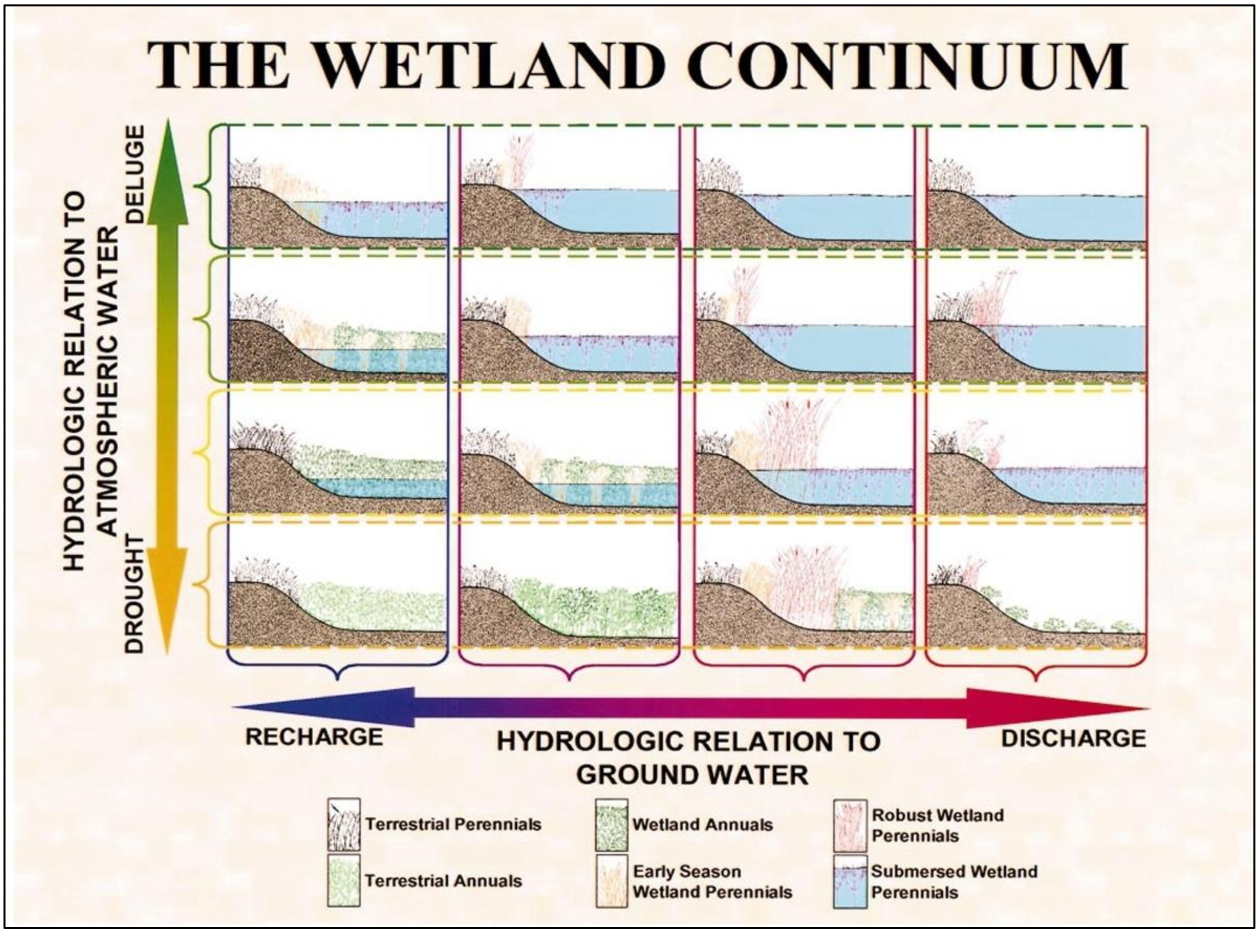

Figure 2.5. The Wetland Continuum's (Euliss et al. 2004) different wetland types are shown based on the atmospheric water (y-axis) and ground water (x-axis). Atmospheric water is represented on a drought/deluge continuum, while the ground water is represented on a recharge/discharge continuum (from Euliss et al. 2004).

Vegetation composition of a recharge wetland during wet conditions will be characterized by early season wetland perennials, submergent and semi-open water vegetation. Discharge wetlands will have submergents and open water vegetation during wet conditions (Euliss et al. 2004). During dry conditions the recharge wetland will have terrestrial annuals and terrestrial perennials, while the discharge wetland will have wetland annuals, robust wetland perennials, and sparse terrestrial perennials. The invertebrate and amphibian structures during wet conditions include passive dispersers, active dispersers, and amphibians with short larval stages within the recharge wetland. The discharge wetland includes planktonic algal cell feeders, overwintering adult active dispersers, and long larval stage amphibians. During dry years the recharge wetland consists of terrestrial invertebrates while the discharge wetland consists of passive dispersers capable of surviving high salt concentrations within the water column. Bird communities utilizing the wetland can change based on this continuum as well. During wet conditions, the recharge wetland consists of dabbling ducks and diving ducks while the discharge wetland consists of foraging and nesting grebes as well as filter feeding ducks. This changes during drought year in which the recharge wetland consists of grassland birds and the discharge wetland is utilized by foraging and breeding shorebirds. Utilizing the wetland continuum will provide wetland scientists and managers a framework that will aid in conceptualizing, describing, and understanding biological community changes within a given wetland (Euliss et al. 2004).

Conclusion

The most widely used wetland classification is the Cowardin System, which was adopted by the USFWS as the official national wetland classification (Schempf 1992, Cowardin and Golet 1995, EPA 2002, Braddock and Hennessey 2018). The Cowardin System was adopted for the sole purpose of providing the protocols for collection of field data that would make up the NWI (Cowardin and Golet 1995, Finlayson and van der Valk 1995). Other wetland classifications such as the HGM approach and Wetland Continuum provide important wetland characteristics that can significantly improve the categorization of wetland ecosystems. The utilization of these wetland classifications by federal, state, and local agencies provides the basis for wetland management. Integrating components from multiple classifications improves the accuracy and knowledge about a single wetland as well as regions of wetlands (NRCS 2008, Mitsch and Gosselink 2015, Braddock and Hennessey 2018). Compiling aspects from different wetland classifications can significantly improve wetland projects such as restoration, creation, and enhancement while driving potential wetland policy by providing chemical, physical, and biological components within each wetland (Mitsch and Gosselink 2015, Braddock and Hennessey 2018). Updating and improving classifications and inventories should be a significant priority as it drives wetland research, wetland management, and wetland policy.

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CHAPTER 3. ASSESSING SEMI-AUTOMATED WETLAND MAPPING TECHNIQUES AND THE DEVELOPMENT OF THE WETLAND LOCATOR MODEL

Abstract

The National Wetland Inventory (NWI) is a nationwide database managed by the United States Fish and Wildlife Service (FWS) aimed at mapping and classifying the nation's wetland and deepwater habitats. The mapping process historically included the use of printed aerial photographs and highly trained image analysts to assess and map wetlands. Since then, accurately identifying and mapping wetlands has become very important in the conservation of these habitats. The evolution of geographic information systems (GIS) has given scientist's cost-effective and accurate software to manage, manipulate, and analyze such data. Through spatial analysis tools, digital elevation models (DEMs), and aerial imagery, wetlands can be identified and mapped through the ArcGIS software. This study analyzes the accuracy of previous wetland mapping methods and develops a new model (Wetland Locator model) which applies weights to these previous methods to improve mapping accuracy and precision. The use of tools within the spatial analyst toolbox such as the hydrology, surface, and classification tools provide ways of developing potential wetland areas on the landscape. The analysis and methods used in this study would lead to more accurate mapping of wetlands and aid in identifying important wetlands overlooked by previous mapping techniques. A weight of equal to or greater than seven showed levels of accuracy reaching 94.4%, a precision rate of 97.5%, and a miss rate of 33.8%. These results suggest that the Wetland Locator Model can be a cost-effective and timely method for determining wetland boundaries while furthering wetland conservation efforts.

Introduction

The Clean Water Act (CWA) of 1972 brought awareness to protection of the United States water resources. More recent policies such as the introduction of Waters of the United States (WOTUS) turned the aim towards protection of wetland resources, specifically those waters that are connected to or impact the physical, chemical, and biological integrity of the nation’s waterbodies (33 U.S.C. 1344, 40 CFR 230.3., 531 U.S. 159, 547 U.S. 715, 80 FR 37054-37127). As wetland policy and regulations evolve the need for updated and accurate wetland inventories becomes significantly important. An updated and accurate inventory has implications for the policy and regulation of wetlands, as well as for wetland restoration, creation, and enhancement projects (Finlayson and van der Valk 1995). The NWI was completed throughout the 1980’s and successfully mapped much of the nation’s wetlands (Wilen and Pywell 1981, Tiner and Wilen 1983, Kloiber et al. 2015, Mitsch and Gosselink 2015, Macleod et al. 2016). This provided the necessary data needed to monitor wetland status and trends, yet the process of identifying wetlands and delineating wetland boundaries was time consuming, labor intensive, and costly (Kloiber et al. 2015). Over the last few decades, USFWS funding for the NWI have greatly reduced and almost entirely eliminated by 2014 (Tiner 2009, NSGIC 2014, Kloiber et al. 2015). The development of GIS and public available data provided the opportunity to improve the process of updating the NWI. This lead to the development of semi-automated wetland mapping methods that utilized image classification tools, hydrology tools, and surface analysis tools. These methods provide a cost effective and timely alternative to wetland delineations and imagery interpretation especially with limited funding.

Previous research has utilized aerial imagery such as Landsat imagery or high-resolution imagery in classification methods and to calculate normalized difference indices (Weier and

Herring 2000, Li and Chen 2005, Pal 2005, Baker et al. 2006, Wolf 2010, Corcoran et al. 2013, McFeeters 2013, Parvianinen et al. 2013, Li and Shoa 2014, Tian et al. 2016). Li and Chen (2005) used Landsat 7 ETM+ to calculate the normalized difference vegetation index (NDVI) and the normalized difference water index (NDWI) as a method for mapping wetlands. The NDWI index is sufficient in identifying waterbodies utilizing either high resolution imagery or Landsat imagery (Gao 1996, McFeeters 2013). High resolution imagery such as the National Agriculture Imagery Program (NAIP) is sufficient in identifying different land uses and producing land cover maps (Li and Shao 2014). Random forest classification methods have be sufficient in identifying land cover as well as wetlands (Pal 2005, Baker et al. 2006, Corcoran et al. 2013, Tian et al. 2016). Tian et al. (2016) classified wetlands through the use of NDVI, NDWI, and rule-based random forest classification. Landsat imagery was classified using random forest classification methods to map land cover over a landscape as well as classify wetlands and riparian areas (Pal 2005, Baker et al. 2006, Corcoran et al. 2013).

Digital elevation models (DEM) have been utilized within hydrologic and surface tools to derive landscape depressions and wetland areas (Haugerud et al. 2003, Li and Chen 2005, Sorensen and Seibert 2007, Wu et al. 2008, Vaze et al. 2010, Hladik and Alber 2012, Kloiber et al. 2015, Macleod et al. 2016, Wu and Lane 2017, McDeid et al. 2018). Li and Chen (2005) developed a rule-based method that utilized DEMs to derive slope gradient which aided in the identification of wetlands. Wetness indices such as the compound topographic index derived from DEMs have shown to identify areas of water accumulation on the landscape (Sorensen and Seibert 2007, Vaze et al. 2010). Wu and Lane (2017) developed a toolbox that identified wetland depressions and catchment boundaries through the use of high definition DEMs. DEMs were used to identify and map drained upland depressions within the Des Moines Lobe of Iowa

(McDeid et al. 2018). First return and bare earth point clouds are derived from LiDAR data can identify land cover and wetlands (Haugerud et al. 2003, Hladik and Alber 2012). Hladik and Alber (2012) utilized LiDAR sensors and returns such as bare earth and first returns to test the accuracy of mapping salt marsh habitat.

This study improves wetland mapping techniques by analyzing the accuracies of previous tools and comparing those accuracies to field verified wetland boundaries. Accuracies were calculated through the use of confusion matrices. Based on the analysis, an improved model of mapping wetland boundaries are developed hereby called the Wetland Locator model. The individual tool processes as well as the processes within the Wetland Locator model are described in great detail.

Site Description

Location

Camp Grafton South (CGS) is located in the southeastern part of Eddy County, North Dakota (Figure 3.1; 3.2). The nearest city is Devil's Lake, N.D. and estimated 64 kilometers (40 miles) north of the Camp and the nearest neighboring town is McHenry, N.D. an estimated 18 kilometers (11 miles) south of CGS. Eddy County is located within the central part of eastern North Dakota. Purchased by the North Dakota Army National Guard in 1990, CGS consists of approximately 3,650 hectares (9060 acres) of land. Mainly used as a training site, Camp Grafton South consists of extensive native grassland and a vast complex of prairie wetlands.

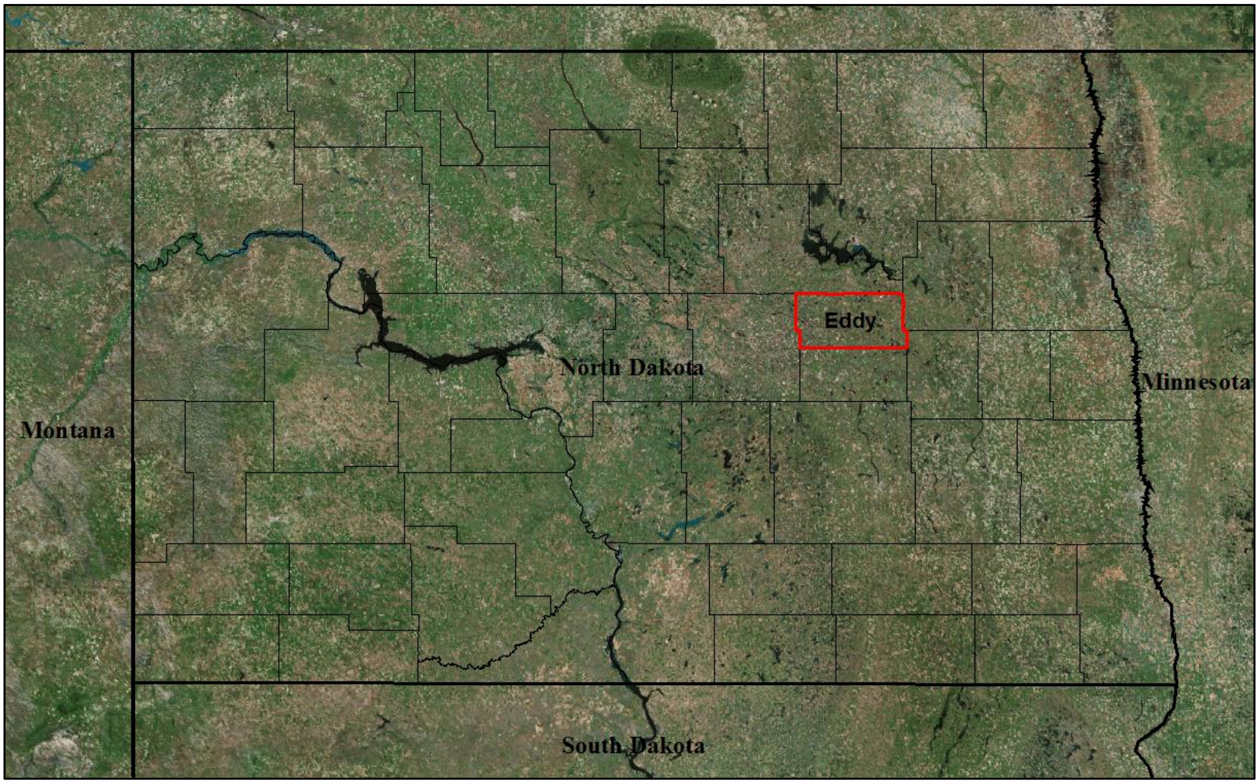


Figure 3.1. Location of Eddy County, North Dakota.

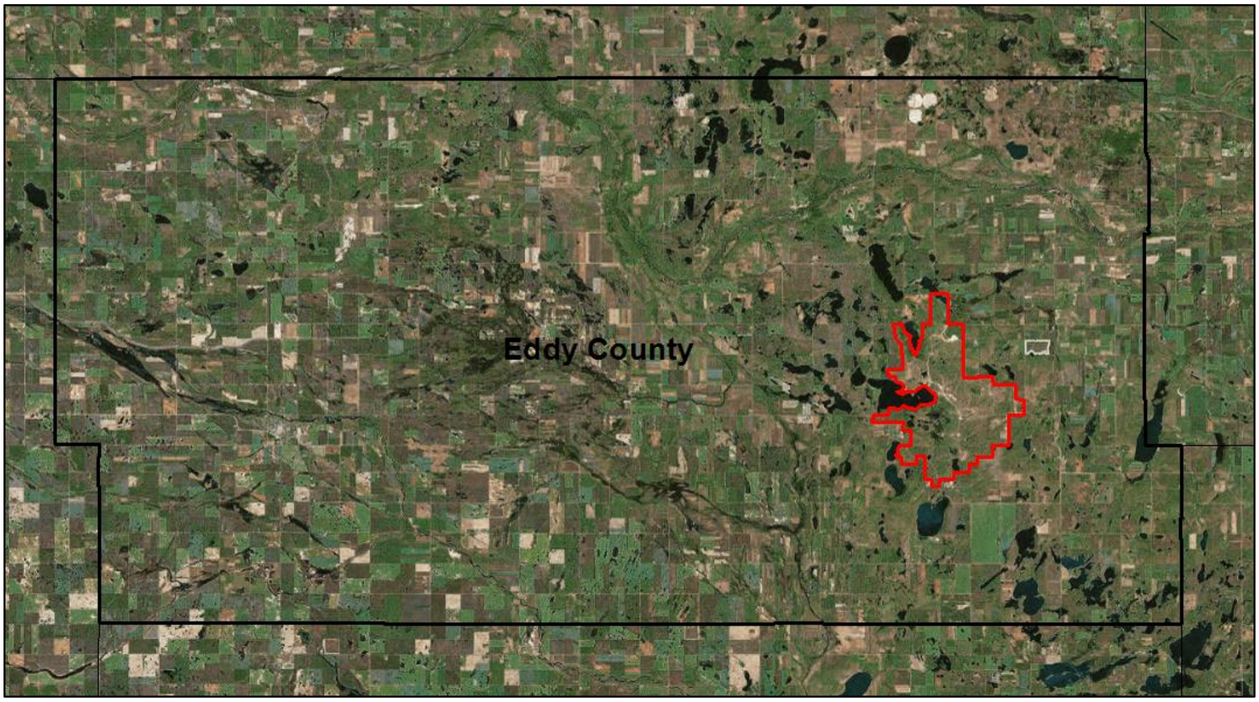


Figure 3.2. Location of Camp Grafton South within Eddy County, North Dakota.

Climate

North Dakota is characterized by a north to south temperature gradient and an east to west precipitation gradient making extreme and variable climates (Johnson et al. 2004; 2005, Renton et al. 2015). Temperature is cooler in the northern portion and warmer in the southern portion of North Dakota. The difference in north to south temperatures are between 1-10 degrees Celsius (Millett 2009, Renton et al. 2015). Temperatures are also extremely variable between seasons with the winters below -40 degrees Celsius and summers above 40 degrees Celsius (Renton et al. 2015) (Figure 3.3; 3.4). Precipitation in North Dakota is least in the western portion of the state and greatest within the eastern portion of the state (Johnson et al. 2004; 2005, Renton et al. 2015). Annual precipitation in North Dakota is different from west to east in which the western part of the state receives an average of 300 millimeters (12 inches) per year compared to the eastern part receiving an average of 900 millimeters (36 inches) per year (Renton et al. 2015) (Figure 3.5). The interrelationship between temperature and precipitation result in periods of droughts and periods of deluge (Johnson et al. 2004; 2005, Renton et al. 2015). The periodic drought and deluge are key in maintaining productivity and biodiversity of prairie wetlands (Johnson et al. 2005). Periods of deluge replace emergent vegetation with submersed vegetation, while periods of drought reduce submerged and emergent vegetation allowing for wet meadow and annual grasses to move in (Euliss et al. 2004). The variability of climate produce very complex wetland landscapes in which vegetation and water presence are increasingly variable from one wetland to the next.

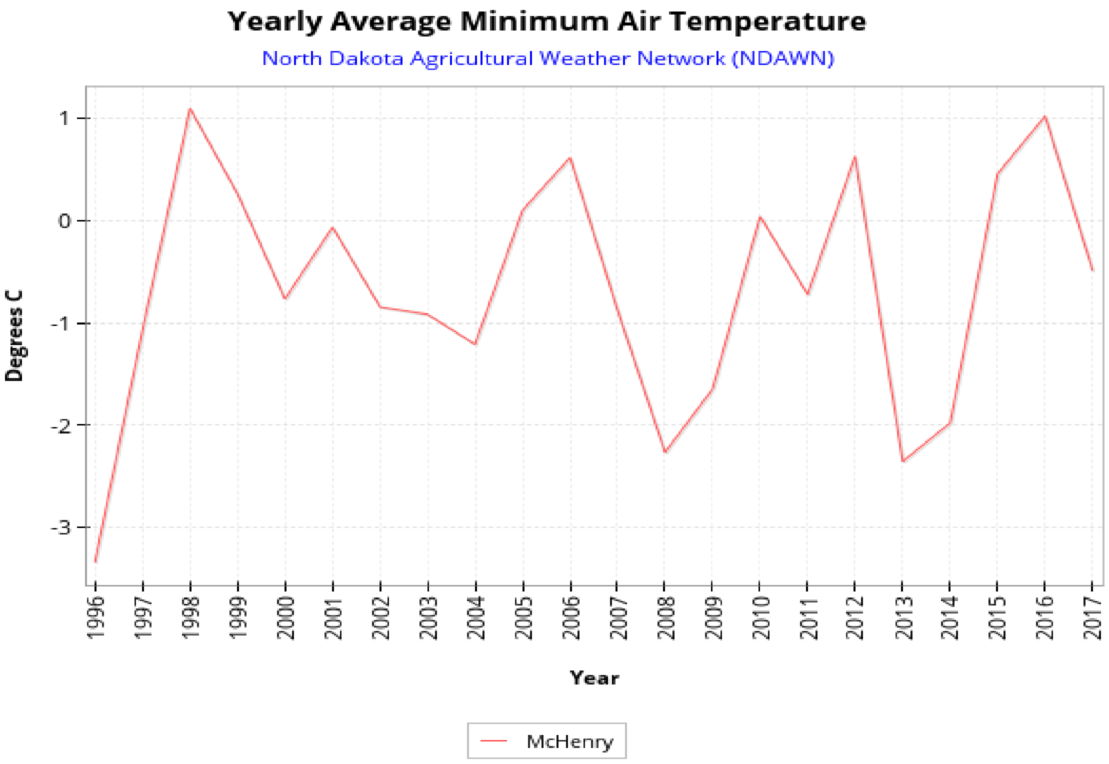


Figure 3.3. The yearly average minimum temperature of McHenry, ND near Camp Grafton South. Data from the North Dakota Agricultural Weather Network.

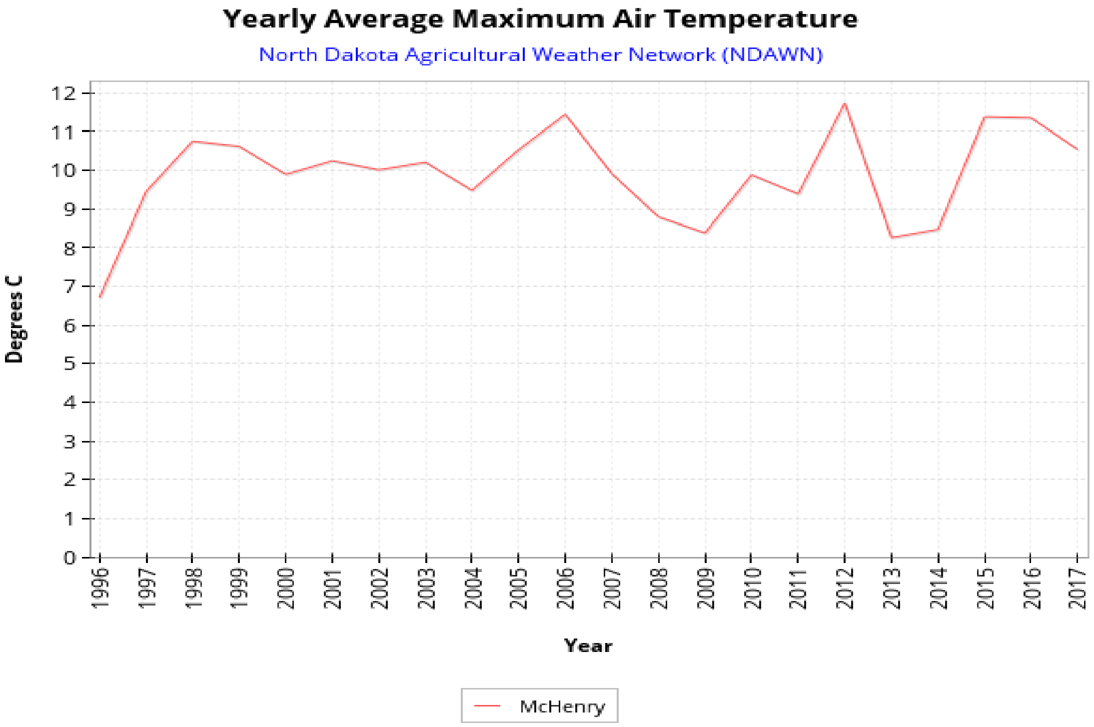


Figure 3.4. The yearly average maximum temperature of McHenry, ND near Camp Grafton South. Data from the North Dakota Agricultural Weather Network.

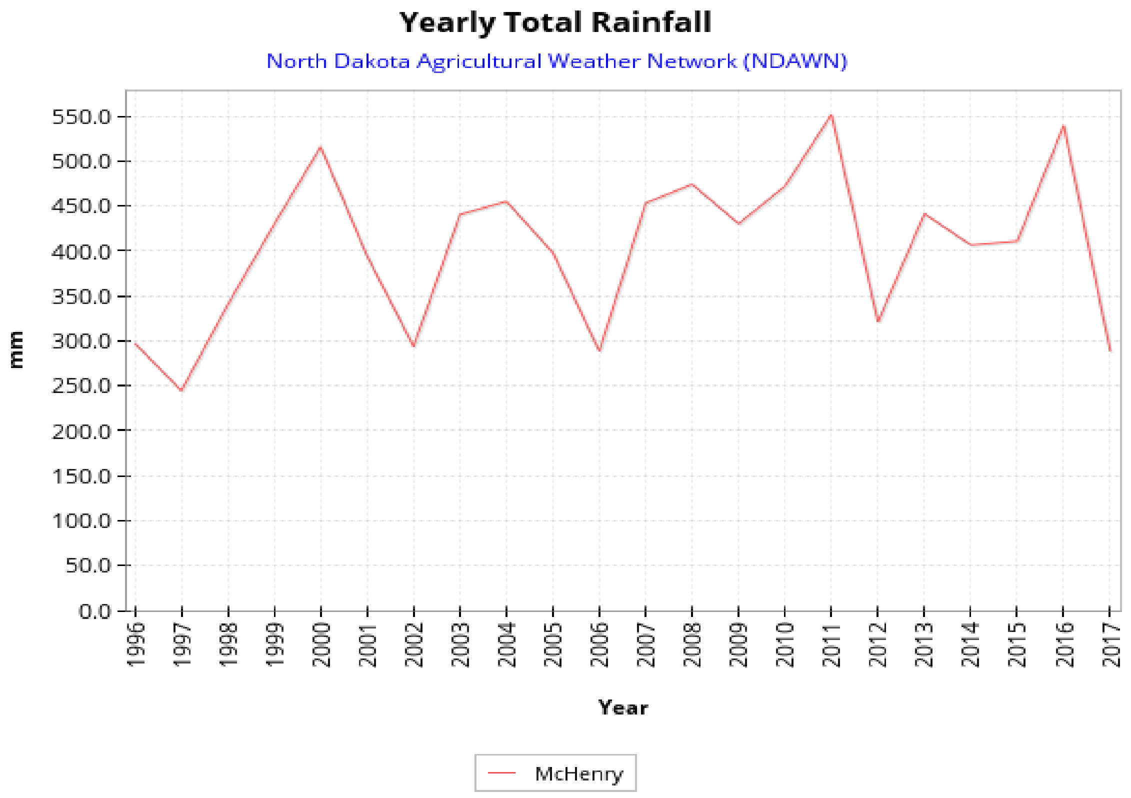


Figure 3.5. The yearly precipitation of McHenry, ND near Camp Grafton South. Data from the North Dakota Agricultural Weather Network.

Wetlands

The receding of the Laurentide ice sheet during the late Pleistocene left a landscape of small depressions known as the Prairie Pothole Region (PPR) (Johnson et al. 2004; 2005, Renton et al. 2015). The PPR extends from Canada down into Montana, North Dakota, South Dakota, Minnesota, and Iowa. Camp Grafton South has a complex wetland landscape with many temporary, seasonal, and semi-permanent wetlands totaling more than 150 wetlands. There are two permanent lakes at CGS, Lake Coe and South Washington Lake. There are multiple spring fed wetlands connected hydrologically to each lake and fen wetlands found on the northeastern portion of the Camp and the east side of Lake Coe.

The USFWS's "Status and Trends of Prairie Wetlands in the United States" determined that within the PPR wetland hydrology is changing. The larger semi-permanent and permanent wetlands are getting wetter resulting in increases in area while the smaller temporary and seasonal wetlands are reducing in wetness and subsequently in area (Dahl 2014). These changes are driven by temperature and precipitation although not entirely the reasons for the loss of smaller wetlands. Analyzing changes in wetland areas from the 1981 NWI map of Camp Grafton compared with the wetland delineations conducted from 2017 and 2018, these changes indicated that some of these smaller type wetlands received overflow from neighboring wetlands and ultimately merging with neighboring wetlands as a result of increasing hydrologic depths. Similar to what was stated in the "Status and Trends" publication (Dahl 2014) many of the temporary wetlands at the Camp are reduced hydroperiods due to recent dry years and high temperatures increasing evapotranspiration rates.

Lying within the PPR, CGS is distinct in that each wetland type described in Stewart and Kantrud (1971) "Classification of Natural Ponds and Lakes in the Glaciated Prairie Region" is represented. There are multiple ephemeral ponds that were mapped on the original NWI as temporary wetlands, yet lacked the indicators (i.e. hydrology, hydric soils, and hydric vegetation) of a wetland. Ephemeral ponds at the camp were represented by upland species like Kentucky Bluegrass (*Poa pratensis*), Quackgrass (*Elymus repens*), Canadian Anemone (*Anemone canadensis*), Western Snowberry (*Symphoricarpos occidentalis*), and Fescue Sedge (*Carex brevior*). Temporary ponds were commonly found to have scattered hydrophyte vegetation and lacking surface water. Hydrophyte vegetation present at the camp included Fowl Bluegrass (*Poa palustris*), Woolly Sedge (*Carex lanuginosa*), Foxtail Barley (*Hordeum jubatum*), Smooth-cone Sedge (*Carex laeviconica*), Common Mint (*Mentha arvensis*), Mexican Dock (*Rumex mexicanus*), Baltic Rush (*Juncus arcticus*), Inland Rush (*Juncus interior*), and Dudley's Rush (*Juncus dudleyi*). Seasonal ponds at CGS were characterized by the dominance of hydrophyte vegetation and scattered surface water presence. The hydrophytes of seasonal ponds included Reed Canarygrass (*Phalaris arundinacea*), Shortawn Foxtail (*Alopecurus aequalis*), Western Sloughgrass (*Beckmannia syzigachne*), American Mannagrass (*Glyceria grandis*), and Spikerush (*Eleocharis palustris*). CGSs semi-permanent ponds are characterized by the dominance of surface water surrounded by deep marsh and wet meadow hydrophytes. The vegetation present include Common Cattail (*Typha latifolia*), Hydrid Cattail (*Typha x glauca*), Spikerush (*Eleocharis palustris*), Hardstem Bulrush (*Schoenoplectus acutus*), Prairie Cordgrass (*Spartina pectinata*), American Mannagrass, and Sago Pondweed (*Stuckenia pectinata*). Based on Stewart and Kantrud (1971) system, South Washington Lake is classified as being the only permanent lake present at CGS. Hydrophyte vegetation present at South Washington Lake including the surrounding vegetative zones include Hardstem Bulrush, American Mannagrass, Pale Bulrush (*Scirpus pallidus*), Hybrid Cattail, Common Cattail, Slough Sedge (*Carex antherodes*), and Baltic Rush. Lake Coe represents an alkali lake type although recent deluge conditions have likely reduced the alkalinity. The vegetation at Lake Coe include Common Cattail, Hybrid Cattail, and Reed Canarygrass. The final wetland type classified in Stewart and Kantrud (1971) is the fen pond and CGS has two fens that border permanent lakes/ponds and a unique fen pond with floating mats vegetation and extensive hummocks located at the northeastern corner of the Camp and the east side of Lake Coe. The vegetation found in this wetland type included Water Sedge (*Carex aquatilis*), Emory’s Sedge (*Carex emoryi*), Spikerush (*Eleocharis palustris*), Silverweed (*Potentilla anserina*), Hybrid Cattail, Northern Reedgrass (*Calamagrostis stricta*), and Baltic Rush.

The two categories mainly utilized to classify CGS’s wetlands based on the Cowardin Classification System (Cowardin et al. 1979) would be lacustrine and palustrine. An exception to that is the presence of multiple intermittent streams which were seasonally flooded which would be classified under riverine. Lake Coe and South Washington Lake are the two waterbodies that would fall under the lacustrine category and further classification would include limnetic or littoral based on water depth, aquatic bed, and semi-permanently/permanently flooded. Each of the other wetlands at CGS are classified under the palustrine category. These wetlands are mainly persistent emergent hydrophyte vegetation and submergent vegetation based upon the water regime. The water regime present at the camp include temporarily flooded, seasonally flooded, and semi-permanently flooded wetlands. Temporarily and seasonally flooded wetlands are dominated by persistent emergent vegetation and often lack submergent vegetation simply from lack of open water. Semi-permanently flooded wetlands are characterized by the presence of both persistent emergent vegetation and submergent vegetation. Multiple wetlands at CGS have been altered to maintain open water for cattle and these wetlands were given a special modifier and classified as an excavated wetland.

Methods

Obtained Public Data

The purpose of the Wetland Locator model was to develop an efficient and accurate process for mapping wetlands boundaries utilizing data available to the public. The original NWI map was provided by the North Dakota National Guard, which was obtained from the USFWS "Wetland Mapper Tool" (https://www.fws.gov/wetlands/data/mapper.html) (Appendix A). The Wetland Mapper data includes polygons that represent wetlands and deepwater habitats. Other data included within the attribute table include the Cowardin Classification Code (PEM1C, PABF, etc.) (Cowardin et al. 1979), wetland type (freshwater pond, freshwater emergent wetland), and the area of each wetland polygon. The original NWI map was completed in 1981 and the mapping process included the use of aerial photography and infrared imagery in which interpreters determined the boundary of each wetland (Wilen and Pywell 1981, Tiner and Wilen 1983, Kloiber et al. 2015, Mitsch and Gosselink 2015, Macleod et al. 2016). The 1981 NWI map was the data used to compare accuracies of other methods of semi-automated wetland mapping.

Soils maps can be used to determine the soil series, soil type, and drainage regime present with a given location. This research utilized the SSRUGO data and was downloaded through the Esri's SSURGO Downloader tool at a sub-basin level (https://www.arcgis.com/apps/OnePane/basicviewer/index.html?appid=a23eb436f6ec4ad6982000dbaddea5ea). The attributes table includes all the information provided within a normal soils series description including information that would indicate the potential location of wetlands. The information found useful for this research included drainage regime and the indication of hydric soils.

The public data used most frequently due to the vast use within hydrological tools in ArcMap was the digital elevation model (DEM) (Appendix A). A DEM is a representation of a landscapes elevation. The data used in ArcMap is in raster format. Raster format is simply a grid of cells that represents data or information and in the case of a DEM each cell represents elevation. Some of the tools that derive information from DEM's include the slope of the landscape, flow direction and accumulation, and potential depressions along the landscape. The DEM was derived from LiDAR and downloaded from the North Dakota's Geographic Information Systems Hub (https://gishubdata.nd.gov/) which is a state wide public data portal.

Aerial imagery was used throughout the process of creating the original National Wetlands Inventory map. Semi-automated methods using aerial imagery have been developed to map land use as well as wetland habitats. Classification methods such as the random forest/trees classifier tool in ArcMap have shown to be sufficient in identifying waterbodies based on aerial imagery (Pal 2005, Baker et al. 2006, Corcoran et al. 2013, Tian et al. 2016). Previous uses of the random forest method tested the classifier on Landsat imagery (Baker et al. 2006, Corcoran et al. 2013, Tian et al. 2016). The most commonly used Landsat imagery include Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 imagery. Launched in 1999, the Landsat 7 ETM+ satellite produces imagery at resolutions between 15 and 30 meters. The satellite is equipped with 8 different spectral wave bands, the first 7 bands have a resolution of 30 meters while the panchromatic band number 8 has a resolution of 15 meters. The Landsat 8 satellite was launched in 2013 and included 10 spectral bands compared to the 8 of Landsat 7 ETM+. Although there are more bands the resolution of Landsat 8 is the exact same as Landsat 7 ETM+ with each band having a resolution of 30 meters with the exception of the panchromatic band, which has a resolution of 15 meters. For this wetland model, Landsat 7 ETM+ imagery for the year 2016 was downloaded using the United States Geological Survey's "Earth Explorer" which includes satellite imagery, aerial imagery, and cartographic products that are publically available (https://earthexplorer.usgs.gov/). Downloading the most recent wet year for CGS would aid in maximizing wetland area identification.

Previous research has shown that normalized difference indices such as the NDVI and the NDWI can be used to identify potential wetland areas (Gao 1996, Weier and Herring 2000, Li and Chen 2005, Wolf 2010, McFeeters 2013, Parvianinen et al. 2013, Li and Shao 2014). These tools provide semi-auto methods of differentiating between vegetation structures as well as wetness on a landscape. The aerial imagery used in this model was NAIP imagery from 2016 which provides aerial imagery at resolutions of 1 meter. Downloading NAIP imagery from the most recent wet year of 2016 will maximized the differences between wet vegetation and dry vegetation. The 4 band RGB aerial imagery was downloaded through the USGS "Earth Explorer" tool (https://earthexplorer.usgs.gov/) and was used to calculate the NDVI and the NDWI of Camp Grafton.

ESRI ArcMap

A geographic information system is a system that displays, analyzes, manipulates, and stores spatial and geographic data. Spatial data is represented by layers in either a raster format or by vector format. Raster format is the representation of data on a grid of cells, while a vector format presents data as polygon, lines, and points. Layers of spatial data can be manipulated through tools and equations with the final product presented visually by maps. One of the most common geographic information system's software comes from the company Esri (ESRI). Esri software products include ArcGIS and ArcMap (ESRI). All tools used in the development of this wetland model were done through Esri ArcMap 10.5 (ESRI, ArcGIS Desktop 2016). The Spatial Analyst tool in ArcMap includes hydrological, surface, topography, and classification tools that are sufficient in identifying potential wetland areas. The Hydrological tools include depressions, flow direction, and flow accumulation. The surface toolbox is utilized to determine the slope of the landscape. The topography toolbox was downloaded as a toolbox extension through the ArcGIS website (https://www.arcgis.com/home/item.html?id=b13b3b40fa3c43d4a23a1a09c5fe96b9). The topographic position index was calculated using the downloaded topography toolbox. The random forest/tree classifier within the classification toolbox was used to classify the Landsat 7 ETM+ imagery. Equations were used to determine the compound topographic index, NDVI, and normalized difference water index utilized the raster calculator to create each raster layer. Light

Detection and Ranging (LiDAR) derived point cloud data was utilized to calculate average elevations and average intensity to aid in identification of wetland areas.

Updated Camp Grafton Wetland Map

Wetland delineations were conducted in the field over the summer months (late May to early August) of 2017 and 2018. Determining the presence of a wetland in the field followed the three components of a wetland described in the Cowardin Classification System (Cowardin et al. 1979). These components include the presence of predominantly hydrophyte vegetation, substrate is predominantly undrained hydric soils, and substrate is saturated with water within the upper part (30cm or 12 inches) or covered by shallow water for 5 percent of the growing season. To be classified as a wetland at least one of the three component needs to be verified in the field (Cowardin et al. 1979). The presence of surface water often provided sufficient information to consider and delineate a wetland. The lack of surface water and/or hydrophyte vegetation resulted in soil cores being taken to determine the presence of a hydric soil. Hydric soil indicators were determined in reference to the Natural Resources Conservation Service's (2016) publication "Field Indicators of Hydric Soils in the United States: A Guide for Identifying and Delineating Hydric Soils." Field data recorded for each wetland included the dominant vegetation type (herbaceous, scrub/shrub, or woody), list of dominant hydrophyte species present, depth and color of hydric soil core, the Cowardin Classification (PEM1C, PABF, etc.), and pictures of both the wetland and the hydric soil core. The boundary of the wetland was recorded using a handheld global positioning system (GPS) and tablet. The Esri software ArcPad was downloaded on the tablet to aid in collection of wetland polygons. The Garmin GPS receiver has an accuracy between one and three meters while updating the spatial position 10 times per second. The GPS connected to the ArcPad software via bluetooth. ArcPad recorded periodic coordinates form the GPS resulting in a path or polygon with a resolution of one to two meters. Attributes such as wetland name, date collected, Cowardin Classification codes, and pictures were linked to each polygon recorded in ArcPad. Collecting wetland boundaries using the ArcPad software aided in data transfer from tablet to desktop. Saved data in ArcPad is the same as ArcMap resulting in the recorded data immediately ready for use in ArcMap (Appendix A).

Slope

The slope tool is a subset of the surface and spatial analyst toolbox (ESRI, ArcGIS Desktop 2016). Slope can identify potential wetland areas by calculating the degree or percent rise of the landscape (Li and Chen 2005, Sorensen and Seibert 2007, Wu et al. 2008, Vaze et al. 2010, Kloiber et al. 2015, MacLeod et al. 2016). Depressional wetlands define the PPR and often these wetlands occur on flat areas or in topological depressions. Areas of low slope are also an indicator of possible wetland areas due to runoff from surrounding landscape with higher slopes (Li and Chen 2005, Kloiber et al. 2015, Macleod et al. 2016). Therefore, determining the low slope areas of CGS could aid in indicating wetland areas. The slope tool uses a surface raster to calculate the slope. The input for this model was a 1-meter resolution DEM of CGS. The tool calculates degree of slope as a default, but percent rise is another option of calculation. The output from the DEM was a raster that represented the landscapes slope. The thresholds of the slope tool were values between 0 and 18300.5 in which potential wetland areas were 0-287.1 and upland areas were 287.2-18300.5. The applicability of the slope tool is endless but the thresholds will change with change in landscape. After classifying the symbology to display the data as low degree slope and high degree slope, the reclassify tool was used to create a raster that displays potential wetlands and upland areas. Values used in the reclassify tool were a value of one represented potential wetlands and a value of zero represented upland areas. Reclassifying the raster this way allows ArcMap to simplify the data displayed and improves the conversion of raster data to vector data. The conversion tool raster to polygon take the input (raster) and converts it into a shapefile (vector). The reclassified raster was used as the input and the output was a layer of polygons. The polygons had a value of one (wetland areas) and a value of zero (upland areas). Once the raster was converted into polygon the resulting slope layer was ready for analysis (Appendix B). The simplified processes is represented by Figure 3.6.

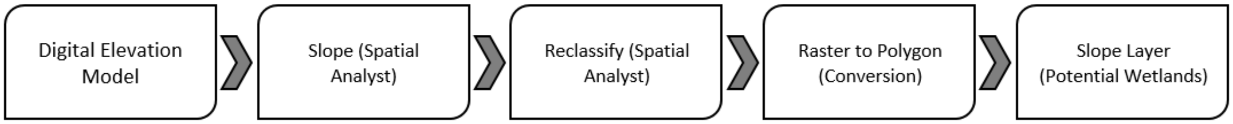


Figure 3.6. Flow chart of the slope tool methodology.

Depressions

Deriving depressions from a DEM can positively identify potential wetlands. Identifying areas lower on the topographic landscape would represent the areas where water would accumulate. The process of deriving depressions from DEMs was illustrated in Wu and Lane (2017) publication. Wu and Lane (2017) created the Hydrological Analyst Toolbox available for download as an extension toolbox in ArcMap. The toolbox was developed to identify depressions along the landscape, extract those depressions, calculate and develop incremental depths from the depressions center outwards to the edge, and finally determine the water flow within each watershed. Without a high-powered computer to run this tool, it was infeasible to extract depressions over the entire 3,650 hectares of CGS. Instead, a similar method to extracting depressions from a DEM is to run the fill tool found in the hydrology tools of the spatial analyst toolbox (ESRI, ArcGIS Desktop 2016, McDeid et al. 2018). The fill tool requires the input to be a DEM. Once the tool was run all sinks within the DEM would be filled. The next step was to use the raster calculator to subtract the filled DEM from the original DEM. The product displayed depressional areas derived from the original DEM with values between -928 and 0.

These values are dependent on the elevation of the landscape and will change within other sites. The next step was to convert the depressions raster into polygons. In order to analyze this depressions layer, values must be given to the polygons that represent wetland and upland. The depressions polygon was merged with the outline of CGS using the union tool. The result of this was a layer that now includes both wetland areas and upland areas. Editing the attribute table was the final step in which the depressions polygon was given the value one and the upland polygons are given the value zero (Appendix B). A simplified process is shown Figure 3.7.

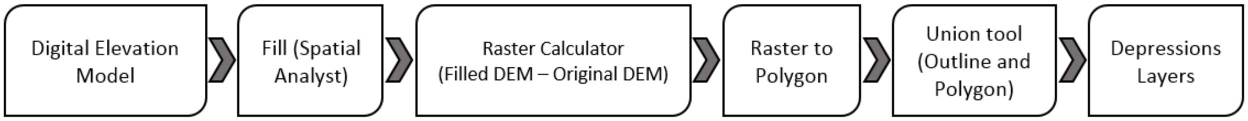


Figure 3.7. Flow chart of the derived depressions methodology.

Topographic Position Index

Topographic Position index (TPI) is an area of cells that have a topographic value less than that of the neighboring cells. The TPI in its simplest form shows areas on the landscape where there is a drop in the elevation such as a depression (Wu et al. 2008, Kloiber et al. 2015, Macleod et al. 2016). This can significantly improve the identification of small depressions that occur at topographic highs such as hills. The Topography Tool was downloaded as an extension through the ArcGIS website (https://www.arcgis.com/home/index.html). This toolbox includes the calculation for topographic position index. The input for the topographic position index was the original DEM. The output was a raster layer with threshold values of -213.97-197.43, wetland areas were determined to have values between -0.1 and 0.1 while all other values were considered upland areas. These thresholds will differ with change in landscape, but the applicability of the tool is universal. After classifying the raster to display potential wetlands and upland areas a reclassify was completed and the output raster was represented by values of one and zero. A value of one representing the topographic lows which are potential wetlands and value zero represents the upland areas. Converting the raster dataset into a polygon dataset gives an analysis ready topographic position index layer (Appendix B). Figure 3.8 shows this process step by step.

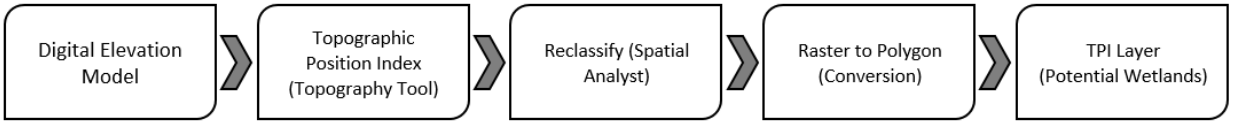


Figure 3.8. Flow chart of the topographic position index tool methodology.

Compound Topographic Index

The compound topographic index (CTI) utilizes both the slope raster and flow accumulation raster in determining the state of wetness within an area (Sorensen and Seibert 2007, Wu et al. 2008, Vaze et al. 2010, Kloiber et al. 2015, Macleod et al. 2016). Macleod et al. (2016) defines CTI as a function of wetness determined by the landscapes slope and the upstream contributing area. Determining the wetness index or CTI of CGS can improve the identification of potential wetland areas. The formula for CTI used in this wetland model was as follows (Kloiber et al. 2015, Macleod et al. 2016):

$$\text{CTI}=\text{Ln}((\text{“flow accumulation”} + 0.001) / ((\text{“slope”} / 100) + 0.001))$$

The flow accumulation attributes for the upstream contributing area while the slope tool attributes for the slope. An important part of calculating CTI was that the slope tool must be a product of percent slope rather than calculated as degree slope. CTI was calculated utilizing the raster calculator inputting the flow accumulation raster and the slope raster (ESRI, ArcGIS Desktop 2016, Kloiber et al. 2015, Macleod et al. 2016). The result was a raster with thresholds between -11.98 and 24.32 representing wetness over the landscape. Determining potential wetland areas resulted in threshold values of 9.25-24.32 while values between -11.98 and 9.24 were considered upland areas. Thresholds are dependent on the landscape present and will change with change in landscape. This tool is not just applicable to the PPR, but rather can be used throughout the world on any landscape. Following classifying the raster to represent only the areas of the most wetness and areas of no wetness, the reclassify tool was used to apply the value of one for areas of potential wetlands and a value of zero to areas not considered a wetland area. The final step was to convert the reclassified raster layer into polygons that represent polygons of wetness. This layer was analysis ready as the CTI layer (Appendix B). The process of calculating the compound topographic index is shown in Figure 3.9.

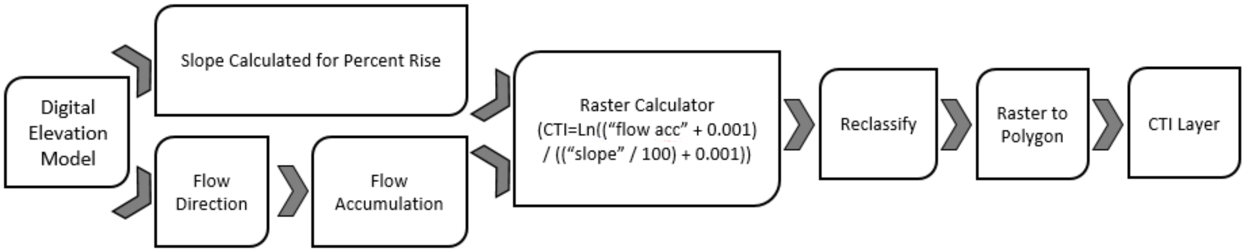


Figure 3.9. Flow chart of the compound topographic index tool methodology.

SSURGO

SSURGO soils data were downloaded through Esri’s SSURGO Downloader tool which downloads soils data at a sub-basin level. The camp falls within the Middle Sheyenne Sub-basin (https://www.arcgis.com/apps/OnePane/basicviewer/index.html?appid=a23eb436f6ec4ad6982000dbaddea5ea). The downloaded data describes the soils of CGS with considerable detail. Details such as the name of each soil series, the suitability of construction and development, the projected horizons and structure of each soil series, the presence of hydric soils, and the drainage regime (Kloiber et al. 2015, Macleod et al. 2016). For use in this wetland model, a filter was used to highlight those soils at CGS with drainage regimes of somewhat poorly drained, poorly drained, and very poorly drained soils. These three drainage regimes were reclassified with the value of one representing areas of potential wetlands, while all other drainage regimes were considered uplands. The conversion from raster to polygons was then used to create a layer of hydric soils ready for analysis (Appendix B). Figure 3.10 represents a simplified process of developing the hydric soils layer.

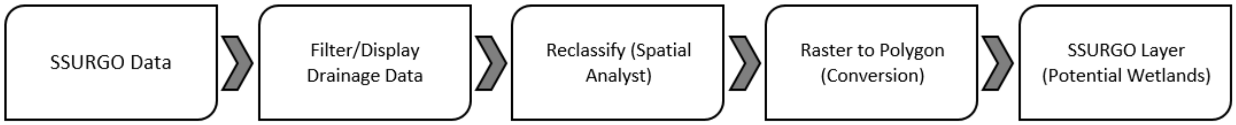


Figure 3.10. Flow chart of the SSURGO soils methodology.

Normalized Difference Vegetation Index

Normalized difference vegetation index (NDVI) describes the density of green cover (vegetation) over a landscape (Weier and Herring 2000). The NDVI distinguishes between vegetation structures and water by utilizing both visible and near-infrared reflectance bands (Weier and Herring 2000, Li and Chen 2005, Wolf 2010, Parvianinen et al. 2013, Li and Shao 2014). Healthy vegetation is absorbed by red and blue wavelengths but significantly reflects green and near infrared wavelengths. The output raster results in a values between -1 and +1. NAIP aerial imagery was used in calculating the NDVI of CGS. NAIP imagery was used over Landsat imagery in order to have increased resolution. The equation used to calculate NDVI in the raster calculator tool was as follows (Wolf 2010):

$$\text{NDVI} = (\text{NIR}-\text{Red}) / (\text{NIR}+\text{Red})$$

In the equation, NIR represents the near-infrared wave while the Red value represents the red band. The resulting raster was classified in symbology to represent water (-0.98- -0.2), possible hydrophyte vegetation (-0.16-0), and upland (-0.19- -0.15, 0.1-0.65). The NDVI tool is applicable for any location with sufficient aerial imagery but the thresholds will vary. A reclassification was done to display a raster in which a value of one represented water and hydrophyte vegetation and a value of zero represents upland areas. This raster was then converted into polygons that represented potential wetlands areas. The result was a NDVI layer that was analysis ready (Appendix B). Figure 3.11 represents the steps taken to determine the NDVI of CGS.

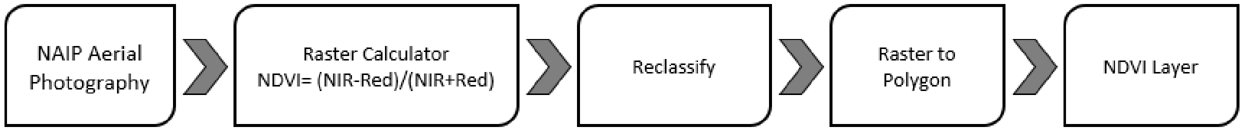


Figure 3.11. Flow chart of the normalized difference vegetation index methodology.

Normalized Difference Water Index

The NDWI is similar in process as the NDVI. The NDWI is an index that is used to enhance waterbody features and determine leaf water content in plants (Gao 1996, Li and Chen 2005, Wolf 2010, McFeeters 2013). The waterbody enhancement would improve wetland boundaries of more permanent wetlands while the leaf water content could indicate possible hydrophyte vegetation thus potential wetland areas (Li and Chen 2005, McFeeters 2013). The NAIP imagery was used to calculate NDWI utilizing the green and infrared wavelength bands. The equation used in this model to calculate NDWI was as follows (Wolf 2010):

$$\text{NDWI} = (\text{Green} - \text{NIR}) / (\text{Green} + \text{NIR})$$

The result of running the calculation using the raster calculator was a raster with values ranging from -0.59-0.98. Areas that indicate water bodies and water content had thresholds of 0.15-0.98 while none water bodies and low water content had thresholds of -0.59-0.14. Much like the NDVI tool, the NDWI tool may be utilized at any location with sufficient aerial imagery. The thresholds will vary along with change in location. Once the boundaries representing potential wetlands and uplands have been determined a reclassify was run to change these values to one or zero. Zero values represent areas that have little to no water content while the value of one represents areas of significant water content and waterbodies. These values would be represented following the conversion from raster to polygons. The layer of polygons was analysis ready and represented the NDWI layer in the wetland model (Appendix B). Figure 3.12 describes a simplified process of calculating NDWI.

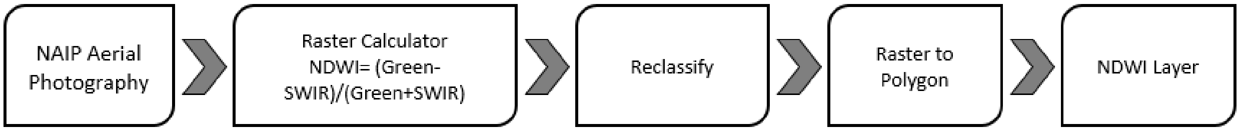


Figure 3.12. Flow chart of the normalized difference water index methodology.

Random Tree Classification

Random forest classifications can identify wetland areas by classifying aerial and satellite imagery (Haralick et al. 1973, Pal 2005, Baker et al. 2006, Corcoran et al. 2013, Li and Shoa 2014, Tian et al. 2016). ArcMap developed a classification toolbox that allows the segmentation and classification of satellite imagery and Landsat imagery (ESRI, ArcGIS Desktop 2016). Random tree/forest classification tool is included within this toolbox (ESRI, ArcGIS Desktop 2016). Esri ArcGIS help defines a random tree classification as “a supervised machine-learning classifier based on constructing a multitude of decision trees, choosing random subsets of variables for each tree, and using the most frequent tree output as the overall classification.” The random forest classifier can be utilized at any location as long as aerial imagery is available. This process can be manipulated by increasing the number of trees used, increasing the depth of such trees, and increasing the number of samples used in each class. For this model, Landsat 7 ETM+ imagery was used as the classification input. The number of trees were increased to seventy-five, the tree depth was increased to fifty, and the default number of samples per class was accepted. The training samples used in this classifier were created manually. Areas of known water, wetland vegetation, forested wetlands, trees, roads/development, and grassland were used as the training samples. The training samples had the following pixel counts water (1,090,408 pixels), wetland vegetation (209,117 pixels), forested wetlands (11,629 pixels), trees (70,486 pixels), roads (127,527 pixels), and grasslands (1,513,729 pixels). The result of running the random tree classifier is an Esri classifier definition file (.ecd) which was be used to classify the image. The classified image represents the defined training samples (water, wetland veg., forested wetlands, trees, roads/development, and grasslands). Using the reclassify tool, these values were categorized as potential wetland areas and non-wetland areas. A value of one was given to the water, wetland vegetation, and forested wetland categories. These represent the areas of potential wetlands. The areas categorized as non-wetland areas and given the value of zero include the grassland, trees, and roads/development categories. Converting the reclassified raster into polygons with values of one and zero was the final set in the process of developing the random forest classification layer (Appendix B). The process can be seen in Figure 3.13.

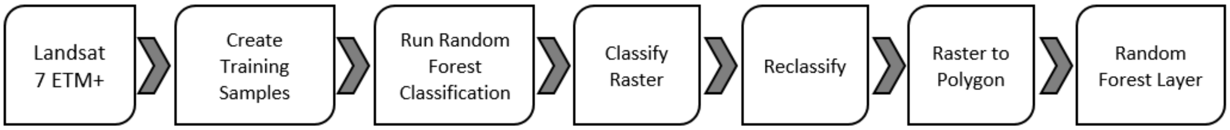


Figure 3.13. Flow chart of the Random Tree/Forest Classification methodology.

Bare Earth Point Cloud

Bare Earth data is elevation data derived from LiDAR that represents the surface of a landscape (Haugerud et al. 2003, Hladik and Alber 2012, Kloiber et al. 2015, Macleod et al. 2016). This is visualized as a point cloud in which points represent elevation but have an x and y coordinate as well as a z-value. This results in a three-dimensional representation of the data. Bare earth data has been manipulated to remove LiDAR returns that never reached the ground. Bare earth data for CGS was downloaded through the State Water Commission’s “ND LiDAR Dissemination Mapservice” (https://lidar.swc.nd.gov/). The bare earth data was downloaded as a LAS file (.las). Average intensity was used in the conversion of the point cloud into raster format. The intensity of LiDAR data represents the strength of a return from a laser pulse and has been used to detect and extract features from the LiDAR data (Kloiber et al. 2015, Macleod et al. 2016). The resulting raster represents the average strength of returns for each cell based on the bare earth LiDAR data. The bare earth intensity derived wetland areas had threshold values of 0-109 while areas of upland were 110-255. This tool is applicable at any location although the thresholds will vary depending on quality of data and location. The raster symbology was then classified to represent areas of wetlands and areas of upland. A raster reclassify was conducted to convert these values into a value of one to represent wetlands and a value of zero to represent upland areas. A conversion from raster to polygons were then conducted to prepare the bare earth layer for analysis (Appendix B). A simplified process is shown in Figure 3.14.

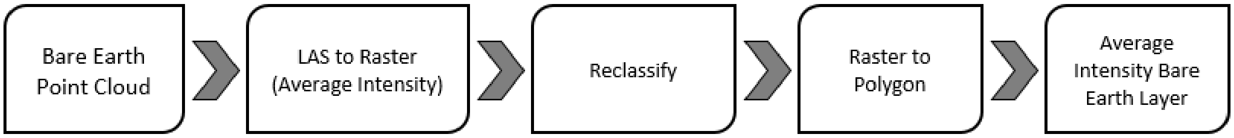


Figure 3.14. Flow chart of the LiDAR derived bare earth point cloud methodology.

First Returns Point Cloud

Very similar to the bare earth layer, the first returns layer is a representation of the un-manipulated LiDAR data. The first return data was also downloaded through the State Water Commission’s “ND LiDAR Dissemination Mapservice” (https://lidar.swc.nd.gov/). First return data is displayed as a point cloud and it represents the highest feature at a given point on the landscape (Hladik and Alber 2012, Kloiber et al. 2015, Macleod et al. 2016). This could represent a tree canopy, cattails, a building, or even the ground if a laser pulse is not disrupted by other features. First return data provides elevation data of each of these features/returns. This can then be used to determine the most likely areas a wetland would occur (Hladik and Alber 2012, Kloiber et al. 2015, Macleod et al. 2016). Average elevation of the first return data was calculated during the conversion of the LAS data into a raster dataset. The results are an elevation model similar to a DEM; however, indicates average elevation of the highest feature throughout the landscape. Manipulation of the raster symbology resulted in the identification of potential wetland areas with values ranging from 443.8-462 as well as areas of upland with values from 463-696.95. Like the bare earth tool, the first returns tool is applicable almost anywhere where quality LiDAR data is available. A reclassification of the raster resulted in the representation of potential wetland areas as a value of one, while the upland areas were represented by a value of zero. A conversion from a raster dataset to a polygon dataset was done so that the average elevation of the first returns data was displayed as a shapefile. The shapefile with polygons that have the value of one or zero allows for easy interpretations and analyses (Appendix B). Figure 3.15 shows a simplified process in determining the first returns layer.

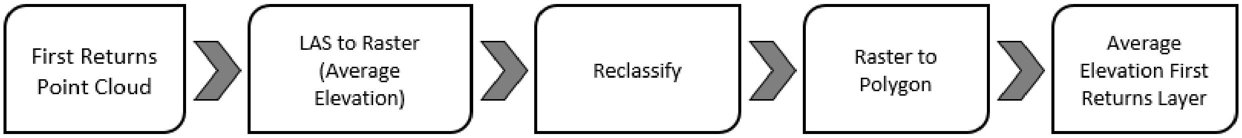


Figure 3.15. Flow chart of the LiDAR derived first return point cloud methodology.

Confusion Matrix Analysis

Analysis was done using a confusion matrix, which allows in-depth look into the accuracy of each tool. A confusion matrix determines the accuracy of a model by comparing a true condition with a predicted condition (Stehman 1997, Lewis and Brown 2001). In this study the true condition was represented by the field verified wetland polygon while the predicted condition would be the tools used in ArcMap. In a confusion matrix there are four outcomes true positive, false positive, false negative, and a true negative (Stehman 1997, Lewis and Brown 2001). A true positive was when the model predicted the presence of a wetland and the field verification shows a wetland was present. A false positive occurs when the model predicts the presence of a wetland, but the field verified data shows the lack of a wetland. A false negative was the result of the model predicting that there was no wetland present, but the field verification shows there was a wetland present. Finally, a true negative was when the model predicts that no wetland was present and the verified wetland data also shows no wetland present (Stehman 1997, Lewis and Brown 2001). This is simplified in Figure 3.16 where positive means there was a wetland and negative means there was not a wetland.

Once each tool was converted into polygons represented by a value of one for potential wetland areas or a value of zero for upland areas, the layer was then compared to the field verified wetland map. The field verified wetland map was reclassified so that the wetland polygons were given a value of one and the upland polygons were given a value of zero. Each tool was compared separately to the field verified wetland map and a confusion matrix was calculated. The general process was as follows: 1. Union of the field verified wetland map and the selected tool, 2. In the resulting layer, calculate the areas in hectares (ha), 3. Use the statistics tool within the attribute table to summarize the sum totals for true positives, false positives, false negatives, and true negatives. In the attribute table, filtering the data to highlight the polygons where the verified map and the model map both had value of one which represents the true positives. Highlighting the polygons where the model has a value of one and the verified map has a value of zero will give you the false positive. Highlighting the polygons where the model has a value of zero and the verified map has a value of one results in a false negative. A true negative occurs when both the model has a value of zero and the verified map has a value of zero. The total hectares for each situation was recorded accordingly. Accuracy and precision was then calculated using the area totals. The accuracy is simply how often in the model was correct in predicting the presence of a wetland or the presence of upland. Accuracy was calculated using the following equation:

$$\text{Accuracy} = (TP + TN) / (TP + FP + FN + TN)$$

Variables: TP= true positive value, TN=true negative value, FP= false positive value, FN=false negative value

Precision is the calculation of how often the model was correct when it predicts the presence of a wetland. Precision was calculated using the following equation:

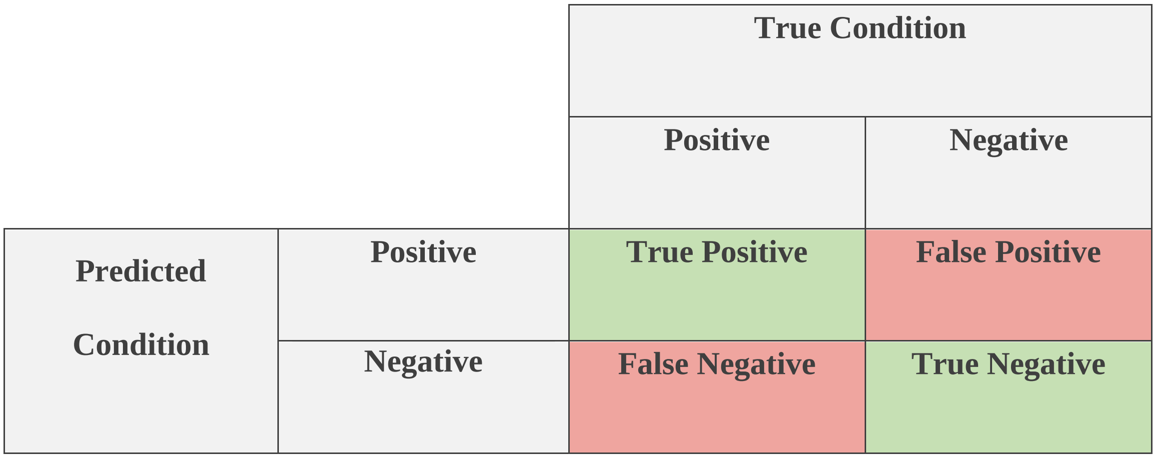
$$\text{Precision} = (TP) / (TP + FP)$$

Variables: TP= true positive value, FP= false positive value

Other calculations that were found to be important include the miss rate (false negative rate). The miss rate determined how often the model predicted that there was not a wetland present when the verified map shows that there was a wetland present. This can be calculated in the following equation:

$$\text{Miss Rate} = (FN) / (FN + TP)$$

Variables: FN= false negative value, TP= true positive value



		True Condition	
		Positive	**Negative**
Predicted Condition	**Positive**	**True Positive**	**False Positive**
	Negative	**False Negative**	**True Negative**

Figure 3.16. Simplified layout of the confusion matrix. The predicted condition represents the tool used in ArcMap while the true condition represents the field verified wetland delineation data.

Wetland Locator model

Previous methods and research combined all layers into a layerstack (Kloiber et al. 2015, Macleod et al. 2016). This was usually done by utilizing the union tool to mosaic all the tools together. While this was a valid way of utilizing all the tools to determine wetland boundaries, many areas would be determined to be a wetland based on what one tool portrays. These areas could be construed specifically with the vegetation and soil tools where a significant area determined to be a wetland was in fact not a wetland.

In order to mitigate this problem, the Wetland Locator model applies weights or rules so that multiple tools must identify an area to be a wetland in order for it to be considered true. All tools are utilized in this process, the rule/weight determines how many of these tools must be present in a given area to be considered a wetland. The Wetland Locator's process begins with using the union tool to combine all the tools together. Using the new union layer, create a new field in the attribute table named weights or rules. Using the field calculator, all values (both values of one and value of zero) were added together. The result indicated the number of layers that are present within a certain location. Next was to create another field to reclassify the values back into values of one and values of zero. In this study, accuracies were compared based on the required amount of layers needed to be present. For example, determining that a requirement of at least three layers be present to be considered a wetland the following process would occur. First filter and highlight all the weights that are equal or greater than three, with the field calculator specify that the new value of one will replace all the highlighted polygons. The same was done with the weights that are less than three, but rather the value of zero was given. Once the values are changed back to one and zero, the normal process of comparing this layer to the verified layer continues. The Wetland Locator's process can be visualized by a flow chart

(Figure 3.17) as well as through the attribute table within ArcMap (Appendix D). Instead of this layer representing one tool it represents all tools with specific rules that will increase the accuracy of the wetland boundary.

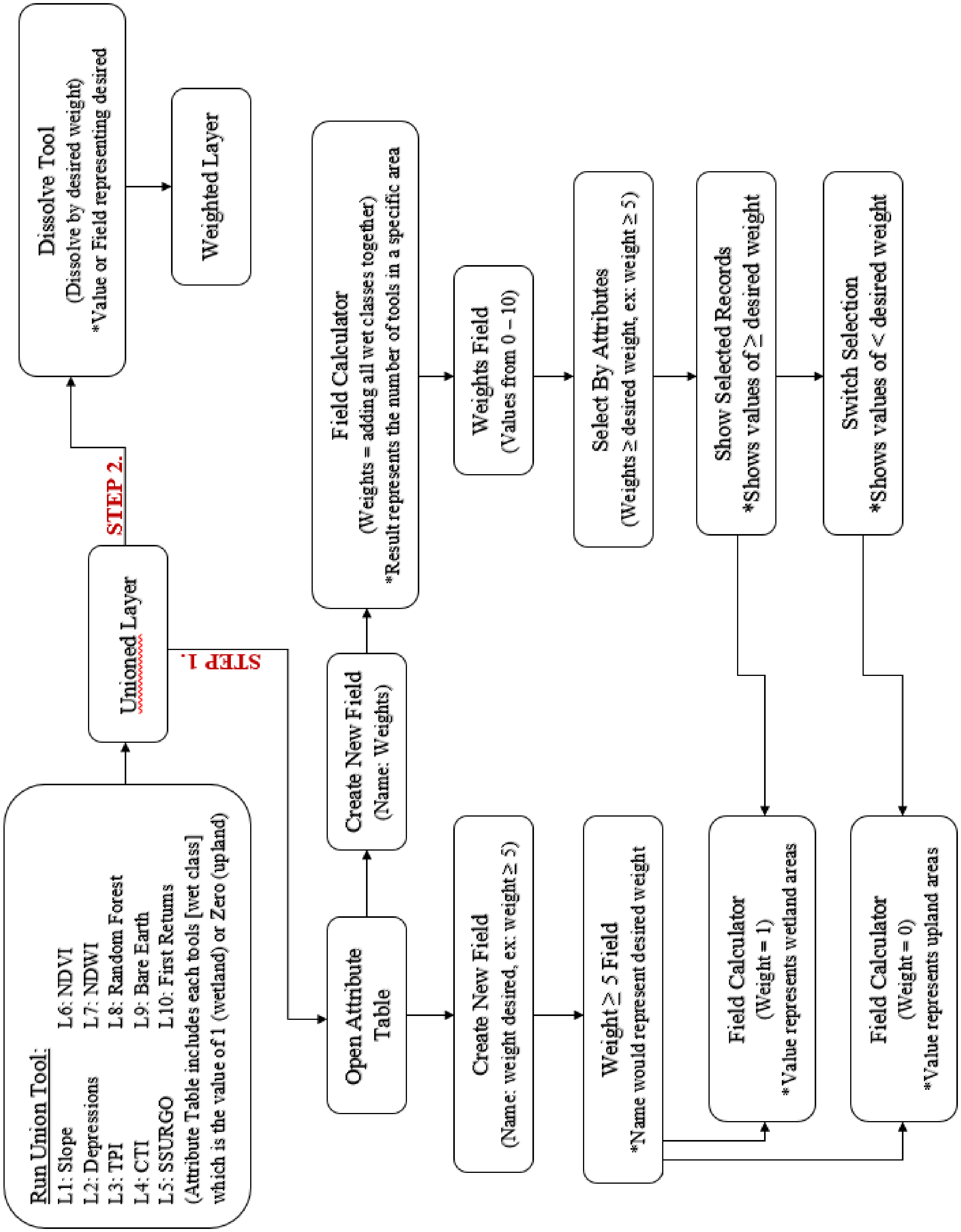


Figure 3.17. A flow chart representing the Wetland Locator's process. The flow chart is broken down into two steps, the first step is the manipulation of data and deriving weights, while the second step is deriving the layers from the weighted values.

Results

Previous research has shown that tools such as topographic position index, compound topographic index, NDVI, NDWI, image classifications, and Lidar derived point clouds provide accurate semi-automated techniques for mapping wetland boundaries (Kloiber et al. 2015, Macleod et al. 2016). Results from this study provide insight into the accuracy, precision, and miss rates of these tools.

Accuracy

The overall accuracy of the tools stayed above 90% accuracy with the exception of the depressions tool, which had an accuracy of 89.8% (Figure 3.18, Table 3.1). A comparison between the original NWI map to a field verified map found that the original NWI map identified wetlands with 93.6% accuracy. The tools with the highest accuracies were the SSURGO soils tool with an accuracy of 93%, while the NDVI, NDWI, and Bare Earth tools followed with accuracies of 92%. Each tool has significant accuracy values that prove to successfully identify correctly wetland areas. Analysis of the Wetland Locator model shows that increasing the required weight also increases the overall accuracy of the wetland map. The accuracy of requiring at least two (weight ≥2) tools to overlay each other to be considered a wetland was 90.2% (Figure 3.21, Table 3.2). As the weights are increased accuracy increases weight ≥3 (91.7%), weight ≥4 (91.1%), weight ≥5 (94.2%), weight ≥6 (94.9%), and weight ≥7 (94.4%). It is important to note that the weights greater than or equal to five (weight ≥5, weight ≥6, and weight ≥7) had higher accuracies than the original NWI map.

Precision

Precision was an important calculation in determining how often a tool demonstrated correctly identifying wetland areas (Stehman 1997, Lewis and Brown 2001). Unlike the calculated values for accuracy, precision was characterized by a wide range of values (Figure 3.19, Table 3.1). Precision values ranged from 64.7% to 93.7%. The lower end of the value range included random forest classification tool (64.7%), depressions tool (65.8%), slope tool (66.7%), CTI tool (66.9%), and First Returns tool (69.9%). The tools at the higher end include SSURGO soils (86.2%), bare earth (88.8%), NDWI (91.4%), and NDVI (93.7%). The original NWI map had a precision of 94% when compared to the field verified delineated wetlands. The results of the Wetland Locator model shows a steady increase in precision as increases in weights occurred. The precision increases ranged from 62.4% to 97.5%, a more detailed look into the accuracies include weight ≥2 (62.4%), weight ≥3 (68%), weight ≥4 (69.8%), weight ≥5 (85.7%), weight ≥6 (92.4%), and weight ≥7 (97.5%) (Figure 3.21, Table 3.2). The precision of weight ≥7 was higher than that of the original NWI map.

Miss Rate

Analyzing the percent in which the model missed the identification of wetland areas that have been verified in the field could have significant impacts on the applicability of each tool (Stehman 1997, Lewis and Brown 2001). Tools that presented undesirably high miss rate values included NDVI tool (45.4%), NDWI tool (44%), and bare earth tool (42%) (Figure 3.20, Table 3.1). The lowest miss rates were found the first returns tool (15%) and the random forest classification tool (6.3%). Compared to the field verified wetland map, the original NWI map had a relatively high miss rate at 35.7%. Analysis of the Wetland Locator model showed a positive correlation between miss rates and increased weights (Figure 3.21, Table 3.2). The miss rate was as follows: weight ≥2 (3.6%), weight ≥3 (10.3%), weight ≥4 (22.5%), weight ≥5 (24.1%), weight ≥6 (26.4%), and weight ≥7 (33.8%). All weights were calculated to have lower miss rates than the original NWI map.

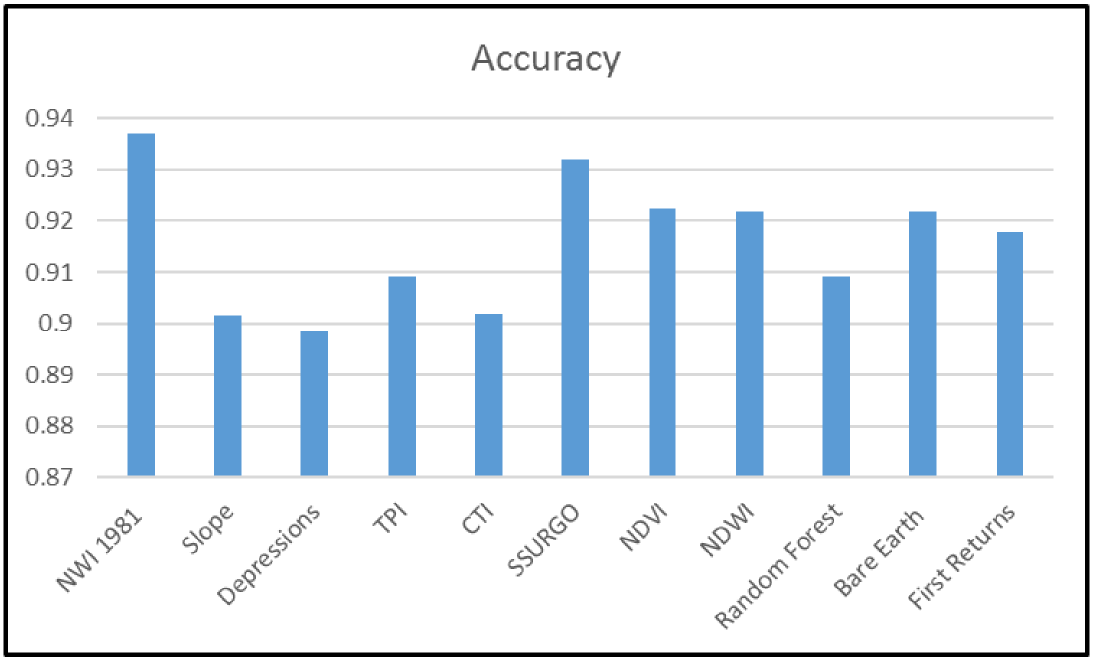


Figure 3.18. The accuracy rates of the individual tools compared to the field verified wetland delineation data. The y-axis represents the percent accuracy.

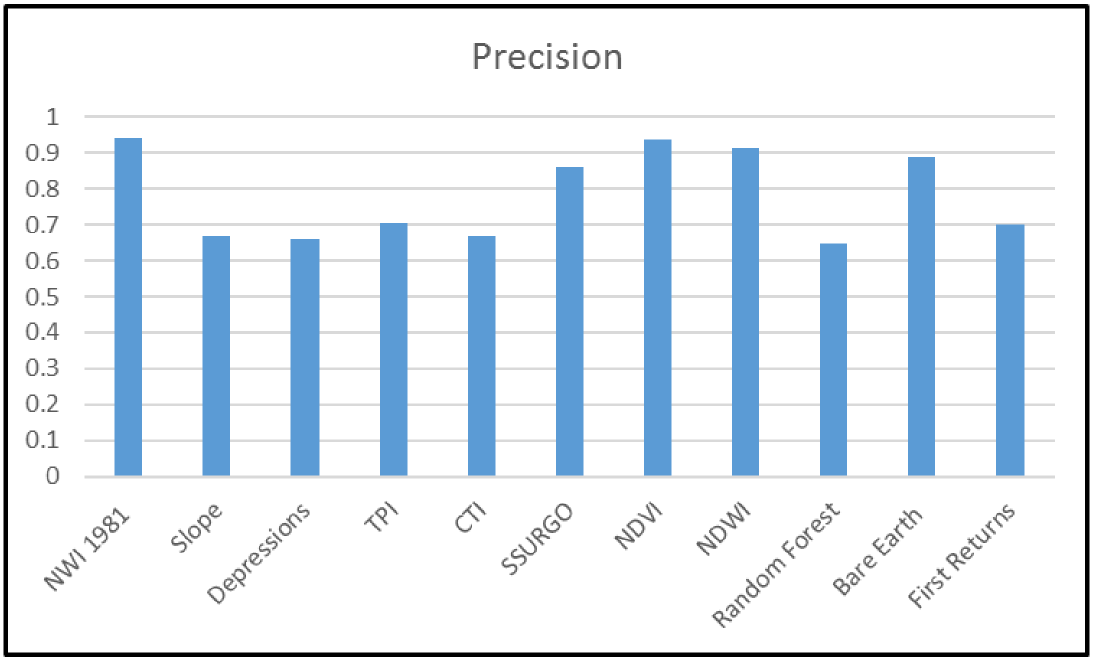


Figure 3.19. The precision rates of the individual tools compared to the field verified wetland delineation data. The y-axis represents the percentage of precision.

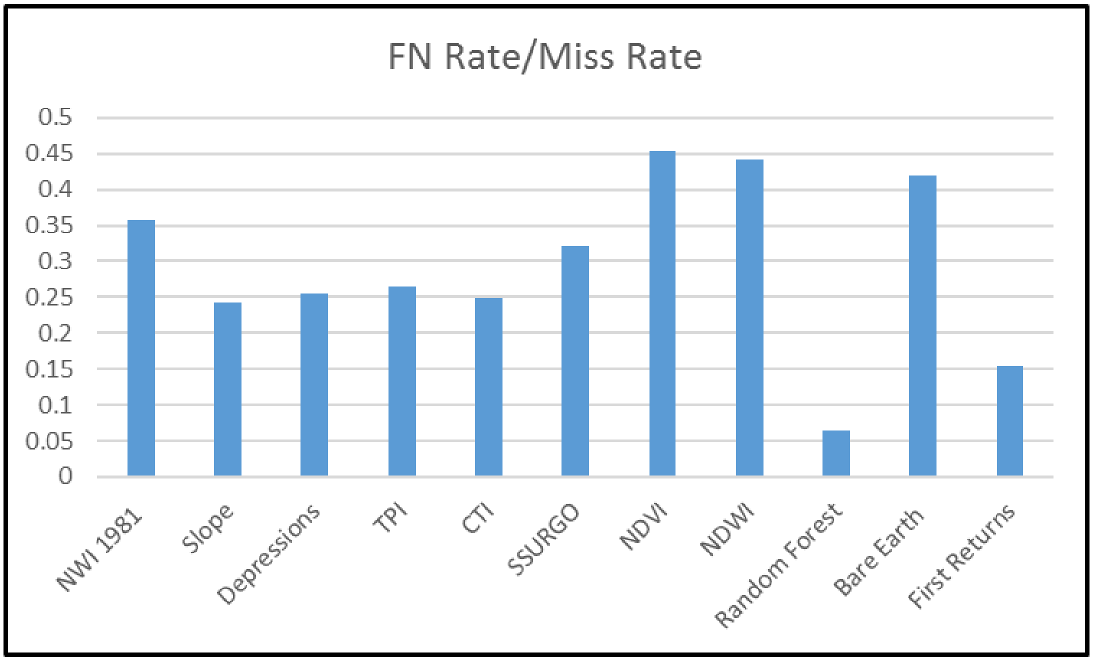


Figure 3.20. The miss rates/false negative rate of the individual tools compared to the field verified wetland delineation data. The y-axis represents the percent miss rate.

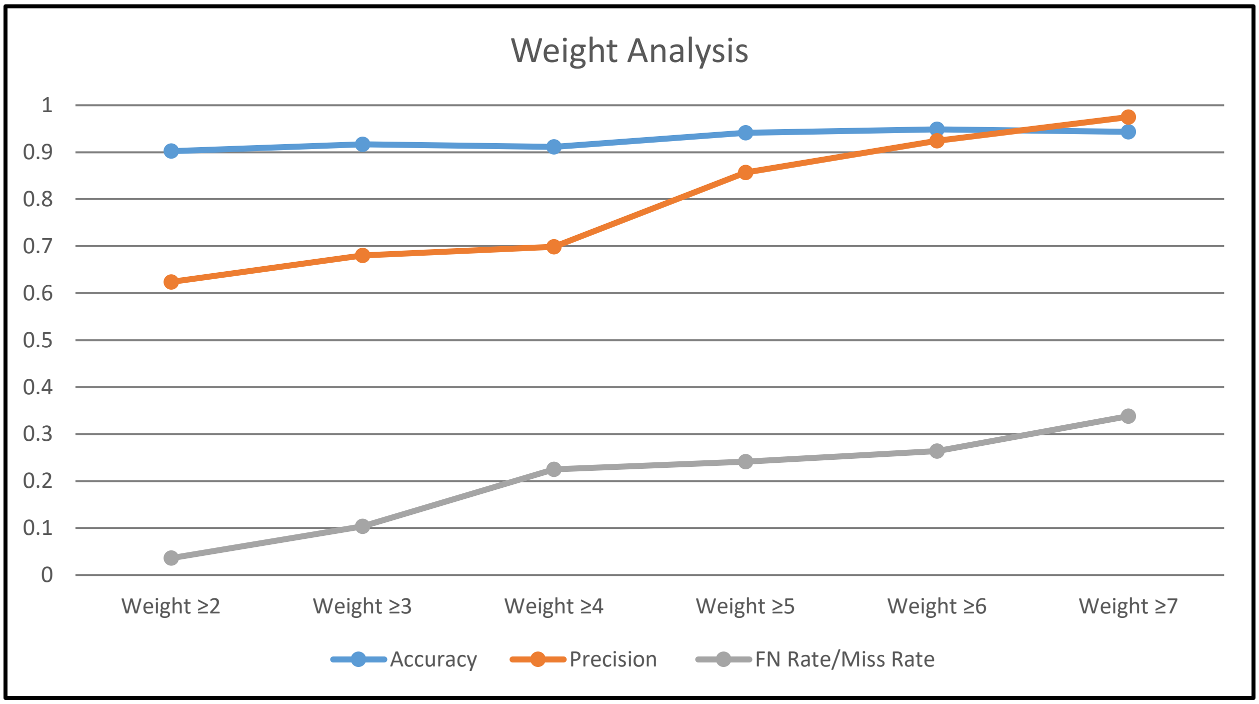


Figure 3.21. The accuracy, precision, and miss rates of the Wetland Locator model compared to the field verified wetland delineation data. The y-axis represents the percent of each calculation.

Table 3.1. The accuracy, precision, and miss rates of each method or tool utilized in the study.

Tool	*Accuracy*	*Precision*	*FN Rate/Miss Rate*
NWI 1981	0.936909575	0.940611306	0.357476994
Slope	0.901676356	0.667041319	0.242053049
Depressions	0.898474054	0.658666151	0.253890145
TPI	0.909223746	0.704999386	0.265365381
CTI	0.901875152	0.669718951	0.248541726
SSURGO	0.931836597	0.862202389	0.321634137
NDVI	0.922259304	0.937507445	0.454085457
NDWI	0.921788237	0.914086022	0.440897716
Random Forest	0.909028031	0.647182763	0.063306023
Bare Earth	0.921844971	0.88829201	0.420172451
First Returns	0.917901055	0.699216868	0.154082115

Table 3.2. The Wetland Locator's accuracy, precision, and miss rates of increasing weights or increasing the required number of layer intersections.

Tool	*Accuracy*	*Precision*	*FN Rate/Miss Rate*
Weight ≥2	0.902253436	0.624040096	0.035935277
Weight ≥3	0.916754173	0.680030223	0.103364857
Weight ≥4	0.911312493	0.698464327	0.225018022
Weight ≥5	0.941733282	0.857166233	0.24120023
Weight ≥6	0.948642361	0.92437887	0.263824122
Weight ≥7	0.943694436	0.974833272	0.338182754

Discussion

Utilizing these tools as a technique for wetland mapping proves to maintain high levels of accuracy. Each tools accuracy was close to or above 90%. The original NWI wetland map showed to have higher accuracy than any tool individually used in ArcMap with accuracy at 93.7%. Combining these tools and utilizing weights showed accuracy and precision higher than the original NWI map.

Analysis of precision show as somewhat random set of values. The precision was the calculation of how often the tool determined a wetland boundary correctly (true positives vs. false positives) (Stehman 1997, Lewis and Brown 2001). Values at the higher range of precision would indicate that a certain tool correctly identified wetland boundaries. The precision values of the slope tool, depression tool, CTI tool, and random forest tool are closer to the 65% value. This means that these particular tools correctly identify (true positives) wetland boundaries 65% of the time, while the other 35% would result in a false positive response. The precision of the original NWI map was high with a value of 94.1%.

There were only two tools that had miss rate values below 20%, these were the random forest classification tool (6.3%) and the first returns tool (15%). The remaining miss rate values ranged from 20% to 45%. The higher the miss rate the more a tool will miss the determination of a wetland (false negatives) (Stehman 1997, Lewis and Brown 2001). One major reason for the higher miss rates in this study was that many of the wetlands at CGS are small temporary or seasonal wetlands where the lack of hydrology results in delineations based on hydrophyte vegetation and hydric soils. The tools used in ArcMap rely heavily on elevation and hydrology, the lack of these in many wetlands at CGS would result in higher miss rates. The original NWI map was found to have a miss rate of 35.7%. This result was due to wetland boundaries of the original NWI map either underrepresenting a wetland or over representing a wetland. This was seen throughout the Camp and most the wetlands the created errors included temporary and seasonal wetlands that lack surface water presence. To limit the amount of error in wetland boundaries each tool was combined together into a layer and given weights which represents the Wetland Locator model.

Analysis of the Wetland Locator model show that accuracies increased as the number of weights increased. The accuracy of weight ≥5 (94.2%), weight ≥6 (94.9%), and weight ≥7 (94.4%) were higher than the accuracy of the original NWI map (93.7%). The USFWS's "Status and Trends" analysis required a minimum level of wetland classification accuracy (95%) utilizing both automated and non-automated processes (National Standards and Support Team 2017). The Wetland Locator's accuracy (94.8%) is comparable to the level accuracy required for the USFWS's "Status and Trends" mapping procedures. The Wetland Locator's automated and semi-automated process has a distinct advantage over the USFWS "Status and Trends" process that utilized non-automated procedures (National Standards and Support Team 2017). Analysis of the Wetland Locator's precision showed to increase (weight ≥2 (62.4%), weight ≥3 (68%), weight ≥4 (69.8%), weight ≥5 (85.7%), weight ≥6 (92.4%), and weight ≥7 (97.5%)) as the number of weights increased. Weight ≥6 (92.4%) was comparable to the precision of the original NWI map (94%) while weight ≥7 (97.5%) had a higher precision rate than the original NWI map. All weights showed lower miss rates than the original NWI map. The Wetland Locator's accuracy and precision rate proves that the replacement of the current "Status and Trends" and NWI methodology with the Wetland Locator model would reduce labor-intensiveness while providing a cost-effective and timely method for developing highly accurate and precise wetland maps.

The semi-automated methodology of the Wetland Locator model proves to have a distinct advantage over current methods that utilize both automated and non-automated methodology such as the USFWS's NWI and "Status and Trends." The results of the Wetland Locator model support this advantage by having higher accuracy and precision rates than the original NWI map while meeting the requirements for the "Status and Trends" publications.

The Wetland Locator model is applicable to each wetland type described in the Cowardin Classification System (Cowardin et al. 1979) providing a distinct benefit to prairie wetland areas where a lack of surface water presence proves difficult to identify in previous methods. The Wetland Locator model would be a beneficial tool for agencies that track changes in wetland area and extent such as the "wetland status and trends" publications from the USFWS (Dahl 2014, National Standards and Support Team 2017). The Wetland Locator model would prove pertinent to the USFWS's development of "Status and Trends" publications and the update of the NWI. This could be a pivotal tool for state and local agencies with limited funding to be able to produce accurate and precise wetland maps resulting in the opportunity to put more wetland conservation in practice. Up-to-date wetland maps and information as a result of the Wetland Locator model would allow agencies to put wetland restoration and enhancement projects on the ground.

Conclusion

The PPR is a unique wetland landscape that has been altered by human activity. Policy, regulations, and improving wetland projects are driven by available and updated wetland information. Updating wetland inventories can be a time consuming and costly process. Field verifications may not be an option for agencies or managers due to a lack of funding. ArcMap provides tools that have been used to update and map wetlands. The development of the Wetland

Locator model has three distinct advantages over previous and current wetland mapping techniques. These advantages are that the process is non-labor intensive, timely, and cost effective. These advantages will provide the vital tools needed to put conservation efforts such as wetland restoration on the ground. Also, Wetland Locator can be used to update wetland inventories such as the USFWS's NWI. Wetland Locator could improve publications that monitor changes of wetland area and extent such as the "Status and trends of prairie wetlands in the United States 1997 to 2009" publication by the USFWS (Dahl 2014, National Standards and Support Team 2017). Following analysis, it is recommended to use the Wetland Locator model and apply the rule of at least seven layers (weight ≥7) be present would develop highly accurate and precise wetland maps.

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APPENDIX A. VISUALIZATION OF DATA USED IN APPLICATION OF EACH TOOL

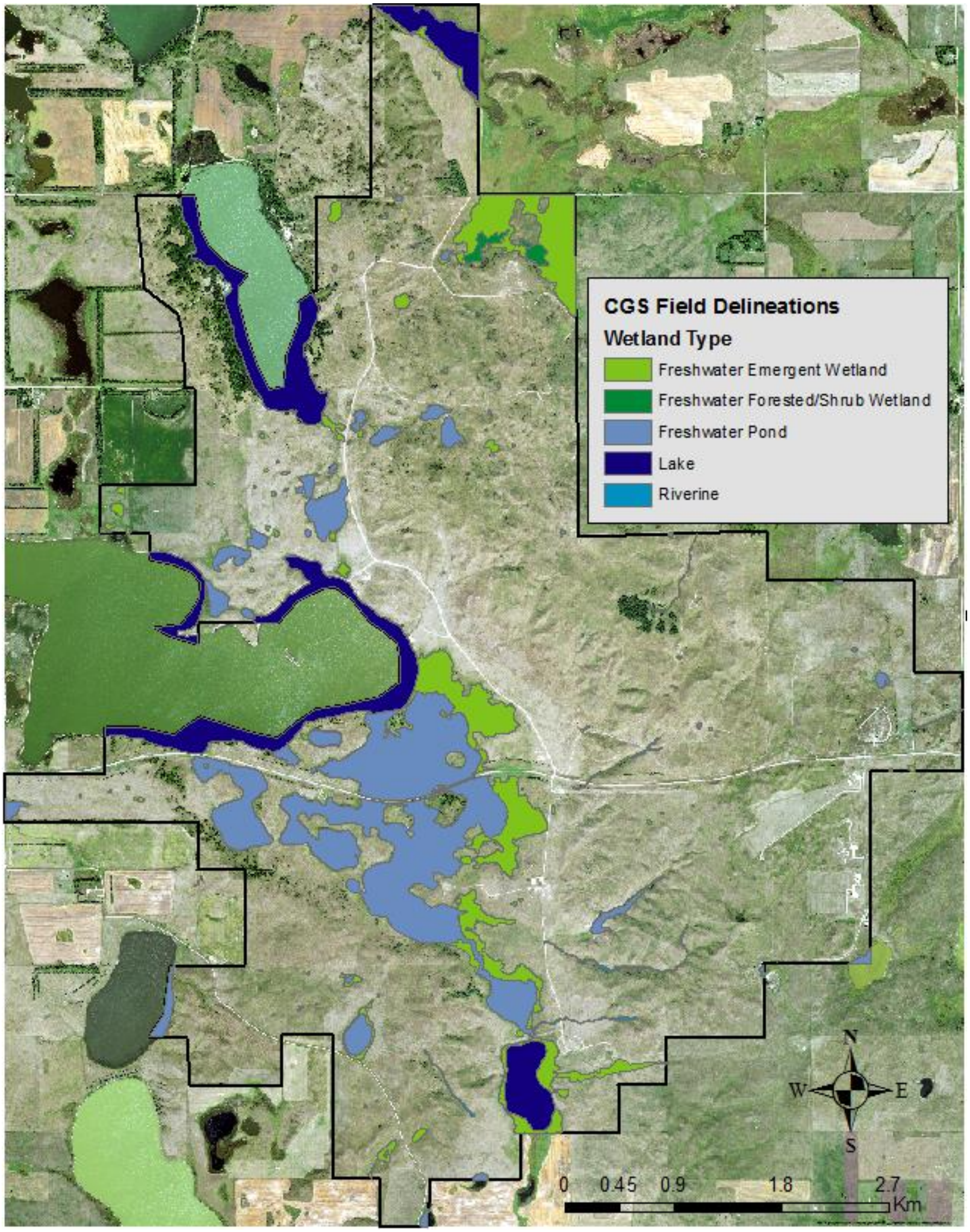


Figure A1. Camp Grafton South Field Delineations

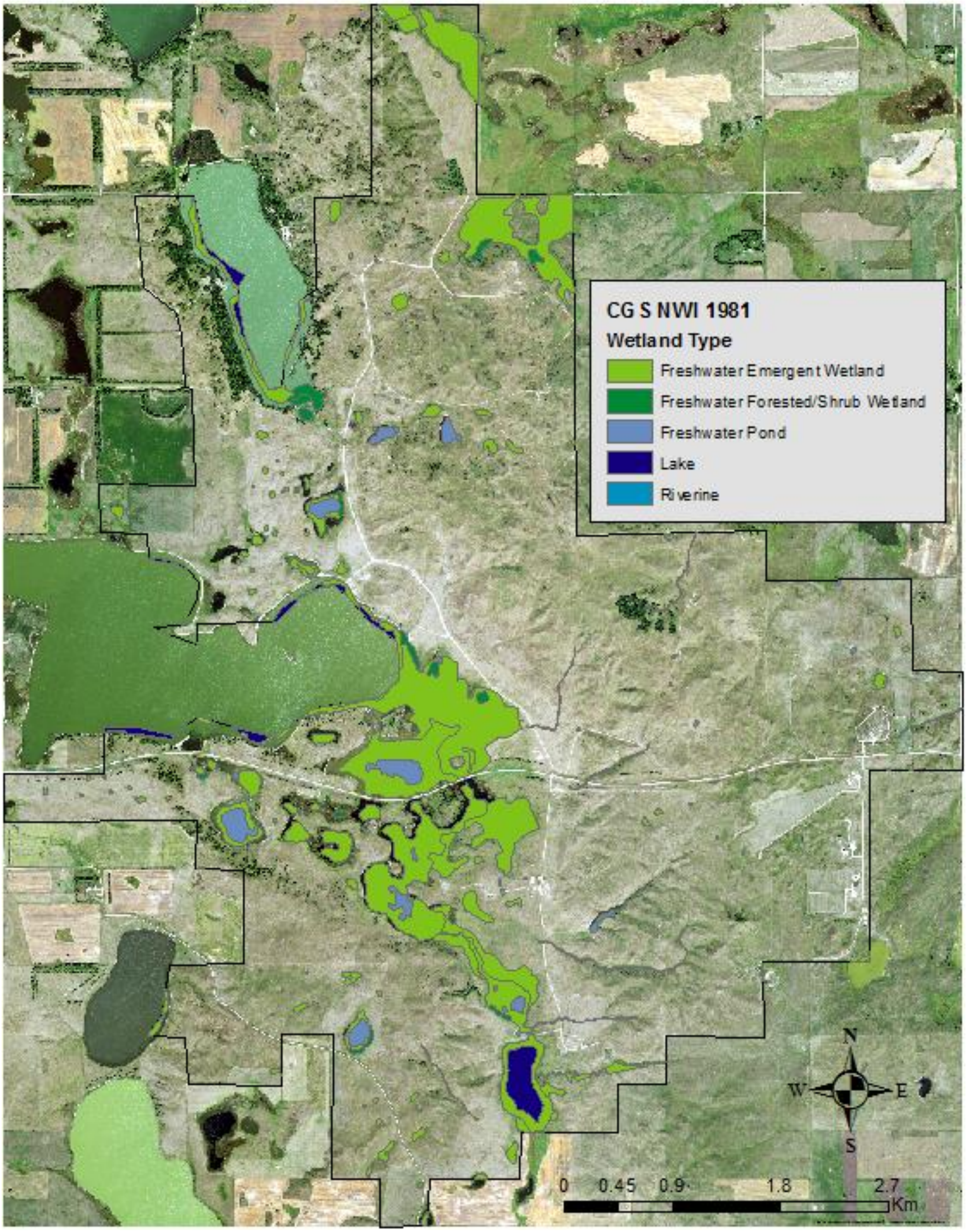


Figure A2. Camp Grafton South Original NWI Map (1981)

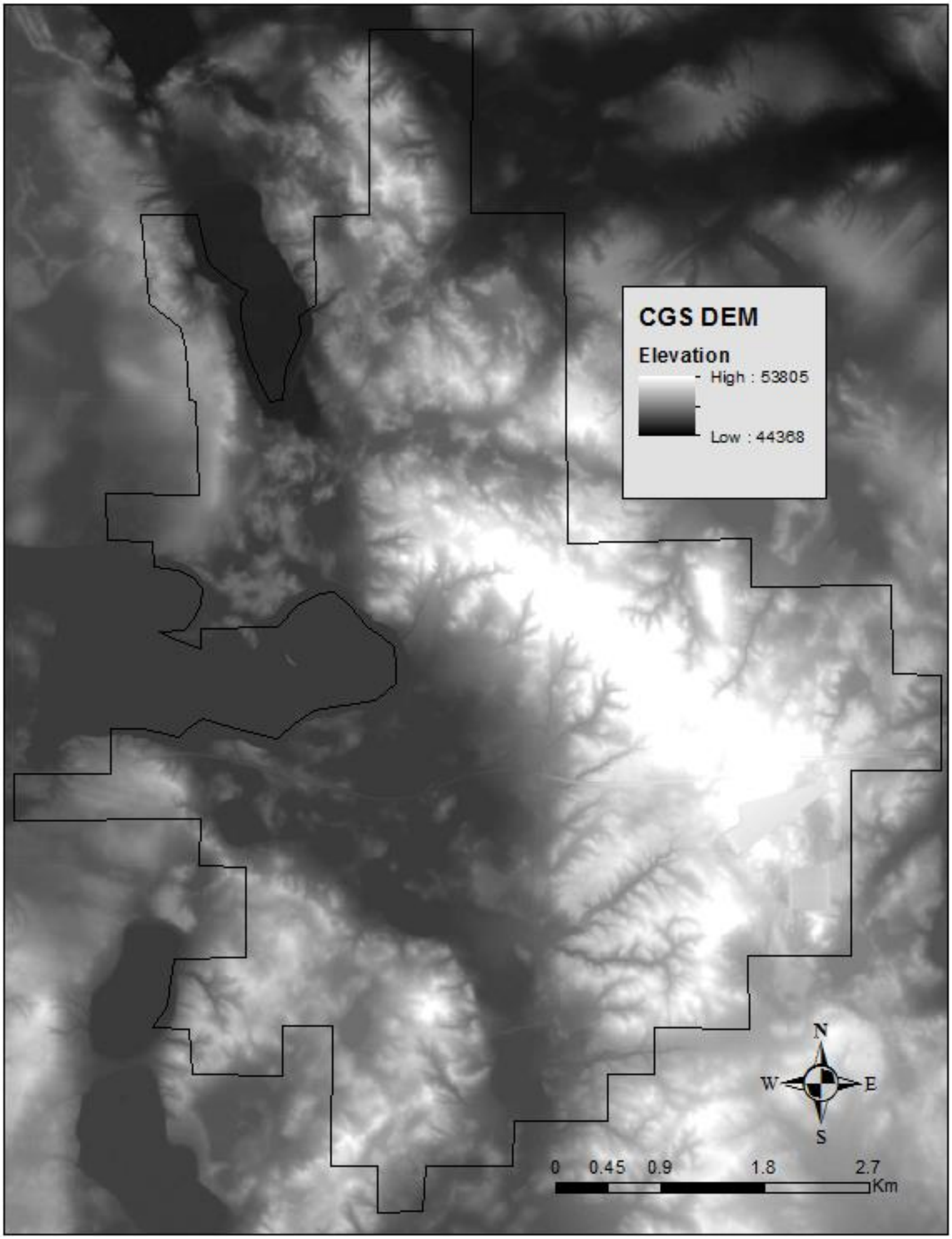


Figure A3. Camp Grafton South Digital Elevation Model

APPENDIX B. DATA VISUALIZATION OF EACH TOOL

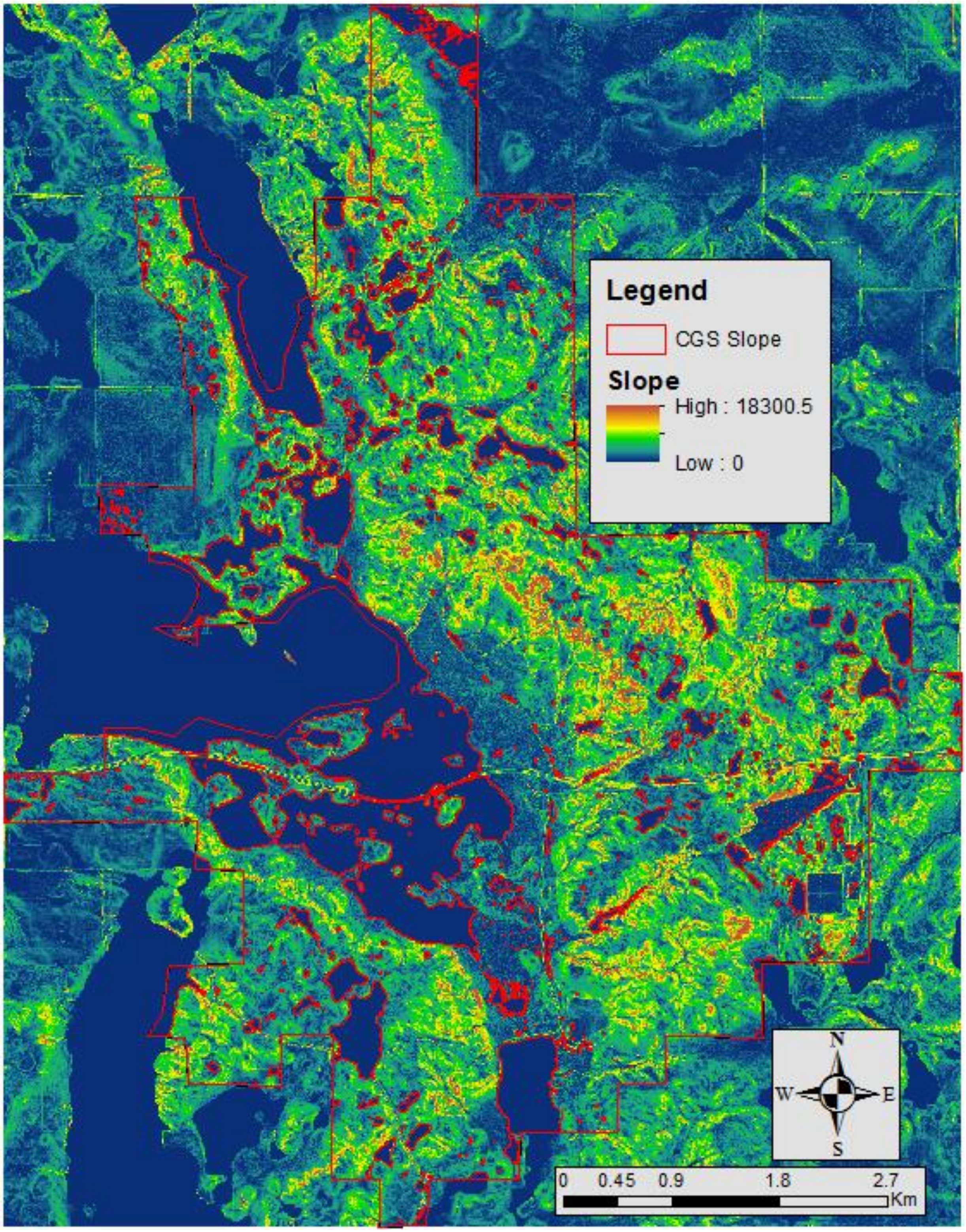


Figure B1. Camp Grafton South Slope Layer

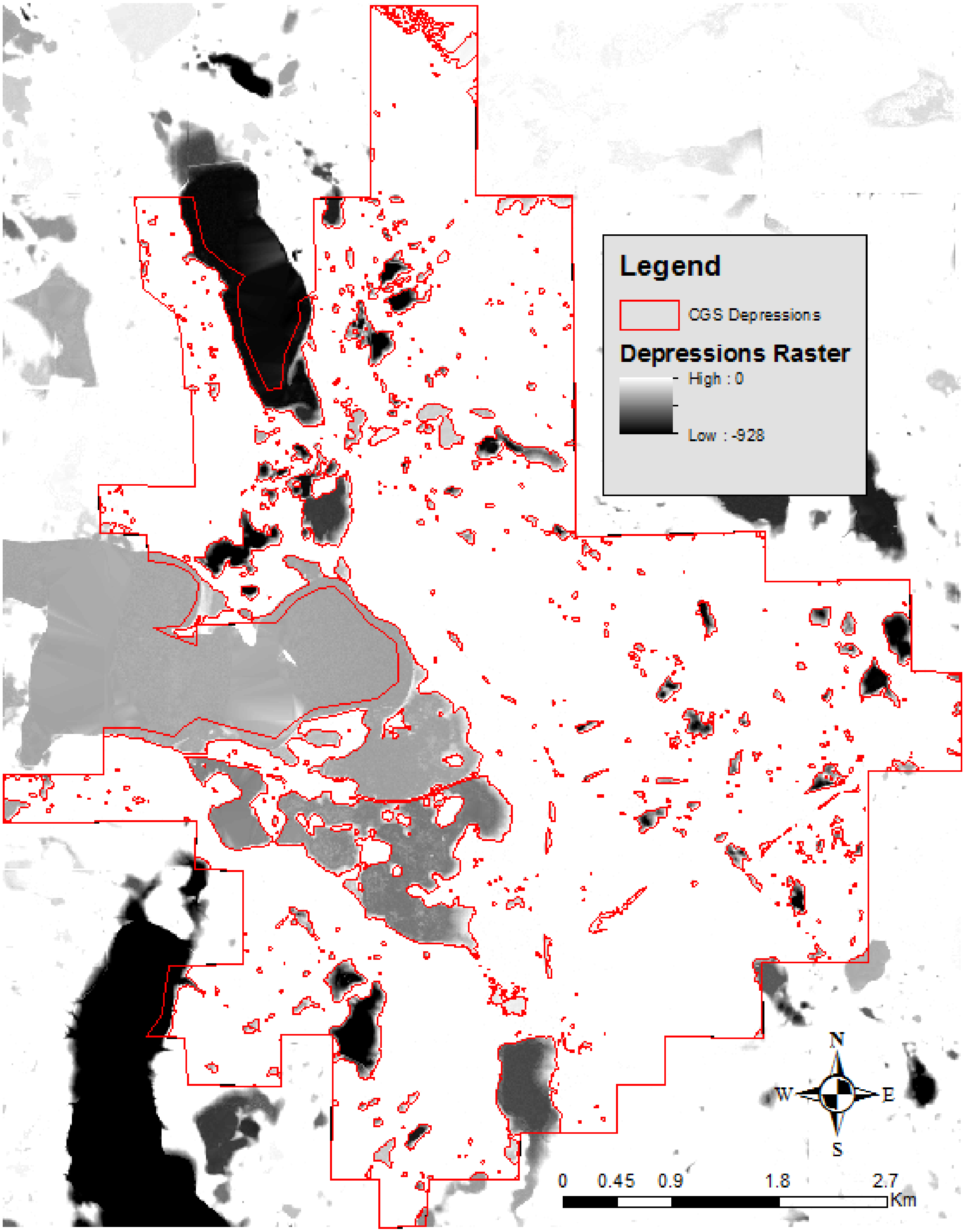


Figure B2. Camp Grafton South Depressions Layer

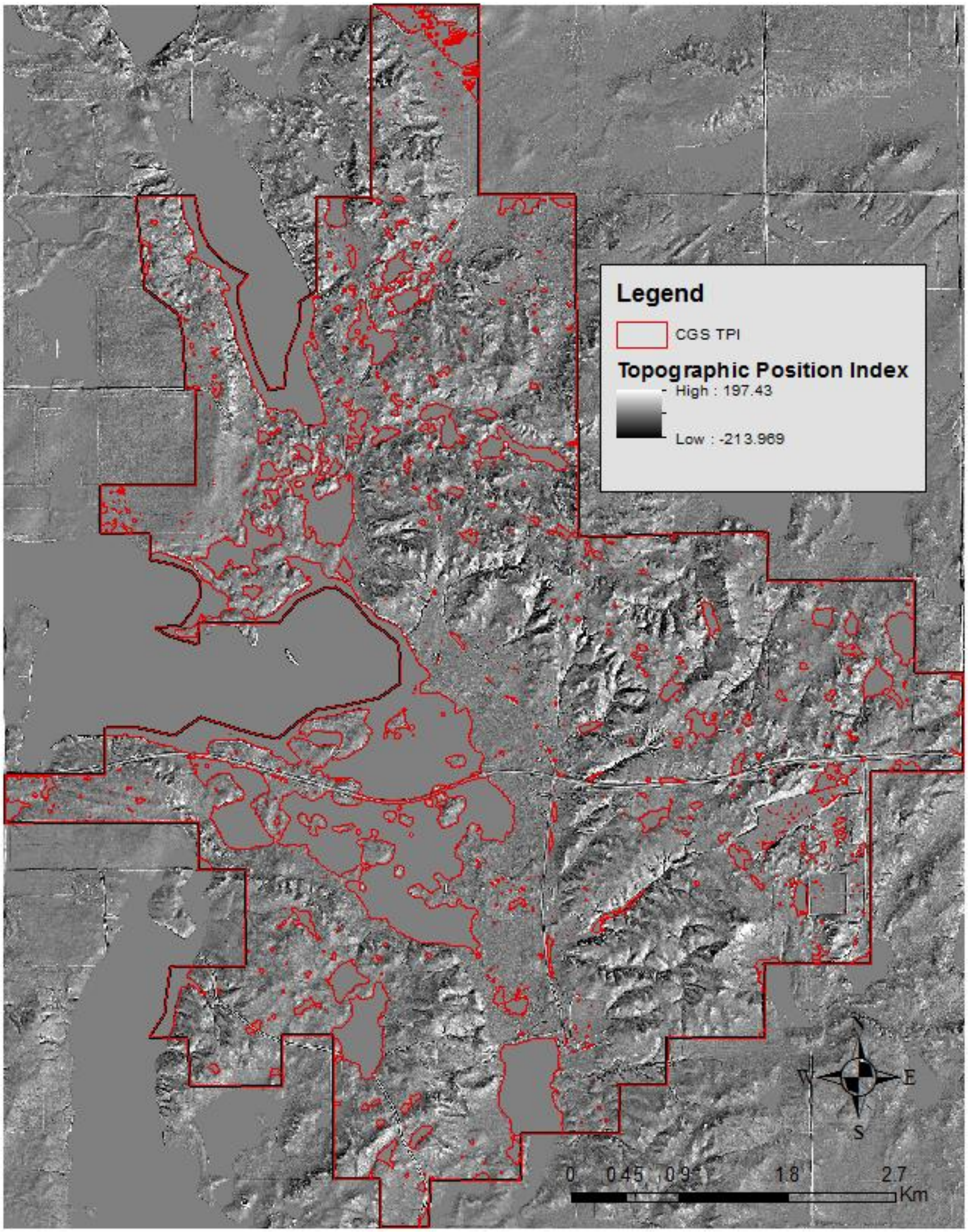


Figure B3. Camp Grafton South Topographic Position Index Layer

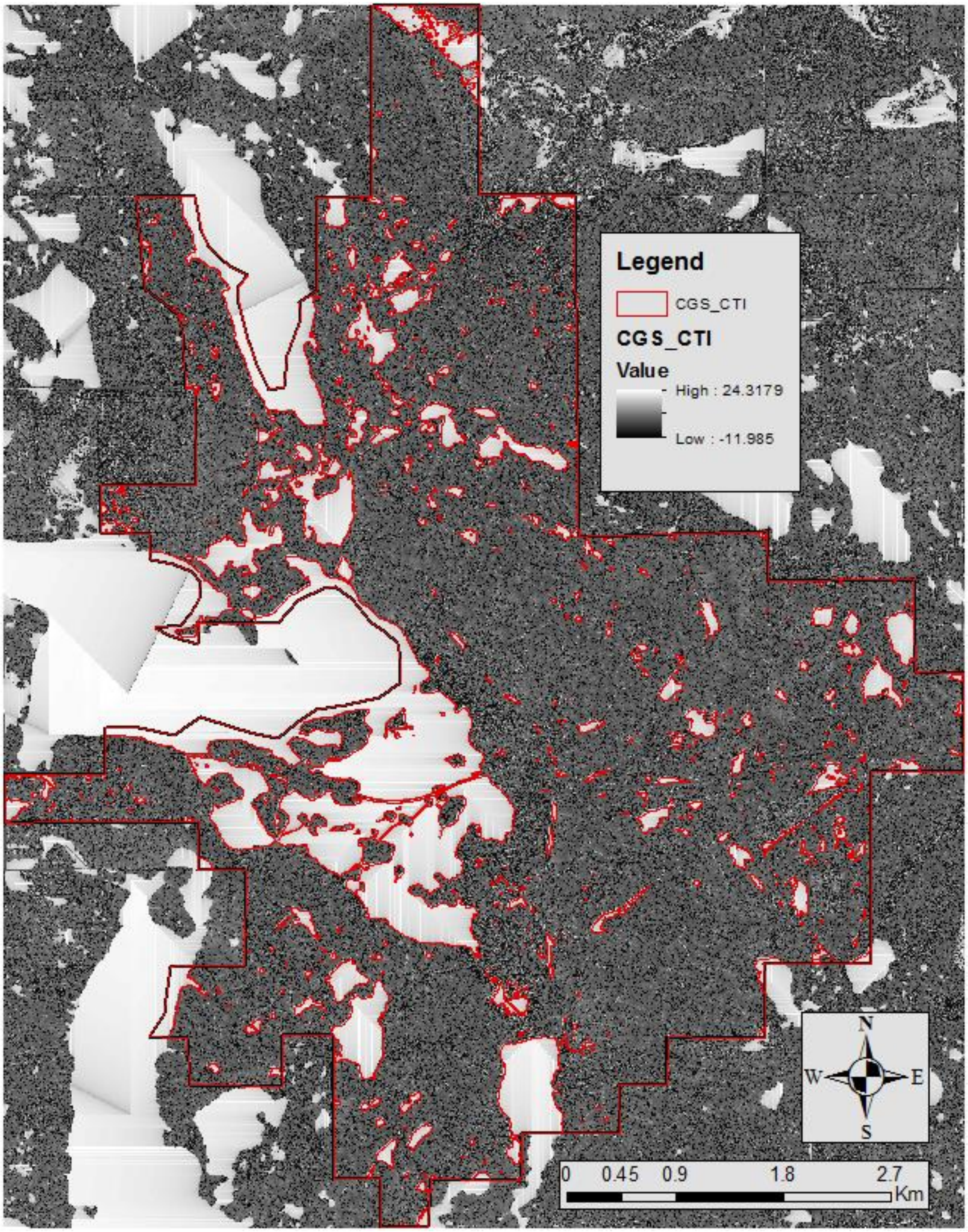


Figure B4. Camp Grafton South Compound Topographic Index Layer

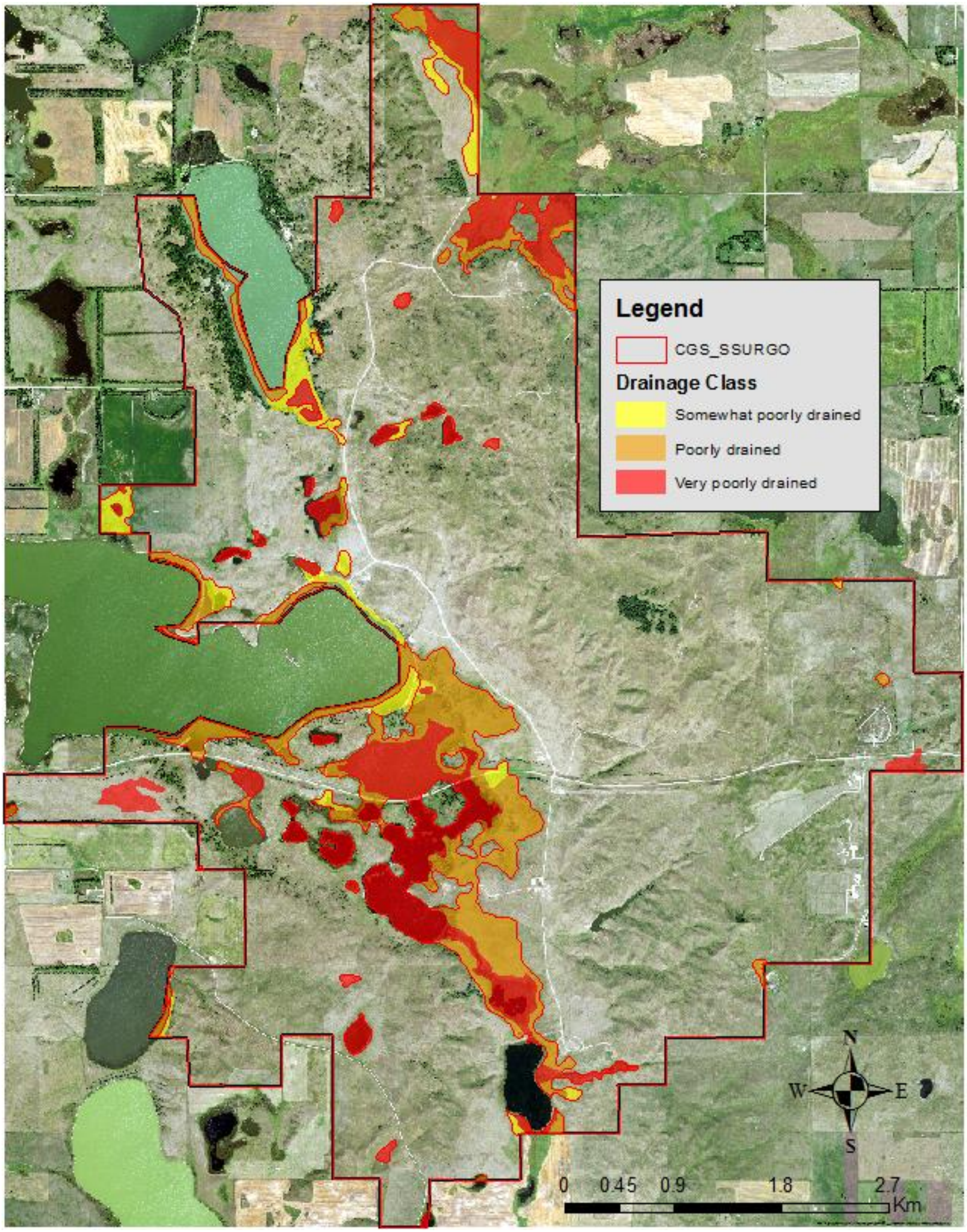


Figure B5. Camp Grafton South SSURGO Soils Layer

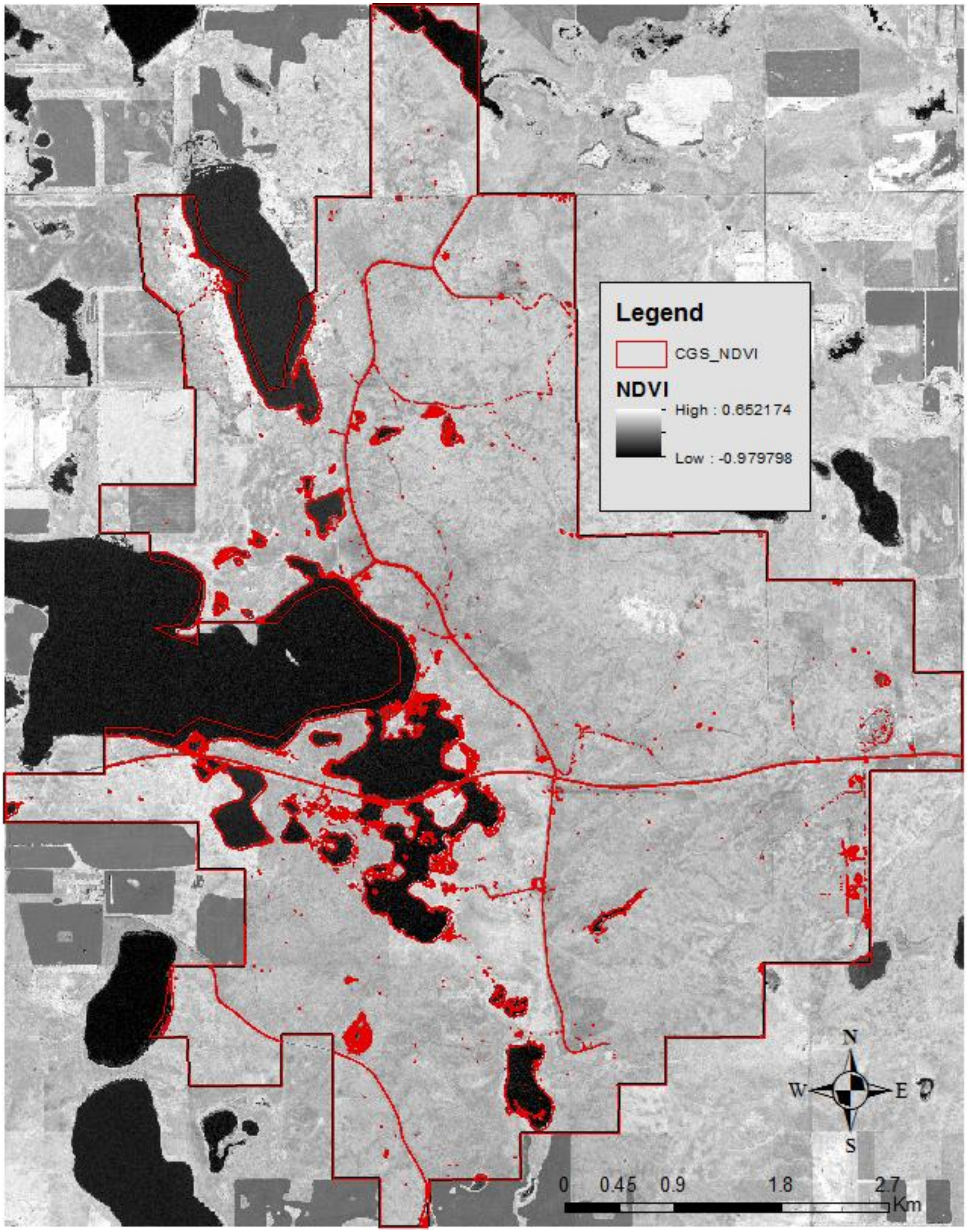


Figure B6. Camp Grafton South Normalized Difference Vegetation Index Layer

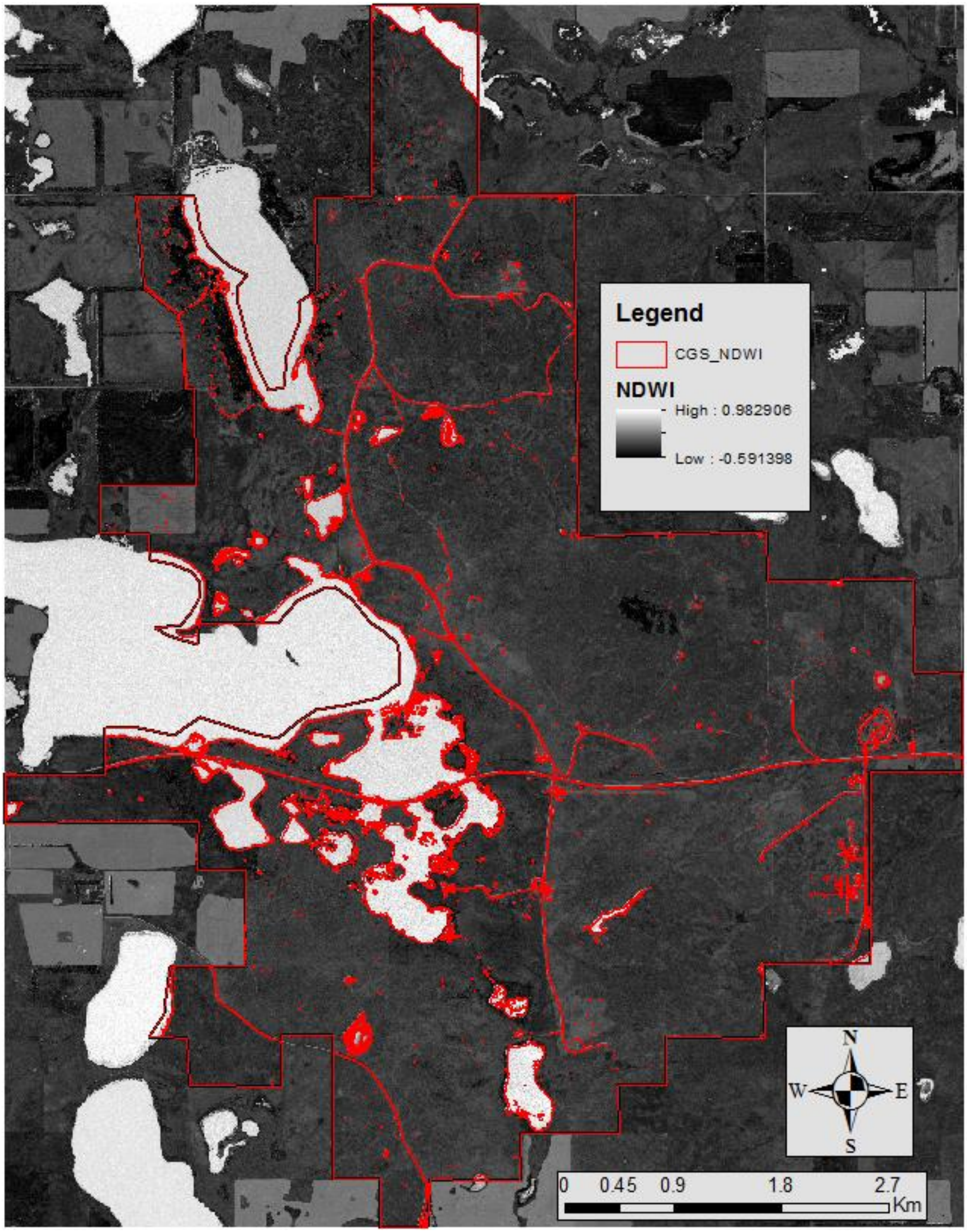


Figure B7. Camp Grafton South Normalized Difference Water Index Layer

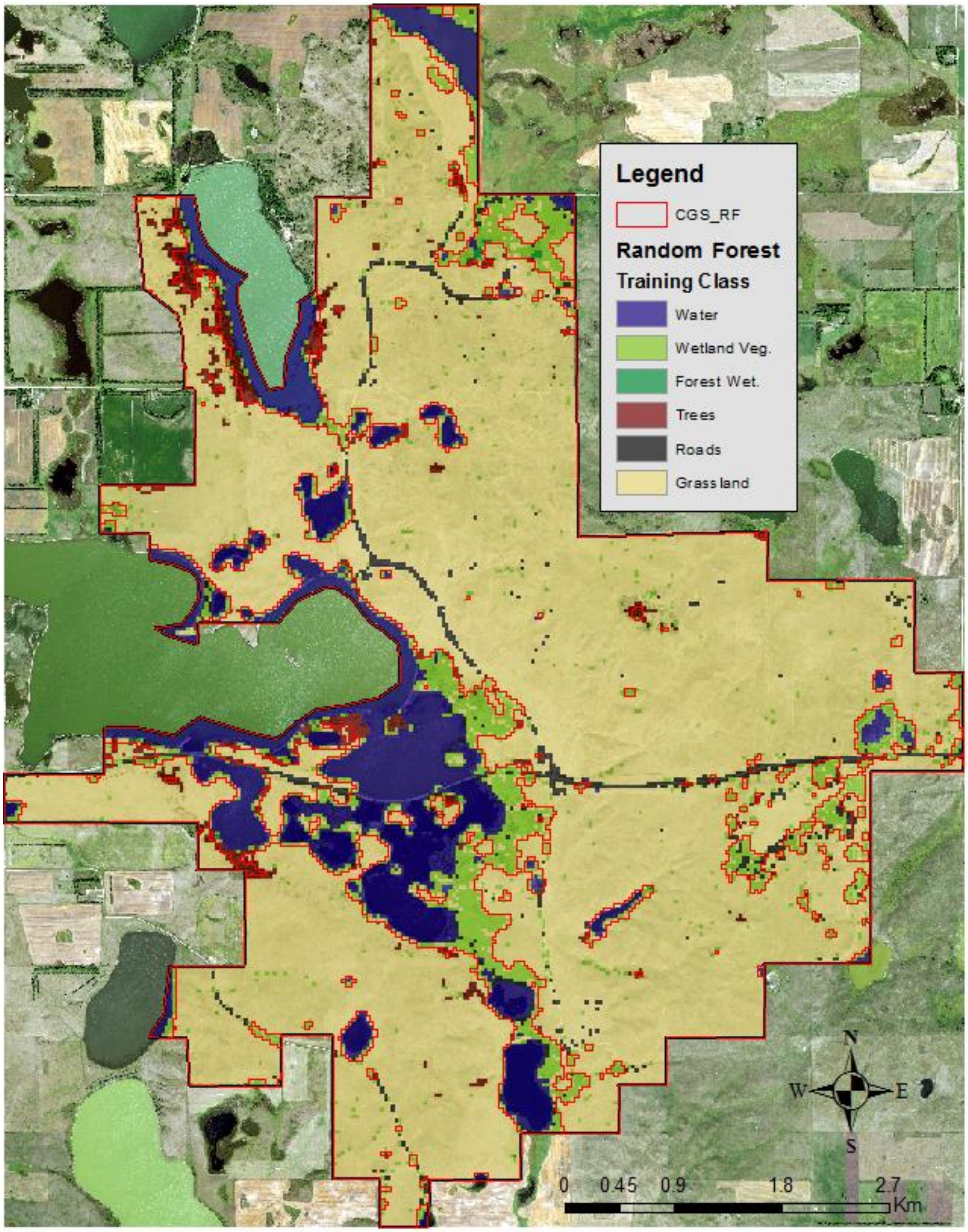


Figure B8. Camp Grafton South Random Forest Layer

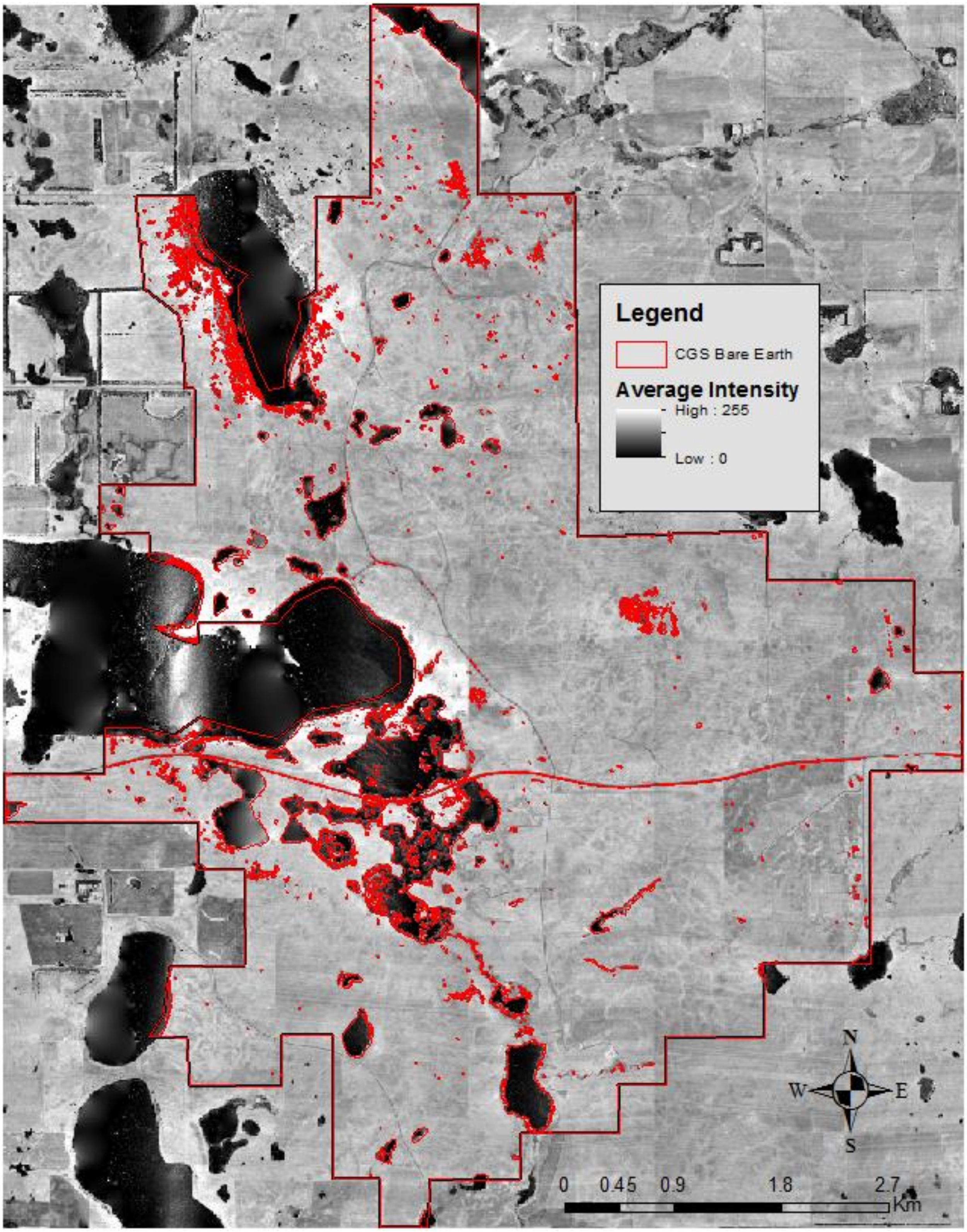


Figure B9. Camp Grafton South Bare Earth Point Cloud Layer

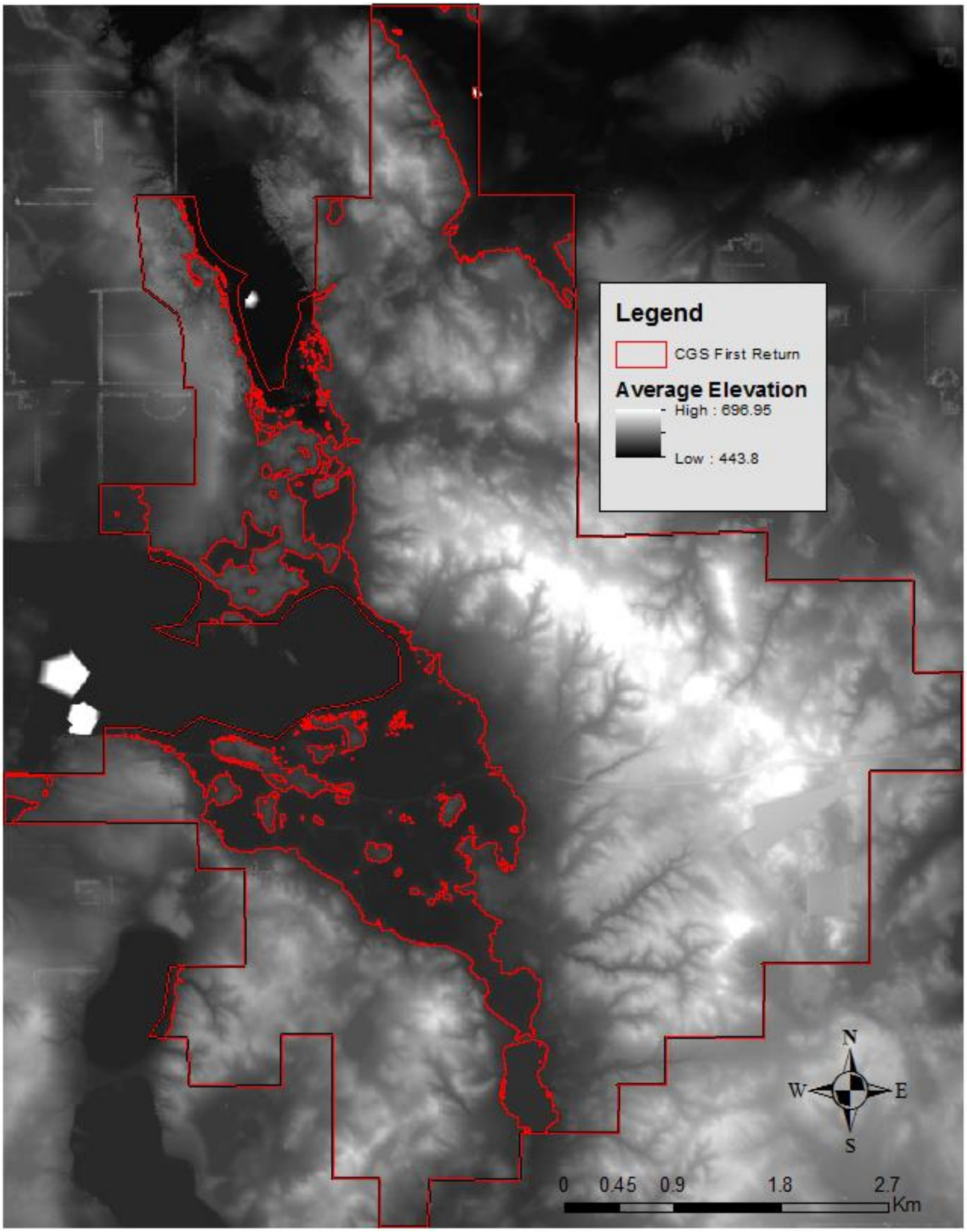


Figure B10. Camp Grafton South First Return Point Cloud Layer

APPENDIX C. WETLAND MAP RESULTS FROM WETLAND LOCATOR MODEL

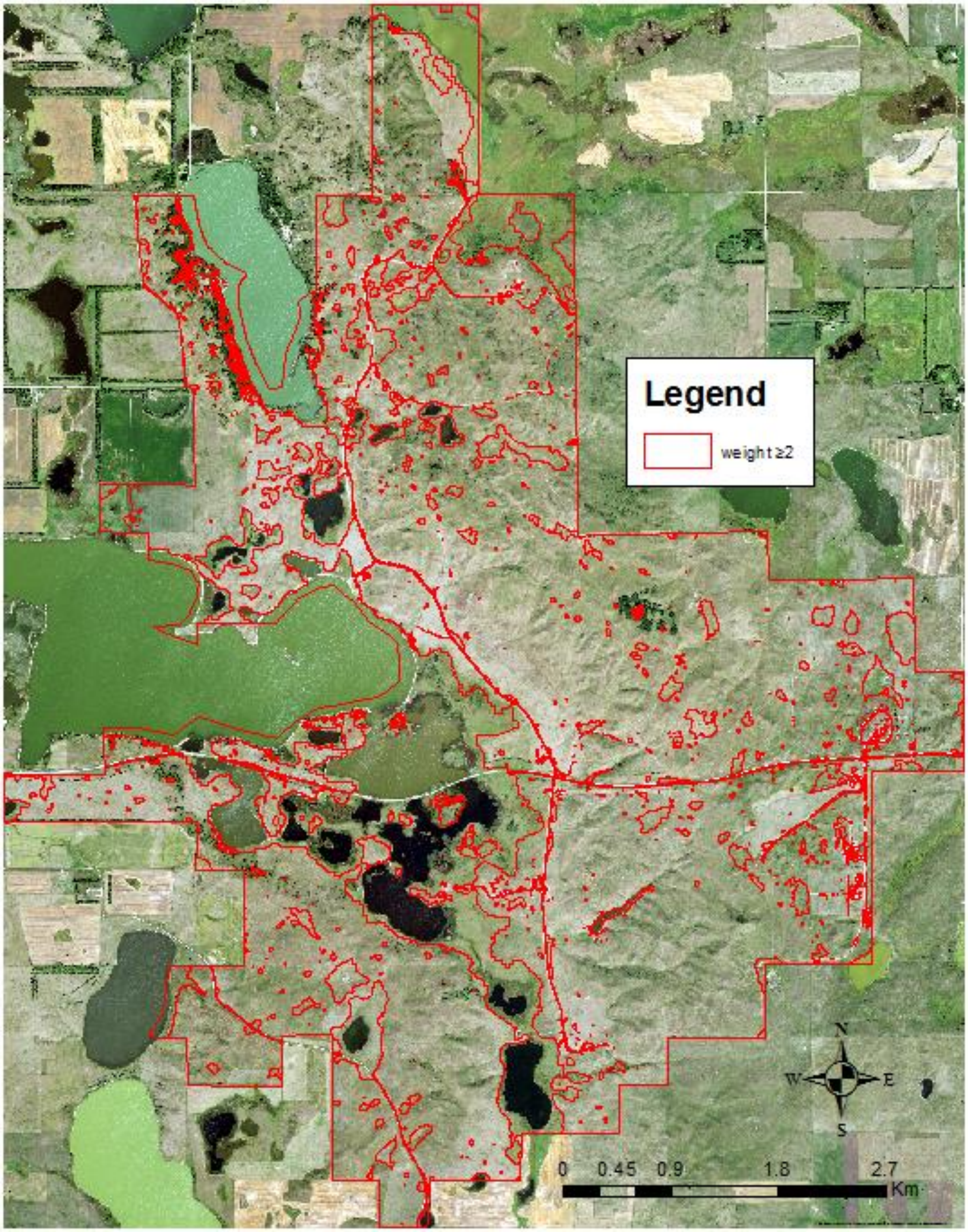


Figure C1. Wetland Map from Applying Weight ≥ 2.

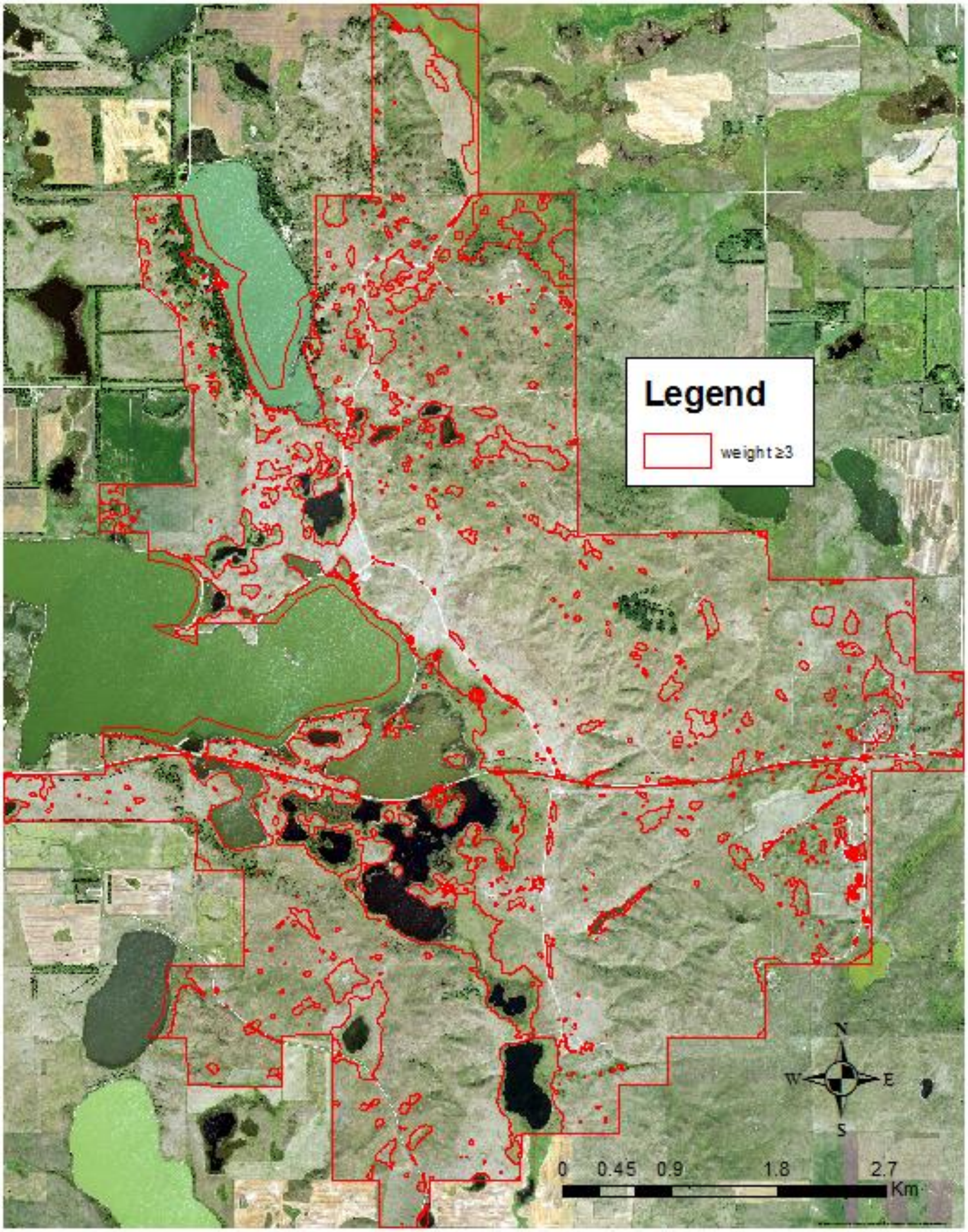


Figure C2. Wetland Map from Applying Weight ≥ 3.

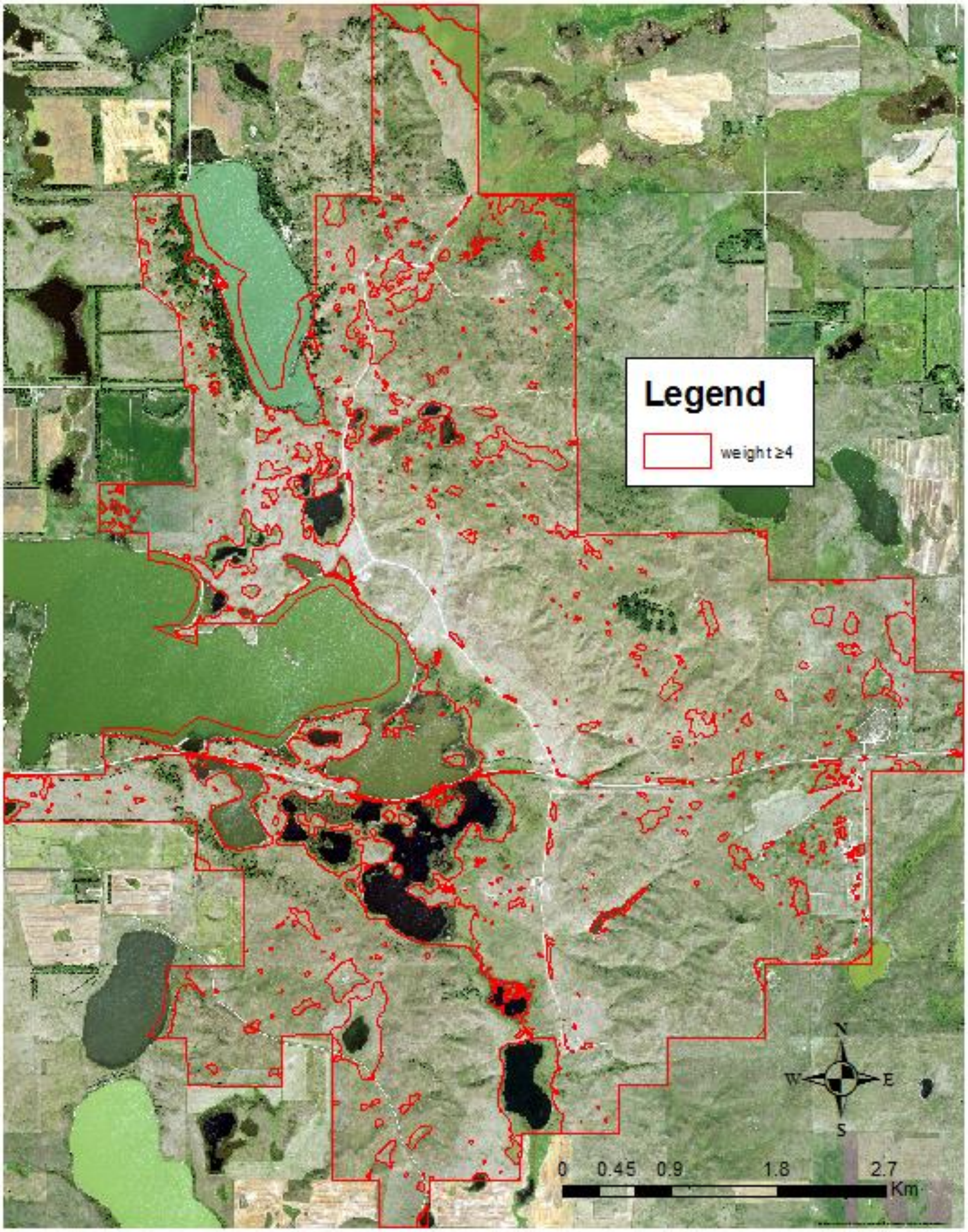


Figure C3. Wetland Map from Applying Weight ≥ 4.

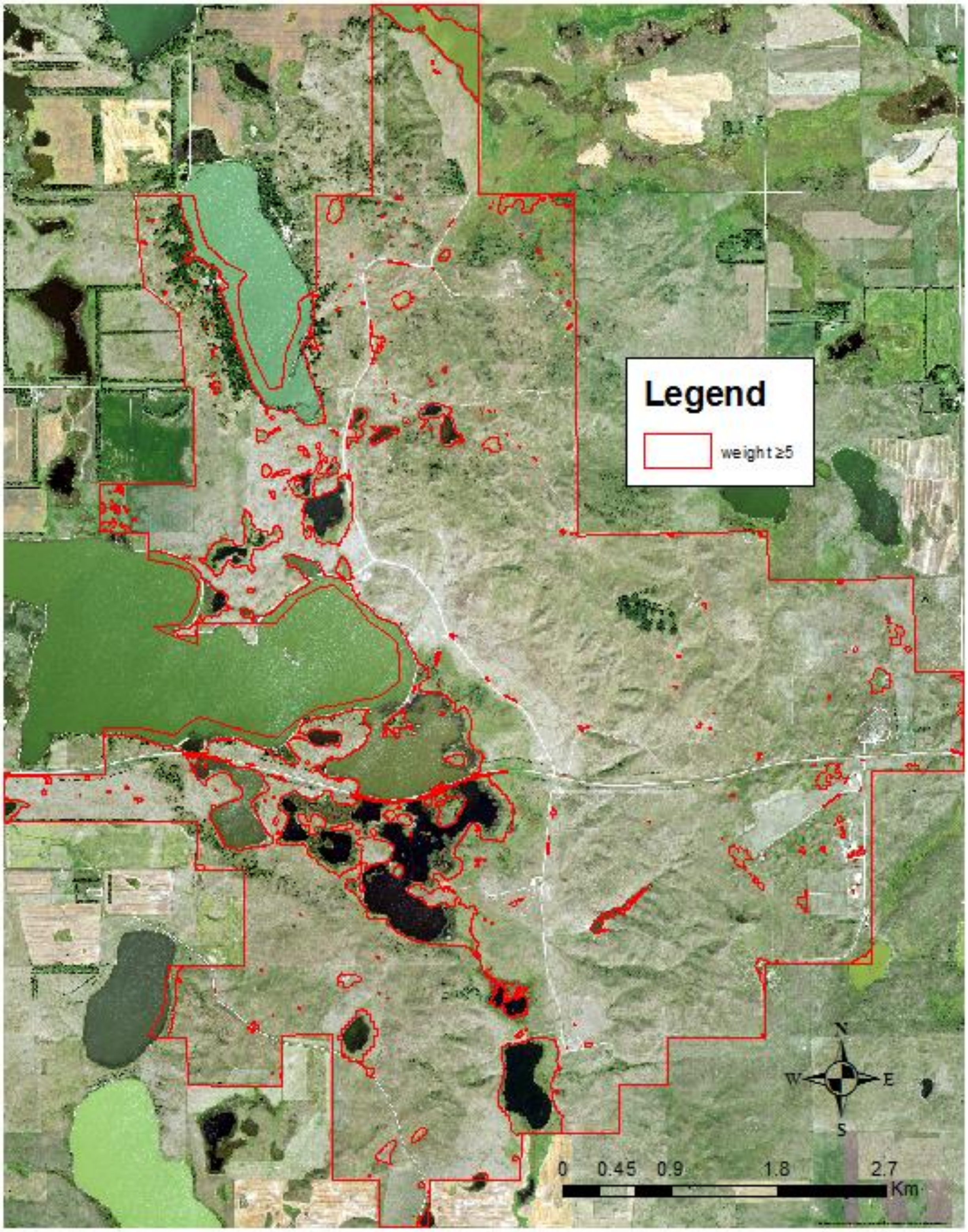


Figure C4. Wetland Map from Applying Weight ≥ 5.

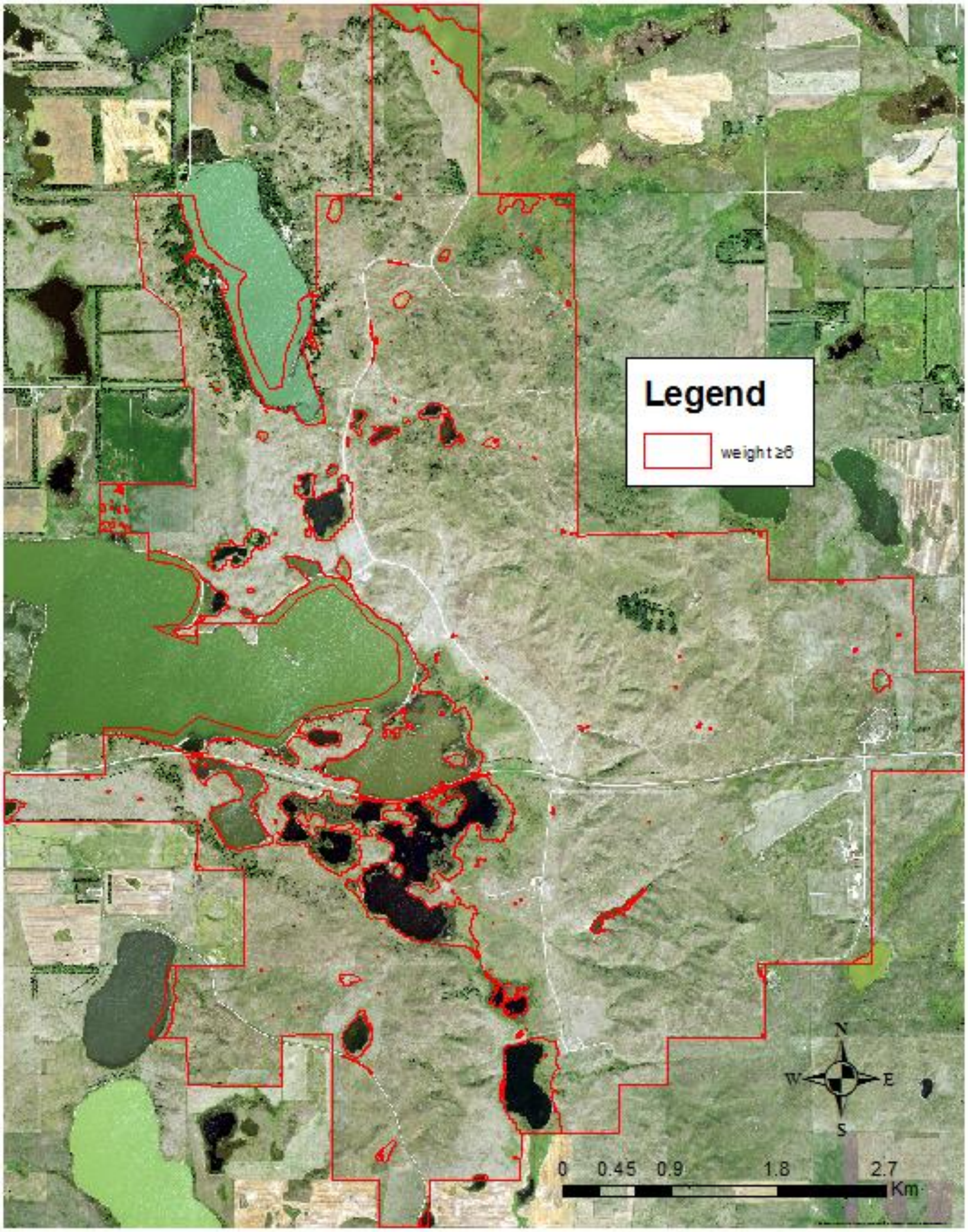


Figure C5. Wetland Map from Applying Weight ≥ 6.

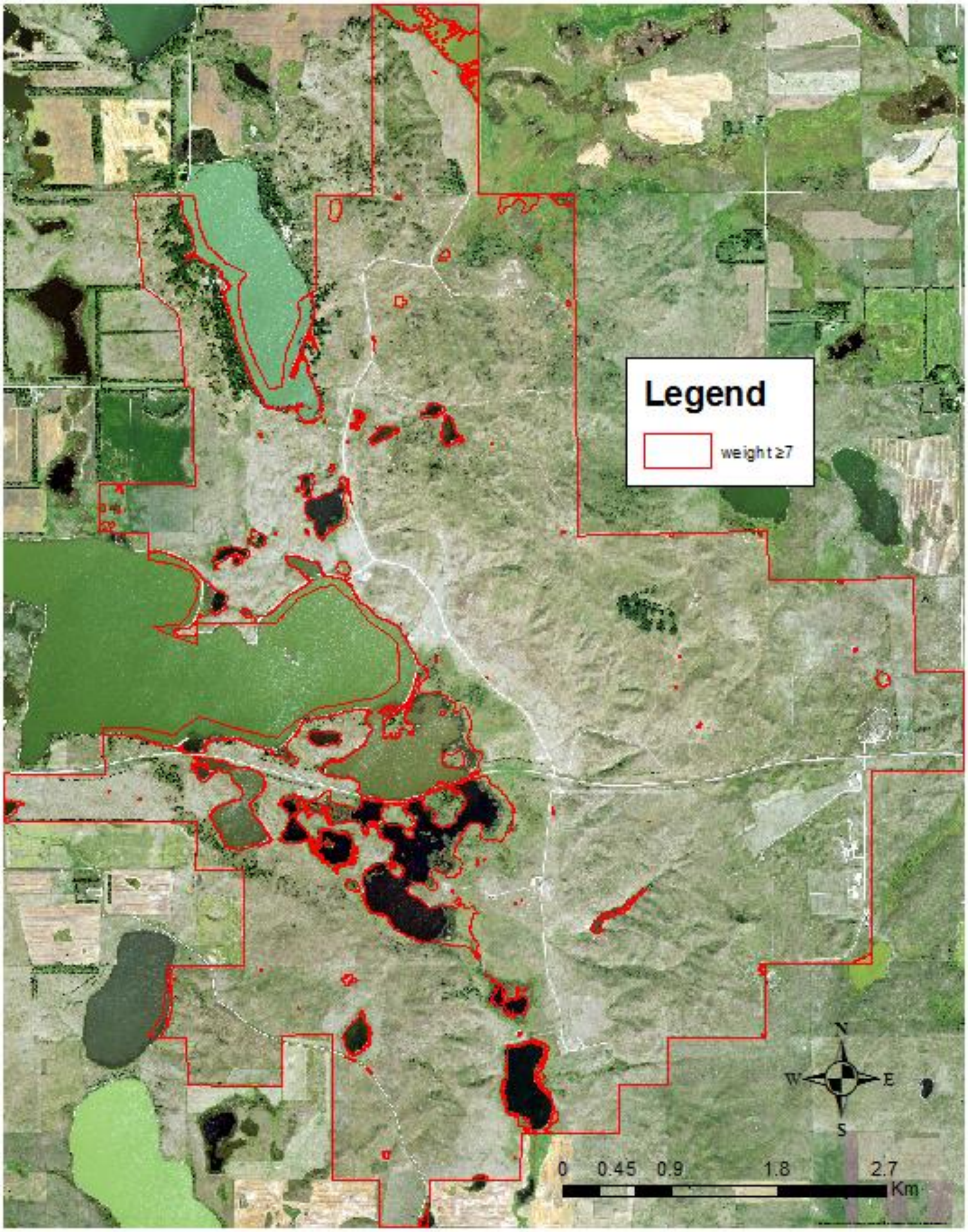
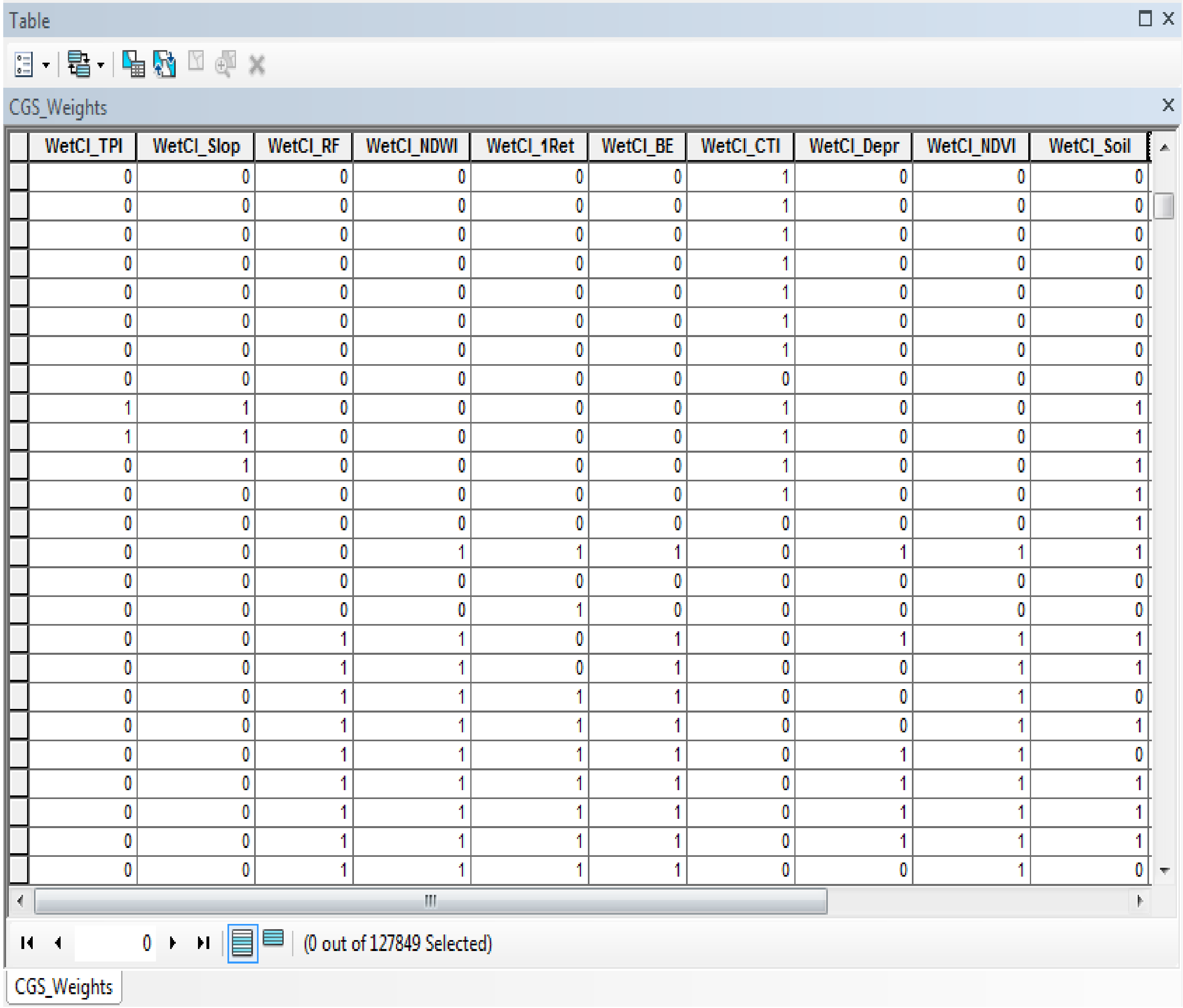


Figure C6. Wetland Map from Applying Weight ≥ 7.

APPENDIX D. ATTRIBUTE TABLE VISUALIZATION OF THE WETLAND LOCATOR MODEL PROCESS



WetCl_TPI	WetCl_Slop	WetCl_RF	WetCl_NDWI	WetCl_1Ret	WetCl_BE	WetCl_CTI	WetCl_Depr	WetCl_NDVI	WetCl_Soil
0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	1	0	0	1
1	1	0	0	0	0	1	0	0	1
0	1	0	0	0	0	1	0	0	1
0	0	0	0	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0	1
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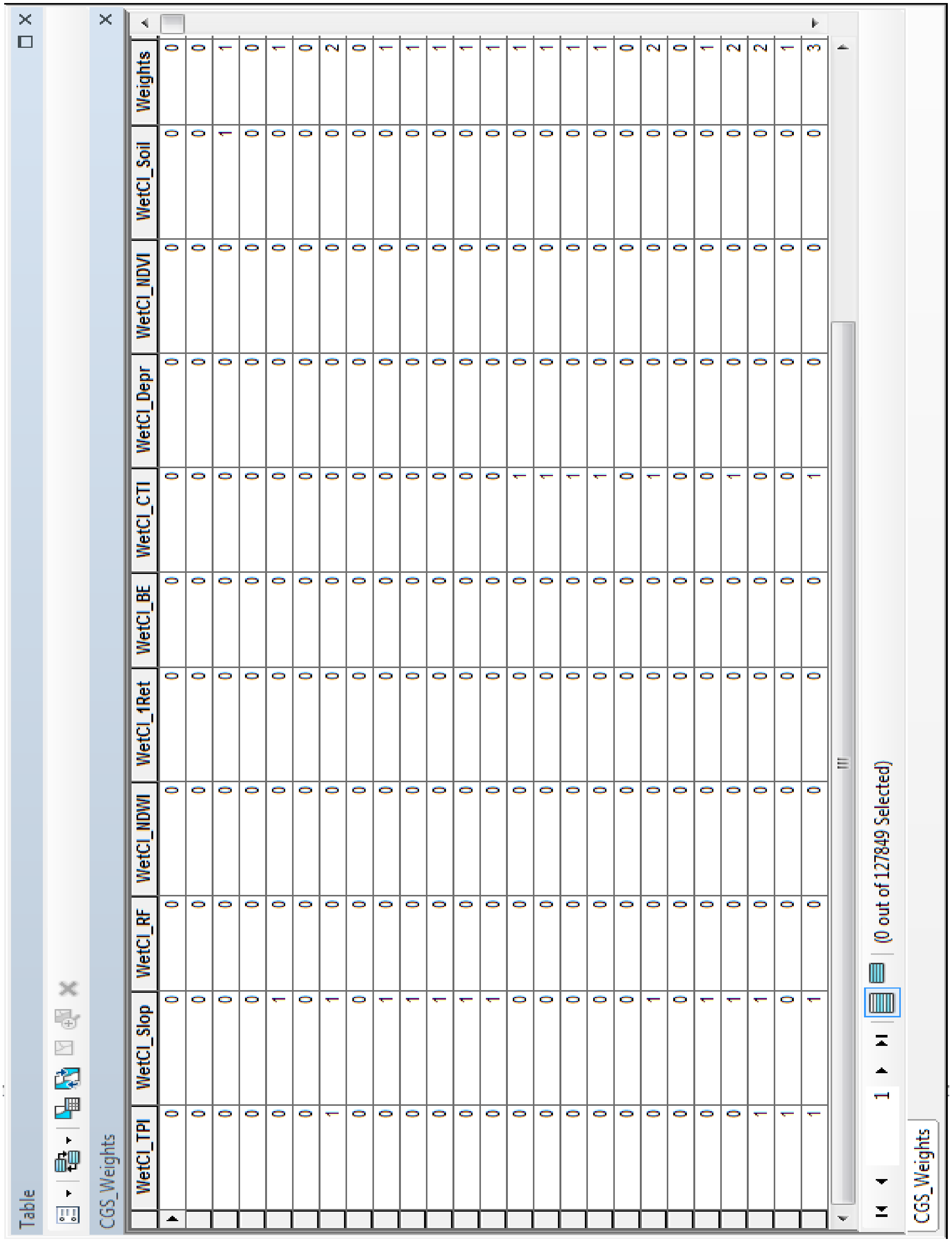
0	0	1	1	0	1	0	1	1	1
0	0	1	1	0	1	0	0	1	1
0	0	1	1	1	1	0	0	1	0
0	0	1	1	1	1	0	0	1	1
0	0	1	1	1	1	0	1	1	0
0	0	1	1	1	1	0	1	1	1
0	0	1	1	1	1	0	1	1	1
0	0	1	1	1	1	0	1	1	1
0	0	1	1	1	1	0	0	1	0

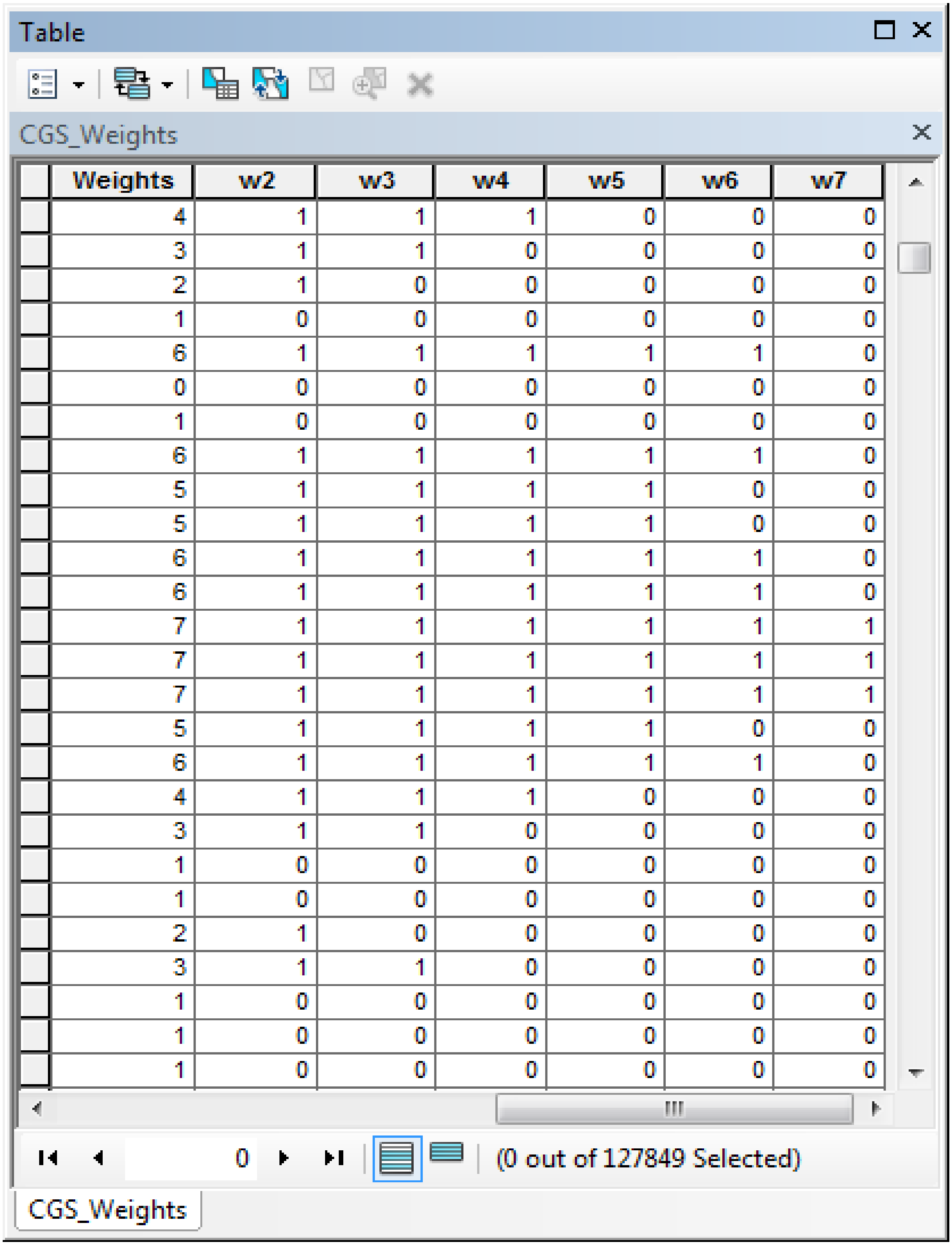
Figure D1. ArcMap attribute table showing the wetland tools unioned together by wet class values.



WetCl_TPI	WetCl_Slop	WetCl_RF	WetCl_NDWI	WetCl_1Ret	WetCl_BE	WetCl_CTI	WetCl_Depr	WetCl_NDVI	WetCl_Soil	Weights
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0	2
0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1
0	1	0	0	0	0	0	0	0	0	1
0	1	0	0	0	0	0	0	0	0	1
0	1	0	0	0	0	0	0	0	0	1
0	1	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	1	0	0	0	1
0	0	0	0	0	0	1	0	0	0	1
0	0	0	0	0	0	1	0	0	0	1
0	0	0	0	0	0	1	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	1	0	0	0	2
0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1
0	1	0	0	0	0	1	0	0	0	2
1	1	0	0	0	0	0	0	0	0	2
1	0	0	0	0	0	0	0	0	0	1
1	1	0	0	0	0	1	0	0	0	3

(0 out of 127849 Selected)

Figure D2. ArcMap attribute table showing the process of adding each wet class together to represent the weights field.



Weights	w2	w3	w4	w5	w6	w7
4	1	1	1	0	0	0
3	1	1	0	0	0	0
2	1	0	0	0	0	0
1	0	0	0	0	0	0
6	1	1	1	1	1	0
0	0	0	0	0	0	0
1	0	0	0	0	0	0
6	1	1	1	1	1	0
5	1	1	1	1	0	0
5	1	1	1	1	0	0
6	1	1	1	1	1	0
6	1	1	1	1	1	0
7	1	1	1	1	1	1
7	1	1	1	1	1	1
7	1	1	1	1	1	1
5	1	1	1	1	0	0
6	1	1	1	1	1	0
4	1	1	1	0	0	0
3	1	1	0	0	0	0
1	0	0	0	0	0	0
1	0	0	0	0	0	0
2	1	0	0	0	0	0
3	1	1	0	0	0	0
1	0	0	0	0	0	0
1	0	0	0	0	0	0
1	0	0	0	0	0	0

Figure D3. ArcMap attribute table showing the weights field and the subsequent wet class for each weighted field. A value of one equal’s wetland area and a value of zero equal’s upland.