NEBRASKA WETLAND CONDITION ASSESSMENT: INTENSIFICATION OF THE NATIONAL WETLAND CONDITION ASSESSMENT THROUGHOUT NEBRASKA

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NEBRASKA WETLAND CONDITION ASSESSMENT:

INTENSIFICATION OF THE NATIONAL WETLAND CONDITION ASSESSMENT THROUGHOUT NEBRASKA

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Even though wetlands provide a habitat for many plants and animals and numerous services for humans, they were not always treated as areas of value. Less than half of the United States' pre-colonial wetlands have survived to the present day. Seeing a need to understand the remaining wetlands more fully, the Environmental Protection Agency developed the National Wetland Condition Assessment to monitor target wetlands throughout the country every five years.

This study is an intensification of the National Wetland Condition Assessment for Nebraska wetlands that allowed us to sample more areas of the state and gather additional information. During the summers of 2016 and 2017, wetlands located within five Biologically Unique Landscapes were surveyed. Measurements were taken for vegetation, soil, water, and hydrology within the assessment area, and land use measurements were taken in the buffer area directly adjacent to the assessment area.

Multimodel inference was used to predict the best fitting linear models for 11 vegetation, soil, and water parameters to better understand what factors drive certain aspects within wetlands. While no binding regulations exist for soil quality or water quality in Nebraska wetlands, very few sites exceeded pseudo standards set up in this study based on values from the EPA and Nebraska Department of Environmental

Quality. Vegetation, soil, and water sampling methods were evaluated to justify the time and money spent during this and future projects. Data from this study will be further used as a baseline for Nebraska wetlands in future Nebraska Wetland Condition Assessments and similar projects.

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CHAPTER 1: INTRODUCTION TO WETLANDS AND THE INTENSIFICATION OF THE NATIONAL WETLAND CONDITION ASSESSMENT: NEBRASKA WETLAND CONDITION ASSESSMENT

Introduction

Wetlands are one of the most important ecosystems on earth. They provide many social, ecological, and economic benefits such as ground water recharge, flood control, wildlife habitat, nutrient storage and cycling, and sediment entrapment (Leitch and Hovde 1996). Globally, wetlands provide more value to humans in ecosystem services per hectare per year than any other biome (Costanza et al. 1997). These services are produced over the whole life of a wetland, providing more services in the long run than industrial or agricultural land uses which may eventually be exhausted (Mitsch and Gosselink 2000). It could be said that the ecosystem services provided by wetlands are of "infinite" value to the global economy since without ecosystem services, the economies of the world would be unable to function (Costanza et al. 1997).

Humans are not the only species to benefit from wetlands. Wetlands in China provide habitat for about 5% of the country's mammal species, 25% of the bird, reptile, and fish species, and for all of the amphibian species. Wetlands are even more important for the endangered species of China, with nearly half of the mammal and bird species, about 80% of the fish and reptile species, and all of the amphibians using wetlands. They also provide habitat for about 5% of China's plant species but 10% of the lost or endangered plant species (An et al. 2007).

Wetlands in Nebraska provide habitat for 100% of the state's amphibian species, 50% of the plant and bird species, and over 35% of the state's reptile and mammal

species (LaGrange 2005), yet wetlands only make up about 4% of the area of Nebraska (Dahl 1990). Wetlands are also habitat for 75% of the state's federally endangered species and 70% of the state-listed species (LaGrange 2005). For example, each year endangered whooping cranes, large numbers of sandhill cranes, and numerous species of waterfowl stop on the Platte and North Platte rivers to forage in the surrounding wetlands and agricultural lands during their yearly migration (U.S. Fish and Wildlife Service 1981, Meyer et al. 2008).

Apart from wildlife habitat, Nebraskan wetlands provide many ecosystem services essential to a rural life style. Wetlands filter and clean water, one of Nebraska's most important resources (LaGrange 2005). They also remove and retain excess nitrogen from the nearby agricultural lands (Meyer et al. 2008).

Even though wetlands provide humans with numerous services, and provide important plant and animal habitat, they were not always treated as areas of value. Wetlands in Great Britain have been converted for agricultural use at least as far back as the time of the Roman Empire (Davidson et al. 1991), while areas of China have been reclaiming wetlands for about 2000 years (An et al. 2007). It has been estimated that the world has lost as much as 87% of its wetlands since 1700 (Davidson 2014). This number does not take into account the areas lost before 1700, which indicates the losses over the time of human civilization to be even higher. Even though humans can now see value in wetlands, wetland loss is still occurring in all regions of the world in the 21st century, with rates highest in Central America, South America, and Asia, and lowest in North America (Davidson 2014).

From the start of colonization, wetlands in the United States have often been viewed as nuisances and were seen as unproductive land to be converted to something more useful (Dahl 1990). From 1780 to 1980, the conterminous United States lost 53% of its wetlands (Dahl 1990). Even though humans are the main cause of degradation, not all of the loss of wetlands in the United States is due to human efforts. Louisiana loses coastal wetlands at a rate of about 100km^2 a year due to waves and extreme weather such as hurricanes (Day et al. 2007).

Nebraska faired only slightly better than the rest of the conterminous United States in terms of wetland loss. Nebraska lost approximately one million acres of wetlands from 1780 to1980, which is a little more than a third of the state's original wetlands (Dahl 1990). While the state as a whole has escaped some of the destruction when compared to the conterminous United States, some areas of the state, such as the Rainwater Basin Wetland Complex, have seen approximately 90% of the original wetlands destroyed since European settlement (Jorgensen et al. 2013).

The need to globally protect wetlands was acknowledged in 1971 with the creation of the Convention on Wetlands, also known as the Ramsar Convention. The Convention is a treaty that is designed to promote conservation of wetlands throughout the world (Mathews 1993). The Ramsar Convention now has 170 contracting parties and has over 228 million hectares of land in the Convention (see www.ramsar.org, accessed 30 January 2017).

With the passage of the Clean Water Act in 1972, the United States saw a shift in the attitude toward wetlands from actively draining and destroying them for agricultural use (McCorvie and Lant 1993) to attempts to protect wetlands and to cause no net

wetland loss (Keddy et al. 2009). The annual wetland loss rate was reduced by about 80% for the period of 1986 to 1997 when compared to the mid 1970's to the mid 1980's (Dahl et al. 1991, Dahl 2000). While this result is not exactly what was meant by "no net wetland loss," it is a step in that direction.

Currently, Nebraska has many strategies to combat local wetland destruction. Nebraska Game and Parks Commission and the University of Nebraska have each set up programs to teach educators and young children about our wetland resources (LaGrange 2005). Many agencies and organizations throughout Nebraska, including the Rainwater Basin Joint Venture, Ducks Unlimited, Natural Resources Conservation Service, U.S. Fish and Wildlife Service, Crane Trust, Sandhills Task Force, The Nature Conservancy, and others, have made efforts to improve wetlands in the state. Since 1994, these organizations have obtained over $100 million of grant funding and helped to conserve over 90,000 acres of wetlands (LaGrange 2015).

The EPA started a cycle of studies using the National Aquatic Resource Survey to examine the ecological condition of US waters. The EPA began with wadable streams in 2004, moved to lakes in 2007, rivers and streams in 2008-2009, and coastal waters in 2010. In 2011, the EPA implemented the first National Wetland Condition Assessment (NWCA), focusing on the wetlands of the US. After the completion of this project, the EPA planned to continue this cycle of five assessments every five years, with National Wetland Condition Assessments planned for years that end in 1 and 6 (USEPA 2016a).

During the first cycle of the National Aquatic Resource Survey, the several states (including Nebraska) and regions of the country conducted additional sampling using the same or similar protocols to the NWCA to examine local wetlands more thoroughly.

From 2011 to 2013, the University of Nebraska-Lincoln and the Nebraska Game and Parks Commission aided a graduate student in the first Nebraska Wetland Condition Assessment. That study examined 10 sites at 11 different Biologically Unique Landscapes (BULs) in Nebraska (LaGrange 2015, USEPA 2016a).

The purpose of this study was to expand on the 2011-2013 study by determining the condition of the five different wetland types across Nebraska based on data collected over the summers of 2016 and 2017. This was accomplished by the collection of soil, water, vegetation, and hydrology data within the wetlands and buffer data from the area around the wetlands. This information was used to make predicative models and to compare current wetland soil and water values to standards of the EPA and state. This information will be used further as baseline data for Nebraska wetlands in future Nebraska Wetland Condition Assessments.

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CHAPTER 2: WETLAND VEGETATION OF FIVE BIOLOGICALLY UNIQUE LANDSCAPES IN NEBRSAKA

Introduction

Vegetation greatly affects processes such as hydrology, water chemistry, and soil formation (USEPA 2016a), and is one of the three variables used to determine if an area is a wetland during wetland delineation (Environmental Laboratory 1987). Not only can they define an area, wetland plants have been shown to be good indicators of wetland condition (Lopez and Fennessy 2002, Miller and Wardrop 2006) and have been used to evaluate the amount of disturbance in a wetland (Miller and Wardrop 2006).

Vegetation type can change soil (Mack et al. 2000, Elith et al. 2006, Jordan et al 2008) and water chemistry values (Ehrenfeld 2003) and vegetative litter adds nutrients back into soil (Ashton et al. 2005) and water (Webster 2009).Wetland plants can reduce the concentration of contaminants in wetlands (Truu et al. 2015). Presence or absence of wetland plant species can facilitate or hinder the growth of other wetland species (Elith et al. 2006, Saltonstall 2002, Jordan et al 2008).

While many vegetative communities in Nebraska are well understood, few if any of the wetland communities in this study have been surveyed in the last 20 years. The objective of this study was to collect the full range of conditions for the vegetation of five Nebraskan wetland types. This information will be used in the short term to inform on current vegetative status of these wetlands, evaluate sampling methods, and create predictive models for vegetation variables. This information will be used in future Nebraska Wetland Condition Assessments and similar studies as baseline information for the vegetation of five Nebraskan wetland types in 2016 and 2017.

Methods

The methods for this study were as described in the National Wetland Condition Assessment (NWCA) 2016 Field Operations Manual developed by the Environmental Protection Agency (EPA) (USEPA 2016c). The purpose of the NWCA is to collect information about the condition of wetlands across the country every 5 years, as well as to monitor changes in five major aspects of those wetlands: hydrology, buffer, vegetation, water quality, and soil. While data were collected on all five of these aspects, this thesis focuses on the latter three: vegetation, water quality, and soil.

Sampling occurred in five priority natural wetland plant communities (Rolfsmeier and Steinauer 2010) in Biologically Unique Landscapes (BUL) in Nebraska (Schneider et al. 2011) over the summers of 2016 and 2017. The five wetland plant communities and BULs were the Sandhill Fens (Cherry County Wetlands BUL) (SH), Western Subirrigated Alkaline Meadows (Upper Niobrara River BUL) (AM), Cottonwood-Diamond Willow Woodlands (Loup River BULs) (LR), Eastern Bulrush Deep Marsh Community (Central Platte River BUL) (CP), and Freshwater Seeps (Verdigris-Bazile Creek BUL) (VB) (Figure 2.1). The Core Team, a group of experts from 11 agencies and organizations, selected these BUL's because they felt these BULs were in generally good condition, are vulnerable to future anthropogenic changes, and/or were areas where information was needed to help with conservation planning (e.g. slough restoration along the Central Platte and wetland permitting issues related to slope wetlands). There were 20 sites sampled in each BUL, which generated 100 total sites for the state.

Within each BUL, the same wetland hydro-geomorphic method (HGM) subclass was sampled to ensure comparability within a complex (LaGrange 2010). Each of the

HGM subclasses for Nebraska was associated with the Nebraska Natural Heritage Program Natural Communities of Nebraska (Rolfsmeier and Steinauer 2010). A list of the Natural Community to target in each Complex/BUL was put together by the Core Team. This list was then associated with representative soil mapping units as determined by the NRCS soil scientist on the Core Team, and representative National Wetland Inventory (NWI) wetland polygons that were available in GIS datasets. Areas where the soils and NWI polygons overlapped within the BUL or a sub-set of the BUL represented a universe of wetlands that were assumed to be within the same HGM subclass and to represent the selected natural community. Appendix A lists the BULs sampled, and their associated soil mapping units, NWI codes, and natural communities.

Specific sample selection GIS processing methods included the following steps:

- The BUL boundary shapefile was used define the geographic extent of where a sample could be drawn from.
    - The BUL boundaries were further clipped in the Upper Loup River BUL by using Loup and Custer Counties as the western most counties included in the search based on suggestions from Bob Steinauer.
- A Soil Mapping Unit was then associated with each Natural Community Type. This was done by Dan Shurtliff (NRCS Assistant State Soil Scientist) or Neil Dominy (NRCS State Soil Scientist) and then reviewed by the Core Team.
- NWI polygon data were clipped by the BUL or Complex boundary.
- NWI polygons of the appropriate Cowardin (Cowardin et al. 1979) wetland classification type (Appendix A) were selected. These types were selected to be

representative of the natural community type and Soil Mapping Unit. Selection of the NWI type was made by Ted LaGrange with input from members of the Core Team.

- The selected NWI polygons were then clipped by the Soil Mapping Unit polygons, and the internal boundaries of the NWI polygons were dissolved.
    - In addition to these methods, an additional GIS layer from Gerry Steinauer was used in the Cherry County Wetland BUL to ensure the sites selected using the GIS methods were fens. All sites selected to be sampled were of the selected soil mapping unit and NWI polygon but were also know fens from the GIS fen data layer.
    - In addition to these methods, an additional GIS layer from the Nebraska Game and Parks Commission's Natural Heritage Program database that mapped known cottonwood diamond willow communities was used in the Upper Loup River BUL to increase the likelihood of sampling the targeted community. All sites selected to be sampled were of the selected soil mapping unit and NWI polygon but we specified that the seven sites mapped in the heritage data base were to be sampled and then randomly selected the other 13 sites to be sampled.
- ArcGIS was used to randomly select 30-60 NWI polygons (with Hawth's Tools, an extension to ArcGIS, http://www.spatialecology.com/index.php). These included 20 wetlands to be sampled if access was permitted, and additional wetlands (overdraw) to select alternates from if access was denied or the wetland was determined to be not suitable as a sample site.
    - Minimum size of a NWI polygon was 500 square meters. This was the minimum size that could accommodate the five vegetation sample plots.

  - The outer edges of sample polygons were at least 280 meters apart. This ensured no overlap of buffer assessment areas (buffer assessment plots extend 140 meters from the sample point).

- A sample point was randomly placed in each of the 30-60 sample polygons. As was done for the NWCA survey, the Intensification Project was characterizing a sample point within a wetland, and not the entire wetland.
  - Because the NWI and soils data did not adequately represent the targeted plant community for the Central Platte BUL, Kirk Schroeder (USFWS Biologist) was asked to review the universe of sample polygons selected in GIS using the NWI and soils data and then select polygons for sampling that he thought could support the targeted wetland plant community. Kirk selected 31 sites for potential sampling and random points were not used.
  - Because the NWI and soils data did not adequately represent the targeted plant community for the Verdigris Bazile BUL, the sample selection method was slightly altered. The soils and NWI (line and polygon) data were used to select the universe of sample polygons. Then these were examined by Ted LaGrange, and he selected the ones (N=36) that appeared to be slope wetlands in the upper ends of the watersheds.

Once permission was granted by landowners to access individual wetland sites, GPS units were used to navigate to the center of the site. From the center of the site, a circle with a radius of 40 meters was measured. This circle created a study area of 0.5 hectares and was known as the Assessment Area (AA). If the AA was more than 10%

non-wetland, such as open water or upland, the AA was shifted up to 60 meters to ensure the AA is at least 90% wetland.

If a circular AA was not possible, a polygon AA was used. The edges of the polygon was designed to get the area of the AA as close to .5 hectares as possible. If both a circular AA and polygon AA were not possible, a wetland boundary AA was used. In this case, the edges of the wetland were used as the edge of the AA (Figure 2.2).

The area of any polygon AA or wetland boundary AA were between 0.1 and 0.5 hectares depending on the size of the wetland. If the wetland was smaller than 0.1 hectares, it was excluded from the study and replaced by the next wetland on the sample draw list.

Each site contained 5 vegetation plots, each $100m^2$. For a standard circular AA, the first and second plots were be placed with their northwest corner 2m and 22m straight south from the center respectively. The third plot had its north east corner 15m west of the center point. The fourth plot had its southeast corner 15m north of the center point, and the fifth plot had its south west corner 20m east of the center point. (Figure 2.3). If a site did not fit a standard circular AA, the vegetation plots were be set up in other configurations within the AA. Greater spacing between a plot and the edge of the AA and greater spacing between plots were preferred (Figure 2.4).

Once each plot was established, it was further subdivided. The southwest corner and northeast corner each contained two smaller nested quadrats: a $1m^2$ quadrat within a 10 m^2 quadrat, within the whole $100m^2$vegetation plot at both the southwest corner and northeast corner (Figure 2.3).

For each plot, a trained botanist defined the dominant wetland type and then identified each plant species within each quadrat. They defined the species height class, and estimated percent cover for the species within the $100m^2$ plot. Any unknown species within the plot was noted and collected for identification later.

After identifying all of the plants, the botanist estimated the percent of the plot covered with water, water depth, cover of bare ground, vegetative litter, cover of vascular vegetation, cover of non-vascular taxa, and cover of downed woody materials. Then, the botanist counted all tree species in the plot by separating them into height classes and by diameter at breast height (DBH).

In addition, the Nebraska Wetland Rapid Assessment Method (NeWRAM) was applied for each wetland with in the CP and VB BULs. These scores were not used in any of the analysis for this thesis, but they would be available for examination by anyone trying to assess the validity of the NeWRAM (LaGrange 2015).

After all of the measurements were taken, any unknown species and 5 randomly selected quality assurance species were collected in 2016. Because of high quality assurance specimen accuracy, only unknown plants were collected in 2017. The unknown species were identified by the field botanist based on descriptions from "The Flora of Nebraska" (Kaul et al. 2006) and all of the collected specimens were pressed. The pressed specimens were sent to Gerry Steinauer (Nebraska Game and Parks Commission) to identify any still unknown species and to verify the identity of the quality assurance species. Specimens were then donated to the Bessey Herbarium within the University of Nebraska State Museum for perseveration.

After analysis, basic information about the BULs such as number of species and most common species was reported. A brief evaluation of the sampling protocol was conducted. This study specifically examined the species gained relative to the effort needed to sample a site sufficiently. A multimodel inference approach was used to determine top predictive models for vegetative variables. Model sets were determined a priori. A delta AICc of 2 (Burnham and Anderson 2002) was used as the cutoff for plausible models in the model set. All possible variable combinations were checked for correlation and any highly correlated variables (correlation ≥ 0.7) were not used in the same model.

Study Site Selection

The Western Subirrigated Alkaline Meadows (AM) are wide spread throughout the upper Niobrara River valley and patchy in the North Platte River valley in the Nebraska Panhandle (Rolfsmeier and Steinauer 2010). The soil is poorly drained, with a sandy loam texture. The water table is generally below the surface, with the depth to water fluctuating from one to three feet with a pH near 8.0 (Rolfsmeier and Steinauer 2010, Hildebrand 1998). The vegetation is dense with common plant species including woolly sedge (*Carex pellita*), clustered field sedge (*Carex praegracilis*), inland saltgrass (*Distichlis spicata*), slender wheatgrass (*Elymus trachycaulus*), foxtail barley (*Hordeum jubatum*), Baltic rush (*Juncus arcticus* var. *balticus*), scratchgrass (*Muhlenbergia asperifolia*), switchgrass (*Panicum virgatum*), alkali cordgrass (*Spartina gracilis*) (Rolfsmeier and Steinauer 2010). The most intact section of AM is near the Niobrara River in Sioux and Box Butte Counties the Nebraska Panhandle (Rolfsmeier and Steinauer 2010), which was the area of focus for this study.

The Eastern Bulrush Deep Marsh (CP) is found in depression and old channels on rivers and stream in the eastern half of Nebraska. The soils are poorly drained and consist of sand silt or muck. Because of this poor drainage, these communities usually have 0.5-1m of standing water. This water may dry up during the mid to late summer, especially during times of drought, but the water table usually remains close to the surface. The species diversity is moderate at most with common species including northern water-plantain (*Alisma triviale*), bald spikerush (*Eleocharis erythropoda*), rice cutgrass (*Leersia oryzoides*), common reed (*Phragmites australis* ssp. *americanus*), swamp smartweed (*Polygonum coccineum*), common arrowhead (*Sagittaria latifolia*), hardstem bulrush (*Schoenoplectus acutus*), threesquare bulrush (*Schoenoplectus pungens*), softstem bulrush (*Schoenoplectus tabernaemontani*), large-fruit bur-reed (*Sparganium eurycarpum*), broadleaf cattail (*Typha latifolia*). While the most undisturbed Eastern Bulrush Deep Marshes are found in northern Nebraska, this study focused on the Central Platte River (Rolfsmeier and Steinauer 2010).

Cottonwood Diamond Willow Woodlands (LR) are found beside the Missouri, Elkhorn, and branches of the Loup Rivers. Soils are sandy loams and are moderately to poorly drained. Mature Cottonwood Diamond Willow Complexes have high species diversity with a very dense canopy, sparse shrub layer, and dense herbaceous layer. The most common species are plains cottonwood (*Populus deltoides*), peachleaf willow (*Salix amygdaloides*), diamond willow (*Salix famelica*). roughleaf dogwood (*Cornus drummondii*), red osier (*Cornus sericea*), green ash (*Fraxinus pennsylvanica*), wolfberry (*Symphoricarpos occidentalis*) riverbank grape (*Vitis riparia*) hog peanut (*Amphicarpaea bracteata*), false nettle (*Boehmeria cylindrica*), sedges (*Carex spp.*), field horsetail

(*Equisetum arvense*), sweet-scented bedstraw (*Galiumtriflorum*), Kentucky bluegrass (*Poa pratensis*), goldenglow (*Rudbeckia laciniata*), and Canada sanicle (*Sanicula canadensis*) (Rolfsmeier and Steinauer 2010). The most representative sites can be found in the Loup Junction Wildlife Management area and Yellowbanks Wildlife Management Area (Rolfsmeier and Steinauer 2010). This study took place in the upper to middle parts of the North and Middle Loup Rivers. Few studies have been conducted in this BUL.

Sandhill fens (SH) are located in the north-central Sandhills of Cherry and Grant Counties (Rolfsmeier and Steinauer 2010). The water is slightly acidic and the soil is primarily composed of peat (LaGrange 2005). The hydrology is most affected by the Ogallala aquifer, causing groundwater to seep aboveground and form wetlands (LaGrange 2005). Most of the SH have been ditched and seeded to exotic grasses. Common plant species include sedges inland star sedge, (*Carex interior*), ripgut sedge (*Carex lacustris*), Nebraska sedge (*Carex nebrascensis*), wholly sedge (*Carex pellita*), fen panicled sedge (*Carex prairea*), bog spikerush (*Eleocharis elliptica*), sensitive fern (*Onoclea sensibilis*), common reed (*Phragmites australis* ssp. *americanus*), common arrowhead (*Sagittaria latifolia*), hardstem bulrush (*Schoenoplectus acutus*), marsh fern (*Thelypteris palustris*), and broadleaf cattail (*Typha latifolia*) (Rolfsmeier and Steinauer 2010). The fens in the interior of Cherry County remain relatively undisturbed with large and representative sites in private property (Rolfsmeier and Steinauer 2010), which was the area of the SH distribution was where this study took place. SH generally have high plant diversity.

Freshwater Seeps (VB) are generally found on or near slopes of hills or bluffs. VB can be found throughout the state where rainwater or snowmelt moves through

permeable soils until it finds an outlet. The soils are usually sandy with organic matter in the west or silt loams from glacial till in the east (Rolfsmeier and Steinauer 2010). Commonly found species include sedges (*Carex* spp.), willow herb (*Epilobium* spp.), common scouringrush (*Equisetum hyemale*), fowl mannagrass (*Glyceria striata*), watercress (*Nasturtium officinale*), bulrushes (*Schoenoplectus* spp.), cattails (*Typha* spp.) (Rolfsmeier and Steinauer 2010). The best preserved sites are located along streams in the Sandhills, in the Pine Ridge, and in the Rock Glen WMA in Jefferson County (Rolfsmeier and Steinauer 2010). This study examined freshwater seeps in the Verdigris-Bazile Creek BUL in northeast Nebraska. Few studies have been conducted in this BUL.

Explanation of Variables

Vegetation

Relative Native Cover: The relative cover of native vegetation compared to a total vegetative cover. This was used to keep measurements consistent instead of total native cover because different heights of plants could cause total cover to exceed 100% (ex. Site with 75% coverage of diamond willow in height class 3 and 75% coverage of Emory's sedge in height class 2). Cover has been used as an indicator of species success obtaining resources (Stohlgren et al. 2003). Reduced native cover can facilitate non-native species growth in wetlands (Catford 2011).

Native Species Richness: The count of total native species at a site. Presence and absence of species can help determine where that species is likely to be found (Elith et al. 2006).

Relative Non-Native Cover: The relative cover of non-native vegetation compared to a total vegetative cover. All nonnative species were determined using the Nebraska Natural Heritage Program’s state plant list (2013). Relative non-native cover

was used to keep measurements consistent instead of total non-native cover because different heights of plants could cause total cover to exceed 100% (ex. Site with 75% coverage of common buckthorn in height class 3 and 75% coverage reed canary grass in height class 2). Species cover has been used as an indicator of species success obtaining resources (Stohlgren et al. 2003).

Non-Native Species Richness: The count of total non-native species at a site. All nonnative species were determined using the Nebraska Natural Heritage Program's state plant list (2013). Non-native species can facilitate invasion of the conspecific and other non-native species by modifying soils (Jordan et al 2008). Non-native species can also displace native species by out competing them for resources (Saltonstall 2002).

Litter: The average of the litter coverages for the five vegetation plots. High litter accumulation can promote non-native species growth (Vaccaro et al. 2009). Litter adds nutrients back into soil (Ashton et al. 2005) and water (Webster 2009). Litter from non-native species has been shown to decompose faster than that of native species (Rothstein et al. 2004).

FQAI (Floristic Quality Assessment Index): A measure of the quality of a site's vegetation. Experts familiar with the habitat assign quality values (Coefficients of Conservation or C-values). This study used C-values developed by the Nebraska Natural Heritage Program (2013). FQAI has very limited, and sometimes misleading, abilities to determine the condition of wetlands. This ability is further reduced when comparing between wetland types (Andreas 2004). FQAI was only calculated during this study because it was a primary tool of the 2011 Nebraska Wetland Condition Assessment.

Biologically Unique Landscape

BUL: The area of the state samples were taken from. The two sampled in 2016 were the Cherry County Wetlands (SH) and the Upper Niobrara River (AM). The three sampled in 2017 were the Upper Loup Rivers (LR), Central Platte (CP), and Verdigris-Bazile (VB). Each has its own vegetation, soil, and water characteristics (Rolfsmeier and Steinauer 2010).

Soil

Soil Nitrogen: Percentage of nitrogen in soil particles small enough to fit through a 2mm sieve from a depth of 0-10cm. Nitrogen and Phosphorus are two of the most important nutrients of plant growth (Jackson, 1958).

Soil Phosphorous: mg/kg of phosphorous from a depth of 0-10cm. Nitrogen and Phosphorus are two of the most important nutrients of plant growth (Jackson, 1958).

Land Use

Hay: A count of haying in the area directly adjacent to the wetland in each of the cardinal directions. Minimum of 0, maximum of 4. Haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998).

Range: A count of evidence of cattle in the area directly adjacent to the wetland in each of the cardinal directions. Minimum of 0, maximum of 4. Grazing affects vegetation composition (Milchunas et al. 1993).

Buffer Non-Native Species: A count of the number of non-native species in the area directly adjacent to the wetland. A species can count more than once if it was found in two or more directions. Presence and absence of species can help determine where that species is likely to be found again (Elith et al. 2006). Non-native species can facilitate

invasion of the conspecific and other non-native species by modifying soils (Jordan et al 2008).

Distance to Road: Distance from the center of the wetland to the closest road. Non-native species abundance has been shown to decrease with increased distance from roads (Flory and Clay 2006).

Row Crop: No information about row crop practices were used in this thesis although it was in the original plan. Only five sites had row crop in the immediate buffer, so the row crop variable was excluded from this thesis.

Explanation of Model Selection

All variables within each model were not correlated (< 0.7) with any other variable in the model. Each model set is composed of a null model, global model, vegetation model, BUL model, soil model, land use models, and every pair of combinations of the vegetation, BUL, soil, and land use models. This gives a grand total of 12 models for each predictor. Models that contain the vegetation, BUL, soil, and land use models use the same variables for each separate predictive model.

Predictive Native Species Richness

Relative native species cover was used because vegetative cover has been used as an indicator of species success obtaining resources (Stohlgren et al. 2003) and reduced native cover can facilitate non-native species growth in wetlands (Catford 2011). Non-native species richness was used because non-native species can displace native species by out competing them for resources (Saltonstall 2002). Litter was used because high litter accumulation can promote non-native species growth (Vaccaro et al. 2009). The BUL models were used because vegetation varies by region (Rolfsmeier and Steinauer

2010). Soil nitrogen and soil phosphorus were used because they are two of the most important nutrients for plant growth (Jackson, 1958). The hay variable was used in the land use model because haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing affects vegetation composition (Milchunas et al. 1993). Buffer non-native was used because presence and absence of species can help determine where that species is likely to be found again (Elith et al. 2006) and non-native species can facilitate invasion of the conspecific and other non-native species by modifying soils (Jordan et al 2008). Distance to roads was used because non-native species abundance has been shown to decrease with increased distance from roads (Flory and Clay 2006).

Predictive Relative Native Cover

Native species richness was used because presence and absence of species can help determine where that species is likely to be found (Elith et al. 2006). Non-native species richness was used because non-native species can displace native species by out competing them for resources (Saltonstall 2002). Litter was used because high litter accumulation can promote non-native species growth (Vaccaro et al. 2009). The BUL models were used because vegetation varies by region (Rolfsmeier and Steinauer 2010). Soil nitrogen and soil phosphorus were used because they are two of the most important nutrients for plant growth (Jackson, 1958). The hay variable was used in the land use model because haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing affects vegetation composition (Milchunas

et al. 1993). Buffer non-native was used because presence and absence of species can help determine where that species is likely to be found again (Elith et al. 2006) and non-native species can facilitate invasion of the conspecific and other non-native species by modifying soils (Jordan et al 2008). Distance to roads was used because non-native species abundance has been shown to decrease with increased distance from roads (Flory and Clay 2006).

Predictive Non-Native Species Richness

Relative native species cover was used because vegetative cover has been used as an indicator of species success obtaining resources (Stohlgren et al. 2003) and reduced native cover can facilitate non-native species growth in wetlands (Catford 2011). Native species richness was used because presence and absence of species can help determine where that species is likely to be found (Elith et al. 2006). Litter was used because high litter accumulation can promote non-native species growth (Vaccaro et al. 2009). The BUL models were used because vegetation varies by region (Rolfsmeier and Steinauer 2010). Soil nitrogen and soil phosphorus were used because they are two of the most important nutrients for plant growth (Jackson, 1958). The hay variable was used in the land use model because haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing affects vegetation composition (Milchunas et al. 1993). Buffer non-native was used because presence and absence of species can help determine where that species is likely to be found again (Elith et al. 2006) and non-native species can facilitate invasion of the conspecific and other non-native species by modifying soils (Jordan et al 2008). Distance to roads was

used because non-native species abundance has been shown to decrease with increased distance from roads (Flory and Clay 2006).

Predictive Relative Non-Native Cover

Native species richness was used because presence and absence of species can help determine where that species is likely to be found (Elith et al. 2006). Non-native species richness was used because non-native species can displace native species by out competing them for resources (Saltonstall 2002). Litter was used because high litter accumulation can promote non-native species growth (Vaccaro et al. 2009). The BUL models were used because vegetation varies by region (Rolfsmeier and Steinauer 2010). Soil nitrogen and soil phosphorus were used because they are two of the most important nutrients for plant growth (Jackson, 1958). The hay variable was used in the land use model because haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing affects vegetation composition (Milchunas et al. 1993). Buffer non-native was used because presence and absence of species can help determine where that species is likely to be found again (Elith et al. 2006) and non-native species can facilitate invasion of the conspecific and other non-native species by modifying soils (Jordan et al 2008). Distance to roads was used because non-native species abundance has been shown to decrease with increased distance from roads (Flory and Clay 2006).

Predictive FQAI

Relative native species cover was used because vegetative cover has been used as an indicator of species success obtaining resources (Stohlgren et al. 2003) and reduced

native cover can facilitate non-native species growth in wetlands (Catford 2011). Non-native species richness was used because FQAI and native species richness were highly correlated (0.92) and non-native species can also displace native species by out competing them for resources (Saltonstall 2002). Litter was used because high litter accumulation can promote non-native species growth (Vaccaro et al. 2009). The BUL models were used because vegetation varies by region (Rolfsmeier and Steinauer 2010). Soil nitrogen and soil phosphorus were used because they are two of the most important nutrients for plant growth (Jackson, 1958). The hay variable was used in the land use model because haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing affects vegetation composition (Milchunas et al. 1993). Buffer non-native was used because presence and absence of species can help determine where that species is likely to be found again (Elith et al. 2006) and non-native species can facilitate invasion of the conspecific and other non-native species by modifying soils (Jordan et al 2008). Distance to roads was used because non-native species abundance has been shown to decrease with increased distance from roads (Flory and Clay 2006).

Predictive Model Sets

Predictive Native Species Richness

1. Native Species ~ 1
2. Native Species ~ Relative Native Cover + Non-native Species + Litter
3. Native Species ~ BUL
4. Native Species ~ Soil Nitrogen + Soil Phosphorus
5. Native Species ~ Hay + Range + Buffer Non-native + Distance to Road
6. Native Species ~ Relative Native Cover + Non-native Species + Litter + BUL
7. Native Species ~ Relative Native Cover + Non-native Species + Litter + Soil Nitrogen + Soil Phosphorus

8. Native Species ~ Relative Native Cover + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
9. Native Species ~ BUL + Soil Nitrogen + Soil Phosphorus
10. Native Species ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
11. Native Species ~ Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road
12. Native Species ~ Relative Native Cover + Non-native Species + Litter + BUL + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Predictive Relative Native Cover

1. Relative Native Cover ~ 1
2. Relative Native Cover ~ Native Species + Non-native Species + Litter
3. Relative Native Cover ~ BUL
4. Relative Native Cover ~ Soil Nitrogen + Soil Phosphorus
5. Relative Native Cover ~ Hay + Range + Buffer Non-native + Distance to Road
6. Relative Native Cover ~ Native Species + Non-native Species + Litter + BUL
7. Relative Native Cover ~ Native Species + Non-native Species + Litter + Soil Nitrogen + Soil Phosphorus
8. Relative Native Cover ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
9. Relative Native Cover ~ BUL + Soil Nitrogen + Soil Phosphorus
10. Relative Native Cover ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
11. Relative Native Cover ~ Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road
12. Relative Native Cover ~ Native Species + Non-native Species + Litter + BUL + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Predictive Non-Native Richness

1. Non-native Species ~ 1
2. Non-native Species ~ Relative Native Cover + Native Species + Litter
3. Non-native Species ~ BUL
4. Non-native Species ~ Soil Nitrogen + Soil Phosphorus
5. Non-native Species ~ Hay + Range + Buffer Non-native + Distance to Road
6. Non-native Species ~ Relative Native Cover + Native Species + Litter + BUL
7. Non-native Species ~ Relative Native Cover + Native Species + Litter + Soil Nitrogen + Soil Phosphorus
8. Non-native Species ~ Relative Native Cover + Native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
9. Non-native Species ~ BUL + Soil Nitrogen + Soil Phosphorus
10. Non-native Species ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
11. Non-native Species ~ Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

12. Non-native Species ~ Relative Native Cover + Native Species + Litter + BUL + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Predictive Relative Non-Native Cover

1. Relative Non-native Cover ~ 1
2. Relative Non-native Cover ~ Native Species + Non-native Species + Litter
3. Relative Non-native Cover ~ BUL
4. Relative Non-native Cover ~ Soil Nitrogen + Soil Phosphorus
5. Relative Non-native Cover ~ Hay + Range + Buffer Non-native + Distance to Road
6. Relative Non-native Cover ~ Native Species + Non-native Species + Litter + BUL
7. Relative Non-native Cover ~ Native Species + Non-native Species + Litter + Soil Nitrogen + Soil Phosphorus
8. Relative Non-native Cover ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
9. Relative Non-native Cover ~ BUL + Soil Nitrogen + Soil Phosphorus
10. Relative Non-native Cover ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
11. Relative Non-native Cover ~ Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road
12. Relative Non-native Cover ~ Native Species + Non-native Species + Litter + BUL + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Predictive FQAI

1. FQAI ~ 1
2. FQAI ~ Relative Native Cover + Non-native Species + Litter
3. FQAI ~ BUL
4. FQAI ~ Soil Nitrogen + Soil Phosphorus
5. FQAI ~ Hay + Range + Buffer Non-native + Distance to Road
6. FQAI ~ Relative Native Cover + Non-native Species + Litter + BUL
7. FQAI ~ Relative Native Cover + Non-native Species + Litter + Soil Nitrogen + Soil Phosphorus
8. FQAI ~ Relative Native Cover + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
9. FQAI ~ BUL + Soil Nitrogen + Soil Phosphorus
10. FQAI ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
11. FQAI ~ Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road
12. FQAI ~ Relative Native Cover + Non-native Species + Litter + BUL + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Results

Site Characteristics

Species abundance and richness varied from BUL to BUL during the 2016 and 2017 field seasons. As an evaluation of Nebraska wetlands as a whole, the most commonly found native species were wholly sedge (*Carex pellita*) at 75 sites, bald spikerush (*Eleocharis erythropoda*) at 71 sites, and American water-horehound (*Lycopus americanus*) at 64 sites. The most commonly found non-native species were reed canary grass (*Phalaris arundinacea*) at 78 sites and Kentucky bluegrass (*Poa pratensis*) at 66 sites. 393 total species were found during this study, 12 species were found in at least half of the sites, and 80 species were found at only one site.

Twenty AM sites located on the Upper Niobrara River BUL were sampled in July of 2016 (Figure 2.5). AM sites averaged 40 total species, 31 of which were native species. The maximum and minimum for native species was 51 and 8 respectively. It also had a maximum and minimum for non-native species of 14 and 4 respectively. This was both the smallest maximum, and largest minimum for non-native species for all BULs sampled in 2016-2017. The AM had more native species on average than all but three of the BULs sampled in 2011-2013 (LaGrange 2015). The most commonly found native species were foxtail barley (*Hordeum jubatum)* at all sites, Baltic rush (*Juncus balticus*) and three-square bulrush (*Schoenoplectus pungens*) at 19 sites, and smooth scouring-rush (*Equisetum laevigatum*) and switchgrass (*Panicum virgatum*) 18 sites. The most commonly found non-native species was creeping bentgrass (*Agrostis stolonifera*) at 16 sites. 148 total species were found in the BUL, 29 species were found in at least half

of the sites, and 36 species were found at only one site in the BUL, and 11 species were only found in this BUL.

Twenty CP sites located near the Central Platte River were sampled in June of 2017 (Figure 2.6). CP sites averaged 23 total species, 18 of which were native species. The maximum and minimum for native species was 32 and 3 respectively. It also had a maximum and minimum for non-native species of 18 and 0 respectively. The CP averaged 10 less plant species than any other BUL sampled in 2016 or 2017. Even considering the this, the CP had more native species than 6 of the 11 sites from the 2011-2013 surveys(LaGrange 2015). The most common native species were three-square bulrush (*Schoenoplectus pungens*) at 16 sites, Emory's sedge (*Carex emoryi*) at 15 sites, and wholly sedge (*Carex pellita*) and bald spikerush (*Eleocharis erythropoda*) at 13 sites. The most common non-native species was reed canary grass (*Phalaris arundinacea*) at 16 sites. 140 total species were found in the BUL, 11 species were found in at least half of the sites, 61 species were found at only one site in the BUL, and 12 species were only found in this BUL.

Twenty LR sites located on the North and Middle Loup Rivers were sampled in late May and early July of 2017 (Figure 2.7). LR sites averaged 70 total species, 61 of which were native species. The maximum and minimum for native species was 81 and 30 respectively. It also had a maximum and minimum for non-native species of 16 and 3 respectively. The LR has the most average total species and native species of the 16 wetland types surveyed in all Nebraska wetland condition assessments (LaGrange 2015). The most commonly found native species were Emory's sedge (*Carex emoryi*) at all sites, and false indigo-bush (*Amorpha fruticose*), sawtooth sunflower (*Helianthus*

grosseserratus), and bluejoint (*Calamagrostis canadensis*) at 19 sites. The most commonly found non-native species was Kentucky bluegrass (*Poa pratensis*) at all sites. 221 total species were found in the BUL, 61 species were found in at least half of the sites, 51 species were found at only one site in the BUL, and 16 species were only found in this BUL.

Twenty SH wetland sites located in central Cherry County were sampled in June of 2016 (Figure 2.8). These sites ranged between true fens with very high levels of peat in the soil and wet meadows with sandier soil. SH sites averaged 42 total species, 35 of which were native species. The BUL maximum and minimum for native species was 58 and 18 respectively. It also had a maximum and minimum for non-native species of 18 and 0 respectively. SH contained two of the three sites in the study without any non-native species and averaged more native species than all but three of the 16 wetland types surveyed in all Nebraska wetland condition assessments (LaGrange 2015). The most commonly found native species were broom sedge (*Carex scoparia*) at 18 sites, and Nebraska sedge (*Carex nebrascensis*), bald spikerush (*Eleocharis erythropoda*), and swamp smartweed (*Polygonum coccineum*) at 17 sites. The most commonly found native species was reed canary grass (*Phalaris arundinacea*) at 18 sites. 177 total species were found in the BUL, 34 species were found in at least half of the sites, 56 species were found at only one site in the BUL, and 19 species were only found in this BUL.

Twenty VB wetlands were surveyed in July of 2017 (Figure 2.9). VB sites averaged 33 total species, 22 of which were native species. The BUL maximum and minimum for native species was 52 and 2 respectively. It also had a maximum and minimum for non-native species of 24 and 1 respectively. The VB had the most non-

native species, accounting for a third of the total species. Non-native species also had over half of the relative cover for the 2016-2017 sampling period and tied for third most proportion of non-native species by count out of the 16 BULs sampled in all Nebraska wetland condition assessments (LaGrange 2015). The most commonly found native species were foxtail barley (*Hordeum jubatum*) at 16 sites and wholly sedge (*Carex pellita*) at 15 sites. The most commonly found non-native species were reed canary grass (*Phalaris arundinacea*) at 18 sites, Kentucky bluegrass (*Poa pratensis*) at 16 sites, and creeping bentgrass (*Agrostis stolonifera*) at 15 sites. 192 total species were found in the BUL, 15 species were found in at least half of the sites, 68 species were found at only one site in the BUL, and 22 species were only found in this BUL.

Number of Vegetation Plots

As an average of all sites, sampling two plots instead of just a single plot gained 37.3% more unique species. Sampling three plots instead of just two plots gained 16.6% more unique species. Sampling four plots instead of just three plots gained 10.1% more unique species. Sampling five plots instead of four plots gained 6.8% more unique species (Figure 2.10).

Predictive Native Species Richness

The vegetation and BUL model (Native Species Richness ~ Relative Native Cover + Non-native Species + Litter + BUL) is the only model with Delta AICc < 2 for the predictive native species richness linear model (Table 2.5). Relative Native Cover, Non-native Species Richness, and BUL were significant at a value of $p < 0.05$ (Table 2.6).

Predictive Relative Native Cover

The vegetation and land use model (Relative Native Cover ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road) and the vegetation model (Relative Native Cover ~ Native Species + Non-native Species + Litter) are the two models with Delta AICc < 2 for the predictive relative native species cover linear model (Table 2.7). Native species richness, non-native species richness, and buffer non-native were all were significant a value of $p < 0.05$ for the vegetation and land use model (Table 2.8), and native species richness and non-native species richness were significant at a value of $p < 0.05$ for the vegetation model (Table 2.9).

Predictive Non-Native Species Richness

The global model (Non-native Species ~ Relative Native Cover + Native Species + Litter + BUL + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road) and the BUL and soil model (Non-native Species ~ BUL + Soil Nitrogen + Soil Phosphorus) are the two models with Delta AICc < 2 for the predictive non-native species richness linear model (Table 2.10). Relative native cover, native species richness, and soil nitrogen were significant a value of $p < 0.05$ for the global model (Table 2.11), and BUL and soil nitrogen were significant at a value of $p < 0.05$ for the BUL and soil model (Table 2.12).

Predictive Relative Non-Native Cover

The vegetation and land use model (Relative Non-native Cover ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road) and the vegetation model (Relative Non-native Cover ~ Native Species + Non-native Species + Litter) are the two models with Delta AICc < 2 for the predictive relative non-native cover linear model (Table 2.13). Native Species Richness, Non-native Species

Richness, and Buffer Non-native were all significant at a value of $p < 0.05$ for the vegetation and land use (Table 2.14), and native species richness and non-native species richness were significant at a value of $p < 0.05$ for the vegetation model (Table 2.15).

Predictive FQAI

The global model (FQAI ~ Relative Native Cover + Non-native Species + Litter + BUL + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road) and the vegetation and BUL model (FQAI ~ Relative Native Cover + Non-native Species + Litter) are the two models with Delta AICc < 2 for the predictive FQAI linear model (Table 2.16). A significance value of $p < 0.05$ was used for all models. Relative native cover, non-native species richness, BUL, soil nitrogen, and range were significant at a value of $p < 0.05$ for the global model (Table 2.17), and relative native cover, non-native species richness, and BUL were all significant (Table 2.18)

Discussion

Site Characteristics

The selection process for wetlands in this study was mostly successful. The AM and SH wetlands were accurately selected during the initial computer generated sample draw in 2016, likely because these areas had been studied in the past (Hildebrand 1998, Steinauer et al. 1996). The 2017 computer generated sample draw was mildly successful for selecting sites in 2017. The LR wetlands were selected for well, although Cottonwoods and diamond willows were only present at 7 and 14 LR sites respectively and eastern red cedar was at 16 sites. The CP sites were generally more of a wet meadow than a deep marsh with 0.5-1m of standing water. Only 10 CP sites had samplable water and only 4 of those were in the expected range for water depth characteristics (Rolfsmeier

and Steinauer 2010).

Comparison between the 2011-2013 study and the 2016-2017 study are difficult (and potentially dangerous) to make. There are too many differences between substrate, precipitation, and typical vegetation (Rolfsmeier and Steinauer 2010) found within each BUL to compare one BUL to another or to describe which are "healthy" and which are "unhealthy" based on one set of criteria. The larger purpose of this study is to provide baseline data to be used as benchmarks for future studies. With this in mind, this study makes no judgments about the "health" or "quality" of any of the wetlands studied.

Number of Vegetation Plots

While an argument could be made that plot 5 is not necessary because new species gained increases by roughly 7% for a 25% increase in sampling effort, the calculation of a 25% increase in sampling effort does not take into account the time to acquire permission to the site or the time it takes to get to a site, set up, tear down, and return to lodging. For a difficult site, this process can easily exceed 2 hours but most sites need about an hour of prep work to be sampled. An easy site usually takes around 2.5 hours to sample 5 vegetation plots, giving 3.5 hour's worth of sampling effort with driving and set up included. At that point, adding a 5^{th} plot generates a 17% increase in sampling efforts for a 7% increase in species richness.

Predictive Native Species Richness

The vegetation and BUL model was the top model for native species richness. Both relative native species cover and non-native species richness had a positive effect on native richness. Keeping native cover high helps inhibit non-native species encroachment (Catford 2011), and while non-native species have been shown to outcompete native

species in some cases (Minchinton and Bertness 2003, Hejda et al. 2009), they have also been show to facilitate native species growth in others (Rodriguez 2006). That said, BUL is likely a more important variable since the other BUL models have lower delta AICcs than models containing the vegetation model (Table 2.5). This is unsurprising since, much like soil and water variables, vegetation varies by location (Rolfsmeier and Steinauer 2010).

Predictive Relative Native Cover

The vegetation and land use model and the vegetation model were the top models for determining relative cover of native species. Land use appears less influential than vegetation as vegetation appears in all of the top models. Non-native species richness inside the plots and within the buffer had a negative effect on relative native cover. Increasing native richness had a positive effect on relative native cover. These results are reasonable because high native cover can inhibit non-native growth in wetlands (Catford 2011).

Predictive Non-Native Species Richness

The top models for non-native species richness were the global model and the BUL and soil model. Only soil nitrogen was significant in both models, but both models showed it had a negative effect on non-native species richness. Though the majority of the literature points to non-native species being better able to invade with large amounts of nitrogen (Rothstein et al. 2004, Vitousek and Walker 1989, Hibbard et al. 2001, Liao 2008), Christan and Wilson (1999) found large amounts of the non-native *Agropyron cristatum* in conjunction with low nitrogen.

Predictive Relative Non-Native Cover

The vegetation and land use model came out as the top model for determining relative cover of non-native species in a very similar way to relative cover of native species. Again, land use appeared less influential than vegetation as vegetation appears in all of the top models. Non-native species richness inside the plots and within the buffer had a positive effect relative non-native cover, possibly because non-native species can facilitate invasion of the conspecific and other non-native species (Jordan et al. 2008). Native richness had a negative effect on relative non-native cover. These results are reasonable because low native cover can facilitate non-native growth in wetlands (Catford 2011).

Predictive FQAI

The global model and vegetation and BUL model were the top models for FQAI. Relative native cover was used instead of native species richness because native species richness was very tightly correlated (92.5%) to FQAI, likely because FQAI is largely based on the number of species at a site. Since native species richness informs on relative native cover, it is unsurprising that native species cover play a large role in determining FQAI values for a site (Andreas et al. 2004). BULs appear in all of the top models and are significant in both models with delta AICc < 2. This information further expands on a primary weakness of FQAI: It has virtually no ability to compare between habitat types (Andreas et al. 2004). FQAI is only able to compare between wetlands of the same size and of very similar species composition (Andreas et al. 2004).

Conclusion

The vegetation plot layout has now been used for two sets of Nebraska wetlands surveys, with a grand total of 209 sites from 16 BULs already taken using the five nested

vegetation plot system. Reducing sampling effort now could make it difficult to compare results of future studies to studies already completed. This is also the system used by the EPA (2016c) during National Wetland Condition Assessments (USEPA 2016a, USEPA 2016c). Making comparison to EPA data will be more difficult if the protocol is changed in the future. In addition, few if any of the BUL and vegetation type combinations have been studied in any detail in the last 20 years. Surveying an extra vegetation plot than is strictly necessary is likely a good idea to get a fuller understanding of rarely sampled habitats. Based on this knowledge, I would recommend that future Nebraska Wetland Condition Assessments continue to use the five nested vegetation plots. I believe the consistency between surveys and additional examination of infrequently visited habitats is worth the extra sampling effort.

As for the models, it would likely be beneficial to look at only a single BUL at a time when doing future vegetation models because three of the five top models contained the BUL model. This could almost be thought of as three of four top models because the relative native cover and relative nonnative cover are essentially the invers of one another. These BULs have very different vegetation types, and know more about them individually will likely be more beneficial than to try to lump all of Nebraska's wetland plants into a single model.

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Tables and Figures

Table 2.1. BUL comparisons for the surveys conducted in 2016 and 2017. Unique species is the sum of all unique species found in each of the 20 sites in a BUL. Average species is the average number of species found per site within a BUL. Max species and min species are the maximum and minimum number of plant species found at a single site in a BUL. Average FQAI is the average FQAI found within a BUL. Max FQAI and min FQAI are the maximum and minimum FQAI found at a single site in a BUL.

BUL	Unique Species	Average Species	Max Species	Min Species	Average FQAI	Max FQAI	Min FQAI
AM	148	40.3	62	15	23.73	30.02	9.90
CP	140	23.5	43	5	16.31	24.57	8.05
LR	221	70.5	97	37	34.78	43.29	21.09
SH	177	42.3	74	21	30.17	42.46	16.97
VB	192	32.8	69	3	17.16	28.71	6.36

Table 2.2. BUL comparisons for the surveys conducted in 2016 and 2017. Unique native species is the sum of all unique native species found in each of the 20 sites in a BUL. Average native species is the average number of native species found per site within a BUL. Max native species and min native species are the maximum and minimum number of native species found at a single site in a BUL. Proportion of native species.

BUL	Unique Native Species	Average Native Species	Max Native Species	Min Native Species	Proportion of Native Species by Count	Proportion of Native Species by Cover
AM	105	31.5	51	8	0.78	0.69
CP	101	17.8	32	3	0.76	0.58
LR	175	61.0	81	30	0.87	0.79
SH	138	35.0	58	18	0.83	0.72
VB	134	21.8	52	2	0.66	0.48

Table 2.3. BUL comparisons for the surveys conducted in 2016 and 2017. Unique non-native species is the sum of all unique non-native species found in each of the 20 sites in a BUL. Average non-native species is the average number of species found per site within a BUL. Max non-native species and min non-native species are the maximum and minimum number of non-native species found at a single site in a BUL.

BUL	Unique Non-native Species	Average Non-native Species	Max Non-native Species	Min Non-native Species	Proportion of Non-native Species by Count	Proportion of Non-native Species by Cover
AM	43	8.8	14	4	0.22	0.31
CP	39	5.7	18	0	0.24	0.42
LR	46	9.5	16	3	0.13	0.21
SH	39	7.4	18	0	0.17	0.28
VB	58	11.0	24	1	0.34	0.52

Table 2.4. The average percentage of new species gained by sampling one additional plot. (Ex. Plot 1 contains 10 species. Plot 2 contains 10 new species, generating a percentage of species gained by sampling site 2 value of 100%. Plot 3 also contains 10 new species, generating a percentage of species gained by sampling site 3 value of 50%.) This was used to determine how many plots are need to sample a site.

	Percentage of Species Gained By Sampling 2 Plots	Percentage of Species Gained By Sampling 3 Plots	Percentage of Species Gained By Sampling 4 Plots	Percentage of Species Gained By Sampling 5 Plots
AM	48.9	18.4	11.4	7.5
CP	29.4	23.8	6.3	6.1
LR	37.4	15.8	7.2	4.7
SH	34.6	17.2	15.4	7.1
VB	31.2	15.2	11.7	7.5
ALL	37.3	16.6	10.1	6.8

Table 2.5. Predictive models for native species richness. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the native species richness predictable from the models.

Model	K	Delta AICc	W	R^2
Vegetation and BUL	9	0	0.86	0.6778
Global	15	3.93	0.12	0.6936
BUL and Land Use	10	7.33	0.02	
BUL	6	18.51	0	
BUL and Soil	8	20.00	0	
Vegetation and Land Use	9	66.40	0	
Soil and Land Use	8	68.98	0	
Vegetation and Soil	7	71.51	0	
Vegetation	5	75.53	0	
Land Use	6	81.91	0	
Soil	4	92.55	0	
Null	2	104.70	0	

Table 2.6. Summary of the vegetation and BUL model (Native Species Richness ~ Relative Native Cover + Non-native Species + Litter + BUL), which is the only model with Delta AICc < 2 for the Predictive Native Species Richness Linear Model. A significance value of $p < 0.05$ was used for all models. Relative Native Cover, Non-Native Species Richness, and BUL were all significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	9.89846	5.12754	1.930	0.056631
Relative Native Cover	17.53557	4.21531	4.160	7.14E-05
Non-native Species Richness	0.85046	0.23704	3.588	0.000537
Litter	0.02598	0.03834	0.678	0.499670
CP BUL	-8.38581	3.73100	-2.248	0.026991
LR BUL	27.52536	3.59504	7.656	1.85E-11
SH BUL	4.83719	3.61408	1.338	0.184055
VB BUL	-7.35870	3.66475	-2.008	0.047580

Table 2.7. Predictive models for relative native species cover. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the relative native species cover predictable from the models.

Model	K	Delta AICc	W	R^2
Vegetation and Land Use	9	0	0.62	0.3422
Vegetation	5	1.48	0.30	0.2974
Vegetation and Soil	7	4.34	0.07	
Vegetation and BUL	9	8.27	0.01	
Global	15	11.39	0	
Soil and Land Use	8	11.77	0	
BUL and Land Use	10	15.11	0	
Land Use	6	15.71	0	
BUL and Soil	8	26.89	0	
BUL	6	27.65	0	
Soil	4	30.09	0	
Null	2	33.35	0	

Table 2.8. Summary of the vegetation and land use model (Relative Native Cover ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road), which is one of the two models with Delta AICc < 2 for the Predictive Relative Native Species Cover Linear Model. A significance value of $p < 0.05$ was used for all models. Native Species Richness, Non-native Species Richness, and Buffer Non-native were all significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	6.06E-01	1.02E-01	5.94800	0.000
Native Species Richness	5.80E-03	1.51E-03	3.83300	0.000
Non-native Species Richness	-1.78E-02	4.94E-03	-3.60300	0.001
Litter	8.91E-04	8.13E-04	1.09700	0.276
Hay	-2.01E-02	1.73E-02	-1.16300	0.248
Range	1.84E-02	1.42E-02	1.29400	0.199
Buffer Non-native	-2.67E-02	1.02E-02	-2.62700	0.010
Distance to Road	-5.78E-06	0.00006	-0.10100	0.920

Table 2.9. Summary of the vegetation model (Relative Native Cover ~ Native Species + Non-native Species + Litter), which is one of the two models with Delta AICc < 2 for the Predictive Relative Native Species Cover Linear Model. A significance value of $p < 0.05$ was used for all models. Native Species Richness and Non-native Species Richness were significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.493514	0.072550	6.802	8.79E-10
Native Species Richness	0.006600	0.001371	4.815	5.48E-06
Non-native Species Richness	-0.018642	0.005046	-3.695	0.000366
Litter	0.001490	0.000826	1.804	0.074381

Table 2.10. Predictive models for non-native species richness. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the non-native species richness predictable from the models.

Model	K	Delta AICc	W	R^2
Global	15	0	0.69	0.3676
BUL and Soil	8	1.64	0.30	0.2874
Vegetation and Soil	7	8.64	0.01	
Vegetation and BUL	9	11.38	0	
Vegetation	5	14.39	0	
Soil	4	16.17	0	
BUL and Land Use	10	19.35	0	
Vegetation and Land Use	9	19.93	0	
Soil and Land Use	8	21.81	0	
BUL	6	23.45	0	
Null	2	28.31	0	
Land Use	6	33.44	0	

Table 2.11. Summary of the global model (Non-native Species ~ Relative Native Cover + Native Species + Litter + BUL + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road), which is one of the two models with Delta AICc < 2 for the Predictive Non-native Species Richness Linear Model. A significance value of $p < 0.05$ was used for all models. Relative Native Cover, Native Species Richness, and Soil Nitrogen were all significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	11.833431	2.845441	4.159	7.55E-05
Relative Native Cover	-3.922739	1.77102	-2.215	0.02941
Native Species Richness	0.101835	0.039657	2.568	0.01196
Litter	0.003567	0.014332	0.249	0.80403
CP BUL	-3.234194	1.880039	-1.720	0.08898
LR BUL	-3.231225	2.329612	-1.387	0.16902
SH BUL	4.057068	2.268063	1.789	0.07717
VB BUL	1.786363	1.731937	1.031	0.30523
Soil Nitrogen	-3.992694	1.450077	-2.753	0.00719
Soil Phosphorus	-0.001287	0.00166	-0.776	0.44011
Hay	-0.587955	0.357866	-1.643	0.10405
Range	0.012901	0.333036	0.039	0.96919
Buffer Non-native	0.227652	0.19904	1.144	0.25590
Distance to Road	-0.001085	0.001046	-1.037	0.30279

Table 2.12. Summary of the BUL and Soil model (Non-native Species ~ BUL + Soil Nitrogen + Soil Phosphorus), which is one of the two models with Delta AICc < 2 for the Predictive Non-native Species Richness Linear Model. A significance value of $p < 0.05$ was used for all models. BUL and Soil Nitrogen were significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	11.682080	1.151308	10.147	< 2e-16
CP BUL	-1.742962	1.427240	-1.221	0.22509
LR BUL	0.524120	1.378022	0.380	0.70456
SH BUL	6.523522	2.206901	2.956	0.00395
VB BUL	3.341123	1.487756	2.246	0.02709
Soil Nitrogen	-4.586184	1.493852	-3.070	0.00281
Soil Phosphorus	-0.002188	0.001723	-1.270	0.20735

Table 2.13. Predictive models for relative non-native species cover. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the relative non-native species cover predictable from the models.

Model	K	Delta AICc	W	R^2
Vegetation and Land Use	9	0	0.62	0.3422
Vegetation	5	1.48	0.30	0.2974
Vegetation and Soil	7	4.34	0.07	
Vegetation and BUL	9	8.27	0.01	
Global	15	11.39	0	
Soil and Land Use	8	11.77	0	
BUL and Land Use	10	15.11	0	
Land Use	6	15.71	0	
BUL and Soil	8	26.89	0	
BUL	6	27.65	0	
Soil	4	30.09	0	
Null	2	33.35	0	

Table 2.14. Summary of the vegetation and land use model (Relative Non-native Cover ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road), which is one of the two models with Delta AICc < 2 for the Predictive Relative Non-native Cover Linear Model. A significance value of $p < 0.05$ was used for all models. Native Species Richness, Non-native Species Richness, and Buffer Non-native were all significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	3.94E-01	1.02E-01	3.871	0.000202
Native Species Richness	-5.80E-03	1.51E-03	-3.833	0.000231
Non-native Species Richness	1.78E-02	4.94E-03	3.603	0.000511
Litter	-8.91E-04	8.13E-04	-1.097	0.275702
Hay	2.01E-02	1.73E-02	1.163	0.247775
Range	-1.84E-02	1.42E-02	-1.294	0.198824
Buffer Non-native	2.67E-02	1.02E-02	2.627	0.010085
Distance to Road	5.78E-06	5.75E-05	0.101	0.920114

Table 2.15. Summary of the vegetation model (Relative Non-native Cover ~ Native Species + Non-native Species + Litter), which is one of the two models with Delta AICc < 2 for the Predictive Relative Non-native Cover Linear Model. A significance value of $p < 0.05$ was used for all models. Native Species Richness and Non-native Species Richness were significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.514067	0.071382	7.202	1.33E-10
Native Species Richness	-0.00760	0.001349	-5.633	1.76E-07
Non-native Species Richness	0.019701	0.004964	3.968	0.00014
Litter	-0.00138	0.000813	-1.704	0.09166

Table 2.16. Predictive models for FQAI. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the FQAI predictable from the models.

Model	K	Delta AICc	W	R^2
Global	15	0	0.6	0.6881
Vegetation and BUL	9	1.03	0.36	0.6553
BUL and Land Use	10	5.23	0.04	
BUL and Soil	8	10.58	0	
BUL	6	13.98	0	
Vegetation and Soil	7	53.65	0	
Soil and Land Use	8	56.17	0	
Soil	4	72.55	0	
Vegetation	5	73.4	0	
Vegetation and Land Use	9	76.62	0	
Land Use	6	88.03	0	
Null	2	98.99	0	

Table 2.17. Summary of the global model (FQAI ~ Relative Native Cover + Non-native Species + Litter + BUL + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road), which is one of the two models with Delta AICc < 2 for the Predictive FQAI Linear Model. A significance value of $p < 0.05$ was used for all models. Relative Native Cover, Non-native Species Richness, BUL, Soil Nitrogen, and Range were all significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	16.227041	3.885486	4.176	7.08E-05
Relative Native Cover	6.300763	2.205091	2.857	0.00536
Non-native Species Richness	0.084535	0.131425	0.643	0.52180
Litter	0.015909	0.018097	0.879	0.38182
CP BUL	-5.828689	2.376039	-2.453	0.01618
LR BUL	11.945847	2.530698	4.720	9.06E-06
SH BUL	3.301362	2.917136	1.132	0.12548
VB BUL	-3.383110	2.186531	-1.547	0.12548
Soil Nitrogen	4.147608	1.903723	2.179	0.03209
Soil Phosphorus	-0.003964	0.002096	-1.891	0.06203
Hay	-0.654410	0.452645	-1.446	0.15188
Range	0.870795	0.413230	2.107	0.03800
Buffer Non-native	0.010620	0.253332	0.042	0.96666
Distance to Road	-0.001152	0.001331	-0.866	0.38887

Table 2.18. Summary of the vegetation and BUL model (FQAI ~ Relative Native Cover + Non-native Species + Litter), which is one of the two models with Delta AICc < 2 for the Predictive FQAI Linear Model. A significance value of $p < 0.05$ was used for all models. Relative Native Cover, Non-native Species Richness, and BUL were all significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	15.50738	2.53868	6.108	2.38E-08
Relative Native Cover	8.07495	2.09939	3.846	0.000221
Non-native Species Richness	0.13069	0.11755	1.112	0.269141
Litter	0.01908	0.01909	0.999	0.320191
CP BUL	-5.57297	1.85485	-3.005	0.003427
LR BUL	10.58310	1.77401	5.966	4.49E-08
SH BUL	6.89741	1.79820	3.836	0.000229
VB BUL	-4.73911	1.82286	-2.600	0.010865

Figure 2.1. Map showing locations of the Biologically Unique Landscapes in this study. The light blue is the Upper Niobrara River BUL (AM), the tan is the Cherry County Wetlands BUL (SH), the dark blue is the Loup River BUL (LR), the light green is the Central Platte River BUL (CP) and the dark green is the Verdigris-Bazile Creek BUL (VB).

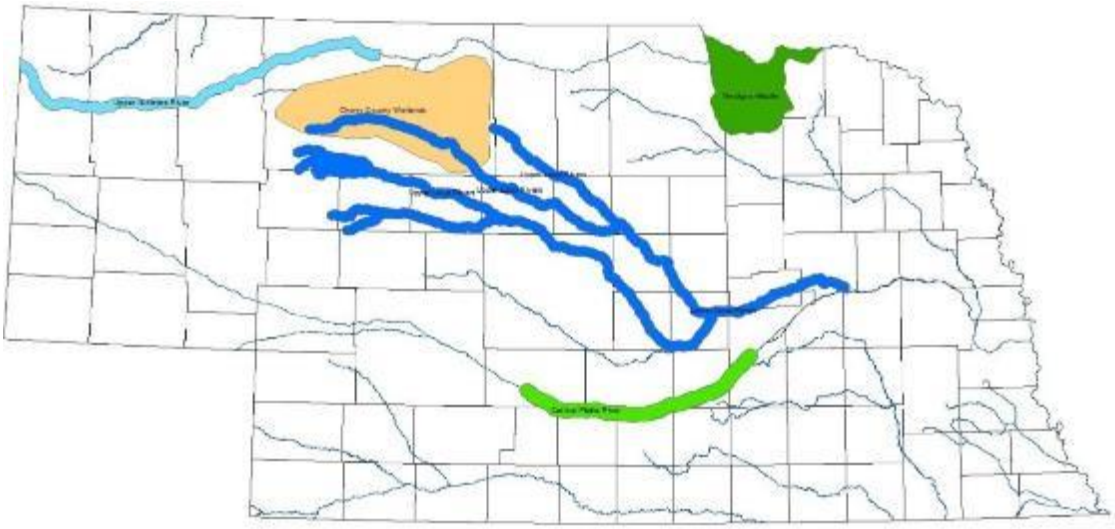


Figure 2.2. Assessment area (AA) configurations based on wetland size and shape. The blue star is the original point for the site. The inclosing dark lines indicate the boundary of the AA. The black flag is the center of the AA. The dotted lines are the transect lines with the red flag denoting the end of the transects. The green dots are the area occupied by the wetland. The dark blue area in the top legend is water deeper than 0.5m and the light blue areas in the bottom two legends are water less than 0.5m deep. Original figure from USEPA 2016c.

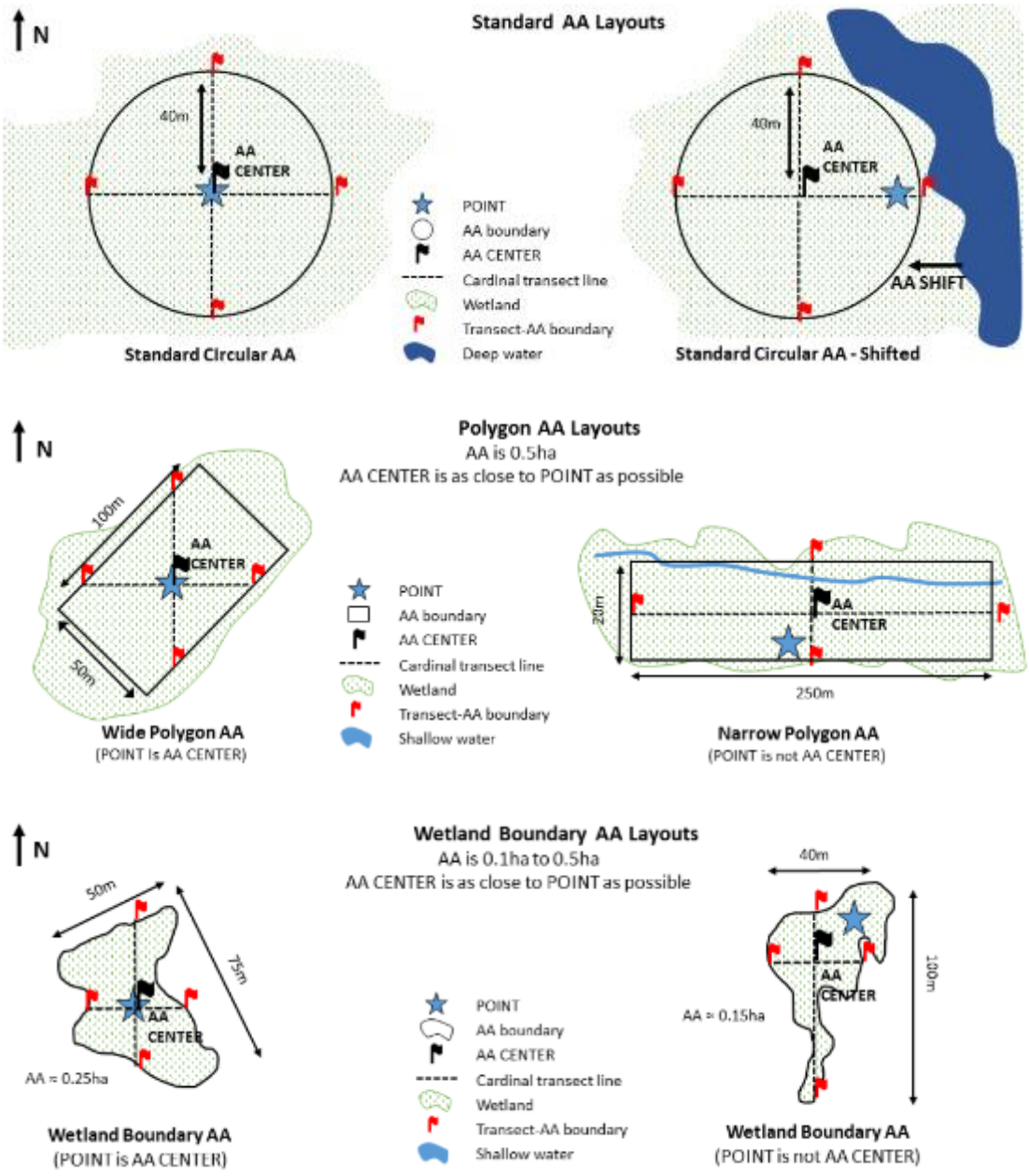


Figure 2.3. Left: Standard vegetation plot layout. Vegetation plot 1 is placed 2 meters from the center. Right: Nested quadrats within each vegetation plot. Original figure from USEPA 2016c.

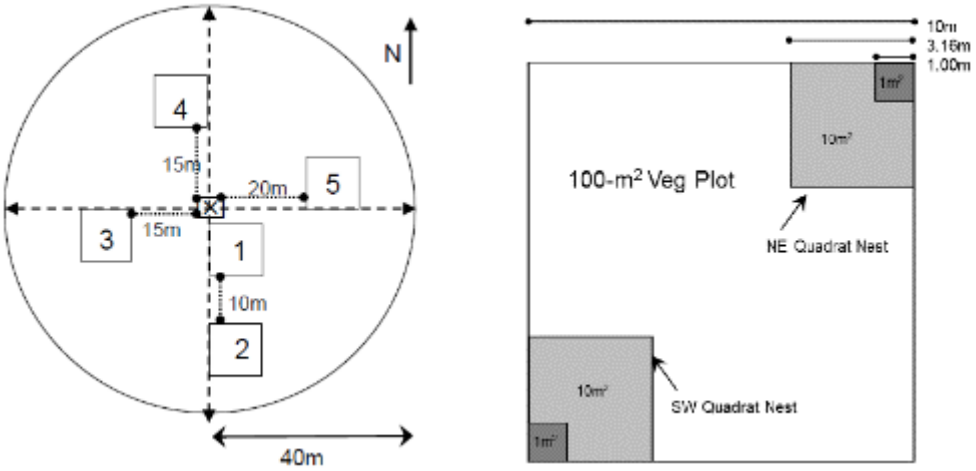


Figure 2.4. Example of vegetation plot layouts for non-circular AAs. Vegetation plots were kept as close to the standard plot layout as possible, but modified to allow five vegetation plots to spaced relatively evenly thought the AA. Original figure from USEPA 2016c.

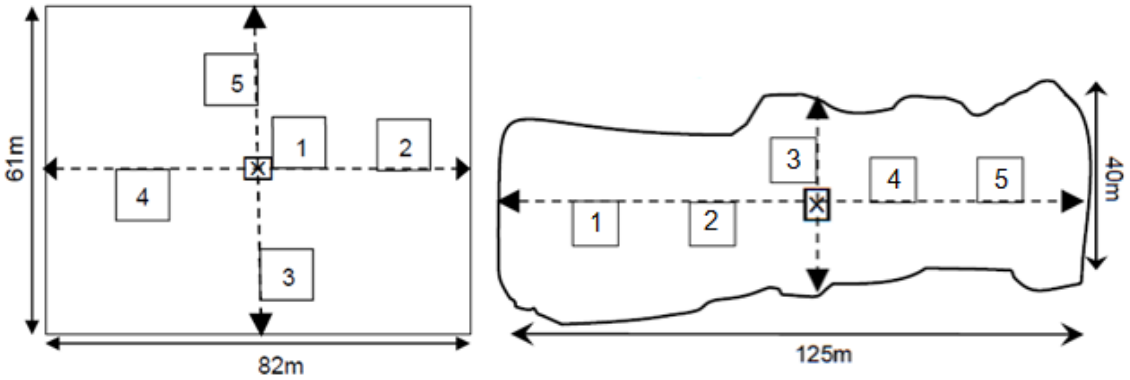


Figure 2.5. Location of 20 wetland sites sampled in 2016 in the Western Subirrigated Alkaline Meadows (Upper Niobrara River BUL) (AM).

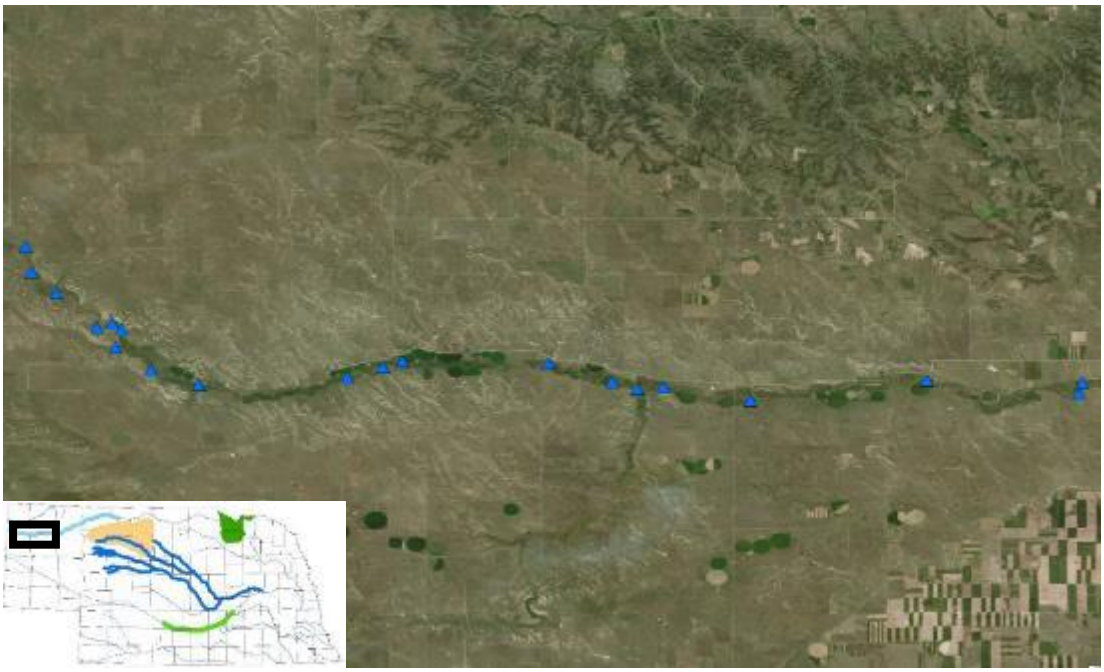


Figure 2.6. Location of 20 wetland sites sampled in 2017 in the Eastern Bulrush Deep Marsh Community (Central Platte River BUL) (CP).

Figure 2.7. Location of 20 wetland sites sampled in 2017 in the Cottonwood-Diamond Willow Woodlands (Loup River BULs) (LR).

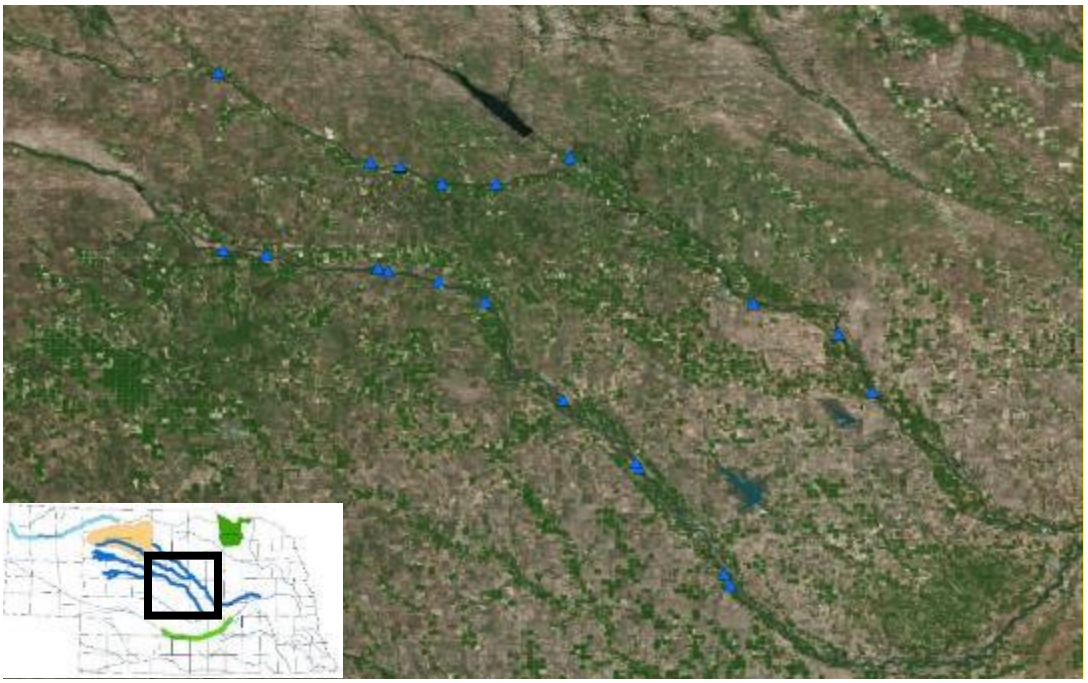


Figure 2.8. Location of 20 wetland sites sampled in 2016 in the Sandhill Fens (Cherry County Wetlands BUL) (SH).

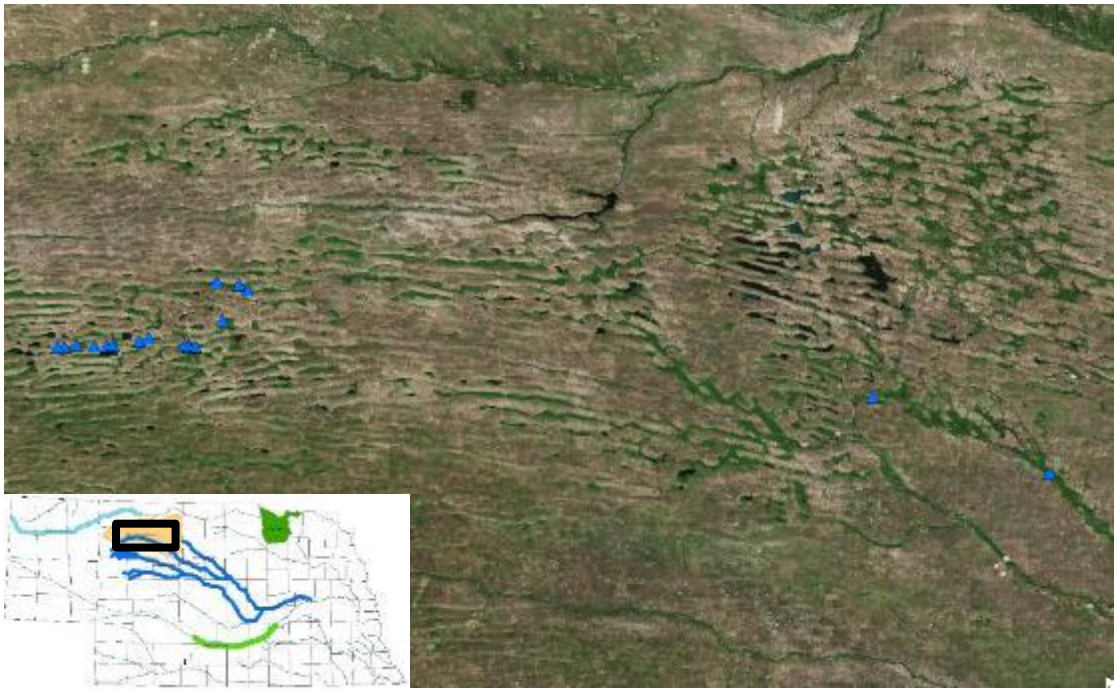


Figure 2.9. Location of 20 wetland sites sampled in 2017 in the Freshwater Seeps (Verdigris-Bazile Creek BUL) (VB).

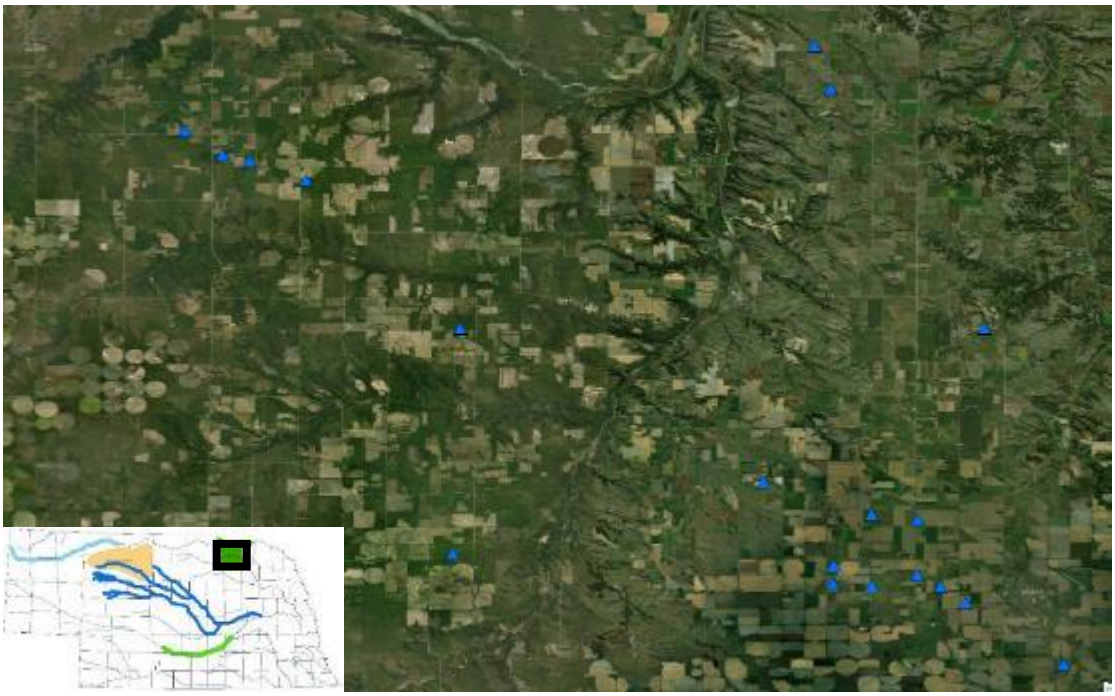
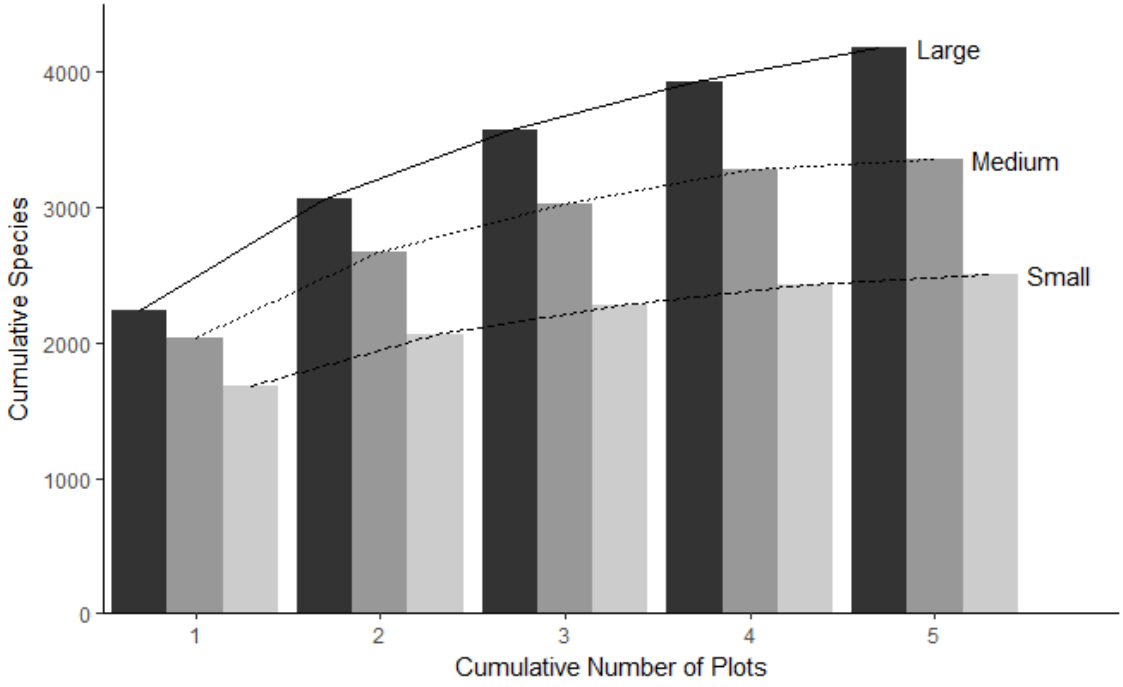


Figure 2.10. Cumulative species for all sites by plot. Large represents the 100^2m plot, Medium is both 10^2m sub plots within the Large 100^2m plot, and Small is both 1^2m sub plots within the Large 100^2m plot. The graph is to help visualize the species gained from increased sampling efforts.



CHAPTER 3: WETLAND SOIL CHARACTERISTICS OF FIVE BIOLOGICALLY UNIQUE LANDSCAPES IN NEBRSAKA

Introduction

Soil is a vital part of a wetland ecosystem. Soil is the foundation of plant communities and different soils dictate what types of vegetation is able to grow in an area. Soil nitrogen and soil phosphorus are two of the most important nutrients for plants (Jackson, 1958) are usually equally limiting in terms of plant growth (Elser et al. 2007). Nitrogen and phosphorus have the ability to drive each other (Schindler 1977, Wang et al. 2007), and can be leached into surface water (Turtola and Paajanea, 1995), leading to eutrophication (Sparks, 2003).

Soil type is one of the three variables used to determine if an area is a wetland during wetland delineation (Environmental Laboratory 1987). The Environmental Protection Agency uses a range of soil chemistry values as a metric to determine the stress applied to a wetland by the soil (EPA 2016a). Other studies have shown bulk density to be a relatively easy and effective way to measure soil condition for wetlands (Meyer et al. 2008).

The objective of this study was to collect the full range of conditions in five wetland subclasses in five biologically unique landscapes within Nebraska by collecting soil chemistry and bulk density samples. This information will be used in the short term to inform on current soil quality measures, evaluate sampling methods, and create predictive models for soil quality measures. This information will be used in future Nebraska Wetland Condition Assessments and similar studies as baseline information about the state of the Nebraska wetlands targeted for sampling in 2016 and 2017.

Methods

The methods for this study were as described in the National Wetland Condition Assessment (NWCA) 2016 Field Operations Manual developed by the Environmental Protection Agency (EPA) (USEPA 2016c). The purpose of the NWCA is to collect information about the condition of wetlands across the country every 5 years, as well as to monitor changes in five major aspects of those wetlands: hydrology, buffer, vegetation, water quality, and soil. While data were collected on all five of these aspects, this thesis focuses on the latter three: vegetation, water quality, and soil.

Sampling occurred in five priority natural wetland plant communities (Rolfsmeier and Steinauer 2010) in Biologically Unique Landscapes (BUL) in Nebraska (Schneider et al. 2011) over the summers of 2016 and 2017. The five wetland plant communities and BULs were the Sandhill Fens (Cherry County Wetlands BUL) (SH), Western Subirrigated Alkaline Meadows (Upper Niobrara River BUL) (AM), Cottonwood-Diamond Willow Woodlands (Loup River BULs) (LR), Eastern Bulrush Deep Marsh Community (Central Platte River BUL) (CP), and Freshwater Seeps (Verdigris-Bazile Creek BUL) (VB) (Figure 3.1). The Core Team, a group of experts from 11 agencies and organizations, selected these BUL's because they felt these BULs were in generally good condition, are vulnerable to future anthropogenic changes, and/or were areas where information was needed to help with conservation planning (e.g. slough restoration along the Central Platte and wetland permitting issues related to slope wetlands). There were 20 sites sampled in each BUL, which generated 100 total sites for the state.

Within each BUL, the same wetland hydro-geomorphic method (HGM) subclass was be sampled to ensure comparability within a complex (LaGrange 2010). Each of the

HGM subclasses for Nebraska was associated with the Nebraska Natural Heritage Program Natural Communities of Nebraska (Rolfsmeier and Steinauer 2010). A list of the Natural Community to target in each Complex/BUL was put together by the Core Team. This list was then associated with representative soil mapping units as determined by the NRCS soil scientist on the Core Team, and representative National Wetland Inventory (NWI) wetland polygons that were available in GIS datasets. Areas where the soils and NWI polygons overlapped within the BUL or a sub-set of the BUL represented a universe of wetlands that were assumed to be within the same HGM subclass and to represent the selected natural community. Appendix A lists the BULs sampled, and their associated soil mapping units, NWI codes, and natural communities.

Specific sample selection GIS processing methods included the following steps:

- The BUL boundary shapefile was used define the geographic extent of where a sample could be drawn from.
    - The BUL boundaries were further clipped in the Upper Loup River BUL by using Loup and Custer Counties as the western most counties included in the search based on suggestions from Bob Steinauer.
- A Soil Mapping Unit was then associated with each Natural Community Type. This was done by Dan Shurtliff (NRCS Assistant State Soil Scientist) or Neil Dominy (NRCS State Soil Scientist) and then reviewed by the Core Team.
- NWI polygon data were clipped by the BUL or Complex boundary.
- NWI polygons of the appropriate Cowardin (Cowardin et al. 1979) wetland classification type (Appendix A) were selected. These types were selected to be

representative of the natural community type and Soil Mapping Unit. Selection of the NWI type was made by Ted LaGrange with input from members of the Core Team.

- The selected NWI polygons were then clipped by the Soil Mapping Unit polygons, and the internal boundaries of the NWI polygons were dissolved.
    - In addition to these methods, an additional GIS layer from Gerry Steinauer was used in the Cherry County Wetland BUL to ensure the sites selected using the GIS methods were fens. All sites selected to be sampled were of the selected soil mapping unit and NWI polygon but were also know fens from the GIS fen data layer.
    - In addition to these methods, an additional GIS layer from the Nebraska Game and Parks Commission's Natural Heritage Program database that mapped known cottonwood diamond willow communities was used in the Upper Loup River BUL to increase the likelihood of sampling the targeted community. All sites selected to be sampled were of the selected soil mapping unit and NWI polygon but we specified that the seven sites mapped in the heritage data base were to be sampled and then randomly selected the other 13 sites to be sampled.
- ArcGIS was used to randomly select 30-60 NWI polygons (with Hawth's Tools, an extension to ArcGIS, http://www.spatialecology.com/index.php). These included 20 wetlands to be sampled if access was permitted, and additional wetlands (overdraw) to select alternates from if access was denied or the wetland was determined to be not suitable as a sample site.
    - Minimum size of a NWI polygon was 500 square meters. This was the minimum size that could accommodate the five vegetation sample plots.

- The outer edges of sample polygons were at least 280 meters apart. This ensured no overlap of buffer assessment areas (buffer assessment plots extend 140 meters from the sample point).

- A sample point was randomly placed in each of the 30-60 sample polygons. As was done for the NWCA survey, the Intensification Project was characterizing a sample point within a wetland, and not the entire wetland.
  - Because the NWI and soils data did not adequately represent the targeted plant community for the Central Platte BUL, Kirk Schroeder (USFWS Biologist) was asked to review the universe of sample polygons selected in GIS using the NWI and soils data and then select polygons for sampling that he thought could support the targeted wetland plant community. Kirk selected 31 sites for potential sampling and random points were not used.

  Because the NWI and soils data did not adequately represent the targeted plant community for the Verdigris Bazile BUL, the sample selection method was slightly altered. The soils and NWI (line and polygon) data were used to select the universe of sample polygons. Then these were examined by Ted LaGrange, and he selected the ones (N=36) that appeared to be slope wetlands in the upper ends of the watersheds.

Once permission was granted by landowners to access individual wetland sites, GPS units were used to navigate to the center of the site. From the center of the site, a circle with a radius of 40 meters was measured. This circle created a study area of 0.5 hectares and was known as the Assessment Area (AA). If the AA was more than 10%

non-wetland, such as open water or upland, the AA was shifted up to 60 meters to ensure the AA is at least 90% wetland.

If a circular AA was not possible, a polygon AA was used. The edges of the polygon was designed to get the area of the AA as close to .5 hectares as possible. If both a circular AA and polygon AA were not possible, a wetland boundary AA was used. In this case, the edges of the wetland were used as the edge of the AA (Figure 3.2).

The area of any polygon AA or wetland boundary AA were between 0.1 and 0.5 hectares depending on the size of the wetland. If the wetland was smaller than 0.1 hectares, it was excluded from the study and replaced by the next wetland on the sample draw list.

Each AA had a single soil pit positioned 3 meters southeast of the southeast corner of the first vegetation plot. If this area was unable to be sampled due to water or dense vegetation, the pit was shifted to another position, with preference going to areas close to the AA center, but in a low traffic area of the AA (Figure 3.3). Lighting condition, time of excavation, and pit location were noted before samples were taken.

Each site had 6 cores taken for a single composite standard depth sample. Two cores were taken from each of 3 locations 1.5 meters from the center of the soil pit and evenly spaced around the center of the soil pit. All cores were collected with a 7.62 cm (3 in) diameter (outside diameter) sharpened steel open-ended cylinder. The area was cleared of vegetation and the corer was pushed into the ground until flush with the ground. The corer was carefully dug from the ground and the excess soil at the bottom of the corer was removed so that the core was flush with the corer. All 6 of these cores were

placed into the same bag, creating a single composite standard depth core sample for each site.

The soil pit was dug to a depth of 1 meter, unless obstructions or non-cohesive soils prevented excavation to that depth. If there was no water evident at 1 meter, the pit was further excavated until water was found, or to a depth of 1.25 meters. If there was still no water present at 1.25 meters, then no water was recorded for the pit. The depth to the water table was calculated by observing the standing water in the pit or evidence of soil saturation on the sides of the pit.

Each pit's soil profile was examined to determine the depth of each soil horizon. Within each horizon, it was determined if an abrupt lower boundary was present, the percentage of rock fragments, percentage of roots, soil matrix color, and the redoximorphic features.

A soil chemistry sample was taken (approximately 1 gallon of soil) for each horizon and placed into a labeled bag. For horizons that were 8 cm or thicker to a depth of 60 cm, 3 bulk density samples were taken with a 7.62 cm (3 in) diameter (outside diameter) sharpened steel open-ended cylinder (Figure 3.4). The area was cleared of vegetation and the corer was pushed into the ground until it is flush. The corer was carefully dug from the ground and the excess soil at the bottom of the corer was removed so that the core was flush with the corer. All cores were placed into different bags, creating three individual bulk density samples for each horizon.

In addition, the Nebraska Wetland Rapid Assessment Method (NeWRAM) was applied for each wetland with in the CP and VB BULs. These scores were not used in any

of the analysis for this thesis, but they would be available for examination by anyone trying to assess the validity of the NeWRAM (LaGrange 2015).

After samples were collected, the pit was filled in with the excavated soil. Samples were stored in a cool, dry place until they could be delivered to the Natural Resource Conservation Service's Kellogg Soil Survey Laboratory in Lincoln, Nebraska for analysis. Soil chemistry samples were tested to determine the presence and amounts of nitrogen, phosphorous, bulk density, and heavy metals (Soil Survey Staff 2014).

After samples were analyzed, an array of t tests ($p < 0.05$) were used to determine if soil in the sampled wetlands differed significantly in their chemistry values at 10cm, 60cm or the depth of the entire pit (roughly 100cm). A brief calculation of soil variables that exceed EPA (USEPA 2016a) stressor levels was conducted. A multimodel inference approach was used to determine top predictive models for soil variables. Model sets were determined a priori. A delta AICc of 2 (Burnham and Anderson 2002) was used as the cutoff for plausible models in the model set. All possible variable combinations were checked for correlation and any highly correlated variables (correlation ≥ 0.7) were not used in the same model. While all samples were analyzed, only the standard depth cores (0-10cm) samples were used in the models. Because of a lack of consistency in depth of bulk density samples, bulk density was excluded from the analysis.

Explanation of Variables

Vegetation

Relative Native Cover: The relative cover of native vegetation compared to a total vegetative cover. This was used to keep measurements consistent instead of total native cover because different heights of plants could cause total cover to exceed 100 (ex. Site

with 75% coverage of diamond willow in height class 3 and 75% coverage of Emory's sedge in height class 2). Cover has been used as an indicator of species success obtaining soil resources (Stohlgren et al. 2003).

Non-native Species Richness: The count of total non-native species at a site. Vegetation can affect resource cycling in the soil (Mack et al. 2000, Elith et al. 2006, Jordan et al 2008).

Litter: The average of the litter coverages for the five vegetation plots. Litter adds nutrients back into soil (Ashton et al. 2005) and water (Webster 2009).

Biologically Unique Landscape

BUL: The area of the state samples were taken from. The two sampled in 2016 were the Cherry County Wetlands (SH) and the Upper Niobrara River (AM). The three sampled in 2017 were the Upper Loup Rivers (LR), Central Platte (CP), and Verdigris-Bazile (VB). Each BUL has its own vegetation, soil, and water characteristics (Rolfsmeier and Steinauer 2010).

Soil

Soil Nitrogen: Percentage of nitrogen in soil particles small enough to fit through a 2mm sieve from a depth of 0-10cm. Soil nitrogen and phosphorus have the ability to drive each other (Schindler 1977, Wang et al. 2007), and are usually equally limiting in terms of plant growth (Elser et al. 2007).

Soil Phosphorous: mg/kg of phosphorous from a depth of 0-10cm. Soil nitrogen and phosphorus have the ability to drive each other (Schindler 1977, Wang et al. 2007), and are usually equally limiting in terms of plant growth (Elser et al. 2007).

Land Use

Hay: A count of haying in the area directly adjacent to the wetland in each of the cardinal directions. Minimum of 0, maximum of 4. Haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996).

Range: A count of evidence of cattle in the area directly adjacent to the wetland in each of the cardinal directions. Minimum of 0, maximum of 4. Grazing effects runoff and erosion (Gilley et al. 1996).

Buffer Non-native: A count of the number of non-native species in the area directly adjacent to the wetland. A species could counted more than once if it was found in two or more directions. Vegetation can affect resource cycling in the soil (Mack et al. 2000, Elith et al. 2006, Jordan et al 2008).

Distance to Road: Distance from the center of the wetland to the closest road. Roads affect water flow, erosion and soil chemistry values (Forman and Alexander 1998).

Explanation of Model Selection

All variables within each model were not correlated (< 0.7) with any other variable in the model. Each model set is composed of a null model, global model, vegetation model, BUL model, soil model, land use models, and every pair of combinations of the vegetation, BUL, soil, and land use models. This gives a grand total of 12 models for each predictor. Models that contain the vegetation, BUL, soil, and land use models use the same variables for each predictive model.

Predictive Soil Nitrogen

Relative native species cover was used because vegetative cover has been used as an indicator of species success obtaining resources (Stohlgren et al. 2003). Non-native species richness was used because vegetation type can affect resource cycling in the soil (Mack et al. 2000, Elith et al. 2006, Jordan et al 2008). Litter was used because litter adds nutrients back into soil (Ashton et al. 2005) and water (Webster 2009). The BUL models were used because each BUL has its own vegetation, soil, and water characteristics (Rolfsmeier and Steinauer 2010). Soil phosphorus was used because soil nitrogen and phosphorus have the ability to drive each other (Schindler 1977, Wang et al. 2007), and are usually equally limiting in terms of plant growth (Elser et al. 2007). The hay variable was used in the land use model because haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing effects runoff and erosion (Gilley et al. 1996). Buffer non-native was used because vegetation can affect resource cycling in the soil (Mack et al. 2000, Elith et al. 2006, Jordan et al 2008). Distance to roads was used because roads affect water flow, erosion and soil chemistry values (Forman and Alexander 1998).

Predictive Soil Phosphorus

Relative native species cover was used because vegetative cover has been used as an indicator of species success obtaining resources (Stohlgren et al. 2003). Non-native species richness was used because vegetation type can affect resource cycling in the soil (Mack et al. 2000, Elith et al. 2006, Jordan et al 2008). Litter was used because litter adds nutrients back into soil (Ashton et al. 2005) and water (Webster 2009). The BUL models were used because each BUL has its own vegetation, soil, and water characteristics

(Rolfsmeier and Steinauer 2010). Soil nitrogen was used because soil nitrogen and phosphorus have the ability to drive each other (Schindler 1977, Wang et al. 2007), and are usually equally limiting in terms of plant growth (Elser et al. 2007). The hay variable was used in the land use model because haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing affects vegetation composition (Milchunas et al. 1993). Buffer non-native was used because vegetation can affect resource cycling in the soil (Mack et al. 2000, Elith et al. 2006, Jordan et al 2008). Distance to roads was used because roads affect water flow, erosion and soil chemistry values (Forman and Alexander 1998).

Predictive Model Sets

Soil Nitrogen

1. Soil Nitrogen ~ 1
2. Soil Nitrogen ~ Relative Native Cover + Non-native Species + Litter
3. Soil Nitrogen ~ BUL
4. Soil Nitrogen ~ Soil Phosphorus
5. Soil Nitrogen ~ Hay + Range + Buffer Non-native + Distance to Road
6. Soil Nitrogen ~ Relative Native Cover + Non-native Species + Litter + BUL
7. Soil Nitrogen ~ Relative Native Cover + Non-native Species + Litter + Soil Phosphorus
8. Soil Nitrogen ~ Relative Native Cover + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
9. Soil Nitrogen ~ BUL + Soil Phosphorus
10. Soil Nitrogen ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
11. Soil Nitrogen ~ Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road
12. Soil Nitrogen ~ Relative Native Cover + Non-native Species + Litter + BUL + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Soil Phosphorous

1. Soil Phosphorus ~ 1
2. Soil Phosphorus ~ Relative Native Cover + Non-native Species + Litter
3. Soil Phosphorus ~ BUL

4. Soil Phosphorus ~ Soil Nitrogen
5. Soil Phosphorus ~ Hay + Range + Buffer Non-native + Distance to Road
6. Soil Phosphorus ~ Relative Native Cover + Non-native Species + Litter + BUL
7. Soil Phosphorus ~ Relative Native Cover + Non-native Species + Litter + Soil Nitrogen
8. Soil Phosphorus ~ Relative Native Cover + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
9. Soil Phosphorus ~ BUL + Soil Nitrogen
10. Soil Phosphorus ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
11. Soil Phosphorus ~ Soil Nitrogen + Hay + Range + Buffer Non-native + Distance to Road
12. Soil Phosphorus ~ Relative Native Cover + Non-native Species + Litter + BUL + Soil Nitrogen + Hay + Range + Buffer Non-native + Distance to Road

Results

Soil Depth Comparisons

While all of the models were calculated with soil chemistry values from only the standard depth cores, soil chemistry samples were taken for the entire depth of each soil pit (Figure 3.4). To determine if soil chemistry varied at different levels of the soil, an array of paired t-tests was conducted between standard depth cores (10cm), a composite of the samples to a depth of 60cm, and a composite of the samples for the entire pit (max 132cm) at a 0.05 level of significance. Only nitrogen varied significantly between the 10cm and the 60cm samples. Only tungsten did not differ significantly ($p<0.05$) when the entire pit depth was considered (Table 3.1).

Soil Standards Comparisons

There are no regulations or laws dictating maximum levels for phosphorus or heavy metals in the soil for Nebraska or the United States. The thresholds in this study were developed by the EPA to determine if soil chemistry is a source of stress for a wetland (USEPA 2016a). They hold no regulatory weight, but are the closest to standards available in the United States (Table 3.2-3.4).

If the values for the entire pit are examined, only 11 sites show up with phosphorus exceeding at least the low threshold as opposed to 12 sites above the low threshold in the standard depth core samples (Table 3.2).

In addition to soil phosphorus, soil chemistry was taken for 12 trace elements commonly found in wetlands. The EPA developed wetland soil heavy metal thresholds based on Alloway (2013) to determine if trace elements are a source of stress for a wetland. They hold no regulatory weight, but are the closest to standards available in the United States (Table 3.3 and 3.4).

Only three sites had heavy metals break the threshold for the EPA's soil chemistry stressors. Only four total measures out of 1,200 break the threshold. Of those four, only one (Cadmium) of those is found above natural background concentrations. VB34 had a value of 2.02 mg/kg for Cadmium (threshold of 1.0 mg/kg) in addition to a value of 1.56mg/kg for Antimony (threshold of 1.0 mg/kg). This Antimony level is within the natural background level (0.1 – 1.9 mg/kg). CP09 and CP29 had cobalt levels of 40.51 mg/kg and 25.10 mg/kg respectively (threshold of 25 mg/kg), although both are within the natural background levels (<50 mg/kg). None of these sites had obvious point sources for these metals (Table 3.3).

Predictive Soil Nitrogen

The BUL and soil model (Soil Nitrogen ~ BUL + Soil Phosphorus) is the only model with Delta AICc < 2 for the predictive soil nitrogen linear model (Table 3.7). BUL and soil phosphorus were significant at a value of $p < 0.05$ (Table 3.8).

Predictive Soil Phosphorous

The BUL soil model (Soil Phosphorus ~ BUL + Soil Nitrogen) is the only model with Delta AICc < 2 for the predictive soil phosphorus linear model (Table 3.9). BUL and soil nitrogen were significant at a value of $p < 0.05$ (Table 3.10).

Discussion

By digging to a depth of 100cm or more, only one more heavy metal was detected beyond the screening threshold and only three sites were found to have values beyond the threshold not found by the stand depth cores. This comes at the cost of 331 horizons samples as opposed to 100 standard depth samples.

The percentage of 2016-2017 standard depth cores and soil horizons that broke thresholds was less than or equal to the percentage 2011-2013 soil horizons that broke thresholds for all heavy metals studied except cobalt, which was not found above the threshold at all in 2011-2013 (Table 3.5).

All but one of the entire pit samples started at 0cm. Because of this, samples were likely taken in the first 5-10cm to ensure the samples were not contaminated with soil from the next deepest horizon. The standard depth cores do the same thing, but in a more uniform and repeatable fashion. The EPA added standard depth cores to their protocol in 2016 because nearly a third of their sites failed to have the top horizon sampled due to thin surface soil horizons (USEPA, 2016b and USEPA, 2016c).

Predictive Soil Nitrogen

The soil and BUL model is the top model. The presence of BUL in the top model is unsurprising since, much like vegetation and water chemistry metrics, soil chemistry varies regionally and by soil type (Batjes 1996). Soil phosphorus had a positive relationship with soil nitrogen. While nitrogen and phosphorus do not need to increase

with each other (Elser et al. 2007), they do have some power to drive each other (Schindler 1977, Wang et al. 2007), and are usually equally limiting in terms of plant growth (Elser et al. 2007).

Predictive Soil Phosphorous

Much like soil nitrogen, the soil and BUL model were the top model for predicting soil phosphorus. Soil nitrogen had a positive relationship with soil phosphorus. As stated above, nitrogen and phosphorus do not need to increase with each other (Elser et al. 2007), but they can affect each other (Schindler 1977, Wang et al. 2007), and are usually equally limiting in terms of plant growth (Elser et al. 2007). Since phosphorus helped drive nitrogen levels in this study, it is unsurprising that phosphorus also helps drive nitrogen levels. Again, the presence of BUL in the top model is unsurprising since soil chemistry varies regionally and by soil type (Batjes 1996).

Conclusion

It takes around 10 minutes to take standard depth cores, but it takes about an hour to sample a simple 100cm soil pit with three thick horizons. It can take three or more hours to sample a 100cm soil pit with eight horizons of varying thicknesses, especially if multiple horizons are deeper than 50cm or the clay content is high. When difficult soil pits occurred, they caused the soil team to finish after the botanist, probably at about 20% of the sites. This generally only added around 30 minutes to surveying time, but it would occasionally (5%) add an additional hour or even two.

Because the NRCS Soil Survey Laboratory has limited space and the Nebraska Wetland Condition Assessment has lower priority than the EPA's National Wetland Condition Assessment, it takes considerable time and space to store ≈200 soil samples.

The cost to analyze every horizon was 3.3 times greater than the standard depth cores, costing around an additional $60,000. By removing this expense, future projects could easily save enough money to examine another BUL (20 sites), assuming the vegetation is not extremely dense and diverse.

Based on this knowledge, I would recommend that soil samples only be taken using standard depth cores (0-10 cm), unless the project has specific plans to test deeper wetland soils. This is the depth suggested by Berrow (1988), parroted by Alloway (2013), and the area of the soil used in analysis by the EPA (2016a). Alloway (2013) does mention that samples for contaminated sites can be taken to a depth of 100cm or greater, although surface soils are also used in different situations. With the removal of the soil pit from the protocol, enough time and money could be saved to sample another wetland complex (20 sites) in another BUL or increase the sampling effort of the selected BULs for 2021. But, if soil is taken deeper than the standard depth cores, samples should be taken to a depth of 100cm because that is where the differences between standard depth cores are found.

I would also recommend adding surface bulk density samples. This project was unable to use the bulk density samples taken because of a lack of standardization. Bulk density samples could be taken at the same time as and in the same manner as the standard depth cores. This would add roughly 5 minutes to sampling a site but would easily generate useful information (Meyer et al. 2008).

With these two changes to the soil protocol, the surveying team would become much more efficient, impacts to the wetland would be reduced without the need to dig a large hole (the area of most concern from landowners), and sites could potentially be

sampled with only three team members (graduate student lead, trained botanist, and single technician). That said, I would still recommend two technicians for the first field season. They will be very helpful for the 10 EPA sites (which will likely keep the 1m soil pit) and there is a bit of a learning curve during the first filed season that is mitigated by having more people at the EPA training. If the soil pit is removed, extra care should be taken at the 10 EPA sites to insure the proper protocols are followed. Multiple protocols were not an issue for this project since the protocols were nearly identical.

As for the models, because the only significant models were the BUL and soil models, it would likely be beneficial to look at only a single BUL at a time when doing future soil models. These soils have very different characteristics, and knowing more about them individually will likely be more beneficial than to infer about Nebraskan wetland soil as a whole.

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Tables and Figures

Table 3.1. Paired t-tests p values for all 14 soil chemistry variables examined in this study with a significance level of 0.05. 10cm is the depth of the standard depth cores. 60cm is the depth to which bulk density samples were taken. The entire pit is all of the horizons of the pit to the maximum depth.

	10cm vs 60cm p-values	10cm vs Entire Pit p-values	60cm vs Entire Pit p-values
Nitrogen	0.02754	2.2e-16	2.448e-16
Silver	0.3053	1.622e-11	4.131e-12
Cadmium	0.07159	2.2e-16	5.283e-16
Cobalt	0.5211	1.24e-05	0.0001808
Chromium	0.9257	6.396e-08	2.1e-08
Copper	0.07333	3.516e-15	4.945e-16
Nickel	0.7071	2.368e-09	1.492e-10
Lead	0.5263	1.594e-15	2.2e-16
Antimony	0.3672	0.0001263	3.445e-05
Tin	0.6366	1.866e-09	1.018e-10
Vanadium	0.9066	2.261e-07	1.693e-08
Tungsten	0.9664	0.2898	0.2929
Zinc	0.2671	4.6e-15	8.239e-13
Phosphorus	0.2307	2.2e-16	2.2e-16

Table 3.2. Soil Phosphorus levels exceeding the thresholds for soil stress determined by the EPA (2016a) by using values between the 75th and 95th percentile of the interior plains reference wetland sites as the medium threshold and values above the 95th percentile of the interior plains reference wetland sites as the high threshold. SCD stands for standard depth core and entire pit are measurements from all horizons sampled.

	Threshold Phosphorus	Site ID for SDC	Site ID for Entire Pit
Medium Threshold (mg P/kg soil)	P > 1110 & P < 1810	CP09, LR36, SH05, SH10, SH13, SH16, SH18, SH22, SH29, SH23, VB30	CP29 0-7cm, SH02 0-19cm, SH05 0-29cm, SH10 0-22cm, SH11 0-6cm, SH12 0-7cm, SH14 0-9cm, SH16 0-10cm, SH22 0-21cm, SH29 0-17cm, VB30 66-100cm
High Threshold (mg P/kg soil)	P > 1810	VB10	VB30 0-66cm

Table 3.3. The left 5 columns are from the 2011 EPA National Wetland Condition Assessment (USEPA, 2016a), which originally determined the values based on the natural background levels given in Alloway (2013). The right column contains the results of the 2016-2017 Nebraska wetland condition assessment.
* Within natural background levels, but still exceeding the screening threshold.

Metal	Primary Anthropogenic Associations	Natural Background (mg/kg)	Screening Threshold (mg/kg)	% 2011 Nation Wide Sites Exceeding Threshold	Nebraska SDC Exceeding Threshold
Silver (Ag)	Industry	0.05 – 1.00	1.0	0.7	NONE
Cadmium (Cd)	Agriculture	0.1 – 1.0	1.0	5.1	VB34
Cobalt (Co)	Industry	< 50	25	1.1	CP09* & CP29*
Chromium (Cr)	Industry	0.5 – 250	125	0.5	NONE
Copper (Cu)	Agriculture / Industry / Roads	2 – 50	50	5.5	NONE
Nickel (Ni)	Industry / Agriculture	0.2 – 450	225	0.1	NONE
Lead (Pb)	Roads / Industry	Mean of 18	35	17.0	NONE
Antimony (Sb)	Industry	0.1 – 1.9	1.0	4.0	VB34*
Tin (Sn)	Industry / Agriculture	1.7 – 50	17	0.3	NONE
Vanadium (V)	Industry / Roads	36 – 150	150	0.2	NONE
Tungsten (W)	Industry / Agriculture	< 2	2.0	1.5	NONE
Zinc (Zn)	Industry / Agriculture	10 – 150	150	6.6	NONE

Table 3.4. The left three columns are from the 2011 EPA National Wetland Condition Assessment (USEPA, 2016a), which originally determined the values based on the natural background levels given in Alloway (2013). Right two columns are results of the 2016-2017 Nebraska wetland condition assessment.
* Within natural background levels, but still exceeding the screening threshold.

Metal	**Natural Background (mg/kg)**	**Screening Threshold (mg/kg)**	**SDC Exceeding Threshold**	**Horizons Exceeding Threshold at Any Depth**
Silver (Ag)	0.05 – 1.00	1.0	NONE	NONE
Cadmium (Cd)	0.1 – 1.0	1.0	VB34	VB34 0-41cm VB34 41-100cm CP29 0-7cm
Cobalt (Co)	< 50	25	CP09* CP29*	CP09 0-22cm* CP29 0-7cm*
Chromium (Cr)	0.5 – 250	125	NONE	NONE
Copper (Cu)	2 – 50	50	NONE	NONE
Nickel (Ni)	0.2 – 450	225	NONE	NONE
Lead (Pb)	Mean of 18	35	NONE	NONE
Antimony (Sb)	0.1 – 1.9	1.0	VB34*	SH17 40-65cm SH17 78-100cm VB34 0-41cm* VB34 41-100cm*
Tin (Sn)	1.7 – 50	17	NONE	NONE
Vanadium (V)	36 – 150	150	NONE	NONE
Tungsten (W)	< 2	2.0	NONE	SH21 57-100cm
Zinc (Zn)	10 – 150	150	NONE	NONE

Table 3.5. The percentage 2011 Nation Wide Sites Exceeding Threshold column is the results of the 2011 EPA National Wetland Condition Assessment (USEPA, 2016a). The middle column are the results of the first Nebraska wetland condition assessment from 2011-2013. The right two columns are results of the 2016-2017 Nebraska wetland condition assessment.

Metal	**% 2011 Nation Wide Sites Exceeding Threshold**	**% 2011-2013 Horizons Exceeding Threshold at Any Depth**	**% 2016-2017 SDC Exceeding Threshold**	**% 2016-2017 Horizons Exceeding Threshold at Any Depth**
Silver (Ag)	0.7	0	0	0
Cadmium (Cd)	5.1	2.6	1.0	0.9
Cobalt (Co)	1.1	0	2.0	0.6
Chromium (Cr)	0.5	0	0	0
Copper (Cu)	5.5	0	0	0
Nickel (Ni)	0.1	0	0	0
Lead (Pb)	17.0	0.6	0	0
Antimony (Sb)	4.0	1.3	1.0	1.2
Tin (Sn)	0.3	0	0	0
Vanadium (V)	0.2	0	0	0
Tungsten (W)	1.5	7.1	0	0.3
Zinc (Zn)	6.6	0	0	0

Table 3.6. Percentage of soil phosphorus levels exceeding the thresholds for soil stress determined by the EPA (2016a) by using values between the 75th and 95th percentile of the interior plains reference wetland sites as the medium threshold and values above the 95th percentile of the interior plains reference wetland sites as the high threshold. SCD stands for standard depth core.

	Threshold Phosphorus	% 2016-2017 Standard Depth Cores Above Standards	% 2016-2017 Horizons Above Standards	% 2011-2013 Horizons Above Standards
Medium Threshold (mg P/kg soil)	P > 1110 & P < 1810	11.0	3.3	5.8
High Threshold (mg P/kg soil)	P > 1810	1.0	0.3	0

Table 3.7. Predictive models for soil nitrogen. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the soil nitrogen predictable from the models.

Model	K	Delta AICc	W	R^2
BUL and Soil	7	0	0.89	0.8106
Global	14	4.24	0.11	0.8210
Vegetation and BUL	9	34.25	0	
BUL	6	53.51	0	
BUL and Land Use	10	57.48	0	
Vegetation and Soil	6	101.51	0	
Soil	3	103.72	0	
Soil and Land Use	7	109.70	0	
Vegetation	5	150.93	0	
Vegetation and Land Use	9	154.96	0	
Null	2	160.48	0	
Land Use	6	165.36	0	

Table 3.8. Summary of the BUL and soil model (Soil Nitrogen ~ BUL + Soil Phosphorus), which is the only model with Delta AICc < 2 for the Predictive Soil Nitrogen Linear Model. A significance value of $p < 0.05$ was used for all models. BUL and soil phosphorus were significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.051667	0.079313	0.651	0.516
CP BUL	-0.045047	0.098433	-0.458	0.648
LR BUL	0.021926	0.095118	0.231	0.818
SH BUL	1.045235	0.107682	9.707	7.72E-16
VB BUL	-0.202461	0.100576	-2.013	0.047
Soil Phosphorus	0.000755	0.000090	8.383	4.99E-13

Table 3.9. Predictive models for soil phosphorus. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the soil phosphorus predictable from the models.

Model	K	Delta AICc	W	R^2
BUL and Soil	7	0	1	0.5907
Global	14	13.54	0	
Vegetation and Soil	6	23.84	0	
Soil	3	26.66	0	
Soil and Land Use	7	32.87	0	
Vegetation and BUL	9	43.50	0	
BUL	6	53.51	0	
BUL and Land Use	10	58.21	0	
Vegetation	5	73.27	0	
Vegetation and Land Use	9	79.95	0	
Null	2	83.42	0	
Land Use	6	88.52	0	

Table 3.10. Summary of the BUL soil model (Soil Phosphorus ~ BUL + Soil Nitrogen), which is the only model with Delta AICc < 2 for the Predictive Soil Phosphorus Linear Model. A significance value of $p < 0.05$ was used for all models. BUL and Soil Nitrogen were all significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	238.67	64.36	3.708	0.000353
CP BUL	189.01	83.17	2.273	0.025331
LR BUL	-40.44	82.37	-0.491	0.624646
SH BUL	-270.49	129.11	-2.095	0.038850
VB BUL	324.45	82.52	3.932	0.000161
Soil Nitrogen	566.98	67.63	8.383	4.99E-13

Figure 3.1. Map showing locations of the Biologically Unique Landscapes in this study. The light blue is the Upper Niobrara River BUL (AM), the tan is the Cherry County Wetlands BUL (SH), the dark blue is the Loup River BUL (LR), the light green is the Central Platte River BUL (CP) and the dark green is the Verdigris-Bazile Creek BUL (VB).

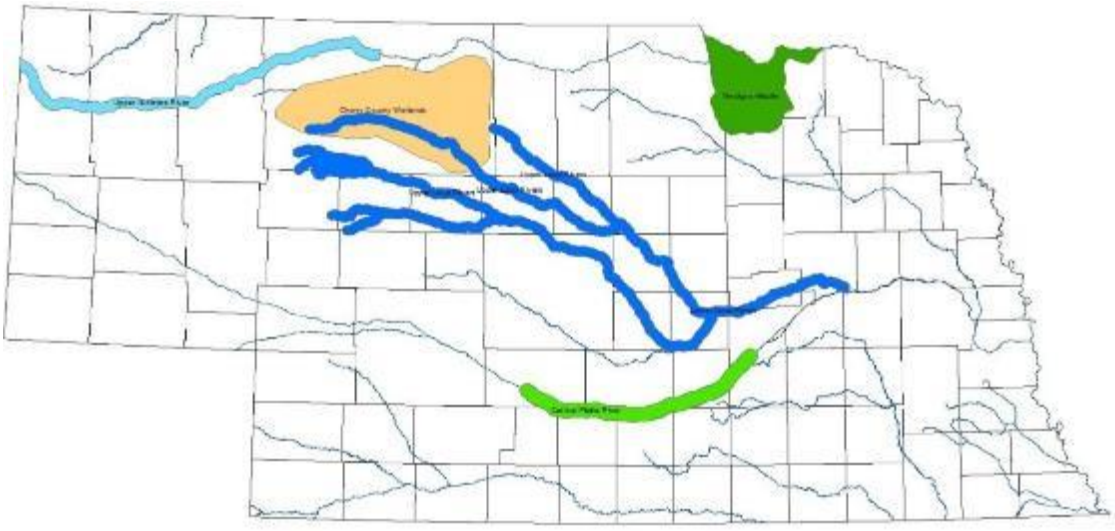


Figure 3.2. Assessment area (AA) configurations based on wetland size and shape. The blue star is the original point for the site. The inclosing dark lines indicate the boundary of the AA. The black flag is the center of the AA. The dotted lines are the transect lines with the red flag denoting the end of the transects. The green dots are the area occupied by the wetland. The dark blue area in the top legend is water deeper than 0.5m and the light blue areas in the bottom two legends are water less than 0.5m deep. Original figure from USEPA 2016c.

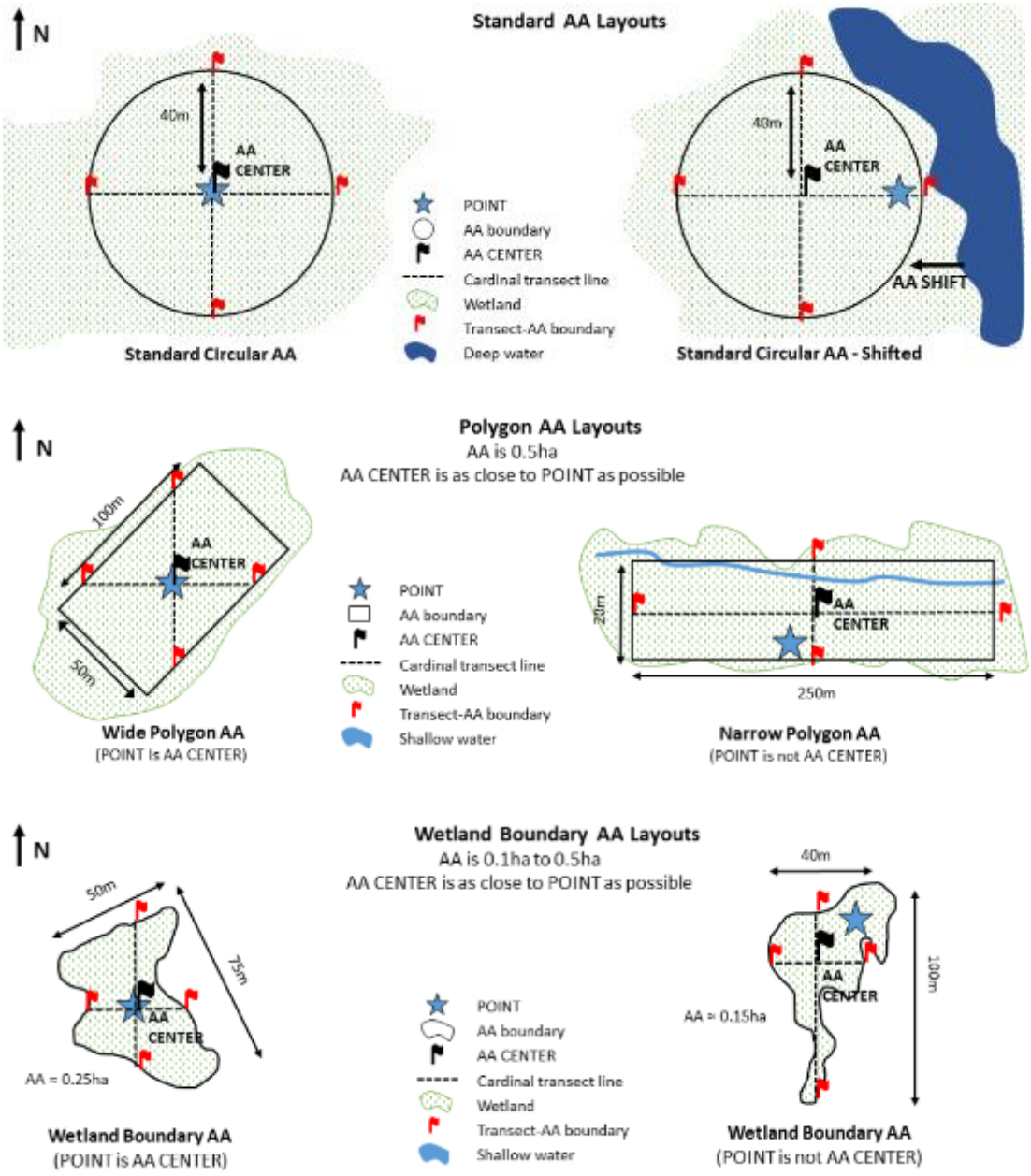


Figure 3.3. Examples of ideal soil pit (star) placement based on vegetation plot configuration. Original figure from USEPA 2016.

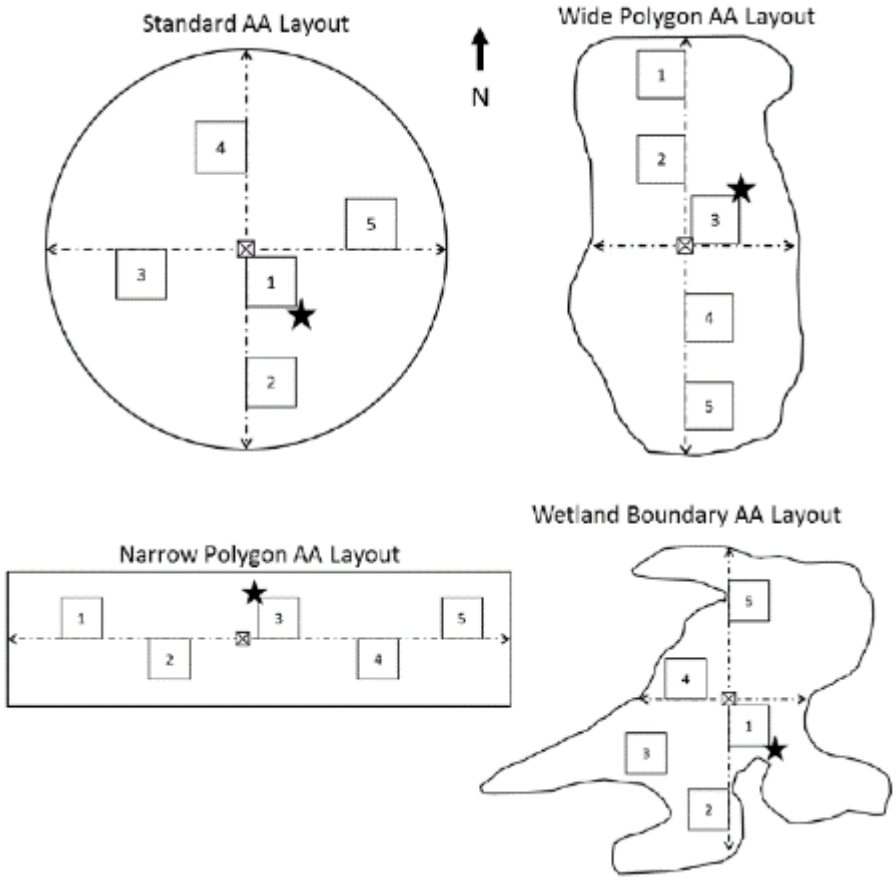
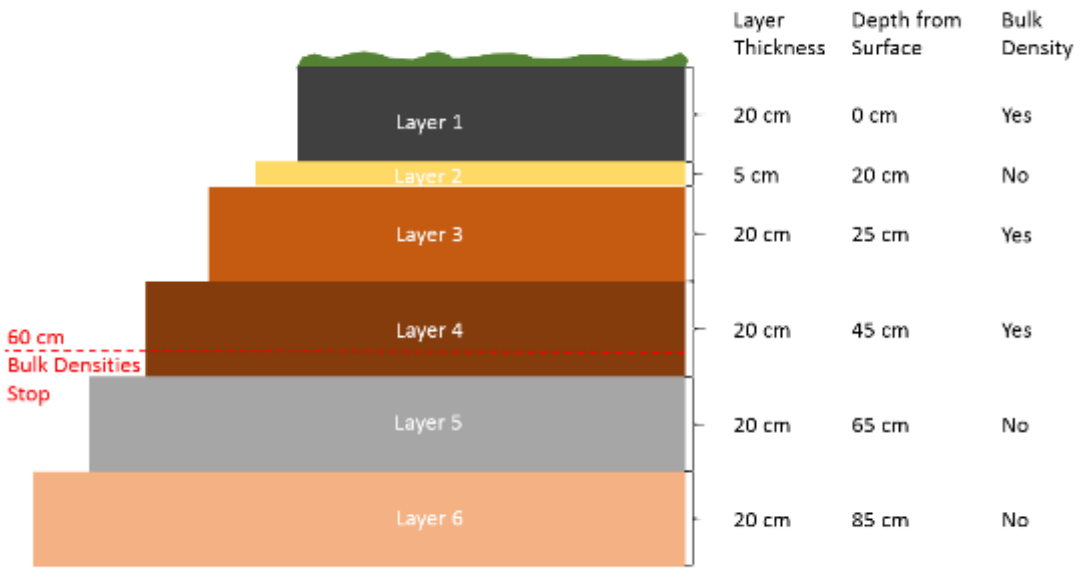


Figure 3.4. Example of layout of horizons and sampling protocol of each horizon. Only layer 1, 3, and 4 would be sampled for bulk density, but all layers would be sampled for soil chemistry.



CHAPTER 4: WETLAND WATER CHARACTERISTICS OF FIVE BIOLOGICALLY UNIQUE LANDSCAPES IN NEBRSAKA

Introduction

Wetlands provide many ecosystem services, many of which center around one of Nebraska's most important resources: Water (LaGrange 2005). Without water, plant communities would be completely different and soil would form differently without inundation (Vepraskas and Craft 2016). Surface water in wetlands directly provide nutrients to wetland plants and soils (Johnston 1991). Many wetlands are specifically constructed to remove nutrients (Moshiri 1993) and pollutants (Wang and Sample 2014) from wastewater.

Though water is important, surface water is not always present in wetlands, as demonstrated by only 56% of the sites from the previous National Wetland Condition Assessment containing samplable surface water (USEPA 2016a). Even with the difficulties, analysis of water can help identify the condition of wetlands since the chemical and physical properties of water are directly linked to the surrounding areas (USEPA 2016b).

Even though wetlands provide many important services, few specifics are known about many Nebraska wetlands. Title 117 - Nebraska Surface Water Quality Standards (Title 117) states that Nebraskan wetland water quality values are based on natural background values, but then gives no values for key water indicators such as nitrogen, phosphorus, or chlorophyll a (Title 117 2014). The objective of this study is to collect the full range of conditions for water quality in Nebraska wetlands. This information will be used in the short term to inform on current water quality measures, evaluate sampling

methods, and create predictive models for water quality measures. This information will be used in future Nebraska Wetland Condition Assessments and similar studies as baseline information about the state of Nebraska wetlands in 2016 and 2017.

Methods

The methods for this study were as described in the National Wetland Condition Assessment (NWCA) 2016 Field Operations Manual developed by the Environmental Protection Agency (EPA) (USEPA 2016c). The purpose of the NWCA is to collect information about the condition of wetlands across the country every 5 years, as well as to monitor changes in five major aspects of those wetlands: hydrology, buffer, vegetation, water quality, and soil. While data were collected on all five of these aspects, this thesis focuses on the latter three: vegetation, water quality, and soil.

Sampling occurred in five priority natural wetland plant communities (Rolfsmeier and Steinauer 2010) in Biologically Unique Landscapes (BUL) in Nebraska (Schneider et al. 2011) over the summers of 2016 and 2017. The five wetland plant communities and BULs were the Sandhill Fens (Cherry County Wetlands BUL) (SH), Western Subirrigated Alkaline Meadows (Upper Niobrara River BUL) (AM), Cottonwood-Diamond Willow Woodlands (Loup River BULs) (LR), Eastern Bulrush Deep Marsh Community (Central Platte River BUL) (CP), and Freshwater Seeps (Verdigris-Bazile Creek BUL) (VB) (Figure 4.1). The Core Team, a group of experts from 11 agencies and organizations, selected these BUL's because they felt these BULs were in generally good condition, are vulnerable to future anthropogenic changes, and/or were areas where information was needed to help with conservation planning (e.g. slough restoration along

the Central Platte and wetland permitting issues related to slope wetlands). There were 20 sites sampled in each BUL, which generated 100 total sites for the state.

Within each BUL, the same wetland hydro-geomorphic method (HGM) subclass was be sampled to ensure comparability within a complex (LaGrange 2010). Each of the HGM subclasses for Nebraska was associated with the Nebraska Natural Heritage Program Natural Communities of Nebraska (Rolfsmeier and Steinauer 2010). A list of the Natural Community to target in each Complex/BUL was put together by the Core Team. This list was then associated with representative soil mapping units as determined by the NRCS soil scientist on the Core Team, and representative National Wetland Inventory (NWI) wetland polygons that were available in GIS datasets. Areas where the soils and NWI polygons overlapped within the BUL or a sub-set of the BUL represented a universe of wetlands that were assumed to be within the same HGM subclass and to represent the selected natural community. Appendix A lists the BULs sampled, and their associated soil mapping units, NWI codes, and natural communities.

Specific sample selection GIS processing methods included the following steps:

- The BUL boundary shapefile was used define the geographic extent of where a sample could be drawn from.
    - The BUL boundaries were further clipped in the Upper Loup River BUL by using Loup and Custer Counties as the western most counties included in the search based on suggestions from Bob Steinauer.
- A Soil Mapping Unit was then associated with each Natural Community Type. This was done by Dan Shurtliff (NRCS Assistant State Soil Scientist) or Neil Dominy (NRCS State Soil Scientist) and then reviewed by the Core Team.

- NWI polygon data were clipped by the BUL or Complex boundary.
- NWI polygons of the appropriate Cowardin (Cowardin et al. 1979) wetland classification type (Appendix A) were selected. These types were selected to be representative of the natural community type and Soil Mapping Unit. Selection of the NWI type was made by Ted LaGrange with input from members of the Core Team.
- The selected NWI polygons were then clipped by the Soil Mapping Unit polygons, and the internal boundaries of the NWI polygons were dissolved.
    - In addition to these methods, an additional GIS layer from Gerry Steinauer was used in the Cherry County Wetland BUL to ensure the sites selected using the GIS methods were fens. All sites selected to be sampled were of the selected soil mapping unit and NWI polygon but were also know fens from the GIS fen data layer.
    - In addition to these methods, an additional GIS layer from the Nebraska Game and Parks Commission's Natural Heritage Program database that mapped known cottonwood diamond willow communities was used in the Upper Loup River BUL to increase the likelihood of sampling the targeted community. All sites selected to be sampled were of the selected soil mapping unit and NWI polygon but we specified that the seven sites mapped in the heritage data base were to be sampled and then randomly selected the other 13 sites to be sampled.
- ArcGIS was used to randomly select 30-60 NWI polygons (with Hawth's Tools, an extension to ArcGIS, http://www.spatialecology.com/index.php). These included 20 wetlands to be sampled if access was permitted, and additional wetlands (overdraw)

to select alternates from if access was denied or the wetland was determined to be not suitable as a sample site.

  - Minimum size of a NWI polygon was 500 square meters. This was the minimum size that could accommodate the five vegetation sample plots.
  - The outer edges of sample polygons were at least 280 meters apart. This ensured no overlap of buffer assessment areas (buffer assessment plots extend 140 meters from the sample point).

- A sample point was randomly placed in each of the 30-60 sample polygons. As was done for the NWCA survey, the Intensification Project was characterizing a sample point within a wetland, and not the entire wetland.
  - Because the NWI and soils data did not adequately represent the targeted plant community for the Central Platte BUL, Kirk Schroeder (USFWS Biologist) was asked to review the universe of sample polygons selected in GIS using the NWI and soils data and then select polygons for sampling that he thought could support the targeted wetland plant community. Kirk selected 31 sites for potential sampling and random points were not used.

Because the NWI and soils data did not adequately represent the targeted plant community for the Verdigris Bazile BUL, the sample selection method was slightly altered. The soils and NWI (line and polygon) data were used to select the universe of sample polygons. Then these were examined by Ted LaGrange, and he selected the ones (N=36) that appeared to be slope wetlands in the upper ends of the watersheds.

Once permission was granted by landowners to access individual wetland sites, GPS units were used to navigate to the center of the site. From the center of the site, a circle with a radius of 40 meters was measured. This circle created a study area of 0.5 hectares and was known as the Assessment Area (AA). If the AA was more than 10% non-wetland, such as open water or upland, the AA was shifted up to 60 meters to ensure the AA is at least 90% wetland.

If a circular AA was not possible, a polygon AA was used. The edges of the polygon was designed to get the area of the AA as close to .5 hectares as possible. If both a circular AA and polygon AA were not possible, a wetland boundary AA was used. In this case, the edges of the wetland were used as the edge of the AA (Figure 4.2).

The area of any polygon AA or wetland boundary AA were between 0.1 and 0.5 hectares depending on the size of the wetland. If the wetland was smaller than 0.1 hectares, it was excluded from the study and replaced by the next wetland on the sample draw list.

Water samples were taken from the undisturbed point closest and deepest to the center of the AA that was deep enough (approximately 8 cm) to sample without disturbing the substrate and contaminating the sample (Figure 4.3). This was as far from inlets and outlets as possible. If the following measurements did not affect the water samples, they were taken before the samples, but if they were disruptive, they were taken after: Type of surface water, water depth, percent of AA covered with surface water, substrate color, substrate type, water clarity, water smell, water surface, and longitude and latitude.

A long handled dipper and all containers used to hold the samples were rinsed three times each with water from the site. A 125 ml bottle was filled to about 110ml for a microcystin sample, sealed with tape and then put on ice. The water chemistry sample was a 1 liter bottle filled completely, sealed with tape and put on ice. For the chlorophyll-a sample, a 1 liter bottle which did not allow light to pass through was filled. The water was then measured and filtered through a Whatman GF/F 47-mm 0.7 micron filter until a green color was easily visible on the filter. After the amount of sampled water was noted, the sides of the filter cup were rinsed with deionized water to wash any remaining drops of the sample onto the filter before adding 2 drops of $MgCO_3$ to the last few milliliters of water to be filtered. The filter was then carefully placed into a centrifuge tube, sealed with tape, wrapped with aluminum foil to prevent any sun light from reaching it, and put on ice. All three samples were kept on ice until they could be delivered to the Water Science Lab at the University of Nebraska–Lincoln for analysis (USEPA 2016d).

In addition, the Nebraska Wetland Rapid Assessment Method (NeWRAM) was applied for each wetland with in the CP and VB BULs. These scores were not used in any of the analysis for this thesis, but they would be available for examination by anyone trying to assess the validity of the NeWRAM (LaGrange 2015).

After analysis, an array of water variables were compared to pseudo state standards derived from Title 117 (2014) and the World Health Organization (2003) to determine if these water variables are outside what would be considered natural levels. A multimodel inference approach was used to determine top predictive models for water variables. Model sets were determined a priori. A delta AICc of 2 (Burnham and Anderson 2002) was used as the cutoff for plausible models in the model set. All possible

variable combinations were checked for correlation and any highly correlated variables (correlation ≥ 0.7) were not used in the same model.

Explanation of Variables

Vegetation

Native Species Richness: The count of total native species at a site. Vegetation types can change water chemistry values (Vitt and Chee 1990, Ehrenfeld 2003).

Non-native Species Richness: The count of total non-native species at a site. Vegetation types can change water chemistry values (Vitt and Chee 1990, Ehrenfeld 2003).

Litter: The average of the litter coverages for the five vegetation plots. Added vegetative litter such as barley straw and deciduous leaves can reduce microcystin levels in the short term (Ridge et al. 1999). Litter adds nutrients back into soil (Ashton et al. 2005) and water (Webster 2009).

Biologically Unique Landscape

BUL: The area of the state samples were taken from. The two sampled in 2016 were the Cherry County Wetlands (SH) and the Upper Niobrara River (AM). The three sampled in 2017 were the Upper Loup Rivers (LR), Central Platte (CP), and Verdigris-Bazile (VB). Each has its own vegetation, soil, and water characteristics (Rolfsmeier and Steinauer 2010).

Soil

Soil Nitrogen: Percentage of nitrogen in soil particles small enough to fit through a 2mm sieve from a depth of 0-10cm. Soil nitrogen and phosphorus can be leached into surface water (Turtola and Paajanea, 1995), leading to eutrophication (Sparks, 2003).

Soil Phosphorous: mg/kg of phosphorous from a depth of 0-10cm. Soil nitrogen and phosphorus can be leached into surface water (Turtola and Paajanea 1995 and Heatwaite and Dils, 2000). The more phosphorus in the soil, the more is leached into the water (Heckrath et al. 1995), leading to eutrophication (Sparks, 2003).

Land Use

Hay: A count of haying in the area directly adjacent to the wetland in each of the cardinal directions. Minimum of 0, maximum of 4. Haying effects species richness (Foster et al. 2009), soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998).

Range: A count of evidence of cattle in the area directly adjacent to the wetland in each of the cardinal directions. Minimum of 0, maximum of 4. Grazing effects runoff and erosion (Gilley et al. 1996).

Buffer Non-native: A count of the number of non-native species in the area directly adjacent to the wetland. A species can count more than once if it was found in two or more directions. Vegetation can change soil and water chemistry values (Ehrenfeld 2003).

Distance to Road: Distance from the center of the wetland to the closest road. Non-native species abundance has been shown to decrease with increased distance from roads (Flory and Clay 2006).

Water

Water Nitrogen: Log nitrogen in the water sample. Excess water nitrogen and phosphorus can lead to blooms of microcystin (Vézie et al. 2002) or high levels of chlorophyll a (Smith et al. 1999).

Water Phosphorus: Log phosphorus in the water sample. Excess water nitrogen and phosphorus can lead to blooms of microcystin (Vézie et al. 2002) or high levels of chlorophyll a (Dillon and Rigler 1974, Smith et al. 1999).

Chlorophyll a: Log chlorophyll a in the water sample. Excess levels of chlorophyll a are the primary method to determine impairment in Nebraska's waters (Title 117 2014).

Microcystin: Log microcystin in the water sample. Microcystin responds positively to additional water nitrogen and phosphorus (Vezie et al. 2002, Downing et al. 2005).

Explanation of Model Selection

All variables within each model were not correlated (< 0.7) with any other variable in the model. Each of the model sets for predicitive log water nitrogen, log water phosphorus, and log chlorophyll a are composed of a null model, global model, vegetation model, BUL model, soil model, land use model, water model, and every pair of combinations of the vegetation, BUL, soil, and land use models. This gives a grand total of 13 models for each predictor. The water model was excluded form the paring of models because the sample size was small (54) for models predicting water variables and because microcystin (the only variable not correlated with log water nitrogen, log water phosphorus or log chlorophyll a) was not expected to have an affect on log water nitrogen, log water phosphorus or log chlorophyll a. Models that contain the vegetation, BUL, soil, water, and land use models use the same variables for each predictive model.

The microcystin data had a large outlier that was removed prior to analysis. The model set for predictive log microcystin composed of a null model, global model,

vegetation model, BUL model, soil model, land use model, water model, and every pair of combinations of the vegetation, BUL, soil, water, and land use models. This gives a grand total of 17 models for each predictor. The water model was included in the paring of models because water nitrogen has been shown to cause microcystin blooms (Vézie et al. 2002).

Predictive Log Water Nitrogen

Native species richness and non-native species richness were used because vegetation can change soil and water chemistry values (Ehrenfeld 2003). Litter adds nutrients back into soil (Ashton et al. 2005) and water (Webster 2009). BUL was used because each has its own vegetation, soil, and water characteristics (Rolfsmeier and Steinauer 2010). Soil nitrogen and phosphorus can be leached into surface water (Turtola and Paajanea, 1995), leading to eutrophication (Sparks, 2003). Hay was used because haying soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing also affects runoff and erosion (Gilley et al. 1996). Buffer non-native were used because vegetation can change soil and water chemistry values (Ehrenfeld 2003). Distance to roads can affect water chemistry values (Forman et al. 2003). Log microcystin was used as a surrogate for water quality because log water phosphorus and log chlorophyll a were correlated (0.71 and 0.78 respectively) with log water nitrogen.

Predictive Log Water Phosphorus

Native species richness and non-native species richness were used because vegetation can change soil and water chemistry values (Ehrenfeld 2003). Litter adds nutrients back into soil (Ashton et al. 2005) and water (Webster 2009). BUL was used

because each has its own vegetation, soil, and water characteristics (Rolfsmeier and Steinauer 2010). Soil nitrogen and phosphorus can be leached into surface water (Turtola and Paajanea, 1995), leading to eutrophication (Sparks, 2003). Hay was used because haying soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing also affects runoff and erosion (Gilley et al. 1996). Buffer non-native were used because vegetation can change soil and water chemistry values (Ehrenfeld 2003). Distance to roads can affect water chemistry values (Forman et al. 2003). Log microcystin was used as a surrogate for water quality because log water nitrogen and log chlorophyll a were correlated (0.71 and 0.76 respectively) with log water phosphorus.

Predictive Log Chlorophyll a

Native species richness and non-native species richness were used because vegetation can change soil and water chemistry values (Ehrenfeld 2003). Litter adds nutrients back into soil (Ashton et al. 2005) and water (Webster 2009). BUL was used because each has its own vegetation, soil, and water characteristics (Rolfsmeier and Steinauer 2010). Soil nitrogen and phosphorus can be leached into surface water (Turtola and Paajanea, 1995), leading to eutrophication (Sparks, 2003). Hay was used because haying soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing also affects runoff and erosion (Gilley et al. 1996). Buffer non-native were used because vegetation can change soil and water chemistry values (Ehrenfeld 2003). Distance to roads can affect water chemistry values (Forman et al. 2003). Log microcystin was used as a surrogate for

water quality because log water nitrogen and water phosphorus log were correlated (0.78 and 0.76 respectively) with log chlorophyll a.

Predictive Log Microcystin

Native species richness and non-native species richness were used because vegetation can change soil and water chemistry values (Ehrenfeld 2003). Added vegetative litter can reduce microcystin levels (Ridge et al. 1999). BUL was used because each has its own vegetation, soil, and water characteristics (Rolfsmeier and Steinauer 2010). Soil nitrogen and phosphorus can be leached into surface water (Turtola and Paajanea, 1995), leading to eutrophication (Sparks, 2003). Hay was used because haying soil chemistry levels (Parr and Way 1988), runoff and erosion (Gilley et al. 1996), and litter cover (Parr and Way 1988, and Schacht et al. 1998). Grazing also affects runoff and erosion (Gilley et al. 1996). Buffer non-native were used because vegetation can change soil and water chemistry values (Ehrenfeld 2003). Distance to roads can affect water chemistry values (Forman et al. 2003). Log nitrogen was used because it was correlated to log phosphorus and log chlorophyll a and because microcystin responds positively to additional water nitrogen and phosphorus (Vezie et al. 2002, Downing et al. 2005).

Predicative Model Sets

Log Water Nitrogen:

1. Log Water Nitrogen ~ 1
2. Log Water Nitrogen ~ Native Species + Non-native Species + Litter
3. Log Water Nitrogen ~ BUL
4. Log Water Nitrogen ~ Microcystin
5. Log Water Nitrogen ~ Soil Nitrogen + Soil Phosphorus
6. Log Water Nitrogen ~ Hay + Range + Buffer Non-native + Distance to Road
7. Log Water Nitrogen ~ Native Species + Non-native Species + Litter + BUL
8. Log Water Nitrogen ~ Native Species + Non-native Species + Litter + Soil Nitrogen + Soil Phosphorus

9. Log Water Nitrogen ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
10. Log Water Nitrogen ~ BUL + Soil Nitrogen + Soil Phosphorus
11. Log Water Nitrogen ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
12. Log Water Nitrogen ~ Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road
13. Log Water Nitrogen ~ Native Species + Non-native Species + Litter + BUL + Microcystin + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Log Water Phosphorous:

1. Log Water Phosphorus ~ 1
2. Log Water Phosphorus ~ Native Species + Non-native Species + Litter
3. Log Water Phosphorus ~ BUL
4. Log Water Phosphorus ~ Microcystin
5. Log Water Phosphorus ~ Soil Nitrogen + Soil Phosphorus
6. Log Water Phosphorus ~ Hay + Range + Buffer Non-native + Distance to Road
7. Log Water Phosphorus ~ Native Species + Non-native Species + Litter + BUL
8. Log Water Phosphorus ~ Native Species + Non-native Species + Litter + Soil Nitrogen + Soil Phosphorus
9. Log Water Phosphorus ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
10. Log Water Phosphorus ~ BUL + Soil Nitrogen + Soil Phosphorus
11. Log Water Phosphorus ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
12. Log Water Phosphorus ~ Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road
13. Log Water Phosphorus ~ Native Species + Non-native Species + Litter + BUL + Microcystin + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Log Chlorophyll a:

1. Log Chlorophyll a ~ 1
2. Log Chlorophyll a ~ Native Species + Non-native Species + Litter
3. Log Chlorophyll a ~ BUL
4. Log Chlorophyll a ~ Microcystin
5. Log Chlorophyll a ~ Soil Nitrogen + Soil Phosphorus
6. Log Chlorophyll a ~ Hay + Range + Buffer Non-native + Distance to Road
7. Log Chlorophyll a ~ Native Species + Non-native Species + Litter + BUL
8. Log Chlorophyll a ~ Native Species + Non-native Species + Litter + Soil Nitrogen + Soil Phosphorus

9. Log Chlorophyll a ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
10. Log Chlorophyll a ~ BUL + Soil Nitrogen + Soil Phosphorus
11. Log Chlorophyll a ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
12. Log Chlorophyll a ~ Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road
13. Log Chlorophyll a ~ Native Species + Non-native Species + Litter + BUL + Microcystin + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Microcystin:

1. Log Microcystin ~ 1
2. Log Microcystin ~ Native Species + Non-native Species + Litter
3. Log Microcystin ~ BUL
4. Log Microcystin ~ Water Nitrogen
5. Log Microcystin ~ Soil Nitrogen + Soil Phosphorus
6. Log Microcystin ~ Hay + Range + Buffer Non-native + Distance to Road
7. Log Microcystin ~ Native Species + Non-native Species + Litter + BUL
8. Log Microcystin ~ Native Species + Non-native Species + Litter + Water Nitrogen
9. Log Microcystin ~ Native Species + Non-native Species + Litter + Soil Nitrogen + Soil Phosphorus
10. Log Microcystin ~ Native Species + Non-native Species + Litter + Hay + Range + Buffer Non-native + Distance to Road
11. Log Microcystin ~ BUL + Soil Nitrogen + Soil Phosphorus
12. Log Microcystin ~ BUL + Water Nitrogen
13. Log Microcystin ~ BUL + Hay + Range + Buffer Non-native + Distance to Road
14. Log Microcystin ~ Soil Nitrogen + Soil Phosphorus + Water Nitrogen
15. Log Microcystin ~ Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road
16. Log Microcystin ~ Hay + Range + Buffer Non-native + Distance to Road + Water Nitrogen
17. Log Microcystin ~ Native Species + Non-native Species + Litter + BUL + Water Nitrogen + Soil Nitrogen + Soil Phosphorus + Hay + Range + Buffer Non-native + Distance to Road

Results

Water Standard Comparisons

Eleven water chemistry variables were analyzed to determine if they were within the levels set by the state. Unfortunately for this study, Nebraska does not have many regulations for direct comparison. Because of this, a set of pseudo standards were used based upon regulations including and similar to the below excerpt from Title 117 – Nebraska Surface Water Quality Standards (2014).

"…traditional water quality parameters in wetlands such as pH, temperature, dissolved oxygen, ammonia, chloride, and conductivity may naturally vary outside accepted ranges for other surface waters. Water quality criteria for specific wetlands or wetland complexes, except numerical criteria for toxic substances (paragraph 004.01C1), petroleum oil (paragraph 004.01D), and residual chlorine (paragraph 004.01F), shall be based on natural background values for traditional water quality parameters. However, these criteria shall be no more stringent than those associated with the Class B Warmwater Aquatic Life classification or the General Criteria for Aquatic Life…" (Title 117, 2014)

Based on the above paragraph, any wetland that meets the requirements for the Class B Warmwater Aquatic Life classification would meet requirements for wetlands. With this in mind, all of the standards for water chemistry levels for Nebraska wetlands in this study are pseudo standards based on similar, but in no way binding, water chemistry standards. These numbers carry no regulatory weight, but are the closest substitutes available.

Only two of the eight SH values fell within the expected SH pH range of 6-6.9 (Rolfsmeier and Steinauer, 2013). SH12 even exceeded the pseudo state standard found in the Warmwater Lakes sections of Title 117 (2014) with a pH of 9.020. In addition, none of the five VB values fell within the expected VB pH range of 6-6.9 (Rolfsmeier and Steinauer, 2013), although none of them were above the pseudo state standard found in the Warmwater Lakes sections of Title 117 (2014) (Table 4.1).

Sulfate was the only tested compound that appeared in levels above the pseudo standards, and only did so in CP wetlands. CP04, CP14, and CP31 had sulfate values of 292mg/l, 310mg/l and 400mg/l respectively (Table 4.1), with the pseudo standard set at 250mg/l (Title 117, 2014).

Nebraska has no levels set for Chlorophyll a, nitrogen, or phosphorus in wetlands. Again, this study uses requirements for the Class B Warmwater Aquatic Life classification as the most stringent requirements that could currently be placed on wetlands. This study is using the Western Lakes criteria both because this is the area that the studied wetlands were located, and because this is the more stringent of the two lake types. It should be noted that Natural Sandhill Lakes are excluded by name from the Western Lakes classification, but this study is including the Sandhill Fens (SH) BUL in the analysis.

For a lake to be impaired in Nebraska, it must have chlorophyll a values over 8ug/l. If chlorophyll a is under 8ug/l, the total phosphorus and total nitrogen are considered to be acceptable, even if they are above 40ug/l and 800ug/l respectively (Title 117, 2014). This method is used because many Nebraskan waters have naturally high levels of phosphorus and nitrogen. It is understood that if a water body has high phosphorus or nitrogen but low chlorophyll a, it is likely still close to its natural state (John Bender, NDEQ, personal correspondence). The EPA disagrees with this approach. They would classify any lake with phosphorus or nitrogen levels above the criteria to be impaired (John Bender, NDEQ, personal correspondence). Because of this discrepancy, this study will examine both criteria. Again, these numbers carry no regulatory weight as

they were designed for warm water lakes, but are used because they are the most stringent guidelines that can currently be placed on Nebraska wetlands.

Based on Nebraska's pseudo standard, all of the wetlands impaired by Chlorophyll a would also be impaired by phosphorus, and all but one site impaired by Chlorophyll a would be impaired by nitrogen. Based on the EPAs interpretation of Nebraska's pseudo standard, there would be the same number of wetlands impaired by Chlorophyll a. Every wetland outside of the AM and three within the AM would be impaired by phosphorus. Nitrogen would impair about 72% of Nebraska's wetlands as opposed to the 30% with Title 117's (2014) pseudo standard (Table 4.2 and 4.3).

Again, these numbers carry no regulatory weight, but are the closest thing to standards for wetlands available. Hopefully the water chemistry values can help inform what the "natural background values for traditional water quality parameters" (Title 117 2014) are for Nebraska.

Log Water Nitrogen

The vegetation and BUL model (Log Water Nitrogen ~ Soil Nitrogen + Soil Phosphorus) is the only model with Delta AICc < 2 for the predictive log water nitrogen richness linear model (Table 4.4). Soil Nitrogen and Soil Phosphorus were both significant at a value of $p < 0.05$ (Table 4.5).

Log Water Phosphorus

The BUL and soil model (Log Water Phosphorus ~ BUL + Soil Nitrogen + Soil Phosphorus), which is the only model with Delta AICc < 2 for the log water phosphorus linear model (Table 4.6). A significance value of $p < 0.05$ was used for all models. BUL was significant at a value of $p < 0.05$ (Table 4.7).

Log Chlorophyll a

The null model (Log Chlorophyll a ~ 1), soil model (Log Chlorophyll a ~ Soil Nitrogen + Soil Phosphorus), and water model (Log Chlorophyll a ~ Microcystin) are the top three models with Delta AICc < 2 for the predictive log chlorophyll a linear model (Table 4.8). None of the variables in any of the models were significant at a value of $p < 0.05$ (Table 4.9, 4.10, and 4.11).

Log Microcystin

The microcystin data had a large outlier that was removed prior to analysis. The BUL model (Log Microcystin ~ BUL), which is the only model with Delta AICc < 2 for the predictive log microcystin linear model (Table 4.12). BUL was significant at a value of $p < 0.05$ (Table 4.13).

Discussion

Water Standard Comparisons

It is difficult to determine the quality of Nebraska's wetlands without solid standards to base collected values on. Only two of the BULs studies had expected pH ranges (Rolfsmeier and Steinauer 2010). None of the target wetland types within the respective BUL's have been studied in the last 20 years.

There were no obvious point sources for the sulfate found within any of the sites in the CP. CP04 and CP14 were about half a mile apart and are both on the same slough. CP31 was over 15 miles away from CP04 and CP14. The most likely explanation is sulfate contamination comes from anthropogenic sources (Keller and Pitblade 1986). CP sites are the closest to larger Nebraska cities. All three of the sites with high sulfate were within 10 miles if Grand Island and the Platte Generating Station, a coal-fired power

plant. While this study did not specifically examine the impacts of the Platte Generating Station, future studies may want to examine the effect of the station as coal fired power plants are generally large sources of sulfate pollution (Querol et al. 1996).

The percentage of 2016-2017 sites that broke thresholds was less than or equal to the percentage of 2011-2013 sites that broke thresholds for all water variables studied except sulfate when chlorophyll a, nitrogen and phosphorus are excluded. When chlorophyll a, nitrogen and phosphorus are included, impairment is very similar based on the states impairment criteria. Nitrogen and phosphorus impairment are higher in the EPA's interpretation for 2011-2013 study than the 2016-2017 study.

Log Water Nitrogen

While both soil nitrogen and soil phosphorus had an effect on log water nitrogen, soil nitrogen had a significantly negative effect on water nitrogen while soil phosphorus had a positive effect. A possible explanation is that decaying organic matter releases about 30% of its nitrogen directly into solution when decomposition occurs anaerobically (Acharya 1935). This could mean that the nitrogen is never reaching the soil, instead staying in solution, increasing the disparity between soil and water nitrogen. This relationship is not extremely strong with an R^2 value of only 0.1031. It should also be noted that while not significant, the null model is also near the top models with 7% of the total weight, further indicating that there are likely other factors important to water nitrogen not measured in this study (Table 4.4).

Log Water Phosphorus

The BUL and soil model came out on top for log water phosphorus. Interestingly, soil phosphorous does not reach the $p < .05$ level of significance in the top model (Table

4.6), although it is close and does appear to have a positive effect on water phosphorus. The leaching of soil phosphorus did not have as large of an effect as BUL did, as BUL is contained in each of the three top models. It is unsurprising to find BUL in the top models as water chemistry values, much like vegetative and soil values, vary by region (Dodds et al. 1998).

Log Chlorophyll a

Although the null model came out on top for the log chlorophyll a analysis, indicating that none of the measures used are likely to predict chlorophyll a levels. This is understandable with the exclusion of water phosphorus and nitrogen from the model set. These two measures were removed because of a tight correlation (76% and 79% respectively) prior to analysis. Water phosphorus and nitrogen are generally thought of as the driving factor of chlorophyll a (Title 117 2014, Dillon and Rigler 1974, Smith et al. 1999).

Log Microcystin

The microcystin data had a large outlier that was removed prior to analysis. After removing this site, the BUL model came out on top. All of the top four models contained the BUL model, with the stand alone BUL model being the only significant model. This indicates that the location of the site within Nebraska is the most important factor when determining microcystin levels. It is unsurprising to find BUL in the top models as water chemistry values, much like vegetative and soil values, vary by region (Dodds et al. 1998).

Conclusion

With this information in mind, I would recommend that water quality samples continue to be taken in the same manner as previous studies. This keeps the Nebraska protocol closer to the national protocol. Water quality samples are very easy to collect and relatively informative for the effort and money needed to collect and analyze them. The most difficult part of sample collection is acquiring permission to the property. If the protocol changes, future studies may consider taking more water samples or test for a wider array of chemicals. Since water samples in this study only provide a single snapshot of a site's water quality, repeat sampling throughout the time that the surveying team in is the area could give a more robust picture of water quality for a BUL that may not be sample for another 20 years.

The lack of information about Nebraska wetlands is revealed in the lack of wetland water quality standards in Title 117 (2014). More studies are needed to more fully understand the waters of Nebraska wetlands. Hopefully the water chemistry values from this study can help inform what the "natural background values for traditional water quality parameters" (Title 117 2014) are for Nebraska.

As for the models, it could be more beneficial to examine water models in a BUL by BUL basis as two of the three models with significant results had BUL as a part of the model. This could be difficult with such a small number of samples, but knowing more about each BUL individually will likely be more beneficial than to infer about Nebraskan wetland water as a whole.

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Tables and Figures

Table 4.1. Pseudo standards for water quality for Nebraska wetlands. These values carry no regulatory weight, but are the closest substitutes available for wetland regulations.
[1] Threshold from the wetland section of Title 117 (2014)
[2] Threshold from the Warmwater Lakes section of Title 117 (2014)
[3] Threshold from the Agricultural Class A Water Supply Use section of Title 117 (2014)
4 Threshold from the Public Drinking Water Supply Use section of Title 117 (2014)
5 Threshold from World Health Organization (2003)
* No numbers are given in Title 117 (2014). Values under 100 NTU are considered to meet this criterion (John Bender, NDEQ, personal correspondence). Max value for this study was 66 NTU.
** 12.5% of SH sites and 1.9% of all sites.
*** 30% of CP sites and 5.6% of all sites.

	Pseudo Standards	Sites Above Standards
Turbidity[1]	100 NTU *	None
pH[2]	6.5-9.0	SH12**
Nitrate-N and Nitrite-N[3]	100mg/l	None
Conductivity[3]	2000uS/cm	None
Chloride[4]	860mg/l	None
Fluoride[4]	4mg/l	None
Sulfate[4]	250mg/l	CP04, CP14, CP31***
Microcystin [5]	20ug/l	None

Table 4.2. The percentage of impaired wetlands based on Title 117's (2014) Western Lakes impairment criteria for each measure. These values carry no regulatory weight, but are the closest substitutes available for wetland regulations. Top row indicates the BUL sampled and the total number of samples taken from each BUL.

Title 117	Threshold	AM (n=13)	CP (n=10)	LR (n=18)	SH (n=8)
Chlorophyll a	8ug/l	8	20	50	50
Phosphorus	40ug/l if Chl-a exceeds threshold	8	20	50	50
Nitrogen	800ug/l if Chl-a exceeds threshold	8	20	44	50

Table 4.3. The percentage of impaired wetlands based on the EPA's impairment criteria for each measure. These values carry no regulatory weight, but are the closest substitutes available for wetland regulations. Top row indicates the BUL sampled and the total number of samples taken from each BUL.

EPA	Threshold	AM (n=13)	CP (n=10)	LR (n=18)	SH (n=8)
Chlorophyll a	8ug/l	8	20	50	50
Phosphorus	40ug/l	23	100	100	100
Nitrogen	800ug/l	77	60	72	75

Table 4.4. Predictive models for log water nitrogen. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the log water nitrogen predictable from the models.

Model	K	Delta AICc	W	R^2
Soil	4	0	0.36	0.1031
BUL and Land Use	10	2.06	0.13	0.0969
Vegetation and Soil	7	2.42	0.11	0.1677
BUL	6	2.43	0.11	0.1272
Vegetation and Land Use	9	2.87	0.09	
Null	2	3.41	0.07	
Water	3	4.15	0.05	
Vegetation	5	5.15	0.03	
BUL and Soil	8	5.38	0.02	
Soil and Land Use	8	5.99	0.02	
Global	16	7.26	0.01	
Vegetation and BUL	9	7.96	0.01	
Land Use	6	9.96	0	

Table 4.5. Summary of the vegetation and BUL model (Log Water Nitrogen ~ Soil Nitrogen + Soil Phosphorus), which is the only model with Delta AICc < 2 for the Predictive Predictive Log Water Nitrogen Richness Linear Model. A significance value of $p < 0.05$ was used for all models. Soil Nitrogen and Soil Phosphorus were both significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.23187	0.081261	2.853	0.00624
Soil Nitrogen	-0.32225	0.126193	-2.554	0.01369
Soil Phosphorus	0.00064	0.000225	2.847	0.00634

Table 4.6. Predictive models for log water phosphorus. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the log water phosphorus predictable from the models.

Model	K	Delta AICc	W	R^2
BUL and Soil	8	0	0.69	0.4733
BUL	6	2.86	0.17	0.4117
Vegetation and BUL	9	3.20	0.14	0.4675
BUL and Land Use	10	11.48	0	
Vegetation and Soil	7	12.85	0	
Soil	4	15.75	0	
Global	16	15.97	0	
Soil and Land Use	8	20.62	0	
Vegetation	5	23.71	0	
Null	2	26.28	0	
Water	3	28.23	0	
Vegetation and Land Use	9	30.19	0	
Land Use	6	30.49	0	

Table 4.7. Summary of the BUL and soil model (Log Water Phosphorus ~ BUL + Soil Nitrogen + Soil Phosphorus), which is the only model with Delta AICc < 2 for the Log Water Phosphorus Linear Model. A significance value of $p < 0.05$ was used for all models. BUL was significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	-0.05476	0.037297	-1.468	0.14868
CP BUL	0.125282	0.042106	2.975	0.00461
LR BUL	0.094398	0.034987	2.698	0.00965
SH BUL	0.121811	0.067898	1.794	0.07924
VB BUL	0.277501	0.053808	5.157	4.93E-06
Soil Nitrogen	-0.042109	0.074318	-0.567	0.57368
Soil Phosphorus	0.000189	0.000105	1.811	0.07654

Table 4.8. Predictive models for chlorophyll a. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the log chlorophyll a predictable from the models.

Model	K	Delta AICc	W	R^2
Null	2	0	0.35	----
Soil	4	0.05	0.34	0.04148
Water	3	1.89	0.14	-0.01934
BUL and Soil	8	3.54	0.06	
BUL	6	3.98	0.05	
Vegetation and Soil	7	5.85	0.02	
Soil and Land Use	8	6.50	0.01	
Land Use	6	6.64	0.01	
Vegetation	5	6.69	0.01	
Vegetation and BUL	9	9.11	0	
BUL and Land Use	10	11.70	0	
Vegetation and Land Use	9	12.81	0	
Global	16	21.25	0	

Table 4.9. Summary of the null model (Log Chlorophyll a ~ 1), which is one of three models with Delta AICc < 2 for the Predictive Log Chlorophyll a Linear Model. A significance value of $p < 0.05$ was used for all models.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.81995	0.08233	9.96	9.69E-14

Table 4.10. Summary of the soil model (Log Chlorophyll a ~ Soil Nitrogen + Soil Phosphorus), which is one of three models with Delta AICc < 2 for the Predictive Log Chlorophyll a Linear Model. A significance value of $p < 0.05$ was used for all models.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.479263	0.183069	2.618	0.0116
Soil Nitrogen	-0.191861	0.284297	-0.675	0.5028
Soil Phosphorus	0.000797	0.000506	1.576	0.1213

Table 4.11. Summary of the water model (Log Chlorophyll a ~ Microcystin), which is one of three models with Delta AICc < 2 for the Predictive Log Chlorophyll a Linear Model. A significance value of $p < 0.05$ was used for all models.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.8545	0.1016	8.415	2.83E-11
Microcystin	-0.8062	1.3693	-0.589	0.559

Table 4.12. Predictive models for log microcystin. K is the number of parameters estimated in the model. Delta AICc is the difference in Akaike Information Criterion with adjustments for different sample sizes. W is the relative weight each model holds. R^2 is the variance of the log microcystin predictable from the models.

Model	K	Delta AICc	W	R^2
BUL	6	0	0.61	0.6783
BUL and Land Use	8	2.48	0.18	0.6783
BUL and Water	7	2.66	0.16	0.6714
Vegetation and BUL	9	5.38	0.04	
BUL and Land Use	10	10.19	0	
Global	15	23.24	0	
Soil and Land Use	8	29.59	0	
Land Use and Water	7	40.46	0	
Land Use	6	40.70	0	
Vegetation and Land Use	7	41.00	0	
BUL and Soil	9	45.94	0	
Soil	4	46.31	0	
Soil and Water	5	48.19	0	
Water	3	54.39	0	
Null	2	54.76	0	
Vegetation and Soil	6	56.51	0	
Vegetation	5	57.54	0	

Table 4.13. Summary of the BUL model (Log Microcystin ~ BUL), which is the only model with Delta AICc < 2 for the Predictive Log Microcystin Linear Model. A significance value of $p < 0.05$ was used for all models. BUL was significant.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.060698	0.004116	14.748	< 2e-16
CP BUL	-0.042498	0.006435	-6.604	2.97E-08
LR BUL	-0.041720	0.005401	-7.724	5.77E-10
SH BUL	0.003651	0.006668	0.547	0.587
VB BUL	-0.047584	0.007809	-6.093	1.81E-07

Table 4.14. Pseudo standards for water quality for Nebraska wetlands. These values carry no regulatory weight, but are the closest substitutes available for wetland regulations.
[1] Threshold from the wetland section of Title 117 (2014)
[2] Threshold from the Warmwater Lakes section of Title 117 (2014)
[3] Threshold from the Agricultural Class A Water Supply Use section of Title 117 (2014)
4 Threshold from the Public Drinking Water Supply Use section of Title 117 (2014)
5 Threshold from World Health Organization (2003)
* No numbers are given in Title 117 (2014). Values under 100 NTU are considered to meet this criterion (John Bender, NDEQ, personal correspondence). Max value for this study was 66 NTU.

	Pseudo Standards	% 2016-2017 Sites Above Standards	% 2011-2013 Sites Above Standards
Turbidity[1]	100 NTU *	0	5.8
pH[2]	6.5-9.0	1.9	6.3
Nitrate-N and Nitrite-N[3]	100mg/l	0	0
Conductivity[3]	2000uS/cm	0	0
Chloride[4]	860mg/l	0	1.9
Fluoride[4]	4mg/l	0	1.9
Sulfate[4]	250mg/l	5.6	3.8
Microcystin [5]	20ug/l	0	NA

Table 4.15. The percentage of impaired wetlands based on Title 117's (2014) Western Lakes impairment criteria for each measure for the first (2011-2013) and second (2016-2017) Nebraska Wetland Condition Assessments. These values carry no regulatory weight, but are the closest substitutes available for wetland regulations. Top row indicates the BUL sampled and the total number of samples taken from each BUL.

Title 117	Threshold	% 2011-2013 Sites Above Threshold	% 2016-2017 Sites Above Threshold
Chlorophyll a	8ug/l	30	31.4
Phosphorus	40ug/l	30	31.4
Nitrogen	800ug/l	30	29.6

Table 4.16. The percentage of impaired wetlands based on the EPA's impairment criteria for each measure for the first (2011-2013) and second (2016-2017) Nebraska Wetland Condition Assessments. These values carry no regulatory weight, but are the closest substitutes available for wetland regulations. Top row indicates the BUL sampled and the total number of samples taken from each BUL.

EPA	Threshold	% 2011-2013 Sites Above Threshold	% 2016-2017 Sites Above Threshold
Chlorophyll a	8ug/l	30	31.4
Phosphorus	40ug/l	95.6	81.4
Nitrogen	800ug/l	98.1	72.2

Figure 4.1. Map showing locations of the Biologically Unique Landscapes in this study. The light blue is the Upper Niobrara River BUL (AM), the tan is the Cherry County Wetlands BUL (SH), the dark blue is the Loup River BUL (LR), the light green is the Central Platte River BUL (CP) and the dark green is the Verdigris-Bazile Creek BUL (VB).

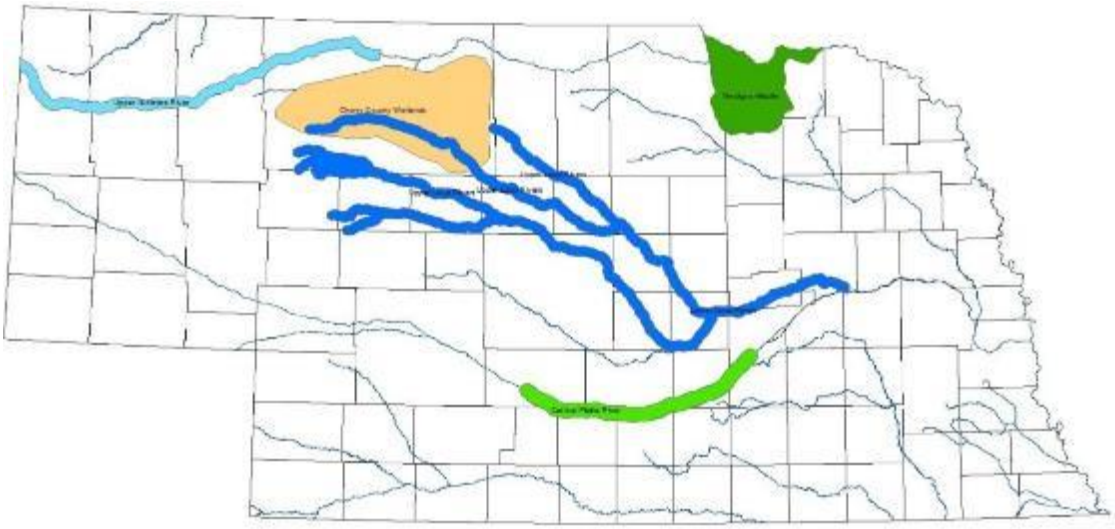


Figure 4.2. Assessment area (AA) configurations based on wetland size and shape. The blue star is the original point for the site. The inclosing dark lines indicate the boundary of the AA. The black flag is the center of the AA. The dotted lines are the transect lines with the red flag denoting the end of the transects. The green dots are the area occupied by the wetland. The dark blue area in the top legend is water deeper than 0.5m and the light blue areas in the bottom two legends are water less than 0.5m deep. Original figure from USEPA 2016c.

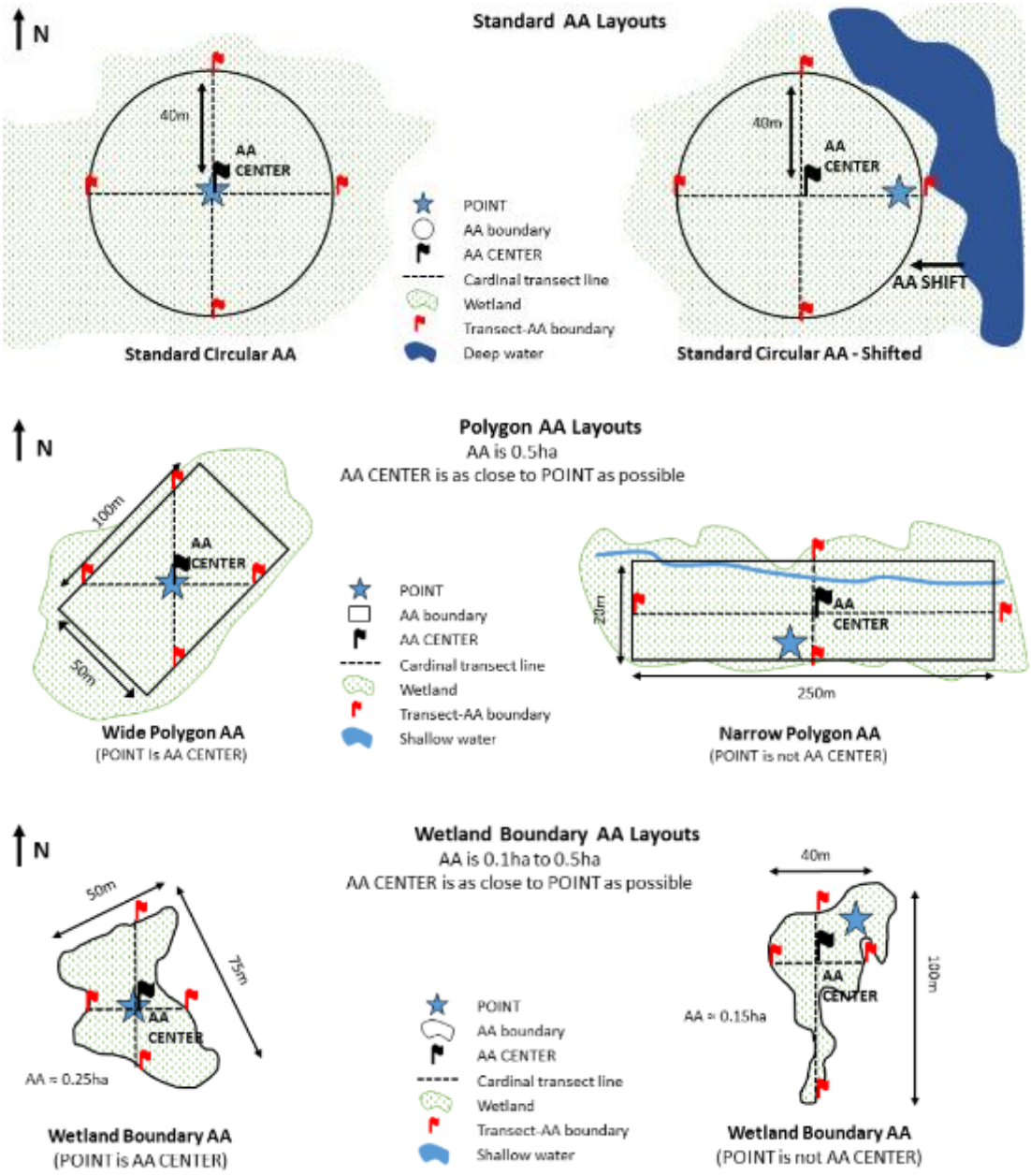
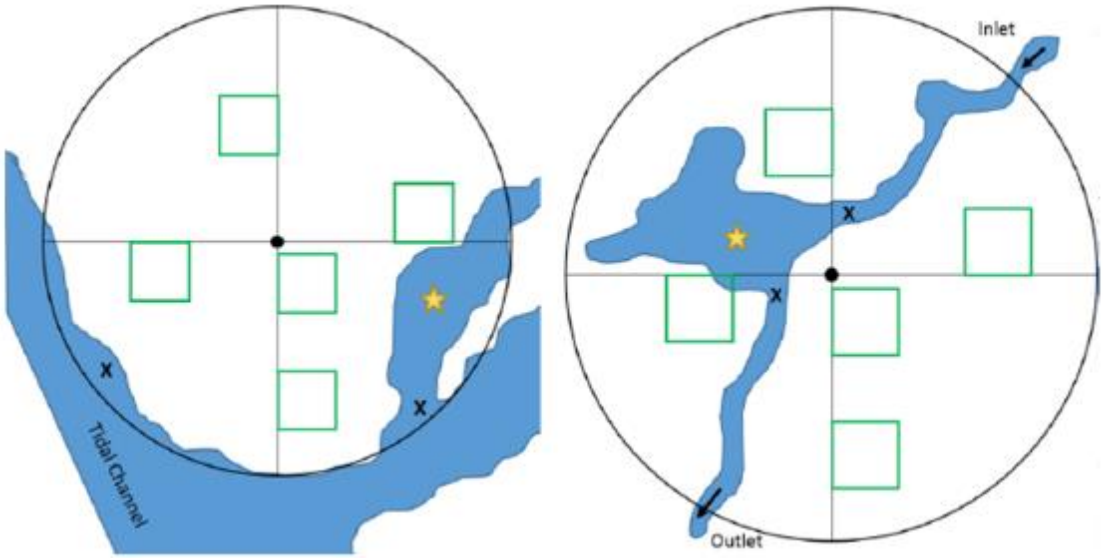


Figure 4.3. Examples of proper water sample placement (star). Left: X indicates poor water sample areas due to distance from the center and because they are within the tidal channel. Right: X indicates poor water sampling areas because they are within the direct flow of the inlets and outlets. Original figure from USEPA 2016c.



APPENDIX A: BULs sampled, and their associated soil mapping units, NWI codes, and natural communities.

Wetland Type	Wetland Complex[1]	Biologically Unique Landscape (BUL)[1]	HGM Subclass	Natural Community to sample	NWI Cowardin Class	Soil Map Unit Name	Soil Map Unit Symbol
Sandhills	Sandhills	Cherry County Wetlands BUL	Organic Soil Flats	Sandhill Fens	PEMA, PEMAd, PEMC, PEMCd	Cutcomb Mucky Peat	4467
Riverine	Niobrara	Upper Niobrara River BUL	Riverine Floodplain Rapid Permeability, w/minimal out of bank flooding	Western Subirrigated Alkaline Meadows	PEMA, PEMAd, PEMC, PEMCd	Las Animas-Lisco Complex, Occasionally Flooded	1188
Riverine	Sandhills	Upper Loup River BUL	Riverine Floodplain Rapid Permeability, w/minimal out of bank flooding	Cottonwood-Diamond Willow Woodlands	PEM/SSC, PSS/EMC, PSSC, PEM/SSA, PSS/EMA, PSSA	Barney fine sandy loam, frequently flooded	6311
Riverine	Sandhills	Upper Loup River BUL	Riverine Floodplain Rapid Permeability, w/minimal out of bank flooding	Cottonwood-Diamond Willow Woodlands	PEM/SSC, PSS/EMC, PSSC, PEM/SSA, PSS/EMA, PSSA	Almeria fine sandy loam, channeled, frequently flooded	4200
Riverine	Sandhills	Upper Loup River BUL	Riverine Floodplain Rapid Permeability, w/minimal out of bank flooding	Cottonwood-Diamond Willow Woodlands	PEM/SSC, PSS/EMC, PSSC, PEM/SSA, PSS/EMA, PSSA	Barney loam, channeled, frequently flooded	6313
Riverine	Sandhills	Upper Loup River BUL	Riverine Floodplain Rapid Permeability, w/minimal out of bank flooding	Cottonwood-Diamond Willow Woodlands	PEM/SSC, PSS/EMC, PSSC, PEM/SSA, PSS/EMA, PSSA	Loup loam, frequently ponded	4673
Riverine	Sandhills	Upper Loup River BUL	Riverine Floodplain Rapid Permeability, w/minimal out of bank flooding	Cottonwood-Diamond Willow Woodlands	PEM/SSC, PSS/EMC, PSSC, PEM/SSA, PSS/EMA, PSSA	Almeria loamy fine sand, channeled, frequently flooded	4205
Riverine	Central Platte	Central Platte River BUL	Floodplain Depressions	Eastern Bulrush Deep Marsh Community/Cattail Shallow Marsh	System=P, and Class= EM or AB or AB/EM	See below for the units selected by Neil Dominy	Appendix B

Wetland Type	Wetland Complex[1]	Biologically Unique Landscape (BUL)[1]	HGM Subclass	Natural Community to sample	NWI Cowardin Class	Soil Map Unit Name	Soil Map Unit Symbol
NA	NA	Verdigris-Bazile Creek BUL	Slope Wetlands	Freshwater Seeps	SYSTEM= P and excluded any of the NWI data with the MODIFIER= H or MODIFIER = h	Kezan Silt loam, occasionally flooded	3642
NA	NA	Verdigris-Bazile Creek BUL	Slope Wetlands	Freshwater Seeps	SYSTEM= P and excluded any of the NWI data with the MODIFIER= H or MODIFIER = h	Obert silt loam, occasionally flooded	6366

APPENDIX B: Central Platte River soils used by counties.

Central Platte Counties	Soil Mapping Units
Hall	Barney Bolent Complex 6322
Buffalo	Barney 6312 Gothenburg 8495
Dawson	Gothenburg 8494 Aquolls 9970
Phelps	Gothenburg 8495 Platte Soils 5632
Kearney	Gothenburg Soils 8495 Gothenburg Loamy Sand 8493
Hamilton	Gothenburg 8493 Barney Loam 6312
Merrick	Barney Loam 6312 Barney Complex 6310 Gothenburg 8495 Gothenburg 8493
Gosper	Platte-Alda Loam 8568 Platte Loam 8563 Gothenburg Soils 8495