ESTIMATING THE IMPACT TO WETLANDS IN WESTERN NORTH DAKOTA FROM DUST AND ROAD USE INCREASES DUE TO ENERGY DEVELOPMENT

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Estimating the impact to wetlands in western North Dakota from dust and road use increases due to energy development

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MASTER OF SCIENCE

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ABSTRACT

Travel on gravel roads in western North Dakota has increased in recent years due mainly to energy development and little information exists on the impacts. This project's objective was to compare high dust impact sites and low dust impact sites to determine the effects of road dust on wetlands. Four aspects were evaluated: 1) dust loading; 2) wetland condition and function; 3) water quality; and 4) trace element changes in the soil. Dust loading was measured utilizing dust collectors. Wetlands were assessed for condition using the Index of Plant Community Integrity and North Dakota Rapid Assessment Method and function using the Hydrogeomorphic model. Monthly water quality measurements were taken and yearly soil samples. Results show greater dust loading in the high impact sites than low impact sites and spatially closer to the road. Information from this study can be used by future land managers of wetlands affected by dust.

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LIST OF ABBREVIATIONS

Bakken…………………………..… Bakken formation

BD…………………………………. Bulk Density

DI……………………………….…. Deionized

EC…………………………………. Electrical Conductivity

FCI……………………………...…. Functional Capacity Indices

HGM……………………………..… Hydrogeomorphic Method

HI5………………………………… Abated high impact site

ICP-MS……………………………. Inductively Coupled Plasma-mass Spectrometry

IPCI………………………………... Index of Plant Community Integrity

MC………………………………… Missouri Coteau

MCS……………………………….. Missouri Coteau Slope

MRPP……………………………… Multi-Response Permutation Procedure

ND…………………………………. North Dakota

NDAWN…………………………... North Dakota Agriculture Weather Network

NDDoH……………………………. North Dakota Department of Health

NDRAM………………………….... North Dakota Rapid Assessment Method

NMS……………………………….. Nonmetric Multi-Dimensional Scaling

NRCS……………………………… Natural Resource Conservation Service

NWGP……………………………... Northwestern Glaciated Plains

NWI……………………………..…. National Wetland Inventory

PHDI………………………………. Palmer Hydrological Drought Index

PPR………………………………... Prairie Pothole Region

INTRODUCTION

Energy development, in the form of oil, has expanded rapidly in recent years in western North Dakota (ND). This expansion has drastically increased the use of both paved and unpaved roads in the western part of the state. The increased traffic is well beyond any prior experience and this additional traffic has the potential to provide additional anthropogenic stress to wetland structure and function.

Oil drilling in western ND started in the 1950s near Tioga, ND and peaked in the early 1980s (Bakken Shale 2014). Hydraulic fracturing was developed in the late 1940s, but it wasn't until about 2003 that new technology made certain types of drilling more feasible. In 2006, energy companies began using new and improved technology in the Bakken formation (Bakken) located mostly in northwestern ND and stretching into northeastern Montana and southern Saskatchewan, Canada (Bakken Shale 2014). This new technology paved the way for increased production in the Bakken and lead to ND's biggest oil boom.

The current oil boom has dramatically increased the population in what once was a relatively unpopulated area of ND. With the increased population and oil development came increased travel and along with increased travel comes dust. There is currently little to no research on the effects of road dust in western ND, and little research on environmental effects of road dust in general. Even though dust issues have been around for centuries, only recently has attention been brought to the "anthropogenic evolution of dust" (Everett 1980). Most of the relevant research on road dust impacts has been conducted in Alaska or arid areas of the world. The road dust research in Alaska focuses on the effects on the thermokarst and other sensitive Alaskan landscapes (Everett 1980, Walker and Everett 1987, Auerbach et al. 1997). In arid areas, dust research has been conducted to determine the effects of ATV trails (Brown 1994) or deserts and sand storms (Neff et al. 2008).

A portion of the Bakken oil development is occurring in the Prairie Pothole Region (PPR). The PPR is one of the most wetland rich regions in the world (Luoma 1985). The PPR is spotted with temporary, seasonal, and semi-permanent depressional wetlands. Wetlands found within the PPR are vital areas for waterfowl habitat and breeding; as well as home to a variety of other organisms (van der Valk 1989, Johnson and Higgins 1997). These wetlands have unique biota and functions when compared with other wetlands of the nation (van der Valk 1989). This area is ecologically critical and it is important to understand the impact road dust has on these resources.

Road dust has the potential to impact many facets of wetlands and our environment. The nutrient budget of wetlands can be impacted in sites next to unpaved roads (Alexander and Miller 1978). Plants are also impacted by dust. Dust can affect how a plant photosynthesizes (Thompson et al. 1984). A plant community structure has been proven to change from increased dust deposition from unpaved roads; and the nutrient and metal levels available to plants are considerably higher next to the road (Farmer 1993). Along with dust deposition, road networks have an impact on the natural hydrology and geomorphology of the landscape (Jones et al. 2000).

Dust deposition contributes to wetland sedimentation and the accumulation of organic carbon, phosphorus, and nitrogen; the degree of impact depends upon the extent of anthropogenic disturbance (Craft and Casey 2000). Findlay and Houlahan (1997) found that there is a negative relationship between plant species richness and road density as well as bird and herptile species richness. The direct cumulative impacts of dust have proven to take years to notice and the affected area is generally much larger than the initial project (Walker and Everett 1987).

The oil boom in western ND is currently waning; however, it is important to determine the impacts and potential mitigation of impacts so when things pick up we can properly deal with problems. In doing so it is important to determine the amount of dust that is being created and the impacts it has on wetlands. This study took the first step in that process.

The specific objectives of this project include:

1) Determine road dust loading at high dust impact (frequently traveled by energy development traffic) and low dust impact (rarely traveled by energy development traffic) wetlands to evaluate dust loading from increased travel in western ND.
2) Evaluate water quality differences at high dust impact and low dust impact wetlands.
3) Assess wetland condition and function at high dust impact and low dust impact wetlands.
4) Evaluate trace element changes in wetland sediment at high dust impact and low dust impact wetlands.

LITERATURE REVIEW

Wetlands are very complex ecosystems that are of great ecological importance. Wetlands are defined as an area with organisms and plants that have adapted to a wet environment due to the presence of shallow water or flooded soils for part of the growing season (Mitsch and Gosslink 2007). The benefits they deliver to our environment include providing habitat, shelter, and food to wildlife; along with, reducing soil erosion and increasing water filtration. Even though wetlands are found in all types of climates around the world, the PPR landscape is one of the most wetland rich (Luoma 1985).

The PPR is a relatively young landscape encompassing 780,000 km^2 across South Dakota, North Dakota, Minnesota, and Saskatchewan and Alberta Canadian provinces (Mitsch and Gosslink 2007). There are numerous depressional lakes and marshes which are an important landscape for waterfowl production and migration with the warm summers and rich soils. These wetlands have dropped in numbers since settlement began. It is estimated that over 500 km^2 of wetlands have been drained primarily for agriculture (Mitsch and Gosslink 2007).

Agriculture is not the only disturbance affecting wetlands in the PPR. Naturally, wetlands change from season to season depending upon a multitude of factors including water levels and salinity (Bryce et al. 1998). Soil type of the wetland and surrounding area may also have an impact. Other potential influences that need to be considered are anthropogenic effects. Anthropogenic effects range from grazing management, haying and mowing to cultivation (Bryce et al. 1998). Most recently there has been increased disturbance in the PPR from of oil and natural gas development. This energy boom has increased traffic along roads that would typically only see local farm traffic; these areas now see dozens, if not hundreds of semi-trucks every day (Tolliver 2014). Most of the well pads and development are along unpaved roads, so the amount of dust created by all of this traffic is a concern (ND GIS 2012). The effects of road dust on plant communities, soil sediments, and water quality have only been minimally researched (Alexander et al. 1978, Farmer 1993, Neff et al. 2008).

Dust Effects

The increased traffic on unpaved roads in western ND most likely increases dust deposition, and there is little to no research on dust effects in this area. Dust creates important ecosystem feedbacks such as control of redistribution of sediment and addition of nutrients dust gives to the soil (Pye 1987, Farmer 1993, Field et al. 2009). In large scale events, such as dust storms and long term dust transportation, dust deposition can have a significant effect on many factors, including soils by changing the soil texture, water quality by increasing sediment and human health by causing respiratory illness (Lancaster 2009).

Local and regional scale dust appears to be mostly a byproduct of human land use decisions (Field et al. 2009). There are three ways dust travels dependent upon the particle size: surface creep, saltation, and suspension (Lancaster 2009). Vehicle speed plays an important role with respect to the size of dust emissions on unpaved roads, while the vehicle shape, size and number of tires have only minor influences on emissions; however, weight of the vehicle can have a distinct effect on the emissions from unpaved roads (Pye 1987, Gillies et al. 2005). Time of year also plays a significant role in dust deposition; more dust falls in the drier months, typically the summer beginning around April (Tamm and Troedsson 1955, Everett 1980). A study done in South Africa (Pye 1987) concludes that human activities have undoubtedly contributed to the increased dust emissions resulting in damage to vehicles, buildings and structures, engines, and respiratory diseases in humans and animals. Long term effects of dust on the behavioral ecology of different species, including fowl, mammals and plants, are still relatively uncertain (Farmer 1993).

There are many different impacts on the surrounding environment from road networks. Many of these impacts decrease with distance from the road. There is a significant correlation between distance and concentration of metals, where the highest concentration is found within a few meters of the road (Muskett and Jones 1981, Walker and Everett 1987, Forman and Alexander 1988, Santelmann and Gorham 1988, Tong 1990, Benfenati et al. 1992). Soils that are directly adjacent to roads typically have higher bulk density (BD) and pH, and lower nutrient levels, organic matter content and shallower root depths compared to soils farther from roads (Smith 1988, Moorhead et al. 1996, Auerbach 1997).

Concentrations in the soil horizon decrease exponentially not only with distance, but also with depth (Dale and Freedman 1982). Soil organic matter and moisture content increase with distance from the road (Muskett and Jones 1981). There is also potential for impacts on belowground decomposition and nutrient mineralization (Moorhead et al. 1996). Road dust has the potential to greatly affect numerous ecosystems and could be reduced if guidelines were set in place that addressed the impacts of road and dust disturbances (Auerbach 1997).

Road dust on plants has been found to increase leaf temperature, which in turn reduces leaf respiration, productivity, and impacts photosynthesis (Everett 1980, Thompson et al. 1984, Farmer 1993, Auerbach et al. 1997, Tworkowski et al. 2002, Zhia Khan et al. 2015). Finer dust particles may have an effect on light absorption and can clog vascular plant stomata, thus restricting gas exchange and also changing the water balance within the leaf (Thompson et al. 1984, Auerbach et al. 1997, Zhia-Khan 2015). Some species are more susceptible to dust effects, such as lichens and mosses (Everett 1980) and biomass is often reduced closest to the road

(Auerbach et al. 1997). When dust is from diverse origins, this may also impact the surrounding ecosystems, because they have different chemical characteristics than naturally found in the area (Farmer 1993). Western ND counties bring in gravel and the red colored scoria not locally found to backfill and grade unpaved roads. Scoria, or clinker, is a deposit that is relatively hard because it has been baked by the heat created from the underlying burned coal bed and most likely has been used as road material since the beginning of road construction (Murphy 2013).

Studies have shown that road networks also increase erosion and nutrient loads. This is correlated with a decrease in roadside vegetation and species richness (Forman and Alexander 1998) and with traffic intensity (Reid and Dunne 1984). Unpaved forest roads with heavy traffic were found to have 7.5 times higher sediment rate than paved roads (Reid and Dunne 1984). Also, organisms, such as frogs, are affected by vibrations from the road and noise pollution (Findlay and Houlahan 1997, Forman and Alexander 1998). Lead and zinc from motor vehicle emissions can also serve as an important source of roadside contamination (Muskett and Jones 1981, Dale and Freedman 1982, Tong 1990, Benfenati et al. 1992).

Local isolated activities, such as energy development, have been shown to produce more severe and longer lasting effects including a reduction in water quality, structure, and function of wetland (Cramer and Hopkins 1982). Wetlands are important in regulating adjoining wetland ecosystems where water exchange is primary in linking wetlands and bordering ecosystems (Hopkins 1992, Detenbeck etal. 2002, Guntenspergen et al. 2002). Alexander and Miller (1978) found wetlands within five meters of the road have significant annual changes in nutrients. Also, leachates from dust that physically settle onto a water surface where nitrogen and phosphorus were naturally limited, doubled the algal biomass (Alexander and Miller 1978).

Sedimentation is a natural process that has been sped up through anthropogenic actions and these actions dictate the degree of disturbance (Craft and Casey 2000). Increased sedimentation leads to lower water levels and there is often direct negative effects on the nutrient budgets in ponds closest to the road (Alexander and Miller 1978). This change in nutrient availability affects the surrounding vegetation quality and composition, which in turn leads to a change in the natural habitat of the wetland (Jurick et al. 1994, Adamus 1996, Kantrud and Newton 1996). There is also an increase in sediment and turbidity from activities taking place adjacent to surface water (Cramer and Hopkins 1982, Gleason and Euliss 1998).

The direct impacts of planned construction, such as road networks and energy development, will expand farther from the road and lag many years behind the actual area of construction activities (Walker et al. 1987). There are broad implications to ecosystem element fluxes and these human-caused changes is dust deposition and production may be more important than previously thought (Neff et al. 2008).

Assessment Methods

Hydrogeomorphic Model

For this study, three methods were used to assess wetland condition and function at each site. The Hydrogeomorphic Model (HGM) was used to gauge wetland function and the physical characteristics compared to reference standards. The HGM was developed by the Natural Resource Conservation Service (NRCS) and Army Corps of Engineers as a means of measuring and reviewing compliance with the Clean Water Act (Gilbert et al. 2006). The HGM serves as a functional assessment of a wetland by utilizing the physical, hydrological and biological characteristics of the site. A number of mathematical models, or functional capacity indices (FCI), are used to quantify/estimate wetland function. Each FCI ranges from 0.0-1.0, where 1.0

indicates the wetland functions at level similar to a reference condition site. The HGM model has been adapted to many regions across the United States, including the PPR (Gilbert et al 2006). There are four important components of the HGM approach to wetland evaluation according to the HGM regional guidebook for the Great Northern Plains. These components include: (1) classification of wetland by hydrogeomorphic class, (2) identification of reference wetlands for comparison, (3) development of assessment variables and models to produce functional indices, and (4) implementation of application protocols specific to the region (Gilbert et al. 2006). Regionally adapted HGM models are used throughout the United States to provide reliable measures of physical characteristics and hydrologic functions of wetlands (Guntenspergen et al. 2002; DeKeyser et al. 2003; Wardrop et al. 2007).

Index of Plant Community Integrity

The Index of Plant Community Integrity (IPCI) was used to assess wetland condition according to plant community characteristics such as structure and composition. The IPCI was initially developed by DeKeyser et al. (2003) and revised by Hargiss et al. (2008). The IPCI is a wetland condition assessment based on vegetation composition and is analysis using nine different metrics. The initial metrics determined by DeKeyser et al. (2003) were based on response to disturbance and ability to form an overall analysis of the plant community. The significance and use of these metrics are explained in depth in DeKeyser et al. (2003). Hargiss et al. (2008) revamped the metric values and ranges to be more encompassing of other ecoregions and sub-ecoregions of the PPR; as well as, encompassing more disturbance regimes. For each wetland, the nine metric scores were added together to produce a total metric score between 0-99. Based on this final score, the wetlands were placed into one of five condition categories of Very Good, Good, Fair, Poor, and Very Poor.

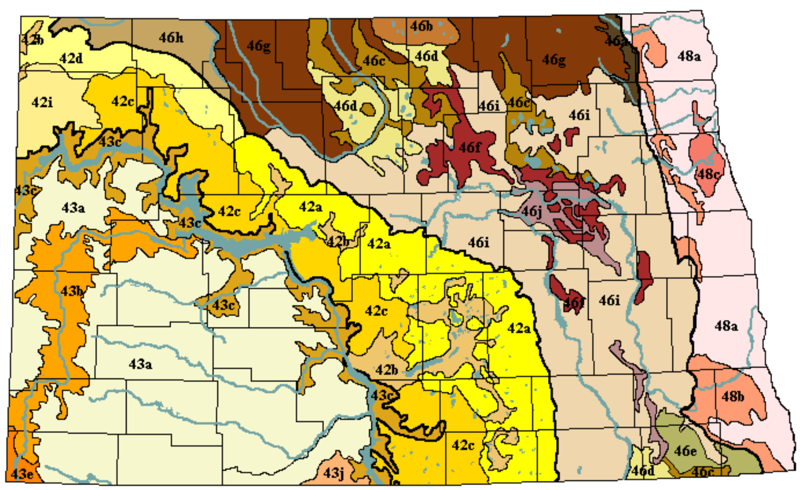
North Dakota Rapid Assessment Method

The North Dakota Rapid Assessment (NDRAM) was developed by Hargiss (2009) as a rapid measurement of wetland condition based on a number of factors, such as vegetation and land use. The NDRAM quickly assesses the overall condition of a wetland based on characteristics such as wetland buffer width, vegetation, hydrology, habitat, soils, management, wetland potential, and overall vegetation condition (Hargiss 2009). The method was intended to have results similar to the IPCI, but to be done in a shorter amount of time. The overall condition rating is on a scale from 0-100, 0 being extremely poor, 100 being similar to reference condition. One of four categories are assigned based on the final score of 0-100, including: Poor, Fair Low, Fair High, and Good.

STUDY AREA

The study was conducted in 2012 and 2013 on wetlands within Mountrail and Ward counties in northwestern ND. The wetlands are all part of the PPR. The PPR is a relatively young landscape. Glaciation created distinct landscape features, combined with climate attributes, the area resulted in a multitude of pothole wetlands due to an absence of well-developed drainage networks (Richardson et al. 1994, Richardson and Vepraskas 2001).

All study sites were within the Northwestern Glaciated Plains (NWGP) ecoregion, which was the western most extent of continental glaciation (Figure 1). The NWGP land use is transitional between farming and ranching and the surface is highly irregular with a high concentration of wetlands (Bryce et al. 1998). The high impact sites were located within the Missouri Coteau Slope (MCS) sub-ecoregion of the NWGP while the low impact sites were located within the Missouri Coteau (MC) sub-ecoregion of the NWGP. Both of these sub-ecoregions are of great importance for waterfowl production in North America (van der Valk 1989). The MC is the most wetland rich area in the PPR while the MCS decreases in elevation



42 Northwestern Glaciated Plains
42a Missouri Coteau
42c Missouri Coteau Slope
Figure 1. Ecoregions of North Dakota (Bryce et al. 1998).

from the MC to the Missouri River (Bryce et al. 1998). The MCS has less depressional wetlands and more cropland due to the gently rolling topography. The MC is filled with depressional wetlands within rolling hummocks from the slow retreat and melting of the Wisconsin glacier thousands of years ago. In the flatter areas the land use is mostly tilled agriculture, but in both sub-ecoregions it is common for cattle to be grazed on steeper slopes that occur along drainages (Bryce et al. 1998).

The MC and MCS sub-ecoregions have some similar features (Bryce et al. 1998). The surficial material and bedrock are glacial till over Tertiary sandstone and Cretaceous Pierre Shale. The temperature is frigid and can range from mean minimum/maximum temperatures in January of -18/-6°C to 14/29°C in July. The moisture regime is semi-arid with annual mean precipitation between 38-45 centimeters and an average of 110-130 frost free days (Bryce et al. 1998).

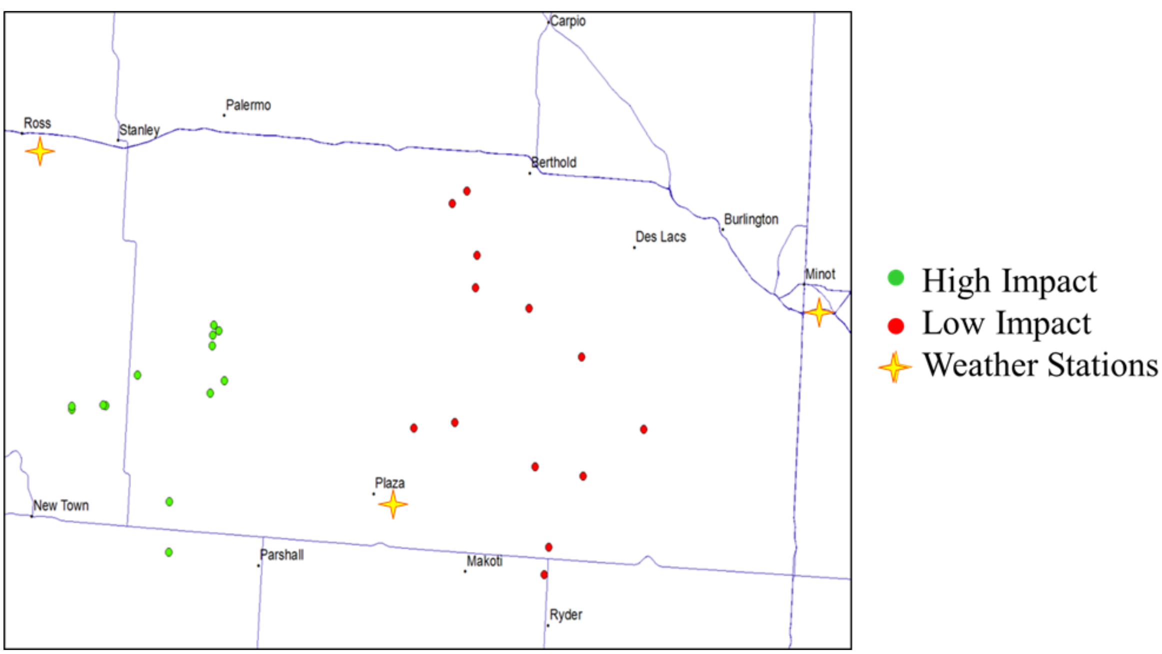


Figure 2. High impact sites, low impact sites, NDAWN weather stations.

The precipitation for the 2012 and 2013 field seasons were very different. During the collection periods, precipitation was monitored using the North Dakota Agriculture Weather

Network (NDAWN) weather stations at Minot, Plaza and Ross (Figure 2). During 2012, at all three weather stations, there was less than average rainfall July-September; during 2013, there was greater than average rainfall April-October (Figure 3, 4 and 5). There was a significant amount of rainfall at all weather stations May-June in 2013 (NDAWN 2014).

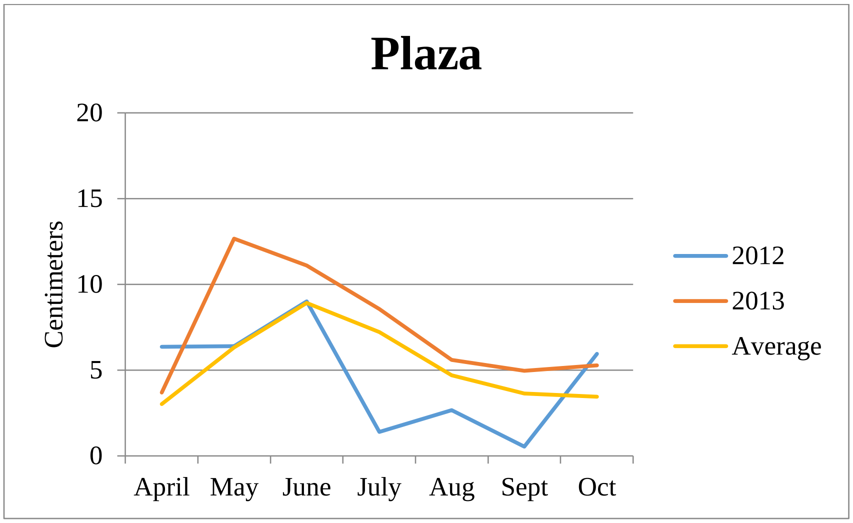


Figure 3. Precipitation at Plaza weather station between April and October of 2012, 2013, 30-year average.

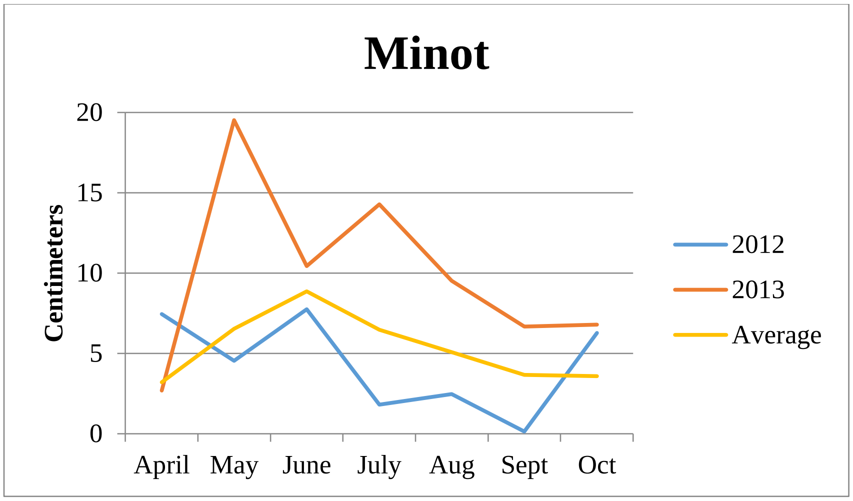


Figure 4. Precipitation at Minot weather station between April and October of 2012, 2013, 30-year average.

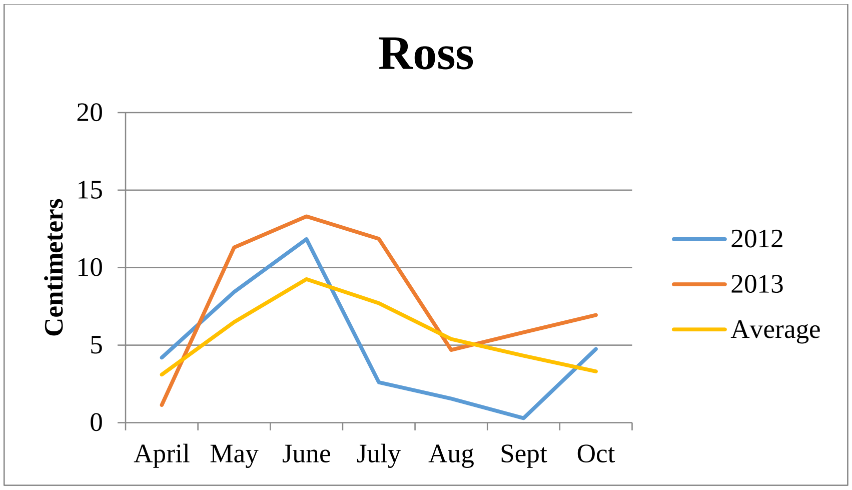


Figure 5. Precipitation at Ross weather station between April and October of 2012, 2013, 30-year average.

The Palmer Hydrological Drought Index (PHDI) was established by Wayne Palmer and is used throughout the world. This index measures the duration and intensity of long-term drought-inducing circulation patterns. Since long-term drought is a cumulative effect, the PHDI looks at the current weather patterns in addition to cumulative patterns over previous months. The PHDI reflects the longer time periods that it takes to develop drought and the longer recovery time of the hydrological impacts of drought (National Climatic 2014). PHDI takes into account long-term soil inundation and prior moisture status. The PHDI for northwestern ND division is shown in Figure 6.

As shown in Figure 6, February-April 2012 had drier conditions with little recovery in June and July. In 2013, there were slightly drier conditions March-May with a change to substantially wetter conditions in June-August. The information found in this graph may further explain why six of the ten high impact sites were too dry for water quality sampling in September 2012.

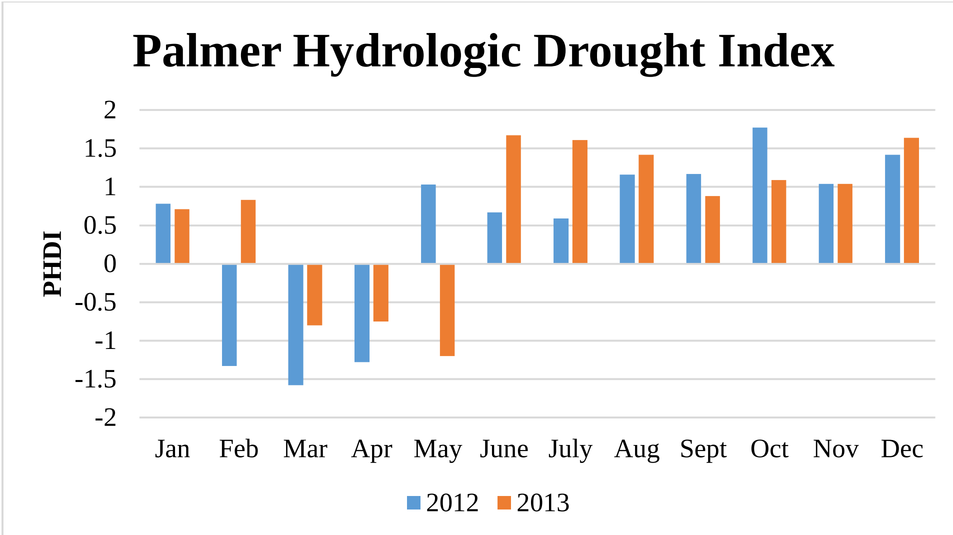


Figure 6. Palmer Hydrological Drought Index data for 2012 and 2013.

Soils

The typical upland and wetland soils of the entire NWGP ecoregion, including MC and MCS sub-ecoregions, are Mollisols (Bryce et al. 1998). Mollisols are the most common soil found throughout the PPR (Richardson et al. 1994). Typically formed under grasslands, Mollisols have a relatively deep and dark A horizon (Gardiner and Miller 2004). Mollisols are considered one of the most fertile soils because they are commonly enriched with organic matter.

Common upland soil series for high impact study sites located in the MCS sub-ecoregion include Williams (fine-loamy, mixed, superactive, frigid Typic Argiustolls), Max (fine-loamy, mixed, superactive, frigid Typic Haplustolls), and Zahl (fine-loamy, mixed, superactive, frigid Typic Calciustolls) (Bryce et al. 1998; USDA-NRCS Soil Survey Division 1998a, 1998b, 2005a). These soil series are characterized by very deep well drained soils that have moderately slow permeability in soils formed from glacial till. The texture is described as fine-loamy and usually contain carbonates.

Common upland soil series for the low impact study sites located in the MC sub-ecoregion include Barnes (fine-loamy, mixed, superactive frigid Calcic Haludolls), Buse (fine-loamy, mixed, superactive, frigid Typic Calciudolls), Zahl (fine-loamy, mixed, superactive, frigid Typic Calciustolls) and Svea-Williams (Svea: fine-loamy, mixed, superactive, frigid Pachic Hapludolls; Williams: fine-loamy, mixed, superactive, frigid Typic Argiustolls). All of these soils series are characterized by very deep well drained soils. Both Barnes and Buse were formed in loamy glacial till, but Buse is found on moraines. Zahl and Svea-Williams were formed in calcareous glacial till. The texture of all of these soils series is fine-loamy and usually contains carbonates (Bryce et al. 1998; USDA-NRCS Soil Survey Division 1998b, 2005b, 2005c, 2014).

Both the MSC and MC sub-ecoregions share the same wetland soil series which are Bowbells and Parnell. The Bowbells series (fine-loamy, mixed, superactive, Pachic Argiustolls) consist of very deep and well to moderately well drained soils that were formed from glacial till and glacial till moraines and plains (USDA-NRCS Soil Survey Division 1998c). These soils have a fine-loamy texture which leads to the upper portion of soil to drain well while soils underneath create a moderately slow to slow permeability into the substratum.

The Parnell soil series (fine, smectitic, frigid, Vertic Argiaquolls) consist of very deep and very poorly drained soils (USDA-NRCS Soil Survey Division 2003). These soils are fine textured and fortified with smectitic clays that result in very poor drainage with ponding at the surface. These soils developed in water-sorted sediments from glacial drift in swales, depressions and drainage ways on glacial moraines.

Vegetation

Grass is the dominant vegetation in the PPR and the Northern Great Plains (Barker and Whitman 1988, 1989; Richardson et al. 1994; Richardson and Vepraskas 2001). There are three genera of grasses that are the most abundant and make up approximately 80% of the region's grassland vegetation – *Elymus*, *Hesperostipa*, and *Bouteloua* (Barker and Whitman 1988, 1989). Potential native vegetation follows an east-west precipitation gradient within the PPR and with that comes notable changes (Richardson and Vepraskas 2001).

The NWGP ecoregion is an area vegetatively known as the mixed grass prairie. The region is dominated by a wheatgrass-needlegrass association in the upland areas (Barker and Whitman 1988, 1989) while northern reedgrass (*Calamagrostis stricta* (Timm) Koeler) and prairie cordgrass (*Spartina pectinata* Bosc ex Link) are found near wetlands (Bryce et al. 1998). The wheatgrass-needlegrass species are found in a large area spanning from eastern Montana and northeastern Wyoming to west central ND and from central Saskatchewan to southern South Dakota. The potential native vegetation of the mixed-grass prairie ecosystem would consist of mid-grass species such as needle and thread (*Hesperostipa comata* (Trin. & Rupr.) Barkworth) and western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Love) and short grass species such as sedges (*Carex* spp.) and blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths). Common species found within the wheatgrass-needlegrass type are prairie junegrass (*Koeleria macrantha* (Ledeb.) Schult.), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), green needlegrass (*Nassella viridula* (Trin.) Barkworth), plains reedgrass (*Calamagrostis montanensis* Scribn. ex Vasey), thickspike wheatgrass (*Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould), Buffalograss (*Bouteloua dactyloides* (Nutt.) J.T. Columbus), slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners), sandberg bluegrass (*Poa secunda* J. Presl), and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve). Kentucky bluegrass (*Poa pratnensis* L.) and smooth bromegrass (*Bromus inermis* Leyss.) are non-native species that have invaded the PPR grasslands (DeKeyser et al. 2010, DeKeyser et al. 2013). The United States

Department of Agriculture PLANTS database is the main reference for all plant species identified later in this thesis (USDA, NRCS 2008).

MATERIALS AND METHODS

Site Selection

All study sites were chosen using a restricted randomization design. A total of ten sites were selected in the high impact area and ten in the low impact area (Figure 7). Specific criteria were used in the selection of wetlands. Wetlands were first identified as seasonal according to the National Wetland Inventory (NWI). The next criteria required was to be within 50 m of an unpaved road. In the end, all selected wetlands were directly adjacent to the road. A minimum buffer of 15 m around the wetland was required to ensure dust collected would not be from other sources, such as farming activity. Restricted areas, one with a high density of active oil wells and one with little/no active wells, were used to select wetlands (Figure 7). Note that all active wells around the low impact sites were drilled previous to 1990; therefore, there is little traffic, if any, due to energy development. Wetlands meeting the criteria within the restricted areas were then randomly selected. A table of all the sites along with GPS location is located in Appendix A.

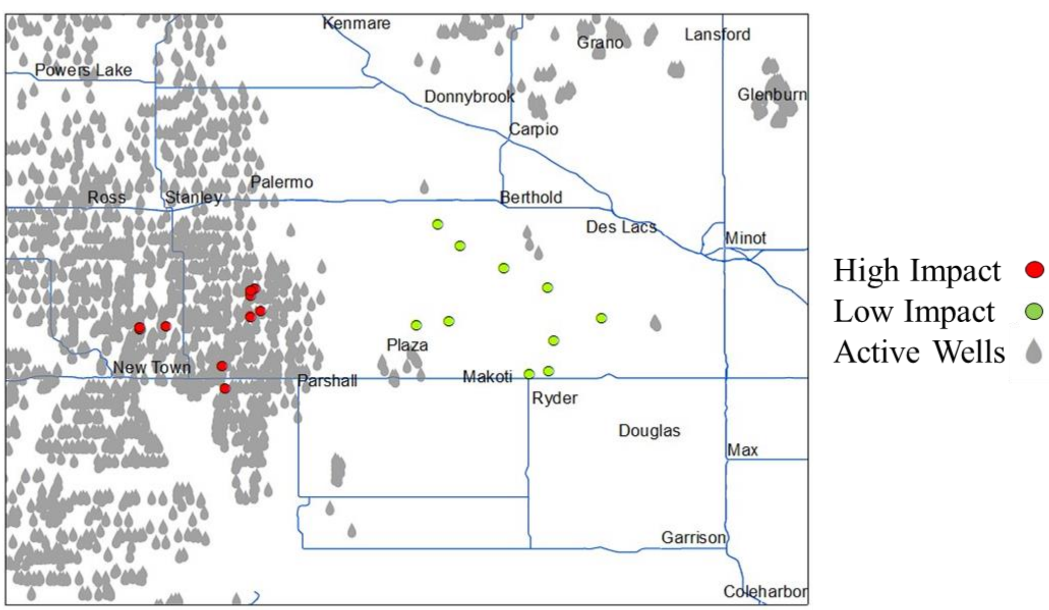


Figure 7. High impact sites, low impact sites, and active oil wells.

Once wetlands were narrowed down through remote assessment, the sites were ground truthed to ensure the wetlands met the study criteria. After ground truthing, a list of restricted randomized sites was generated and landowners were identified using township, range, and section information and county courthouse data. Landowners were contacted for permission to survey sites. If a landowner did not give permission to access a site, permission was sought for the next randomly selected wetland.

Dust Collection

A passive method was used to collect dust at all 20 sites using a design similar to Stetler et al. (2008). Dust collectors were able to measure passive dust deposition. The collectors sat approximately 1.5 m above ground and were secured by a T-post and guy wires. A cross section of the dust collector can be found in Figure 8. A larger bucket (37 cm height and 30 cm diameter; 5 gallon) ensconces a smaller bucket (24 cm height and 24 cm diameter; 2 gallon) on the inside for dust collection. A funnel atop the larger bucket with weather stripping along the edge was held down by bungees cords to ensure no air flow in or out of the buckets. The funnel rested in a hole of the lid on the smaller bucket. During the time of collection, the smaller bucket was removed and covered for transport and replaced with a clean bucket. Ten grams of a multi-purpose algaecide was placed in each smaller bucket to protect against biological activity. The amount of algaecide was subtracted when weighing the dust samples to produce the weight of only the dust. Because of the variability of algaecide loss rates, all negative values were changed to zero for statistical purposes.

There were three dust collectors set up at each site at 10 m, 40 m, and 80 m from the center of the gravel road in cardinal directions. Dust collectors were in place in 2012 from July-October and 2013 from April-October. Each small bucket was replaced monthly, aside from the

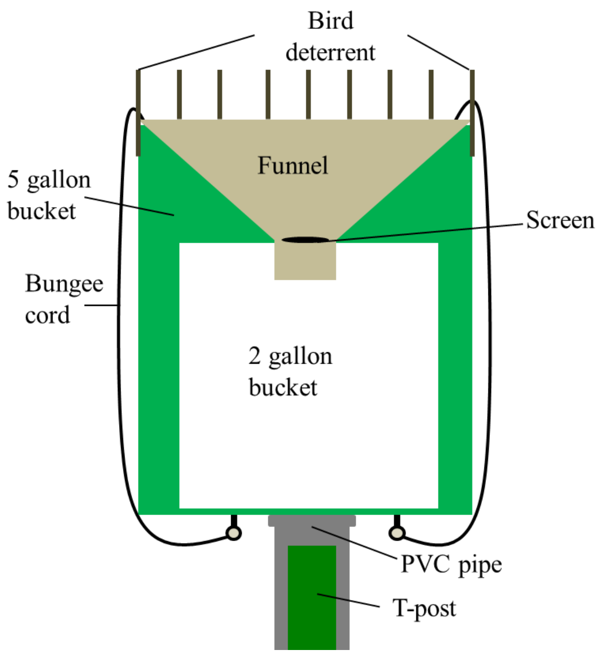


Figure 8. Cross section of dust collector.

June 2013 sample where samples were collected twice due to abnormally high precipitation and combined for a composite sample. The small buckets were returned to NDSU to desiccate the water in an environment with no air flow to ensure no extra dust would fall into samples. Once samples were air dried the content was transferred into a sterile four ounce specimen cup and placed in an oven at 105 °C for a minimum of 24 hours or until the sample was completely dry. The samples were then placed in a desiccator for a minimum of 24 hours to equilibrate all samples to the same relative humidity. Each sample was weighed on a scale measuring to the one hundredth of a gram. Samples were then covered and stored.

Water Quality

Water samples were collected monthly in 2012 (July-September) and 2013 (May-September) at all 20 wetlands, water level permitting. There is no data for six of the ten high impact wetlands from September 2012 due to abnormally dry weather. Temperature, conductivity, dissolved oxygen percent, dissolved oxygen, pH and chlorophyll were measured on site using a YSI meter 650 MDS with Sonde 600 QS at each wetland. Following North Dakota Department of Health (NDDoH) protocol, water was collected at 0-0.5 m surface depth in the most open and deepest wadeable section of the wetland closest to the road. Samples were properly handled, preserved, cooled, and transported to the NDDoH state lab for processing. Parameters measured at the lab and details of NDDoH water sampling procedures can be found in Appendix B.

Soil Sampling

Soil samples were taken at each wetland during the 2012 and 2013 field season in a manner similar to Guy et al. (2012). The soil samples were taken in the wet meadow zone of each wetland around 10 m from the road to assure there was no road gravel in the sample. Soil samples were extracted using a 7.6 cm diameter stainless steel cylinder, stainless steel equipment, and nitrile gloves were worn to safeguard against cross contamination. Once the sediment was removed, sample sections were taken at 0-0.5 cm and 5-6 cm to compare the top of the soil with the resident soil. Four cores were taken at each depth for one composite sample at each wetland. Separate samples were taken at both depths for BD analysis. Field equipment was washed with a 4:1 methanol/deionized (DI) water solution between samples to ensure no residue was transferred. Samples were then transported in coolers to the NDSU soil lab for analysis.

Samples were processed at NDSU by air drying and grinding using an acid-washed chemical porcelain mortar and pestle. Bulk density was determined after drying at 105 °C for 24 hours. Each soil core was analyzed for electrical conductivity (EC) and pH using a 1:1 or 1:2 ratio of soil/DI water, depending upon organic matter content in the sample. The remaining soil samples were analyzed for 53 elements using aqua regia digestion and inductively coupled plasma-mass spectrometry (ICP-MS) (vendor code 1F04; Acme Analytical Laboratories Ltd., Vancouver, BC, Canada). The list of elements can be found in Appendix C. Concentrations were normalized for BD, due to varying BD values between depths and across locations. All elements below detection limit were changed to zero before analysis.

Hydrogeomorphic Model

The HGM was conducted at each wetland in 2013 to assess wetland function relative to reference standards (Gilbert et al. 2006). Data collected in the field included soil measurements, GPS information, vegetation assessments, and catchment basin area assessments. Aerial photos and GIS software were used to collect data in the lab. Specific attributes measured and reference standards are listed in Appendix D. Data were then input into mathematical formulas created for assessing wetland function. Functions and formulas are listed in Appendix E.

There are several FCI's used by the HGM to analyze each wetland (Appendix E). The six FCIs defined by the model include: 1) water storage; 2) groundwater recharge; 3) retention of particulates; 4) removal, conversion, and sequestration of dissolved substances (biogeochemical processes); 5) plant community resilience and carbon cycling; and 6) provision of faunal habitat. The HGM is a function-based assessment so each FCI measures the function of each wetland in comparison to a reference standard. Each FCI is given a score between 0.0-1.0. A wetland that functions at the equivalent of the reference standard would be given an FCI of 1.0, while any wetland given an FCI lower than 1.0 functions at a lower level than the reference standard.

Index of Plant Community Integrity

Vegetation composition can be used to analyze the condition of a wetland and this study used the IPCI to obtain vegetation information and condition. At each of the 20 seasonal wetlands in 2013, the quadrat method was used to measure vegetation cover, similar to methods used by and Kantrud and Newton (1996), Euliss and Gleason (1997), DeKeyser et al. (2003), Hargiss et al. (2008), and Hargiss (2009). Each seasonal wetland has three zones: low prairie; wet meadow; and shallow marsh. Within each zone, 1 m^2 quadrats were set at equal distances using visual estimation in a circular fashion (Figure 9). In the low prairie zone eight quadrats were sampled, seven quadrats in the wet meadow zone, and five in the shallow marsh zone for a total of 20 quadrats at each wetland. The species identified within each quadrat were considered primary species, while a separate list of species found between quadrats within a zone were considered secondary species. Within each 1m^2 quadrat, all plants were identified by species and a percent aerial cover was assigned. The depth of water, amount of water, depth of litter, amount of litter and amount of bare ground at each quadrat were also measured.

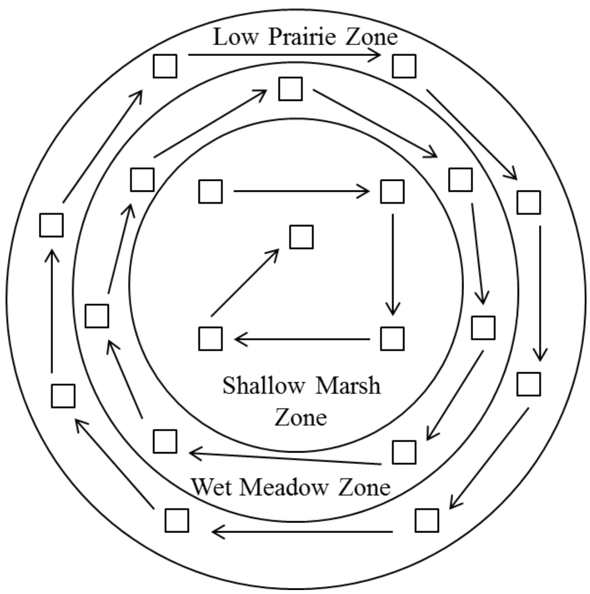


Figure 9. Example of quadrat arrangement within zones of a seasonal wetland.

IPCI data were analyzed according to the multimetric system used by DeKeyser et al. (2003) and Hargiss et al. (2008). A complete list of the metrics used and value ranges can be found in Appendix F. At each wetland, metric values were calculated using the primary plant species found within the quadrats along with the secondary species found between quadrats. A comprehensive plant species list found during assessment of high impact sites and low impact sites including scientific name, common name, C-Value, life form, origin and indicator category is given in Appendix G and H.

Four value ranges were assigned to each metric dependent upon the vegetative data collected in each wetland. Each metric was assigned a 0, 4, 7, or 11 depending upon which value range the data occupy. The total metric score (0-99) for each wetland was calculated by adding all nine metric scores (Appendix F). Wetlands are then separated into one of five condition categories of Very Good, Good, Fair, Poor, and Very Poor based on the total metric score (Table 1). The condition category and total metric score for each wetland indicates the condition of the wetland and are related to the degree of disturbance impacting the wetland.

Table 1. Total score ranges and subsequent condition categories for seasonal wetlands.

Condition Category	**Total Score Range**
Very Good	80-99
Good	60-79
Fair	40-59
Poor	20-39
Very Poor	0-19

North Dakota Rapid Assessment Method

The NDRAM was another assessment done at all sites in 2013 to evaluate the condition of each wetland using a rapid procedure (Hargiss 2009). This assessment method takes approximately 20 minutes to conduct; therefore, best professional judgment is used and has the potential to be more variable. Land use/management, and hydrologic features, such as hydrology, hydrologic vegetation and hydric soils were measured using a three metric system. The sum of these metrics provides a total score of 0-100, 0 being a wetland with very poor condition and 100 being a wetland at reference condition. Based on the final score each wetland is put into a conditional category of Good, Fair High, Fair Low, and Poor. Details on the NDRAM and the metrics can be found in Appendix I.

Statistical Analysis

Average daily dust loading values for distance and season were analyzed as two-way analysis of variance using PROC GLM (Copyright © 2011, SAS Institute Inc., Cary, NC, USA). Mean comparison was done with the Tukey test. Comparisons between high impact and low impact sites used all sample periods and were analyzed using a t-test with unequal variances.

Soil and water data were analyzed using Nonmetric Multidimensional Scaling (NMS) (Kruskal 1964, Mather 1976) which was used to graphically display and study the patterns for all 20 sites for both years (2012, 2013). Version 6 of PC-Ord (McCune and Mefford 2011) was used to run NMS analysis. The distance measure used for the water data was Euclidean and the soil data was Relative Euclidean. Structure in the data was found by running PC-Ord with 500 repetitions of the data reducing to one axis from 6 with an instability criterion of $0.1x10^{-6}$, "250 runs with real data with a different random starting point, and 250 randomized runs" (McCune and Grace 2002). Dimensions and model selection was based on: 1) a significant randomization test ($p<0.05$); 2) model with a stress <25; 3) instability <0.0001; and 4) selection of axes was discontinued if the next axis did not reduce stress >5.

Multi-Response Permutation Procedures (MRPP) in PC-Ord using the Euclidean distance measure were utilized to test comparisons between water and soil variables: 1) water variables were tested between high impact and low impact and among years; and 2) soil variables were tested by depth between high impact and low impact and years. All pair-wise comparisons adjusted using the Bonferroni correction for multiple p-values (Gotelli and Ellison 2004). The high impact and low impact sites were compared using a t-test with unequal variances for the HGM, IPCI, and NDRAM values.

RESULTS

Dust Analysis

A total of nine-month long sample periods were conducted in 2012 (June-October) and 2013 (April-October) (Table 2). Due to the substantial rainfall between May and June in 2013, dust was collected twice in June and combined for one composite sample. Dust loading was quantified into g/m^2/day for all distances over the sample periods: 10 m, 40 m, and 80 m (Figure 10). The overall average dust loading for the high impact sites were significantly different for all distances: the 10 m had a 212% increase above low impact site levels (p=<0.001, t=1.98); the 40 m had a 30% increase above low impact site levels (p=0.002, t=1.97); and the 80 m had a 24% increase above low impact site levels (p=0.029, t=1.97).

Table 2. High impact and low impact sites mean and standard deviation of dust loading by distance and sampling period measured in g/m^2/day. Distances correspond to the distance from the centerline of roads where samplers were placed.

	Low Impact						High Impact					
	10 m		40 m		80 m		10 m		40 m		80 m	
Sampling Period	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
6/25/12-8/14/12	0.757	0.333	0.647	0.207	0.600	0.180	1.252	0.393	0.741	0.374	0.732	0.289
8/14/12-9/11/12	1.196	0.427	1.121	0.325	0.960	0.208	3.150	2.029	1.233	0.235	1.121	0.307
9/11/12-10/16/12	0.928	0.430	0.661	0.160	0.617	0.301	2.257	1.365	0.879	0.378	0.755	0.296
4/1/13-5/13/13	0.524	0.298	0.541	0.132	0.383	0.239	1.841	1.712	0.534	0.218	0.461	0.227
5/14/13-6/12/13	1.213	1.220	0.688	0.888	0.707	0.853	6.407	1.952	1.445	0.405	1.523	0.243
6/12/13-7/17/13	1.178	0.619	1.176	0.546	0.991	0.577	3.606	2.119	1.352	0.675	0.793	0.550
7/17/13-8/13/13	1.220	1.012	0.808	0.645	0.727	0.526	3.840	2.966	1.243	0.546	0.737	0.529
8/13/13-9/10/13	1.155	1.134	0.865	0.480	0.736	0.307	2.851	1.516	1.034	0.307	1.023	0.423
9/10/13-10/22/13	0.478	0.358	0.358	0.255	0.211	0.219	1.834	0.967	0.490	0.305	0.219	0.187

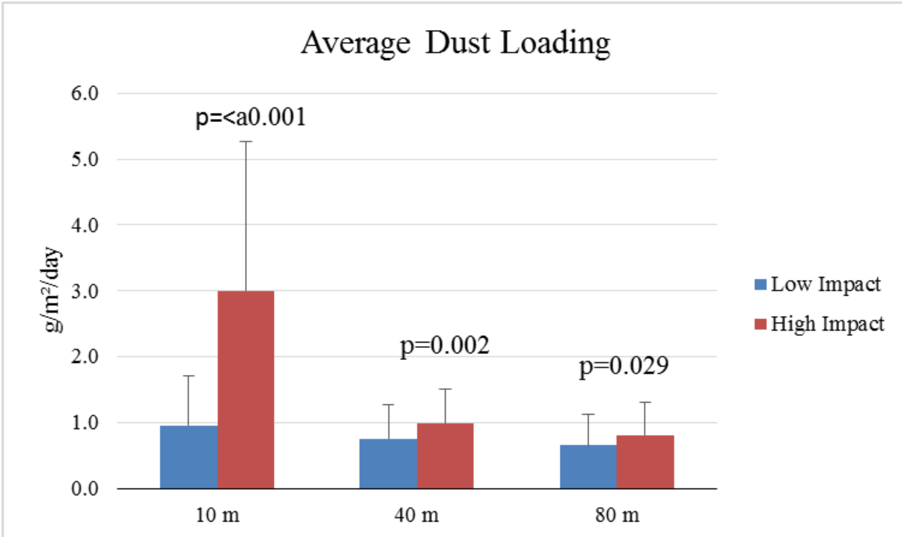


Figure 10. Average dust loading (g/m^2/day) for the high impact and low impact sites.

Dust loading by season was evaluated where spring includes April-May, summer includes June-August, and fall includes September-October. Daily dust loading for the high impact sites was significant for both main effects of season and distance from road ($p<0.001$), but the interaction between season and distance was not significantly different ($p>0.05$) so the responses were consistent but at different levels (Figure 11). The low impact sites were significantly different for season and distance ($p<0.001$) while the interaction between season and distance was not significantly different ($p>0.05$). Dust loading for the high impact sites at the 10 m distance was 267% higher compared to the 80 m distance, while for the low impact it was only 46% times higher when comparing the 10 m to the 80 m. The 40 m distance for the high impact and low impact sites were not significantly different from the 80 m distances and in the low impact sites the 40 m was not significantly different from the 10 m distance. Daily dust loading by season found that summer season was about 96% significantly higher compared to the spring and fall for the high impact sites and the low impact summer season was about 75% higher.

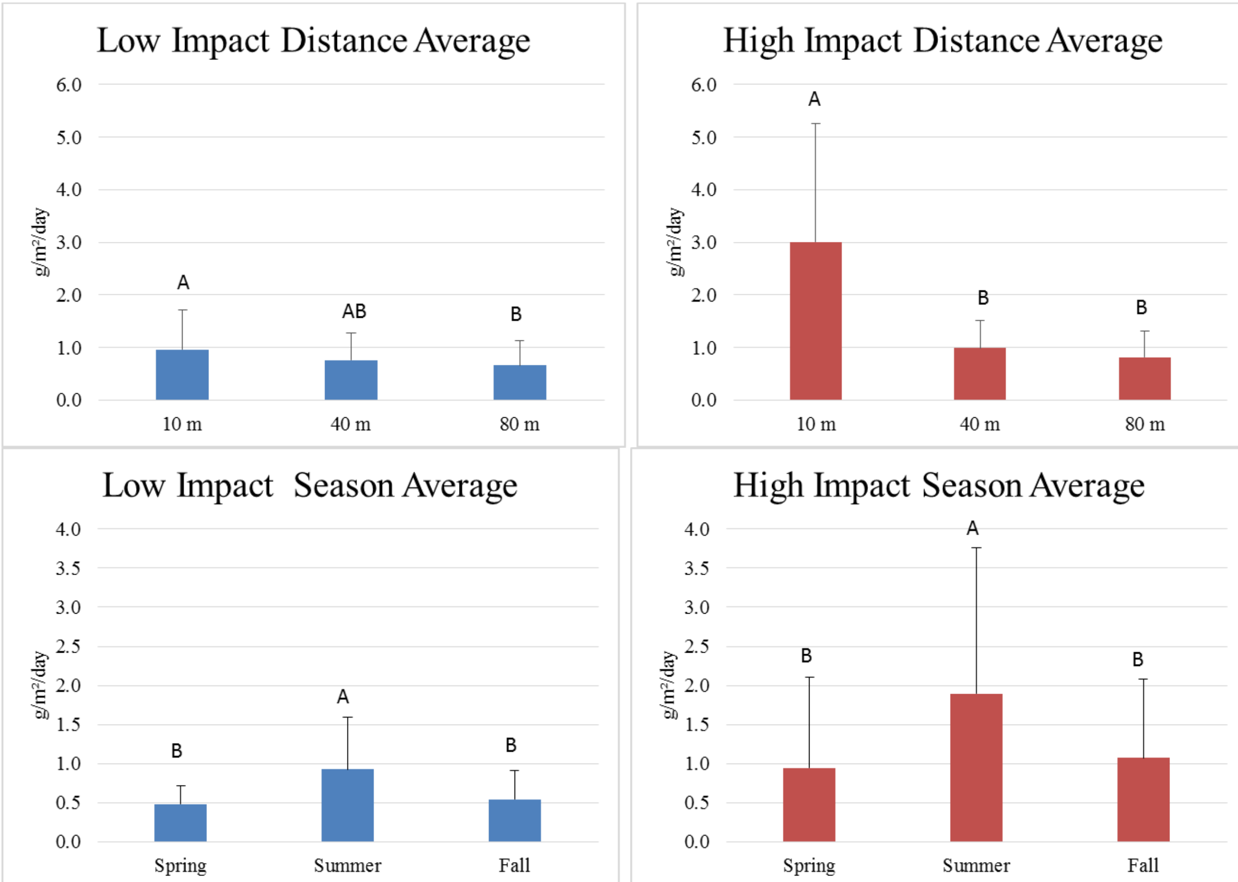


Figure 11. Comparisons of the average daily dust loading (g/m^2/day) by distance and season within the high impact and low impact sites. Different letters denote significance at p=<0.001.

To obtain an estimate of the amount of dust produced at high impact and low impact sites between April-October in a given year we multiplied the average dust loading/day for the season by the numbers of days in the given season and added this information for the spring, summer, and fall seasons. At all distances the high impact sites were greater when compared to the low impact sites. The high impact sites accumulated 647 g/m^2 over this period (214 days), while the low impact sites collect only 197 g/m^2 at the 10 m location a 228% increase. The same trend occurs with the other distances, but with a lower increase, with 40 m high impact sites at 205 g/m^2 and low impact sites of 154 g/m^2, a 33% increase. The 80 m distance had the least increase between the high and low sites with 171 g/m^2 at the high impact sites and 132 g/m^2 at the low impact sites, a 29% increase.

There was one site of the high impact sites that was abated (HI5) throughout the sampling period. The average dust loading for the abated site was less than the average of all of the high impact sites for all the 10 m, 40 m, and 80 m distances (Figure 12). The abated site had more dust than the low impact sites at 10 m and 40 m, but less at 80 m.

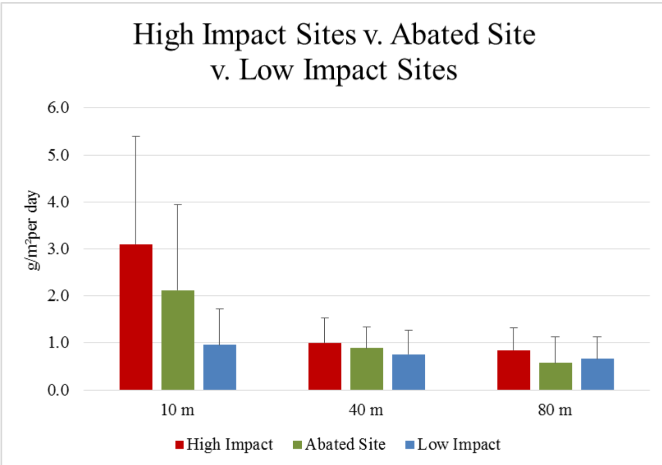


Figure 12. Comparative graph of the one high impact abated site average dust loading (g/m^2/day) versus the overall high impact dust loading average and low impact dust loading average.

Water Quality Analysis

NMS analysis of the water quality dataset produced a final solution with 1 dimension representing 99.5% of the variation in the data (Figure 13). Strong negative correlations were found with axis 1 these being: higher levels of total dissolved solids (-0.995); higher levels of conductivity (-0.984); higher levels of sulfates (-0.983); higher levels of hardness (-0.966); higher levels of magnesium (-0.932); higher levels of calcium (-0.921); and higher levels of sodium (-0.900). Because the MRPP analysis tests the spread of data in addition to location, the tight grouping of the water quality values in low impact 2013 were found to be significantly different than the high impact 2012, 2013 and low impact 2012. There was no difference in the results when Chlorophyll A and B were included in the analysis. Chlorophyll A and B were not included in the final analysis because of missing data in 2012.

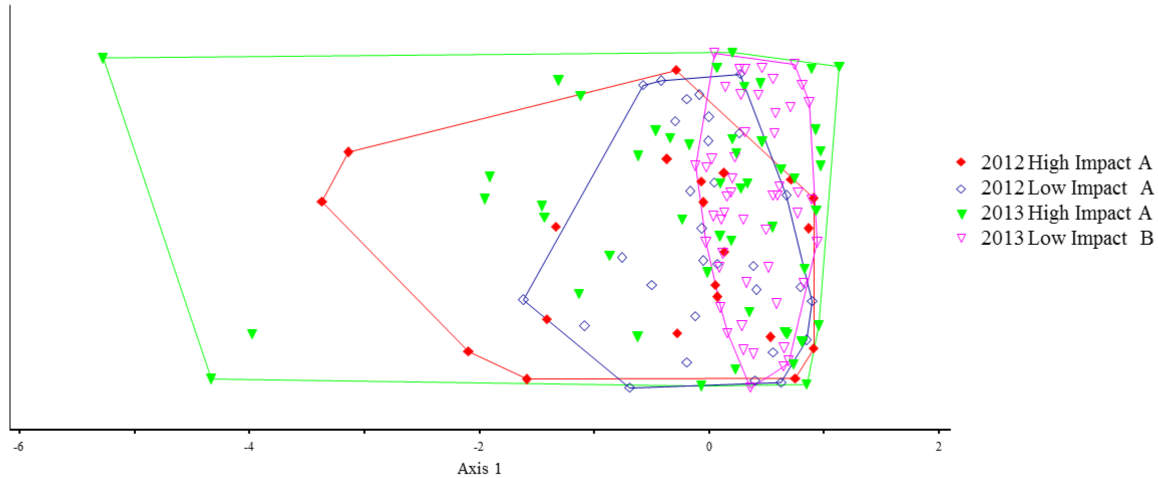


Figure 13. Nonmetric Multidimensional Scaling ordination of water quality data 2012 high impact, 2012 low impact, 2013 high impact, and 2013 low impact showing axis 1. Legend items followed by different letters were significantly different at $p<0.05$. (Points in ordination space represent individual wetland sites).

Soil Analysis

NMS analysis of the soil data by depth produced a final solution with 1 dimension representing 99% of the variation in the data (Figure 14). There was no significant difference between depths, therefore the final analysis did not include the lower depths in the analysis. NMS analysis of the soil dataset by year and site produced a final solution with 1 dimension representing 99% of the variation in the data (Figure 15). Strong negative correlations with axis 1 were: higher levels of EC (-0.710) and higher levels of sulfur (-0.694); and strong positive correlation with axis 1 were with higher levels of BD (0.629). The only significant difference found was between years for low impact sites. There were no differences between low impact and high impact sites.

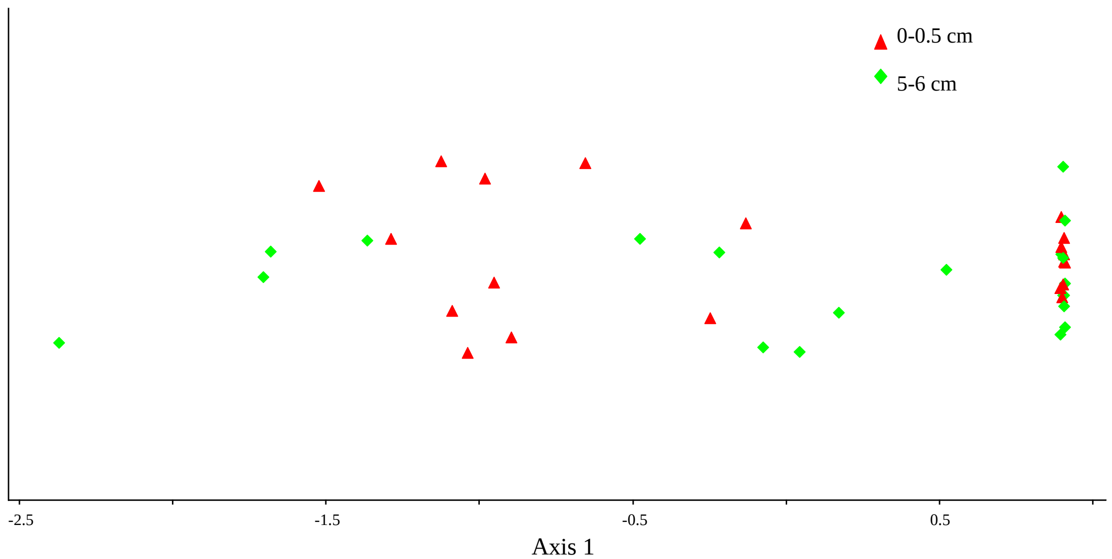


Figure 14. Nonmetric Multidimensional Scaling ordination of soil depth data 0-0.5 cm and 5-6 cm showing axis 1. (Points in ordination space represent individual depths).

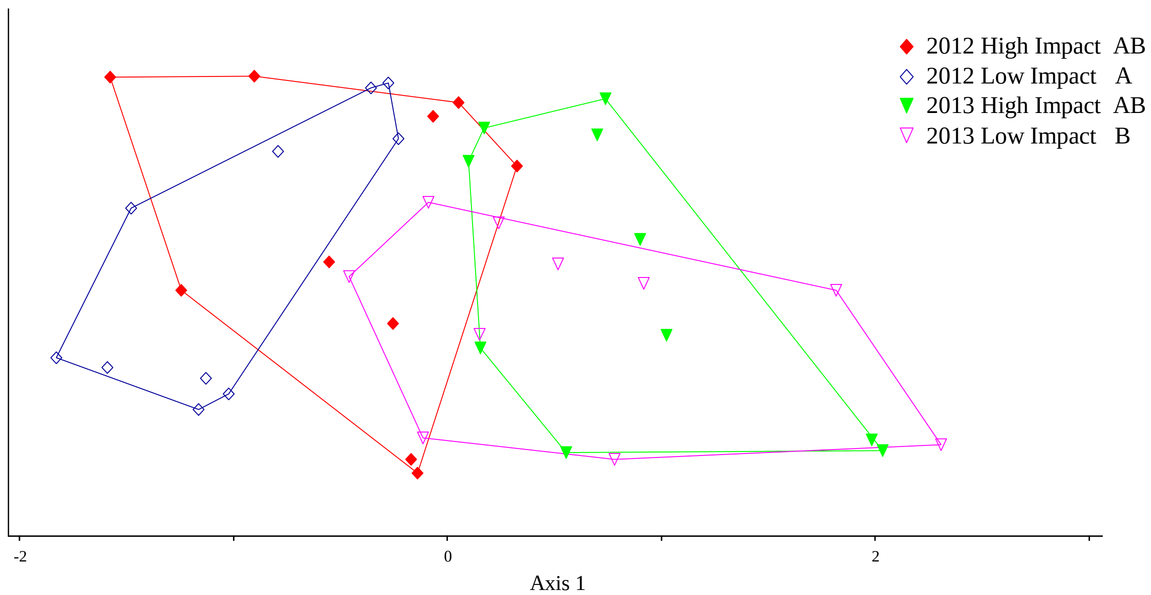


Figure 15. Nonmetric Multidimensional Scaling ordination of soil data 2012 high impact, 2012 low impact, 2013 high impact, 2013 low impact showing axis 1. (Points in ordination space represent individual wetland sites).

Hydrogeomorphic Model Analysis

FCI scores were calculated for all 20 wetlands using six wetland functions and formulas in the HGM model (Table 3). The six functions defined by the model include: (1) water storage; (2) groundwater recharge; (3) retention of particulates; (4) removal, conversion, and sequestration of dissolved substances (biogeochemical processes); (5) plant community resilience and carbon cycling; and (6) provision of faunal habitat. FCI scores ranged from 0.55-0.93. The results of the tests for the functions found that comparisons between high impact and low impact were not significantly different except for HGM 6 (p=0.01).

Table 3. Hydrogeomorphic Model scores for high impact and low impact sites.

	Site	HGM1	HGM 2	HGM 3	HGM 4	HGM 5	HGM 6
High Impact	I2	0.801	0.747	0.897	0.782	0.796	0.755
	I3	0.776	0.768	0.830	0.766	0.791	0.800
	I5	0.635	0.598	0.790	0.580	0.596	0.621
	I11	0.662	0.605	0.834	0.655	0.682	0.614
	I17	0.664	0.667	0.625	0.775	0.776	0.705
	I18	0.747	0.736	0.848	0.728	0.777	0.744
	I19	0.810	0.754	0.928	0.792	0.811	0.794
	I20	0.795	0.667	0.867	0.766	0.752	0.669
	I21	0.796	0.755	0.838	0.748	0.759	0.721
	I27	0.615	0.631	0.678	0.553	0.557	0.545
Low Impact	U17	0.805	0.786	0.914	0.800	0.821	0.808
	U24	0.738	0.718	0.781	0.785	0.798	0.800
	U27	0.796	0.750	0.895	0.775	0.800	0.814
	U40	0.810	0.733	0.888	0.785	0.777	0.766
	U135	0.697	0.680	0.702	0.745	0.766	0.767
	U163	0.721	0.680	0.749	0.783	0.793	0.786
	U165	0.758	0.662	0.803	0.770	0.792	0.802
	U172	0.731	0.677	0.769	0.776	0.788	0.756
	U210	0.801	0.683	0.918	0.798	0.817	0.808
	U214	0.805	0.679	0.849	0.759	0.732	0.724

Index of Plant Community Integrity Analysis

IPCI results of the 10 high impact wetlands indicate that: 1 (10%) is in Very good condition; 3 (30%) are in Good condition; 5 (50%) are in Fair condition; 1 (10%) is in Poor condition; and there were 0 (0%) in Very Poor condition (Table 4). IPCI results of the 10 low impact wetlands indicate that: 2 (20%) are in Very Good condition; 4 (40%) are in Good condition; 3 (30%) are in Fair condition; 1 (10%) is in Poor condition; and there were 0 (0%) in Very Poor condition. There was no significant difference between IPCI scores of high impact and low impact (p>0.05) (Figure 16).

Table 4. Index of Plant Community Integrity final scores and condition.

Site: High Impact	Score	Condition Category	Site: Low Impact	Score	Condition Category
I2	80	Very Good	U17	79	Good
I3	48	Fair	U24	80	Very Good
I5	65	Good	U27	73	Good
I11	50	Fair	U40	27	Poor
I17	69	Good	U135	77	Good
I18	62	Good	U163	72	Good
I19	61	Good	U165	77	Good
I20	54	Fair	U172	80	Very Good
I21	72	Good	U210	55	Fair
I27	31	Poor	U214	51	Fair

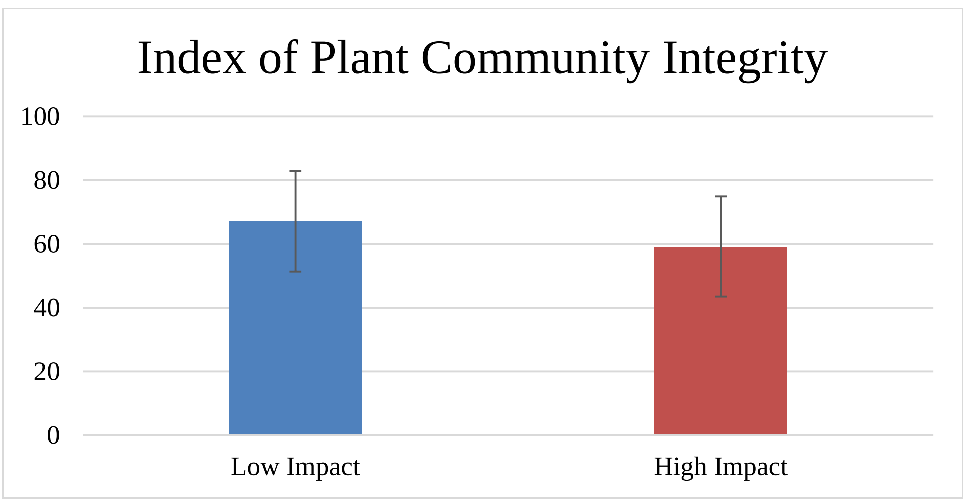


Figure 16. Comparison of IPCI high impact site average with low impact site average.

North Dakota Rapid Assessment Method Analysis

NDRAM results of the 10 high impact wetlands indicate that: 0 (0%) are in Good condition; 4 (40%) are in Fair High condition; 6 (60%) are in Fair Low condition; and 0 (0%) are in Poor condition (Table 5). NDRAM results of the 10 low impact wetlands indicate that: 2

(20%) are in Good condition; 8 (80%) are in Fair High condition; 0 (0%) are in Fair Low condition; and 0 (0%) are in Poor condition. The NDRAM scores for the low impact were significantly higher compared to high impact sites (p=0.001) (Figure 17).

Table 5. North Dakota Rapid Assessment Method final scores and condition.

Site: High Impact	Score	Condition Category	Site: Low Impact	Score	Condition Category
I2	63	Fair High	U17	59	Fair High
I3	52	Fair Low	U24	69	Good
I5	34	Fair Low	U27	71	Good
I11	58	Fair High	U40	57	Fair High
I17	47	Fair Low	U135	62	Fair High
I18	46	Fair Low	U163	67	Fair High
I19	38	Fair Low	U165	62	Fair High
I20	57	Fair High	U172	67	Fair High
I21	56	Fair High	U210	54	Fair High
I27	44	Fair Low	U214	57	Fair High

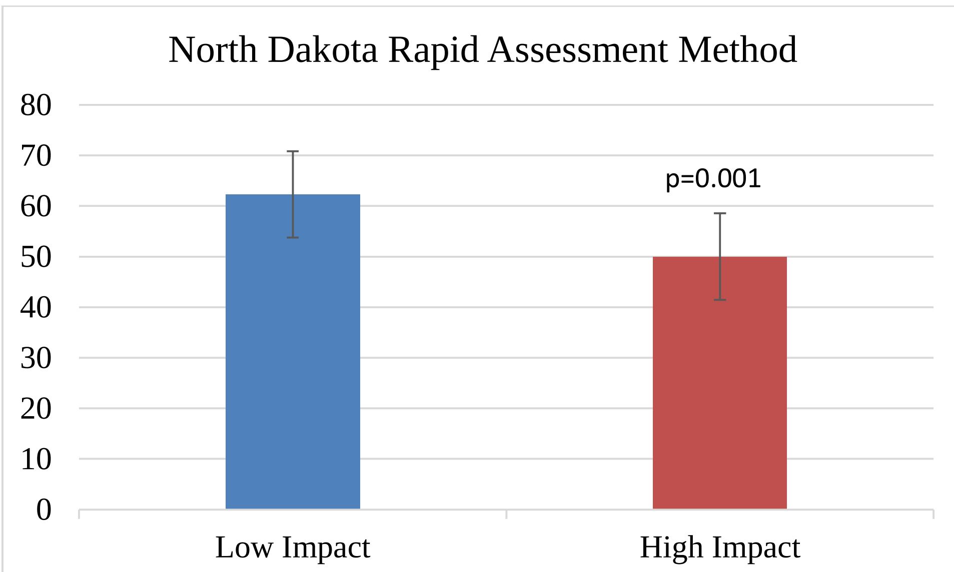


Figure 17. Comparison of NDRAM high impact site average with low impact site average.

DISCUSSION

Dust creation is a natural process, but there are certain conditions that produce more dust. The current influx of people and increased energy development in western ND create those conditions. There was more dust loading occurring within the high impact sites than the low impact sites by overall loading, distance, and season.

The high impact sites dust loading showed a significant difference among the different distances of 10 m, 40 m, and 80 m from the centerline of the road when compared to the low impact sites. Even though there was a significant difference between high and low impact sites the dust was much higher at the 10 m sampler and dropped off quickly the greater distance from the road. At the 10 m distance there was a 228% increase in dust or an additional 450 g/m^2 (0.45 kg or 1 lb) of dust loaded from April to October. At the further distances increased dust loading was less: 1) 40 m, 33% increase or 51 g/m^2 April – October; and 2) 80 m, 29% increase or 39 g/m^2 April – October. Other dust studies show a similar decrease in dust loading with distance (Tamm and Troedsson 1955, Alexander and Miller 1978, Everett 1980, Komarkova 1985, Walker and Everett 1987). Even though this study did not look at the chemical constituents of the dust, it is interesting to note that other studies have observed that along with an increase in dust loading closest to the road, the concentration of certain elements is also higher and decreases quickly with distance (Dale and Freedman 1982, Benfenati et al. 1992, Farmer 1993, Auerbach et al. 1997).

The summer months proved to have the greatest dust loading when compared by season. Other studies have found similar results in that summer was the time of year when the most road dust was created (Tamm and Troedsson 1955, Everett 1980, Tanaka and Chiba 2006). This makes sense as summer is the most arid time of year. Fall, spring and winter tend to have more precipitation and water on the surface of roads in the form of rain, snow, or ice that will help minimize the dust (Everett 1980, NDAWN 2014).

This study did not look specifically at dust abatement; however, one of the study sites (HI5) was abated with dust during the sampling period. Even with the abated site included in the high impact sites, the analysis showed no outliers within the data set. The abated site average dust loading was slightly lower than the overall high impact average, but it was still higher than the low impact sites. We are unsure what abatement techniques were used on the site during the study period, but abatement techniques currently being tested/used in ND include: calcium chloride; magnesium chloride; Durablend; WISP; Rhino Snot; Coherex; Durabond; freshwater; crude oil; oil field produced salt water (brine water) in varying concentrations; and native clay (Schwindt 2013).

Based on GIS data and a short site visit it is difficult to determine sites that will hold water throughout the year. PPR wetlands are complex systems and water tables in these settings are hard to predict as many factors including hydrologic setting, topographic location, climactic changes, soils, and vegetation all play a part in the amount of standing water and water quality at a site at any given time (USGS 1996, Rosenberry and Winter 1997). Therefore, seasonal sites were chosen and it was researchers' intent that sites would hold water into the fall season. However, in 2012 due to dry conditions six of the ten high impact sites dried up in the fall.

Overall, the water quality data showed small differences between the high and low impact sites, but there were certain measurements that were accounting for the spread in the data. The spread for the water quality data was driven by total dissolved solids, conductivity, sulfates, hardness, magnesium, calcium and sodium in the high impact area. Fluctuations in these factors are greatly affected by changes in precipitation, hydrology, and landscape position (USGS 1996, Rosenberry and Winter 1997). These changes are naturally occurring as one goes further west in the state of ND. Given that there is a 40 km range from east to west in the sites selected, the fact that there is a noticeable change in these factors between sites is not surprising. It is interesting to note that if dust was a main factor impacting the wetland one could speculate that Chlorophyll A and B (as indicators of photosynthetic rate) should be impacted. However, analysis of the results did not show that there was a difference in Chlorophyll A and B between the high and low impact sites. In the Everett (1980) study researchers found that chlorophyll and photosynthetic rates were lowest where road dust was heaviest. At this time it is unclear if the dust had an effect on water quality. More research would be needed in the future, as the dust impacts accumulate, to determine if the water quality parameters driving the data could be attributed to dust or to precipitation changes, hydrology, and general landscape position. Future research could also include sediment core samples taken throughout the year to quantify and/or identify the dust and other materials that settle in wetlands. Water samples taken as part of this project were surface water samples taken in an undisturbed area of the wetland according to NDDoH wetland sampling protocol. Much of the dust that enters the wetland through the water column settles to the bottom.

The soil data showed no significant difference between the top 0-0.5 cm of soil (most affected by dust) and the 5-6 cm of soil (resident soil) that was sampled. This would indicate that at this time dust is not the main factor driving changes in the soil data or that the dust had similar concentrations of elements as the resident soil. There was a stronger correlation between years than there was between high and low impact sites. The soil data differences driving the data were EC, sulfur, and BD. These are all factors in wetlands that can be affected by both landscape position and precipitation differences (Miller et al. 1981, Richardson and Bigler 1984, Rosenberry and Winter 1997). Therefore, it is most likely that the changes in soil data are due to the precipitation differences between 2012 and 2013 and the difference in landscape position at the sites rather than dust.

Another factor that may have contributed to differences in water quality and soil data are the difference in site locations in the two different sub-ecoregions. The MC, which is east of the MSC, has a higher concentration of depressional wetlands. The MSC has a more gently rolling topography and a different drainage pattern (Bryce et al. 1998). The slight differences in soils, topography, landscape position, and hydrology between sites in the different sub-ecoregions may have also contributed to differences in soil and water quality data.

Looking at wetland function, out of FCI's 1-6, the HGM only showed a slight difference in FCI 6 between high impact sites and low impact sites. FCI 6 evaluates the ability of the wetland to provide habitat for aquatic and terrestrial invertebrate and vertebrate species during some portion of their life cycle (Gilbert et al. 2006). The ability of a wetland to provide habitat changes seasonally and yearly depending upon different factors such as water table and vegetation. While there is a difference in the wetlands ability to provide faunal habitat between high and low impact sites there are no other differences in function between the high and low sites. It is unlikely that dust contributed to this difference between high and low sites. It is most likely a factor of site selection. For this study sites were randomly selected within areas of high impact and low impact. In general some of those wetlands will be in better condition and/or function than other wetlands. The differences between high and low impact sites can be attributed to differences in individual wetlands due to random site selection rather than an impact from dust.

The IPCI showed little difference in vegetation between the study areas and no significant differences were found between high and low impact sites. This study was only done during a two-year period so distinct changes would not be likely. Since energy development is relatively new changes in vegetation are not likely, changes in vegetation may not be seen for decades (Walker and Everett 1987).

The NDRAM showed the low impact sites are in slightly better condition than the high impact sites. The NDRAM is a more subjective measurement of condition as it only takes approximately 20 minutes to conduct and relies very heavily on best professional judgment. Therefore, differences seen in the results between high and low impact sites may have seemed larger at a quick glance than when the wetland was fully surveyed. Also, as with the other condition and function measurements used in this study, wetland selection is probably the main reason for the differences between high and low impact sites.

MANAGEMENT IMPLICATIONS

The oil boom in western ND has brought with it traffic increases that may be the new normal. With the increased traffic there will inevitably be increased dust created on roadways. It is important to understand how much dust is being created, what is in the dust, and the impacts on the environment so we can learn to manage the issue. This study took the first steps to understanding dust by determining that dust is significantly higher in areas of increased travel from energy development (high impact sites) when compared to typical western ND travel without energy development (low impact sites). The amount of dust created is most significant next to the road and then tapers off farther from the road; however, even at 80 m from the road there is still significantly more dust at high impact sites than low impact sites. Also, there is significantly more dust created in the summer months than in the spring and fall.

The effects to wetlands from dust are minimal, if any at this time. There was little difference in condition and function between the high and low impact sites; and the difference that did exist can be attributed to random site selection. Water quality and soil analysis showed that the changes in precipitation between 2012 (dry) and 2013 (exceptionally wet) had a larger effect on water quality and soil than did dust. However, the increased travel is relatively new. It could take years to show effects from dust on wetlands such as sedimentation and changes to vegetation, function, and condition.

There are already efforts underway to determine how to mitigate (abatement) the amount of dust that is created. Water and magnesium chloride is one of the most common abatement measures used; and there are efforts underway to determine the effectiveness of oil produced water "brine" as an abatement technique (Goodrich et al. 2009). Continued research on these abatement methods will be important to understand what the safest and most effective methods are for controlling dust.

The current study was conducted based on concern voiced by citizens in western ND on the amount of road dust being produced. Citizens' were concerned over impacts to crops, grasses being fed to cattle, and human and animal health. While the current study didn't address these issues, they are issues that should be researched to determine the actual impact of road dust. According to the Environmental Protection Agency, dust particles as large as 10 micrometers in size can be harmful to human health, but fine particles smaller than 2.5 micrometers pose the greatest threat (EPA 2014). These small particles contain microscopic solids can cause serious health issues by imbedding deep in lung tissue. Some of the health issues include aggravated asthma, irregular heartbeat, decreased lung function and increased respiratory symptoms. Children, older adults and people with lung or heart disease are more likely to be affected by these particles (EPA 2014).

Many local ranchers hay road ditches as feed for livestock. The road ditch always falls within 10-15m of the road where dust loading is the greatest. The potential effects of livestock consuming dusty vegetation is unknown and should be researched further. It is also important to understand the effects of dust on crop production in the 100m adjacent to the unpaved roads. Road dust could potentially reduce: biomass; grass and seed components including crude protein; and yield which farmers depend on for their income and livelihood.

Future research is needed to more fully understand road dust, its impact on the environment, and how to better control it. This project was a snapshot in time. Research to determine the changes over a longer period of time (5-10+ years) would be important to see how wetland condition and function are affected by dust in the long term. Also, more research is needed on dust quantity and constituents. This project took place in one area of energy development; the Bakken in ND alone covers over 62,000 km (American Petroleum Institute 2008). It is important to expand this research to more areas to determine the amount of dust that is being created on a larger scale. Information from this study can be used as baseline data on the effects of dust to wetlands and also to help guide decision makers on the best ways to deal with road dust.

LITERATURE CITED

Adamus, P.R. 1996. Bioindicators for assessing ecological integrity of prairie wetlands. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Western Ecology Division, Corvallis, OR, USA. EPA/600/R-96/082.

Alexander, V. and M.C. Miller. 1978. Effects of the pipeline haul road on nearby ponds and lakes across Alaska's North Slope. Annual Progress Report, U.S. Energy Research and Development Administration Report No. RLO 2229-T9-2. pp. 51.

American Petroleum Institute. 2008. Strategic energy resources: Bakken Shale, ND. Exploring for America's Future API Article Winter 2008. http://www.api.org/~/media/Files/Policy/Exploration/Energy-Resources/StrategicEnergyResources-BakkenShale.pdf. [Accessed on 24 July 2014]

Auerbach, N.A., M.D. Walker, and D.A. Walker. 1997. Effects of roadside disturbance on substrate and vegetation properties in arctic tundra. Ecological Applications 7:218-235.

Bakken Shale: News, Marketplace, Jobs. 2014. URL http://bakkenshale.com/ [Accessed on 28 June 2014]

Barker, W.T. and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10: 266-272.

Barker, W.T. and W.C. Whitman. 1989. Vegetation of the Northern Great Plains. North Dakota State University, Agriculture Experiment Station Research Report No. 111. Fargo, ND. Rangelands 10: 266-272.

Benfenati, E., S. Valzacchi, G. Mariani, L. Airoldi, R. Fanelli. 1992. PCDD, PCDF, PCB, PAH, 56ty cadmium and lead in roadside soil: relationship between road distance and concentration. Chemosphere 24: 1007-1083.

Brown, K. J. 1994. River-bed sedimentation caused by off-road vehicles at river fords in the Victorian Highlands, Australia. Journal of the American Water Resources Association, 30: 239–250. doi: 10.1111/j.1752-1688.1994.tb03287.x

Bryce, S., J.M. Omernik, D.E. Pater, M. Ulmer, J. Schaar, J. Freeouf, R. Johnson, P. Kuck, and S.H. Azevedo. 1998. Ecoregions of North Dakota and South Dakota. Jamestown, ND: Northern Prairie Wildlife Research Center Online. URL http://www.npwrc.usgs.gov/resource/habitat/ndsdeco/index.htm [accessed on 15 April 2014]

Craft, C.B. and W.P. Casey. 2000. Sediment and nutrient accumulation in floodplain and depressional freshwater wetlands of Georgia, USA. Wetlands 20(2):323-332.

Cramer, G.H. II and W.C. Hopkins Jr. 1982. Effects of Dredged Highway Construction on Water Quality in a Louisiana Wetland. Transportation Research Record 896: 47–51.

Dale, J.M. and B. Freedman. 1982. Lead and Zinc contamination of roadside soil and vegetation in Halifax Nova Scotia. Proceedings of the Nova Scotian Institute of Science 32: 327-336.

DeKeyser, E.S. 2000. A vegetative classification of seasonal and temporary wetlands across a disturbance gradient using a multimetric approach. Ph.D. Dissertation. North Dakota State University, Fargo, ND.

DeKeyser, E.S., D.R. Kirby, and M.J. Ell. 2003. An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. Ecological Indicators 3:119-133.

DeKeyser, E.S., M. Meehan, G. Clambey, and K. Krabbenhoft. 2013. Cool season invasive grasses in Northern Great Plains natural areas. Natural Areas Journal 33(1):81-90.

DeKeyser, S., M. Meehan, K. Sedevic, and C. Lura. 2010. Potential management alternatives for invaded rangelands in the Northern Great Plains. Rangelands 32(5):26-31.

Detenbeck N.E., C.M. Elonen, D.L. Taylor, A.M. Cotter, F.A. Puglisi, and W.D. Sanville. 2002. Effects of agricultural activities and best management practices on water quality of seasonal prairie pothole wetlands. Wetlands Ecology and Management 10:335-354.

EPA. United States Environmental Protection Agency. 2014. URL http://www3.epa.gov/pm/health.html [Accessed on June 2014]

Euliss Jr., N.H. and R.A. Gleason. 1997. Standard operating procedures: Extensive variables for study plan 168.01: Evaluation of restored wetlands in the Prairie Pothole Region of the United States (Draft). U.S. Geological Survey, Biological Resources Division, Northern Prairie Wildlife Research Center, Jamestown, N.D.

Everett, K.R. 1980. Distribution and properties of road dust along the northern portion of the Haul Road. Environmental Engineering and Ecological Baseline Investigations along the Yukon River-Purdhoe Bay Haul Road. US Army Cold Regions Research and Engineering Laboratory. CCREL Report 80-19 pp. 101-128.

Farmer, A.M. 1993. The effects of dust on vegetation – a review. Environmental Pollution 79:63-75.

Field, J. P., J. Belnap, D.D. Breshears, J.C. Neff, G.S. Okin, J.J. Whicker, T.H. Painter, S. Ravi, M.C. Reheis, and R.L. Reynolds. 2009. The ecology of dust: Frontiers in Ecology and the Environment 8:423-430.

Findlay, C.S. and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation Biology 11:1000-1009.

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207-231.

Gardiner, D.T. and R.W. Miller. 2004. Soils in our environment. Pearson Education, Inc. Upper Saddle River, NJ.

Gilbert, M.C., P.M. Whited, E.J. Clairain, Jr., and R.D. Smith. 2006. A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of prairie potholes. US Army Corps of Engineers. Omaha, NE. 114 pp. + app.

Gillies, J.A., V. Etyemezian, H. Kuhns, D. Nikolic, and D.A. Gillette. 2005. Effect of vehicle characteristics on unpaved road dust emissions. Atmospheric Environment 39:2341-2347.

Gleason, R.A., and N.H. Euliss, Jr. 1998. Great Plains Research: A Journal of Natural and Social Sciences. Paper 363.

Goodrich, B.A., R.D Koski, & W. R. Jacobi, 2009. Monitoring surface water chemistry near magnesium chloride dust suppressant treated roads in Colorado. Journal of Environmental Quality. 38: 2373-2381.

Gotelli, N. J. and A. M. Ellison. 2004. A Primer of Ecological Statistics. Sinauer Associates, Sunderland, Massachusetts

Great Plains Flora Association. 1986. Flora of the Great Plains. University Press of Kansas. Lawrence, Kansas. 1402 pp.

Guntenspergen, G.R., S.A. Peterson, S.G. Leibowitz, and L.M. Cowardin. 2002. Indicators of wetland condition for the Prairie Pothole Region of the United States. Environmental Monitoring and Assessment 78:229-52.

Guy, A.C., T.M. DeSutter, F.X.M. Casey, R. Kolka, and H.Hakk. 2012. Water quality, sediment, and soil characteristics near Fargo-Moorhead urban areas as affected by major flooding of the Red River of the North. Journal of Environmental quality. 41:554-563.

Hargiss, C.L.M. 2009. Estimating wetland quality for the Missouri Coteau ecoregion in North Dakota. Ph.D. Dissertation. North Dakota State University, Fargo, ND.

Hargiss, C.L.M., E.S. DeKeyser, D.R. Kirby, and M.J. Ell. 2008. Regional assessment of wetland plant communities using the index of plant community integrity. Ecological Indicators 8:303-307.

Hopkins, C.S., Jr. 1992. A comparison of ecosystem dynamics in freshwater wetlands. Estuaries 15:549-562.

Johnson, R.R., and K.F. Higgins. 1997. Wetland resources of eastern South Dakota. South Dakota State University. Brookings, SD, USA.

Jones, J.A., F.J. Swanson, B.C. Wemple, and K.U. Snyder. 2000. Effects of roads on hydrology, geomorphology and disturbance patches in stream networks. Conservation Biology 14:76-85.

Jurik, T.W., S-C. Wang, and AG. Van der Valk. 1994. Effects of sediment load on seedling emergence from wetland seed banks. Wetlands 14:159-165.

Kantrud, H.A. and W.E. Newton. 1996. A test of vegetation-related indicators of wetland quality in the Prairie Pothole Region. Journal of Aquatic Ecosystem Health 5:177-191.

Komarkova, V. 1985: Vegetation changes on road disturbances along the Dalton Highway, 1977-1983. In Webber, P. J., Walker, D. A., Komarkovai, V., and Ebersole, J. J., Base-line monitoring methods and sensitivity analysis of Alaskan arctic tundra. Final report to U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH 03755. Contract no. DACA89-81-K-006, Attachment A. 19 pp. plus appendices.

Kruskal, J.B. 1964. Nonmetric multidimensional scaling: a numerical method. Psychometrika 29:115-129.

Lancaster, N. 2009. Aeolian features and processes. Geologic Society of America. P 1-25 doi: 10.1130/2009.monitoring(01).

Larson, G.E. 1993. Aquatic and wetland vascular plants of the Northern Great Plains. USDA Forest Service, General Technical Report RM-238. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO., 681 pp. + Ill.

Luoma, J.R. 1985. Twilight in pothole country. Audubon 87(5):66-85.

Mather, P.M. 1976. Computational methods of multivariate analysis in physical geography. J. Wiley & Sons, London. 532pp.

McCune, B. and M. J. Mefford. 2011. PC-ORD. Multivariate Analysis of Ecological Data. Version 6. MjM Software, Gleneden Beach, Oregon, U.S.A.

McCune, B., and J.B. Grace, with a contribution from D.L. Urban. 2002. Analysis of Ecological Communities. MjM Software Desgin. Gleneden Beach, OR. 299 pps.

Miller, M.R., P.L. Brown, J.J. Donovan, R.N. Bergatino, J.L Sonderegger, and F.A Schmidt. 1981. Saline seep development and control in the North American Great Plain – hydrogeological aspects. Agricultural Water Management 4:115-141.

Mitsch, W.J. and J.G. Gosslink. 2007. Wetlands. John Wiley & Sons, Inc. Hoboken, NJ.

Moorhead, D.L., A.E. Linkins and K.R. Everett. 1996. Road dust alters extracellular enzyme activities in tussock tundra soils, Alaska, USA. Arctic and Alpine Research 28:346-351.

Murphy, E. C. 2013. Clinker ("scoria") as Road Surfacing Material in Western North Dakota. NDGS Newsletter. 40(1):2-4.

Muskett, C.J. and M.P. Jones. 1981. Soil respiratory activity in relation to motor vehicle pollution. Water, Air, Soil Pollution (Neth.) 15:329-342.

National Climatic Data Center staff, National Oceanic and Atmospheric Administration. Updated 15 May 2013. URL http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/palmer.html [Accessed on 7 June 2014]

NDAWN. 2014. North Dakota Agricultural Weather Network Homepage. URL http://ndawn.ndsu.nodak.edu/ [Accessed on 12 January 2014]

ND GIS. North Dakota Geographical Information System Hub. 2012. URL https://www.nd.gov/itd/statewide-alliances/gis/maps-and-data [Accessed on 20 May 2012]

Neff, J.C., A.P. Ballantyne, G.L. Famer, N.M. Mahowald, J.L. Conroy, C.C. Landry, J.T. Overpeck, T.H. Painter, C.R. Lawrence and R.L. Reynolds. 2008. Increasing eolian dust deposition in the western United States linked to human activity. Nature-Geosciences 1:189-195. doi:10.1038/ngeo133

Pye, K. Aeolian dust and dust deposits. 1987. Academic Press:London.

Reed, P.B., Jr. 1988. National list of plant species that occur in wetlands: Northern Plains (Region 4). U.S. Department of the Interior, Fish and Wildlife Service. Washington, D.C. Biological Report 88(26.4).

Reid, L.M. and T. Dunne. 1984. Sediment production from forest road surfaces. Water Resources Research 20(11):1753-1761.

Richardson, J.L. and M.J. Vepraskas. 2001. Wetland soils: genesis, hydrology, landscapes, and classification. Lewis Publishers. Boca Raton, FL. 417 pps.

Richardson, J.L. and R.J. Bigler. 1984. Principal component analysis of prairie pothole soils in North Dakota. Soil Science Society of America Journal 48:1350-1355.

Richardson, J.L., J.L. Arndt, and J. Freeland. 1994. Wetland soils of the prairie potholes. Advances in Agronomy 52:121-171.

Rosenberry, D.O., and T.C. Winter. 1997. Dynamics of water-table fluctuations in an upland between two prairie-pothole wetlands in North Dakota. Journal of Hydrology 191:266-289.

Santelmann, M. and E. Gorham. 1988. The influence of airborne road dust on the chemistry of Sphagnum mosses. Journal of Ecology 76:1219-1231.

Schwindt, F. 2013. Investigation of methodologies to control dust on county roads in western North Dakota; Dunn and McKenzie counties. Draft Final Report for Contract No. G025-054 for the Industrial Commission of North Dakota.

Smith, P.W., E.J. Depuit, and B.Z. Richardson. 1988. Plant community development on petroleum drill site in northwestern Wyoming. Journal of Range Management 41:372-377.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. URL http://websoilsurvey.nrcs.usda.gov/ [Accessed on 2 June 2014]

Stetler, L.D. and J.J. Stone. 2008. Human health impacts from surface dust near abandoned uranium mines in Harding Co., South Dakota. Proceedings of the South Dakota Academy of Science 87:237-247.

Tamm, C.O. and T. Troedsson. 1955. An example of the amounts of plant nutrients supplied to the ground in road dust. Oikos. 6:61-70.

Tanaka, T.Y. and M. Chiba. 2006. A numerical study of the contributions of dust source regions to the global dust budget. Global Planetary Change 52:88–104.

The Northern Prairie Great Plains Floristic Quality Assessment Panel. 2001. Coefficients of conservatism for the vascular flora of the Dakotas and adjacent grasslands: U.S.

Thompson, J.R., P.W. Mueller, W. Fluckiger, and A.J. Rutter. 1984. The effect of dust on photosynthesis and its significance for roadside plants. Environmental Pollution 34:171-190.

Tolliver, D. (2014) Transportation systems for oil & gas development: case study of the Bakken Shale. NDSU Upper Great Plains Transportation Institute, 93rd Annual Meeting of the Transportation Research Board. URL: http://cta.ornl.gov/TRBenergy/trb_documents/2014 _presentations/238_Tolliver.pdf. [Accessed 3 Apr 2015]

Tong, S.T.Y. 1990. Roadside dusts and soils contamination in Cincinnati, Ohio, USA. Environmental Management 14:107-113.

Tworkowski, T.J., D.M. Glenn, and G.J. Puterka. 2002. Response of bean to applications of hydrophobic mineral particles. Candian Journal of Plant Sciences 82:217-219.

United State Geological Survey. 1996. National Water Summary on Wetland Resources. USGS Water-Supply Paper 2425.

USDA, NRCS. 2008. The PLANTS Database URL http://plants.usda.gov [Accessed on 5 May 2014]

USDA-NRCS Soil Survey Division. 1998a. Official Series Description – Williams Series. URL http://www2.ftw.nrcs.usda.gov/osd/dat/W/WILLIAMS.html [Accessed on 7 June 2014]

USDA-NRCS Soil Survey Division. 1998b. Official Series Description – Zahl Series. URL http://www2.ftw.nrcs.usda.gov/osd/dat/Z/ZAHL.html [Accessed on 7 June 2014]

USDA-NRCS Soil Survey Division. 1998c. Official Series Description – Bowbells Series. URL http://www2.ftw.nrcs.usda.gov/osd/dat/B/BOWBELLS.html [Accessed on 7 June 2014]

USDA-NRCS Soil Survey Division. 2003. Official Series Description – Parnell Series. URL http://www2.ftw.nrcs.usda.gov/osd/dat/P/PARNELL.html [Accessed on 7 June 2014]

USDA-NRCS Soil Survey Division. 2005a. Official Series Description – Max Series. URL https://soilseries.sc.egov.usda.gov/OSD_Docs/M/MAX.html [Accessed on 7 June 2014]

USDA-NRCS Soil Survey Division. 2005b. Official Series Description – Barnes Series. URL https://soilseries.sc.egov.usda.gov/OSD_Docs/B/BARNES.html [Accessed on 7 June 2014]

USDA-NRCS Soil Survey Division. 2005c. Official Series Description – Buse Series. URL http://www2.ftw.nrcs.usda.gov/osd/dat/B/BUSE.html [Accessed on 7 June 2014]

USDA-NRCS Soil Survey Division. 2014. Official Series Description – Svea Series. URL https://soilseries.sc.egov.usda.gov/OSD_Docs/S/SVEA.html [Accessed on 7 June 2014]

van der Valk, A.G. 1989. Northern Prairie Wetlands. Iowa State University Press. Ames, IA.

Walker, D.A. and K.R. Everett. 1987. Road dust and its environmental impact on Alaskan taiga and tundra. Arctic and Alpine Research 19(4):479-489.

Walker, D.A., P.J. Webber, E.F. Binnian, K.R. Everett, N.D. Lederer, E.A. Nordstrand, and M.D. Walker. 1987. Cumulative impacts of oil fields on Northern Alaskan landscapes. Science 238:757-761.

Wardrop, D.H., M.E. Kentula, S.F. Jensen, D.L. Stevens, Jr., K.C. Hychka, and R.P. Brooks. 2007. Assessment of wetlands in the Upper Juniata watershed in Pennsylvania, USA, using the hydrogeomorphic approach. Wetlands 27:432-445.

Zhia-Khan, S., W. Spreer, Y. Pengnian, Z. Zhao, H. Othmanli, X. He, and J. Muller. 2015. Effect of dust deposition on stomatal conductance and leaf temperature of cotton in northwest China. Water 7:116-131.

APPENDIX A. STUDY SITES, LEGAL DESCRIPTION, COUNTY, STATE, AND GPS LOCATION

ID*	Section	Township	Range	County	State	GPS Location of Center Point**
HI2	16	153	91	Mountrail	ND	X -102.389797 Y 48.080952
HI3	23	154	90	Mountrail	ND	X -102.224232 Y 48.140605
HI5	14	154	90	Mountrail	ND	X -102.215374 Y 48.153613
HI11	12	152	91	Mountrail	ND	X -102.278652 Y 48.002077
HI17	2	153	90	Mountrail	ND	X -102.2238 Y 48.099231
HI18	13	153	92	Mountrail	ND	X -102.439954 Y 48.075061
HI19	23	154	90	Mountrail	ND	X -102.224228 Y 48.149442
HI20	25	152	91	Mountrail	ND	X -102.273911 Y 47.959115
HI21	13	153	92	Mountrail	ND	X -102.440162 Y 48.077976
HI27	36	154	90	Mountrail	ND	X -102.202615 Y 48.110648
LI17	4	154	86	Ward	ND	X -101.7279 Y 48.194266
LI24	29	153	85	Ward	ND	X -101.630334 Y 48.051813
LI27	3	155	87	Ward	ND	X -101.857883 Y 48.280315
LI40	17	154	85	Ward	ND	X -101.641833 Y 48.155367
LI135	15	152	86	Ward	ND	X -101.678808 Y 47.987933
LI163	10	153	87	Ward	ND	X -101.836175 Y 48.090296
LI165	8	153	87	Ward	ND	X -101.900492 Y 48.082913
LI172	1	153	85	Ward	ND	X -101.537852 Y 48.096187
LI210	23	155	87	Ward	ND	X -101.814597 Y 48.237136
LI214	11	152	86	Ward	ND	X -101.641554 Y 47.992801

APPENDIX B. STANDARD OPERATING PROCEDURES FOR THE COLLECTION AND PRESERVATION OF WADABLE WETLAND WATER COLUMN SAMPLES FOR CHEMICAL ANALYSIS AND PARAMETERS MEASURED

Summary

Water column samples of shallow wetlands should be reflective of the whole wetland. To be representative of the entire wetland, samples must be carefully collected, properly preserved, and appropriately analyzed.

Generally, one sample is collected from the wetlands deepest most open area in the largest aquatic zone present. Shallow wetlands are waded or canoed for sample collection. Care must be taken to sample undisturbed water not influenced by bottom sediments stirred up by mucking about. This often requires collecting a mobile sample where the sampler continues to move in a forward direction away from the sediment plume.

Equipment and Supplies

Life Vest
Vest or other garment large enough to carry sampling supplies
Waders
Sample containers.
Acid for sample preservation.
Sample labels.
Coolers with ice or frozen gel packs.
Deionized water for sample blanks and decontamination.
Filter apparatus.
For vacuum method.
Vacuum filter holder.
Vacuum pump.
0.45 µm membrane filters (Millipore HAWP 047 00 or equivalent).
Pre-filters (Millipore AP40 0047 05 or equivalent).
Stainless steel forceps.
For peristaltic method.
Power Drive (Compact Cat No. P-07533-50 or equivalent)
Paristalic head (Easy Load II Cat No. P-77200-62 or equivalent).
In-line 0.45 µm cartridge filters (Geotech dispos-a-filter or equivalent).
In-line 5.0 µm cartridge pre-filters (Geotech dispos-a-filter or equivalent).
Tubing (Masterflex silicone Cat No. P-96400-24 or equivalent).
Churn Splitter.
Field report form.
Sample ID/Custody Record.
Black ballpoint pen or mechanical pencil.
Sample and blank log forms.
Power ice auger (winter sampling).
Ice skimmer (winter sampling).
Sled (winter sampling).

Procedure

Following collection of the temperature/dissolved oxygen concentration(s), collect sample at fifty percent of the water depth.

Triple rinse each sample bottle three times using water from below the surface. This is accomplished by leaving the lid on the bottle, inserting to the correct depth, removing the lid and allowing the bottle to fill with no forward motion.

The sample is collected at fifty percent the total water depth using the same method as described in step 2.

Preserve the nutrient samples to a pH of ≤ 2 with 2 ml 1/5th sulfuric. Preserve the ICP metals or ICP and Trace metals samples to a pH of 2 with 2 ml concentration nitric acid. Note: Do not preserve the total dissolved phosphorus sample until after filtration which will be accomplished on shore.

Place a label on each sample container (Figure 7.07.4). Each sample container should be labeled accordingly with the appropriate analyte group as indicated in Figure 7.07.2.

Place the samples in a cooler on ice.

Fill out the field report form (Figure 7.07.3), Sample ID/Custody Record (Figure 7.07.2), and the water column chemistry sample log (Figure 7.07.1).

Field Bottle Blank Sample Collection

1. Field bottle blank samples are collected with the first sample and every tenth sample (i.e., 1, 10, 20...).

2. Triple rinse each sample bottle using deionized water.

3. Fill each bottle with deionized water.

4. Preserve each sample appropriately. Note: Do not preserve the total dissolved phosphorus sample until after filtering.

5. Place a label on each sample container (Figure 7.07.4). Note: Field bottle blanks should be identified with STORET number 389990. Be sure to indicate on the label the lake name, associated site identification number and the depth of the sample being duplicated.

6. Place the sample in a cooler on ice.

Field Duplicate Sample Collection

1. Field duplicates are collected on the first sample and every tenth sample (i.e., 1, 10, 20....). If the sample log indicates a duplicate should be collected, follow the steps below.

2. Collect the sample following step (2) in the procedure for Field Sample Collection.

3. Place a label on each sample container (Figure 7.07.4). Note: Field sample duplicates should be identified with STORET number 389999. Be sure to indicate on the label the lake name, associated site identification number and the depth of the sample being duplicated.

4. Place the samples in a cooler on ice.

Field Sample Filtration Vacuum Method

1. Unpreserved total dissolved phosphorus samples should be filtered immediately.

2. Remove filter holder from the plastic bag and assemble.

3. Put on latex gloves

4. Rinse the filter apparatus three times with approximately 250 ml of deionized water each time.

5. Load a pre-filter in the filter apparatus and connect the vacuum pump.

6. Leach the filter twice with approximately 250 ml of deionized water.

7. Filter the sample through the pre-filter. Place the sample back into the sample container.

8. Remove the pre-filter from the filter apparatus and repeat step 4.

9. Load a 0.45 µm filter into the filter apparatus and connect the vacuum pump.

10. Repeat step 6.

11. Filter the sample through the 0.45 µm filter.

12. Triple rinse the sample container with deionized water.

13. Transfer the filtered sample back into the sample container.

14. Preserve the sample with 2 ml 1/5 sulfuric acid lowering the pH to 2 or less.

15. Place the preserved sample in the cooler on ice.

16. If additional samples require filtration, repeat steps 3 through 15.

<u>Field Sample Filtration Peristaltic Method</u>

Peristaltic filtration method is used to collect dissolved nutrient(s), dissolved mineral(s) and dissolved metal(s). The dissolved nutrient and/or dissolved mineral and metal samples should be filtered and preserved immediately upon reaching shore.

Rinse a churn splitter three (3) times with water from the sampling depth.

Fill churn splitter with water from the appropriate depth. Note: This often requires taking a 500 or 1000 ml bottle along and filling and emptying it into the churn splitter multiple time until full.

Assemble and attach pump head to power drive.

Plug in power drive.

Put on latex gloves.

Remove acid rinsed tubing from plastic bag, taking care to prevent contamination and place in head draping a long end into the churn splitter and dangling the short end out of contact with anything.

Turn on pump and rinse tubing with a minimum of 250 ml of sample water from churn splitter.

As tubing rinses remove cartridge filter from plastic bag and insert cartridge while pump is still running. Care should be taken to ensure filter cartridge is inserted in the correct direction.

Run 250 ml of sample water through cartridge filter.

Place labels on bottles.

Triple rinse the sample bottles and lids with sample water coming out of the filter cartridge.

Fill sample bottles.

Preserve nutrient sample with 2 ml 1/5 sulfuric acid and ICP Metals or Trace metals with 2 ml concentrated nitric acid lowering the pH to 2 or less.

Place samples in the cooler on ice.

If cartridge becomes plugged, repeat steps 6 through 15 with an in-line 2.0 µm pre-filter placed between the pump and the in-line prior to the 0.45 µm filter.

Water Quality Field Log
North Dakota Department of Health
Division of Water Quality
Telephone: 701.328.5210
Fax: 701.328.5200

Sample No.	Storet No.	Location/ Comment	Depth	Date	Time	QA/QC		Observer
						DUP	BLK	

North Dakota Department of Health
Sample Identification Record
Division of Laboratory Services–Chemistry
Telephone: 701.328.6140
Fax: 701.328.6280

For Laboratory Use Only Lab ID:	
Preservation: Yes □	Temperature:
Initials:	

Surface Water Sample Identification Code R (Water samples)
Samples received without this sheet or without all necessary sections fully completed will be rejected and not analyzed.

Sample Collection/Billing Information			
Account #	**Project Code:**	**Project Description:**	
Customer (Name, Address, Phone): SWQMP, Division of Water Quality, Gold Seal Center, 4th Floor			
Date Collected:	**Time Collected:**	**Matrix:** Water	**Site ID:**
Site Description:			
Alternate ID:	**Collected By:**		
County Number:	**County Name:**		
Comment:			
Comment:			

Field Information/Measurements					
Sample Collection Method (Circle One): Grab DI* DWI** 0-2 meter column		**Depth:**	**Units:**	**Discharge:**	**Stage:**
Conductivity:	**pH:**	**Temp:**	**Dissolved O_2**	**Turbidity:**	
Comment:					

Analysis Requested			
☐ 5) SW-Major Cations/Anions	☐ 74) SW-PAHs	☐ 33120) SW-E. coli	
☐ 7) SW-Trace Metals	☐ 84) SW-PCBs	☐ SW-TOC	
☐ 21) SW-Carbamates	☐ 105) SW-Chlorophyll-a & b Volume	☐ SW-DOC	

	Filtered:________________mL		
□ 23) SW-Acid Herbicides	□ 118) SW-TSS	□ SW-C-BOD-5day	
□ 25) SW-Base/Neut. Pest	□ 144) SW-Trace Metals-dissolved	Other:	
□ 30) SW-Nutrients, Complete	□ 160) SW-Nutrients, Complete-dis		
□ 50) SW-Nutrients, Total P-dis.	□ 33080) SW-Fecal coliform bacteria		

North Dakota Department of Health
Division of Water Quality
Lake and Wetland Profile Field Log
Telephone: 701.328.5210
Fax: 701.328.5200

Project Code:		**Project Name:**	
Site Identification:		**Site Description:**	
Date: / /	**Time: :**	**Ambient Temp:**	**Wind Speed:**
Wind Direction:	**%Cloud Cover:**	**Secchi Disk:** (m)	**Baro:** (mm/Hg)
Chlorophyll-a:	**Phytoplankton:**	**Initial DO:**	**Final DO:**
Sample Depths:___________ Meters ___________		**Meters ___________ Meters ___________**	
Sampler(s):			
Comments:			

Depth (m)	Temp (c)	DO (Mg/L)	pH	Specific Conduct.	Comments

Project Code   Project Description

Sample ID   Site Description

Analysis: (DC Code)   SW-Analyte Group
Container: Preservative:
Date:_ /_ /_   Time:_ :_   Depth:
Sampler

Project Code   Project Description

389990   Field Bottle Blank Sample

Analysis: (DC Code)   SW-Analyte Group
Container: Preservative:
Date:_ /_ /_   Time:_ :_   Depth:
Sampler

Project Code   Project Description

389999   Duplicate Sample

Analysis: (DC Code) SW-Analyte Group
Container: Preservative:
Date:_ /_ /_   Time:_ :_   Depth:
Sampler

Table 2. Water Quality Monitoring Parameters

General Chemistry	Detection Limit	Trace Elements[1]	Detection Limit	Nutrients	Detection Limit
Sodium	3.00 mg/L	Aluminum	50 ug/L	Ammonia (Total)	0.030 mg/L
Magnesium	1.00 mg/L	Antimony	1.00 ug/L	Nitrate-nitrite (Total)	0.030 mg/L
Potassium	1.00 mg/L	Arsenic	1.00 ug/L	Total Kjeldahl Nitrogen	NL[2]
Calcium	2.00 mg/L	Barium	1.00 ug/L	Total Nitrogen	0.015 mg/L
Manganese	0.010 mg/L	Beryllium	1.00 ug/L	Total Phosphorus	0.004 mg/L
Iron	0.050 mg/L	Boron	50 ug/L	Total Organic Carbon	0.300 mg/L
Chloride	0.300 mg/L	Cadmium	1.00 ug/L		
Sulfate	0.300 mg/L	Chromium	1.00 ug/L		
Carbonate	NL[2]	Copper	1.00 ug/L		
Bicarbonate	NL[2]	Lead	1.00 ug/L		
Hydroxide	NL[2]	Nickel	1.00 ug/L		
Alkalinity	3.30 mg/L	Silver	1.00 ug/L		
Hardness	NL[2]	Selenium	1.00 ug/L		
Total Dissolved Solids	NL[2]	Thallium	1.00 ug/L		
Total Suspended Solids	5 mg/L	Zinc	1.00 ug/L		

[1]Analyzed as total recoverable metals
[2] No detection limit

APPENDIX C. SOIL ELEMENTS TESTED BY ACME LAB USING ICP-MS ANALYSIS

Element	Symbol	Detection Limit	Element	Symbol	Detection Limit
Aluminum	Al	0.01	Nickel	Ni	0.1
Antimony	Sb	0.02	Niobium	Nb	0.02
Arsenic	As	0.1	Palladium	Pd	10
Barium	Ba	0.5	Phosphorus	P	0.001
Beryllium	Be	0.1	Platinum	Pt	2
Bismuth	Bi	0.02	Potassium	K	0.01
Boron	B	20	Rhenium	Re	1
Cadmium	Cd	0.01	Rubidium	Rb	0.1
Calcium	Ca	0.01	Scandium	Sc	0.1
Cerium	Ce	0.1	Selenium	Se	0.1
Cesium	Cs	0.02	Silver	Ag	2
Chromium	Cr	0.5	Sodium	Na	0.001
Cobalt	Co	0.1	Strontium	Sr	0.5
Copper	Cu	0.01	Sulfur	S	0.02
Gallium	Ga	0.1	Tantalum	Ta	0.05
Germaniuum	Ge	0.1	Tellurium	Te	0.02
Gold	Au	0.2	Thallium	Tl	0.02
Hafnium	Hf	0.02	Thorium	Th	0.1
Indium	In	0.02	Tin	Sn	0.1
Iron	Fe	0.01	Titanium	Ti	0.001
Lanthanum	La	0.5	Tungsten	W	0.05
Lead	Pb	0.01	Uranium	U	0.05
Lithium	Li	0.1	Vanadium	V	2
Magnesium	Mg	0.01	Yttrium	Y	0.01
Manganese	Mn	1	Zinc	Zn	0.1
Mercury	Hg	5	Zirconium	Zr	0.1
Molybdenum	Mo	0.01			

APPENDIX D. PRAIRIE POTHOLE HYDROGEOMORPHIC MODEL VARIABLES AND DEFINITIONS USED TO CALCULATE FUNCTIONAL CAPACITY INDICES (MODIFIED FROM GILBERT ET AL. 2006)

Variable Category	Variable	Definition
Vegetation	VGRASSCONT	continuity of grassland adjacent to the wetland
	VGRASSWIDTH	width of grassland perpendicular to the wetland
	VVEGCOMP	vegetation composition
Soils	VRECHARGE	estimated soil recharge potential
	VSED	sediment deposition in the wetland
	VSQI	soil quality index
	VSOM	soil organic matter
Hydrogeomorphic	VOUT	wetland surface outlet
	VSUBOUT	subsurface drainage
	VSOURCE	reduction or increase in catchment area
	VEDGE	modified shoreline irregularity index
	VCATCHWET	ratio of catchment area to wetland area
Land use and landscape	VUPUSE	land use within the catchment
	VWETPROX	proximity to nearest wetlands
	VWETAREA	wetland density in the landscape assessment area
	VBASINS	number of basins in the landscape assessment area
	VHABFRAG	sum of the length of roads and ditches in the landscape assessment area

APPENDIX E. FUNCTIONAL CAPACITY INDICES OF THE PRAIRIE POTHOLE HYDROGEOMORPHIC MODEL (MODIFIED FROM GILBERT ET AL. 2006)

Function	Functional Capacity Index and Definition
Water Storage	$FCI = ((\text{Minimum of } V_{OUT}, V_{SUBOUT}) \times ((V_{SED} + ((V_{SOURCE} + V_{UPUSE})/2)/2))^{1/2}$
	Capacity of a prairie pothole wetland to collect and retain inflowing surface water, direct precipitation, and discharging groundwater as standing water above the soil surface, pore water in the saturated zone, or soil moisture in the unsaturated zone
Groundwater Recharge	$FCI = ((\text{Minimum of } V_{OUT}, V_{SUBOUT}) \times (((V_{RECHARGE} + V_{EDGE} + V_{CATCHWET})/3)/2 + ((V_{SQI} + V_{SOM})/2)/2))^{1/2}$
	Capacity of a prairie pothole wetland to move surface water downward into local or regional groundwater flow paths
Retain Particulates	$FCI = ((V_{SED} \times ((V_{UPUSE} + V_{GRASSCONT} + V_{GRASSWIDTH})/3) + (((V_{VEGCOMP} + (\text{Minimum of } V_{OUT}, V_{SUBOUT}))/2))/2))^{1/2}$
	Capacity of a wetland to physically remove and retain inorganic and organic particulates >0.45 µm from the water column.
Remove, Convert, and Sequester Dissolved Substances	$FCI = (((\text{Minimum of } V_{OUT}, V_{SUBOUT}) \times ((V_{GRASSWIDTH} + V_{GRASSCONT})/2) + ((V_{SOURCE} + V_{UPUSE} + V_{SED})/3) + ((V_{VEGCOMP} + V_{SOM})/2))/3)^{1/3}$
	Capacity of a wetland to remove and sequester imported nutrients, contaminants, and other elements and compounds
Plant Community Resilience and Carbon Cycling	$FCI = ((\text{Minimum of } V_{OUT}, V_{SUBOUT}) \times (((V_{UPUSE} + V_{GRASSCONT} + V_{GRASSWIDTH})/3) + ((V_{SED} + V_{SOM})/2) + V_{VEGCOMP})/3)^{1/2}$
	Capacity of a pothole wetland to sustain native plant community patterns and rates of processes in response to the variability inherent in its natural disturbance regimes
Provide Faunal Habitat	$FCI = ((\text{Minimum of } V_{OUT}, V_{SUBOUT}) \times (((V_{UPUSE} + V_{SED})/2) + ((V_{HABFRAG} \times ((V_{BASINS} + V_{WETAREA})/2))^{1/2}) + V_{VEGCOMP})/3)^{1/2}$
	Capacity of a prairie pothole to support aquatic and terrestrial vertebrate and invertebrate populations during some or part of their life cycle

APPENDIX F. INDEX OF PLANT COMMUNITY INTEGRITY METRICS AND VALUE RANGES FOR SEASONAL WETLANDS (MODIFIED FROM HARGISS ET AL. 2008)

Species Richness of Native Perennials
Number of Genera of Native Perennials
Assemblages: Native Grass and Grass-Like Species[1]
Percentage of Annual, Biennial, and Introduced Species of Entire Species List
Number of Native Perennial Species in the Wet Meadow Zone
Number of Species with a C-Value $\geq$ 5
Number of Species with a C-Value $\geq$ 4 in the Wet Meadow Zone
Average C-Value[2]
Floristic Quality Index[3]

[1] Assemblages: Native Grass and Grass-Like Species – Poaceae, Cyperaceae, Juncaceae.
[2] Average C-Value – Numbers Assigned by the Northern Prairie Plains Quality Assessment Panel (TNGPFQAP 2001).
[3] Floristic Quality Index – Average C-Value multiplied by the square root of the total number of species.

Metrics	Value Range for 0	Value Range for 4	Value Range for 7	Value Range for 11
Sp. Rich.[1]	0-19	20-31	32-41	42+
# Genera[2]	0-14	15-24	25-32	33+
Grass-like[3]	0-6	7-10	11-17	18+
% of intro.[4]	41.1+	30.8-41.0	21.1-30.7	0.0-21.0
# Nat. in WMZ[5]	0-8	9-16	17-24	25+
# C $\geq$ 5[6]	0-7	8-17	18-26	27+
# C $\geq$ 4 in[7]	0-4	5-9	10-16	17+
Avg. C[8]	0.00-2.60	2.61-3.12	3.13-3.52	3.53+
FQI[9]	0.00-10.00	10.01-16.11	16.12-22.99	23.00+

[1] Species richness of native perennial plant species.
[2] Number of genera of native perennial plant species.
[3] Number of grass and grass-like species (Poaceae, Juncaceae, and Cyperaceae).
[4] Percentage of the total species list that are annual, biennial, and introduced.
[5] Number of native perennial plant species found in the wet meadow zone.
[6] Number of plant species with a C-value $\geq$ 5*.
[7] Number of plant species with a C-value $\geq$ 4 found in the wet meadow zone*.
[8] Average C-value of all species present*.
[9] Floristic Quality Index = Average C-value multiplied by the square root of the total number of species*.
* C-value assigned by the Northern Great Plains Floristic Quality Assessment Panel (TNGPFQAP 2001).

APPENDIX G. PLANT SPECIES ENCOUNTERED WITHIN HIGH IMPACT SITES

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Ori[4]	Ind[5]
Acer negundo	Box Elder	1	P	Native	FAC
Achillea millefolium subsp. lanulosa	Yarrow	3	P	Native	UPL
Agropyron caninum subsp. majus var. majus	Slender Wheatgrass	6	P	Native	FAC-
Agropyron cristatum	Crested Wheatgrass	*	P	Introduced	UPL
Agropyron elongatum	Tall Wheatgrass	*	P	Introduced	UPL
Agropyron repens	Quackgrass	*	P	Introduced	FAC
Agropyron smithii	Western Wheatgrass	4	P	Native	UPL
Agrostis hyemalis	Ticklegrass	1	P	Native	FACW
Agrostis stolonifera	Redtop	*	P	Introduced	FACW
Alisma subcordatum	Common Water Plantain	2	P	Native	OBL
Alopecurus aequalis	Shortawn Foxtail	2	P	Native	OBL
Amaranthus retroflexus	Rough Pigweed	0	A	Native	FACU
Ambrosia artemisiifolia	Common Ragweed, Short Ragweed	0	A	Native	FACU
Ambrosia psilostachya	Western Ragweed	2	P	Native	FAC
Anemone canadensis	Meadow Anemone	4	P	Native	FACW
Apocynum cannabinum	Indian Hemp Dogbane, Prairie Dogbane	4	P	Native	FAC
Artemisia absinthium	Wormwood	*	P	Introduced	UPL
Artemisia biennis	Biennial Wormwood	*	B	Introduced	FAC
Artemisia cana	Dwarf Sagebrush	7	P	Native	FACU
Artemisia frigida	Prairie Sagewort	4	P	Native	UPL
Artemisia ludoviciana var. ludoviciana	White Sage	3	P	Native	UPL
Artemisia tridentata	Big Sagebrush	7	P	Native	UPL
Asclepias syriaca	Common Milkweed	0	P	Native	UPL
Aster ericoides	White Aster	2	P	Native	FACU
Aster simplex var. ramosissimus	Panicled Aster	3	P	Native	FACW
Beckmannia syzigachne	American Sloughgrass	1	A	Native	OBL
Bidens frondosa	Beggar-ticks	1	A	Native	FACW
Bouteloua hirsuta	Hairy Grama	7	P	Native	UPL
Brassica hirta	White Mustard	*	A	Introduced	UPL
Brassica kaber	Charlock	*	A	Introduced	UPL
Bromus inermis	Smooth Brome	*	P	Introduced	UPL
Calamagrostis stricta	N/A	5	P	Native	FACW+
Campanula rotundifolia	Harebell	7	P	Native	FAC
Capsella bursa-pastoris	Shepherd's Purse	*	A	Introduced	FACU
Cardaria pubescens	Whitetop	*	P	Introduced	UPL
Carex atherodes	Slough Sedge	4	P	Native	OBL
Carex brevior	Fescue Sedge	4	P	Native	FACU
Carex lanuginosa	Woolly Sedge	4	P	Native	OBL
Carex praegracilis	Clustered-field Sedge	5	P	Native	FACW
Carex sartwellii	N/A	5	P	Native	FACW
Carex vulpinoidea	Fox Sedge	2	P	Native	OBL
Ceratophyllum demersum	Hornwort, Coontail	4	P	Native	OBL
Chenopodium berlandieri	Pitseed Goosefoot	0	A	Native	FACU
Chenopodium gigantospermum	Maple-leaved Goosefoot	5	A	Native	UPL
Chenopodium glaucum	Oak-leaved Goosefoot	*	A	Introduced	FACW
Chenopodium rubrum	Alkali Blite	2	A	Native	OBL
Cicuta maculata	Common Water Hemlock	4	P	Native	OBL
Cirsium arvense	Canada Thistle, Field Thistle	*	P	Introduced	FACU
Cirsium flodmanii	Flodman's Thistle	5	P	Native	FAC
Comandra umbellata	N/A	8	P	Native	UPL
Convolvulus arvensis	Field Bindweed	*	P	Introduced	UPL
Conyza canadensis	Horseweed	0	A	Native	FACU
Crataegus rotundifolia	Northern Hawthorn	6	P	Native	FACU
Dalea purpurea var. purpurea	Purple Prairie Clover	8	P	Native	UPL
Descurainia sophia	Flixweed	*	A	Introduced	UPL
Distichlis spicata var. stricta	Inland Saltgrass	2	P	Native	FACW
Echinacea angustifolia	Purple Coneflower	7	P	Native	UPL
Echinochloa crusgalli	Barnyard Grass	*	A	Introduced	FACW
Elaeagnus angustifolia	Russian Olive	*	P	Introduced	FAC-
Eleocharis acicularis	Needle Spikesedge	3	P	Native	OBL
Eleocharis macrostachya	Spike Rush	4	P	Native	OBL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Ori[4]	Ind[5]
Elymus canadensis	Canada Wild Rye	3	P	Native	FACU
Epilobium ciliatum subsp. ciliatum	Willow-herb	3	P	Native	OBL
Epilobium paniculatum	Willow Herb	3	A	Native	UPL
Equisetum laevigatum	Smooth Scouring Rush	3	P	Native	FAC
Eragrostis cilianensis	Stinkgrass	*	A	Introduced	UPL
Erigeron philadelphicus	Philadelphia Fleabane	2	B	Native	FACW
Eriophorum polystachion	Narrowleaf Cottonsedge	8	P	Native	OBL
Erysimum cheiranthoides	Wormseed Wallflower	*	A	Introduced	FACU
Erysimum inconspicuum	Smallflower Wallflower	7	P	Native	UPL
Galium boreale	Northern Bedstraw	4	P	Native	FACU
Glycyrrhiza lepidota	Wild Licorice	2	P	Native	FACU
Grindelia squarrosa var. squarrosa	Curly-top Gumweed	1	B	Native	UPL
Helianthus annuus	Common Sunflower	0	A	Native	FACU
Helianthus maximilianii	Maximilian Sunflower	5	P	Native	FACU
Helianthus nuttallii subsp. nuttallii	Nuttall's Sunflower	8	P	Native	FAC
Helianthus rigidus subsp. subrhomboideus	Stiff Sunflower	8	P	Native	UPL
Hordeum jubatum	Foxtail Barley	0	P	Native	FACW
Iva xanthifolia	Marsh Elder	0	A	Native	FACU
Juncus balticus	Baltic Rush	5	P	Native	FACW
Juncus dudleyi	Dudley Rush	4	P	Native	FAC
Juncus interior	Inland Rush	5	P	Native	FACW
Juncus torreyi	Torrey's Rush	2	P	Native	FACW
Kochia scoparia	Kochia, Fire-weed	*	A	Introduced	FAC
Lactuca oblongifolia	Blue Lettuce	1	P	Native	FACU
Lemna minor	Duckweed	9	P	Native	OBL
Lemna trisulca	Star Duckweed	2	P	Native	OBL
Lepidium densiflorum	Peppergrass	0	A	Native	FACU
Liatris ligulistylis	Gay-feather	10	P	Native	FAC
Linum perenne var. lewisii	Blue Flax	6	P	Native	UPL
Lycopus americanus	American Bugleweed	4	P	Native	OBL
Lycopus asper	Rough Bugleweed	4	P	Native	OBL
Lysimachia hybrida	Loosestrife	5	P	Native	OBL
Malva neglecta	Common Mallow	*	A	Introduced	UPL
Matricaria chamomilla	False Chamomile	*	A	Introduced	FACW
Medicago lupulina	Black Medick	*	P	Introduced	FACU
Medicago sativa	Alfalfa	*	P	Introduced	UPL
Melilotus alba	White Sweet Clover	*	A	Introduced	UPL
Melilotus officinalis	Yellow Sweet Clover	*	A	Introduced	FACU-
Mentha arvensis	Field Mint	3	P	Native	FACW
Monarda fistulosa var. fistulosa	Wild Bergamot	5	P	Native	UPL
Muhlenbergia richardsonis	Mat Muhly	10	P	Native	FAC
Oenothera biennis	Common Evening Primrose	0	B	Native	FACU
Panicum dichotomiflorum	Fall Panicum	0	A	Native	FAC
Panicum virgatum	Switchgrass	5	P	Native	FAC
Phalaris arundinacea	Reed Canarygrass	0	P	Native	FACW+
Phleum pratense	Timothy	*	P	Introduced	FACU
Phragmites australis	Common Reed	0	P	Native	FACW
Plantago major	Common Plantain	*	P	Introduced	FAC
Poa palustris	Fowl Bluegrass	4	P	Native	FACW
Poa pratensis	Kentucky Bluegrass	*	P	Introduced	FACU
Polygonum amphibian var. emersum	Swamp Smartweed	0	P	Native	OBL
Polygonum amphibian var.stipulaceum	Water Smartweed	6	P	Native	FACW
Polygonum arenastrum	Knotweed	0	A	Native	UPL
Polygonum erectum	Erect Knotweed	0	A	Native	OBL
Polygonum lapathifolium	Pale Smartweed	1	A	Native	OBL
Polygonum pensylvanicum	Pennsylvania Smartweed	0	A	Native	FACW
Potamogeton pusillus var. pusillus	Baby Pondweed	2	P	Native	OBL
Potentilla anserina	Silverweed	2	P	Native	OBL
Potentilla argentea	Silvery Cinquefoil	*	P	Introduced	FACU
Potentilla arguta	Tall Cinquefoil	8	P	Native	FACU
Potentilla norvegica	Norwegian Cinquefoil	0	A	Native	FAC
Prunus americana	Wild Plum	4	P	Native	UPL
Prunus virginiana	Choke Cherry	4	P	Native	FACU-
Psoralea argophylla	Silver-leaf Scurf-pea	4	P	Native	UPL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Ori[4]	Ind[5]
Ranunculus cymbalaria	Shore Buttercup	3	P	Native	OBL
Ranunculus gmelinii	Small Yellow Buttercup	8	P	Native	FACW+
Ranunculus pensylvanicus	Bristly Crowfoot	4	A	Native	FACW+
Ratibida columnifera	Prairie Coneflower	3	P	Native	UPL
Rosa arkansana	Prairie Wild Rose	3	P	Native	FACU
Rosa woodsii	Western Wild Rose	5	P	Native	FACU
Rudbeckia hirta	Black-eyed Susan	5	B	Native	FACU
Rumex crispus	Curly Dock	*	P	Introduced	FACW
Rumex maritimus	Golden Dock	1	A	Native	FACW
Rumex mexicanus	Willow-leaved Dock	1	P	Native	FACW
Salix exigua subsp. exigua	Coyote Willow	3	P	Native	FACW+
Salix exigua subsp. interior	Sandbar Willow	3	P	Native	FACW+
Salsola iberica	Russian Thistle, Tumbleweed	*	A	Introduced	UPL
Scirpus acutus	Hard-stem Bulrush	5	P	Native	OBL
Scirpus fluviatilis	River Bulrush	2	P	Native	OBL
Scirpus maritimus var. paludosus	Prairie Bulrush	4	P	Native	OBL
Scirpus pungens	N/A	4	P	Native	OBL
Scirpus validus	Soft-stem Bulrush	3	P	Native	OBL
Scolochloa festucacea	Sprangletop	6	P	Native	OBL
Setaria glauca	Yellow Foxtail	*	A	Introduced	FACU
Sium suave	Water Parsnip	3	P	Native	OBL
Solidago canadensis var. canadensis	Canada Goldenrod	1	P	Native	FACU
Solidago gigantea	Late Goldenrod	4	P	Native	FACW
Solidago missouriensis	Prairie Goldenrod	5	P	Native	UPL
Solidago mollis	Soft Goldenrod	6	P	Native	UPL
Solidago rigida	Rigid Goldenrod	4	P	Native	FACU-
Sonchus arvensis	Field Sow Thistle	*	P	Introduced	FAC
Spartina pectinata	Prairie Cordgrass	5	P	Native	FACW
Stipa viridula	Green Needlegrass	5	P	Native	UPL
Suaeda depressa	Sea Blite	2	A	Native	UPL
Symphoricarpos occidentalis	Western Snowberry	3	P	Native	UPL
Taraxacum officinale	Common Dandelion	*	P	Introduced	FACU
Teucrium canadense var. boreale	American Germander, Wood Sage	3	P	Native	FACW
Thalictrum dasycarpum	Purple Meadow Rue	7	P	Native	FAC
Tragopogon dubius	Goat's Beard	*	B	Introduced	UPL
Triglochin concinna var. debilis	N/A	8	P	Native	OBL
Triglochin maritima var. elata	Arrowgrass	5	P	Native	OBL
Typha latifolia	Broad-leaved Cattail	2	P	Native	OBL
Typha x glauca	Hybrid Cattail	*	P	Introduced	OBL
Urtica dioica	Stinging Nettle	0	P	Native	FACW
Utricularia vulgaris	Common Bladderwort	2	P	Native	OBL
Verbena bracteata	Prostrate Vervain	0	A	Native	FACU
Vicia americana var. americana	American Vetch	6	P	Native	UPL
Viola pedatifida	Prairie Violet, Larkspur-violet	8	P	Native	FACU
Xanthium strumarium	Cocklebur	0	A	Native	FAC

[1] Species scientific names follow the nomenclature of the USDA Plants Database (USDA, NRCS 2008). Authorities of plant species can be found in the USDA Plants Database. All plant species identification was accomplished with the use of Flora of the Great Plains (Great Plains Flora Association 1986) and Aquatic and Wetland Vascular Plants of the Northern Great Plains (Larson 1993).

[2] C-Values were assigned by the Northern Great Plains Floristic Quality Assessment Panel (TNGPFQAP 2001).

[3] Life-form – P = perennial, A = annual, B = biennial.

[4] Origin.

[5] Indicator categories follow those in National List of Plant Species that Occur in Wetlands: Northern Plains (Region 4) (Reed 1988).

APPENDIX H. PLANT SPECIES ENCOUNTERED WITHIN LOW IMPACT SITES

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Ori[4]	Ind[5]
Achillea millefolium subsp. lanulosa	Yarrow	3	P	Native	UPL
Agropyron caninum subsp. majus var. majus	Slender Wheatgrass	6	P	Native	FAC-
Agropyron cristatum	Crested Wheatgrass	*	P	Introduced	UPL
Agropyron elongatum	Tall Wheatgrass	*	P	Introduced	UPL
Agrostis hyemalis	Ticklegrass	1	P	Native	FACW
Agropyron intermedium	Intermediate Wheatgrass	*	P	Introduced	UPL
Agropyron repens	Quackgrass	*	P	Introduced	FAC
Agropyron smithii	Western Wheatgrass	4	P	Native	UPL
Agrostis stolonifera	Redtop	*	P	Introduced	FACW
Alisma subcordatum	Common Water Plantain	2	P	Native	OBL
Agropyron intermedium	Intermediate Wheatgrass	*	P	Introduced	UPL
Artemisia tridentata	Big Sagebrush	7	P	Native	UPL
Alisma subcordatum	Common Water Plantain	2	P	Native	OBL
Amaranthus retroflexus	Rough Pigweed	0	A	Native	FACU
Ambrosia artemisiifolia	Common Ragweed, Short Ragweed	0	A	Native	FACU
Ambrosia psilostachya	Western Ragweed	2	P	Native	FAC
Andropogon gerardii	Big Bluestem	5	P	Native	FACU
Andropogon scoparius	Little Bluestem	6	P	Native	UPL
Anemone canadensis	Meadow Anemone	4	P	Native	FACW
Anemone cylindrica	Candle Anemone	7	P	Native	UPL
Antennaria microphylla	Pink Pussy-toes	7	P	Native	UPL
Antennaria neglecta	Field Pussy-toes	5	P	Native	UPL
Apocynum cannabinum	Indian Hemp Dogbane, Prairie Dogbane	4	P	Native	FAC
Artemisia absinthium	Wormwood	*	P	Introduced	UPL
Artemisia biennis	Biennial Wormwood	*	B	Introduced	FAC
Artemisia cana	Dwarf Sagebrush	7	P	Native	FACU
Artemisia frigida	Prairie Sagewort	4	P	Native	UPL
Artemisia ludoviciana var. ludoviciana	White Sage	3	P	Native	UPL
Arctium minus	Common Burdock	*	B	Introduced	UPL
Artemisia tridentata	Big Sagebrush	7	P	Native	UPL
Asclepias ovalifolia	Ovalleaf Milkweed	9	P	Native	UPL
Asclepias syriaca	Common Milkweed	0	P	Native	UPL
Astragalus canadensis	Canada Milk-vetch	5	P	Native	FACU
Aster ericoides	White Aster	2	P	Native	FACU
Aster simplex var. simplex	Panicled Aster	3	P	Native	FACW
Avena fatua	Wild Oats	*	A	Introduced	UPL
Beckmannia syzigachne	American Sloughgrass	1	A	Native	OBL
Bidens frondosa	Beggar-ticks	1	A	Native	FACW
Bouteloua gracilis	Blue Grama	7	P	Native	UPL
Bouteloua hirsuta	Hairy Grama	7	P	Native	UPL
Brassica campestris	Wild Turnip	*	A	Introduced	UPL
Brassica kaber	Charlock	*	A	Introduced	UPL
Bromus inermis	Smooth Brome	*	P	Introduced	UPL
Calamovilfa longifolia	Prairie Sandreed	5	P	Native	UPL
Calamagrostis stricta	N/A	5	P	Native	FACW+
Camelina microcarpa	Small-seeded False Flax	*	A	Introduced	FACU
Campanula rotundifolia	Harebell	7	P	Native	FAC
Carex brevior	Fescue Sedge	4	P	Native	FACU
Carex lanuginosa	Woolly Sedge	4	P	Native	OBL
Cerastium arvense	Prairie Chickweed	2	P	Native	FACU
Ceratophyllum demersum	Hornwort, Coontail	4	P	Native	OBL
Chenopodium glaucum	Oak-leaved Goosefoot	*	A	Introduced	FACW
Chenopodium rubrum	Alkali Blite	2	A	Native	OBL
Cicuta maculata	Common Water Hemlock	4	P	Native	OBL
Cirsium arvense	Canada Thistle, Field Thistle	*	P	Introduced	FACU
Cirsium canescens	Platte Thistle	8	P	Native	UPL
Cirsium flodmanii	Flodman's Thistle	5	P	Native	FAC
Collomia linearis	Collomia	5	A	Native	FACU
Convolvulus arvensis	Field Bindweed	*	P	Introduced	UPL
Conyza canadensis	Horseweed	0	A	Native	FACU

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Ori[4]	Ind[5]
Carex atherodes	Slough Sedge	4	P	Native	OBL
Carex brevior	Fescue Sedge	4	P	Native	FACU
Carex lanuginosa	Woolly Sedge	4	P	Native	OBL
Carex praegracilis	Clustered-field Sedge	5	P	Native	FACW
Carex sartwellii	N/A	5	P	Native	FACW
Cynoglossum officinale	Hound's Tongue	*	B	Introduced	UPL
Dalea purpurea var. purpurea	Purple Prairie Clover	8	P	Native	UPL
Descurainia sophia	Flixweed	*	A	Introduced	UPL
Distichlis spicata var. stricta	Inland Saltgrass	2	P	Native	FACW
Echinacea angustifolia	Purple Coneflower	7	P	Native	UPL
Echinochloa crusgalli	Barnyard Grass	*	A	Introduced	FACW
Elaeagnus commutata	Silverberry	5	P	Native	FAC
Eleocharis acicularis	Needle Spikesedge	3	P	Native	OBL
Eleocharis macrostachya	Spike Rush	4	P	Native	OBL
Scirpus pallidus	N/A	5	P	Native	OBL
Epilobium ciliatum subsp. ciliatum	Willow-herb	3	P	Native	OBL
Equisetum laevigatum	Smooth Scouring Rush	3	P	Native	FAC
Erigeron philadelphicus	Philadelphia Fleabane	2	B	Native	FACW
Eriophorum polystachion	Narrowleaf Cottonsedge	8	P	Native	OBL
Erysimum cheiranthoides	Wormseed Wallflower	*	A	Introduced	FACU
Euphorbia esula	Leafy Spurge	*	P	Introduced	UPL
Galium boreale	Northern Bedstraw	4	P	Native	FACU
Geum triflorum	Torch Flower, Maidenhair	8	P	Native	FACU
Glycyrrhiza lepidota	Wild Licorice	2	P	Native	FACU
Glyceria striata	Fowl Mannagrass	6	P	Native	OBL
Grindelia squarrosa var. squarrosa	Curly-top Gumweed	1	B	Native	UPL
Helianthus annuus	Common Sunflower	0	A	Native	FACU
Helianthus maximilianii	Maximilian Sunflower	5	P	Native	FACU
Helianthus nuttallii subsp. nuttallii	Nuttall's Sunflower	8	P	Native	FAC
Helianthus rigidus subsp. subrhomboideus	Stiff Sunflower	8	P	Native	UPL
Hordeum jubatum	Foxtail Barley	0	P	Native	FACW
Iva annua	Marsh Elder	*	A	Introduced	FAC
Juncus balticus	Baltic Rush	5	P	Native	FACW
Juncus dudleyi	Dudley Rush	4	P	Native	FAC
Juncus interior	Inland Rush	5	P	Native	FACW
Juncus torreyi	Torrey's Rush	2	P	Native	FACW
Kochia scoparia	Kochia, Fire-weed	*	A	Introduced	FAC
Koeleria pyramidata	Junegrass	7	P	Native	UPL
Lactuca biennis	Blue Wood Lettuce	6	B	Native	FAC
Lactuca oblongifolia	Blue Lettuce	1	P	Native	FACU
Lactuca biennis	Blue Wood Lettuce	6	B	Native	FAC
Lemna minor	Duckweed	9	P	Native	OBL
Lemna turionifera	N/A	1	P	Native	OBL
Lemna trisulca	Star Duckweed	2	P	Native	OBL
Lepidium densiflorum	Peppergrass	0	A	Native	FACU
Liatris ligulistylis	Gay-feather	10	P	Native	FAC
Liatris punctata	Blazing Star	7	P	Native	UPL
Linaria dalmatica	Toadflax	*	P	Introduced	UPL
Linum perenne var. lewisii	Blue Flax	6	P	Native	UPL
Linum rigidum var. compactum	Stiffstem Flax	5	A	Native	UPL
Linum usitatissimum	Common Flax	*	A	Introduced	UPL
Lotus purshianus	Prairie Trefoil, Deer Vetch	3	A	Native	UPL
Lycopus americanus	American Bugleweed	4	P	Native	OBL
Lycopus asper	Rough Bugleweed	4	P	Native	OBL
Lysimachia hybrida	Loosestrife	5	P	Native	OBL
Malva neglecta	Common Mallow	*	A	Introduced	UPL
Malva rotundifolia	Common Mallow	*	A	Introduced	UPL
Matricaria matricarioides	Pineapple Weed	*	A	Introduced	UPL
Medicago lupulina	Black Medick	*	P	Introduced	FACU
Medicago sativa	Alfalfa	*	P	Introduced	UPL
Melilotus alba	White Sweet Clover	*	A	Introduced	UPL
Melilotus officinalis	Yellow Sweet Clover	*	A	Introduced	FACU-
Mentha arvensis	Field Mint	3	P	Native	FACW
Muhlenbergia richardsonis	Mat Muhly	10	P	Native	FAC

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Ori[4]	Ind[5]
Panicum virgatum	Switchgrass	5	P	Native	FAC
Parietaria pensylvanica	Pennsylvania Pellitory	3	A	Native	FACU
Phalaris arundinacea	Reed Canarygrass	0	P	Native	FACW+
Phlox pilosa subsp. fulgida	Prairie Phlox	10	P	Native	UPL
Phleum pratense	Timothy	*	P	Introduced	FACU
Phragmites australis	Common Reed	0	P	Native	FACW
Plantago major	Common Plantain	*	P	Introduced	FAC
Poa palustris	Fowl Bluegrass	4	P	Native	FACW
Poa pratensis	Kentucky Bluegrass	*	P	Introduced	FACU
Polygala alba	White Milkwort	5	P	Native	UPL
Polygonum amphibian var. emersum	Swamp Smartweed	0	P	Native	OBL
Polygonum aviculare	Knotweed	0	A	Native	FACU
Polygonum erectum	Erect Knotweed	0	A	Native	OBL
Polygonum lapathifolium	Pale Smartweed	1	A	Native	OBL
Polygonum pensylvanicum	Pennsylvania Smartweed	0	A	Native	FACW
Polygonum ramosissimum	Bushy Knotweed	3	A	Native	FACU
Potentilla anserina	Silverweed	2	P	Native	OBL
Potentilla argentea	Silvery Cinquefoil	*	P	Introduced	FACU
Potentilla anserina	Silverweed	2	P	Native	OBL
Potentilla arguta	Tall Cinquefoil	8	P	Native	FACU
Potentilla norvegica	Norwegian Cinquefoil	0	A	Native	FAC
Potamogeton pectinatus	Sago Pondweed	0	P	Native	OBL
Potamogeton pusillus var. pusillus	Baby Pondweed	2	P	Native	OBL
Prunus americana	Wild Plum	4	P	Native	UPL
Prunus virginiana	Choke Cherry	4	P	Native	FACU-
Psoralea argophylla	Silver-leaf Scurf-pea	4	P	Native	UPL
Puccinellia nuttalliana	Alkali-grass	4	P	Native	OBL
Ranunculus cymbalaria	Shore Buttercup	3	P	Native	OBL
Ranunculus gmelinii	Small Yellow Buttercup	8	P	Native	FACW+
Ranunculus longirostris	White Water Crowfoot	7	P	Native	OBL
Ratibida columnifera	Prairie Coneflower	3	P	Native	UPL
Rosa arkansana	Prairie Wild Rose	3	P	Native	FACU
Rosa woodsii	Western Wild Rose	5	P	Native	FACU
Rudbeckia hirta	Black-eyed Susan	5	B	Native	FACU
Rumex crispus	Curly Dock	*	P	Introduced	FACW
Rumex maritimus	Golden Dock	1	A	Native	FACW
Rumex mexicanus	Willow-leaved Dock	1	P	Native	FACW
Salix amygdaloides	Peachleaf Willow	3	P	Native	FACW
Salix exigua subsp. interior	Sandbar Willow	3	P	Native	FACW+
Salsola iberica	Russian Thistle, Tumbleweed	*	A	Introduced	UPL
Andropogon scoparius	Little Bluestem	6	P	Native	UPL
Scirpus acutus	Hard-stem Bulrush	5	P	Native	OBL
Scirpus fluviatilis	River Bulrush	2	P	Native	OBL
Scirpus pungens	N/A	4	P	Native	OBL
Scolochloa festucacea	Sprangletop	6	P	Native	OBL
Senecio congestus	Swamp Ragwort	2	A	Native	FACW+
Setaria glauca	Yellow Foxtail	*	A	Introduced	FACU
Sium suave	Water Parsnip	3	P	Native	OBL
Symphoricarpos occidentalis	Western Snowberry	3	P	Native	UPL
Solidago canadensis var. canadensis	Canada Goldenrod	1	P	Native	FACU
Solidago missouriensis	Prairie Goldenrod	5	P	Native	UPL
Solidago mollis	Soft Goldenrod	6	P	Native	UPL
Solidago rigida	Rigid Goldenrod	4	P	Native	FACU-
Sonchus arvensis	Field Sow Thistle	*	P	Introduced	FAC
Sonchus oleraceus	Common Sow Thistle	*	A	Introduced	FACU
Sparganium eurycarpum	Giant Burreed	4	P	Native	OBL
Spartina gracilis	Alkali Cordgrass	6	P	Native	FACW
Spartina pectinata	Prairie Cordgrass	5	P	Native	FACW
Sporobolus heterolepis	Prairie Dropseed	10	P	Native	UPL
Stipa viridula	Green Needlegrass	5	P	Native	UPL
Stipa spartea	Porcupine-grass	8	P	Native	UPL
Stipa viridula	Green Needlegrass	5	P	Native	UPL
Symphoricarpos occidentalis	Western Snowberry	3	P	Native	UPL
Taraxacum officinale	Common Dandelion	*	P	Introduced	FACU

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Ori[4]	Ind[5]
Teucrium canadense var. boreale	American Germander, Wood Sage	3	P	Native	FACW
Tragopogon dubius	Goat's Beard	*	B	Introduced	UPL
Triglochin concinna var. debilis	N/A	8	P	Native	OBL
Triglochin maritima var. elata	Arrowgrass	5	P	Native	OBL
Typha angustifolia	Narrow-leaved Cattail	*	P	Introduced	OBL
Typha x glauca	Hybrid Cattail	*	P	Introduced	OBL
Typha latifolia	Broad-leaved Cattail	2	P	Native	OBL
Urtica dioica	Stinging Nettle	0	P	Native	FACW
Utricularia vulgaris	Common Bladderwort	2	P	Native	OBL
Vicia americana var. americana	American Vetch	6	P	Native	UPL
Viola pedatifida	Prairie Violet, Larkspur-violet	8	P	Native	FACU
Xanthium strumarium	Cocklebur	0	A	Native	FAC
Zizia aptera	Meadow Parsnip	8	P	Native	UPL

[1] Species scientific names follow the nomenclature of the USDA Plants Database (USDA, NRCS 2008). Authorities of plant species can be found in the USDA Plants Database. All plant species identification was accomplished with the use of Flora of the Great Plains (Great Plains Flora Association 1986) and Aquatic and Wetland Vascular Plants of the Northern Great Plains (Larson 1993).
[2] C-Values were assigned by the Northern Great Plains Floristic Quality Assessment Panel (TNGPFQAP 2001).
[3] Life-form – P = perennial, A = annual, B = biennial.
[4] Origin.
[5] Indicator categories follow those in National List of Plant Species that Occur in Wetlands: Northern Plains (Region 4) (Reed 1988).

APPENDIX I. NORTH DAKOTA RAPID ASSESSMENT METHOD FOR WETLANDS

Directions:

The NDRAM for wetlands was created to rapidly assess temporary, seasonal, and semi-permanent wetlands in the Prairie Pothole Region based on the plant communities present. Results of the NRDAM should indicate results similar to the Index of Plant Community Integrity (IPCI) (DeKeyser 2000, DeKeyser et al. 2003, Kirby and DeKeyser 2003, and Hargiss 2008).

Before conducting the NDRAM employees should complete the short NDRAM field training course. This course will teach them the methods involved in the NDRAM, how to identify significant characteristics of the wetland, and the basic plant community information needed to properly use the NDRAM. Additional training on the HGM Model and the IPCI may also be helpful, but not necessary, to complete the NDRAM. Another additional resource that may be helpful is Stewart and Kantrud (1971).

The NDRAM can be completed by anyone who has had the short field course. The NDRAM should be used as an indicator of wetland condition in an area. However, further investigation into plant communities present and land use practices will be helpful in making recommendations for management of an area. The NDRAM can be used every few years to indicate change in wetland condition. When combined with the IPCI over a larger area, regional wetland plant community trends can also be determined.

References:

DeKeyser, E.S., 2000. A vegetative classification of seasonal and temporary wetlands across a disturbance gradient using a multimetric approach. Ph.D. Dissertation. North Dakota State University, Fargo, ND.

DeKeyser, E.S., Kirby, D.R., Ell, M.J., 2003. An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. Ecological Indicators 3, 119-133.

Hargiss, C.L.M., E.S. DeKeyser, D.R. Kirby, and M.J. Ell. 2008. Regional assessment of wetland plant communities using the index of plant community integrity. Ecological Indicators 8:303-307.

Kirby, D.R., DeKeyser, E.S., 2003. Index of wetland biological integrity development and assessment of semi-permanent wetlands in the Missouri Coteau Region of North Dakota. Final Report for North Dakota Department of Health. Section 104[b](3) Wetland Grant funds.

Stewart, R.E., Kantrud, H.E., 1971. Classification of natural ponds and lakes in the glaciated prairie region. U.S. Fish and Wildlife Service. Resource Publication 92, 57 pp. Washington D.C.

North Dakota Rapid Assessment Method Form:

Site Name___________________________ **Date**____________________________

Land Ownership______________________

Person(s) assessing wetland____

Legal Description____

County____

GPS Information:

Datum______________

N__________________

W__________________

General Site Description____

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Photo's

Photo Number	**Direction Facing**	**Description**

Use space below to draw a detailed picture of the wetland. Be sure to include different groups of vegetation and any distinct features. Create a legend for your map. Circle the % cover of the different types of plants on the right.

Sedges	**0-25%**	**25-50%**	**50-75%**	**75-100%**
Cattails	**0-25%**	**25-50%**	**50-75%**	**75-100%**
Grasses	**0-25%**	**25-50%**	**50-75%**	**75-100%**
Rushes	**0-25%**	**25-50%**	**50-75%**	**75-100%**
Forbs	**0-25%**	**25-50%**	**50-75%**	**75-100%**
Shrubs	**0-25%**	**25-50%**	**50-75%**	**75-100%**
Trees	**0-25%**	**25-50%**	**50-75%**	**75-100%**
Other:_______	**0-25%**	**25-50%**	**50-75%**	**75-100%**

N ↑

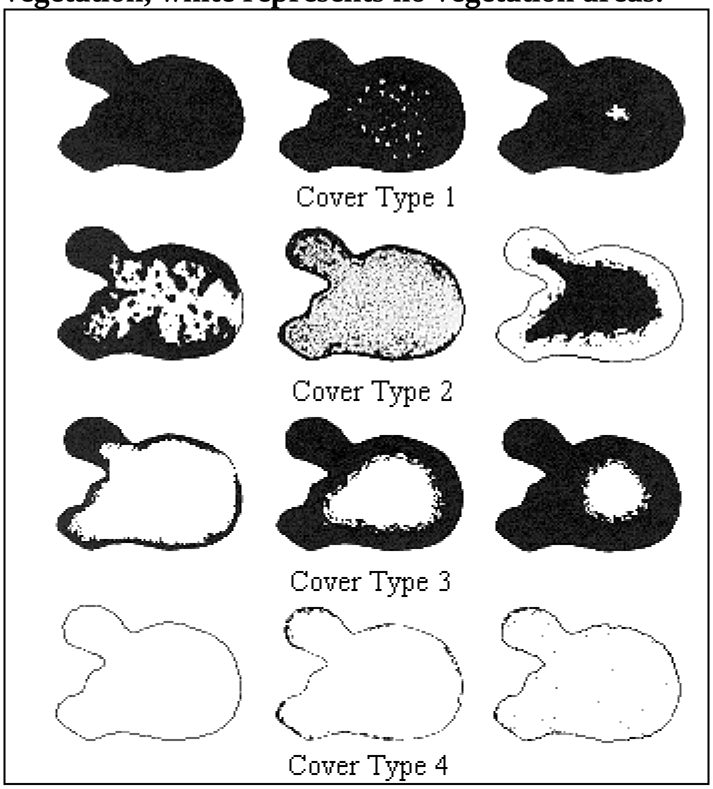
1 square = ____ m
Overall wetland is approximately ________m X ________m
Hydrologic classification (temporary, seasonal, etc.) ____________________________

Site Characterization:

Estimate amount of standing water:

Total wetland area covered by standing water	0	1-25	26-50	51-75	76-100
If water is present:					
Percentage of water <1 ft. deep	0	1-25	26-50	51-75	76-100
Percentage of water 1-3 ft. deep	0	1-25	26-50	51-75	76-100
Percentage of water >3 ft. deep	0	1-25	26-50	51-75	76-100

Estimate (by circling picture below) amount and distribution of cover. Black represents vegetation, white represents no vegetation areas.



Land use and disturbances (check all that apply):

	Dugout		Haying
	Road/prairie trail		Drought
	Cropping		Restored/Reclaimed
	Drain		Idle
	Grazed		Other__________________________

Wetland Classification:

Poor Condition: Poor condition wetlands are wetlands that are highly disturbed with low functioning (Example: cropped, drained, etc.).

Fair Condition: Fair condition wetlands are wetlands that have been disturbed in the past or are currently moderately disturbed. They perform many wetland functions, but are not at full potential compared to less disturbed native wetlands (Example: hayed, mowed, CRP, etc.).

Good Condition: Good condition wetlands are native properly functioning wetlands that are for the most part undisturbed (Example: grazed, native areas).

Preliminary Observations:

#	Question	Circle One	
1	Critical Habitat. Is the wetland in an area that has been designated by the U.S. Fish and Wildlife Service as "critcal habitat" for any threatened and endangered species?	Yes Wetland should be evaluated for possible Good condition status.	No
2	Critical Habitat. Is this wetland a fen or does it contain a fen?	Yes Wetland should be evaluated for possible Good condition status.	No
3	Threatened or Endangered Species. Is the wetland known to contain an individual of, or documented occurrences of, federal or state-listed threatened or endangered plant or animal species?	Yes Wetland should be evaluated for possible Good condition status.	No
4	Poor Condition Wetland. Is the wetland completely plowed through all zones on a regular basis and planted with a crop?	Yes Wetland is a poor condition wetland.	No
5	Good Condition Wetland. Is the wetland in an area that has never been disturbed other than light-moderate grazing, and contains mostly native perennial species?	Yes Wetland should be evaluated for possible Good condition status.	No

Metrics

Metric 1. Buffers and surrounding land use.

1a. Calculate Average Buffer Width

Score	Rating Description
	WIDE. Buffer averages 50m or more around wetland perimeter (10pts)
	MEDIUM. Buffer average 25m to <50m around wetland perimeter (7 pts)
	NARROW. Buffer averages 10m to <25m around wetland perimeter (4 pt)
	VERY NARROW. Buffer averages <10m around wetland perimeter (0 pts)
	OTHER.

1b. Intensity of Surrounding Land Use. Select one or more, average the scores.

Score	Rating Description
	VERY LOW. Native prairie, light to moderate grazing, etc. (10 pts)
	LOW. Hayed prairie area, CRP, etc. (7 pts)
	MODERATELY HIGH. Farm, conservation tillage, planted alfalfa (4 pts)
	HIGH. Urban, row cropping, etc (1 pt)
	OTHER.

	Total for Metric 1 (out of possible 20).

Metric 2. Hydrology, Habitat alteration, and Development.

2a. Substrate/Soil Disturbance. This metric evaluates physical disturbances to the soil and surface substrates of the wetland. The labels on the categories are intended to be descriptive but not controlling. Examples of disturbance include: filling, grading, plowing, hoove action, vehicle use, sedimentation, dredging, etc.

Score	Rating Description
	NONE. There are no disturbances, or beneficial disturbances Ex. light to moderate grazing and fire (7 pts).
	RECOVERED. The wetland appears to have recovered from past disturbances (5 pts).
	RECOVERING. The wetland appears to be in the process of recovering from past disturbances (3 pts).
	RECENT OR NO RECOVERY. Complete removal of vegetation and soil exposed, the disturbances have occurred recently, and/or the wetland has not recovered from past disturbances, and/or the disturbances are ongoing (1 pt).
	OTHER

2b. Plant Community and Habitat Development. This metric asks the rater to assign an overall rating of how well-developed the wetland is in comparison with other ecologically or hydrogeomorphically similar wetlands; based on the quality typical of the region.

Score	Rating Description
	EXCELLENT. Wetland appears to represent best of its type or class. Ex. the wetland is found on native prairie and appears to be diverse in native plant species. (12 pts)
	VERY GOOD. Wetland appears to be a very good example of its type or class but is lacking characteristics which would make it excellent. Ex. wetland may be on native prairie but is lacking diversity because of being left idle or herbicide application. (10 pts)
	GOOD. Wetland appears to be a good example of its type or class but because of past or present disturbances, successional state, or other reasons, it is not excellent. (8 pts)
	MODERATELY GOOD. Wetland appears to be a fair to good example of its type or class. Ex. wetland has past disturbances such as heavy grazing, restoration, or draining that have affected the area. (6 pts)
	FAIR. Wetland appears to be a moderately good example of its type or class, but because of past or present disturbances, successional state, etc. it is not good. Ex. a combination of native and non-native portions to the wetland with low diversity of plant species. (4 pts)
	POOR TO FAIR. Wetland appears to be a good to fair example of its type or class. Ex. wetland may be a monoculture of one plant species or may have native species in a buffer around the wetland, but outer zones are cropped. (2 pts)
	POOR. Wetland appears to not be a good example of its type or class because of past or present disturbances, successional state, etc. Ex. wetland may be completely cropped through with no perennial plant community present. (0 pt)

2c. Habitat Alteration and Recovery from Current and Past Disturbances. This metric evaluates the disturbance level of wetland habitat and the ability to recover from habitat alterations. Ideal management involves some form of disturbance such as moderate grazing or fire to maintain plant vigor and diversity. Leaving areas idle and haying can lead to a monoculture of species. Restored and CRP areas take time to become properly functioning communities and are often planted with at least partially non-native species.

Score	Rating Description
	MOST SUITABLE. The wetland appears to have recovered from past alterations and alterations have been beneficial to habitat. (10 pts).
	NONE OR NONE APPARENT. There are no alterations, or no alterations that are apparent to the rater (7 pts).
	RECOVERING. The wetland appears to be in the process of recovering from past alterations (4 pts).
	RECENT OR NO RECOVERY. The alterations have occurred recently, and/or the wetland has not recovered from past alterations, and/or the alterations are ongoing (1 pt).
	OTHER.

2d. Management.

	Fire or Moderate Grazing. If the area has been burned or is moderately grazed at proper intervals. (4 pts)
	Restored, CRP, Hayed, or Idle. If the area is restored, hayed, planted with CRP, left idle, or has large buffer before cropping begins. (2 pts)
	Cropped. If the wetland is cropped through or cropped with only a very narrow buffer. (0 pts)
	OTHER.

2e. Modifications to Natural Hydrologic Regime. This question asks the rater to identify alterations to the hydrologic regime of the wetland (ex. ditches, drains, etc.) and the amount of recovery from such alterations.

Score	Rating Description
	NONE. There are no modifications or non modifications that are apparent to the rater (12 pts).
	RECOVERED. The wetland appears to have recovered from past modifications to the fullest extent possible. Ex. long established road (8 pts).
	RECOVERING. The wetland appears to be in the process of recovering from past modifications (4 pts).
	RECENT OR NO RECOVERY. The modifications have occurred recently, and/or has not recovered from past modifications, and/or the modifications are ongoing (1 pt).
	OTHER.

2f. Potential of Wetland to Reach Reference (Native) Condition for the Area. This question asks the rater to use their best professional judgment and determine the condition of the wetland and whether it is trending in a positive or negative direction (questions 2a – 2e may help in this determination). In this metric reclamation refers to taking off soil and replacing with wetlands soils and seed bank (strip mining), restoration involves seeding and management of wetland area, management includes a management system such as light to moderate grazing and/or fire and may include spraying of unwanted species.

Score	Rating Description
	EXCELLENT. Wetland is at or near reference condition (12 pts).
	GOOD POTENTIAL. Wetland is disturbed in some way so not at reference condition, but could achieve reference condition easily over time (10 pts).
	MODERATE POTENTIAL. Wetlands is disturbed, but with proper management and time it could return to reference condition (7 pts).
	MODERATELY POOR POTENTIAL. Through proper management and potential restoration/reclamation the wetland may return to reference condition. (5 pts).
	POOR POTENTIAL. Minor potential for return to reference condition, but restoration/reclamation would be needed (2 pt).
	NO POTENTIAL. No potential for return to reference condition without extreme restoration/reclamation efforts (0 pts).

	Total for Metric 2 (out of possible 57).

Metric 3. Vegetation

3a. Invasive species (include in estimate of 3m buffer of low prairie zone). Amount of aerial plant covered by invasived species. Invasive species (native or non-native) include but are not limited to brome, reed canary, quack, kentucky blue, and crested wheat grasses, as well as canada thistle and leafy spurge. Annual crops and weeds should be considered invasives.

Score	Rating Description
	ABSENT. (3 pts)
	NEARLY ABSENT. <5% aerial cover of invasive species (1 pt)
	SPARSE. 5-25% aerial cover of invasive species (0 pt)
	MODERATE. 25-75% aerial cover of invasive species (-1 pts)
	EXTENSIVE. >75% aerial cover of invasive species (-3 pts)

3b. Overall condition of wetland based on plant species using best professional judgment from professional wetland botanist. Walk around wetland area making mental note of plant species present, variety, abundance, etc.

Score	Rating Description
	VERY GOOD (20 pts). Undisturbed native area with a variety of plant species throughout wetland (grasses, sedges, rushes, forbs, etc). Moderate grazing may be utilized. No major impairments to area.
	GOOD (15 pts). Area is still relatively native with a good variety of species. There is an impairment (road, haying, spraying, etc) that has affected the condition of the wetland.
	FAIR (10 pts). Area has been impaired either in the past and is recovering or is currently being impaired but not by something that would decimate the plant community. (CRP, haying, etc.)
	POOR (5 pts). Area is heavily disturbed but there are some plant species still intact. Plant community will consist mostly of non-native annual species, but there may be some native or perennials present. Large populations of invasive species may be present.
	VERY POOR (0 pt). Wetland is heavily disturbed (cropping, hayland, etc) and the plant community if one exists consists of mostly non-native annual species with very little variety. Invasive species may dominate the plant community.

	Total for Metric 3 (out of possible 23).

TOTAL.

Score	
	Total from Metric 1.
	Total from Metric 2.
	Total from Metric 3.
	Rapid Assessment Score

Total points possible is 100:

Condition Ratings are as follows:
Good = 69-100
Fair High = 53-68
Fair Low = 27-52
Poor = 0-26

Score	
	Total for entire wetland.
	Overall condition rating for wetland (Good, Fair, or Poor).

Comments____

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