ASSESMENT OF WETLAND WATER QUALITY AND PLANT SPECIES COMPOSITION ACROSS THE RURAL, PERI-URBAN, AND URBAN GRADIENT

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Alexis Amber Steinman

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Natural Resources Management

March 2017

Fargo, North Dakota

North Dakota State University
Graduate School

Title

ASSESMENT OF WETLAND WATER QUALITY AND PLANT SPECIES COMPOSITION ACROSS THE RURAL, PERI-URBAN, AND URBAN GRADIENT

By

Alexis Amber Steinman

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Christina Hargiss
Chair

Dr. Jack Norland

Dr. Thomas Desutter

Approved:

March 29, 2017	Edward Shawn Dekeyser
Date	Department Chair

ABSTRACT

The Prairie Pothole Region, specifically eastern North Dakota, has experienced intense disturbance from agricultural demands and urban sprawl. This study assessed wetlands across the rural, peri-urban, and urban gradient to determine the impacts of urbanization on water quality and vegetation composition. Thirty wetlands were randomly selected and compared based on land use type and the impervious to pervious surface ratio within one mile of each wetland. Water quality samples were taken in 2015 and 2016, and a vegetation assessment was completed at all wetlands. Results indicate disturbance from urbanization impacts wetland water quality and vegetation composition. Rural wetland water quality and vegetation significantly differ from both peri-urban and urban wetlands, whereas peri-urban and urban wetland water quality and vegetation do not differ. Information from this study is useful to wetland professionals across the globe as urban development and sprawl continue to impact wetlands.

ACKNOWLEDGEMENTS

I would like to thank my major professor Dr. Christina Hargiss for the opportunity to grow as an individual academically and professionally. Dr. Hargiss challenged, mentored, and inspired me throughout my graduate assistantship. I would also like to thank Dr. Jack Norland for his time, knowledge, and assistance on many aspects of my graduate research in the office and out in the field. I am grateful for the many occasions where Dr. Norland met with me to explain and mentor my work with statistical analysis software, data interpretation, and study design. Thank you, Dr. Thomas DeSutter for your guidance and support during my graduate research. I appreciate your insight, knowledge, and attention to detail that improved my study and writing. A special thank you to Mike Ell and the North Dakota Department of Health for their financial support of this project. Also, thank you to Dr. Eakalak Khan and the North Dakota Water Resource Research Institute for my selection as a fellow and financial support for this project.

I would also like to thank the many people that assisted me during my fieldwork and data entry. Kayla Graber, Amy Gnoinsky, and Jesse Riley each spent many hours out in the field with me. Their positive attitude, hard work ethic, and support regardless of the weather conditions helped me immensely. Jeremy Hackley and Greg Lund both spent numerous hours entering and organizing my vegetation data.

Finally, I would like to thank my family, fiancé, and close friends. The support and encouragement from all of you has helped me work hard, maintain my focus, and keep working through each obstacle I encountered over the past two years. Each of you was a vital component to my success.

Alexis Amber Steinman

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Global human population growth and urban development have caused concern as human activities alter and degrade natural areas across the landscape. Urban development and sprawl create a gradient of development. Rural (undeveloped), peri-urban (semi-developed), and urban (developed) areas experience various types, intensities, and durations of disturbances that influence wetland water quality and vegetation. However, the extent of degradation from anthropogenic disturbances, including the urban environment, on wetland water quality in eastern North Dakota has not been previously assessed. The Fargo-Moorhead Metropolitan area comprised of urban areas such as Fargo and West Fargo, North Dakota, USA and Moorhead, Minnesota, USA have experienced population growth and urban sprawl outward into the surrounding predominantly agricultural production focused rural landscape. The impact of urban sprawl on rural, peri-urban, and urban wetlands within and surrounding the cities of Fargo and West Fargo is unknown. Therefore, the purpose of this project was to determine whether water quality and vegetation of wetlands are impacted by urban development. The specific objectives of the project include:

1) Determine if urbanization impacts wetland water quality and vegetation;
2) Acquire baseline water quality data of urban and peri-urban wetlands within North Dakota;
3) Compare physical and chemical water quality parameters between rural, peri-urban, and urban wetlands;
4) Assess the changes in wetland plant species composition (annual/biennial/perennial, native/introduced) across the gradient; and

5) Compare Floristic Quality Index (FQI) scores and C-Values between rural, peri-urban, and urban wetlands.

CHAPTER 1. LITERATURE REVIEW

Urban ecology is a relatively new field of study compared to other divisions of ecology that are older and more extensively studied. Traditional ecology began approximately 150 years ago, and studies primarily focused on natural ecosystem processes, patterns, and distribution of organisms (Alberti 2005). Traditional ecology did not initially consider humans as drivers of change within the natural environment. However, observational studies related to created, restored, and heavily modified spaces by humans eventually lead to the development of the field of urban ecology (McDonnell and Pickett 1990; Gaston 2010). The field of urban ecology began approximately 30 years ago to address environmental concerns associated with humans and urban areas (Gaston 2010). The field of urban ecology recognizes urban ecosystems as complex systems that require an understanding of a wide range of ecological processes, social interactions, and land use modifications that influence the urban environment (McDonnell and Pickett 1990; Alberti 2005; Gaston 2010).

Current and future research are imperative as global urbanization and urban sprawl continue to increase. Approximately 50 percent of the world's population currently lives in urban areas, and the urban population density is expected to increase to approximately 66 percent by 2050 (United Nations 2015). As a result, the amount of area impacted by urban development and land use changes have increased.

1.1. Rural, Peri-Urban, and Urban Gradient

Typically, areas that have historically been classified as natural or rural communities shift towards developed urban and semi-developed peri-urban areas. One major problem within the field of urban ecology; however, is the lack of cohesion between professionals' definitions of urban areas. There is not one clear definition or universal standard to classify urban areas. Each country is allowed to use their own criteria to characterize and define urban areas. However, within the literature, urban areas are typically defined by the degree of population density or presence of impervious infrastructures such as roads, electricity, piped water, and sewers (McDonnell and Pickett 1990; United Nations 2015; U.S. Census Bureau 2016). In addition, peri-urban areas do not have a universal definition or standard. Across the literature, peri-urban areas are a developing transitional zone between the rural and urban environment, which is sometimes referred to as the suburban, outskirts, or fringe of an urban area (McKinney 2002; Nechyba and Walsh 2004). Rural areas within the literature have a more cohesive definition. Rural areas are typically classified by a high-density pervious surfaces, low population density, and land use associated with agriculture practices (United Nations 2015; US Census Bureau 2015).

The rate of urbanization and land use alterations along the rural to urban gradient is influenced by the availability of natural resources, the local economy, and linkages to other cities (Rees and Wackernagel 1996; United Nations 2015). The rural to urban gradient typically has a population density that decreases as the distance from the urban core increases (McDonnell and Pickett 1990; McKinney 2002; Alberti 2005). Areas that were previously classified as urban areas experience new development and urban sprawl outward from the urban center, which results in encroachment on agricultural and natural landscapes within the surrounding area (Nechyba and Walsh 2004; United Nations 2015). This transition from an undeveloped rural environment to a semi-developed peri-urban environment and finally to a developed urban environment occurs as people move out of the rural environment to gain economic incentives provided within the urban center (United Nations 2015).

The rural to urban gradient experiences frequent human disturbances. Previous studies have found that as commercial and residential urban development increase, land use changes disrupt the function of ecosystem services (Foley et al. 2005), degrade water quality (Brown and Vivas 2005; Foley et al. 2005), cause watershed impairment (Brown and Vivas 2005; Foley et al. 2005), and fragment and degrade wildlife habitat (Foley et al. 2005). In addition, land use changes like urban development influence wetland plant communities across the gradient. Similar results were found by several studies, which determined that the total number of introduced, non-native, or exotic species present increased, the total number of native perennials decreased, and the total number of annual species increased as urbanization increased (McDonnell and Pickett 1990; Hass and McDonnell 2007; Ehrenfeld 2008).

1.1.1. Rural Wetlands

Rural wetlands form from precipitation that infiltrates into the soil and eventually discharges into wetlands, which is characteristic of the depressional wetlands of the Prairie Pothole Region (Kantrud et al. 1989). The lack of impervious surfaces within the rural (undeveloped) landscape allows water to naturally flow, infiltrate, and recharge wetlands. Thus, rural natural wetlands typically contain plant species within the low prairie, wet meadow, and shallow marsh wetland vegetative zones (Kantrud et al. 1989; Booth 1991). Potential problems associated with rural wetlands include disturbances from agricultural practices, livestock grazing, application of herbicides, and hydrological alterations such as drainage and irrigation ditches (NRCS 2006).

1.1.2. Peri-Urban Wetlands

Peri-urban wetlands are on the edge or fringe between the rural landscape and the dense urban development (Nechyba and Walsh 2004). These wetlands receive combined disturbances to hydrology and plant species composition from agricultural, industrial, commercial, and residential areas (Nechyba and Walsh 2004). Hydrological influences from urban areas include surface ratio alterations and artificial construction of detention ponds. The surface ratio alterations result in impervious surfaces causing runoff and a higher influx of water into the system (Brabec et al. 2002). Thus, hydrological alterations may impact the plant communities present at each peri-urban site by creating fluctuating dry and wet conditions that influence the presence of tolerant and intolerant species to the frequently fluctuating conditions.

1.1.3. Urban Wetlands

Urban wetlands are often constructed and highly altered systems. Many urban wetlands manage storm water runoff and surges artificially (Owen 1995; Brabec et al. 2002; Dahl 2011) or provide aesthetic recreational opportunities (Ehrenfeld 2000). Anthropogenic disturbances and alterations of the urban landscape influence the hydrology and plant communities of constructed wetlands (Kennedy and Mayer 2002; Seabloom and Van Der Valk 2003). Alterations to wetland hydrology include the use of culverts, dikes, concrete, berms, buildings, and parking lots (Brabec et al. 2002; Dahl 2011). These hydrological alterations ultimately influence the urban wetland plant communities by increasing the quantity, intensity, and frequency of water flowing through the system (Brabec et al. 2002). Thus, plant species that are not tolerant to stressful conditions such as frequent periods of wetting and drying may not be able to survive. The widespread impervious surfaces concentrate and transport excess nutrients, pollutants, and metals within the system leading to higher concentrations of salts, oils, and sediments (Brabec et al. 2002; Khatri and Tyagi 2015).

Problems associated with urban wetlands are the lack of undisturbed natural habitat, high rates of disturbance, and extensive degradation of existing wetlands (Grayson et al. 1999). In addition, the amount of impervious surfaces within urban areas has distorted the balance between impervious and pervious surfaces, which effects storm water quality and quantity within the system (Brabec et al. 2002). As a result, city planners are challenged with mitigating the effects of increased storm water surges and increased pollutants (Dahl 2011). Thus, constructed wetlands or storm water detention/retention ponds are built to handle the excess water, and compensate for loss of natural wetlands across the gradient (Owen 1995; Brabec et al. 2002; Dahl 2011). Constructed wetlands are designed as multi-use systems to manage storm water surges as wet detention ponds (Owen 1995), remove excess nutrients (Vymazal 2007), and provide recreational opportunities (Ehrenfeld 2000).

Urban-constructed wetlands typically have an impermeable layer of rock and other materials, often termed “riprap,” used for aesthetics or erosion control surrounding the edge of the wetland, which is used at peri-urban and urban wetlands to improve the aesthetics of the area by creating a clean and neat appearance that many urban dwellers prefer (Smardon 1988; Brabec et al. 2002). The thick layer of rock prevents vegetation from penetrating and establishing within the wet meadow and shallow marsh zones.

1.2. Water Quality in the Prairie Pothole Region

Hydrologic setting, topographic location, climatic changes, soil type, vegetation presence or absence, and human activities are all factors that influence the water quantity and quality of PPR wetlands (USGS 1996). Wetlands typically remediate pollutants naturally through absorption and transformation; however, if the rate of input of sediment, organic matter, and nutrients exceeds the functional capacity of a given wetland, then the wetland no longer has the capability to treat excess contaminants (Seelig and Dekeyser 2006; Gooddy et al. 2014). Excess contaminants left untreated have the potential to contaminate other bodies of water, and eventually concentrations will become high enough for eutrophication or toxicity to occur (MPCA 2007; Seelig and Dekeyser 2006; Dalh 2011).

Typically, water quality parameters are monitored to provide a method to gauge the quality of water within rivers, streams, lakes, or wetlands. The North Dakota Department of Health (NDDoH) protocol for a general chemistry analysis requires adequate samples to assess water quality parameters including total suspended solids (TSS), total dissolved solids (TDS), nutrients complete (TKN, NO_2, NO_3, NH_3, NH_4, and P), nutrients complete dissolved, major cations and anions, trace metals, and e.coli (NDDoH 2011). All of these parameters are found naturally across the landscape; however, human activities are linked to higher concentrations from disturbance (Neary et al. 1988; NRCS 2006; MPCA 2007).

The U.S. Geological Survey and NDDoH are two of the agencies that monitor water quality within the state of North Dakota. However, monitoring efforts primarily focus on river, stream, and lake water quality, and exclude wetlands that do not qualify as a ‘small lake’ within the region (NDDoH 2003). Studies have been conducted within the PPR specifically to assess water quality of wetlands (Cruezer et al. 2016), but to the author’s knowledge, few if any have looked at water quality in urban areas and a comparison of water quality across the rural, peri-urban, and urban gradient has not been previously assessed.

1.2.1. Water Quality in Urban Areas Across the Globe

Land use changes from increased urban development are strongly correlated with water chemistry parameters (Tran et al. 2010; Hettiarchchi et al. 2011; Khatri and Tyagi 2015). The USGS completed a national survey of water quality that included rural and urban development trends across the United States (USGS 1999). The USGS (1999) found that rivers and streams surrounded by agricultural land and urban developments contained medium-to-medium high concentrations of nitrogen, phosphorous, herbicides, and insecticides. Rivers near agricultural land contained higher concentrations of nitrogen and phosphorous, whereas rivers near urban areas contained higher concentrations of insecticides and phosphorous.

Kovacic et al. (2006) assessed water quality in the densely agricultural Mississippi River Basin. Non-point source surface water and tile drainage were assessed in two wetlands before entering the Lake Bloomington reservoir to determine if water quality changed. Kovacic et al. (2006) found that both wetlands absorbed and transformed the nitrogen and phosphorous contaminants from runoff which in turn effectively reduced the amount of nitrogen and phosphorous loaded into the reservoir.

Khatri and Tyagi (2015) compared surface and ground water quality of wetlands in both rural and urban areas, but did not distinguish the peri-urban areas. They discussed three categories of factors that influence water quality: 1) natural (wind deposition, geology, climate, weathering, etc.); 2) rural (agriculture, runoff from croplands, feedlots, mining operations, pasture land); and 3) urban (industrial discharge, municipal discharge, landfills, domestic effluent, impervious surfaces). They determined that differences exist between rural and urban water quality mainly in nitrates, phosphates, total dissolved solids, and heavy metals, which they related back to rural and urban sources of contamination.

Hettiarchchi et al. (2011) studied wetland water quality surrounding the City of Colombo, Sri Lanka for a five-year period. They found that water quality declined over time as the city’s population grew. Water quality parameters including phosphates, fecal coliforms, and heavy metals exceeded ambient water quality standards. Hettiarchchi et al. (2011) determined that domestic wastewater from the city was drastically degrading water quality of the surrounding wetlands within a short period of time.

Gooddy et al. (2014) assessed water quality for three years within a peri-urban floodplain adjacent to the city of Oxford, United Kingdom. Nitrogen concentrations were assessed to determine if a nearby landfill was contaminating ground or surface water within the floodplain. Piezometers were installed at various distances along the floodplain to monitor ground water, and surface water samples were periodically taken for analysis. Results determined that peri-urban areas are an important buffer that acted as a sink for nitrogen from the landfill, but acted as a source of nitrogen once concentrations rose above the absorption and transformation functional capacity as water moved between developed and undeveloped land (Gooddy et al. 2014).

1.3. Wetland Vegetation in the Prairie Pothole Region

The Glacial Lake Agassiz Basin (GLAB) historically supported native tall grass prairie vegetation including big blue stem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), indiangrass (*Sorghastrum nutans*), and little blue stem (*Schizachyrium scoparium*) (NRCS 2006). Common tree species found in the GLAB include Bur oak (*Quercus macrocarpa*), American basswood (*Tilia americana*), American elm (*Ulmus americana*), eastern cottonwood (*Populus deltoids*), green ash (*Fraxinus pennsylvanica*), and willows species (*Salix spp*.) (NRCS 2006). The United States Department of Agriculture PLANTS database and the Department of the Interior technical report, *Coefficients of Conservatism for the Vascular Flora of the Dakotas and Adjacent Grasslands*, were both references used to identify vegetation within the GLAB (TNGPFQAP 2001; NRCS 2008).

Previous research suggests that anthropogenic disturbances influence plant communities of rural wetlands. Rural wetlands throughout the PPR have been extensively studied, but the majority of research in North Dakota has focused on the Missouri Coteau sub-ecoregion of the PPR. The Missouri Coteau is the largest waterfowl production area within the state of North

Dakota, and currently contains the highest density of depressional wetlands within the state (Kantrud and Newton 1996).

Dekeyser et al. (2003) developed the Index of Plant Community Integrity (IPCI), which is a method used to assess wetland plant communities. This study included wetlands that experienced varying intensities of disturbance from low disturbance native rangeland to highly disturbed cropland. Plant data from wetland sites was used to classify each wetland based on the quality of the vegetation present within the wetland as very good, good, fair, poor, very poor (Dekeyser et al. 2003). This work was continued by Hargiss et al. (2008) and Hargiss et al. (2017) and assessed numerous wetlands using the IPCI and similar methods across the PPR to understand the condition of wetlands under a variety of disturbances. These studies all compared wetland plant data based on intensity of disturbance; however, none of them included urban development as a source of disturbance.

Additional research within the PPR by Euliss et al. (2006) focused on land use changes and restoration potential of depressional wetlands to perform ecosystem services. Assessments included restored, drained, non-drained, and reference condition seasonal and semi-permanent wetlands within the PPR. Carbon sequestration within plant tissues, accumulation in sediments, and soil organic carbon were the focus of Euliss et al. (2006); however, the degradation and loss of PPR wetlands was evident throughout the article.

Dekeyser et al. (2009) assessed the physical parameters of plant communities within the low prairie vegetative zone as a function of disturbances i.e. cropland, rangeland, and introduced monocultures of grass stands. Methods included use of the Hydrogeomorphic Model (HGM), which determined that the low prairie plant community is at risk of invasion by exotic plant species as disturbance increases (Dekeyser et al. 2009).

Although the Missouri Coteau sub-ecoregion of the PPR has had extensive rural vegetative assessments conducted, few studies have been completed in the GLAB of eastern North Dakota and western Minnesota. Galatowitsch et al. (1998) assessed wetland wet meadow vegetation in relation to land use within eastern North Dakota and western Minnesota. They found that disturbances from urbanization and agriculture decrease the overall native abundance of plant species within the wet meadow zone and increase the abundance of non-native and weedy species present (Galatowitsch et al. 1998).

1.4. Urban Vegetation Research

Reinelt et al. (1998) studied the impact that urbanization had on depressional wetlands near Puget Sound, Washington to create a management plan for wetlands and stormwater. Plant community and amphibian data was collected for seven years at 19 wetlands to determine if conversion of land altered the communities. Researchers found that the watershed imperviousness significantly affected the hydroperiod. Any wetlands that experienced at least a 20 cm change contained fewer species within the wet meadow and shallow marsh zone (Reinelt et al. 1998).

Previous urban wetland studies, outside of the study area, have not always specifically referred to the peri-urban area. Rather, studies determined the effect of land use on suburban, semi-developed, industrial, or fringe of the urban environment. Wetland studies by Galatowitsch et al. (1998) and McKinney (2008) each determined that peri-urban wetlands had intermediate levels of disturbance that promote a peak in species richness, whereas excessive disturbance or lack of disturbance will lead to plant communities with low species richness overall. In addition, previous studies by Hope et al. (2003) and Ehrenfeld (2008), not within the PPR, have found that species abundance increases within the peri-urban environment due to the addition of landscaping ornamental species and urban gardens that add additional species to the already existing native and introduced communities present. To the author's knowledge, prior research has not specifically focused on assessing peri-urban wetland plant communities within the PPR.

Previous research suggests that urban wetlands typically contain species located within the wet meadow and shallow marsh zones that are tolerant of hydrological fluctuations and frequent wetting and drying periods associated with storm water runoff (Galatowitsch et al. 1989; Seabloom and Van Der Valk 2003; Doherty and Zedler 2014). Galatowitsch et al. (1989) observed that *Lemna minor, Typha x glauca, and Phalaris arundinacea* are typical species found in areas receiving stormwater, and all three species are tolerant of frequent disturbance. Doherty and Zedler (2014) determined that dominant gramminoid species like *Typha x glauca* and *Phalaris arundinacea* were likely to establish and outcompete less dominant species and sensitive carex species within wetlands absent management or control strategies. McKinney (2008) focused on biodiversity of plants in urban areas and found that management and land use can strongly influence the species present within the urban environment. Plant diversity increased in urban areas as a result of unintentional seed dispersion from traffic routes and pets, or intentional seed dispersion from the incorporation of landscaping ornamentals, food for pets, or other human uses (McKinney 2008).

Hope et al. (2003) and Ehrenfeld (2008) found that the diversity of vegetation present within urban areas along with areas frequently disturbed by humans increased. Hope et al. (2003) determined that increased socioeconomic status of urban dwellers allowed a higher diversity of plant species within urbanized areas, since these areas typically contain commercial and residential developments with landscaping and urban gardens. Similar to Hope et al. (2003), Ehrenfeld (2008) determined that plant species present in urban residential and commercial areas are influenced by the surrounding land-use. Urban areas had a higher diversity of species present including native, non-native, and ornamental species. However, industrial and commercial areas had fewer non-native and invasive species than the urban areas, which Ehrenfeld (2008) hypothesized was a result of the lack of ornamental plantings frequently found in urban residential areas.

1.5. Prairie Pothole Region Characteristics

The PPR of North America is one of the most wetland rich ecosystems in the world encompassing an area of 780,000 km^2 within Canada, North Dakota, South Dakota, Minnesota, Montana, and Iowa (Luoma 1985). The GLAB is a sub-eco region of the PPR located along the eastern edge of North Dakota (Figure 1.1, 48a) (Bryce et al. 1998). The GLAB was formed from the late Pleistocene's fluctuating glacial activity, which left behind deposits as Lake Agassiz drained (Sloan 1972). Historically, the GLAB contained the highest density of prairie pothole wetlands within the state of North Dakota prior to drainage (Kantrud and Newton 1996). The prairie pothole wetlands created from deglaciation have unique geology and hydrology that influence the distribution and plant species composition of wetlands (Stewart and Kantrud 1971; Kantrud et al. 1989; Euliss et al. 2006).

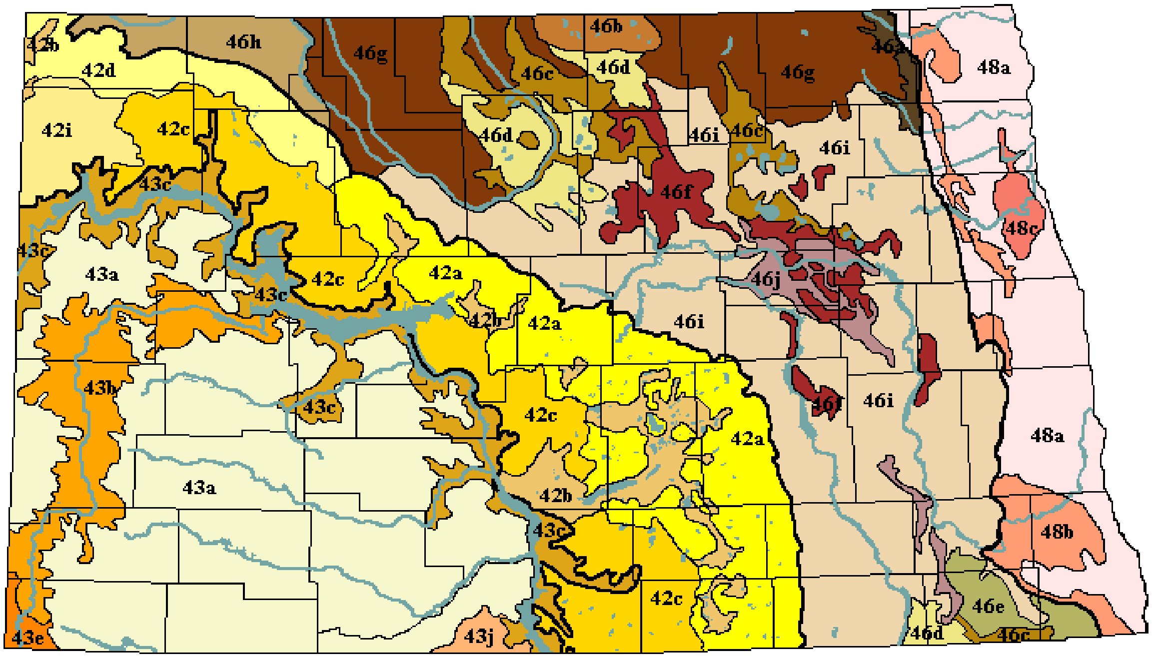


Figure 1.1. Ecoregions of North Dakota (Bryce et al. 1998). 48a – Glacial Lake Agassiz Basin

1.5.1. Climate

North Dakota has a continental climate with long cold winters and short hot summers (Johnson et al. 2005), and the average annual precipitation for the GLAB is 18 to 24 inches (NRCS 2006). The average daily temperatures and precipitation are highly variable across the PPR; however, the variability influences vegetation tolerance and establishment within the region (Kantrud et al. 1989). The North Dakota Agriculture Weather Network (NDAWN) Fargo station was used to acquire the monthly growing season precipitation for 2015 and 2016 (Figure 1.2).

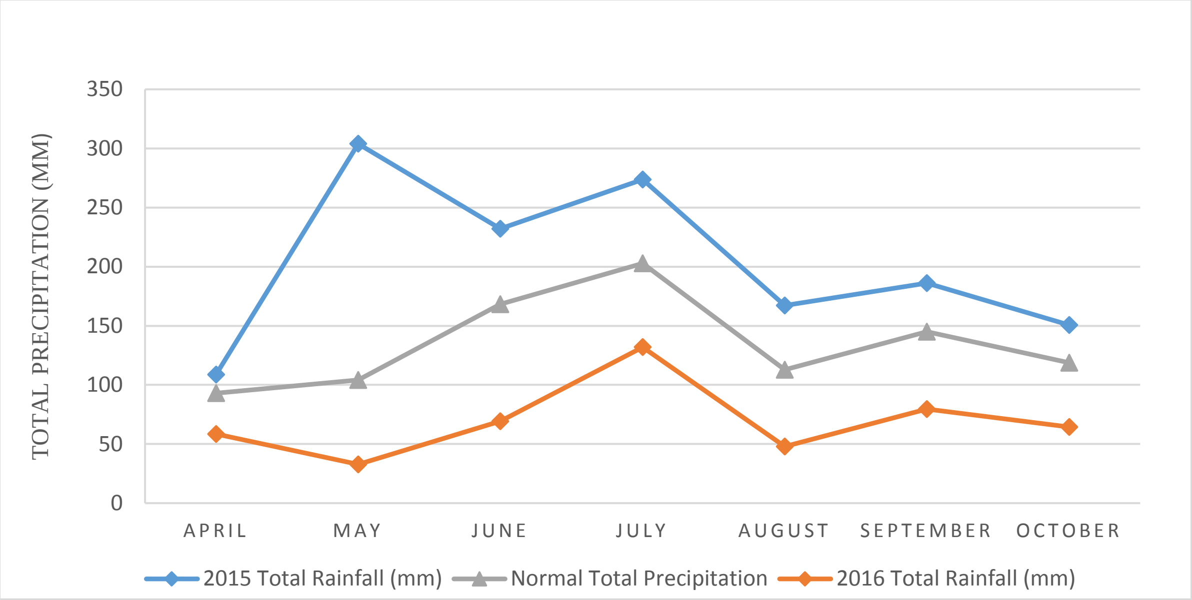


Figure 1.2. Comparison of 2015 and 2016 total precipitation (mm) for Fargo, ND (NDAWN 2017).

1.5.2. Soils

Soils within the region belong to the soil order of Mollisols or Vertisols, and typically are loamy or clayey textured, and poorly drained or very poorly drained (NRCS 2006). Soils within the GLAB are nutrient rich and fertile for agricultural production. Common soil series within the GLAB included in this study include: Bearden, Fairdale, Fargo, Hegne, Kindred, LaDelle, Lindaas, Nutley, Overly, Rauville, Ryan, and Urban Land – Aquerts Complex (NRCS 2016).

1.5.3. Land-Use

Wetlands across the rural, peri-urban, and urban gradient within the PPR are susceptible to anthropogenic disturbances related to land-use. The combination of a high abundance of fertile Mollisols and an extremely flat landscape make the GLAB one of the top agricultural production areas within the continental United States (USGS 2016). The main row crops include *Triticum aestivum* (spring wheat), *Glycine max* (soybeans), *Solanum tuberosum* (potatoes), *Beta vulgaris* (sugar beets), *Zea mays* (corn), oil-producing crops, and edible beans (NRCS 2006).Thus, approximately 79% of the GLAB is regularly plowed and drained for agricultural production, 20% of wetlands remain, and 1% of land is classified as urban (NRCS 2006). Although the primary industry in the GLAB is agriculture production, urban areas such as Fargo and West Fargo, North Dakota, USA and Moorhead, Minnesota, USA, which make up the Fargo-Moorhead Metropolitan area are experiencing growth and expansion.

The cities of West Fargo and Fargo combined are the largest metropolitan area within the state of North Dakota stretching 163.84 square kilometers with a population of 928.47 people per square kilometer (U.S. Census Bureau 2016). The combined population of West Fargo and Fargo in 2010 was 131,382, which grew to 152,120 in 2015 (U.S. Census Bureau 2016). The West Fargo and Fargo's urban development includes 14,196 commercial businesses and 60,716 residential dwellings (U.S. Census Bureau 2016). City officials believe that the City of Fargo's urban population growth is a direct result of refugee resettlement programs, local economic growth, and the recent Bakken oil boom (City of Fargo 2015). Land-use changes and urban sprawl are occurring within the study area to compensate for urban population growth within Fargo and West Fargo. The metropolitan area has a clear gradient of development that includes undeveloped rural areas to semi-developed peri-urban fringe, and a developed urban center.

1.5.4. Hydrological Alterations

Frequent hydrological alterations have occurred within the GLAB to improve agriculture production and urban development. The GLAB contains the Red River Basin hydrological unit codes 090201 and 090202 (USGS 2016). This portion of eastern North Dakota encompasses highly fertile mollisol soils with an extremely flat topography, which promotes agriculture production within the area (Brookes 2016). However, the flat topography throughout the watershed causes frequent flooding and ponding of water within depressions (Kantrud et al.

1989). These depressional wetlands can be cumbersome for agricultural production and urban development. Therefore, approximately 80% of the wetlands in the Red River Basin are drained, filled, or altered (NRCS 2006).

In addition, hydrological alterations associated with urban development are prevalent within the region. Residential and commercial construction such as dredging, soil compaction, removal of vegetation, addition of buildings, the installation of culverts and lift stations to control storm flows, and other impermeable infrastructure impact the hydrological regime (McDonnell and Pickett 1990; Brabec et al. 2002; United Nations 2015). These activities have been found to promote erosion and sedimentation (Werner and Zedler 2002), increase nutrients, heavy metals, and other pollutants within the system (Brabec et al. 2002; Wang et al. 2007), influence plant communities (Owen 1999; Galatowitsch et al. 1998; Ehrenfeld 2008) and disrupt the water regime (Brabec et al. 2002; Dahl 2011).

1.5.5. Prairie Pothole Region Wetland Vegetative Zones

Stewart and Kantrud (1971) defined PPR wetland zones and determined that the presence or absence of wetland zones combined with the distribution pattern of the zones are the primary factors for classifying wetlands within the PPR. The diversity and origin (native or non-native) of plant species and presence or absence of each zone helps indicate the overall condition of the wetland (Kantrud et al. 1989). Each wetland zone is a result of the hydro period of the wetland (Kantrud et al. 1989). The specific flood duration and frequency, disturbance frequency and intensity, and tolerance of plant species to these specific conditions in each wetland zone influences the presence of plant species within each wetland zone (Stewart and Kantrud 1971; Kantrud et al. 1989). Seasonal wetlands within the PPR typically have three observed zones (low prairie, wet meadow, and shallow marsh), which contain specific species tolerant of the conditions within that zone. Occasionally semi-permanent wetlands have a fourth zone (deep marsh), but our analysis excluded this zone due to the high variability of species present and the typical absence of vegetation across the gradient within the deep marsh.

1.5.5.1. Low Prairie Zone

Stewart and Kantrud (1971) described the low prairie zone of semi-permanent wetlands as an exterior zone of vegetation surrounding a wetland that primarily has dryer soil conditions than the wet meadow or shallow marsh zones. This zone typically has highly porous soils that prevent water from saturating the soil and pooling at the soil surface, which allows rapid infiltrations of precipitation and surface water runoff (Stewart and Kantrud 1971). The occasional flooding during extremely high water events like storm water surges and early spring snowmelt temporarily flood this zone, but does not last for an extended period. Thus, the low prairie zone usually contains plant species such as grasses and forbs that are adapted to dryer soils (Stewart and Kantrud 1971). Disturbance within the low prairie zone such as agriculture practices or urban development support the establishment of many non-native weedy species (Stewart and Kantrud 1971). Galatowitsch et al. (1998) determined that agricultural practices can lead to a low prairie vegetative zone that contains introduced and weedy species of grasses and forbs. Common low prairie zone anthropogenic disturbances across the gradient include mowing, grazing, herbicide use, and commercial agricultural practices, which have been shown to establish a monoculture of primarily corn or soybeans surrounding each rural wetland with other weedy disturbance tolerant species (NRCS 2006).

1.5.5.2. Wet Meadow Zone

Characteristics of the wet meadow zone classified by Stewart and Kantrud (1971) include rapid water infiltration, but occurs at a rate slower than the low prairie zone. The reduced infiltration results in an accumulation of surface water ranging from a duration of a few days to a few weeks within the wetland zone (Stewart and Kantrud 1971). Typical plant species found within this zone are delicate grasses, rushes, and sedges with low structure that are tolerant of fluctuating water levels but intolerant of excessive disturbance (Stewart and Kantrud 1971). Anthropogenic disturbances such as cultivation and urban development affect the delicate wet meadow zone (Galatowitsch et al. 1998). The frequent disturbance and water level fluctuations lead to the replacement of vegetation with bare ground that is susceptible to weedy and non-native plant species that are adapted to invade and establish within the disturbed wet meadow zone (Stewart and Kantrud 1971).

Previous research suggests that disturbance and land-use changes impact the species abundance of wet meadows (Galatowitsch et al. 1998; Seabloom and Van Der Valk 2003). Seabloom and Van Der Valk (2003) assessed plant communities of natural and restored wetlands within the PPR to determine whether restored wetlands, five to seven years old, contained typical zonal patterns that natural, undisturbed, wetlands contain. They found that natural and restored wetlands had different plant communities, restored wetlands lacked a well-developed wet meadow containing sedge species, and restored wetland zonation patters were present, however, they were not as defined as a natural wetland (Seabloom and Van Der Valk 2003).

1.5.5.3. Shallow Marsh Zone

Stewart and Kantrud (1971) described the shallow marsh zone of semi-permanent wetlands as the fringe between the wet meadow and deep marsh zones, which frequently sustains ponded surface water for an extended period (spring and early summer), but frequently dries during late summer and fall. Grasses, sedges, water tolerant forbs, and periodically present aquatic vegetation within the deeper open water dominate the shallow marsh zone (Stewart and

Kantrud 1971). Frequent periods of low precipitation may cause natural drawdown to occur, which results in shallow water levels or exposed bare soil in some cases. Non-native weedy plant species may establish during dry periods, however, these species typically do not tolerate the inundation that occurs within the shallow marsh zone during wet periods. Thus, shallow marsh species are able to re-establish and outcompete the weedy species (Stewart and Kantrud 1971).

1.6. Assessment Methods

1.6.1. Plant Species Composition Inventory

This study used a modified quadrat method using a 1.0 m^2 quadrat to assess the low prairie, wet meadow, and shallow marsh vegetative zones (Stewart and Kantrud 1971; Kantrud et al. 1989; Euliss and Mushet 2011). Previous studies by Dekeyser et al. (2003) and Hargiss et al. (2009) have utilized a similar method to assess the species found within each wetland zone and the overall species abundance of PPR wetlands. The quadrats were evenly distributed clockwise around the wetland; eight quadrats were measured within the low prairie zone, seven in the wet meadow, and five in the shallow marsh (Figure 1.3) (Dekeyser et al. 2003; Hargiss et al. 2009). Individual plant species found within the quadrat were identified and given a percent aerial cover. A secondary species list was also compiled and accounted for all species outside of the quadrat, but within the respective zone. Information from all primary and secondary species were compiled to give a complete plant species list for each zone, and an additional list of all plants within zones was compiled to give an entire plant species list for each site.

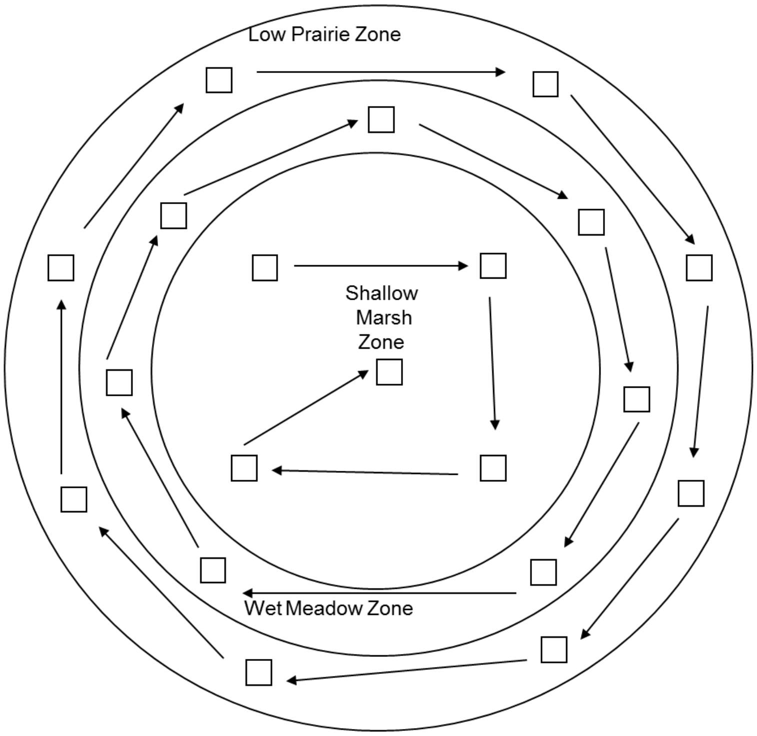


Figure 1.3. Vegetation inventory quadrat distribution method adapted from Hargiss 2009. Illustrates the three zones (Low Prairie, Wet Meadow, and Shallow Marsh) present within a typical seasonal wetland within the Prairie Pothole Region. The squares represent the 1.0 m^2 quadrat distributed clockwise around the wetland.

1.6.2. Floristic Quality Index

Wetland sites were assessed using the floristic quality index (FQI) acquired from the Coefficients of Conservatism for the Vascular Flora of the Dakotas and Adjacent Grasslands (TNGPFQAP 2001). The FQI evaluates the floristic quality of sites by assessing the species richness of the native plant community based on the plant species list. The FQI has been used to assess wetlands in the PPR and across the nation (Lopez and Fennesy 2002; Miller and Wardrop 2006; Hargiss et al. 2017). The following equation was utilized to calculate the $FQI = \sum C / \sqrt{N}$; where C is the coefficient of conservatism value for each native species on the species list and N is the number of native species on the species list (TNGPFQAP 2001). Non-native species are not included in FQI assessments, but rather influence scores based on their effects on native species that are recorded.

Lopez and Fennessy (2002) utilized the FQI to assess depressional wetland function in Ohio, USA. The wetland FQI scores declined as human disturbance increased, the total number of species per site decreased, and native perennial species present at urban sites declined (Lopez and Fennessy 2002). Overall, Lopez and Fennessy (2002) found that plants that are typically found in heavily cultivated or urban areas dominated wetlands with lower FQI scores.

1.7. Literature Cited

Alberti M (2005) The effects of urban patterns on ecosystem function. International Regional Science Review. 2: 168 – 192

Booth DB (1991) Urbanization and the natural drainage system – impacts, solutions, and prognosis. The Northwest Environmental Journal. 7(1): 105

Brabec E, Schulte S, Richards P (2002) Impervious surfaces and water quality: a review of current literature and its implications for watershed planning. Journal of Planning Literature. 16(4): 499 – 514

Brookes MS (2016) Lake Agassiz Plain ecoregion summary. United States Geological Survey. Date accessed: January 9, 2017. https://landcovertrends.usgs.gov/gp/eco48Report.html

Brown MT, Vivas MB (2005) Landscape development intensity index. Environmental Monitoring and Assessment. 101: 289–309

Bryce SA, Omernik JM, Pater DE, Ulmer M, Schaar J, Freeouf J, Johnson R, Kuck P, Azevedo SH (1998) Ecoregions of North Dakota and South Dakota. (Two sided color poster with map, descriptive text, summary tables, and photographs.) Reston,Virginia: U.S. Geological Survey (scale 1:1,500,000). ISBN 0-607-89384-2

City of Fargo (2015) City of Fargo, North Dakota consolidated plan housing and community development. Strategic Plan 2015 – 2019. 1-175

Cruezer J, Hargiss CLM, Norland JE, Desutter T, Casey FX, Dekeyser ES, Ell M (2016) Does increased road dust due to energy development impact wetlands in the Bakken region? Water Air Soil Pollution 227: 39 DOI 10.1007/s11270-015-2739-1

Cuffney TF, Meador MR, Porter SD, Gurtz ME (2000) Responses of physical, chemical, and biological indicators of water quality to a gradient of agricultural land use in the Yakima River Basin, Washington. Environmental Monitoring and Assessment. 64: 259-270

Dahl TE (2011) Status and trends of wetlands in the conterminous United States 2004 to 2009. U.S. Fish and Wildlife Service - Washington, DC, USA. Report to Congress. 1-112

DeKeyser ES, Kirby DR, Ell MJ (2003) An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. Ecological Indicators 3: 119-133

Dekeyser ES, Biondini M, Kirby D, Hargiss C (2009) Low prairie plant communities of wetlands as a function of disturbance: physical parameters. Ecological Indicators. 9: 296 – 306

Doherty JM, Zedler JB (2014) Dominant graminoids support restoration of productivity but not diversity in urban wetlands. Ecological Engineering. 65: 101-111
Ehrenfeld JG (2000) Evaluating wetlands within an urban context. Ecological Engineering. 15: 253 – 265

Ehrenfeld JG (2008) Exotic invasive species in urban wetlands: environmental correlates and implications for wetland management. Journal of Applied Ecology. 45: 1160 – 1169

Euliss Jr. NH, Gleason RA, Olness A, McDougal RL, Murkin HR (2006) North American prairie wetlands and important nonforested land-based carbon storage sites. USGS Northern Prairie Wildlife Research Center. Paper 23

Euliss Jr. NH, Mushet DM (2011) A multi-year comparison of IPCI scores for prairie wetlands: implications of temporal and spatial variation. USGS Northern Prairie Wildlife Research Center. Paper 273

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Pretice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science. 309: 570 – 574

Galatowitsch SM, Whited DC, Lehtinen R, Husveth J, Schik K (1998) The vegetation of wet meadows in relation to their land-use. Environmental Monitoring and Assessment. 60: 121 – 144

Gaston KJ (2010) Urban Ecology. Ecological Reviews. Cambridge University Press.

Gooddy DC, Macdonald DMJ, Lapworth DJ, Bennett SA, Griffiths KJ (2014) Nitrogen sources, transport and processing in peri-urban floodplains. Science of the Total Environment. 494-495

Grayson JE, Chapman MG, Underwood AJ (1999) The assessment of habitat in urban wetlands. Landscape and Urban Planning. 43: 227 – 236

Hargiss CLM, DeKeyser ES, Kirby DR, Ell MJ (2008) Regional assessment of wetland plant communities using the index of plant community integrity. Ecological Indicators 8:303-307

Hargiss CLM (2009) Estimating wetland quality for the Missouri Coteau ecoregion in North Dakota. Ph.D. Dissertation. North Dakota State University, Fargo, ND

Hargiss CLM, Dekeyser ES, Norland JE, Ell MJ (2017) Comparing tiers of a multi-tiered wetlands assessment in the Prairie Pothole Region. Wetlands Ecology Management. DOI 10.1007/s11273-017-9540-4

Hahs AK, McDonnell MJ (2007) Composition of the plant community in remnant patches of grassy woodland along an urban – rural gradient in Melbourne, Australia. Urban Ecosystems. 10: 355 – 377

Hettiarchchi M, Anurangi J, De Alwis A (2011) Characteristics and description of surface water quality in the threatened urban wetlands around the city of Colombo. Journal of Wetlands Ecology. 5: 10 – 19

Hope D, Gries C, Zhu W, Fagan W, Redman C, Grimm NB, Nelson AL, Martin C, Kinzig A (2003) Socioeconomics drive urban plant diversity. PNAS. 100: 8788 -8792

Johnson LB, Richards C, Host GE, Arthur JW (1997) Landscape influences on water chemistry in midwestern stream ecosystems. Freshwater Biology. 37: 193 -208

Johnson WC, Millett BV, Tagir G, Voldseth RA, Guntenspergen GR, Naugle DE (2005) Vulnerability of northern prairie wetlands to climate change. Bioscience. 55 (10): 863-872

Kantrud HA, Krapu GL, Swanson GA, Allen JA. (1989) Prairie basin wetlands of the Dakotas: a community profile. U.S. Fish and Wildlife Service Biological Report 85(7.28): 116

Kantrud HA, Newton WE (1996) A test of vegetation-related indicators of wetland quality in the prairie pothole region. Journal of Aquatic Ecosystem Health. 5(3): 177-191

Kennedy G, Mayer T (2002) Natural and constructed wetlands in Canada: an overview. Water Quality Resources Canada. 37 (2): 295 – 325

Khatri N, Sanjiy T (2015) Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. Frontiers in Life Science. 8: 23-39, DOI: 10.1080/21553769.2014.933716

Kovacic DA, Twait RM, Wallace MP, Bowing JM (2006) Use of created wetlands to improve water quality in the Midwest – Lake Blommington case study. Ecological Engineering. 28: 258 – 270

Lopez RD, Fennessy MS (2002) Testing the floristic quality assessment index as an indicator of wetland condition. Ecological Applications. 12 (2): 487 – 497

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

McDonnell MJ, Pickett STA (1990) Ecosystem structure and function along urban-rural gradients: An unexploited opportunity for ecology. Ecology. 71 (4): 1232 – 1237

McKinney ML (2008) Effects of urbanization on species richness: a review of plants and animals. Urban Ecosystems. 11:161 – 176
Miller SJ, Wardrop DH (2006) Adapting the floristic quality assessment index to indicate anthropogenic disturbance in central Pennsylvania wetlands. Ecological Indicators 6:313–326

Minnesota Pollution Control Agency (2007) Phosphorous: sources, forms, impact on water quality – a general overview. Water Quality – Impaired Waters 3 (12): 1-2

Natural Resources Conservation Service - United States Department of Agriculture (2006) Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296. 152-153
Natural Resources Conservation Service - United States Department of Agriculture (2008) Plants database. Available online at https://plants.usda.gov/java/. Accessed January – November 2016

Natural Resources Conservation Service - United States Department of Agriculture (2016) Web Soil Survey. Available online at http://websoilsurvey.sc.egov.usda.gov/. Accessed November 28, 2016

Neary DG, Swank WT, Riekerk H (1988) An overview of nonpoint source pollution in the southern United States. In proceedings of the symposium: the forested wetlands of the southern united states, Orlando, FL, USA, 12–14 July 1988. Gen. Tech. Rep. SE-50

Nechyba TJ, Walsh RP (2004) Urban sprawl. The Journal of Economic Perspectives. 18: 177-200

North Dakota Agricultural Weather Network (2017) NDAWN Fargo station total precipitation. North Dakota State University – NDAWN Center. Available online at: https://ndawn.ndsu.nodak.edu/. Date accessed: February – March 2017.

North Dakota Department of Health (2011) Standard operating procedures for field samplers. March 2011 (revised).Bismarck: North Dakota Department of Health, Division of Water Quality.

Owen CR (1995) Water budget and flow patterns in an urban wetland. Journal of Hydrology.169:171 – 187

Rees W, Wackernagel M (1996) Urban ecological footprints: Why cities cannot be sustainable – and why they are a key to sustainability. Environmental Impact Assesment Revision. 16: 223-248

Reinelt L, Horner R, Azous A (1998) Impacts of urbanization on palustrine (depressional freshwater) wetlands – research and management in the Puget Sound region. Urban Ecosystems. 2: 219 – 236

Seabloom EW, Van der Valk AG (2003) The development of vegetative zonation patterns in restored prairie pothole wetlands. Journal of Applied Ecology. 40: 92-100

Seelig B, Dekeyser ES (2006) Water quality and wetland function in the northern prairie pothole region. NDSU Extension Service. WQ – 1313: 1-30

Smardon RC (1988) Perception and aesthetics of the urban environment: review of the role of vegetation. Landscape and Urban Planning. 15: 85-106

Stewart RE, Kantrud HA (1971) Classification of natural ponds and lakes in the glaciated prairie region. Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service, Washington, D.C., USA. Resource Publication 92. 57

The Northern Great Plains Floristic Quality Assessment Panel (2001) Coefficients of conservation for the vascular flora of the Dakotas and adjacent grasslands: U.S. Geologic Survey, Biological Resources Division, Information and Technology Report USGS/BRD/ITR – 2001 -0001, 32.

Tran CP, Bode RW, Smith AJ, Klepper GS (2010) Land-use proximity as a basis for assessing stream water quality in New York State (USA). Ecological Indicators. 10 (3): 727-733

United Nations (2015) World urbanization prospects. The 2014 revision. Report. 1-157

United States Census Bureau (2015) Fargo, North Dakota quick facts. Date accessed: January 13, 2017. http://www.census.gov/quickfacts/table/POP060210/3825700

United States Census Bureau (2017) US and world population clock. Date Accessed: January 13, 2017. http://www.census.gov/popclock/

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

United States Geological Survey (1999) The quality of our nation's waters; nutrients and pesticides – national findings and their implications for water quality policies. Circular 1225

United States Geological Survey (2016) Boundary descriptions and names of regions, subregions, accounting units and cataloging units. Date Accessed: February 21, 2017. https://water.usgs.gov/GIS/huc_name.html#Region09

Vymazal J (2007) Removal of nutrients in various types of constructed wetlands. Science of the Total Environment 380: 48 – 65

Wang J, Da L, Song K, Li BL (2008) Temporal variations of surface water quality in urban, suburban, and rural areas during rapid urbanization in Shanghai, China. Environmental Pollution. 152: 387 – 393

Werner KJ, Zedler JB (2002) How sedge meadow soils, microtopography, and vegetation respond to sedimentation. Wetlands. 22 (3): 451 – 466

Wilcox DA, Kowalski KP, Hoare HL, Carlson ML, Morgan HN (2008) Cattail invasion of sedge/grass meadows in Lake Ontario: photointerpretation analysis of sixteen wetlands over five decades. Environmental Science and Biology Faculty Publications. Paper 55.

CHAPTER 2. ASSESMENT OF WETLAND PLANT COMMUNITIES ACROSS THE RURAL, PERI-URBAN, AND URBAN GRADIENT

2.1. Abstract

Wetlands across the rural, peri-urban, and urban gradient are impacted by anthropogenic activities such as agricultural production, industrial manufacturing, and urban development. Wetlands within the Glacial Lake Agassiz Basin sub-ecoregion of the Prairie Pothole Region, have experienced an increase in urban development and sprawl as the population density increases. A total of thirty wetlands (10 rural, 10 peri-urban, and 10 urban) were randomly selected for the study based on surrounding land use and the impervious to pervious surface ratio within one mile of each wetland. The vegetation community at each site was assessed using a quadrat method and data was used to compare the composition of wetlands within the three areas; as well as, the C-value and Floristic Quality Index (FQI). The study found that plant communities of rural wetlands differed from both urban and peri-urban wetlands. Peri-urban wetlands contained the highest species richness likely due to the introduction of weedy and ornamental species, and urban wetlands contained the lowest abundance of species likely due to the high density of riprap surrounding the wetland edge. Rural wetlands had a relatively high species richness; however, some rural wetland sites were permeated with a monoculture of *Typha x glauca,* an invasive cattail species. FQI scores and C-values declined across the gradient. Rural wetlands had the highest FQI scores and C-values, and urban wetlands had the lowest. Information from this study is useful to wetland professionals across the globe and city planners as urban development and sprawl continue to impact natural habitat and wetlands.

2.2. Introduction

Urbanization and urban sprawl are increasing across the world as the human population continues to increase. Approximately 50 percent of the world's population currently lives in urban areas, and the urban population density is expected to increase to approximately 66 percent by 2050 (United Nations 2015). As a result, the amount of area impacted by urban development has increased across the world. Approximately three percent of the world's land surface area or 3,506,830 km^2 is classified as urban land (CIESIN et al. 2011). Urban land is expected to increase as urban areas become more populated (United Nations 2015). Multiple factors promote the increased inhabitation of urban areas across the globe including technological advances, availability of resources, thriving local economies, and improved establishment of transportation linkages between cities (Rees and Wackernagel 1996; United Nations 2015).

As urban development sprawls across the world, the natural landscape is impacted. Previous research suggests that increased commercial and residential urban development across the world causes land-use changes that disrupt the function of ecosystem services (Foley et al. 2005), degrade water quality (Brown and Vivas 2005; Foley et al. 2005), cause watershed impairment (Brown and Vivas 2005; Foley et al. 2005), and degrade wildlife habitat (Foley et al. 2005). In addition, land-use changes can cause the number of invasive species within the plant community to increase (McDonnell and Pickett 1990; Alberti 2005; Ehrenfeld 2008).

Previous research has focused on determining the extent that urban development influences plant communities. These studies suggest that nonnative plant species distribution is associated with land use, land cover, and anthropogenic activities i.e. transportation routes, agricultural practices, and recreation (McDonnell and Pickett 1990; Ehrenfeld 2008; Decker et al. 2012). Both human population density and wide-scale agricultural practices have been shown to increase the abundance of nonnative plant species within an area (Ehrenfeld 2008; Decker et al. 2012). Also, land use alterations and human disturbances may cause the total number of perennial species to decline and the total number of annual species to increase within an area (Decker et al. 2012).

The plant communities present within rural and urban areas have been compared in previous research (Decker et al. 2012; Ehrenfeld 2008). However, most studies do not include the peri-urban component of the rural to urban gradient. Assessment of the rural, peri-urban, and urban gradient is vital to fully comprehend the influence that urbanization has on plant communities. Peri-urban areas have been shown to have increased plant species abundance due to species invasion from agricultural fields, ornamental plantings, and urban gardens (Nechyba and Walsh 2004). Yet, previous wetland research has not encompassed the peri-uban environment or the complete rural, peri-urban, and urban gradient.

Prairie Pothole Region (PPR) wetlands across the rural, peri-urban, and urban gradient experience a variety of disturbances based on their location in terms of land use. Rural wetlands are usually drained or filled for agricultural production, grazed by livestock, and receive agricultural runoff high in nitrogen and phosphorous from surrounding agricultural lands (Kantrud et al. 1989; Gleason et al. 2011). Peri-urban wetlands receive disturbances from both the rural and urban environment as these transitional wetlands receive agricultural runoff, urban storm water runoff, and invasion of plants from agricultural fields, ornamental plantings, and urban gardens (Nechyba and Walsh 2004). Urban wetlands are typically constructed storm water detention basins that artificially mitigate storm events (Brabec et al. 2002; Dahl 2011), experience frequent water level fluctuations, and have many introduced plant species from urban gardens and ornamental plantings (Brabec et al. 2002; Hope et al. 2002; Ehrenfeld et al. 2008).

As urban development is rapidly altering the global natural landscape, information on how different anthropogenic disturbances affect wetland plant communities across the gradient would be useful to mitigate potential impacts. The current state of wetland plant communities along the rural to urban gradient is not understood. Thus, this is the first study to specifically assess wetland vegetation across the entire rural, peri-urban, and urban gradient.

2.3. Methods and Materials

2.3.1. Study Area

The Glacial Lake Agassiz Basin (GLAB) is a part of the Lake Agassiz Plain Level III ecoregion located in eastern North Dakota (Bryce et al. 1998). Historically, the GLAB contained the highest density of prairie pothole wetlands within the state prior to drainage (Kantrud and Newton 1996). Today, approximately 20% of original wetlands remain within the GLAB (NRCS 2006). The combination of a high abundance of fertile mollisols and an extremely flat landscape make the GLAB one of the top agricultural production areas within the continental United States (Brookes 2016). Thus, approximately 79% of the GLAB is regularly plowed and drained for agricultural production (NRCS 2006).

Although the primary industry in the GLAB is agriculture production, urban areas such as Fargo and West Fargo, North Dakota, USA are experiencing growth and expansion. Fargo is the largest metropolitan area within the state stretching 163.84 square kilometers with a population of 928.47 people per square kilometer (U.S. Census Bureau 2015). The combined population of West Fargo and Fargo in 2010 was 131,382 citizens, which grew to 152,120 citizens in 2015 (U.S. Census Bureau 2015). The West Fargo and Fargo’s urban development includes 14,196 commercial businesses and 60,716 residential dwellings (U.S. Census Bureau 2015). Thus, land use changes and urban sprawl are occurring within the study area, and created the gradient of rural, peri-urban, and urban wetlands necessary to complete the study.

2.3.2. Site Selection

Aerial imagery, Web Soil Survey data, and ArcMap GIS software were utilized to locate potential wetland sites within 32 kilometers of the current urban boundary of West Fargo and Fargo. All wetlands were classified as rural, peri-urban, or urban wetlands based on the current land use from the National Land Cover Database (NLCD 2011), which was combined with ArcMap GIS software. The NLCD is a limited classification system, but a more detailed classification system is not available. Thus, the calculated surface ratios may under estimate the amount of pervious surfaces surrounding each wetland, ie. a backyard of a house while pervious would still likely show up as impervious. The zonal statistics tool in ArcMap GIS was used to calculate the ratio of impervious (developed) to pervious (undeveloped) surfaces found within 1.6 kilometers of each wetland. A compiled list of cover class data and calculated surface ratios per site are located within Appendix B. Thirty wetland sites, comprised of 10 rural, 10 peri-urban, and 10 rural wetlands, were randomly selected from a compiled list of 106 potential wetlands (Figure 2.1).

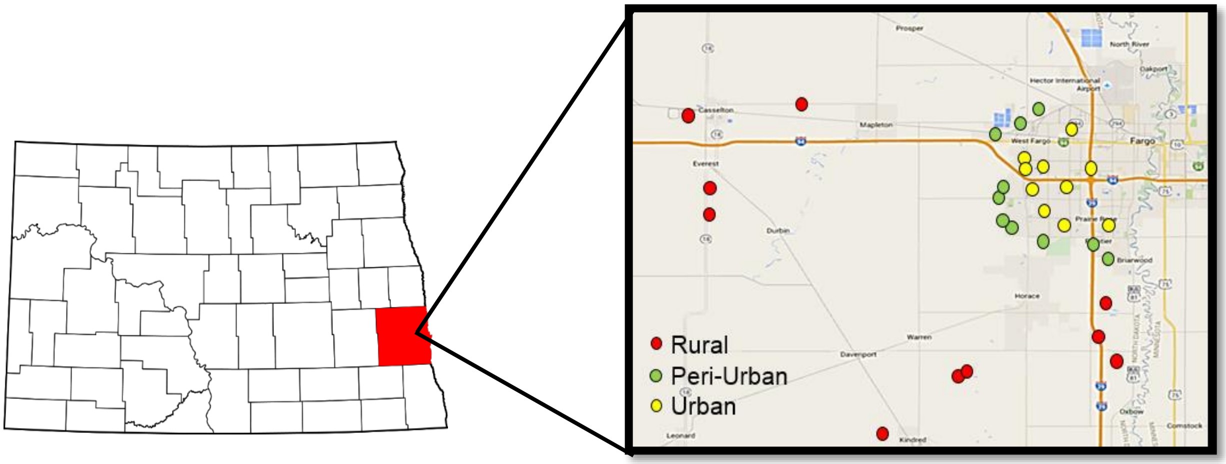


Figure 2.1. Study area and location of wetlands within Cass County, North Dakota. Yellow dots represent the ten urban wetlands, green dots represent the ten peri-urban wetlands, and red dots represent the ten rural wetlands.

The combined ArcMap software and NLCD layer determined a definitive rural, peri-urban, and urban gradient based on calculated surface ratios (Figure 2.2). Calculated surface ratios determined that rural wetlands within the GLAB had on average 9 percent impervious (developed) surfaces and 91 percent pervious (undeveloped) surfaces within 1.6 kilometers of each wetland. Peri-urban wetlands had on average 49 percent pervious (undeveloped) surfaces and 51 percent impervious (developed) surfaces; and urban wetlands had on average 3 percent pervious (undeveloped) surfaces and 97 percent impervious (developed) surfaces.

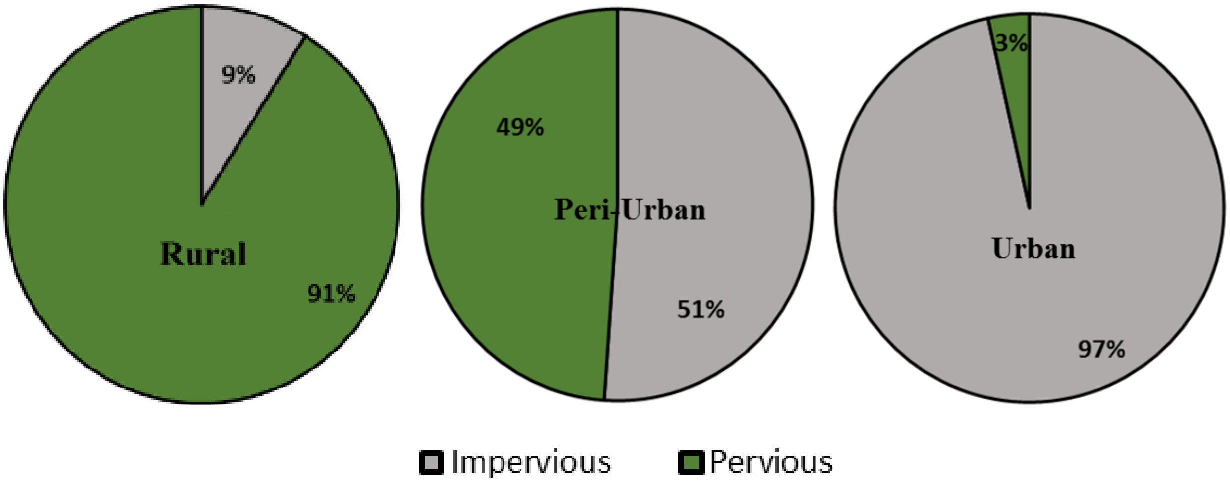


Figure 2.2. Calculated average impervious (developed) to pervious (undeveloped) surface ratios within 1.6 kilometers of each wetland across the rural, peri-urban, and urban gradient.

2.3.3. Vegetation Assessment

Wetland plant communities were assessed during July and August of the 2015 field season at all 30 sites. This study focused on entire plant species list for a site as well as the three vegetative zones of seasonally ponded wetlands in the PPR (Stewart and Kantrud 1971). The low prairie zone is the adjacent upland to the wetland, and usually contains plant species such as grasses and forbs that are adapted to dryer soils. The wetland boundary is the line between the wet meadow and low prairie zones. The wet meadow zone is the outer most zone of the wetland that typically contains the largest diversity of plant species including grasses, rushes, and sedges; and is typically the zone most indicative of disturbance (Stewart and Kantrud 1971; Dekeyser et al. 2003). The shallow marsh zone is the inner most zone of seasonally ponded wetlands and is surrounded by the wet meadow zone. This zone is typically the least diverse zone due to periodic inundation, plants found here include grasses, sedges, water tolerant forbs, and periodic aquatic vegetation within the deeper open water (Stewart and Kantrud 1971).

A modified quadrat method was utilized using a 1.0 m^2 quadrat to assess the low prairie, wet meadow, and shallow marsh vegetative zones (Stewart and Kantrud 1971; Kantrud et al.

1989; Euliss and Mushet 2011). The quadrats were evenly distributed clockwise around the wetland; eight quadrats were measured within the low prairie zone, seven in the wet meadow, and five in the shallow marsh (Dekeyser et al. 2003; Hargiss et al. 2008). Individual plant species found within the quadrat were identified and given a percent aerial cover. A secondary species list was also compiled and accounted for all species outside of the quadrat, but within the respective zone. Information from all primary and secondary species were compiled to give a complete plant species list for each zone, and an additional list of all plants within zones was compiled to give an entire plant species list for each site.

Wetland sites were assessed using the Floristic Quality Index (FQI) acquired from the Coefficients of Conservatism for the Vascular Flora of the Dakotas and Adjacent Grasslands (TNGPFQAP 2001). The FQI evaluates the floristic quality of sites by assessing the species richness of the native plant community based on the plant species list. The FQI has been used to assess wetlands in the PPR and across the nation (Lopez and Fennessy 2002; Miller and Wardrop 2006; Hargiss et al. 2017). The following equation was utilized to calculate the $FQI=\sum C/\sqrt{N}$; where C is the coefficient of conservatism value for each native species on the species list and N is the number of native species on the species list (TNGPFQAP 2001). Non-native species are not included in FQI assessments, but influence scores based on their effects on native species.

2.3.4. Statistical Analysis

Statistical analysis of the thirty rural, peri-urban, and urban wetlands' plant species were compared by assessing the species abundance for each wetland vegetative zone. Vegetation data was analyzed using Nonmetric Multidimensional Scaling (NMS) to graphically display the dissimilarity of plant species found at all thirty wetland sites. The NMS analysis was completed using PC-ORD Version 6 software (McCune and Grace 2011). The Relative Sorenson

Coefficient was the distance measure used to assess the vegetation data. Structure in the data was found by running PC-ORD with 500 of iterations of the data reducing to one axis from six with an instability criterion of 0.0001. Dimensions and model selection was based on: (1) a significant Monte Carlo test ($p<0.05$); (2) a model with a stress <25; (3) an instability <0.0001; and (4) a selection of axes was discontinued if the next axis did not reduce stress >5. Pearson's Correlation Coefficient $r\geq0.4$ or $r\leq-0.4$ were used to explain the ordination and appropriately reflect an interpretable effect size (McCune and Grace 2011).

Multi-Response Permutation Procedure (MRPP) was completed in PC-ORD Version 6 using the Relative Sorenson Coefficient distance measure to test comparisons between rural, peri-urban, and urban wetland groups. All pair-wise comparisons were adjusted using the Bonferroni correction for multiple *p* values (Gotelli and Ellison 2004).

Statistical analysis of variance for FQI scores and C-Values were compared between rural, peri-urban, and urban wetland groups by conducting a 1-way Anova test completed with SAS® software, Version 9.4 of the SAS System for Windows (Copyright © 2015 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). Significance of multiple pairwise comparisons was determined using Tuckey's method at the $p < 0.05$ significance level.

2.4. Results and Discussion

2.4.1. Vegetation by Zone Across the Gradient

The NMS analysis of the gradient's low prairie comprehensive plant species dataset produced a final solution with three dimensions which represented 83% of the variation (Final Stress = 11.22898; Final Instability = 0.00000; Number of Iterations = 77) in the data. Axis 1 represented 49.1% of the variation in the data, axis 2 represented 27.1% of the variation, and axis

3 represented 14% of the variation in the data (Figure 2.3 and 2.4). MRPP analysis determined that rural sites were significantly different from peri-urban, and urban wetland sites ($p < 0.05$), with the rural sites located at the left side of the NMS configuration while peri-urban and urban wetland sites are located on the right side of the NMS configuration.

All low prairie species positively associated with axis 2 were native perennials; whereas, species positively associated with axis 1 were a mix of native perennial, exotic perennial, and native annual species. Rural sites were highly variable due to rural low prairie zones experiencing intense disturbance from agricultural practices. Similar results have been documented in agriculture dominated wetland areas, which likely caused some of the low prairie zones to become degraded by dominant exotic and weedy species (Dekeyser et al. 2003). However, other rural sites contained low prairie zones with native perennial species including *Aster novae-angliae*, *Andropogon gerardii*, *Achillea millefolium*, *Andropogon scoparius*, and *Zizia aptera* that had a positive correlation with axis two. These sites typically did not experience disturbance from agricultural practices (e.g. cultivation or grazing). Rather, some rural landowners managed weedy species through herbicide applications and specifically planted native vegetation surrounding wetlands on their property.

All low prairie species positively associated with axis 3 were native perennials species except for *Euphorbia esula*. *Euphorbia esula* is an introduced perennial that is listed as a noxious weed within the state of North Dakota (Lym 2015). Previous research has found that *Euphorbia esula* outcompetes native species, establishes quickly within an area, and is not readily consumed by livestock (Olson and Cholewa 2009; Lym 2015).

The urban and peri-urban low prairie zones tended to contain a variety of native and introduced species along with annual and perennial species. However, similar to the rural sites, several peri-urban sites contained a high richness of native perennial species, which caused spread along axis 2 in the NMS configuration. These sites typically were planted and managed within city parks as urban initiatives to promote the establishment and restoration of native prairie vegetation within the city study area. Adding native plantings or native restoration areas within urban areas is a current trend (McDonnell and Pickett 1990; Hope et al. 2003; Ehrenfeld 2008).

The land use changes and disturbances associated with the peri-urban and urban environments promoted the presence of native annual species such as *Polygonum lapathifolium* within the low prairie zone; similar to results found in urban areas by Galatowitsch et al. (1998). Introduced species found in the low prairies of urban and peri-urban sites included *Taraxacum officinale, Poa pratensis, Plantago major, Setaria glauca, and Sonchus arvensis.* These species were found in the urban and peri-urban wetlands, but were not found to have a strong correlation with rural sites. Previous studies have found that these species are common weeds of urban environments (Lym 2015; Zuk et al. 2015). Urban and peri-urban sites had a strong correlation with *Ambrosia artemisiifolia* and *Hordeum jubatum.* The presence of *Hordeum jubatum* is associated with disturbed areas from excessive mowing and areas with high salt concentrations in the soil (Tesky 1992).

The NMS ordination of the rural, peri-urban, and urban gradient's wet meadow zone produced a two dimensional final solution representing 79.1% of the variation (Final Stress = 13.89292; Final Instability = 0.00000; Number of Iterations = 48) in the data; with axis one representing 55.0% and axis two representing 24.1% (Figure 2.5). MRPP analysis determined that rural sites were significantly different from peri-urban, and urban wetland sites ($p < 0.05$), with the rural sites located at the left side of the NMS configuration while peri-urban and urban wetland sites are located on the right side of the NMS configuration.

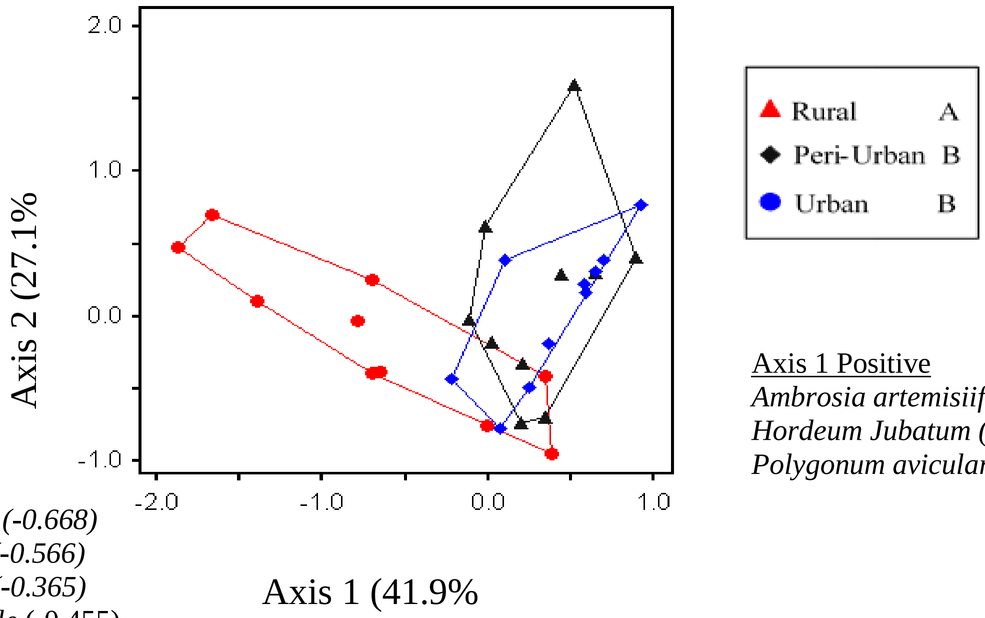
Rural, peri-urban, and urban sites contained introduced species in the wet meadow zone including *Phalaris arundinacea, Typha x glauca*, *and Bromus inermis. Typha x glauca* and *Bromus inermis* are introduced species within the study area (TNGPFQAP 2001). Previous research has found that species like *Typha x glauca*, *Bromus inermis,* and *Phalaris arundinacea* are dominant species that invade and outcompete less dominant species to form a dense monoculture (Seabloom and Van der Valk 2003; Wilcox et al. 2008). In addition, Stewart and Kantrud (1971) determined that many species associated with axis 1 are indicative of PPR wetlands that are degraded, but have not recently experienced cultivation through the wetland.

However, no species in the wet meadow zone NMS were found to have a correlation with the positive axis 1. Both urban and peri-urban sites were located at the positive end of axis 1. Riprap was present at eight of the ten urban wetlands and four of the ten peri-urban wetlands. These wetlands contained a limited number of species or did not contain any species within the wet meadow or shallow marsh vegetative zones.

NMS Comparing Rural, Peri-Urban, and Urban Low Prairie Species Richness along Axis 1 and Axis 2

Axis 2 Positive
Achillea millefolium (0.551)
Andropogon gerardii (0.537)
Andropogon scoparius (0.467)
Aster novae-angliae (0.537)

Axis 2 Negative (r< -0.4)
Aster simplex (-0.462)
Carex aquatilis (-0.399)
Cyperus erythrorhizos (-0.466)
Plantago major (-0.506)
Poa pratensis (-0.457)
Salix exigua (-0.441)
Setaria glauca (-0.514)
Sonchus arvensis (-0.522)



Axis 1 Negative
Asclepias syriaca (-0.668)
Bromus inermis (-0.566)
Euphorbia esula (-0.365)
Equisetum hyemale (-0.455)
Fraxinus pennsylvanica (-0.455)
Parthenocissus quinquefolia (-0.414)
Sagittaria cuneata (-0.365)
Sparganium eurycarpum (-0.490)
Thalictrum dasycarpum (-0.365)
Urtica dioica (-0.551)
Vitis riparia (-0.365)

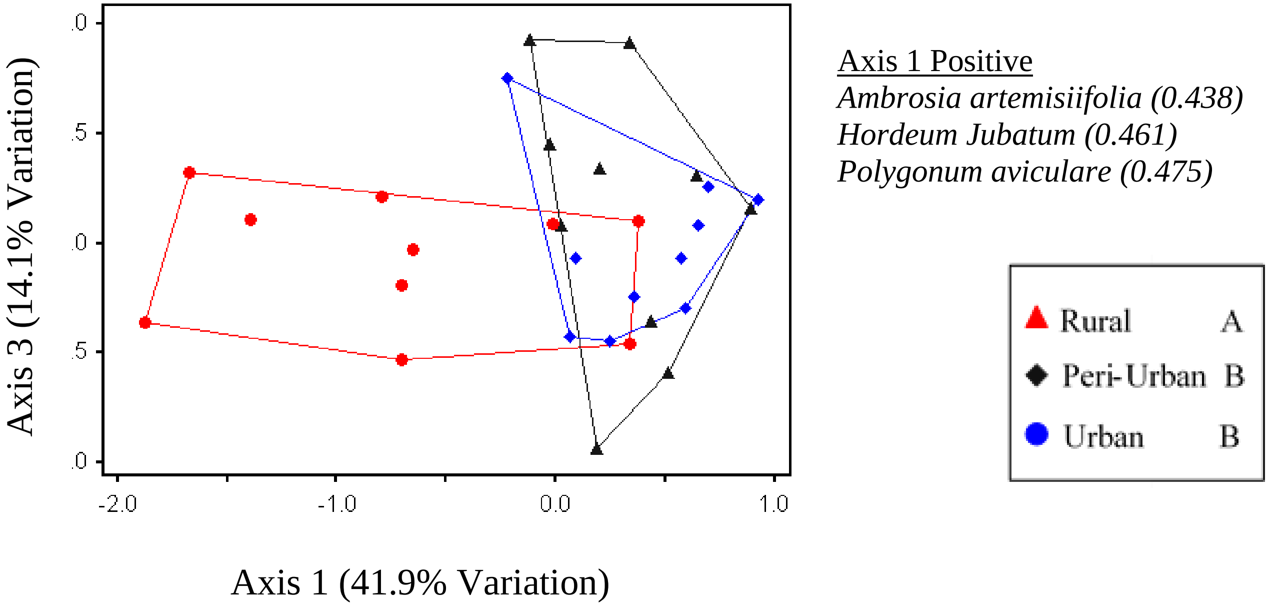
Axis 1 Positive
Ambrosia artemisiifolia (0.438)
Hordeum Jubatum (0.461)
Polygonum aviculare (0.475)

Figure 2.3. Nonmetric Multidimensional Scaling (NMS) ordination of low prairie plant species composition data along axis 1 and axis 2. Three convex hull polygons are displayed representing the Rural, Peri-Urban, and Urban wetland groups. All points in ordination space represent individual wetland sites from across the gradient. Groups followed by a different letter were significantly different ($p < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Plant species listed were associated with positive or negative correlations; r values are given in parenthesis.

NMS Comparing Rural, Peri-Urban, and Urban Low Prairie Species Richness along Axis 1 and Axis 3

Axis 3 Positive

Agropyron smithii (0.391)
Agrostis stolonifera (0.392)
Aster ericoides (0.382)
Aster simplex (0.466)
Coreopsis palmata (0.401)
Euphorbia esula (0.363)
Helianthus maximilianii (0.494)
Melilotus officinalis (0.0.672)
Monarda fistulosa (0.389)
Panicum virgatum (0.389)
Polygonum amphibian (0.397)
Salix exigua (0.359)
Scirpus acutus (0.399)
Solidago canadensis (0.415)
Solidago gigantea (0.397)



Axis 1 Positive

Ambrosia artemisiifolia (0.438)
Hordeum Jubatum (0.461)
Polygonum aviculare (0.475)

Axis 3 Negative

Cyperus erythrorhizos (-0.402)
Medicago lupulina (-0.437)
Poa annua *(-0.402)*
Poa pratensis (-0.485)
Taraxacum officinale (-0.391)
Trifolium repens (-0.432)

Axis 1 Negative

Asclepias syriaca (-0.668)
Bromus inermis (-0.566)
Euphorbia esula (-0.365)
Equisetum hyemale (-0.455)
Fraxinus pennsylvanica (-0.455)
Parthenocissus quinquefolia (-0.414)
Parthenocissus quinquefolia (-0.414)
Sagittaria cuneata (-0.365)
Sparganium eurycarpum (-0.490)
Thalictrum dasycarpum (-0.365)
Urtica dioica (-0.551)
Vitis riparia (-0.365)

Figure 2.4. Nonmetric Multidimensional Scaling (NMS) ordination of low prairie plant species composition data along axis 1 and axis 3. Three convex hull polygons are displayed representing the Rural, Peri-Urban, and Urban wetland groups. All points in ordination space represent individual wetland sites from across the gradient. Groups followed by a different letter were significantly different ($p < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Plant species listed were associated with positive or negative correlations; r values are given in parenthesis.

Riprap, an impermeable layer of rock and other materials used for aesthetics or erosion control, is used at peri-urban and urban wetlands to improve the aesthetics of the area by creating a clean and neat appearance that many urban dwellers prefer (Smardon 1988; Brabec et al. 2002). However, the presence of riprap caused the plant community to be reduced within the urban wet meadow and shallow marsh zones. The thick layer of rock prevents vegetation from penetrating and establishing within the wet meadow and shallow marsh zones.

Species located within the urban wet meadow and shallow marsh zones typically included plant species known to tolerate hydrological fluctuations from frequent wetting and drying periods associated with stormwater runoff. These species included the *Lemna minor*, *Typha x glauca*, and *Phalaris arundinacea.* Galatowitsch et al. (1989) observed that *Lemna minor*, *Typha x glauca, and Phalaris arundinacea* are typical species found in areas receiving stormwater, and all three species are tolerant of frequent disturbance. Doherty and Zedler (2014) determined that dominant gramminoid species like *Typha x glauca* and *Phalaris arundinacea* were likely to establish and outcompete less dominant species within wetlands absent management or control strategies. Urban wetlands within this study typically contained persistent dominant gramminoids or no species within the wet meadow or shallow marsh vegetative zones. Thus, the prevalence of riprap within the urban wetland wet meadow and shallow marsh zone resulted in a limited number of species or no species present that were counted as bare ground.

Urban and peri-urban sites lacked native perennial species in comparison to rural wetland sites including *Populus deltoids*, *Cornus stolonifera*, *Agropyron smithii*, *Salix exigua, Aster simplex,* and *Salix amygdaloides*. Four of these species are tree species that are common within the study area (TNGPFQAP 2001). The addition of riprap within the wet meadow zone likely reduced the presence of these species at urban and peri-urban sites which may account for why there are no species positively associated axis 1 at those sites (Smardon 1988).

Graphical NMS ordination of the shallow marsh data matrix was not produced by PC-Ord. The software's inability to produce a visual representation of the data occurred because of the lack of data structure and variability between the species found at each site. MRPP concluded that significant differences exist between the rural shallow marsh and the peri-urban and urban shallow marsh. Species found within the peri-urban and urban shallow marsh were not significantly different.

The species found within the shallow marsh were compared between rural, peri-urban, and urban wetlands. The analysis found that a few species dominated within the shallow marsh zone across the gradient, and other species were rarely found. *Typha x glauca, Lemna minor,* and *Potamogeton pectinatus* dominated the limited species found across the gradient's shallow marsh zone. Forty-three percent of the rural wetlands' shallow marsh contained *Typha x glauca,* forty-two percent contained *Lemna minor,* and fifteen percent contained *Potamogeton pectinatus*. This contrasted with the urban wetlands' shallow marsh, which contained twenty-three percent *Typha x glauca,* seventy-seven percent contained *Potamogeton pectinatus*, and *Lemna minor* was absent.

The rural wet meadow and shallow marsh plant communities were more diverse; however, the species richness within each zone was highly variable. Some rural wetlands were permeated by *Typha x glauca* (hybrid cattail), an invasive species in the area, and likely outcompeted and prevented the establishment of other plant species within the wet meadow and shallow marsh zones as has been shown by Wilcox et al. (2008). Other rural wetlands with limited anthropogenic influence and/or intensive management of cattails and reed canary had

NMS Comparing Rural, Peri-Urban, and Urban Wet Meadow Species Richness

Axis 2 Positive
Achillea millefolium (0.480)
Andropogon gerardii (0.496)
Aster novae-angliae (0.540)
Polygonum lapathifolium (0.384)

Axis 2 Negative
Agrostis stolonifera (-0.502)
Agropyron smithii (-0.506)
Aster simplex (-0.524)
Bidens frondosa (-0.368)
Cornus stolonifera (-0.500)
Populus deltoids (-0.491)
Salix amygdaloides (-0.594)
Trifolium pretense (-0.510)

Axis 1 Negative
Bromus inermis (-0.524)
Calamagrostis stricta (-0.359)
Convolvulus arvensis (-0.358)
Carex aquatilis (-0.359)
Lemna minor (-0.384)
Phalaris arundinacea (-0.744)
Polygonum lapathifolium (-0.509)
Scirpus fluviatilis (-0.395)
Sonchus arvensis (-0.358)
Sparganium eurycarpum (-0.394)
Typha x glauca (-0.401)
Urtica dioica (-0.428)

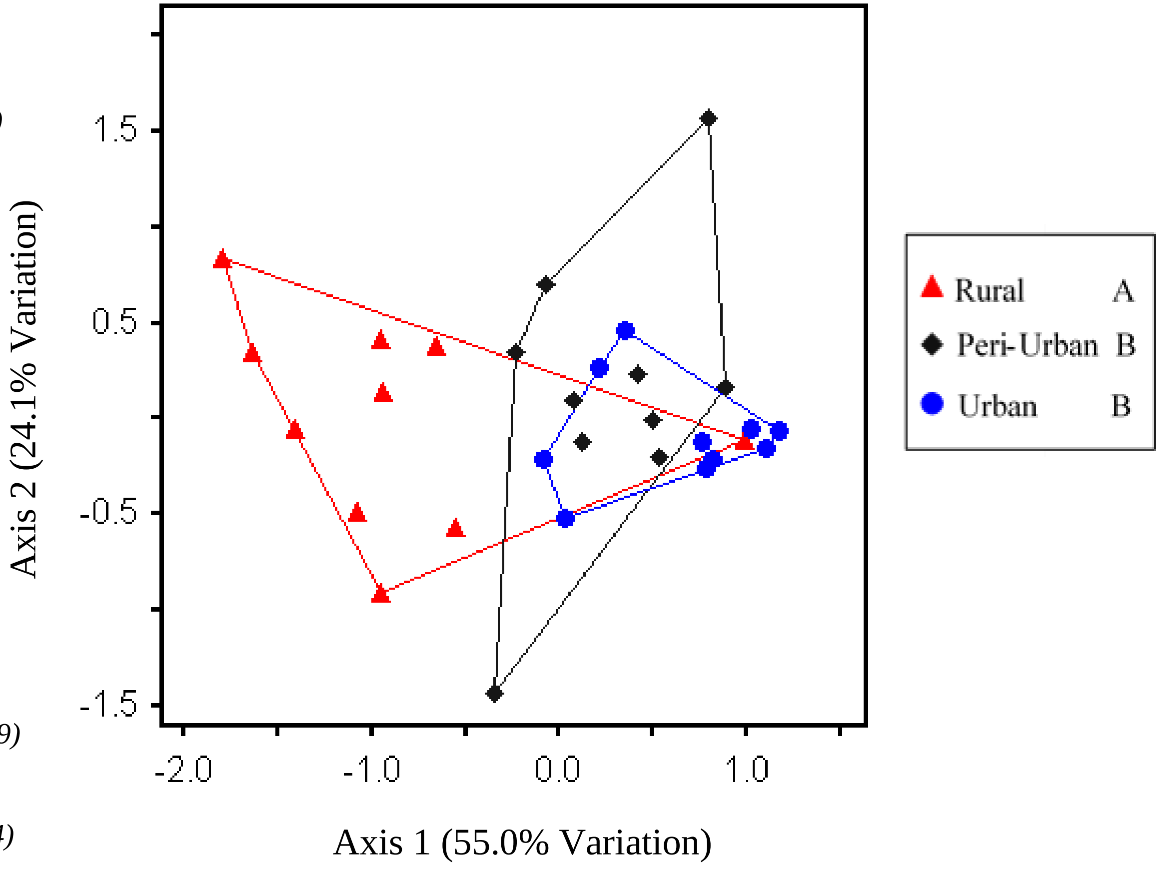


Figure 2.5. Nonmetric Multidimensional Scaling (NMS) ordination of wet meadow plant species composition data. Three convex hull polygons are displayed representing the Rural, Peri-Urban, and Urban wetland groups. All points in ordination space represent individual wetland sites from across the gradient. Groups followed by a different letter were significantly different ($p < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Plant species listed were associated with positive or negative correlations; r values are given in parenthesis.

highly diverse wet meadow and shallow marsh zones. Both zones contained species anticipated within the PPR’s natural depressional wetlands including numerous native grasses, sedges, rushes, and forbs that were not found as urbanization increased across the gradient (Stewart and Kantrud 1989).

Urban wetland plant species were highly variable by zone. The urban low prairie, the outer most zone of the wetland adjacent to the uplands, had highly diverse low prairie zones with planted and managed native grass and forb species, a mix of non-native and native species, and in some cases additional annual species transferred from urban gardens and flowerbeds. These results are similar to previous studies (McDonnell and Pickett 1990; McKinney 2008). McDonnell and Pickett (1990) determined along the rural to urban gradient urbanization promotes the establishment of a mix of native, non-native, and ornamental species that are either intentionally or unintentionally introduced into the area. McKinney (2008) focused on biodiversity of plants in urban areas and found that management and land use can strongly influence the species present within the urban environment. Plant diversity increased in urban areas as a result unintentional seed dispersion from traffic routes and pets, or intentional seed dispersion from the incorporation of landscaping ornamentals, food for pets, or other human uses (McKinney 2008).

2.4.2. Average C-Value and Floristic Quality Index

Assessment of the gradient’s plant species list illustrated a decline from rural to urban sites for the average C-value of native perennials with rural values significantly higher than and urban wetlands (Figure 2.6). The peri-urban C-value was not different from the others and were between the higher rural and lower urban values.

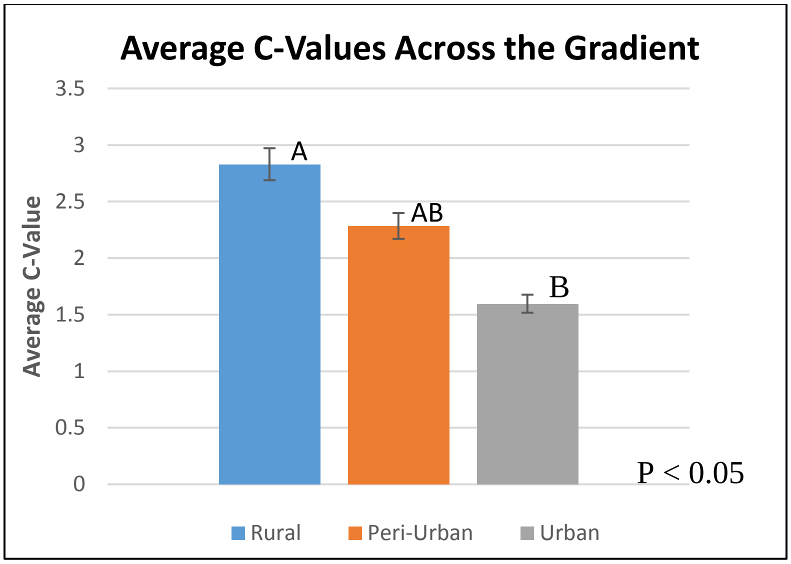


Figure 2.6. Average C-value of plant species found in rural, peri-urban, and urban wetlands across the gradient. Groups followed by a different letter were significantly different ($p < 0.05$).

C-values can potentially range from zero to ten within the region, where: 1) zero is indicative of weedy species that can inhabit and excel in highly disturbed areas; 2) one to four includes species that are found in both natural and degraded areas; 3) five to nine include species that are found in natural areas but have a low tolerance to disturbance; and 4) ten indicates species that are found in pristine and undisturbed natural areas (TNGPFQAP 2001). Euliss et al. (2006) found that C-values declined as degradation occurred due to the loss of disturbance intolerant species with high C-values. Our study's average C-values were low across the gradient. All three average C-value scores for rural, peri-urban, and urban wetlands were within the one to four category, which indicates that most species found across the gradient are found in both natural and degraded areas. The average C-values of native species across the gradient were utilized to calculate the FQI for rural, peri-urban, and urban wetlands.

Further assessment of the gradient's plant species list illustrated a decline from rural to urban sites for the average FQI value of native perennials with rural values significantly higher than the urban wetlands (Figure 2.7). The peri-urban FQI value was not different from the others and were between the higher rural and lower urban values. The FQI score was expected to decline as urbanization increased due to the increased disturbance in urban areas, a decrease in the overall total number of species at each site, and a decrease in native perennial species present at urban sites. Lopez and Fennessy (2002) found that wetlands with lower FQI scores were dominated by plants that are typically found in heavily cultivated or urban areas. Our study's findings partially contradict Lopez and Fennessy (2002), since rural wetlands had the highest average FQI score recorded across the gradient. The C-value and FQI results further support the NMS results above, which showed that wetlands across the gradient were in disturbed condition, but the species found in the rural and urban areas differed.

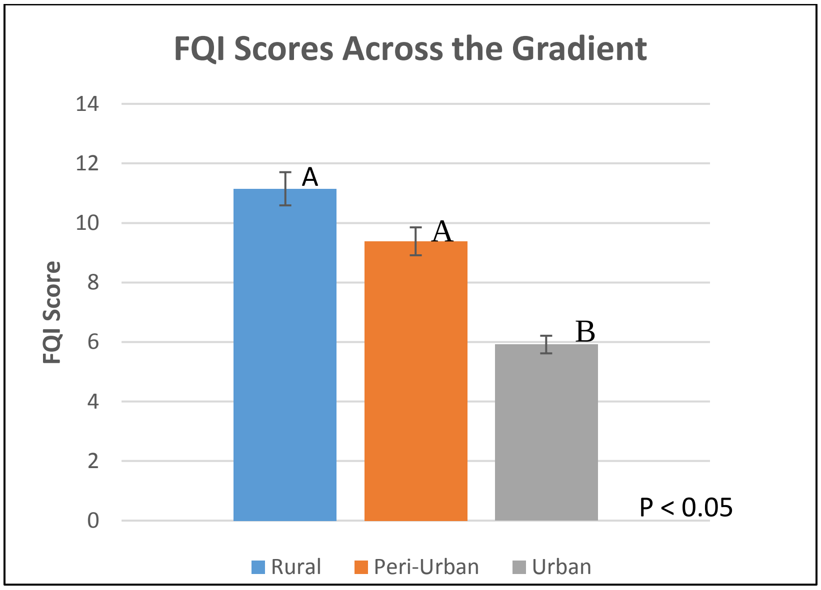


Figure 2.7. FQI score of plant species found in the rural, peri-urban, and urban wetlands across the gradient. Groups followed by a different letter were significantly different ($p < 0.05$).

2.4.3. Total Species Richness Across the Gradient

Analysis of the rural, peri-urban, and urban gradient's wetland species richness by zone indicated changes in the total number of species present within each rural, peri-urban, and urban wetland group (Table 2.1). The total number of observed species within wetlands across the rural, peri-urban, and urban gradient included species observed in the three vegetative zones (low prairie, wet meadow, and shallow marsh), the total number of native species and introduced species observed, and the total number of annual, biennial, and perennial species recorded. The full wetland vegetation comprehensive species lists including the scientific name, common name, C-Value, life form, origin, and indicator category can be found in Appendix C for rural wetlands, Appendix D for peri-urban wetlands, and Appendix E for urban wetlands.

Table 2.1. Cumulative observed wetland species richness per wetland zone.

Wetland Zone	**Total # Species Observed**	**Total # Species by Zone**	**Native**	**Introduced**	**Annual**	**Biennial**	**Perennial**
Rural	200						
Low Prairie		83	57	26	14	6	63
Wet Meadow		90	67	23	22	3	65
Shallow Marsh		27	23	4	6	0	21
Peri-Urban	247						
Low Prairie		98	62	36	27	3	68
Wet Meadow		128	93	35	39	6	83
Shallow Marsh		21	16	5	4	0	17
Urban	147						
Low Prairie		99	59	40	26	6	67
Wet Meadow		21	54	34	24	5	59
Shallow Marsh		27	23	4	6	2	19

The cumulative rural wetland species list contained 200 vegetative species, 247 species in the peri-urban area, and 147 species in the urban area. The peri-urban wetland plant species list contained a higher number of species than the rural or urban lists. Previous research on terrestrial areas across the gradient have found similar results and suggest that intermediate levels of disturbance promote a peak in species richness, whereas excessive disturbance or lack of disturbance will lead to plant communities with low species richness overall (Galatowitsch et al.

1998; Zerbe et al. 2003; McKinney 2008). In addition, studies have found the increase in species abundance within the peri-urban environment is due to the addition of ornamental horticulture species and urban gardens that add additional species to the already existing native and introduced communities present (Hope et al. 2003; Foley et al. 2005 and Ehrenfeld 2008). The current study did not assess the origin of plant species present, but only what was present on site. However, similar to previous research, we assume that there was additional ornamental horticulture species attributing to the higher number of species in the peri-urban environment.

Comparisons between average species richness per wetland between rural, peri-urban, and urban wetland groups for each wetland zone determined that the average number of species observed were not significantly different (Table 2.2). The average number of native perennials found in the low prairie, wet meadow, and shallow marsh zones of rural, peri-urban, and urban wetland sites were not significantly different. Significant differences were found between introduced species within the wet meadow zone between peri-urban and rural wetland sites, but urban wetland sites were not significantly different ($p<0.05$). Peri-urban wetlands contained the highest number of introduced species within the wet meadow zone, rural sites contained the lowest number of introduced species, and urban sites contained an average number of introduced species between the rural and peri-urban wetland sites.

Table 2.2. Observed average wetland species richness per wetland zone. Groups within a zone and species category followed by a different letter were significantly different ($p < 0.05$), and groups not followed by a letter were not significantly different ($p > 0.05$).

Wetland Zone	Total Species Observed	Native	Introduced
Low Prairie			
Rural	13.3	7.2	6.1
Peri-Urban	13.9	7.2	6.7
Urban	14.6	5.1	9.5
Wet Meadow			
Rural	9.3	5.7	3.6 B
Peri-Urban	12.9	6.6	6.3 A
Urban	11.1	6.9	4.2 AB
Shallow Marsh			
Rural	3.3	2.7	0.6
Peri-Urban	2	1.5	0.5
Urban	1.9	1.4	0.5

The vegetative richness increased within the peri-urban low prairie and wet meadow zones due to increased heterogeneity and moderate disturbance. The addition of urban landscaping and gardens added species to the already existing native and non-native species present. These findings are similar to Hope et al. (2003) and Ehrenfeld (2008). Both articles found that the richness of vegetation present within urban areas along with areas frequently disturbed by humans increased. Hope et al. (2003) determined that increased socioeconomic status of urban dwellers allowed a higher diversity of plant species within urbanized areas, since these areas typically contain commercial and residential developments with landscaping and urban gardens. Similar to Hope et al. (2003), Ehrenfeld (2008) determined that plant species present in urban residential and commercial areas are influenced by the surrounding land-use. Urban areas had a higher richness of species present including native, non-native, and ornamental species. However, industrial and commercial areas had fewer introduced and invasive species than the urban areas, which Ehrenfeld (2008) hypothesized was a result of the lack of ornamental plantings frequently found in urban residential areas.

Overall, native perennial species declined across the gradient. Rural wetlands on average contained 12 native perennial species, peri-urban wetlands contained 11, and urban wetlands contained 8 native perennial species. Rural wetlands on average contained 13 introduced perennials, annual, or biennial species, peri-urban wetlands contained 18, and urban wetlands contained 19 introduced perennial, annual, and biennial species. However, statistical analysis of the native perennial species and introduced, annual, and biennial species at each site across the gradient were not significantly different. These findings are likely due to increased disturbance that shifted the richness of native perennials, which are outweighed by the establishment of annuals, biennials, or non-native perennial species (Galatowitsch et al. 1998; Ehrenfeld 2008).

2.4.3.1. Low Prairie Zone

The cumulative species list indicated that the low prairie zone found in rural wetlands had a combined total of 83 species present, peri-urban wetlands had 98 species present, and urban wetlands had 99 species present. The total number of introduced species increased across the gradient within the low prairie wetland vegetative zone from 26 species recorded at the rural sites, 36 species recorded at the peri-urban sites, and 40 species recorded at the urban sites. Also, the total number of annual species increased across the gradient from 14 species recorded at the rural sites, 27 species recorded at the peri-urban sites, and 26 species recorded at the urban sites. The average number of species found in the low prairie zone at each rural wetland was 13.3 species, each peri-urban wetland was 13.9 species, and each urban wetland was 14.6 species. These findings were not significantly different.

The lack of significant differences between the rural, peri-urban, and urban low prairie vegetative zone likely occurred due to various anthropogenic disturbances across the gradient. Herbicide use and commercial agricultural practices used for corn and soybean production, the two primary agricultural crops produced within the state of North Dakota, may have influenced the area surrounding some rural wetlands promoting weedy disturbance tolerant species (NRCS 2006). Galatowitsch et al. (1998) determined that agricultural practices and urbanization can lead to a low prairie vegetative zone that contains introduced and weedy species of grasses and forbs.

The total number of species present at rural, peri-urban, and urban wetland sites were similar; however, as urbanization and disturbance increased the total number of introduced species increased, and the total number of annuals and introduced perennials increased. These findings are similar to other studies in which urban development and human disturbance influenced the total number of introduced, non-native, or exotic species present, and also found that the total number of native perennials decreased and the total number of annual species increased (McDonnell and Pickett 1990; Grimm 2000; Ehrenfeld 2008).

2.4.3.2. Wet Meadow Zone

The wet meadow zone for rural wetlands contained 90 species, while peri-urban wetlands had 128 species, and urban wetlands had 21 species. Previous research suggests that disturbance and land-use changes influence the species found in the wet meadow zone based on the presence of ornamental species, dominant introduced species, presence of riprap, and hydrological fluctuations (Galatowitsch et al. 1998; Seabloom and Van Der Valk 2003). We found that the richness of introduced species within the wet meadow was highest in the peri-urban wetlands at 6.3 species. Richness of introduced species was 4.2 in the urban wetlands, and introduced species richness was lowest in rural wetlands at 3.6. The wet meadow introduced species richness of rural and urban sites were significantly different. This is likely a result of the disturbance occurring within the urban area, a lack of established wet meadow in the urban areas, presence of riprap, and the response of sensitive wet meadow species to disturbance (Galatowitsch et al. 1998; Seabloom and Van Der Valk 2003).

2.4.3.3. Shallow Marsh Zone

The rural and urban shallow marsh zones contained a similar total number of native, introduced, and annual species present. Cumulatively, the rural wetlands had 27 species present, peri-urban wetlands had 21 species present, and the urban wetlands had 27 species present within the shallow marsh zone. The total number of native species within both the rural and urban shallow marsh zone were 23 species, whereas the total number of native species within the peri-urban shallow marsh zone was 16 species. The total number of introduced species within the rural and urban wetland shallow marsh zone were four species, whereas the total number of introduced species in the peri-urban shallow marsh was five species. The total number of perennial species and biennial species differed slightly between rural, peri-urban, and urban wetlands. Authors are unaware of any research that has specifically focused on the shallow marsh and its response to disturbance and urbanization. Comparisons between shallow marsh species richness per wetland across the gradient were not significantly different. On average, rural wetlands contained 3.3 shallow marsh species per site, peri-urban wetlands contained two species per site, and urban wetlands contained 1.9 species per site.

2.4. Conclusion

Wetland vegetation differed by zone and as a whole across the rural to urban gradient. Anthropogenic disturbances and alterations influenced the plant species distribution and composition of the study’s thirty wetlands. Rural and peri-urban wetlands typically had species in all three vegetative zones, whereas the urban wetlands did not consistently have an established wet meadow or shallow marsh zone due to riprap and frequent disturbance. Species richness increased within the peri-urban wetlands due to intermediate levels of disturbance and the introduction of ornamental species, whereas species richness declined in the urban wetlands.

Results from this project are vital for understanding the impact of urban development on wetlands of the PPR and the world. Wetlands, both natural and created, have the potential to provide ecosystem services to communities across the gradient. Effective incorporation of existing wetlands and improved management of constructed wetlands has the potential to improve water quality, flood mitigation, nutrient cycling, and plant species diversity. Establishment of vegetation and restoration of functioning wetland zones rather than riprapping or excessively mowing wetland zones will drastically improve the potential of ecosystem services. Further consideration of wetlands across the gradient as an interconnected system will increase wetland quality at the landscape level. Proper wetland management at a landscape level has the potential to improve water quality, increase wildlife habitat, and diversify plant species found across the rural to urban gradient.

2.5. Literature Cited

Alberti M (2005) The effects of urban patterns on ecosystem function. International Regional Science Review. 2: 168 – 192

Booth DB (1991) Urbanization and the natural drainage system – impacts, solutions, and prognosis. The Northwest Environmental Journal. 7(1): 105

Brabec E, Schulte S, Richards P (2002) Impervious surfaces and water quality: a review of current literature and its implications for watershed planning. Journal of Planning Literature. 16(4): 499 – 514

Brookes MS (2016) Lake Agassiz Plain ecoregion summary. United States Geological Survey. Date accessed: January 9, 2017. https://landcovertrends.usgs.gov/gp/eco48Report.html

Brown MT, Vivas MB (2005) Landscape development intensity index. Environmental Monitoring and Assessment. 101: 289–309

Bryce SA, Omernik JM, Pater DE, Ulmer M, Schaar J, Freeouf J, Johnson R, Kuck P, Azevedo SH (1998) Ecoregions of North Dakota and South Dakota. (Two sided color poster with map, descriptive text, summary tables, and photographs.) Reston,Virginia: U.S. Geological Survey (scale 1:1,500,000). ISBN 0-607-89384-2

Dahl TE (2011) Status and trends of wetlands in the conterminous United States 2004 to 2009. U.S. Fish and Wildlife Service - Washington, DC, USA. Report to Congress. 1-112

Decker KL, Allen CR, Acosta L, Hellman ML, Jorgensen CF, Stutzman RJ, Unstad KM, Williams A, Yans M (2012) Land use, landscapes, and biological invasion. Invasive Plant Science and Management. 5: 108-116

DeKeyser ES, Kirby DR, Ell MJ (2003) An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. Ecological Indicators 3: 119-133

Doherty JM, Zedler JB (2014) Dominant graminoids support restoration of productivity but not diversity in urban wetlands. Ecological Engineering. 65: 101-111

Ehrenfeld JG (2008) Exotic invasive species in urban wetlands: environmental correlates and implications for wetland management. Journal of Applied Ecology. 45: 1160 – 1169

Euliss Jr. NH, Gleason RA, Olness A, McDougal RL, Murkin HR (2006) North American prairie wetlands and important nonforested land-based carbon storage sites. USGS Northern Prairie Wildlife Research Center. Paper 23

Euliss Jr. NH, Mushet DM (2011) A multi-year comparison of IPCI scores for prairie wetlands: implications of temporal and spatial variation. USGS Northern Prairie Wildlife Research Center. Paper 273

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Pretice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science. 309: 570 – 574

Galatowitsch SM, Whited DC, Lehtinen R, Husveth J, Schik K (1998) The vegetation of wet meadows in relation to their land-use. Environmental Monitoring and Assessment. 60: 121 – 144

Gleason RA, Euliss NH, Tangen BA, Laubhan MK, Brown BA (2011) USDA conservation program and practice effects on wetland ecosystem services in the Prairie Pothole Region. Ecological Applications. 21 (3): S65 – S81

Gotelli NJ, Ellison AM (2004) A primer of ecological statistics. Sinauer Associates, Sunderland, Massachusetts

Grimm NB, Grove JM, Pickett ST, Redman CL (2000) Integrated approaches to long-term studies of urban ecological systems. Bioscience. 50: 571-584

Hargiss CLM, DeKeyser ES, Kirby DR, Ell MJ (2008) Regional assessment of wetland plant communities using the index of plant community integrity. Ecological Indicators 8:303-307

Hargiss CLM, Dekeyser ES, Norland JE, Ell MJ (2017) Comparing tiers of a multi-tiered wetlands assessment in the Prairie Pothole Region. Wetlands Ecology Management. DOI 10.1007/s11273-017-9540-4

Hope D, Gries C, Zhu W, Fagan W, Redman C, Grimm NB, Nelson AL, Martin C, Kinzig A (2003) Socioeconomics drive urban plant diversity. PNAS. 100: 8788 -8792

Johnson WC, Millett BV, Tagir G, Voldseth RA, Guntenspergen GR, Naugle DE (2005) Vulnerability of northern prairie wetlands to climate change. Bioscience. 55 (10): 863-872

Kantrud HA, Krapu GL, Swanson GA, Allen JA. (1989) Prairie basin wetlands of the Dakotas: a community profile. U.S. Fish and Wildlife Service Biological Report 85(7.28): 116

Kantrud HA, Newton WE (1996) A test of vegetation-related indicators of wetland quality in the prairie pothole region. Journal of Aquatic Ecosystem Health. 5(3): 177-191

Lopez RD, Fennessy MS (2002) Testing the floristic quality assessment index as an indicator of wetland condition. Ecological Applications. 12 (2): 487 – 497

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

Lym RG (2015) Identification and control of invasive and troublesome weeds in North Dakota. NDSU Extension Service. 1-76

McCune B, Mefford MJ (2011) PC-ORD. Multivariate analysis of ecological data. Version 6. MjM Software, Gleneden Beach, Oregon, U.S.A.

McDonnell MJ, Pickett STA (1990) Ecosystem structure and function along urban-rural gradients: An unexploited opportunity for ecology. Ecology. 71 (4): 1232 – 1237

McKinney ML (2008) Effects of urbanization on species richness: a review of plants and animals. Urban Ecosystems. 11:161 – 176

Miller SJ, Wardrop DH (2006) Adapting the floristic quality assessment index to indicate anthropogenic disturbance in central Pennsylvania wetlands. Ecological Indicators 6:313–326

Mushet DM, Euliss Jr. NH, Shaffer TL (2002) Floristic quality assessment of one natural and three restored wetland complexes in North Dakota, USA. Wetlands. 22 (1): 126 – 138

National Land Cover Database (2011) United States Geological Survey. Accessed from North Dakota GIS Hub: ND.HUB.LANDCLASS_ NASS_ 2013. Date accessed: June 2015

Natural Resources Conservation Service - United States Department of Agriculture (2006) Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296. 152-153

Nechyba TJ, Walsh RP (2004) Urban sprawl. The Journal of Economic Perspectives. 18: 177-200

Olson C, Cholewa AF (2009) Guide to nonnative invasive plants inventoried in the north. United States Forest Service Technical Report 201012. 1-189

Rees W, Wackernagel M (1996) Urban ecological footprints: Why cities cannot be sustainable – and why they are a key to sustainability. Environmental Impact Assesment Revision. 16: 223-248

Seabloom EW, Van der Valk AG (2003) The development of vegetative zonation patterns in restored prairie pothole wetlands. Journal of Applied Ecology. 40: 92-100

Smardon RC (1988) Perception and aesthetics of the urban environment: review of the role of vegetation. Landscape and Urban Planning. 15: 85-106

Stewart RE, Kantrud HA (1971) Classification of natural ponds and lakes in the glaciated prairie region. Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service, Washington, D.C., USA. Resource Publication 92. 57

Tesky JL (1992) Hordeum jubatum. Fire Effects Information System, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Web. Data Accessed: March 5, 2017. http://www.fs.fed.us/database/feis/

The Northern Great Plains Floristic Quality Assessment Panel (2001) Coefficients of conservation for the vascular flora of the Dakotas and adjacent grasslands: U.S. Geologic Survey, Biological Resources Division, Information and Technology Report USGS/BRD/ITR – 2001 -0001, 32.

United Nations (2015) World urbanization prospects. The 2014 revision. Report. 1-157

United States Census Bureau (2015) Fargo, North Dakota quick facts. Date accessed: January 13, 2017. http://www.census.gov/quickfacts/table/POP060210/3825700

United States Census Bureau (2017) US and world population clock. Date Accessed: January 13, 2017. http://www.census.gov/popclock/

Wilcox DA, Kowalski KP, Hoare HL, Carlson ML, Morgan HN (2008) Cattail invasion of sedge/grass meadows in Lake Ontario: photointerpretation analysis of sixteen wetlands over five decades. Environmental Science and Biology Faculty Publications. Paper 55.

Zerbe S, Maurer U, Schmitz S, Sukopp H (2003) Biodiversity in berlin and its potential for nature conservation. Landscape and Urban Planning 62 (3): 139-148

Zuk A, Knodel J, and Smith R (2015) Home lawn problems and solutions in North Dakota. NDSU Extension Service. 1-3

CHAPTER 3. ASSESSMENT OF WETLAND WATER QUALITY ACROSS THE RURAL, PERI-URBAN, AND URBAN GRADIENT

3.1. Abstract

Prairie Pothole Region of eastern North Dakota has experienced intense disturbance from increased agricultural demands and urban sprawl. This study assessed wetlands across the rural, peri-urban, and urban gradient for the first time in the region to determine the impacts of urbanization on water quality. Thirty wetlands (ten rural, ten peri-urban, and ten urban) were randomly selected and compared based on land use type and the impervious to pervious surface ratio within one mile of each wetland. Water quality samples were taken in 2015 and 2016. Assessment included chemical and physical parameters, which were compared spatially across the gradient and temporally between sampling periods. Results indicate disturbance from urbanization impacts wetland water quality. Spatially across the gradient, rural wetland water quality is significantly different from both peri-urban and urban wetlands, whereas peri-urban and urban wetland water quality are not significantly different. Temporally, differences between water quality parameters and sampling periods indicate that surrounding land use, land cover, and precipitation influence parameter concentrations within rural, peri-urban, and urban wetlands. Information from this study is useful to wetland professionals across the globe as urban development and sprawl continue to impact natural habitat and wetlands.

3.2. Introduction

Global urban development is occurring rapidly as the human population continues to grow exponentially worldwide. The current global human population is approximately 7.4 billion people (US Census Bureau 2017), and approximately half of those individuals live in urban areas (United Nations 2015). Future forecasts predict that the human population will continue to grow, increasing the density of current urban centers, and further stimulating the expansion of urban development outward into the surrounding less populous rural areas (United Nations 2015). Thus, the less populous areas will shift from a rural environment to a semi-developed peri-urban environment, and finally grow into an urbanized environment to accommodate the population growth (Rees and Wackernagel 1996). Typically, the rural to urban shift occurs as resources become available, technology improves, economies grow, and transportation between urban centers improves (Rees and Wackernagel 1996; United Nations 2015). However, this rapid growth and expansion of urban areas disturbs natural resources and ecosystem services within urban areas and the surrounding natural landscape.

The impact of urban sprawl and development on wetland water quality are widely unknown across the globe. Previous research has concentrated on the influence of urban development on water quality at the watershed scale (Houlahan and Findlay 2004). Urban development and land use changes critically impair watershed function (Johnson et al. 1997; Cuffney et al. 2001; Brown and Vivas 2005), increase pollutants within the system (Brabec et al. 2002; Wang et al. 2007), increase sedimentation (Werner and Zedler 2002), and shift the water regime due to an increase in impervious surfaces within the urban environment (Brabec et al. 2002; Dahl 2011).

Previous research specifically focused on urban development and wetland water quality suggests that land use and urbanization decrease wetland water quality (Brabec et al. 2002; Houlahan and Findlay 2004; Wang et al. 2007). Wetlands in urban areas tend to have surface water nutrient levels based on the surrounding land-use (Houlahan and Findlay 2004), and these nutrient levels are influenced by the surrounding infrastructure and impervious surfaces within the urban environment that capture and transport pollutants (Owen 1995; Göbel et al. 2007). The degradation of water quality that is commonly observed within urban areas and typically results from the influx of heavy metals, road salt applications, and excessive nutrient inputs from fertilizer applications (Göbel et al. 2007).

In general, wetland water quality is impaired by point and non-point sources of pollution, geology, and surrounding land use classified as agriculture, urban, or other natural areas (Johnson et al. 1997; USGS 1999). Various studies have found water quality in rural areas is degraded by runoff of excessive nitrogen and phosphorous from agricultural fertilizer and pesticide applications, the addition of excessive nutrients from grazing operations and feedlots, and typically have an altered water regime from ditching, tile drainage, filling, and irrigation (Berka et al. 2001; Cuffney et al. 2001).

Peri-urban wetlands receive pollutants from both rural and urban sources including residential, commercial, agricultural, and industrial pollutants (Rees and Wackernagel 1996). Urban wetlands are typically designed as multi-use systems to artificially manage storm water surges (Owen 1995; Brabec et al. 2002; Dahl 2011), manage and remove excessive nutrient levels (Vymazal 2007), and provide recreational opportunities (Ehrenfeld 2000). Potential urban sources of water quality degradation include contaminants from residential, commercial, and industrial sectors (Houlahan and Findlay 2004). Contaminants include high concentrations of heavy metals, road salt, and excessive nutrient inputs from lawn care and domestic pets contained in storm water runoff (Göbel et al. 2007).

Previous research looking at the impacts of urbanization on wetland water quality have not focused on changes that occur across the gradient of development that is created between the undeveloped rural environment, semi-developed peri-urban environment, and the developed urban environment. Additionally, to the author’s knowledge, there have been no studies conducted in the Prairie Pothole Region (PPR) focused on the impact of urbanization on wetland water quality. Thus, the specific objectives of this study were to: 1) assess water quality changes across the urban-rural gradient; 2) evaluate water quality of urban wetlands in the PPR; 3) gauge specific water quality parameters similarities and differences between land use groups (rural, peri-urban, urban).

3.3. Methods

3.3.1. Study Area

This study took place in the Red River Basin hydrological unit codes 090201 and 090202 (USGS 2016), which is within the PPR, one of the most wetland rich ecoregions in the world (Luoma 1985). The Red River Basin of eastern North Dakota encompasses highly fertile mollisol soils with an extremely flat topography, which promotes agriculture production within the area (Brookes 2016). However, the flat topography throughout the watershed causes frequent flooding and ponding of water within depressions (Kantrud et al. 1989). These depressional wetlands can be cumbersome for agricultural production and urban development. Therefore, approximately 80% of the wetlands in the Red River Basin are drained (NRCS 2006). This study took place on wetlands within and surrounding the city of Fargo and West Fargo, which is North

Dakota’s largest metropolitan area sprawling across 163.84 square kilometers with a population of 928.47 people per square kilometer (U.S. Census Bureau 2015).

3.3.2. Site Selection

Aerial imagery, Web Soil Survey data, and ArcMap GIS software were utilized to locate potential wetland sites within 32 kilometers of the current urban boundary of Fargo, North Dakota. Thirty wetland sites, comprised of 10 rural, 10 peri-urban, and 10 rural wetlands were randomly selected from a compiled list of 106 potential wetlands (Figure 3.1).

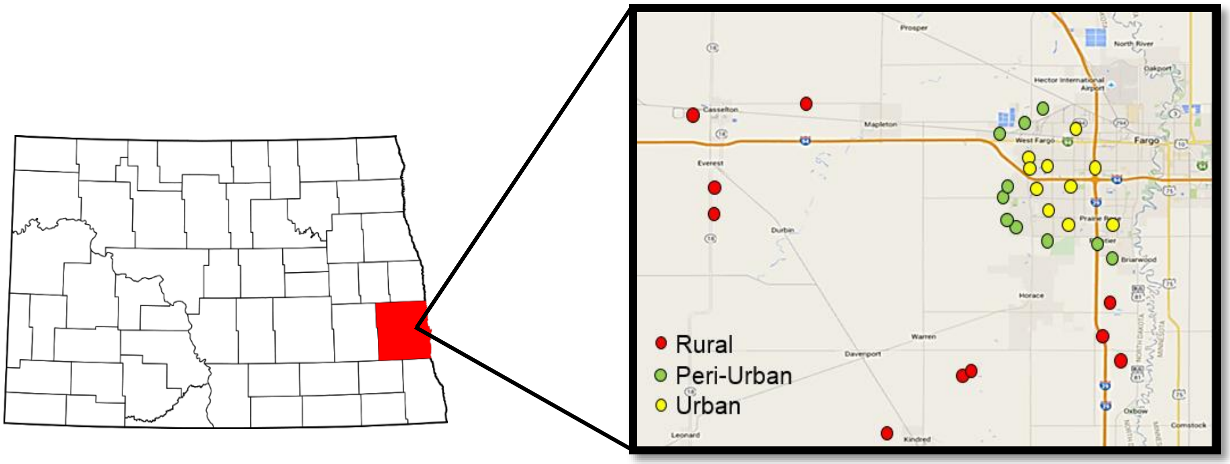


Figure 3.1. Site selection and classification across the gradient illustrates the location of sites selected for this study within Cass County of North Dakota. Yellow dots represent the ten urban wetlands, green dots represent the ten peri-urban wetlands, and red dots represent the ten rural wetlands.

All wetlands were classified as rural, peri-urban, or urban wetlands based on the current land use from the most recent National Land Cover Database (NLCD 2011). The NLCD provided the most accurate land cover data available to classify each wetland. Unfortunately, the NLCD may have overestimated the amount of impervious surfaces surrounding each wetland. ArcMap GIS software was used to calculate the ratio of impervious (developed) to pervious (undeveloped) surfaces found within 1.6 kilometers of each wetland using the Special Analysis

Tool and Zonal Statistics Tool. Geomorphic Change Detection (GCD) was used to determine topographic spatial changes, and calculate the resulting surface ratios. A compiled list of cover class data, GCD, and calculated impervious to pervious surface ratios per site are located within Appendix B.

The calculated surface ratios created a clear separation of wetlands across the rural, peri-urban, and urban gradient (Figure 3.2). Calculated surface ratios determined that rural wetlands within the Red River Basin had on average 9 percent impervious (developed) surfaces and 91 percent pervious (undeveloped) surfaces within 1.5 kilometers of each wetland. Peri-urban wetlands had on average 49 percent pervious (undeveloped) surfaces and 51 percent impervious (developed) surfaces; and urban wetlands had on average 3 percent pervious (undeveloped) surfaces and 97 percent impervious (developed) surfaces.

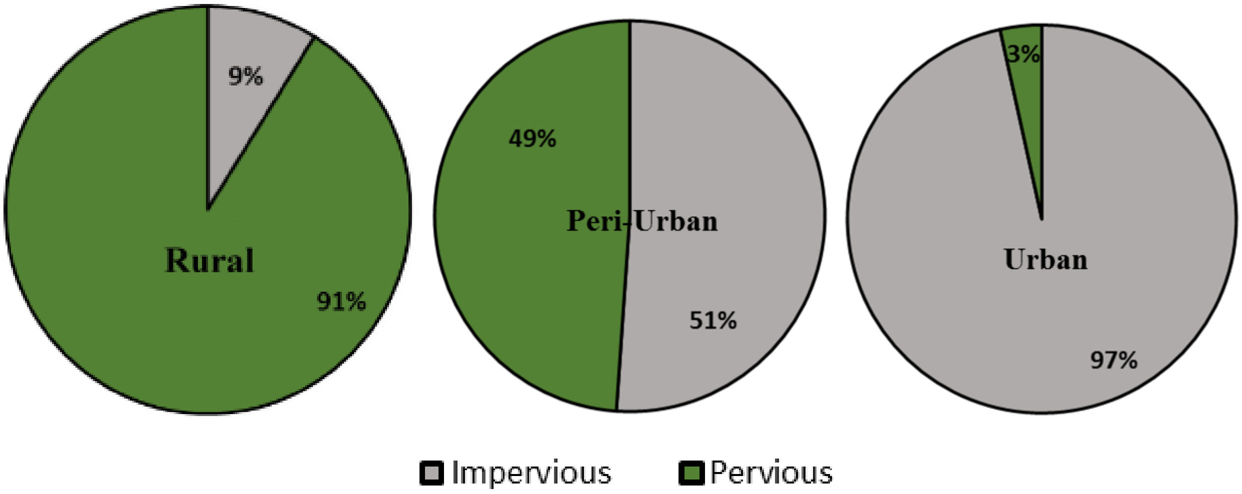


Figure 3.2. Calculated average impervious (developed) to pervious (undeveloped) surface ratios within 1.6 kilometers of each wetland across the rural, peri-urban, and urban gradient.

3.3.3. Water Quality Assessment

Water quality samples were gathered in compliance with the North Dakota Department of Health's (NDDoH) protocol (Appendix A) (NDDoH 2011). Samples were obtained once per month, July through September 2015 and April through September 2016, from each of the 30 sites. In compliance with NDDoH protocol, grab samples were taken from the 0-0.5 m surface depth after wading out to the deepest accessible point of the wetland with open water. Samples were properly labeled, preserved with sulfuric or nitric acid dependent upon the sample requirements, cooled to 4^{o}C, recorded on the custody form, and transported to the NDDoH's lab in Bismarck for further analysis. Water quality parameters measured during the lab's analysis include total suspended solids (TSS), nutrients complete (TKN, NO_2, NO_3, NH_3, NH_4, and P), nutrients complete dissolved, major cations and anions, trace metals, and e. coli. Parameters and detection limits can be found in Appendix A. Additional measurements were recorded in the field using a Yellow Spring Instrument Co. YSI model 650 MDS data logger combined with a model 600 QS Sonde to measure temperature, electrical conductivity, pH, and dissolved oxygen.

3.3.4. Statistical Analysis

Permutational multivariate analysis of variance (PERMANOVA) was conducted to determine differences in the rural, peri-urban, and urban wetland water quality parameters collected. A repeated measures experimental design was completed using PRIMER version 7 software with the PERMANOVA + add-on (Anderson et al. 2008). The data was standardized and the distance measure used was a Relative Euclidean distance. The permutation method utilized permutation of residuals under a reduced model with 9999 permutations. The analysis included three factors: time, treatment, and site. Two factors, time (2015= 3 months; 2016=6 months) and treatment (3 = rural, peri-urban, or urban), were fixed, whereas site (30 Total =

Rural 1-10; peri-urban 1-10; and urban 1-10) was random. The exact paired comparison permutation p-values are reported without an adjustment for multiple comparisons as suggested by Anderson et al. (2008). The permutation p-values are recognized as an exact test, which were utilized to create a triangular resemblance matrix to determine the similarities or dissimilarities between each pair of groups and further identify differences in the within-group variability (Anderson et al. 2008).

Water quality data was analyzed using Nonmetric Multidimensional Scaling (NMS) to graphically display the dissimilarity of observed water quality parameters at all thirty wetland sites. The NMS analysis was completed using PC-ORD Version 6 software (McCune and Grace 2011). The Relative Euclidean distance measure was used to assess the data. Structure in the data was found by running PC-ORD with 500 iterations of the data reducing to one axis from six with an instability criterion of 0.0001. Dimensions and model selection was based on: (1) a significant Monte Carlo test ($p<0.05$); (2) a model with a stress <25; (3) an instability <0.0001; and (4) a selection of axes was discontinued if the next axis did not reduce stress >5. Pearson's Correlation Coefficient $r\geq0.4$ or $r\leq-0.4$ were used to explain the ordination and appropriately reflect an interpretable effect size (McCune and Grace 2011).

3.4. Results and Discussion

The NMS analysis of the gradient's 2015 water quality parameter dataset based on rural, peri-urban, and urban groups produced a final solution with two dimensions. Axis 1 represented 98.5% of the variation in the data, and axis 2 represented < 1.5% of the variation in the data (Final Stress = 0.19847; Final Instability = 0.00000; Number of Iterations = 67). PERMANOVA analysis determined significant differences exist between urban, peri-urban, and urban wetland groups (Figure 3.3) (Pseudo-F: 10.207; P= 0.0012) and between the July, August, and September sampling periods (Figure 3.4) (Pseudo-F: 3.991; P=0.0044). PERMANOVA determined significant differences for the interaction among the three month sampling time periods combined with the rural (Figure 3.5), peri-urban (Figure 3.6), and urban (Figure 3.7) treatments (Pseudo-F 2.8819; P= 0.0063).

NMS ordination of the gradient's 2016 water quality dataset produced a final solution with two dimensions representing 100% of the variation in the data. Axis 1 represented 58.4% of the variation in the data, and axis 2 represented 41.6% of the variation in the data (Final Stress = 0.43429; Final Instability = 0.00000; Number of Iterations = 120). PERMANOVA analysis determined significant differences exist between urban, peri-urban, and urban wetland groups (Figure 3.8) (Pseudo-F: 4.7027; P= 0.0101) and between the April, May, June, July, August, and September sampling periods (Figure 3.9) (Pseudo-F: 4.3971; P=0.0006). PERMANOVA determined significant differences exist for the interaction among the six month sampling time periods combined with the rural (Figure 3.10), peri-urban (Figure 3.11), and urban (Figure 3.12) treatments (Pseudo-F: 11.658; P= 0.0001). The average value for each water quality parameter from the urban, peri-urban, and rural wetland sites in both 2015 and 2016 can be found in Appendix F.

PERMANOVA analysis is sensitive to differences in multivariate position and dispersions amongst groups (Anderson et al. 2008). Thus, differences illustrated by the NMS figures between rural, peri-urban, and urban sites may be related to position or dispersion of the data. The dispersion of 2015 and 2016 rural and urban sites were both highly variable in comparison to the peri-urban sites. Peri-urban samples were consistent throughout the 2015 three-month sampling period and 2016 six month sampling period, which is evident by the close proximity of sites in multivariate space. Rural sites had the highest variability and dispersion in comparison to urban and peri-urban sites.

The consistency and lack of variability of peri-urban sites throughout this study likely occurred because eight of the ten peri-urban sites did not experience frequent disturbance or conversion from the surrounding land use during the study. Two sites, PU 4 and PU 10, were disturbed by construction of residential areas. Both wetland sites are outliers on the NMS graphics, which likely influenced the dispersion of sites in multivariate space. The established vegetation surrounding the undisturbed peri-urban wetland sites likely acted as a buffer zone to filter nutrients and sediments (Bentrup 2008).

Optimal buffer zone width for best management practices (BMP) to improve wetland water quality have been extensively studied (Castelle et al. 1993; Houlahan and Findlay 2004; Bentrup 2008). Castelle et al. (1993) determined effective buffer widths ranged between three meters to two hundred meters dependent upon specific site conditions. The optimal buffer width to improve wetland water quality was at least fifteen meters (Castelle et al. 1993). Bentrup (2008) provided buffer guidelines from the Natural Resource Conservation Service (NRCS) for wetlands based on surrounding land use. Wetland buffers between twenty-five and fifty meters were recommended for areas influenced by impervious surfaces. Overall, peri-urban sites within this study were surrounded by a sufficient width of buffer vegetation recommended by both Castelle et al. (1993) and Bentrup (2008), which likely influenced the concentration of contaminants and consistency of samples gathered at peri-urban sties.

Hydrologic setting, topographic location, climatic changes, soil type, vegetation presence or absence, and human activities are all factors that influence the physical and chemical water quality and quantity of wetlands (USGS 1996; Khatri and Tyagi 2015). The water quality parameters assessed (TDS, TSS, cation sum, anion sum, etc.) naturally occur across the landscape, but human activities have been found to cause the concentrations to increase (Neary et al. 1988; USGS 1996; Khatri and Tyagi 2015).

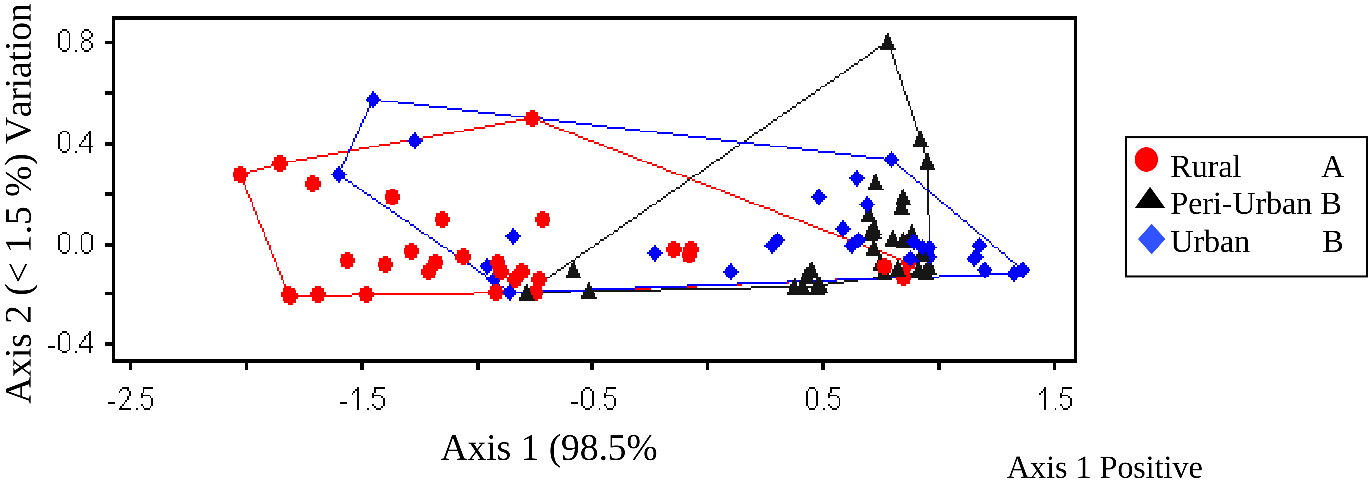
Consistently between 2015 and 2016, differences between urban and peri-urban sites compared to rural sites appears to be related to a correlation for high cation and anion sums and TDS, along with high pH in 2015 for urban and peri-urban sites; and a strong correlation for rural sites with alkalinity and phosphorus. Khatri and Tyragi (2015) found similar results, which indicated that rural and urban water quality differences are mainly associated with concentrations of TDS, nitrates, phosphates, and heavy metals.

Trace metals and e.coli were excluded from analysis since concentrations were below the detection limit (NDDoH 2011), and therefore inadequate to influence the data. Both of these findings contradict previous studies that emphasize high concentrations of heavy metals and e.coli based on land use (Scholes et al. 1998; Göbel et al. 2007; Khatri and Tyagi 2015). Scholes et al. (1998) found that urban and sub-urban (peri-urban) runoff contained elevated concentrations of heavy metals in constructed wetland sediments, plant tissue, and soils.

Similar to Scholes et al. (1998), Göbel et al. (2007) compared surface water quality concentrations to the surrounding areas surface type (i.e. impermeable, permeable, urban, rural, etc). Göbel et al. (2007) determined that runoff from areas with higher densities of impervious surfaces had higher concentrations of water pollutants such as metals, TSS, nitrogen, phosphorus, and salts. Surface waters and ground water receiving urban stormwater runoff and seepage had higher concentrations of contaminants than rural areas. Our findings partially align with Göbel et al. (2007).

2015 NMS Comparing Rural, Peri-Urban, and Urban Wetland Groups

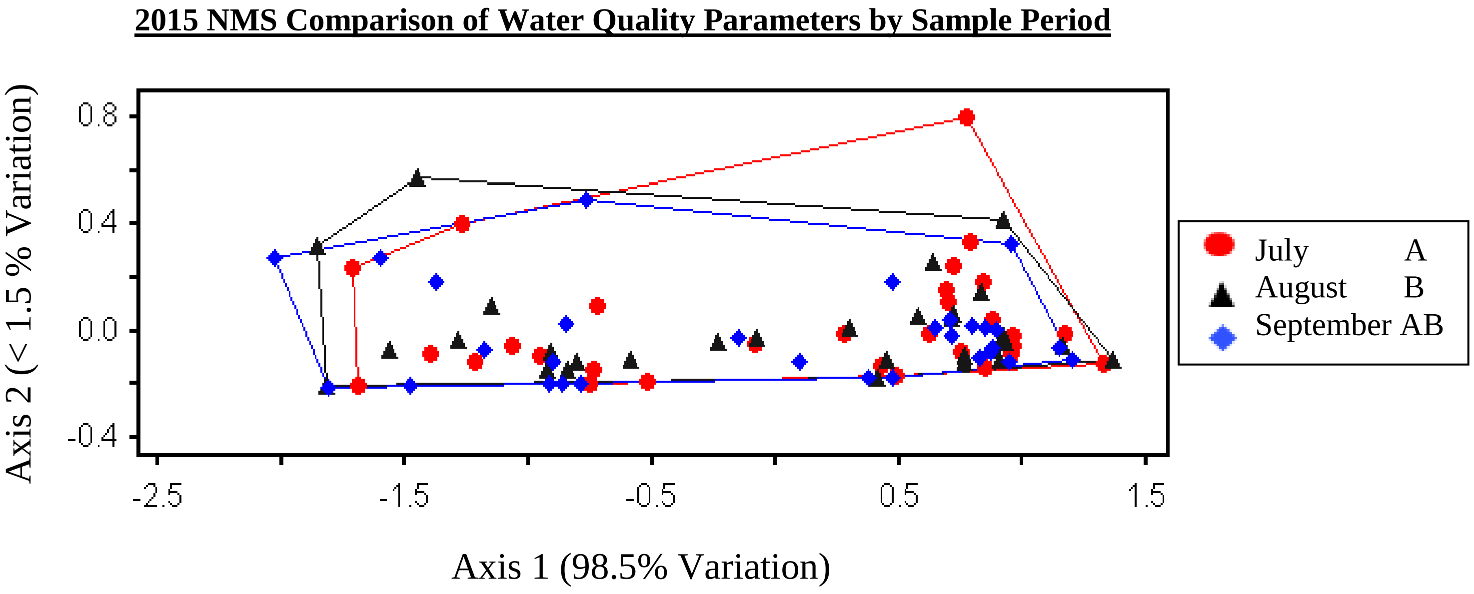
Axis 2 Positive
TSS (0.799)



Axis 1 Positive
Anion Sum (0 .712)
Cation Sum (0.698)
pH (0.423)
TDS (0.735)

Axis 1 Negative
Total Phosphorous (- 0.381)
Dissolved Phosphorous (-0.403)

Figure 3.3. Nonmetric Multidimensional Scaling (NMS) ordination of water quality data gathered in July - Septembe of 2015 along Axis 1 and Axis 2. Three convex hull polygons are displayed representing the Rural, Peri-Urban, and Urban groups. All points in ordination space represent individual wetland sites from across the gradient. Groups followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations; r values are given in parenthesis.



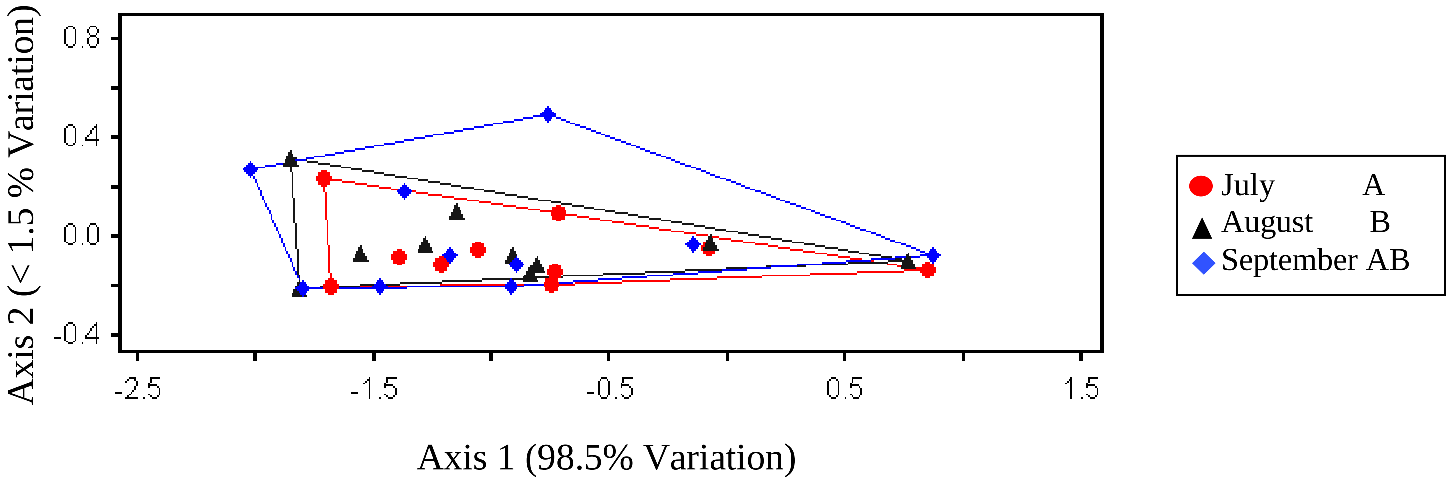
Axis 2 Positive
TSS (0.799)

Axis 1 Negative
Total Phosphorous (- 0.381)
Dissolved Phosphorous (-0.403)

Axis 1 Positive
Anion Sum (0 .712)
Cation Sum (0.698)
pH (0.423)
TDS (0.735)

Figure 3.4. Nonmetric Multidimensional Scaling (NMS) ordination of water quality data by sampling period gathered during the 2015 field season along axis 1 and 2. Three convex hull polygons are displayed representing the July, August, and September sampling period groups. All points in ordination space represent individual wetland sites. Groups followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations r values are given in parenthesis.

2015 NMS Comparing Rural Wetlands and Sampling Periods



Axis 2 Positive
TSS (0.799)

Axis 1 Negative
Total Phosphorous (- 0.381)
Dissolved Phosphorous (-0.403)

Axis 1 Positive
Anion Sum (0 .712)
Cation Sum (0.698)
pH (0.423)
TDS (0.735)

Figure 3.5. Nonmetric Multidimensional Scaling (NMS) ordination of rural water quality data gathered during the 2015 field season along axis 1 and 2. Three convex hull polygons are displayed representing the July, August, and September sampling period groups. All points in ordination space represent individual wetland sites. Groups followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations; r values are given in parenthesis.

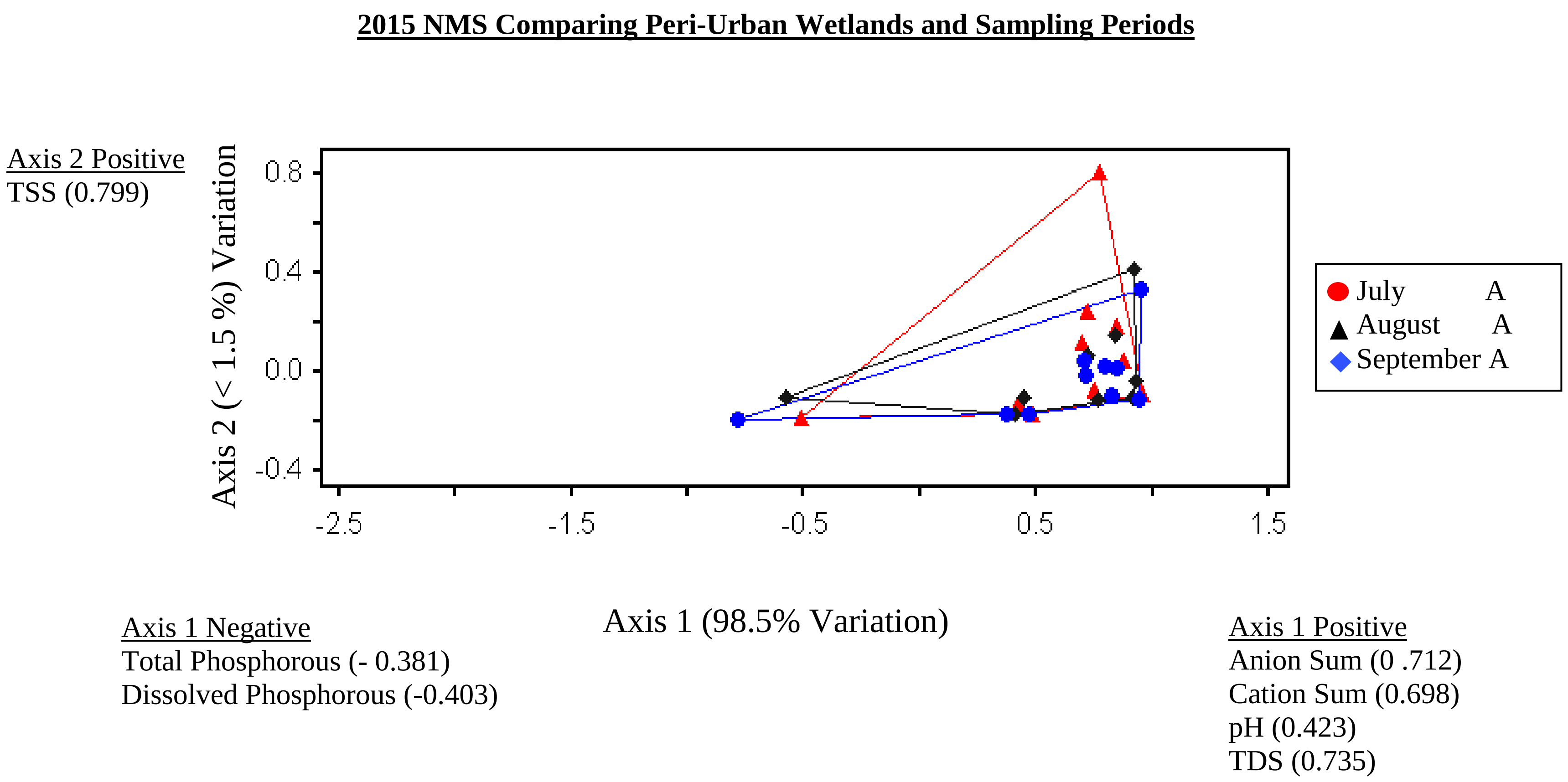
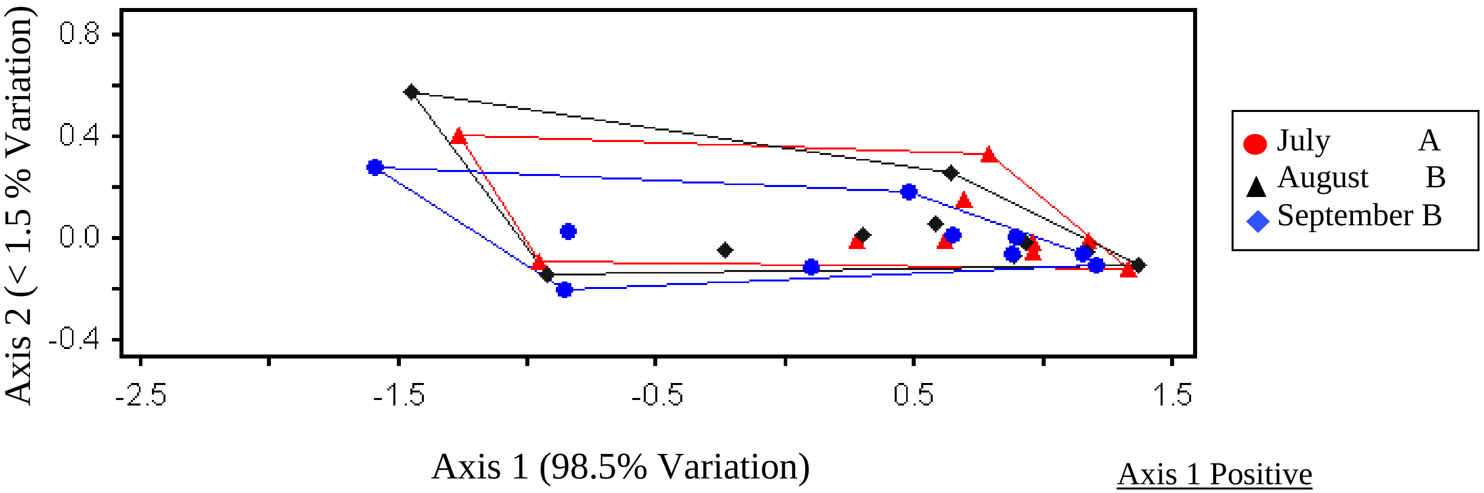


Figure 3.6. Nonmetric Multidimensional Scaling (NMS) ordination of peri-urban water quality data gathered during the 2015 field season along axis 1 and 2. Three convex hull polygons are displayed representing the July, August, and September sampling period groups. All points in ordination space represent individual wetland sites. Months followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations; r values are given in parenthesis.

2015 NMS Comparing Urban Wetlands and Sampling Periods



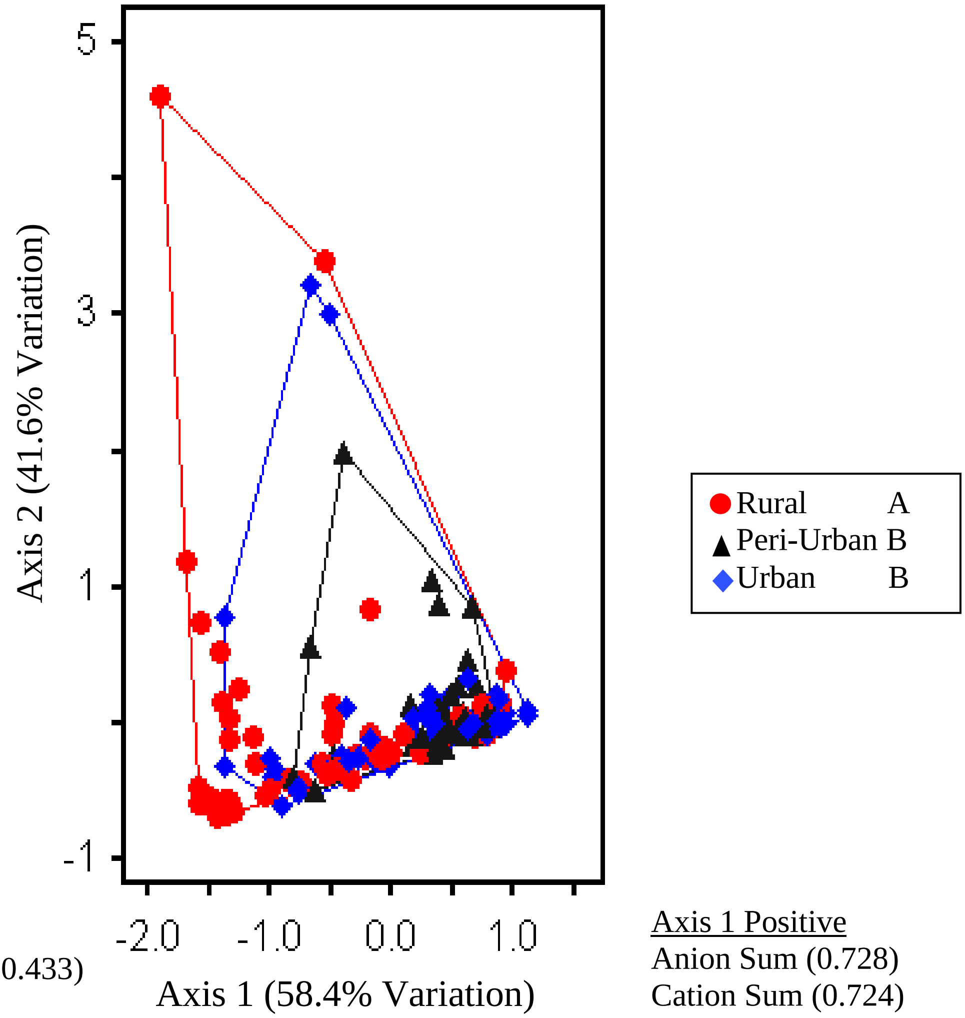
Axis 2 Positive
TSS (0.799)

Axis 1 Negative
Total Phosphorous (- 0.381)
Dissolved Phosphorous (-0.403)

Axis 1 Positive
Anion Sum (0 .712)
Cation Sum (0.698)
pH (0.423)
TDS (0.735)

Figure 3.7. Nonmetric Multidimensional Scaling (NMS) ordination of urban water quality data gathered during the 2015 field season along axis 1 and 2. Three convex hull polygons are displayed representing the July, August, and September sampling period groups. All points in ordination space represent individual wetland sites. Groups followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations; r values are given in parenthesis.

2016 NMS Comparing Rural, Peri-Urban, and Urban Wetland Groups



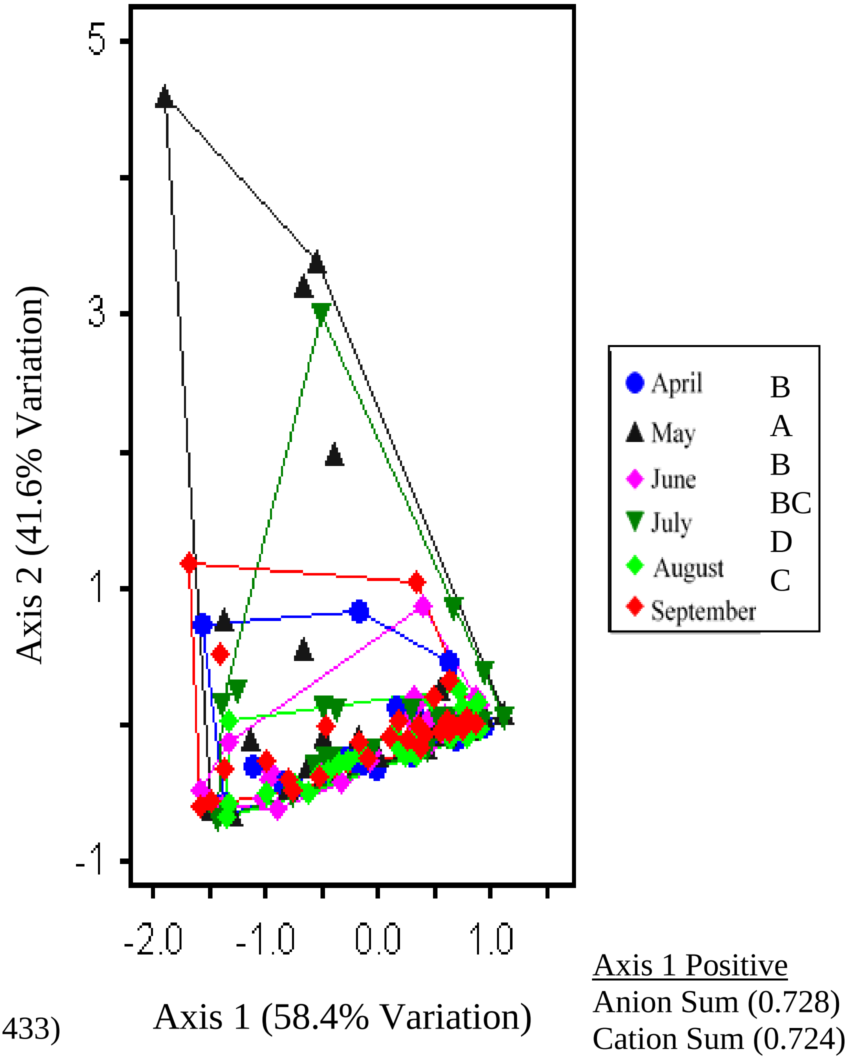
Axis 2 Positive
TSS 0.940

Axis 1 Negative
Total Alkalinity (-0.433)

Axis 1 Positive
Anion Sum (0.728)
Cation Sum (0.724)
TDS (0.753)

Figure 3.8. Nonmetric Multidimensional Scaling (NMS) ordination of water quality data gathered in April - September of 2016 along Axis 1 and Axis 2. Three convex hull polygons are displayed representing the Rural, Peri-Urban, and Urban groups. All points in ordination space represent individual wetland sites from across the gradient. Groups followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations; r values are given in parenthesis.

2016 NMS Comparison of Water Quality Parameters by Sample Period



Axis 2 Positive
TSS 0.940

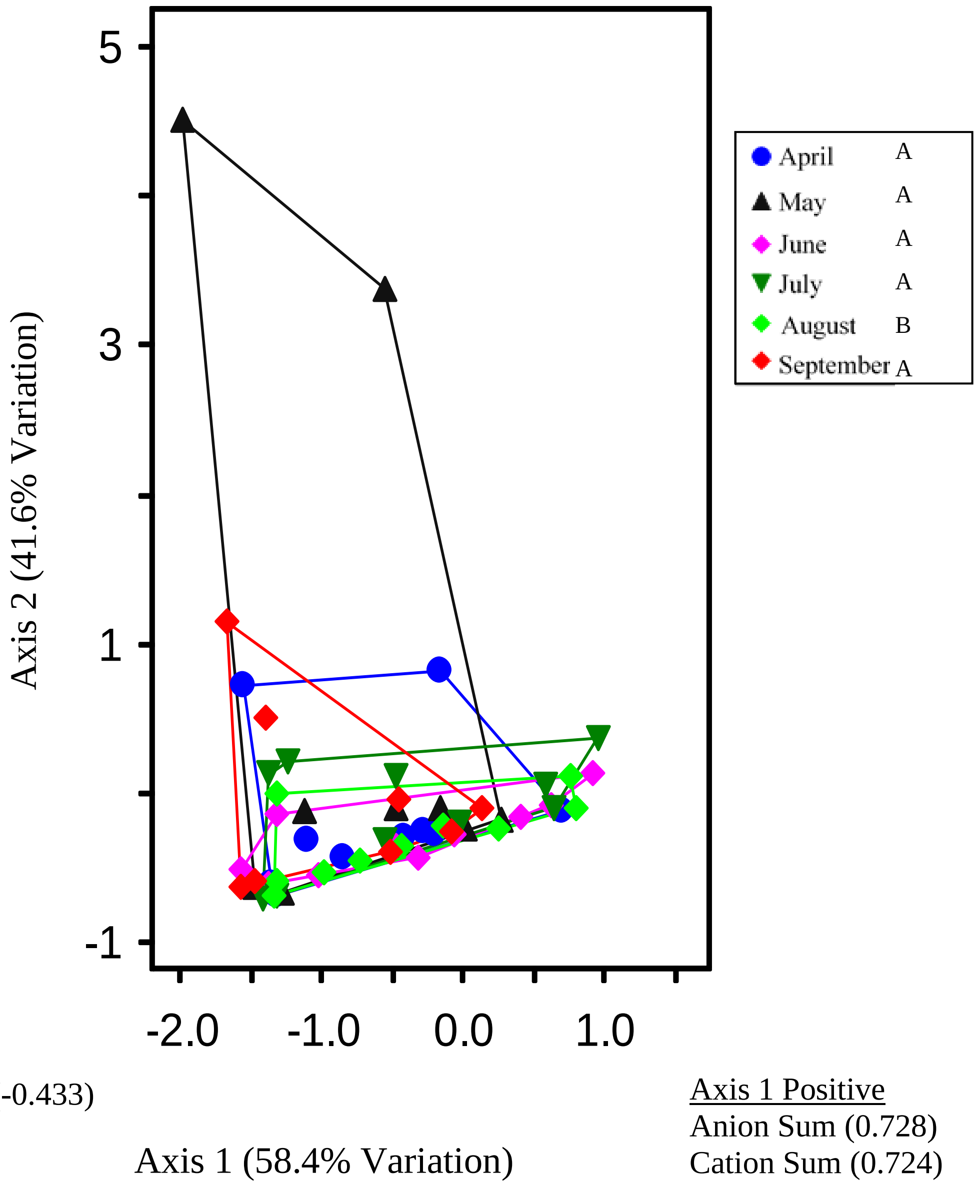
Axis 1 Negative
Total Alkalinity (-0.433)

Axis 1 Positive
Anion Sum (0.728)
Cation Sum (0.724)
TDS (0.753)

Figure 3.9. Nonmetric Multidimensional Scaling (NMS) ordination of water quality data gathered in April - September of 2016 along Axis 1 and Axis 2. Three convex hull polygons are displayed representing the Rural, Peri-Urban, and Urban groups. All points in ordination space represent individual wetland sites from across the gradient. Groups followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations; r values are given in parenthesis.

2016 NMS Comparing Rural Wetlands with Sampling Periods

Axis 2 Positive
TSS 0.940



Axis 1 Negative
Total Alkalinity (-0.433)

Axis 1 Positive
Anion Sum (0.728)
Cation Sum (0.724)
TDS (0.753)

Figure 3.10. Nonmetric Multidimensional Scaling (NMS) ordinations of rural water quality data gathered during the 2016 field season along axis 1 and 2. Six convex hull polygons are displayed representing the April, May, June, July, August, and September sampling period groups. All points in ordination space represent individual wetland sites. Groups followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations; r values are given in parenthesis.

2016 NMS Comparing Peri-Urban Wetlands with Sampling Periods

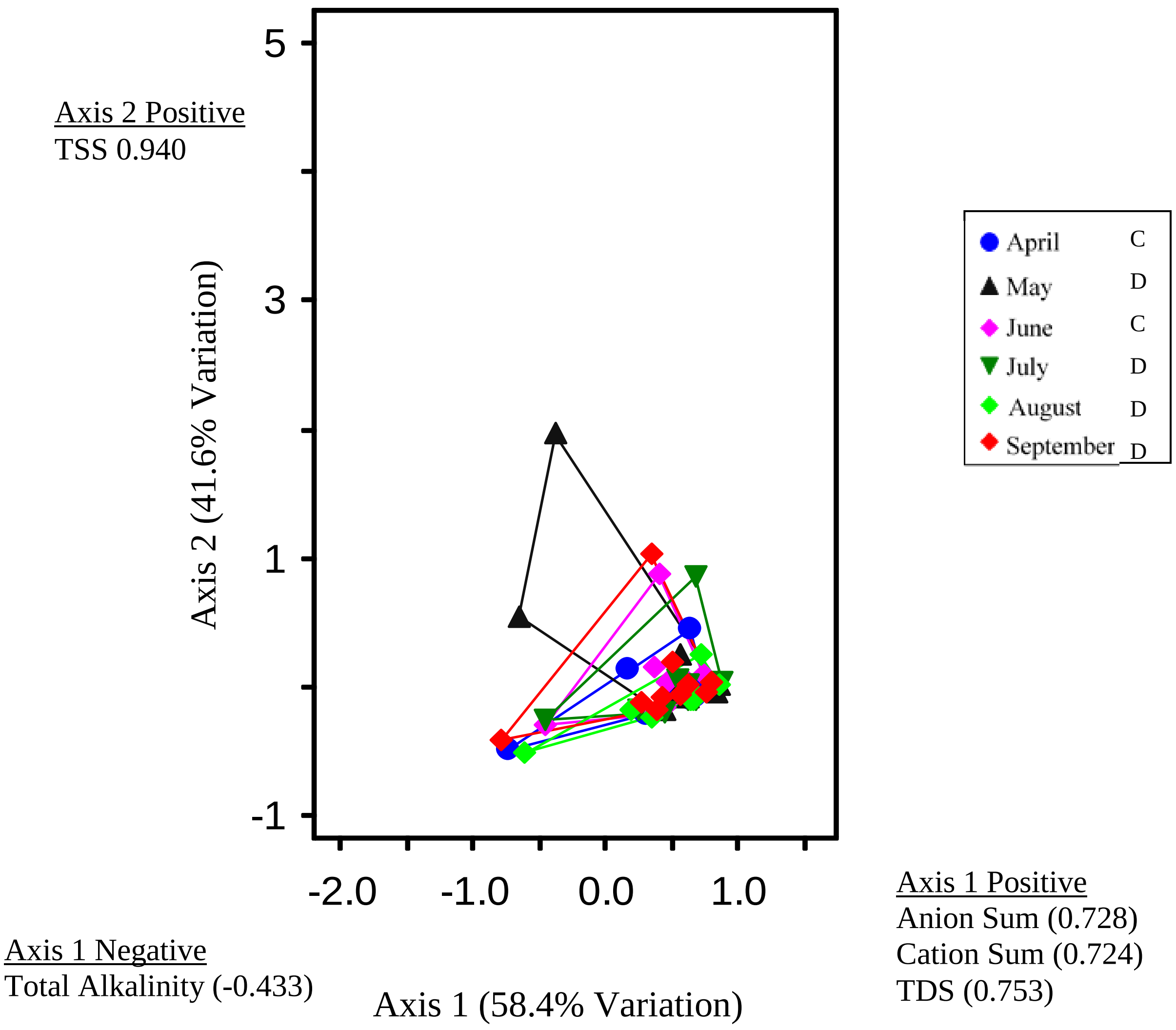


Figure 3.11. Nonmetric Multidimensional Scaling (NMS) ordinations of peri-urban water quality data gathered during the 2016 field season along axis 1 and 2. Six convex hull polygons are displayed representing the April, May, June, July, August, and September sampling period groups. All points in ordination space represent individual wetland sites. Groups followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations; r values are given in parenthesis.

2016 NMS Comparing Urban Wetlands with Sampling Periods

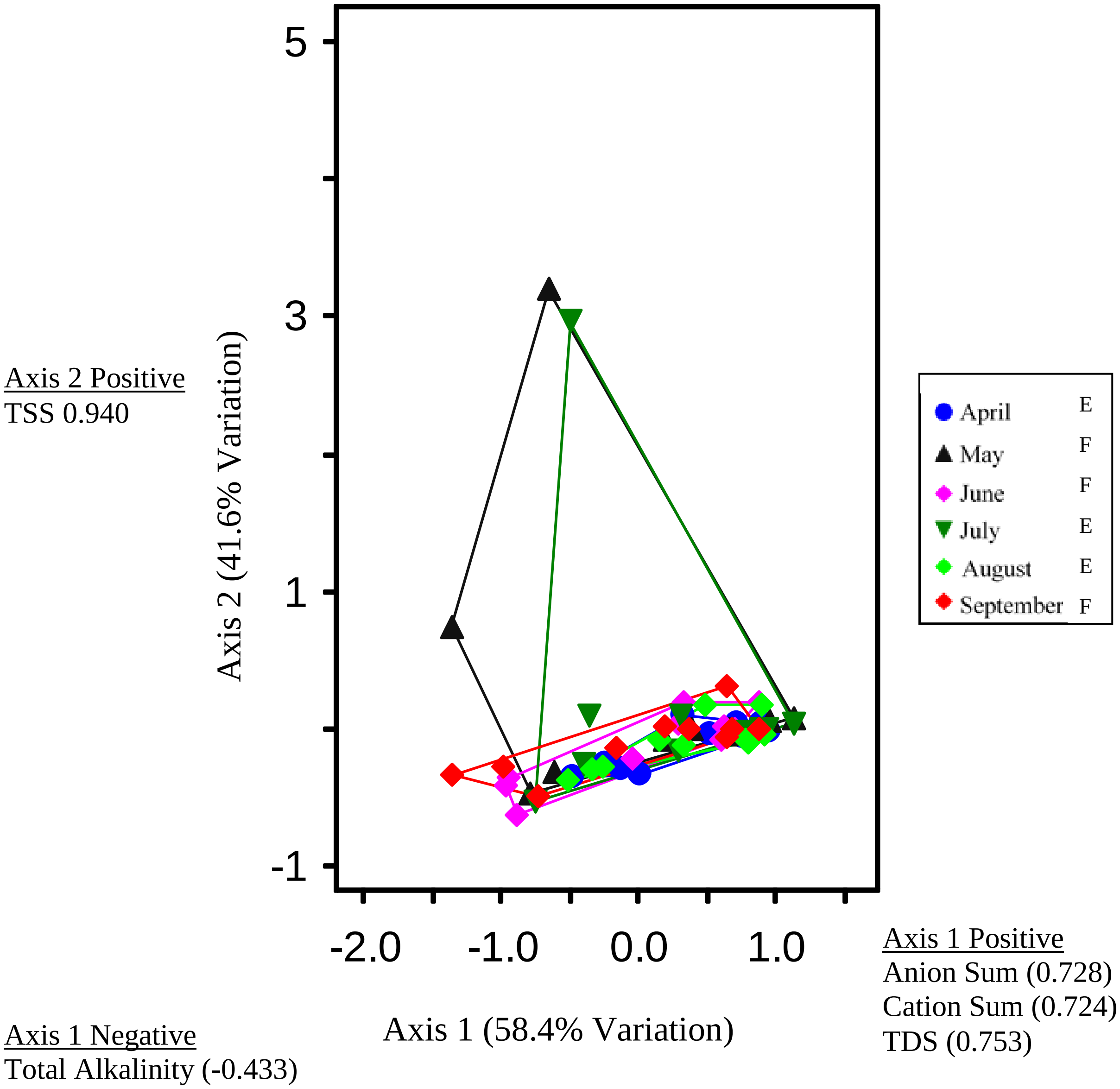


Figure 3.12. Nonmetric Multidimensional Scaling (NMS) ordinations of urban water quality data gathered during the 2016 field season along axis 1 and 2. Six convex hull polygons are displayed representing the April, May, June, July, August, and September sampling period groups. All points in ordination space represent individual wetland sites. Groups followed by a different letter were significantly different ($P < 0.05$). The percentage of variation explained by each axis is listed in parenthesis. Water quality parameters listed were associated with positive or negative correlations; r values are given in parenthesis.

We found that higher levels of TSS and salts at our urban sites compared to our peri-urban sites, but we did not find higher concentrations within our rural sites than our urban sites. However, we did not find high concentrations of trace metals at our wetland sites as has been shown in previous research. The lack of trace metal concentrations within our study's wetland water quality samples is likely related to the lack of industrialization in West Fargo and Fargo, whereas previous studies by Scholes et al. (1998), Göbel et al. (2007), and Khatri and Tyagi (2015) were conducted in areas that have intense industrialization that may have influenced the metal concentrations.

Samples gathered at peri-urban and urban sites in both 2015 and 2016 had a positive correlation with TDS, cation sum, and anion sum. TDS includes cations, anions, metals, salts, and minerals that are dissolved in the water and pass through a filter (Khatri and Tyagi 2015). TDS, cations, and anions are components of the overall electrical conductivity of water, which is influenced by human activities that increase the concentration of minerals, salts, and fertilizers within an area (Neary et al. 1998; Göbel et al. 2007). Ion concentrations of the study area's surface waters are naturally influenced by salt affected soils, preciptiation driven surface runoff, evapotranspiration, and saline ground water disharge (Strobel and Haffield 1995). However, anthropogenic disturbances have been found to increase ion concentrations within surface water (EPA 1999; Li et al. 2008; Khatri and Tyagi 2015). Li et al. (2008) determined that land use impacted TDS, and that TDS concentrations were higher in vegetated areas than non-vegetated areas.

In 2016, TSS influenced the spread of the data. TSS is strongly correlated (r=0.94) with axis 2 which ordered and dispersed the data between rural, peri-urban, and urban sample groups and sample periods along axis 2. TSS includes organic and inorganic materials suspended in the water that will not pass through a filter (EPA 1999; MPCA 2007). Rural and urban storm water flows transport debris, e.g. sediment, industrial waste, plastic, wood, and pet feces, over impervious surfaces within urban areas (EPA 1999; Göbel et al. 2007; MPCA 2017). Excessive TSS that remain in solution are eventually transported through storm drains to waterways, which can lead to water pollution and eutrophication (EPA 1999). Rural sites had a higher average TSS concentration (89.0 mg/L) than urban (56.2 mg/L) and peri-urban sites (3.8 mg/L). Both the rural and urban average TSS concentration exceeded the EPA's recommended limit value of 50 mg/L (EPA 2001).

In 2015, rural wetlands had a correlation with higher average concentrations of total phosphorous (0.4 mg/L) than urban (0.19 mg/L) and peri-urban sites (0.11 mg/L). However, higher phosphorous concentrations were found in both the rural and urban wetlands in July. Peri-urban wetlands do not appear to have a correlation with high phosphorus concentrations. Similar results were found in a studies by the USGS (1999), EPA (1999), and Bowden et al. (2015) where results determined that urban areas had higher concentrations of phosphorous than semi-developed areas. Total phosphorous is a measurement of chemically active dissolved ortho-phosphate and phosphorous concentrated in organic plant and animal tissues (EPA 1999; MPCA 2007). Sources of total phosphorous include point and non-point sources such as agricultural runoff, pesticide and fertilizer applications, industrial sites, urban storm water, and pet feces (EPA 1999; MPCA 2007; Metson et al. 2015). This study found that the average total phosphorus concentration of rural, peri-urban, and urban sites did not exceed the EPA's recommended limit value of 0.5 mg/L (EPA 2001).

In 2015, rural, peri-urban, and urban wetland sites had a correlation with high pH (pH > 7.0). In 2016, urban and peri-urban sites have a correlation with high pH, and rural sites have a correlation with low pH ($pH < 7$). This indicates that in 2016 water pH at rural sites were trending to just below neutral. However, pH did not exceed the recommended pH level (6.5 to 8.5) for sustaining aquatic life (NDDoH 2011).

Differences between the 2015 July samples compared to August and September samples is likely related to a correlation for high concentrations of anion sum, cation sum, pH, TDS, and TSS. In 2016, differences between rural samples gathered in August compared to April, July, and September appears to be related to a correlation for high anion sum, cation sum, and TDS. Differences between peri-urban samples gathered in June compared to July and August and April samples compared to August samples appears to be related to a correlation for high TSS. Differences between urban samples gathered in September compared to April and August along with differences between May and July appears to be related to a correlation for high TSS.

Seasonal changes between the months of April and September in North Dakota most likely influenced the parameter results for the rural, peri-urban, and urban sites. April typically experiences warm temperatures, snow melt, potential flooding, and bare ground from unestablished vegetation; whereas August typically experiences warm temperatures with established vegetation to intercept runoff and improve infiltration (USDA 1997). September in North Dakota is at the end of the growing season, and thus has higher quantities of biomass to intercept rainfall than April. However, many crops are harvested during the month of September across the state (USDA 1997), which likely increased the TSS within rural sites.

Land-use changes that occurred during 2015 and 2016 potentially influenced the water quality across the rural, peri-urban, and urban gradient. Alterations were observed during routine visits and water quality sampling periods. Landowners at several urban, peri-urban, and rural sites applied herbicide and fertilizer to control weedy plant species and promote a more vibrant lawn. Both herbicide and fertilizer applications have been linked to increased nutrient levels within surface water (MPCA 2007). Also, the study's urban and peri-urban wetlands experienced activities associated with residential and commercial construction such as dredging, soil compaction, removal of vegetation, addition of buildings and other impermeable infrastructure, and the installation of culverts and lift stations to control storm flows. These activities have been found to promote erosion and sedimentation (Werner and Zedler 2002), increase nutrients, heavy metals, and other pollutants within the system (Brabec et al. 2002; Wang et al. 2007), and disrupt the water regime (Dahl 2011).

3.5. Conclusion

Spatial and temporal differences were observed between the study's wetlands in 2015 and 2016. Wetland water quality parameters spatially differed across the rural, peri-urban, and urban gradient, which indicated a correlation between urban development and water quality. This has major implications for watersheds across the globe that are increasingly impacted by urban development and expansion. In addition, water quality parameters gathered at different time periods throughout the study contained different concentrations and results; which stresses the importance of taking samples on a regular basis to assess water quality changes over time. Additionally, using best management practices to prevent water quality degradation and impairment is crucial.

Further research is needed to determine the exact causes of water quality degradation within the study area. Our study found that water quality samples in rural, peri-urban, and urban wetlands did not contain significant levels of metals within acquired samples. This raises questions regarding metal transportation and deposition across the rural, peri-urban, and urban gradient. In addition, specific rate and quantities of fertilizer applications in rural, peri-urban, and urban areas were not assessed. Unexpectedly, water quality parameters gathered at the peri-urban wetlands were consistent and similar between sampling periods, whereas the parameters from rural and urban wetlands were highly variable. Future research is necessary to determine the cause of the stability of water quality parameters among peri-urban wetlands in comparison to rural and urban wetlands. If stability is maintained through permanent park space or similar areas surrounding a city, then peri-urban wetlands may serve as a useful buffer for reducing the impact of human disturbance on water quality across the rural, peri-urban, and urban gradient.

3.6. Literature Cited

Anderson MJ, Gorley RN, Clarke KR (2008) PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E: Plymouth, UK.

Berka C, Schreier H, Hall K (2001) Linking water quality with agricultural intensification in a rural watershed. Water, Air, and Soil Pollution. 127: 389-401

Bowden C, Konovalske M, Allen J, Curran K, Touslee S (2015)Water quality assessment: the effects of land use and land cover in urban and agricultural land. Natural Resources and Environmental Sciences. Kansas State University. 1-22

Brabec E, Schulte S, Richards P (2002) Impervious surfaces and water quality: a review of current literature and its implications for watershed planning. Journal of Planning Literature. 16(4): 499 – 514

Brookes MS (2016) Lake Agassiz Plain ecoregion summary. United States Geological Survey. Date accessed: January 9, 2017. https://landcovertrends.usgs.gov/gp/eco48Report.html

Brown MT, Vivas MB (2005) Landscape development intensity index. Environmental Monitoring and Assessment. 101: 289–309

Cuffney TF, Meador MR, Porter SD, Gurtz ME (2000) Responses of physical, chemical, and biological indicators of water quality to a gradient of agricultural land use in the Yakima River Basin, Washington. Environmental Monitoring and Assessment. 64: 259-270

Dahl TE (2011) Status and trends of wetlands in the conterminous United States 2004 to 2009. U.S. Fish and Wildlife Service - Washington, DC, USA. Report to Congress. 1-112

Ehrenfeld JG (2000) Evaluating wetlands within an urban context. Ecological Engineering. 15: 253 – 265

Environmental Protection Agency (1999) Preliminary data summary of urban storm water best management practices. Office of Water – EPA-821-R-99-012

Environmental Protection Agency (2001) Parameters of water quality: interpretation and standards. Office of Water – EPA - 1-84096-015-3

Göbel P, Dierkes C, Coldewey WG (2007) Storm water runoff concentration matrix for urban areas. Journal of Contaminant Hydrology. 91: 26-42

Houlahan JE, Findlay SC (2004) Estimating the 'critical' distance at which adjacent land-use degrades wetland water and sediment quality. Landscape Ecology. 19: 677 – 690

Johnson LB, Richards C, Host GE, Arthur JW (1997) Landscape influences on water chemistry in Midwestern stream ecosystems. Freshwater Biology. 37. 193 -208

Kantrud HA, Krapu GL, Swanson GA, Allen JA. (1989) Prairie basin wetlands of the Dakotas: a community profile. U.S. Fish and Wildlife Service Biological Report 85(7.28): 116

Khatri N, Sanjiy T (2015) Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. Frontiers in Life Science. 8: 23-39, DOI: 10.1080/21553769.2014.933716

Li S, Gu S, Liu W, Han H, Zhang Q (2008) Water quality in relation to land use and land cover in the upper Han River Basin, China. Catena. 75: 216 – 222

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

McCune B, Mefford MJ (2011) PC-ORD. Multivariate analysis of ecological data. Version 6. MjM Software, Gleneden Beach, Oregon, U.S.A.

Metson GS, Iwaniec DM, Baker LA, Bennett EM, Childers DL, Cordell D, Grimm NB, Grove JM, Nidzgorski DA, White S (2015) Urban phosphorus sustainability: systematically incorporating social, ecological, and technological factors into phosphorus flow analysis. Environmental Science & Policy. 1 – 11

Minnesota Pollution Control Agency (2007) Phosphorous: sources, forms, impact on water quality – a general overview. Water Quality – Impaired Waters 3 (12): 1-2

Neary DG, Swank WT, Riekerk H (1988) An overview of nonpoint source pollution in the southern United States. In proceedings of the symposium: the forested wetlands of the southern united states, Orlando, FL, USA, 12–14 July 1988. Gen. Tech. Rep. SE-50

National Land Cover Database (2011) United States Geological Survey. Accessed from North Dakota GIS Hub: ND.HUB.LANDCLASS_ NASS_ 2013. Date accessed: June 2015

North Dakota Department of Health (2011) Standard operating procedures for field samplers. March 2011 (revised).Bismarck: North Dakota Department of Health, Division of Water Quality

Owen CR (1995) Water budget and flow patterns in an urban wetland. Journal of Hydrology.169:171 – 187

Rees W, Wackernagel M (1996) Urban ecological footprints: Why cities cannot be sustainable – and why they are a key to sustainability. Environmental Impact Assesement Revision. 16: 223-248

Scholes L, Shutes RBE, Revitt DM, Forshaw M, Purchase D (1998) The treatment of metals in urban runoff by constructed wetlands. The Science of the Total Environment. 214: 211-219

Strobel ML, Haffield ND (1955) Salinity in surface water in the Red River of the North basin, northeastern North Dakota. U.S. Geological Survey water-resources investigations report 95-4082. 1-18

United Nations (2015) World urbanization prospects. The 2014 revision. Report. 1-157

United States Census Bureau (2015) Fargo, North Dakota quick facts. Date accessed: January 13, 2017. http://www.census.gov/quickfacts/table/POP060210/3825700

United States Census Bureau (2017) US and world population clock. Date Accessed: January 13, 2017. http://www.census.gov/popclock/

United States Department of Agriculture (1997) Usual planting and harvesting dates for U.S. field crops. Agricultural Handbook Number 628. 1-51

Natural Resources Conservation Service - United States Department of Agriculture (2006) Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296. 152-153

United States Geological Survey (1996) National water summary on wetland resources. USGS Water-Supply Paper 2425

United States Geological Survey (1999) The quality of our nations waters: nutrients and pesticides. U.S. Geological Survey Circular 1225, 82

United States Geological Survey (2016) Boundary descriptions and names of regions, subregions, accounting units and cataloging units. Date Accessed: February 21, 2017. https://water.usgs.gov/GIS/huc_name.html#Region09

Vymazal J (2007) Removal of nutrients in various types of constructed wetlands. Science of the Total Environment 380: 48 – 65

Wang J, Da L, Song K, Li BL (2008) Temporal variations of surface water quality in urban, suburban, and rural areas during rapid urbanization in Shanghai, China. Environmental Pollution. 152: 387 – 393

Werner KJ, Zedler JB (2002) How sedge meadow soils, microtopography, and vegetation respond to sedimentation. Wetlands. 22 (3): 451 – 466

APPENDIX A. 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.

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: <u>Do not</u> 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: <u>Do not</u> 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.

Field Sample Filtration Peristaltic Method

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:**	**DissolvedO_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 Filtered: ________________ mL	☐ SW-DOC	
☐ 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

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		

APPENDIX B. SURFACE RATIOS AND GEOMORPHIC CHANGE DETECTION DATA FOR EACH WETLAND ACROSS THE URBAN GRADIENT ACQUIRED FROM ARCMAP GIS SOFTWARE

Site ID	Impervious (m2)	Pervious (m2)	GCD (m2)	GCD Ratio
PU1	5552100	5821200	900	6169:6468
PU2	4911300	4210200	900	5457:4678
PU3	501300	253800	900	557:282
PU4	4041000	4718700	900	4490:5243
PU5	4077900	4951800	900	4531:5502
PU6	3350700	6204600	2700	1241:2298
PU7	5544000	2920500	49500	112:59
PU8	3730500	5226300	900	4145:5807
PU9	4446000	5003100	900	4940:5559
PU10	3482100	5436900	900	3869:6041
U1	2892	6928200	12	241:577350
U2	8640000	1023300	2700	3200:379
U3	7134300	2144700	900	7927:2383
U4	6117300	1922400	900	6797:2136
U5	7314300	1030500	900	8127:1145
U6	8623800	35100	2700	3194:13
U7	7441200	1699200	3600	2067:472
U8	4527000	4894200	1800	2515:2719
U9	5355000	3481200	1800	2975:1934
U10	7423200	1563300	900	8248:1737
R1	454500	8270100	900	505:9189
R2	366300	8154900	900	407:9061
R3	828000	8132400	3600	230:2259
R4	317700	8010900	900	353:8901
R5	2001600	10067400	1800	1112:5593
R6	718200	9072000	37800	19:240
R7	801900	9648900	900	891:10721
R8	901800	7771500	900	1002:8635
R9	1377900	7367400	900	1531:8186
R10	554400	7956900	6300	88:1263

APPENDIX C. COMPREHENSIVE PLANT SPECIES LIST OBSERVED AT RURAL SITES

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Ind[5]
Acer negundo	Box Elder	1	P	Native	FAC
Agropyron repens	Quackgrass	*	P	Introduced	FAC
Alyssum alyssoides	Pale Alyssum	*	A	Introduced	UPL
Amaranthus retroflexus	Rough Pigweed	0	A	Native	FACU
Ambrosia artemisiifolia	Common Ragweed,	0	A	Native	FACU
Apocynum cannabinum	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
Asclepias incarnata	Swamp Milkweed	5	P	Native	OBL
Asclepias syriaca	Common Milkweed	0	P	Native	UPL
Aster ericoides	White Aster	2	P	Native	FACU
Aster simplex	Panicled Aster	3	P	Native	FACW
Beckmannia syzigachne	American Sloughgrass	1	A	Native	OBL
Bidens cernua	Nodding Beggar-ticks	3	A	Native	OBL
Bromus inermis	Smooth Brome	*	P	Introduced	UPL
Calamagrostis stricta	N/A	5	P	Native	FACW+
Ceratophyllum demersum	Hornwort, Coontail	4	P	Native	OBL
Chenopodium glaucum	Oak-leaved Goosefoot	*	A	Introduced	FACW
Cirsium arvense	Canada Thistle	*	P	Introduced	FACU
Cirsium vulgare	Bull Thistle	*	B	Introduced	UPL
Convolvulus arvensis	Field Bindweed	*	P	Introduced	UPL
Cornus stolonifera	Red Osier	5	P	Native	FACW
Carex aquatilis	Water Sedge	10	P	Native	OBL
Cyperus erythrorhizos	Redrooted Cyperus	2	A	Native	OBL
Echinochloa crusgalli	Barnyard Grass	*	A	Introduced	FACW
Echinocystis lobata	Wild Cucumber	3	A	Native	FAC
Eleocharis acicularis	Needle Spikesedge	3	P	Native	OBL
Epilobium angustifolium	Willow-herb	5	P	Native	UPL
Epilobium ciliatum	Willow-herb	3	P	Native	OBL
Epilobium paniculatum	Willow Herb	3	A	Native	UPL
Equisetum hyemale	Common Scouring Rush	3	P	Native	FACW
Euphorbia esula	Leafy Spurge	*	P	Introduced	UPL
Euphorbia glyptosperma	Ridge-seeded Spurge	0	A	Native	FACU
Fraxinus pennsylvanica	Green Ash	5	P	Native	FAC
Hordeum jubatum	Foxtail Barley	0	P	Native	FACW

Scientific Name[1]	**Common Name**	**C-Val[2]**	**Life[3]**	**Origin[4]**	**Ind[5]**
Impatiens capensis	Spotted Touch-me-not	4	A	Native	FACW
Juncus balticus	Baltic Rush	5	P	Native	FACW
Lechea stricta	Pinweed	8	P	Native	UPL
Lemna minor	Duckweed	9	P	Native	OBL
Leonurus cardiaca	Motherwort	*	P	Introduced	FACU
Lycopus americanus	American Bugleweed	4	P	Native	OBL
Lycopus asper	Rough Bugleweed	4	P	Native	OBL
Medicago lupulina	Black Medick	*	P	Introduced	FACU
Melilotus officinalis	Yellow Sweet Clover	*	A	Introduced	FACU-
Mentha arvensis	Field Mint	3	P	Native	FACW
Nymphaea odorata	Fragrant White Waterlily	9	P	Native	OBL
Oenothera biennis	Common Evening Primrose	0	B	Native	FACU
Panicum capillare	Common Witchgrass	0	A	Native	FAC
Parthenocissus quinquefolia	Virginia Creeper	2	P	Native	FAC
Phalaris arundinacea	Reed Canarygrass	0	P	Native	FACW+
Pilea pumila	Clearweed	4	A	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	Swamp Smartweed	0	P	Native	OBL
Polygonum aviculare	Knotweed	0	A	Native	FACU
Polygonum lapathifolium	Pale Smartweed	1	A	Native	OBL
Populus deltoides	Cottonwood	3	P	Native	FAC
Potamogeton pectinatus	Sago Pondweed	0	P	Native	OBL
Potentilla rivalis	Brook Conquefoil	3	A	Native	OBL
Ranunculus hispidus	Marsh Buttercup	7	P	Native	OBL
Ranunculus sceleratus	Cursed Crowfoot	3	A	Native	OBL
Rosa arkansana	Prairie Wild Rose	3	P	Native	FACU
Rudbeckia hirta	Black-eyed Susan	5	B	Native	FACU
Rumex crispus	Curly Dock	*	P	Introduced	FACW
Rumex mexicanus	Willow-leaved Dock	1	P	Native	FACW
Sagittaria cuneata	Arrowhead	6	P	Native	OBL
Salix amygdaloides	Peachleaf Willow	3	P	Native	FACW
Salix exigua	Sandbar Willow	3	P	Native	FACW+
Scirpus acutus	Hard-stem Bulrush	5	P	Native	OBL

Scientific Name[1]	**Common Name**	**C-Val[2]**	**Life[3]**	**Origin[4]**	**Ind[5]**
Scirpus fluviatilis	River Bulrush	2	P	Native	OBL
Scirpus pungens	N/A	4	P	Native	OBL
Scutellaria lateriflora	Mad-dog Skullcap	6	P	Native	FACW
Setaria glauca	Yellow Foxtail	*	A	Introduced	FACU
Solidago canadensis	Canada Goldenrod	1	P	Native	FACU
Solidago gigantea	Late Goldenrod	4	P	Native	FACW
Sonchus arvensis	Field Sow Thistle	*	P	Introduced	FAC
Sparganium eurycarpum	Giant Burreed	4	P	Native	OBL
Taraxacum officinale	Common Dandelion	*	P	Introduced	FACU
Thalictrum dasycarpum	Purple Meadow Rue	7	P	Native	FAC
Thlaspi arvense	Field Pennycress	*	A	Introduced	FACU
Trifolium pratense	Red Clover	*	P	Introduced	FACU
Trifolium repens	White Clover	*	P	Introduced	FACU
Typha x glauca	Hybrid Cattail	*	P	Introduced	OBL
Urtica dioica	Stinging Nettle	0	P	Native	FACW
Verbena hastata	Blue Vervain	5	P	Native	FACW
Vitis riparia	River-bank Grape	3	P	Native	FAC
Xanthium strumarium	Cocklebur	0	A	Native	FAC

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 D. COMPREHENSIVE PLANT SPECIES LIST OBSERVED AT PERI-URBAN WETLAND SITES

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Achillea millefolium	Yarrow	3	P	Native	UPL
Agropyron caninum	Slender Wheatgrass	6	P	Native	FAC-
Agropyron elongatum	Tall Wheatgrass	*	P	Introduced	UPL
Agropyron repens	Quackgrass	*	P	Introduced	FAC
Agropyron smithii	Western Wheatgrass	4	P	Native	UPL
Agrostis stolonifera	Redtop	*	P	Introduced	FACW
Alyssum alyssoides	Pale Alyssum	*	A	Introduced	UPL
Ambrosia artemisiifolia	Common 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
Apocynum cannabinum	Prairie Dogbane	4	P	Native	FAC
Artemisia biennis	Biennial Wormwood	*	B	Introduced	FAC
Asclepias syriaca	Common Milkweed	0	P	Native	UPL
Aster ericoides	White Aster	2	P	Native	FACU
Aster novae-angliae	New England Aster	8	P	Native	FACW
Bidens cernua	Nodding Beggar-ticks	3	A	Native	OBL
Bidens frondosa	Beggar-ticks	1	A	Native	FACW
Brassica campestris	Wild Turnip	*	A	Introduced	UPL
Bromus inermis	Smooth Brome	*	P	Introduced	UPL
Ceratophyllum demersum	Hornwort, Coontail	4	P	Native	OBL
Chenopodium glaucum	Oak-leaved Goosefoot	*	A	Introduced	FACW
Cirsium arvense	Canada Thistle, Field Thistle	*	P	Introduced	FACU
Cirsium vulgare	Bull Thistle	*	B	Introduced	UPL
Convolvulus arvensis	Field Bindweed	*	P	Introduced	UPL
Conyza canadensis	Horseweed	0	A	Native	FACU
Coreopsis palmata	Finger Coreopsis	8	P	Native	UPL
Cornus stolonifera	Red Osier	5	P	Native	FACW
Carex aquatilis	Water Sedge	10	P	Native	OBL
Carex lanuginosa	Woolly Sedge	4	P	Native	OBL
Cyperus erythrorhizos	Redrooted Cyperus	2	A	Native	OBL
Dalea purpurea	Purple Prairie Clover	8	P	Native	UPL
Desmanthus illinoensis	Illinois Bundleflower	5	P	Native	FACU
Echinochloa crusgalli	Barnyard Grass	*	A	Introduced	FACW
Eleocharis acicularis	Needle Spikesedge	3	P	Native	OBL

Scientific Name[1]	**Common Name**	**C-Val[2]**	**Life[3]**	**Origin[4]**	**Indicator[5]**
Elymus canadensis	Canada Wild Rye	3	P	Native	FACU
Epilobium angustifolium	Willow-herb	5	P	Native	UPL
Epilobium paniculatum	Willow Herb	3	A	Native	UPL
Euphorbia esula	Leafy Spurge	*	P	Introduced	UPL
Euphorbia glyptosperma	Ridge-seeded Spurge	0	A	Native	FACU
Eupatorium perfoliatum	Boneset	9	P	Native	OBL
Helianthus annuus	Common Sunflower	0	A	Native	FACU
Helianthus maximilianii	Maximilian Sunflower	5	P	Native	FACU
Helianthus nuttallii	Nuttall's Sunflower	8	P	Native	FAC
Hibiscus trionum	Venice Mallow	*	A	Introduced	UPL
Hordeum jubatum	Foxtail Barley	0	P	Native	FACW
Iris missouriensis	Western Blue Flag	6	P	Native	FACW+
Juncus torreyi	Torrey's Rush	2	P	Native	FACW
Kochia scoparia	Kochia, Fire-weed	*	A	Introduced	FAC
Lactuca serriola	Prickly Lettuce	*	A	Introduced	FACU
Lemna minor	Duckweed	9	P	Native	OBL
Lotus corniculatus	Bird's-foot Trefoil	*	P	Introduced	FACU
Lycopus americanus	American Bugleweed	4	P	Native	OBL
Lycopus asper	Rough Bugleweed	4	P	Native	OBL
Matricaria maritima	Wild Chamomile	*	A	Introduced	FAC
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-
Monarda fistulosa	Wild Bergamot	5	P	Native	FACU-
Oenothera biennis	Common Evening Primrose	0	B	Native	FACU
Panicum capillare	Common Witchgrass	0	A	Native	FAC
Panicum virgatum	Switchgrass	5	P	Native	FAC
Phalaris arundinacea	Reed Canarygrass	0	P	Native	FACW+
Plantago major	Common Plantain	*	P	Introduced	FAC
Poa compressa	Canada Bluegrass	*	P	Introduced	FACU
Poa palustris	Fowl Bluegrass	4	P	Native	FACW
Poa pratensis	Kentucky Bluegrass	*	P	Introduced	FACU
Polygonum amphibian	Water Smartweed	6	P	Native	FACW
Polygonum arenastrum	Knotweed	0	A	Native	UPL
Polygonum aviculare	Knotweed	0	A	Native	FACU
Polygonum erectum	Erect Knotweed	0	A	Native	OBL
Polygonum lapathifolium	Pale Smartweed	1	A	Native	OBL

Scientific Name[1]	**Common Name**	**C-Val[2]**	**Life[3]**	**Origin[4]**	**Indicator[5]**
Polygonum ramosissimum	Bushy Knotweed	3	A	Native	FACU
Populus deltoides	Cottonwood	3	P	Native	FAC
Potamogeton pectinatus	Sago Pondweed	0	P	Native	OBL
Potamogeton pusillus	Baby Pondweed	2	P	Native	OBL
Rudbeckia hirta	Black-eyed Susan	5	B	Native	FACU
Rumex acetosella	Sheep Sorrel	*	P	Introduced	FAC
Rumex crispus	Curly Dock	*	P	Introduced	FACW
Salix amygdaloides	Peachleaf Willow	3	P	Native	FACW
Salix exiguar	Sandbar Willow	3	P	Native	FACW+
Scirpus acutus	Hard-stem Bulrush	5	P	Native	OBL
Scirpus fluviatilis	River Bulrush	2	P	Native	OBL
Scirpus pallidus	N/A	5	P	Native	OBL
Scirpus validus	Soft-stem Bulrush	3	P	Native	OBL
Setaria glauca	Yellow Foxtail	*	A	Introduced	FACU
Solidago canadensis	Canada Goldenrod	1	P	Native	FACU
Solidago gigantea	Late Goldenrod	4	P	Native	FACW
Sonchus arvensis	Field Sow Thistle	*	P	Introduced	FAC
Sorghastrum nutans	Indian Grass	6	P	Native	FACU
Spartina pectinata	Prairie Cordgrass	5	P	Native	FACW
Taraxacum officinale	Common Dandelion	*	P	Introduced	FACU
Trifolium pratense	Red Clover	*	P	Introduced	FACU
Trifolium repens	White Clover	*	P	Introduced	FACU
Typha x glauca	Hybrid Cattail	*	P	Introduced	OBL
Xanthium strumarium	Cocklebur	0	A	Native	FAC
Zizia aptera	Meadow Parsnip	8	P	Native	UPL

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 E. COMPREHENSIVE PLANT SPECIES LIST OBSERVED AT URBAN WETLAND SITES

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Acer negundo	Box Elder	1	P	Native	FAC
Acer saccharinum	Silver Maple	4	P	Native	FACW
Agropyron caninum	Slender Wheatgrass	6	P	Native	FAC-
Agropyron elongatum	Tall Wheatgrass	*	P	Introduced	UPL
Agropyron intermedium	Intermediate Wheatgrass	*	P	Introduced	UPL
Agropyron repens	Quackgrass	*	P	Introduced	FAC
Agrostis stolonifera	Redtop	*	P	Introduced	FACW
Alyssum alyssoides	Pale Alyssum	*	A	Introduced	UPL
Amaranthus retroflexus	Rough Pigweed	0	A	Native	FACU
Ambrosia artemisiifolia	Common Ragweed	0	A	Native	FACU
Ambrosia psilostachya	Western Ragweed	2	P	Native	FAC
Andropogon gerardii	Big Bluestem	5	P	Native	FACU
Apocynum cannabinum	Prairie Dogbane	4	P	Native	FAC
Artemisia biennis	Biennial Wormwood	*	B	Introduced	FAC
Asclepias incarnata	Swamp Milkweed	5	P	Native	OBL
Asclepias syriaca	Common Milkweed	0	P	Native	UPL
Aster ericoides	White Aster	2	P	Native	FACU
Aster simplex	Panicled Aster	3	P	Native	FACW
Bouteloua gracilis	Blue Grama	7	P	Native	UPL
Brassica hirta	White Mustard	*	A	Introduced	UPL
Bromus inermis	Smooth Brome	*	P	Introduced	UPL
Calamagrostis stricta	N/A	5	P	Native	FACW+
Cardaria pubescens	Whitetop	*	P	Introduced	UPL
Cerastium vulgatum	Common Mouse-ear Chickweed	*	P	Introduced	UPL
Chenopodium berlandieri	Pitseed Goosefoot	0	A	Native	FACU
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	*	P	Introduced	FACU
Cirsium vulgare	Bull Thistle	*	B	Introduced	UPL
Convolvulus arvensis	Field Bindweed	*	P	Introduced	UPL
Conyza canadensis	Horseweed	0	A	Native	FACU
Cornus stolonifera	Red Osier	5	P	Native	FACW
Carex atherodes	Slough Sedge	4	P	Native	OBL
Carex brevior	Fescue Sedge	4	P	Native	FACU

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Dalea purpurea var. purpurea	Purple Prairie Clover	8	P	Native	UPL
Echinochloa crusgalli	Barnyard Grass	*	A	Introduced	FACW
Eleocharis acicularis	Needle Spikesedge	3	P	Native	OBL
Elodea canadensis	Waterweed	8	P	Native	OBL
Elymus canadensis	Canada Wild Rye	3	P	Native	FACU
Epilobium ciliatum	Willow-herb	3	P	Native	OBL
Epilobium paniculatum	Willow Herb	3	A	Native	UPL
Erigeron philadelphicus	Philadelphia Fleabane	2	B	Native	FACW
Euphorbia esula	Leafy Spurge	*	P	Introduced	UPL
Euphorbia glyptosperma	Ridge-seeded Spurge	0	A	Native	FACU
Fraxinus pennsylvanica	Green Ash	5	P	Native	FAC
Fragaria virginiana	Wild Strawberry	4	P	Native	FACU
Glecoma hederacea	Ground Ivy	*	P	Introduced	FACU
Glycyrrhiza lepidota	Wild Licorice	2	P	Native	FACU
Helianthus annuus	Common Sunflower	0	A	Native	FACU
Helianthus maximilianii	Maximilian Sunflower	5	P	Native	FACU
Hordeum jubatum	Foxtail Barley	0	P	Native	FACW
Iris missouriensis	Western Blue Flag	6	P	Native	FACW+
Juncus balticus	Baltic Rush	5	P	Native	FACW
Juncus bufonius	Toad Rush	1	A	Native	OBL
Juncus torreyi	Torrey's Rush	2	P	Native	FACW
Kochia scoparia	Kochia, Fire-weed	*	A	Introduced	FAC
Lactuca canadensis	Wild Lettuce	6	B	Native	FACU
Lotus corniculatus	Bird's-foot Trefoil	*	P	Introduced	FACU
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-
Miscanthus sinensis	Chinese Silvergrass	N/A	P	Introduced	N/A
Oxalis stricta	Yellow Wood Sorrel	0	P	Native	FACU
Panicum capillare	Common Witchgrass	0	A	Native	FAC
Panicum virgatum	Switchgrass	5	P	Native	FAC
Phalaris arundinacea	Reed Canarygrass	0	P	Native	FACW+
Plantago major	Common Plantain	*	P	Introduced	FAC
Poa pratensis	Kentucky Bluegrass	*	P	Introduced	FACU
Polygonum amphibian	Swamp Smartweed	0	P	Native	OBL
Polygonum aviculare	Knotweed	0	A	Native	FACU
Polygonum erectum	Erect Knotweed	0	A	Native	OBL

Scientific Name[1]	**Common Name**	**C-Val[2]**	**Life[3]**	**Origin[4]**	**Indicator[5]**
Polygonum lapathifolium	Pale Smartweed	1	A	Native	OBL
Populus deltoides	Cottonwood	3	P	Native	FAC
Populus tremuloides	Quaking aspen	4	P	Native	FAC
Portulaca oleracea	Common Purslane	*	A	Introduced	FACU
Potentilla argentea	Silvery Cinquefoil	*	P	Introduced	FACU
Potamogeton pectinatus	Sago Pondweed	0	P	Native	OBL
Ranunculus cymbalaria	Shore Buttercup	3	P	Native	OBL
Ranunculus gmelinii	Small Yellow Buttercup	8	P	Native	FACW+
Rudbeckia hirta	Black-eyed Susan	5	B	Native	FACU
Rumex crispus	Curly Dock	*	P	Introduced	FACW
Rumex mexicanus	Willow-leaved Dock	1	P	Native	FACW
Salix amygdaloides	Peachleaf Willow	3	P	Native	FACW
Salix exigua	Sandbar Willow	3	P	Native	FACW+
Scirpus acutus	Hard-stem Bulrush	5	P	Native	OBL
Scirpus validus	Soft-stem Bulrush	3	P	Native	OBL
Setaria glauca	Yellow Foxtail	*	A	Introduced	FACU
Solidago canadensis	Canada Goldenrod	1	P	Native	FACU
Solidago gigantea	Late Goldenrod	4	P	Native	FACW
Sonchus arvensis	Field Sow Thistle	*	P	Introduced	FAC
Sorghastrum nutans	Indian Grass	6	P	Native	FACU
Spartina pectinata	Prairie Cordgrass	5	P	Native	FACW
Taraxacum officinale	Common Dandelion	*	P	Introduced	FACU
Thlaspi arvense	Field Pennycress	*	A	Introduced	FACU
Tragopogon dubius	Goat's Beard	*	B	Introduced	UPL
Trifolium pratense	Red Clover	*	P	Introduced	FACU
Trifolium repens	White Clover	*	P	Introduced	FACU
Typha x glauca	Hybrid Cattail	*	P	Introduced	OBL
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 F. WETLAND WATER QUALITY PARAMETERS AVERAGED OVER SITES WITHIN YEAR AND RURAL, PERI-URBAN, AND URBAN LAND USE CATEGORY

Wetland water quality parameters averaged over samples gathered from sites in 2015 and rural, peri-urban, or urban land use category. Standard deviations are provided in parentheses following the averages. The following elements were analyzed but never detected or used in an analysis: arsenic, beryllium, cadmium, chromium, copper, silver, titanium, and zinc. The first three parameters were measured in the field.

Parameter (Units)	**2015**		
	Rural	**Peri-Urban**	**Urban**
Conductivity – Field (µS/cm)	929.9 (859.9)	1285.6 (264.9)	1302.5 (753.6)
Dissolved Oxygen - Field (mg/L)	6.43 (3.2)	8.2 (2.0)	8.3 (0.6)
pH Field	7.5 (0.6)	7.8 (1.6)	8.2 (0.6)
Alkalinity total (mg/L)	263.2 (88.7)	179.9 (34.8)	160.3 (52.8)
Anion Sum (mg/L)	10.9 (11.3)	14.6 (3.1)	14.3 (7.9)
Bicarbonate (mg/L)	317.4 (110.8)	208.3 (43.1)	179.3 (64.7)
Calcium (mg/L)	69.5 (57.1)	85.1 (19.6)	85.1 (80.7)
Carbonate (mg/L)	1.9 (4.3)	5.6 (9.7)	8.0 (6.1)
Cation Sum (mg/L)	11.2 (12.2)	15 (3.3)	14.4 (7.9)
Chloride (mg/L)	23.6 (27.6)	32.3 (21.3)	99.4 (197.3)
Conductivity – Lab (µS/cm)	933.7 (837.5)	1308.2 (261.8)	1323.8 (746.1)
E coli MF	78.0 (99.7)	77.0 (119.0)	80.6 (100.8)
Hardness (mg/L)	395.6 (436.4)	493.2 (115.0)	463.9 (296.2)
Nitrogen-Total (mg/L)	1.7 (1.5)	0.9 (0.4)	0.8 (0.2)
pH - Lab	8.1 (0.3)	8.3 (0.4)	8.5 (0.3)
Potassium (mg/L)	12.3 (6.4)	6.1 (1.3)	0.1 (0.1)
Phosphorus - Total (mg/L)	0.4 (0.4)	0.11 (0.1)	0.19 (0.34)
Phosphorus – Dissolved (mg/L)	0.3 (0.4)	0.06 (0.1)	0.14 (0.3)
Sodium %	24.5 (15.4)	32.7 (6.8)	35.0 (12.0)
Sodium (mg/L)	68.2 (87.2)	113.6 (38.7)	112.1 (58.5)
Sodium Adsorption Ratio	1.5 (1.4)	2.2 (0.7)	2.3 (1.0)
Sulfate (mg/L)	233.6 (441.5)	480.6 (149.6)	393.8 (308.6)
Total Dissolved Solids (mg/L)	623.7 (715.6)	897.2 (207.1)	857.8 (488.4)
Total Kjeldahl Nitrogen (mg/L)	1.4 (0.8)	0.8 (0.4)	0.7 (0.2)
Total Suspended Solids (mg/L)	20.2 (23.8)	36.9 (47.7)	27.6 (19.8)

Wetland water quality parameters averaged over samples gathered from sites in 2016 and rural, peri-urban, or urban land use category. Standard deviations are provided in parentheses following the averages. The following elements were analyzed but never detected or used in an analysis: arsenic, beryllium, cadmium, chromium, copper, silver, titanium, and zinc. The first three parameters were measured in the field.

Parameter (Units)	**2016**		
	Rural	**Peri-Urban**	**Urban**
Conductivity – Field (µS/cm)	879.4 (537.0)	1382.3 (353.2)	1121.1 (707.9)
Dissolved Oxygen - Field (mg/L)	7.2 (4.2)	8.7 (4.1)	8.2 (4.6)
pH Field	7.5 (1.9)	8.2 (1.2)	7.9 (2.2)
Alkalinity total (mg/L)	228.1 (74.6)	15.5 (4.5)	143.3 (62.1)
Anion Sum (mg/L)	10.7 (7.6)	4.2 (7.2)	12.1 (7.5)
Bicarbonate (mg/L)	272.8 (89.9)	6.8 (1.9)	163.3 (72.0)
Calcium (mg/L)	86.6 (75.3)	16.3 (4.9)	68.8 (56.3)
Carbonate (mg/L)	6.3 (12.0)	1406.4 (334.0)	9.1 (8.9)
Cation Sum (mg/L)	11.1 (8.0)	0.1 (0.01)	12.4 (7.9)
Chloride (mg/L)	31.8 (37.1)	4.9 (7.6)	71.7 (114.2)
Conductivity – Lab (µS/cm)	1007 (608.0)	0.1 (0.1)	1158.2 (647.4)
E coli	52.8 (91.8)	96.3 (258.5)	64.2 (112.1)
Hardness (mg/L)	418.2 (308.4)	221.3 (71.8)	403.7 (256.2)
Nitrogen-Total (mg/L)	1.9 (2.0)	0.9 (0.4)	0.9 (0.4)
pH - Lab	8.3 (0.6)	8.5 (0.7)	8.4 (1.2)
Potassium (mg/L)	15.4 (10.2)	76.3 (26.9)	7.2 (5.4)
Phosphorus - Total (mg/L)	0.4 (0.5)	0.1 (0.1)	0.2 (0.2)
Phosphorus – Dissolved (mg/L)	0.3 (0.4)	0.6 (0.7)	0.1 (0.2)
Sodium %	26.7 (17.0)	133.3 (40.4)	35.9 (12.6)
Sodium (mg/L)	72.4 (69.9)	0.07 (0.04)	106.9 (66.8)
Sodium Adsorption Ratio	1.7 (1.5)	0.1 (0.01)	2.3 (1.04)
Sulfate (mg/L)	277.4 (329.2)	979.4 (265.5)	359.0 (303.7)
Total Dissolved Solids (mg/L)	650.8 (498.7)	12.6 (4.8)	748.0 (461.88)
Total Kjeldahl Nitrogen (mg/L)	1.6 (0.9)	0.8 (0.3)	0.9 (0.3)
Total Suspended Solids (mg/L)	89.0 (266.8)	3.8 (6.5)	56.2 (177.1)