EFFECTS OF MAJOR FLOODING ON WATER AND SEDIMENT CHARACTERISTICS IN AN URBAN ENVIRONMENT

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Impacts of Major Flooding on Water and Sediment Quality

In an Urban Environment

By

Adam Christopher Guy

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

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ABSTRACT

Guy, Adam Christopher, M.S., Department of Soil Science, College of Agriculture, Food Systems, and Natural Resources, North Dakota State University, March 2011. Effects of Major Flooding on Water and Sediment Characteristics in an Urban Environment. Major Professor: Dr. Thomas DeSutter.

Spring flooding of the Red River of the North is a common phenomenon, but no information exits on how these flooding events impact both water and sediment quality within an urban area. The objectives of this study were to assess if urban environments affect floodwater quality and to determine the quality of sediment deposited in an urban environment after floodwaters recede. Water samples were taken on 12 dates from two locations before and after the city limits of Fargo, North Dakota and Moorhead, Minnesota (F-M), and were measured for 12 variables including total sediment, PO_4, 17ß-estradiol, and diesel range organics. Sediment and underlying soil samples were collected from three locations within F-M where, at each location, there were three equidistant transects parallel to the river channel, and analyzed for 40 variables including dry sediment mass, carbon, nitrogen, diesel and gasoline range organics, and trace elements. Considering river discharge and total sediment and PO_4 concentrations at each sampling date, about 4500 Mg of sediment and 30 Mg of PO_4 were estimated to have been deposited within F-M. 17ß-estradiol was detected in 9 of 24 water samples with an average concentration of 0.61 ng L^{-1} and diesel range organics were detected in 8 of 24 samples with an average concentration of 80.0 $\mu g\ L^{-1}$. Average mass of sediment across locations and transects ranged from about 2 to 10 kg m^{-2} where transects closest to the river channel had the higher mass deposits of sediment. Total carbon and nitrogen within the sediment was determined to be mostly organic and ranged from about 40 to 59 g kg^{-1} and about 1,760 to 4,930 mg kg^{-1}, respectively, with the highest concentrations occurring at the transect furthest from the

river channel. No gasoline range organics were detected, but diesel range organics were detected in 26 of the 27 sediment samples analyzed with a maximum concentration of 49.2 $\mu g\ g^{-1}$. Total Hg concentrations in the sediment and soil averaged about 55 and 61 $ng\ g^{-1}$, respectively, and all trace elements detected in the sediments were within ranges for non-contaminated sites. Although sediments remaining after floodwaters recede can be unsightly and cleanup efforts can be labor intensive, these sediments can also provide essential plant nutrients for urban riverine ecosystems, which may include turf grass, fruits and vegetables, and horticultural plants.

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DEDICATION

I would like to dedicate this research project to the following:

> My wife and best friend Ashley Guy for her love, support, and encouragement throughout my life; and
>
> My daughter Eden Grace Guy for her bright smiles, laughter, and personality as she has given me so much to be thankful for.

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GENERAL INTRODUCTION

Flooding of the Red River of the North (RR) is a major detriment to economic, social, and agricultural communities. The average annual costs of flood damage for Fargo, North Dakota and Moorhead, Minnesota (F-M) exceed $190 million (US) (US Army Corps of Engineers, 2010). The RR basin is predominantly agricultural (Stoner et al., 1993) and there is a concern for high volumes of sediment loading into the RR because constituents attached to sediments may affect water and sediment quality in floodwaters (Du Laing et al., 2008; Lair et al., 2009; Ongley, 1996b; Sterk et al., 1996).

Problems associated with flooding in an urban environment may be multi-faceted. Impacts from runoff or contaminated floodwater to an urban environment may include surface and groundwater degradation (Cihacek et al., 1993; Ongley, 1996b), impairment to aquatic species (Schueler, 1994; Schoenfuss et al., 2011; Toft and Baatrup, 2001), recreational and aesthetic values (Dudgeon, 2000; Hearne, 2007; Schoenfuss et al., 2011), and economic losses to farmers and communities (James and Korum, 2001; Leitch and Schultz, 2003; Ongley, 1996b). The response or prevention of these challenges may determine how these impacts affect the economic, social, and agricultural communities overall (IJC, 2001). Floodwater is the general and temporary condition of partial or complete inundation of normally dry land from overland flow or rapid accumulation of surface water runoff from any source (FEMA, 2010).

There are many potential environmental impacts associated with flooding in an urban environment (Goonetilleke et al., 1995; Ongley, 1996b; Tsihrintzis and Hamid, 1997). To reduce the potential impacts of flooding, many decisions and actions could be considered to minimize the effects of flooding on water and sediment quality, which may include the selection of sustainable agricultural practices (Ongley, 1996b), socially responsible floodplain development (Leitch, 2003), and minimizing impervious surfaces (Niemczynowicz, 1999; Tsihrintzis and Hamid, 1997). However, little research has been done on the impacts of flooding on sediment deposition and its quality or water quality through an urban environment in the RR basin. The purpose of this study was to determine if urban environments affect floodwater constituents and to assess quality of the sediment deposited in an urban environment after floodwaters recede.

LITERATURE REVIEW

Floodplain Features and the Red River Valley of the North

The simplified definition of floodplain is an area adjacent to a body of water that is periodically inundated (FEMA, 2003). However, there are other technical definitions of a floodplain, which include its formation by periodical deposition of suspended sediments from river water during flood events (Du Laing et al., 2008); characterization of the shifting mosaic of interconnected aquatic, semi-aquatic and terrestrial habitats and are among the most productive and heterogeneous ecosystems on continents (Lair et al., 2009); and a strip of relatively flat-lying land bordering a stream and is underlain by sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current (USGS, 2008). Even though soils of many floodplains developed before human influence, some major sedimentation events were a result of human settlement. Deforestation, cultivation, and flood protection measures are a few human activities that had an impact on sedimentation (Du Laing et al., 2008).

Flood damage has been a persistent characteristic of human use and settlement of the RR, and, as a result, has been a hazard for communities within its basin (Todhunter, 1998). In March 2009, the RR at Fargo-Moorhead (F-M) experienced the highest flood stage in recorded basin history (USGS, 2010b). When floods reach this magnitude costly consequences can occur. Flooding in the RR is a major detriment to economic, social, and agricultural communities where the average annual flood damage for F-M exceeds $190 million (US) (US Army Corp of Engineers, 2010), and annually across the US average over $3 billion (US) (Pielke and Downton, 2009). With nearly 6 million buildings within the boundaries of a 100-year floodplain in the United States, flood damages are widespread (averaging $115 million (US) per week) and will probably continue (Congressional Natural Hazard Caucus Work Group, 2001).

The magnitude of spring flooding in the RR basin is affected by a series of factors contributing to the rapid water-level rise and eventual flooding. These factors include: (i) precipitation amounts in the fall that produce above average soil moisture before soil freeze-up; (ii) above-normal winter snowfall; (iii) the depth and moisture content of the seasonally frozen soils that prohibit water infiltration; (iv) above-normal precipitation during spring thaw; (v) the duration and rate of spring snowmelt; (vi) temporary dams of ice (ice jams) on the river; and (vii) the gentle slope of the main channel, ranging from 0.25 m km^{-1} at Wahpeton, 0.095 m km^{-1} at Grand Forks, and only 0.038 m km^{-1} at the North Dakota and Canada border (IJC, 2000; Macek-Rowland, 1997; Todhunter, 2001).

Some areas of the United States, such as the RR basin, are plagued with flooding (Leitch, 2003), however, pressures for new housing developments in flood-prone areas (near rivers and lakes) continue (Pinter, 2005). There are many reasons why development of floodplains remains high. For example, floodplains are among the most unique landscapes and are characterized by high biodiversity (vegetation and wildlife), productivity, and for recreational and aesthetic values (Lair et al., 2009; Magilligan et al, 1998; Ravenga et al., 2000; Tockner and Stanford, 2002).

Floodplains are known for their cultural and economic importance; early civilizations thrived in fertile floodplains, and throughout history humans have learned to use floodplains extensively (Hillel, 1991; Tockner and Stanford, 2002). For example, 46% of floodplains in the United States are intensively cultivated; and between 60 and 99% of floodplains have been transformed to cropland or urbanized in Asia and Europe (Ravenga et al., 2000; Tockner and Stanford, 2002). Currently over 60 percent of the world's population lives within 1 km of surface water, commonly along rivers and coastlines (Tockner and Stanford, 2002). Flood damages have increased due to the extensive development of floodplains (Burby, 2002).

Many studies have been conducted on the RR involving the social, economic, geologic, and land use related issues (Hearne, 2007; James and Korum, 2001; Leitch and Schultz, 2003; Schwert, 2003; Simonovic and Carson, 2003). The 1997 flood forced 75,000 North Dakotans from their homes (James and Korum, 2001). Land use in the RR basin plays a major role in the environmental impacts directly relating to the soil and water quality of the RR. In 1972, approximately 75% of the land base in the RR basin was used for production agriculture (Souris-Red-Rainy River Basins Commission, 1972). Commonly grown production crops in the basin include corn (*Zea mays*), soybeans (*Glycine max*), sugar beets (*Beta vulgaris*), and wheat (*Triticum spp.*) (USDA-NASS, 2010). Approximately 3% of the RR basin is urban lands (Souris-Red-Rainy River Basins Commission, 1972); however, urban areas play a sizeable role in contaminating watersheds (Davis et al., 2001; Goonetilleke et al., 2005; Gromaire-Mertz et al., 1999, Sartor and Boyd, 1972; Tsihrintzis and Hamid, 1997). Water from approximately 19% (about 1.8 million ha) of the RR drainage basin flows through F-M (Stoner et al., 1993). Along the 43 river-km in F-M, urban development (residential homes) encompasses much of the land area, but over 20 public and recreational areas (parks, community gardens, school campuses, and golf courses) also occupy lands along its banks in F-M.

Land Use Impacts

Land use impacts contributing to flood events can be urban and rural and both can contribute positive and negative attributes to flood events. In 2009, many factors contributed to the highest recorded levels of the RR in the F-M area, which can include: (i) substantial amount of precipitation in the fall that produces high levels of soil moisture before soil freeze-up; (ii) above-average winter snowfall covering the vast amounts of agricultural acreage; (iii) the depth and moisture content of the seasonally frozen soils that prohibits water infiltration; (iv) above-normal precipitation during spring thaw; (v) and the duration and rate of spring snowmelt; (Macek-Rowland, 1997; Simonovic and Carson, 2003; Todhunter, 2001).

Human activities associated with settlement, around the early 19th century, have changed the hydrologic landscape, which includes flooding, the dynamics of stream channels and the associated floodplains, and erosion, transportation, deposition of sediments (Knox, 2006). Many factors affect the quality of runoff with land use having the most impact. Land use changes, such as vegetation removal, increases in impervious surfaces, construction, cultivation practices, and changing drainage channels, coupled with urbanization may result in surface runoff alterations (Cooper and Gillespie, 2001; Du Laing et al., 2008; Goonetilleke et al., 2005; Lair et al., 2009; Sartor & Boyd, 1972; Tsihrintzis and Hamid, 1997). Future floodplain land use must aid in long-term storage of contaminants through soil conservation (Lair et al., 2009) because many studies have tried to correlate land use with contaminant loadings, but the results reported have been inconsistent (Hall and Anderson, 1986; Parker et al., 2000; Sartor and Boyd, 1972).

Urban Characteristics

Positive.

There is little research available on the benefits of urban flooding. Observations of the spring 2009 RR flood might suggest that lands along the river are managed for and covered with turf grass. Functional benefits from turf grass may include: soil erosion and dust stabilization thereby protecting the soil resource; improved recharge of groundwater, plus flood control; entrapment of and biodegradation of nutrients (N and P), contaminants (Hg, Pb, and Zn), and organic compounds (hydrocarbons) (Beard and Green, 1994).

Negative.

Urban runoff is a source of water contamination and has been shown to contribute nutrients (total N and P), trace metals (Cu, Hg, Pb, and Zn), polycyclic aromatic hydrocarbons (PAHs) (pyrene, benzol[a]pyrene, and chrysene), organic compounds (fecal coliform), and sediment to receiving waters (Bakri et al., 2008; Herngren et al., 2010; Niemczynowicz, 1999; USEPA, 1990; Vaze and Chiew, 2002). These contaminants can adversely affect water bodies by degrading aquatic habitats, depreciating recreation and aesthetics, or by causing algae to grow uncontrollably (Herngren et al., 2010; Hunter et al., 1979; Settacharnwit et al., 2003). In addition, high concentration levels of these contaminants coming from suspended solids, pathogens (e.g., animal waste), nutrients (N and P), and toxic chemicals (PAHs, Hg, Pb, and Zn) (Bay et al., 2003; Boxall and Maltby, 1995; Carr et al., 2000) affect the organisms living in these environments. Urban runoff can be highly contaminated, and above tolerable environmental standard concentration levels (Taebi and Droste, 2004a,b).

Potential concerns from the environmental presence of hormones include their ability to alter sexual behavior and endocrine systems of animals and aquatic species (Larsson et al., 2000) and increased incidences of cancer (Davis and Bradlow, 1995). Most of these hormones are produced and released into the environment by livestock (manure), wildlife, and humans (urine and feces) (Shore et al., 1998; Shore and Shemesh, 2003). 17ß-estradiol strongly binds to the organic phase of soil particles and does not dissolve or transport in soil water (Casey et al., 2003; Anderson et al., 2005).

In addition to the numerous environmental impacts, urban runoff may contribute to social and economic hardships (James and Korum, 2001). For example, recreational and aesthetic values may be diminished (Dudgeon, 2000; Hearne, 2007; Schoenfuss et al., 2011) through impairment to aquatic species (Schueler, 1994; Schoenfuss et al., 2011; Toft and Baatrup, 2001), considerable cleanup costs (Burby, 2002 ; James and Korum, 2001), closing of businesses for extended periods of time (IJC, 2000; James and Korum, 2001), and the loss of community members caused from relocating (James and Korum, 2001).

Urban environments may be affected by contaminants introduced through human activities (Goonetilleke et al., 2005). There is a difference between contaminant and pollutant, but for the purpose of this paper contaminant will be used. A contaminant is above background levels but has not been found to cause harm, whereas a pollutant is above background levels and has been deemed to potentially cause harm. As a result, activities associated with urbanization have a direct influence on the quality of stormwater runoff. Stormwater runoff is water from rain or melting snow that runs off across the land instead of seeping into the ground and usually flows into the nearest water body and is commonly untreated (FEMA, 2010). Land use and imperviousness are important factors in water quality management and contaminant loading into water bodies (Anon., 1981; O'Loughlin, 1994;Schueler, 1994; Tsihrintzis and Hamid, 1997). As a result of increased impervious surfaces, greater concentration levels of contaminants have been found in urban runoff (Hwang and Foster, 2006).

Rural Characteristics

Rural environments, specifically correlated with agricultural inputs, provide both positive and negative attributes to flood zones.

Positive.

Positive attributes from rural environments to flood zones may not be as evident as the negative attributes. Through management practices humans have a certain amount of control to minimize erosion. For example, losses of soil at the rate of 200 Mg ha^{-1} (100 tons ac^{-1}) under fallow or up-and-down-hill cultivation might lose only 20 Mg ha^{-1} (10 tons ac^{-1}) when planted with small grains; 4 Mg ha^{-1} (2 tons ac^{-1}) when in good pasture; and less that 2 Mg ha^{-1} (< 1 ton ac^{-1}) when in good forest cover (Gottschalk and Jones, 1955). Considerable reductions in soil erosion such as this example can equate to retaining more than two centimeters (1 inch) of topsoil from being removed annually (Gottschalk and Jones, 1955). Choosing management practices for certain terrains or soil types may reduce the impacts of erosion on water quality.

Historically, flooding has nourished and sustained river valleys for millennia (Hillel, 1991). For example, flooding brought fertile alluvium to the Nile River valley, which sustained more than five millennia of civilization without disruption. The flooding events were considered a "gift from the Nile", which included both silt, nutrients, and water. Heavy monsoonal rains would scour the landscape, detaching the rich loose sediments, and transporting them to the banks of the Nile. Upon reaching the valley, the waters would overflow the banks and deposit a thin layer of new sediment on the floodplain. The amount of sediment deposited was not enough to choke off the irrigation canals or cover the seedlings, but it was fertile enough to add nutrients to the land. Floods were beneficial because of the favorable mixture of water, soil, nutrients, and organic matter (Hillel, 1991). The RR basin too was dubbed the "Nile of the Western Hemisphere" on an early map that tried to recruit settlers to this area (Hall, 1908).

Once sediments settle out from the water column or have accumulated on the channel banks after floodwaters recede, nutrients can become stored within the sediments, transform through nutrient cycling, or become plant available (Nahlik and Mitsch, 2008). The organic matter content plays an important role in nitrogen cycling because certain forms of nitrogen (e.g., NH_4-N) are bound to organic matter until decomposition or by plant uptake (Mitsch and Gosselink, 2007). The process of sedimentation contributes to the removal of these physical and chemical parameters in the water column (Nahlik and Mitsch, 2008).

Negative.

Rural lands account for approximately 75 percent (93,200 km^2) of the total land base (116,500 km^2) (Souris-Red-Rainy River Basins Commission, 1972) in the RR basin, thus playing a contributing role in flood events and impacts. Negative characteristics from rural environments can include elevated concentrations of soil detachment (Bielders et al., 2003; Brunet and Astin, 2008; Hansen et al., 2000), nutrients (Hansen et al., 2000; Nahlik and Mitsch, 2008; Pease et al., 2010; Rekolianen, 1989; Shigaki et al., 2009), trace metals (Balogh et al., 2000; Buccolieri et al., 2010; Sando et al., 2003), and organic compounds

(Brigham et al., 1997; Tornes and Brigham, 1995). For example, incoming water to an Australian urban catchment received moderate to high levels of P (up to 2.0 mg L^{-1}), N (up to 14 mg L^{-1}), suspended solids (up to 660 mg L^{-1}), heavy metals (Zn ($\leq$ 0.05 mg L^{-1}); Pb (0.25 to 0.74 mg L^{-1}); Cu (0.05 to 0.14 mg L^{-1})), and fecal coliforms (up to 69,000 CFU 100 mL^{-1}) (Bakri et al., 2008). Some of these contaminants increased as the floodwater passed through urban areas, but rural stormwater runoff also showed relatively high concentrations of nutrients before reaching the urban catchment.

Artificially high nutrient inputs lead to an impoverished floodplain community (van den Brink et al., 1996). For example, floodplains along many southeast Asian rivers may serve as contaminant sinks when intensive cultivation or deforestation takes place (Dudgeon, 2000). The RR valley is like many southeast Asian rivers because of its agriculture land base (extensive cultivation). Nutrients and contaminants easily bind to clay-sized particles and organic matter (Dudgeon, 2000; Du Laing et al., 2008), of which the RR basin is primarily comprised. Other sources contributing to elevated contaminant levels include sewage, animal waste, and industrial waste that are discharged into rivers during seasonal floods (Dudgeon, 2000). However, streams are typically more contaminated in the dry seasons when low flows are insufficient to dilute contaminants (Dudgeon, 2000), which does not indicate that floods are good, but that floods dilute contaminant concentrations.

Water and Wind Erosion Impacts

Human activities, mainly related to agricultural land use over the past 200 years, have altered aspects relating to floods, which include erosion, transportation, and deposition of sediments associated with floodplains (Knox, 2006). Water-erodible sediments can be major sources of contamination to water bodies (Bielders et al., 2003; Hansen et al., 2000; Hubbard et al., 2011; Walling et al., 2003). When the rate of precipitation, or water content, in the soil exceeds the intake capacities of the soil, water that is not absorbed moves across the land as surface flow or evaporates (Osborn, 1955). The amount of soil displaced, or in motion, is a function of the energy of the runoff water and total suspended and dissolved solid levels. When the ground is frozen beneath the thawing surface layer, like during the 2009 RR spring flood, the topsoil becomes saturated and highly vulnerable to detachment and transport by surface flow (Osborn, 1955).

Sediment from agricultural runoff and erosion can be extensive in quantity and may facilitate transport of contaminants downstream. Sediment runoff and erosion is not necessarily the primary concern involved in flooding events. However, tillage practices may determine how much sediment loss will occur from agriculture lands. Choosing the appropriate tillage practice for a particular soil over time will often decrease soil erosion and increase available soil water for vegetation (Myers and Wagger, 1996). Conservation tillage practices, such as no-till, are generally credited with reducing soil losses compared to conventional tillage (Blevins et al., 1990; Mills et al., 1986; Myers and Wagger, 1996). Runoff and sediment losses from different tillage systems are often affected by regional characteristics of soils. For example, conservation practices, like no-till, have not been adopted in the RR valley because producers cannot easily convert from conventional to no-till due to cool soil temperatures, soil compaction, and poor water drainage (imperfectly drained clay soils) (Chen and Wylde, 2007). The loss of fertile topsoil by erosion commonly corresponds to a loss of productive land, nutrients, and organic matter (Ongley, 1996b). To maintain soil productivity, farmers replace this loss with fertilizer. Control of agricultural runoff usually starts with measures to control erosion and sediment runoff (Ongley, 1996b).

Although erosion is a natural phenomenon, the rate of soil loss is greatly increased by poor agricultural practices, which increase sediment loads in surface waters. To protect surface waters, soil must be managed well, which may require changes in land use and management (Ongley, 1996a). Sediments act as physical pollutants where high levels of sedimentation in rivers lead to physical disruption of the hydraulic characteristics of the channel (Ongley, 1996a). This phenomenon can have major impacts on navigation through reduction in depth of the channel, and can increase flooding events due to a reduction in capacity of the river channel to efficiently route water through the drainage basin. Suspended sediment concentrations typically peak during spring runoff (Bhowmik et al., 1986), whereas the growing season is not usually associated with sediment production, because landscapes are commonly well vegetated (Magilligan et al., 1998).

Nutrients, trace metals, organic compounds, and other contaminants have high affinity or sorption to mineral and organic particulate matter transported in the surface flow from agriculture lands (Du Laing et al., 2008; Hansen et al., 2000; Ongley, 1996a; Pease et al., 2010; Rinklebe et al., 2007; Walling et al., 2003). Sediment retention is a major mechanism of nutrient retention in floodplains (Olde Venterink et al., 2006). However, the retention of the physical and chemical inputs from sediment deposition can be questioned because of the possibility of being resuspended in future floods (Olde Venterink et al., 2006).

Agriculture sediments in the RR basin are highly susceptible to being displaced by wind and can be a source of contamination to RR water quality. These sediments can accumulate in dune-like deposits in road ditches, drainage ditches, and along banks of streams (Cihacek et al., 1993). In the Great Plains region of the United States in 2007, where the RR basin is located, more soil was lost by wind erosion (210 million metric tons) than water erosion (155 million metric tons) (USDA-NRI, 2007a,b, 2009). Wind-erodible sediments, like water erodible-sediments, are transport mechanisms of nutrients and minerals (NO_3-N, P, K, and organic C), trace metals (Hg, Zn, MN, and Cu), organic compounds (atrazine and acetochlor), and other contaminants (dust) to non-target destinations (Cihacek et al., 1993; Clay et al., 2001; DeSutter et al., 1998). However, the impact of these sediments on surface water quality in the RR basin is unknown (Cihacek et al., 1993).

Non-point Source Contamination

Urban runoff, as a whole, was reported as the second most frequent cause of contamination of surface waters, after agriculture (Anon., 1986), and the prevalence of such impacts is becoming more common in urban water bodies (Lehner et al., 1999; Makepeace et al., 1995; Marsalek, 1991; Sartor & Boyd, 1972; USEPA, 2000). Contaminant loadings in urban stormwater can be appreciably higher than in treated domestic sewage (Haiping and Yamada, 1998). Among the various contaminants, polycyclic aromatic hydrocarbons (PAHs), which are detrimental to ecosystems and human health, are commonly found in urban runoff (Estebe et al., 1997). Polycyclic aromatic hydrocarbons in urban runoff are generated from residential, industrial, and commercial urban land use and are commonly associated with particulate matter (Herngren et al., 2010; Makepeace et al., 1995; Marsalek et al, 1997). Contaminants transported in water downstream of urban environments can adversely affect water quality and land areas.

Therefore, it is important to know what activities and where in the urban environments contamination is generated to avoid downstream contamination (Niemczynowicz, 1999).

Street surface contaminants can directly impact contaminant concentrations in stormwater runoff, and may include all components related to vehicles (paint, rust, lubricants, fuel, and exhaust), atmospheric deposition (DDT, PCBs, and Cd, Hg, N, and Pb compounds), litter (trash), deliberate and accidental spills (oil, fertilizers, and residential and industrial chemicals), seasonal pavement compounds (ice control chemicals, publicly used chemicals, coal-tar pavement sealcoat), and human activities (Gnecco et al. 2005; Sartor & Boyd, 1972; Sartor et al., 1974; USEPA, 2009b; Van Metre and Mahler, 2010). In addition to the frozen soils in the RR basin in 2009, the impervious surfaces contribution may have increased contaminant loading while the area was flooding. Consideration must be given to the sources and route of transportation into and out of watersheds (Barkdoll et al., 1977).

Reducing Contamination Impacts

Urban surface water contamination is a challenge, but there are many measures and activities that can help improve the quality of urban and rural water bodies. Craft and Casey (2000) suggest that anthropogenic land use within a river basin or watershed is the primary factor affecting sediment and nutrient runoff and/or retention. Riparian vegetation is useful in retaining suspended sediments and its associated nutrients (Brunet and Astin, 2008). Long-term effects from implementing conservation tillage practices can reduce excessive amounts of sediment erosion and retain nutrients, otherwise transported in runoff, for agricultural production (Myers and Wagger, 1996).

Flooding events are not always predictable, controllable, or preventable. However, the more that is known about floods, the better-prepared humans can be to minimize flood impacts (social, economical, and environmental). Watershed planning and management should be considered in an effort to reduce the concentration levels of contaminants in urban and rural runoff. Therefore, adopting and implementing conservation practices that reduce contaminant loadings in urban stormwater runoff and rural overland flow might include: effective street cleaning operations; car parking controls and street zoning restrictions; reducing the number of impervious drainage channels; increasing water catchment areas and rain gardens in residential areas; reducing the amount of applications and compounds used in winter deicing operations; more effective street and sewer sanitation maintenance in commercial and industrial sectors; increase riparian vegetation; and implementation of conservation tillage practices (Tsihrintzis and Hamid, 1997).

EFFECTS OF MAJOR FLOODING ON WATER AND SEDIMENT CHARACTERISTICS IN AN URBAN ENVIRONMENT

Introduction

Flooding in the Red River Valley of the North (RR) is a major detriment to economic, social, and agricultural communities where the average annual flood damage to the F-M area exceeds $190 million (US) (US Army Corp of Engineers, 2010). The magnitude of spring flooding in the RR basin is hinged on a series of varying factors contributing to the rapid rise and eventual flooding. These factors include: (i) precipitation amounts in the fall that produce above average soil moisture before soil freeze-up; (ii) above-normal winter snowfall; (iii) the depth and moisture content of the seasonally frozen soils that prohibit water infiltration; (iv) above-normal precipitation during spring thaw; (v) the duration and rate of spring snowmelt; (vi) temporary dams of ice (ice jams) on the river; and (vii) the gentle slope of the main channel, ranging from 0.25 m km^{-1} at Wahpeton, 0.095 m km^{-1} at Grand Forks, and only 0.038 m km^{-1} at the Canadian border (IJC, 2000; Macek-Rowland, 1997; Todhunter, 2001). In 2009, these factors contributed to the historic levels of the RR in the F-M area.

The predominant land use in the RR drainage basin is agriculture where the main crops are corn (*Zea mays*), soybeans (*Glycine max*), sugar beets (*Beta vulgaris*), and wheat (*Triticum spp.*) (USDA-NASS, 2010). Water from approximately 19 percent (about 1.8 million ha) of the RR drainage basin flows through F-M (Stoner et al., 1993). Along the 43 river km in F-M, urban development (residential homes) encompasses much of the land area, but over 20 public and recreational areas (parks, community gardens, school campuses, and golf courses) also occupy lands along its banks.

Chemicals, dissolved in water and attached to sediments, transported via rural and urban flooding from target to non-target areas may impact water quality and the quality of the sediments deposited after floodwaters recede. Chemicals may include inorganics (Hubbard et al., 2011; Owens and Walling, 2002; Tian and Zhou, 2007), organics (Herngren et al., 2010;), and trace elements (Du Laing et al., 2008; Lair et al., 2009). An evaluation of N and P removed from the landscape during the June 2008 eastern Iowa flooding would have supplied enough N to fertilize six percent of all tillable land in the state and enough P for one percent of all tillable land in the state (Hubbard et al., 2011). Many of these chemicals may not negatively impact the environment; however, fruits and vegetables grown on contaminated soils can uptake trace elements and organic chemicals affecting food safety (Kipopoulou et al., 1999; Samsoe-Peterson et al., 2002; Voutsa et al., 1996).

In March 2009, the RR at F-M reached the highest flood stage in its recorded history (275.1 m above sea level) (Figure 1) (USGS, 2010b). Much of this area was flooded for more than 10 weeks, which allowed deposition of extensive quantities of sediment on this urban landscape (up to 4 cm).

Although many social and economic studies regarding RR flooding have been conducted (Burn, 1999; Hearne, 2007; IJC, 2000; James and Korum, 2001; Leitch and Shultz, 2003; Simonovic and Carson, 2003; Stoner et al., 1993), no environmental studies have been conducted regarding major flooding through an urban area in the southern RR basin. A combination of factors from both rural and urban environments, which may include chemicals (gasoline, diesel fuel, motor oil, pesticides, and fertilizers) stored in outbuildings, flooded motorized equipment, detached fuel-oil tanks, and detached soil

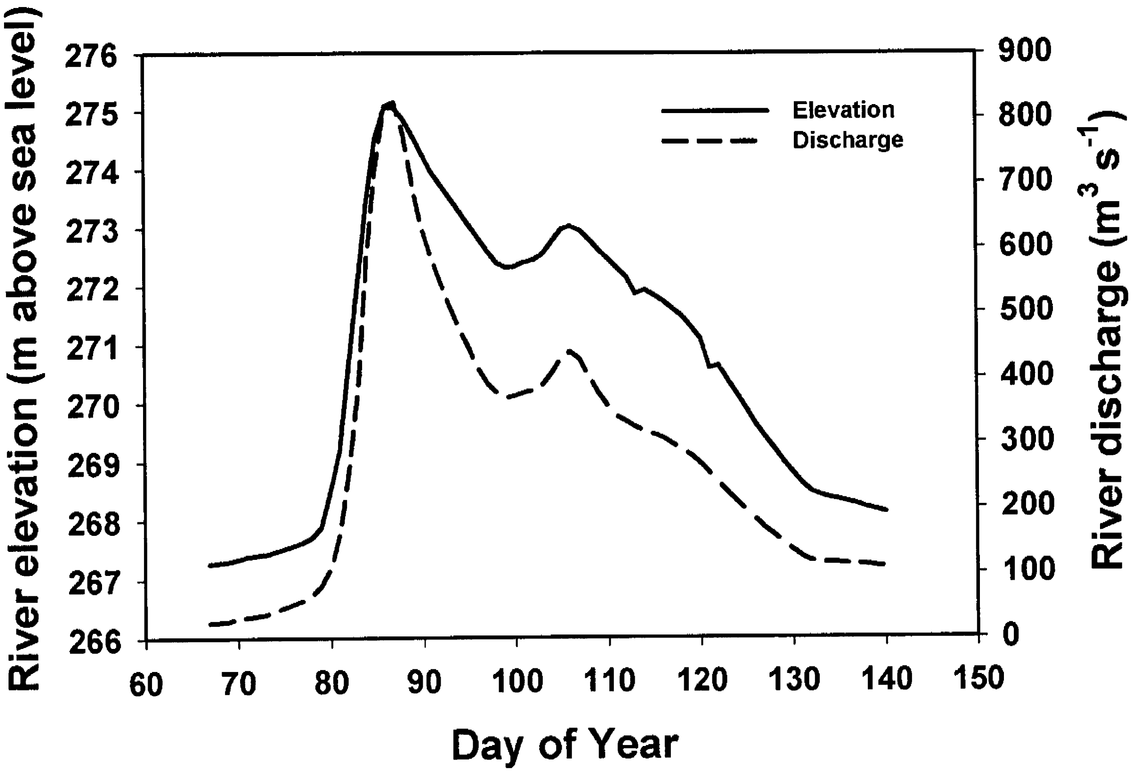

Figure 1. 2009 Red River of the North elevation above sea level and discharge recorded at the USGS gaging station in Fargo, North Dakota (http://fargoflood.dreamhosters.com/level2009/data.cgi).

carrying plant nutrients might influence water and sediment quality. The objectives of this study were to (i) determine if the F-M area affects floodwater quality and (ii) determine the quality of the sediment deposited in the F-M area after floodwaters recede.

Materials and Methods

Water Sampling

Water samples from the RR were taken on 12 days of year (DOY) 83, 84, 85, 86, 89, 91, 93, 98, 105, 112, 119, and 126 from two locations during the spring 2009 flood to assess water quality. Location one was the 52nd Ave S Bridge (-96.796789 W, 46.803362 N) on the south side of F-M, which is upstream of the most populated urban areas. Location two was the 40th Ave N Bridge (-96.791386 W, 46.933856 N) on the north edge and downstream of the main urban areas (Figure 2). Water samples were collected from the middle of the RR from each bridge by lowering a 2-L stainless steel beaker attached to a rope about 0.25 m below the water surface. This was done three times before a sample was collected for analysis. Samples for gasoline range organics (GRO) and diesel range organics (DRO) were stored in manufacturer-cleaned 500 mL glass bottles. All samples from both locations were taken within 1 hr of each other. Water samples for total sediment (suspended plus dissolved), NO_3-N, NH_4-N, and PO_4, pH, EC, SO_4, and Cl were stored in plastic 500 mL bottles. Samples for 17ß-estradiol and estrone were stored in 50 mL narrow-mouth high-density polyethylene (HDPE) bottles and were frozen until analysis.

Water pH and EC were measured using an ion probe (SensIon 378; HACH Co., Loveland, Colorado). Nitrate-N and NH_4-N concentrations were measured using EPA methods 350.1 and 353.2, respectively (US EPA, 1993b,c), with flow injection (FIAlab 2500; FIAlab Instruments, Inc., Bellevue, Washington). Orthophosphate concentration was determined using EPA method 365.1 (US EPA, 1993d) with flow injection (FIAlab 2500). Sulfate and chloride concentrations were determined using the EPA methods 375.2 and 140.4, respectively (US EPA, 1993e,a) with flow injection (FIAlab 2500). Total sediment (suspended plus dissolved ions) was determined by oven-drying (105°C, 24 hr) 50 mL of each sample. Each of these chemical constituents was quantified within 48 hr after collection.

17ß-estradiol and estrone were quantified following the methods of Thompson et al. (2009) at the USDA-ARS Biosciences Research Laboratory (Fargo, North Dakota). Gasoline and diesel range hydrocarbons were determined by the North Dakota Department of Health (Bismarck, North Dakota) using EPA methods 5035 and 8260B, and3550C and

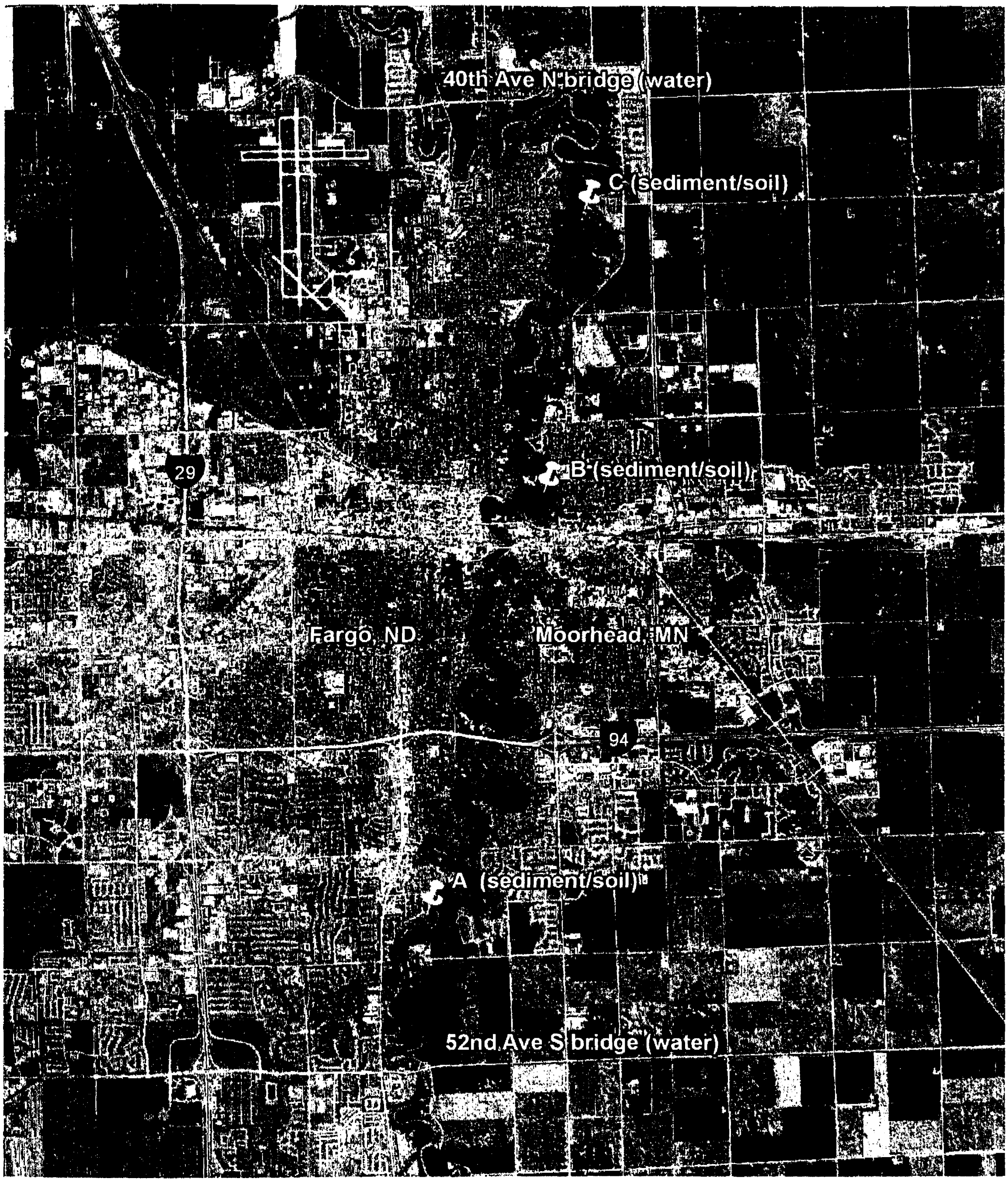

Figure 2. Aerial map depicting water and sediment/soil sampling locations near the Red River of the North at Fargo, North Dakota and Moorhead, Minnesota. (Note: Image from Google Earth).

8270D, respectively (USEPA, 1996a,b; 2007a,b).

Average mass (Mass (Mg)) of each parameter was calculated by multiplying the average concentration (Mass/Volume) by the average discharge (Volume/Time) by the elapsed time: (i.e. Mass = (Mass/Volume) x (Volume/Time) x (Time) = Concentration x discharge x elapsed time). Mass was calculated for both locations and the difference calculated whether there was a gain (+) or loss (-) in mass between sampling locations. A gain between locations indicated an input into F-M and a loss output from F-M.

Sediment and Soil Sampling

Sediment and soil samples were collected at three locations in F-M and are referred to as locations A, B, and C. Location A was a residential lawn in south Fargo and the most upstream sampling location that was accessible for the study. Location B was a centrally located city park in Fargo. Location C was a residential lawn north of Moorhead and was the most downstream sampling location (Figure 2).

All sediment and soil samples were collected as soon as floodwaters receded to a safe level. Each location included three transects regularly parallel to the river channel at a constant elevation. Transect 1 was furthest from the river channel, Transect 2 was between Transects 1 and 3, and Transect 3 was closest to the river channel (Table 1 and Figure 3). Transects at each location were measured for equal points of elevation using a rod and transit. Each transect was comprised of 17 sampling locations of sediment and underlying soil, which allowed for a distribution of samples across each transect. Sampling locations were approximately 2 m apart from each other.

Table 1. Transect elevations in meters above sea level at Locations A, B, and C along the banks of the Red River of the North at Fargo, North Dakota and Moorhead, Minnesota.

Location	Transect 1	Transect 2	Transect 3
		m above sea level	
A†	272.0	271.2	270.2
B	270.4	268.7	268.4
C	270.8	268.2	267.6

† A, B, and C indicate the upstream residential lawn, the central city park, and the downstream residential lawn, respectively.

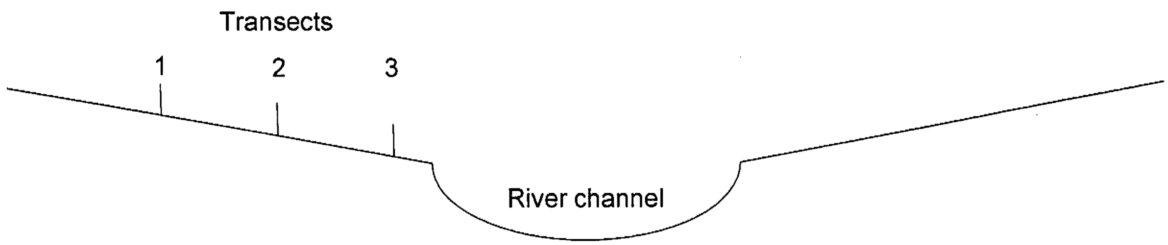

Figure 3. Transect locations relative to the river channel.

Sediment and soil samples were from the Cashel soil series (Cashel fine, smectitic, calcareous, frigid, Aquertic Udifluvents) (USDA-NRCS, 2002). Sediment samples were collected at each point within an area of 0.06 m^2 using cleaned plastic spatulas, placed in plastic bags, and put in coolers for transport. After sediment was removed, four soil cores to a depth of 10 cm were extracted using a 3.2 cm-i.d. stainless steel probe and stored as noted above for the sediment. All sediment and soil samples were transported to North Dakota State University, Fargo, North Dakota where they were weighed and sub-sampled for trace elements, gravimetric water measured, and all samples were frozen within 24 hr. Both sediment and soil samples for nutrients were air-dried, ground to pass through a 2 mm sieve and stored in plastic bags until analysis. Samples for trace element determination were air-dried and ground using a clean mortar and pestle.

Total C and N were measured by high-temperature combustion (TruSpec CHNS; LECO, St. Joseph, Michigan). Nitrate-N and NH_4-N were extracted with 1M KCl and quantified using flow injection (FIAlab-2500) following EPA methods 350.1 and 353.2, respectively (US EPA, 1993b,c). Organic N was calculated as the difference between total N and the sum of the inorganic N species. Inorganic C was determined using a modified pressure-calcimeter method of Sherrod et al. (2002). Organic C was determined to be the difference between total and inorganic C. Olsen-P (Olsen et al., 1954) and water extractable P (Olsen and Sommers, 1982) were both quantified with a flow injection analyzer (FIAlab 2500). Sulfate-S was extracted with a 0.25M KCl and determined using the method of Tabatabai (1982) and flow injection (FIAlab 2500). Sediment and soil were analyzed for pH and EC in 1:1 soil:deionized water at 25°C using ion probes (SensIon 378; HACH Co., Loveland, CO). The method of Polemio and Rhoades (1977) was used to determine cation exchange capacity (CEC) where NH_4-N was quantified using flow injection (FIAlab 2500) and EPA method 353.2 (USEPA, 1993c). No attempt was made to determine the contribution to CEC by organic matter.

Gasoline range organics and DROs from the sediment and soil were collected on the same transect elevations outside the sampling areas (one replication per transect) into manufacturer-washed glass jars, and extracted and analyzed by the North Dakota Department of Health using EPA SW846 methods 5035 and 8260D (USEPA, 1996a,b), and EPA SW846 methods 3550C and 8207D (USEPA, 2007a,b), respectively. Particle size analysis was determined on both sediment and soil from five sampling areas from each transect with a hydrometer (ASTM 152-H Soil Hydrometer; H-B Instrument Co., Collegeville, Pennsylvania) following the procedure of Gee and Bauder (1979). From these same transects As, B, Ba, Bi, Cd, Co, Cr, Cu, Ga, La, Mo, Mn, Ni, Pb, Sb, Sc, Se, Sr, Te, Ti, U, V, W, and Zn were determined by a private laboratory (Lab code 1DX2; Acme Analytical Laboratories, Vancouver BC Canada) and quantified using ICP-MS. Total Hg was determined using EPA method 7473 (USEPA, 2009a) and a direct Hg analyzer (DMA-80; Milestone Inc., Shelton, Connecticut). Quantifications of Se, Te, and W were generally below the laboratory's quantification limit and are not reported here.

Statistical Analyses

Statistical analyses were performed using JMP 8 software (ver. 8.0 SAS Institute Inc., Cary, North Carolina). Tukey-Kramer HSD was used to test for differences in physical and chemical parameters of the sediment and soil between transects at each location). Student's t-test was used to test for differences between sample sediment and soil. Statistical results were considered significant at the $p \leq 0.05$ level.

Results and Discussion

Water Quality

Total solids (suspended plus dissolved) in water samples ranged from 300 to 600 mg L^{-1} (Figure 4). Mean concentrations across locations and dates were similar to other samples collected within F-M from 2001 to 2008 (mostly summer months) (Ivashchenko, 2009; Ryberg 2006). Water at the 40th Ave N location had higher total solids concentration in the first half of sampling than in the second half (Figure 4), possibly due to deposition as river discharge rates decreased (Figure 1). Average NO_3-N concentrations in water samples (0.3 mg L^{-1}) were similar to, or less than, Ivashchenko (2009) and Ryberg (2006) (Figure 4). This is to be expected, since contaminant concentrations are commonly greater during dry seasons and low flow (Dudgeon, 2000). Ammonium-N concentrations averaged 0.04 mg L^{-1} and varied little across sampling dates whereas NO_3-N peaked on DOY 98 and then trended back to initial concentrations (Figure 4). Overall, 6.1 and 9.2 Mg of NO_3-N and NH_4-N, respectively, were estimated to have exited F-M, and over 4,000 Mg of solids were estimated to be deposited between the sampling locations (Figure 5).

Average PO_4 concentrations in water samples from both locations were 0.1 mg L^{-1} and little variation was observed between the two sampling points (Figure 4). Although

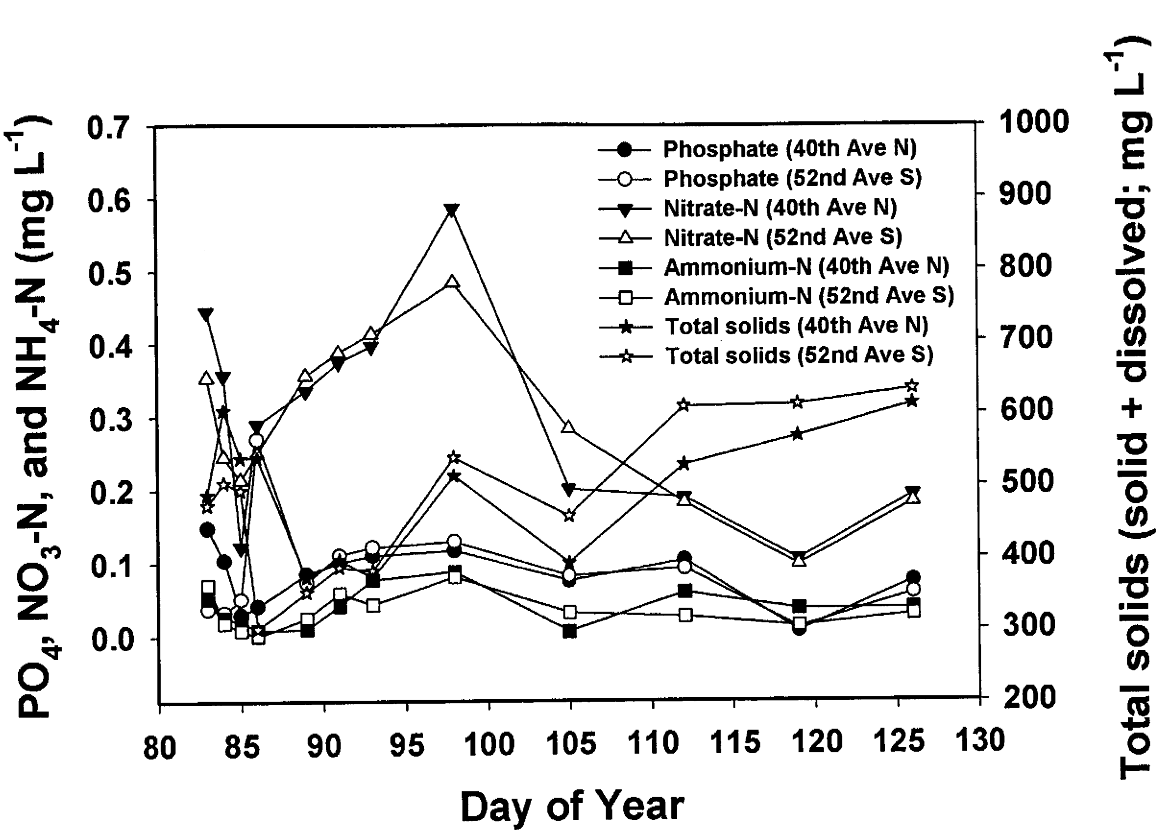

Figure 4. Concentrations of PO_4, NO_3-N, NH_4-N, and total solids (suspended plus dissolved) at two locations during the spring 2009 Red River of the North flood at Fargo, North Dakota and Moorhead, MN.

differences in PO_4 between upstream and downstream F-M were not observed here, Ivashchenko (2009) showed that PO_4 concentrations were generally higher downstream of the two F-M wastewater treatment plants, which would be upstream of the 40th Ave N location in this study. Samples in Ivashchenko's study were collected over a longer time period and river discharges ranged from 21 to 113 $m^3\ s^{-1}$. However, Ryberg (2006) reported average PO_4 concentrations three times greater than the average concentration reported here. Considering river discharge (Figure 1) and PO_4 concentrations (Figure 4) at each sampling date, about 30 Mg of PO_4 were estimated to have been deposited within F-M (Figure 5). Concentrations of PO_4, NO_3-N, and NH_4-N were coupled with the river discharge information (Figure 5) to estimate nutrient input into or output from F-M.

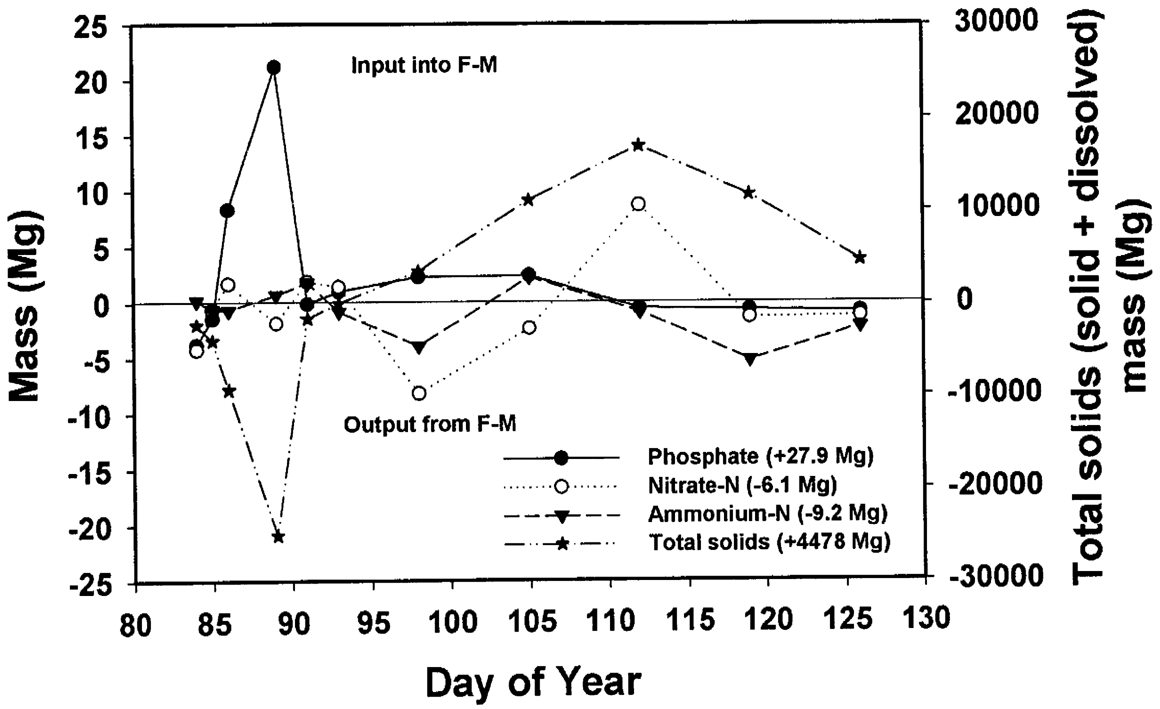

Figure 5. Estimated mass additions to (positive numbers) and losses from (negative numbers) the Fargo, North Dakota and Moorhead, Minnesota urban area of PO_4, NO_3-N, and NH_4-N during the spring 2009 Red River of the North flood. (Note: estimated total mass additions (+) and losses (-) are reported in the figure legend).

The pH values averaged 7.8 at both water-sampling locations (Figure 6). Electrical conductivities of floodwater were similar at both sampling locations. Average SO_4 and Cl concentrations were about 105 and 11 mg L^{-1} at both locations, respectively, and both trended upward as dates of floodwater inundation increased (Figure 6), perhaps due to decreased dilution (Dudgeon, 2000; Ryberg, 2006). None of these values were considered detrimental to water quality of the RR. Electrical conductivity and pH values are similar to those reported in Ivashchenko (2009) and Ryberg (2006). The SO_4 results reported here were about 50 mg L^{-1} less than the average value reported by Ryberg (2006), who collected samples within F-M across both high and low river flows.

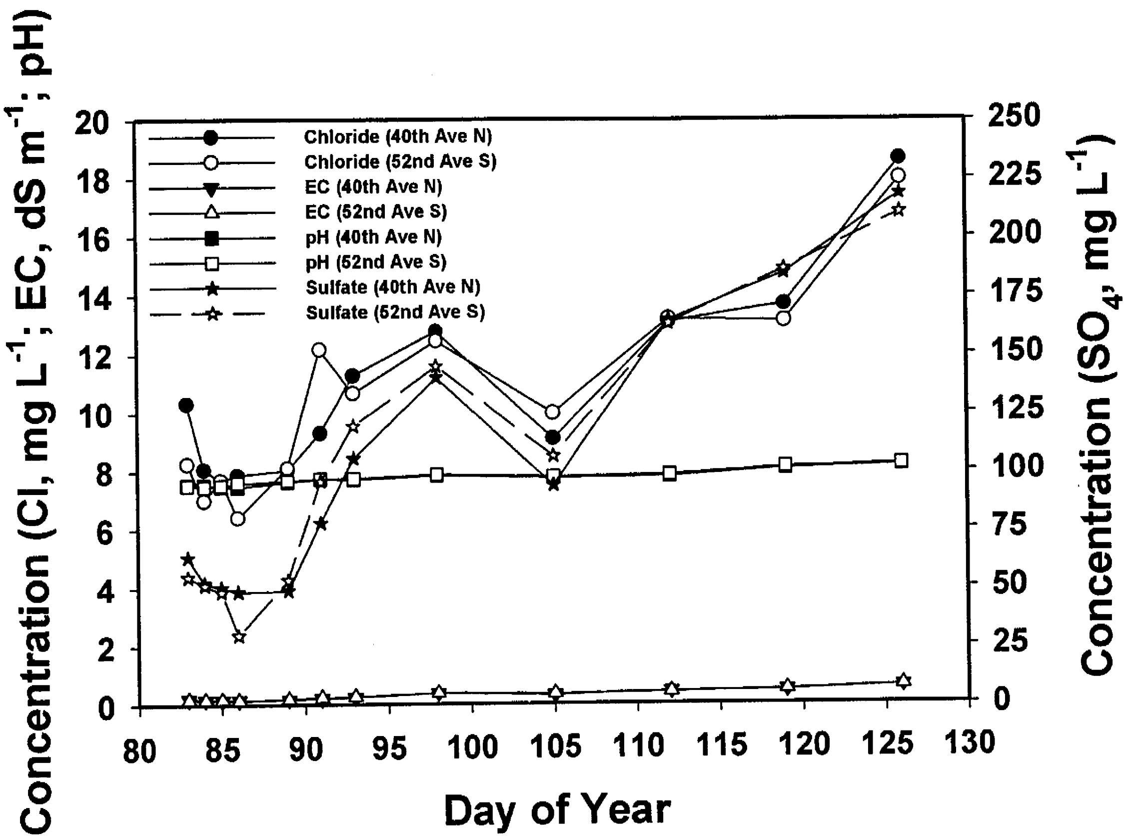

Figure 6. Concentrations of Cl, SO_4 and values of EC and pH at two locations during the spring 2009 Red River of the North flood at Fargo, North Dakota and Moorhead, MN.

17ß-estradiol (E2) was detected in 9 of 24 water samples with an average concentration of 0.61 ng L^{-1} and no detection of estrone (E1) was found in any sample (Kolpin et al., 2002). Concentrations here are similar those found by Kolpin et al. (2002) where they detected 17ß-estradiol in 85 of 139 streams sampled across 30 states during 1999 and 2000 with at concentrations ranging from 0.0 to 1.5 ng L^{-1}. The results from this thesis are the first known values reported for flooding waters. Concerns surrounding these hormones are their capability to alter sexual behavior and endocrine systems of wildlife and aquatic species (Larsson et al., 2000). Minor reductions in spawning behavior and sperm production in male goldfish (*Carassius auratus*) have been found at concentrations as low as 50 ng L^{-1} of E2 (Schoenfuss et al., in press). However, three studies on guppies did not find reproductive impairment at 30 ng L^{-1} E2 exposure (Toft and Baatrup, 2001; Schoenfuss et al., 2011), and saw no behavioral impairment at 100 ng L^{-1} E2 exposure (Schoenfuss et al., 2011). Diesel range organics were detected in 8 of 24 samples with an average concentration of 80.0 μg L^{-1}, while no GRO was found in any sample. The concentration range of DRO was 0.0 to 108 ng L^{-1}.

Sediment and Soil Characterization

The days that each transect was inundated ranged from 31 to 59 (Table 2). Due to the elevations of each transect with respect to flooding waters and safety concerns, not all transects were sampled on the same date and thus the days between submergence and sampling varied. The deposition of sediment across all transects at all locations was a function of duration of flooding and landscape position. The average mass of sediment across locations and transects ranged from 2.01 kg m^{-2} to 10.3 kg m^{-2} (Tables 3, 4, and 5). The sediment layer covering the riverbanks after floodwaters receded was typically less than 5 cm thick.

Table 2. Number of days that each location and transect was inundated by floodwaters and the number of days between submergence and sediment and soil sampling.

Location	Transect	Days Inundated	Days Between Submergence and Sampling	Day of Year
A†	1	31	15	127
	2	37	9	127
	3	59	1	138
B	1	41	10	128
	2	44	10	139
	3	54	5	139
C	1	42	5	127
	2	57	1	138
	3	59	1	138

† A, B, and C indicate the upstream residential lawn, the central city park, and the downstream residential lawn, respectively.

Sediment mass at all locations increased significantly ($p \leq 0.05$) as distance to the river channel decreased. Texture of both the sediment and soil was predominately clay and silt and generally contained less than 10 g kg^{-1} sand-sized fractions (see Appendix A, B, and C). Some significant differences did occur for clay and silt content between soil and sediment across transects at each location, but in general, clay concentrations in the sediment were greater than in the underlying soil and silt concentrations were typically greater in the underlying soil. Sediment enriched in the clay-sized fraction is an essential transport mechanism for nutrients and contaminants (Ongley, 1996a,b). Nutrients and contaminants have a high affinity to clay-sized particles, which are easily transported in runoff and floodwater (Lair et al., 2009).

Electrical conductivities were consistent across transects and averaged 1.1 and 0.7 dS m^{-1} across all sediment and soil, respectively (Tables 2, 3, and 4) (estimated saturated paste EC of 2.5 and 1.3 dS m^{-1}, respectively, as computed from Franzen (2007)). At all transects the sediment had significantly greater ($p \leq 0.05$) EC than the underlying soil, which indicates that the sediment characteristics were either different than previous flooding events or that the soluble salts in the parent material had leached below the depth of soil sampling. All EC values reported here are considered "non-saline" (Richards, 1954), and should not hinder most plants grown in this environment (USDA-NRCS, 1996). However, some vegetables, such as carrots (*D. carota*), Jerusalem artichoke (*H. tuberosus*), and turnip (*B. rapa L. Rapifera group*), will have decreased yields at threshold saturated paste EC values of less than 1.0 dS m^{-1} (Francois, 1984; Maas, 1986; Newton et al., 1991).

The pH values across locations and transects ranged from 7.2 to 7.5 across all sediment and soil (Tables 3, 4, and 5). Although some statistical differences did occur, the values reported here do not indicate the sediment pH is different from the underlying soil. The pH of the sediment was similar to values measured in the water analysis (Figure 3).

Table 3. Physical and chemical variables for sediment (SED) and soil (SOIL) (0-10cm) from location A along the Red River of the North near Fargo, North Dakota. No gasoline range organics were found.

Parameter	Sample	Transect 1†	2	3
Dry SED (kg m^{-2})	SED	2.8 (1.0)‡C§	6.5 (1.0)B	8.4 (1.3)A
Clay (g kg^{-1})	SED	497 (26.8)a¶,A	469 (4.5)a,B	441 (5.5)a,C
	SOIL	406 (24.9)b	391 (16.9)b	418 (6.1)b
Silt (g kg^{-1})	SED	503 (26.8)b,B	529 (5.5)b,B	559 (5.5)b,A
	SOIL	594 (24.9)a	609 (16.9)a	582 (6.1)a
EC (dS m^{-1})	SED	0.98 (0.20)a,B	1.0 (0.07)a,AB	1.1 (0.18)a,A
	SOIL	0.74 (0.09)b	0.70 (0.08)b	0.58 (0.10)b
pH	SED	7.2 (0.06)a,C	7.3 (0.05)a,B	7.4 (0.08)b,A
	SOIL	7.2 (0.07)a	7.2 (0.10)a	7.5 (0.04)a
CEC# $cmol_{(+)}$ kg^{-1}	SED	30.7 (1.3)b,A	25.1 (1.8)b,B	21.2 (5.5)b,C
	SOIL	33.3 (1.1)a	30.6 (1.2)a	26.4 (1.5)a
Total C (g kg^{-1})	SED	54.9 (2.9)a,A	49.9 (3.4)a,B	40.0 (2.3)b,C
	SOIL	54.3 (3.5)a	47.3 (1.5)b	41.4 (1.2)a
Organic C (g kg^{-1})	SED	46.0 (3.3)b,A	36.3 (3.4)b,B	29.5 (2.2)a,C
	SOIL	49.1 (3.6)a	40.0 (1.4)a	28.9 (1.1)a
Inorganic C (g kg^{-1})	SED	8.9 (0.54)a,C	13.6 (0.32)a,B	10.5 (0.70)b,A
	SOIL	5.2 (0.87)b	7.3 (0.40)b	12.6 (0.44)a
Total N (mg kg^{-1})	SED	4460 (235)b,A	3940 (376)b,B	2740 (293)b,C
	SOIL	5260 (345)a	4370 (182)a	3250 (183)a
Organic N (mg kg^{-1})	SED	4330 (228)b,A	3830 (374)b,B	2680 (293)b,C
	SOIL	5220 (342)a	4350 (181)a	3230 (183)a
NH_4^+-N (mg kg^{-1})	SED	128 (16.9)a,A	113 (12.7)a,B	51.6 (9.1)a,C
	SOIL	13.3 (10.3)b	7.7 (1.4)b	6.1 (0.87)b
NO_3^--N (mg kg^{-1})	SED	1.4 (0.78)b,B	1.5 (0.82)b,B	3.1 (1.4)b,A
	SOIL	28.6 (9.3)a	20.0 (6.1)a	15.8 (1.9)a
Olsen P (mg kg^{-1})	SED	35.5 (12.2)a,A	32.6 (3.0)a,AB	27.0 (8.1)a,B
	SOIL	25.5 (4.9)b	24.9 (5.2)b	26.3 (3.9)a
Water-soluble P (mg kg^{-1})	SED	3.9 (0.75)b,A	3.2 (0.54)b,B	2.0 (0.35)b,C
	SOIL	7.2 (1.9)a	4.4 (0.79)a	3.8 (1.0)a
SO_4^{2-} (mg kg^{-1})	SED	2430 (509)a,B	2120 (564)a,B	4140 (733)a,A
	SOIL	501 (150)b	441 (66.1)b	378 (78.9)b
DRO†† (µg g^{-1})	SED	34.9 (11.2)a,AB	49.2 (7.8)a,A	18.1 (2.8)a,B
	SOIL	1.8 (3.2)b	1.4 (2.4)b	0.0 (0.0)b

† Transect 1 is furthest from the river channel, Transect 2 is between Transect 1 and 3, and Transect 3 is closest to the river channel.
‡ Numbers in parentheses represent the standard deviation.
§ Different capitalized letters by parameter and sample within rows indicate statistical significance at the $p \leq 0.05$ level by using the Tukey-Kramer Honestly Significant Difference (HSD) test.
¶ Different lower case letters by parameter within columns indicate statistical significance at the $p \leq 0.05$ level by using the Student's t-test.
# CEC – Cation Exchange Capacity.
†† DRO – Diesel Range Organics.

The CEC of the sediment and soil across locations and transects ranged from 21.2 to 32.4 ($cmol_c$ kg^{-1}) and 24.6 to 33.3 ($cmol_c$ kg^{-1}), respectively (Tables 3, 4, and 5). At locations A and B, soil CEC was significantly greater ($p \leq 0.05$) than the sediment at all transects (Tables 3 and 4). Although all locations were the same vegetation type (predominantly turf grass) and the same soil series (Cashel), this study did not attempt to determine long-term management of the locations, which may contribute to the differences in CEC determined

Table 4. Physical and chemical variables for sediment (SED) and soil (SOIL) (0-10cm) from location B along the Red River of the North near Fargo, North Dakota. No gasoline range organics were found.

Parameter	Sample	Transect 1†		Transect 2		Transect 3	
Dry SED (kg m^{-2})	SED	5.0	(2.0)‡B§	9.3	(2.4)A	10.3	(3.3)A
Clay (g kg^{-1})	SED	385	(25.0)a¶,A	411	(12.1)a,A	399	(22.9)b,A
	SOIL	350	(5.6)b	392	(17.6)a	424	(8.0)a
Silt (g kg^{-1})	SED	615	(25.1)b,A	589	(12.1)a,A	601	(22.9)a,A
	SOIL	650	(5.6)a	607	(15.9)a	576	(8.0)b
EC (dS m^{-1})	SED	0.98	(0.11)a,B	1.1	(0.18)a,AB	1.2	(0.30)a,A
	SOIL	0.67	(0.06)b	0.62	(0.05)b	0.63	(0.08)b
pH	SED	7.3	(0.05)b,B	7.3	(0.05)a,A	7.4	(0.04)b,A
	SOIL	7.3	(0.04)a	7.3	(0.05)b	7.5	(0.03)a
CEC# $cmol_{(+)}$ kg^{-1}	SED	25.0	(2.3)b,A	22.3	(0.90)b,B	21.5	(0.98)b,B
	SOIL	29.6	(1.2)a	29.3	(1.5)a	25.5	(1.5)a
Total C (g kg^{-1})	SED	59.0	(5.6)a,A	46.1	(4.3)b,B	40.9	(2.5)b,C
	SOIL	57.0	(4.3)a	49.3	(2.0)a	47.3	(1.2)a
Organic C (g kg^{-1})	SED	44.3	(6.2)a,A	32.7	(4.4)b,B	26.1	(2.5)b,C
	SOIL	48.5	(4.3)a	36.1	(1.6)a	33.0	(1.1)a
Inorganic C (g kg^{-1})	SED	12.6	(0.91)a,C	13.4	(0.61)a,B	14.8	(0.25)a,A
	SOIL	10.5	(0.76)b	13.2	(0.74)a	14.3	(0.43)b
Total N (mg kg^{-1})	SED	3320	(540)b,A	2580	(359)b,B	2280	(253)b,B
	SOIL	4540	(275)a	3410	(218)a	2950	(140)a
Organic N (mg kg^{-1})	SED	3270	(530)b,A	2560	(358)b,B	2260	(253)b,B
	SOIL	4520	(274)a	3390	(218)a	2930	(140)a
NH_4^+-N (mg kg^{-1})	SED	53.9	(14.6)a,A	24.7	(3.4)a,B	25.1	(3.7)a,B
	SOIL	5.3	(1.4)b	4.0	(1.2)b	3.1	(0.48)b
NO_3^--N (mg kg^{-1})	SED	0.85	(0.40)b,A	0.70	(0.65)b,A	1.1	(1.0)b,A
	SOIL	22.2	(6.0)a	14.9	(2.4)a	14.4	(2.1)a
Olsen P (mg kg^{-1})	SED	25.3	(3.5)a,A	17.8	(2.1)a,B	21.0	(3.5)a,B
	SOIL	10.3	(2.5)b	15.6	(3.0)b	17.1	(3.4)b
Water-soluble P (mg kg^{-1})	SED	2.9	(1.4)a,A	0.74	(0.35)b,B	0.69	(0.22)b,B
	SOIL	1.8	(0.83)b	3.7	(0.93)a	3.0	(0.80)a
SO_4^{2-} (mg kg^{-1})	SED	3520	(1040)a,AB	3370	(776)a,B	4700	(2260)a,A
	SOIL	409	(164)b	326	(74.0)b	462	(91.4)b
DRO†† (µg g^{-1})	SED	49.0	(2.0)a,A	21.6	(18.9)a,A	37.0	(12.1)a,A
	SOIL	12.1	(2.2)b	3.2	(2.8)a	3.2	(2.8)b

† Transect 1 is furthest from the river channel, Transect 2 is between Transect 1 and 3, and Transect 3 is closest to the river channel.
‡ Numbers in parentheses represent the standard deviation.
§ Different capitalized letters by parameter and sample within rows indicate statistical significance at the $p \leq 0.05$ level by using the Tukey-Kramer Honestly Significant Difference (HSD) test.
¶ Different lower case letters by parameter within columns indicate statistical significance at the $p \leq 0.05$ level by using the Student's t-test.
# CEC – Cation Exchange Capacity.
†† DRO – Diesel Range Organics.

here (permanent vs. pH dependent charges). A similarly associated soil series (Fargo soil series, Cass County, ND, SO8ND017-002a, USDA-NRCS-NSSC, 2010) measured 47.0 ($cmol_c$ kg^{-1}) in the top 0 to 10 cm. The CEC values reported here for the sediment are within the typical range for soils of the RR (L. Swenson, personal communication, 2010).

Inorganic C concentrations of the sediment and soil across all locations and transects ranged from 8.9 to 14.8 g kg^{-1} and 5.2 to 14.3 g kg^{-1} (Tables 3, 4, and 5).

Table 5. Physical and chemical variables for sediment (SED) and soil (SOIL) (0-10cm) from location C along the Red River of the North near Moorhead, Minnesota. No gasoline range organics were found.

Parameter	Sample	Transect 1†	2	3
Dry SED (kg m^{-2})	SED	2.0 (0.79)‡C§	4.8 (1.9)B	9.1 (1.6)A
Clay (g kg^{-1})	SED	495 (6.1)a¶,A	505 (9.4)a,A	488 (25.9)a,A
	SOIL	403 (49.4)b	479 (11.0)b	495 (30.8)a
Silt (g kg^{-1})	SED	505 (6.5)b,A	495 (9.5)b,A	512 (25.9)a,A
	SOIL	597 (49.1)a	521 (11.0)a	505 (31.0)a
EC (dS m^{-1})	SED	1.6 (0.20)a,A	1.3 (0.12)a,B	0.88 (0.04)a,C
	SOIL	0.74 (0.13)b	0.72 (0.07)b	0.72 (0.08)b
pH	SED	7.2 (0.06)b,C	7.2 (0.06)a,B	7.4 (0.04)b,A
	SOIL	7.3 (0.07)a	7.3 (0.06)a	7.5 (0.04)a
CEC# ($cmol_{(+)}$ kg^{-1})	SED	32.4 (7.8)a,A	29.8 (2.5)a,A	24.1 (0.82)a,B
	SOIL	30.0 (2.5)b	24.7 (1.7)b	24.6 (0.67)a
Total C (g kg^{-1})	SED	50.6 (4.2)a,A	44.6 (4.3)a,B	39.4 (2.0)a,C
	SOIL	44.8 (4.4)b	34.5 (2.6)b	34.5 (0.94)b
Organic C (g kg^{-1})	SED	40.9 (4.7)a,A	32.2 (4.0)a,B	25.1 (1.7)a,C
	SOIL	38.1 (4.3)a	23.6 (9.5)b	21.2 (1.0)b
Inorganic C (g kg^{-1})	SED	9.7 (0.49)a,C	12.4 (0.56)a,B	14.4 (0.71)a,A
	SOIL	6.7 (2.3)b	10.8 (0.38)b	13.4 (0.31)b
Total N (mg kg^{-1})	SED	3870 (238)a,A	3000 (318)a,B	2470 (147)a,C
	SOIL	3370 (333)b	2300 (255)b	1950 (114)b
Organic N (mg kg^{-1})	SED	3740 (232)a,A	2930 (313)a,B	2390 (146)a,C
	SOIL	3320 (327)b	2270 (252)b	1930 (114)b
NH_4^+-N (mg kg^{-1})	SED	125 (25.0)a,A	67.6 (11.5)a,B	69.7 (8.5)a,B
	SOIL	23.9 (5.0)b	13.9 (4.4)b	14.5 (3.4)b
NO_3^--N (mg kg^{-1})	SED	6.0 (7.5)b,A	1.7 (0.46)b,B	1.1 (0.26)b,B
	SOIL	25.0 (11.7)a	12.2 (3.4)a	9.9 (1.7)a
Olsen P (mg kg^{-1})	SED	29.9 (3.5)a,A	22.5 (3.9)a,B	27.9 (2.8)a,A
	SOIL	15.4 (3.8)b	12.8 (5.7)b	25.5 (2.2)b
Water-soluble P (mg kg^{-1})	SED	4.6 (1.4)a,A	3.0 (0.63)a,B	2.0 (0.37)b,C
	SOIL	4.2 (1.2)a	2.2 (0.73)b	3.4 (0.98)a
SO_4^{2-} (mg kg^{-1})	SED	6040 (2460)a,A	3540 (939)a,B	1740 (247)a,C
	SOIL	383 (191)b	426 (116)b	444 (74)b
DRO†† (μg g^{-1})	SED	22.3 (0.83)a,A	22.2 (5.1)a,A	17.0 (1.7)a,A
	SOIL	0.0 (0.0)b	2.7 (3.8)b	1.6 (2.8)b

† Transect 1 is furthest from the river channel, Transect 2 is between Transect 1 and 3, and Transect 3 is closest to the river channel.
‡ Numbers in parentheses represent the standard deviation.
§ Different capitalized letters by parameter and sample within rows indicate statistical significance at the $p \leq 0.05$ level by using the Tukey-Kramer Honestly Significant Difference (HSD) test.
¶ Different lower case letters by parameter within columns indicate statistical significance at the $p \leq 0.05$ level by using the Student's t-test.
# CEC – Cation Exchange Capacity.
†† DRO – Diesel Range Organics.

Organic C concentrations of the sediment and soil across all locations and transects ranged from 25.1 to 46.0 g kg^{-1} and 21.2 to 49.1 g kg^{-1}, respectively (Tables 3, 4, and 5). The highest total C reported here is greater than a similar soil in the RR (37 g kg^{-1}) (Fargo soil series, Cass County, ND, SO8ND017-002a, USDA-NRCS-NSSC, 2010).

Sediment OC concentrations for Transect 1 at all locations were significantly greater ($p \leq 0.05$) than for Transect 2, which was significantly greater ($p \leq 0.05$) than for Transect 3 (Tables 3, 4, and 5). A reason for the difference in OC between transects might be that OC is prevalent in the low flow areas of the flood (i.e., edges) and as the flood stage decreases, the OC (i.e., plant material and microbial matter) will collect primarily on the edges of the floodwaters. In turn, as floodwaters drop, there is less OC available to accumulate the closer the water levels recede to bankfull. Visual evidence during sampling suggested that the light fraction of OC was greater at higher elevations on the riverbank (Transects 1 and 2) compared to Transect 3. Velocities on the edges of the river are slower as a result of frictional forces compared to the higher velocities in the center of the stream, where there is less friction, which in this case, would allow OC to collect near the edges of flow (Chow, 1959).

Organic C concentrations between sediment and soil varied, with no discernable pattern (Tables 3, 4, and 5). Variation in C between bulk soil and eroded sediments has been reported. For example, Clay et al. (2001) determined that potentially wind-eroded sediments had less OC than bulk soil (>1.7 mm) and Sterk et al. (1996) determined that dust had about 32 times greater C than top soil. However, Cihacek et al. (1993) did not find differences in soil OC between wind eroded sediments and surface soil in the RRV.

Total N of the sediment and soil across all locations and transects ranged from 1,760 to 4,930 mg kg^{-1} and 1,730 to 5,810 mg kg^{-1}, respectively. Total N concentrations decreased with decreasing distance from the river channel for both sediment and soil (Tables 3, 4, and 5). Of the samples collected, less than 5% of the total N was inorganic (NH_4-N + NO_3-N). Ammonium-N concentrations were significantly greater ($p \leq 0.05$) in all sediment samples compared to the underlying soil, while all NO_3-N were significantly greater ($p \leq 0.05$) in the soil compared to the sediment (Tables 3, 4, and 5). The high concentrations of NH_4-N in the sediment indicate that this N form has not yet been oxidized to NO_3-N, which is the dominant inorganic N species in these soils. Given the length of time between sediment exposure to the atmosphere and when samples were collected (Table 1) the elevated concentrations of NH_4-N may have been due to mineralization and not sediment transport, but this was not investigated for this study. To provide context, the total N values here are greater than those reported for soils directly underlying cattle lagoons in Kansas (DeSutter et al., 2005). Using the area of submergence at location A during this flooding event (about 3,300 m^2) and the average total N and dry sediment deposition values across the transects, about 68 kg of N was deposited on this residential property during this flooding event. Most of the N found in the sediment is organic and, thus, has the potential to be oxidized and become plant available, leached, or denitrified. Given the high concentrations of organic N in the soils reported here, much of it may be very stable. None of the locations investigated here had been fertilized in the past 10 yr.

Olsen P of the sediment and soil across locations and transects ranged from 17.8 to 35.5 mg kg^{-1} and 10.3 to 26.3 mg kg^{-1}, respectively (Tables 3, 4, and 5). A reason why P is higher in the sediment is possibly due to P being bound to fine-grained sediment transported in runoff (Rekolainen, 1989). Water-soluble P (WSP) of the sediment and soil across locations and transects ranged from 0.69 to 4.6 mg kg^{-1} and 1.8 to 7.2 mg kg^{-1}, respectively (Tables 3, 4, and 5). Although the WSP concentrations were lower than Olsen P for sediment and soil, this solubility allows for a simple transition from solid to solution phase, thereby increasing the ease of movement to surface waters. Phosphorus concentrations observed within a single watershed and within a single runoff event are a result of several interacting factors, which include season (growing and non-growing), tillage practices, vegetation type, and application of fertilizers (Rekolainen, 1989).

Sulfate-S was significantly greater ($p<0.05$) for all sediment samples than for respective soil samples (Tables 3, 4, and 5), up to 16 times greater (Table 5). Sources of S may include weathering rocks, agricultural runoff, precipitation, fuel combustion, and waste disposal (Allan, 1995). Another source of SO_4 may be the atmosphere, since SO_4 wet deposition in the RR valley was estimated to be between 3 and 9 kg ha^{-1} yr^{-1} between 1985 to 2005 (National Atmospheric Deposition Program, 2009). Runoff would concentrate this chemical near the river channel during flooding events. However, dissolution of gypsum ($CaSO_4$), which is widely distributed in soils of the RR, may also be contributing to these elevated concentrations.

Deposition of plant nutrients from flooding waters is not unique. The "Gifts of the Nile" were both nutrients and silt, which sustained crop productivity for thousands of years in Egypt (Hillel, 1991). In fact, the RR was termed "The Nile of the West" as government agencies were trying to convince people to farm this region. The plant nutrient deposition rates that occurred at study locations indicate that additional fertilizer would not be recommended and property owners are encouraged to have their soils tested prior to fertilizer application.

Diesel range organics (DRO) within the sediment and soil across locations and transects ranged from 17.0 to 49.2 μg g^{-1} and 0 to 12.1 μg g^{-1}, respectively (Tables 3, 4, and 5). Overall, DRO was present in 26 out of the 27 sediment samples analyzed, indicating their presence in flooding water sediments. Diesel range organics were measured as high as 2,100 μg g^{-1} in flooded sediment from Hurricane Katrina floodwaters (Reible et al., 2006). The source of DRO was not a focus of this study. There was no gasoline range organics (GRO) detected in the sediment or soil.

In general, trace element concentrations were not statistically different between sediment and soil or across transects at all locations and were within levels for non-contaminated soils (Kabata-Pendias, 2011) (Tables 6, 7, and 8). Mercury in the sediment and soil, for example, had mean concentrations of 54.8 and 60.6 ng g^{-1}, respectively, across all locations and transects, which indicates similarity between sources and sinks. These values are greater than concentrations determined in a North Dakota roadside ditch (up to 49 ng g^{-1}) (DeSutter et al., 2010) and also greater than a statewide survey of surface soils in North Dakota that had an average concentration of 32 ng g^{-1} (DeSutter et al., 2009).

The trace element that was higher than would normally be found in surface soils was Mn. Manganese values across locations and transects ranged from 668 to 1070 mg kg^{-1} across all sediment and soil, respectively (Tables 6, 7, and 8). Although some statistical differences did occur, the values reported here do not indicate that sediment Mn is generally different from underlying soil and the concentrations of Mn found in this study are not unexpected. Mean Mn concentrations in surface soils in Richland County, just south of Fargo (Cass County) (upstream) are about 540 mg kg^{-1} (USGS-National Geochemical Database, 2010a).

Table 6. Trace element variables for sediment (SED) and soil (SOIL) (0-10cm) from location A along the Red River of the North near Fargo, North Dakota.

		Transect		
Parameter	Sample	1†	2	3
			mg kg^{-1}	
As	SED	6.8 (0.18)‡b§,A¶	6.8 (0.33)a,A	6.8 (0.33)a,A
	SOIL	7.7 (0.22)a	6.5 (0.26)a	16.4 (23.8)a
B	SED	16.6 (1.3)a,A	16.0 (1.2)b,AB	14.8 (0.84)a,B
	SOIL	17.2 (1.3)a	19.2 (1.8)a	14.6 (0.84)a
Ba	SED	177 (7.0)a,AB	179 (4.7)a,A	171 (3.2)a,B
	SOIL	180 (6.7)a	146 (80.8)a	171 (5.8)a
Bi	SED	0.22 (0.04)a,A	0.20 (0)a,A	0.20 (0.0)a,A
	SOIL	0.26 (0.05)a	0.24 (0.05)a	0.22 (0.04)a
Cd	SED	0.62 (0.08)a,A	0.58 (0.08)a,AB	0.50 (0.07)a,B
	SOIL	0.68 (0.08)a	0.60 (0.07)a	1.4 (2.0)a
Co	SED	26.8 (38.1)a,A	9.9 (0.26)b,A	10.0 (0.51)a,A
	SOIL	10.7 (0.31)a	10.4 (0.24)a	9.9 (0.30)a
Cr	SED	31.2 (5.3)a,A	29.2 (2.0)a,A	27.8 (2.7)a,A
	SOIL	30.2 (4.0)a	31.8 (7.0)a	25.0 (2.1)a
Cu	SED	25.8 (0.69)a,A	23.8 (0.85)b,B	22.5 (1.6)a,B
	SOIL	27.2 (1.2)a	26.1 (1.1)a	23.4 (0.79)a
Ga	SED	4.8 (0.45)a,A	4.8 (0.45)a,A	4.0 (0.0)a,B
	SOIL	5.0 (0.0)a	4.8 (0.45)a	4.0 (0.0)a
La	SED	19.2 (0.84)b,AB	19.4 (0.55)b,A	18.4 (0.55)a,B
	SOIL	20.6 (0.55)a	20.2 (0.45)a	18.6 (0.55)a
Mn	SED	792 (38.2)b,A	824 (40.6)b,A	812 (63.7)a,A
	SOIL	948 (41.8)a	906 (48.6)a	782 (58.5)a
Mo	SED	0.78 (0.36)a,A	0.68 (0.13)a,A	0.64 (0.18)a,A
	SOIL	0.58 (0.22)a	0.64 (0.39)a	0.62 (0.16)a
Ni	SED	27.0 (0.86)b,A	26.9 (0.58)a,A	26.5 (1.4)a,A
	SOIL	30.1 (1.2)a	28.1 (1.5)a	27.0 (0.95)a
Pb	SED	14.0 (0.20)b,A	12.8 (0.16)b,B	12.1 (0.40)b,C
	SOIL	37.2 (19.0)a	17.3 (1.8)a	13.2 (0.74)a
Sb	SED	0.30 (0.0)a,A	0.30 (0.0)a,A	0.30 (0.0)a,A
	SOIL	0.48 (0.30)a	0.30 (0.0)a	0.30 (0.0)a
Sc	SED	3.3 (0.13)a,A	3.4 (0.11)a,A	3.4 (0.25)a,A
	SOIL	3.2 (0.09)a	3.3 (0.15)a	3.4 (0.19)a
Sr	SED	57.0 (2.0)a,A	56.6 (0.55)a,A	56.8 (1.8)a,A
	SOIL	41.0 (0.07)b	45.4 (2.2)b	51.2 (1.1)b
Ti	SED	0.30 (0.0)a,A	0.30 (0.0)a,A	0.28 (0.0)a,A
	SOIL	0.30 (0.0)a	0.30 (0.0)a	0.28 (0.0)a
U	SED	1.6 (0.05)a,A	1.6 (0.04)a,A	1.5 (0.07)a,B
	SOIL	1.3 (0.04)b	1.4 (0.0)b	1.4 (0.08)b
V	SED	51.2 (1.1)b,A	50.2 (2.2)a,A	47.2 (1.3)a,B
	SOIL	53.8 (1.1)a	52.4 (2.3)a	44.8 (3.6)a
Zn	SED	93.6 (3.0)a,A	86.2 (2.2)b,B	76.8 (2.8)b,C
	SOIL	96.4 (2.7)a	94.4 (6.9)a	84.0 (3.5)a
Hg (ng g^{-1})	SED	48.0 (6.1)b,A	42.9 (5.5)b,B	45.7 (6.0)b,AB
	SOIL	58.6 (9.0)a	50.3 (5.4)a	49.1 (3.1)a

† Transect 1 is furthest from the river channel, Transect 2 is between Transect 1 and 3, and Transect 3 is closest to the river channel.

‡ Numbers in parentheses represent the standard deviation.

§ Different lower case letters by parameter within columns indicate statistical significance at the $p \leq 0.05$ level by using the Student's t-test.

¶ Different capitalized letters by parameter and sample within rows indicate statistical significance at the $p \leq 0.05$ level by using the Tukey-Kramer Honestly Significant Difference (HSD) test.

Table 7. Trace element variables for sediment (SED) and soil (SOIL) (0-10cm) from location B along the Red River of the North near Fargo, North Dakota.

Parameter	Sample	Transect 1[†]	Transect 2	Transect 3
			mg kg^{-1}	
As	SED	7.1 (0.34)[‡]a[§],A[¶]	7.8 (0.98)a,A	18.3 (25.5)a,A
	SOIL	6.5 (0.25)b	6.4 (0.68)a	6.3 (0.26)a
B	SED	15.8 (1.3)a,A	14.0 (1.9)a,A	14.2 (1.6)a,A
	SOIL	16.8 (0.84)a	16.0 (1.0)a	14.8 (1.3)a
Ba	SED	189 (4.1)a,B	198 (8.0)a,A	194 (4.9)a,AB
	SOIL	166 (91.6)a	214 (17.7)a	196 (11.0)a
Bi	SED	0.24 (0.05)a,A	0.26 (0.05)a,A	0.24 (0.05)a,A
	SOIL	0.26 (0.05)a	0.26 (0.05)a	0.28 (0.04)a
Cd	SED	0.46 (0.05a,A	0.54 (0.09)a,A	0.50 (0.0)a,A
	SOIL	0.52 (0.04)a	0.52 (0.04)a	0.56 (0.09)a
Co	SED	9.3 (0.30)a,A	10.2 (1.1)a,A	9.5 (0.34)a,A
	SOIL	9.1 (0.16)a	9.0 (0.29)b	9.2 (0.34)a
Cr	SED	29.2 (6.2)a,A	26.8 (2.8)a,A	35.4 (16.1)a,A
	SOIL	27.6 (8.2)a	24.8 (2.2)a	25.0 (2.6)a
Cu	SED	22.0 (0.85)a,B	24.6 (2.8)a,A	23.2 (1.3)a,AB
	SOIL	22.8 (0.74)a	24.0 (1.7)a	24.3 (0.65)a
Ga	SED	3.4 (0.55)a,A	3.4 (0.55)a,A	4.0 (0.0)a,A
	SOIL	3.4 (0.55)a	3.8 (0.45)a	4.0 (0.0)a
La	SED	16.4 (0.55)a,B	16.8 (0.44),B	18.0 (0.0)b,A
	SOIL	17.2 (0.84)a	17.4 (0.90)a	18.6 (0.55)a
Mn	SED	738 (17.9)b,A	668 (19.1)a,B	768 (71.3)a,A
	SOIL	853 (13.7)a	683 (378)a	668 (369)a
Mo	SED	1.0 (0.40)a,A	0.85 (0.52)a,A	1.3 (1.1)a,A
	SOIL	0.82 (0.47)a	0.58 (0.11)a	0.52 (0.19)a
Ni	SED	23.9 (0.72)a,B	25.7 (1.7)a,A	24.3 (1.2)a,AB
	SOIL	23.7 (0.80)a	23.7 (1.5)a	24.4 (0.54)a
Pb	SED	31.3 (4.0)a,AB	34.8 (9.8)a,A	24.4 (3.6)a,B
	SOIL	28.3 (4.2)a	25.2 (4.1)a	22.3 (1.8)a
Sb	SED	0.40 (0.0)a,A	0.48 (0.08)a,A	0.40 (0.10)a,A
	SOIL	0.36 (0.05)a	0.34 (0.05)b	0.30 (0.0)a
Sc	SED	2.8 (0.13)a	3.0 (0.25)a	3.1 (0.11)a
	SOIL	2.4 (0.16)b	2.8 (0.15)a	3.0 (0.15)a
Sr	SED	68.2 (2.6)a,A	69.2 (3.6)a,A	67.6 (1.3)a,A
	SOIL	58.2 (2.8)b	65.4 (7.3)a	63.8 (0.84)b
Ti	SED	0.20 (0.0)b,B	0.22 (0.0)a,AB	0.26 (0.0)a,A
	SOIL	0.28 (0.0)a	0.28 (0.0)a	0.30 (0.0)a
U	SED	1.5 (0.05)a,A	1.5 (0.07)a,A	1.5 (0.04)a,A
	SOIL	1.4 (0.04)a	1.5 (0.08)a	1.5 (0.05)a
V	SED	39.8 (1.8)a,A	41.4 (2.9)a,A	42.4 (1.3)a,A
	SOIL	39.8 (2.8)a	41.2 (2.7)a	44.2 (1.8)a
Zn	SED	88.2 (6.1)a,A	95.4 (10.0)a,A	87.6 (5.5)a,A
	SOIL	85.6 (4.9)a	84.8 (8.5)a	86.4 (1.7)a
Hg (ng g^{-1})	SED	61.8 (8.7)b,A	67.4 (10.7)b,A	60.9 (14.6)b,A
	SOIL	81.3 (8.2)a	77.5 (8.7)a	74.7 (11.1)a

† Transect 1 is furthest from the river channel, Transect 2 is between Transect 1 and 3, and Transect 3 is closest to the river channel.
‡ Numbers in parentheses represent the standard deviation.
§ Different lower case letters by parameter within columns indicate statistical significance at the $p \leq 0.05$ level by using the Student's t-test.
¶ Different capitalized letters by parameter and sample within rows indicate statistical significance at the $p \leq 0.05$ level by using the Tukey-Kramer Honestly Significant Difference (HSD) test.

Table 8. Trace element variables for sediment (SED) and soil (SOIL) (0-10cm) from location C along the Red River of the North near Moorhead, Minnesota.

Parameter	Sample	Transect 1[†]	Transect 2	Transect 3
			mg kg^{-1}	
As	SED	8.7 (0.65)[‡]a[§],A[¶]	7.3 (0.50)a,B	7.9 (0.33)a,B
	SOIL	7.0 (0.62)b	6.9 (0.27)a	8.2 (0.22)a
B	SED	23.8 (3.2)a,A	16.2 (1.8)a,B	14.2 (1.1)a,B
	SOIL	18.2 (1.6)b	14.0 (1.6)a	14.4 (1.1)a
Ba	SED	157 (87.4)a,A	185 (6.3)a,A	181 (3.3)b,A
	SOIL	190 (2.2)a	172 (4.7)b	187 (2.6)a
Bi	SED	0.28 (0.04)a,A	0.24 (0.05)a,A	0.22 (0.04)a,A
	SOIL	0.20 (0.0)b	0.26 (0.05)a	0.26 (0.05)a
Cd	SED	0.62 (0.08)a,A	0.58 (0.08)a,A	0.56 (0.05)a,A
	SOIL	0.62 (0.04)a	0.50 (0.0)a	0.58 (0.04)a
Co	SED	10.4 (0.63)a,A	9.9 (0.31)a,A	9.9 (0.16)b,A
	SOIL	10.1 (0.18)a	9.7 (0.27)a	10.4 (0.44)a
Cr	SED	31.2 (0.84)a,A	35.2 (15.3)a,A	28.4 (4.6)a,A
	SOIL	30.0 (4.6)a	27.2 (5.1)a	28.0 (2.2)a
Cu	SED	26.6 (1.7)a,A	24.4 (1.0)a,B	21.6 (0.56)b,C
	SOIL	24.6 (1.2)a	22.2 (0.58)b	23.2 (0.74)a
Ga	SED	5.8 (0.45)a,A	4.8 (0.45)a,B	4.0 (0.0)b,C
	SOIL	4.8 (0.45)b	4.0 (0.0)b	4.6 (0.55)a
La	SED	20.0 (0.71)a,A	18.8 (0.45)a,B	17.6 (0.55)b,C
	SOIL	20.2 (0.45)a	18.2 (0.45)a	18.6 (0.55)a
Mn	SED	903 (59.7)a,B	964 (118)a,AB	1070 (62.8)a,A
	SOIL	966 (53.8)a	835 (43.6)a	956 (43.3)b
Mo	SED	0.66 (0.05)a,A	1.1 (1.0)a,A	0.70 (0.23)a,A
	SOIL	0.78 (0.36)a	0.58 (0.29)a	0.56 (0.05)a
Ni	SED	28.0 (1.5)a,A	26.4 (0.77)a,B	25.1 (0.82)b,B
	SOIL	27.2 (1.1)a	25.7 (0.65)a	26.9 (0.84)a
Pb	SED	14.2 (0.15)a,A	13.4 (0.37)a,B	13.4 (0.61)a,B
	SOIL	14.8 (1.2)a	13.2 (0.38)b	14.2 (0.51)a
Sb	SED	0.38 (0.04)a,A	0.30 (0.0)a,B	0.28 (0.04)a,B
	SOIL	0.30 (0.07)a	0.28 (0.04)a	0.28 (0.04)a
Sc	SED	4.2 (0.38)a,A	3.4 (0.11)a,B	3.4 (0.23)b,B
	SOIL	3.1 (0.38)b	3.4 (0.15)a	3.8 (0.17)a
Sr	SED	53.2 (26.0)a,A	63.0 (2.7)a,A	61.0 (1.2)a,A
	SOIL	46.2 (5.2)a	41.8 (20.7)a	50.2 (1.9)a
Ti	SED	0.30 (0.0)a,A	0.30 (0.0)a,A	0.30 (0.0)a,A
	SOIL	0.30 (0.0)a	0.30 (0.0)a	0.30 (0.0)a
U	SED	1.7 (0.07)a,A	1.6 (0.05)a,B	1.4 (0.07)a,B
	SOIL	1.3 (0.05)b	1.3 (0.08)b	1.4 (0.0)a
V	SED	58.0 (4.1)a,A	48.0 (2.5)a,B	45.8 (2.2)a,B
	SOIL	48.2 (4.0)b	44.2 (2.7)a	48.6 (2.7)a
Zn	SED	105 (5.2)a,A	95.6 (8.6)a,B	83.4 (3.2)a,C
	SOIL	90.2 (2.6)b	82.2 (2.2)b	85.4 (2.1)a
Hg (ng g^{-1})	SED	57.3 (11.3)a,A	54.6 (7.9)a,A	54.7 (6.3)a,A
	SOIL	46.7 (6.0)b	51.9 (5.4)a	55.4 (4.0)a

† Transect 1 is furthest from the river channel, Transect 2 is between Transect 1 and 3, and Transect 3 is closest to the river channel.
‡ Numbers in parentheses represent the standard deviation.
§ Different lower case letters by parameter within columns indicate statistical significance at the $p \leq 0.05$ level by using the Student's t-test.
¶ Different capitalized letters by parameter and sample within rows indicate statistical significance at the $p \leq 0.05$ level by using the Tukey-Kramer Honestly Significant Difference (HSD) test.

General Conclusions

The objectives of this study were to (i) determine if flooding affects F-M area surface water and sediment quality and (ii) determine the quality of the sediment deposited in the F-M area after floodwaters recede. Even though the impacts from agricultural practices, floodplain development, impervious surfaces, and precipitation were not directly studied during this study flood event, it is important to note that these factors combined may have been considerable. The physical and chemical parameters within the sediment and soil sampled in this study were within the tolerable concentration levels for the United States. There was a tendency for C and N to be higher further from the river channel than near the channel. However, the mass of sediment was greater closer to the channel than away from it. The study also determined that the constituents in floodwater were under United States Environmental Protection Agency standards.

The results of this study indicate that major flooding of the RR through an urban center poses little environmental risk with respect to water and sediment quality and treating sandbags as hazardous material may not be necessary. This study also determined that F-M area did not influence water quality appreciably, but sediment loading did tend to occur, possibly due to the residential barriers, meandering river channel, or large oak trees that create low flow areas. Major flooding has economic, social, and environmental consequences. Although sediment remaining after floodwaters recede can be unsightly and cleanup efforts can be labor intensive, these sediments can also provide essential plant nutrients for urban riverine ecosystems, which may include turf grass, fruits and vegetables, and horticultural plants.

REFERENCES

Allan, J.D. 1995. Stream ecology – structure and function of running waters. London, Champan & Hall, 388p.

Anderson, H.R., M. Hansen, J. Kjolholt, P. Stuer-Lauridsen, T. Ternes, and B. Halling-Sorensen. 2005. Assessment of the importance of sorption for steroid estrogens removal during activated sludge treatment. Chemosphere 61:139-146.

Anon. 1981. Characterisation of pollution in urban stormwater runoff. Technical Paper No. 60. Australian Water Resources Council and Department of National Development and Energy, Canberra.

Anon. 1986. Meeting the challenge of nonpoint source control. J. Water Pollut. Control Fed. 58:730-740

Bakri, D.A., S. Rahman, and L. Bowling. 2008. Sources and management of urban stormwater pollution in rural catchments. J. Hydrology 356:299-311.

Balogh, S.J., M.L. Meyer, N.C. Hanson, J. Moncrief, and S.C. Gupta. 2000. Transport of mercury from a cultivated field during snowmelt. J. Environ. Qual. 29:871-874.

Barkdoll, M.P., D.E. Overton, and R.P. Betson. 1977. Some effects of dustfall on urban stormwater quality. J. Water Pollut. Control Fed. 49:1976-1984.

Bay, S., B.H., Jones, K. Schiff, and L. Washburn. 2003. Water quality impacts of stormwater discharges to Santa Monica Bay. Marine Environ. Res. 56:205-223.

Beard, J.B, and RL. Green. The role of turfgrasses in environmental protection and their benefits to humans. J. Environ. Qual. 23:452-460.

Bhowmik, N.G., J.R. Adams, A.P. Bonini, A.M. Klock, and M. Demise. 1986. Sediment load of Illinois streams and rivers. Illinois State Water Survey Rept. Invest. 106:167.

Bielders, C.L., C. Ramelot, and E. Persoons. 2003. Farmer perception of runoff and erosion and extent of flooding in the silt-loam belt of the Belgian Walloon Region. Environ. Sci. Policy 6:85-93.

Blevins, R.L., W.W. Frye, P.L. Baldwin, and S.D. Robertson. 1990. Tillage effects on sediment and soluble nutrient losses from a Maury silt loam. J. Environ. Qual. 19:683-686.

Boxall, A.B.A., and L. Maltby. 1995. The characterization and toxicity of sediment contaminated with road runoff. Water Res. 29:2043-2050.

Brigham, M.E., R.M. Goldstein, and L.H. Tornes. 1997. Trace Elements and Organic Chemicals in Stream-Bottom Sediments and Fish Tissues, Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1992-95: U.S. Geological Survey Water-Resources Investigations Report 97-4043.

Brunet, R.-C., and K.B. Astin. 2008. A comparison of sediment deposition in two adjacent floodplains of the River Adour in southwest France. J. Environ. Manage. 88:651-657.

Buccolieri, A., G., Buccolieri, A. Dell'Atti, G. Strisciullo, and R. Gagliano-Candela. 2010. Monitoring of total and bioavailable heavy metals concentration in agricultural soils. Environ. Monit. Assess. 168:547-560.

Burby, R.J. 2002. Flood insurance and floodplain management: the US experience. Environmental Hazards.

Burn, D.H. 1999. Perceptions of flood risk: A case study of the Red River flood of 1997. Water Resour. Res. 35:3451-3458.

Carr, R.S., PA. Montagna, J.M. Biedenbach, R.Kalke, M.C. Kennicutt, R. Hooten, and G. Cripe. 2000. Impact of storm-water outfalls on sediment quality in Corpus Christi Bay, Texas, USA. Environ. Toxic. Chemistry 19:561-574.

Casey, F.X.M., G.L. Larsen, H. Hakk, and J. Simunek. 2003. Fate and transport of 17ß-estradiol in soil-water systems. Environ. Sci. Technol. 38:790-798.

Chen, Y., and J. Wylde. 2007. Transition from conventional to no tillage in a poorly drained clay soil. ASABE Paper 071099. Am Soc. Agric. and Biol. Eng., St. Joseph, MI.

Chow, V.T. 1959. Open Channel Hydraulics. McGraw-Hill, USA, 680p.

Cihacek, L.J., M.D. Sweeney, and E.J. Deibert. 1993. Characterization of wind erosion sediments in the Red River Valley of North Dakota. J. Environ. Qual. 22:305-310.

Clay, S.A., T.M. DeSutter, and D.E. Clay. 2001. Herbicide concentration and dissipation from surface wind-erodible soil. Weed Sci. 49:431-436.

Cooper, C.M., and W.B. Gillespie Jr. 2001. Arsenic and mercury concentration in major landscape components of an intensively cultivated watershed. Environ Pollution 111:67-74.

Congressional Natural Hazards Caucus Work Group. 2001. Discussion paper for Congressional Natural Hazards Caucus [Online]. Available at <http//www.agiweb.org/workgroup>.

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

Davis, A.P., M. Shokouhian, H. Sharma, and C. Minami. 2001. Laboratory study of biological retention for urban stormwater management. Water Environ. Res. 73:5-14.

Davis, D.L., and H.L. Bradlow. 1995. Sci. Am. 272:166-172.

DeSutter, T.M., S.A. Clay, and D.E. Clay. 1998. Attrazine, alachlor, and total inorganic nitrogen concentrations of water wind-eroded sediment samples. J. Environ. Sci. Health B33:683-691.

DeSutter, T.M., G.M. Pierzynski, and J.H. Ham. 2005. Movement of lagoon-liquor constituents below four animal-waste lagoons. J. Environ. Qual. 34:1234-1242.

DeSutter, T.M., D.W. Franzen, F. Casey, D. Hopkins, B. Saini-Eidukat, A. Akyuz, and V. Jyoti. 2009. Distribution of total mercury in North Dakota Soils. *In* Annual meeting abstracts [CD-ROM]. ASA, CSSA, and SSSA, Madison, WI.

DeSutter, T., E. Viall, I. Rijal, M. Murdoff, A. Guy, X. Pang, S. Koltes, R. Luciano, X. Bai, K. Zitnick, S. Wang, F. Podrebarac, F. Casey, and D. Hopkins. 2010. Integrating field-based research into the classroom: An environmental sampling exercise. J. Nat. Resour. Life Sci. Educ. 39:132-136.

Dudgeon, D. 2000. The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. Annual Reviews Ecology Systematics 31:239-263.

Du Laing, G., J. Rinklebe, B. Vandercasteele, E. Meers, and F.M.G. Tack. 2008. Trace metal behaviour in estuarine and riverine floodplain soils and sediments: A review. Sci. Tot. Environ. 407:3972-3985.

Estebe, A., H. Boudries, J.-M. Mouchel, and D.R. Thevenot. 1997. Urban runoff impacts on particulate metal and hydrocarbon concentration in river seine: suspended solid and sediment transport. Water Sci. Technol. 36:185-193.

Francois, L.E., 1984. Salinity effects on germination, growth, and yield of turnips. Hort. Sci.19:82-84.

Franzen, D. 2007. Managing saline and sodic soils in North Dakota [Online]. Available at <http://www.ag.ndsu.edu/pubs/plantsci/soilfert/sf1087.pdf> (verified 11 November 2010).

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. p. 383-411. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Gnecco, I., C. Berretta, L.G. Lanza, P. La Barbera. 2005. Storm water pollution in the urban environment of Genoa, Italy. Atmospheric Res. 77:60-73.

Goonetilleke, A., E. Thomas, S. Ginn, and D. Gilbert. 2005. Understanding the role of land use in urban stormwater quality management. J. Environ. Manage. 74:31-42.

Gottschalk, L.C., and V.H. Jones. 1955. p. 135-143 Valleys and hills, erosion and sedimentation. *In* Water: Yearbook of Agriculture.

Gromaire-Mertz, M.C., S. Garnaud, A. Gonzalez, and G. Chebbo. 1999. Characterisation of urban runoff pollution in Paris. Water Sci. Tech. 39:1-8.

Haiping, Z., and K. Yamada. 1998. Simulation of nonpoint source pollutant loadings from urban areas during rainfall: an application of a physically based distributed model. Water Sci. Tech. 38:199-206.

Hall, C.M. 1908. Official state map and preliminary geologic and economic map of North Dakota. Agricultural College Survey of North Dakota and the US Geological Survey.

Hall, M.J., and B.C. Anderson. 1986. The toxicity and chemical composition of urban stormwater runoff. Canadian J. Civil Eng. 15:98-105.

Hansen, N.C., S.C. Gupta, and J.F. Moncrief. 2000. Snowmelt runoff, sediment, and phosphorus losses under three different tillage systems. Soil Tillage Res. 57:93-100.

Hearne, R. 2007. Evolving water management institutions in the Red River basin. Environ. Manage. 40:842-852.

Herngren, L., A. Goonetilleke, G.A. Ayoko., M.M.M. Mostert. 2010. Distribution of polycyclic aromatic hydrocarbons in urban stormwater in Queensland, Australia. Environ. Pollut. 158:2848-2856.

Hillel, D. 1991. The gifts of the Nile. p.88-94. *In* D. Hillel (ed) Out of the earth: civilization and life of the soil. Univ. California Press, Barkley and Los Angeles, CA.

Hubbard, L., D.W. Kolpin, S.J. Kalkoff, and D.M Robertson. 2011. Nutrient and sediment concentrations and corresponding loads during the historic June 2008 flooding in eastern Iowa. J. Environ. Qual. 40:166-175.

Hunter, J.V., T. Sabatino, R. Gomperts, and M.J. MacKenzie. 1979. Contribution of urban runoff to hydrocarbon pollution. J. Water Pollut. Control Fed. 51:2129-2138.

Hwang, H.M., and G.D. Foster. 2006. Characterization of polycyclic aromatic hydrocarbons in urban stormwater runoff flowing into the tidal Anacostia River, Washington, DC, USA. Environ. Pollut. 140:416-426.

International Joint Commission. 2000. Living with the Red: A Report to the Governments of Canada and the United States on Reducing Flood Impacts in the Red River Basin. International Joint Commission, November 2000.

Ivashchenko, A. Potential urban impacts on water quality of the Red River of the North. M.S. paper. North Dakota State Univ., Fargo.

James, L.D., and S.F. Korum. 2001. Lessons from Grand Forks: planning nonstructural flood control measures. Natural Hazards Review 2:182-192.

Kabata-Pendias, A. 2011. Trace elements in soils and plants. Fourth Ed. CRC Press, Boca Raton, FL.

Kipopoulou, A.M., E. Manoli, and C. Samara. 1999. Bioconcentration of polycyclic aromatic hydrocarbons in vegetables grown in an industrial area. Environ. Pollut. 106:369-380.

Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, and H.T. Buxton. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: a national reconnaissance. Environ. Sci. Technol. 36:1202-1211.

Knox, J.C. 2006. Floodplain sedimentation in the Upper Mississippi Valley: natural versus human accelerated. Geomorphology 79:286-310.

Lair, G.J., F Zehtetner, M. Fiebig, M.H. Gerzabek, C.A.M., van Gestel, T. Hein, S. Hohensinner, P. Hsu, K.C. Jones, G. Jordan, A.A. Koelmans, A. Poot, D.M.E. Slijkerman, K.U. Totsche, E. Bondar-Kunze, and J.A.C. Barth. 2009. How do long-term development and periodical changes of river-floodplain systems affect the fate of contaminants? Results from European rivers. Environ. Pollut. 157:3336-3346.

Larsson, D.G.J., H. Hällman, and L. Förlin. 2000. More male fish embryos near a pulp mill. Environ. Toxicol. Chem. 19:2911-2917.

Lehner, P.H., G.P.A. Clarke, D.M. Cameron, and A.G. Frank. 1999. Stormwater strategies. Natural Resources Defense Council, New York.

Leitch, J.A. 2003. Floodplains and the tyranny of small decisions. News & Views 15:1, 10-12.

Leitch, J.A., and S. Schultz. 2003. Floods and Flooding. Encyclopedia of Water Sci. 300-305.

Maas, E.V. 1986. Salt tolerance of plants. Appl. Agric. Res. 1:12-26.

Macek-Rowland, K.M. 1997. 1997 Floods in the Red River of the North and Missouri River Basins in North Dakota and Western Minnesota. United States Geological Survey Open-File Report. 97-575, 8pp.

Magilligan, F.G., J.D. Phillips, L.A. James, and B. Gomez. 1998. Geomorphic and sedimentological controls on the effectiveness of an extreme flood. J. Geology 106:87-95.

Makepeace, D.K., D.W. Smith, and S.J. Stanley. 1995. Urban stormwater quality: summary of contaminant data. Critical Reviews Environ. Sci. Tech. 25:93-139.

Marsalek, J. 1991. Pollutant loads in urban stormwater: Review of methods for planning-level estimates. Water Resour. Bull. 27:283-291.

Mills, W.C., A.W. Thomas, and G.W. Langdale. 1986. Estimating soil loss probabilities for southern Piedmont cropping-tillage systems. Trans. ASAE 29:948-955.

Mitsch, W.J., and J.G. Gosselink. 2007. Wetlands, 4th ed. John Wiley & sons, New York.

Myers, J.L., and M.G. Wagger. 1996. Runoff and sediment loss from three tillage systems under simulated rainfall. Soil Tillage Res. 39:115-129.

Nahlik, A.M., and W.J. Mitsch. 2008. The effect of river pulsing on sedimentation and nutrients in created riparian wetlands. J. Environ. Qual. 37:1634-1643.

National Atmospheric Deposition Program. 2009. Animated maps: Sulfate [Online]. Available at <http://nadp.sws.uiuc.edu/data/animaps.aspx> Verified 11 November 2010.

Newton, P.J., B.A., Myers, and D.W. West. 1991. Reduction in growth and yield of Jerusalem artichoke caused by soil salinity. Irrig. Sci. 12:213-221.

Niemczynowicz, J. 1999. Urban hydrology and water management – present and future challenges. Urban Water. 1:1-14.

North Dakota Department of Health. 2006. How minerals affect water supplies [Online]. Available at http://www.health.state.nd.us/WQ/GW/pubs/mineral.htm [cited 13 May 2010]. NDDH, Bismarck, ND.

North Dakota Department of Health. 2008. Mercury [Online]. Available at http://www.ndhealth.gov/AQ/mercury/MERCURYinfo.pdf [cited 10 June 2010]. NDDH, Bismarck, ND.

Olde Venterink, H., J.E. Vermaat, M. Pronk, F. Wiegman, G.E.M. van der Lee., M.W. van der Hoorn, L.W.G. Higler, and J.T.A. Verhoeven. 2006. Importance of sediment deposition and denitrification for nutrient retention in floodplain wetlands. Applied Vegetation Sci. 9:163-174.

O'Loughlin, G. 1994. Pollution prevention and politics – the recent experience in Sydney. Water Sci. and Technol. IAWQ. 30:13-22.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. Of Agric. Circ. 939.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403-430. *In* Page, A.L. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Ongley, E. 1996a. Pollution by sediments. *In* E. Ongley (ed.) Control of water pollution from agriculture: FAO Irrigation and Drainage Papers – 55 [Online]. Available at <http://www.fao.org/docrep/W2598E/w2598e05.htm> [cited 17 Nov. 2010].

Ongley, E. 1996b. Sediment measurements. *In* J. Bartram and R. Balance (ed.) Water quality monitoring – a practical guide to the design and implementation of freshwater quality studies and monitoring programmes [Online]. Available at <http://www.who.int/water_sanitation_health/resourcesquality/wqmonitor/en/> [cited 17 Nov. 2010].

Osborn, B. 1955. How rainfall and runoff erode soil in Water: Yearbook of Agriculture1955. U.S. Government Printing Office, Washington, D.C., pp. 126-135.

Owens, P.N. and D.E. Walling. 2002. The phosphorus content of fluvial sediment in rural and industrialized river basins. Water Res. 36:685-701.

Parker, J.T.C., K.D. Fossum, and T.L. Ingersoll. 2000. Chemical characteristics of urban stormwater sediments and implication for environmental management, Maricopa County, Arizona. Environ. Manage. 26:99-115.

Pease, L.M., P. Oduor, and G. Padmanabhan. 2010. Estimating sediment, nitrogen, and phosphorus loads from the Pipestem Creek watershed, North Dakota, using AnnAGNIPS. Computers & Geosciences 36:282-291.

Pielke Jr., R.A., and M.W. Downton. 2009. Flood Damage in the United States, 1926-2003: A Reanalysis of National Weather Service Estimates [Online]. Available at <http://www.flooddamagedata.org/use_interpretation.html>.

Pinter, N. 2005. One step forward, two steps back on U.S. floodplains. Science 308:207-208 [DOI: 10.1126/science.1108411].

Polemio, M., and J.D. Rhoades.1977. Determining cation exchange capacity: A new procedure for calcareous and gypsiferous soils. Soil Sci. Soc. Am. J. 41:524-528.

Ravenga, C., J. Brunner, N. Henninger, K. Kassem, and R. Payne. 2000. Pilot Analysis of Global Ecosystems. Freshwater Systems. Washington DC, USA: World Resources Institute.

Reible, D.D., C.N. Haas, J.H. Pardue, and W.J. Walsh. 2006. Toxic and contaminant concerns generated by Hurricane Katrina. The Bridge 36:5-17.

Rekolainen, S. 1989. Effect of snow and soil frost melting on the concentrations of suspended solids in phosphorus in two rural watersheds in Western Finland. Aquatic Sci. 51(3):211-223.

Richards, L.A. (ed). 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook 60. Wash. D.C.

Rinklebe, J., C. Franke, and H.-U. Neue. 2007. Aggregation of floodplain soils based on classification principles to predict concentrations of nutrients and pollutants. Geoderma 141:210-223.

Ryberg, K.R. 2006. Continuous Water-Quality Monitoring and Regression Analysis to Estimate Constituent Concentrations and Loads in the Red River of the North, Fargo, North Dakota, 2003-05: U.S. Geological Survey Scientific Investigations Report 2006-5241, 35 p.

Samsoe-Peterson, L., P.H. Larsen, P.B. Larsen, and P. Bruun. 2002. Uptake of trace elements and PAHs by fruit and vegetables from contaminated soils. Environ. Sci. Technol. 36:3057-63.

Sando, S.K., G.J. Wiche, R.F. Lundgren, and B.A. Sether. 2003. Reconnaissance of Mercury in Lakes, Wetlands, and Rivers in the Red River of the North Basin, North Dakota, March Through August 2001: U.S. Geological Survey Water-Resources Investigations Report 03-4078.

Sartor, J.D., and G.B. Boyd. 1972. Water pollution aspects of street surface contaminants. Report No. EPA-R2-72/081. US Environmental Protection Agency, Washington, DC.

Sartor, J.D., G.B. Boyd, and F.J. Agardy. 1974. Water pollution aspects of street surface contaminants. J. Water Pollut. Control Fed. 46:458-467.

Schoenfuss, H.L., J.T. Levitt, G. Van Der Kraak, P.W. Sorensen. in press. Ten week exposure to treated sewage discharge has relatively minor, variable effects on reproductive behavior and sperm production in goldfish. Environ. Toxicol. Chem.

Schoenfuss, H.L., D. Martinovic, and P.W. Sorensen. 2011. Effects of exposure to low levels of water-born 17b-estradiol on nest holding ability and sperm quality in fathead minnows. J. Contemporary Water Res. Educ. 120:49-55.

Schueler, T.R. 1994. The importance of imperviousness. Watershed Protection Techniques. 1:100-111.

Schwert, D.P. 2003. A geologist's perspective on the Red River of the North: history geography, and planning/management issues. Proceedings 1st International Water Conference, Red River Basin Institute, Moorhead, MN. 16pp.

Settacharnwit, S., R.T. Buckney, and R.P. Lim. 2003. The nutrient status of Nong Han, a shallow tropical lake in north-eastern Thailand: spatial and temporal variations. Lakes and Reservoirs: Res. Manage 8:189-200.

Sherrod, L.A., G. Dunn, G.A. Peterson, and R.L. Kolberg. 2002. Inorganic carbon analysis by modified pressure-calcimeter method. Soil Sci. Soc. Am. J. 66:299-305.

Shore, L.S., and M. Shemesh. 2003. Naturally produced steroid hormones and their release into the environment. Pure Appl. Chem. 75:1859-1871.

Shore, L.S., M. Shemesh, and R. Cohen. 1998. The role of estradiol and estrone in chicken manure silage in hyperestrogenism in cattle. Aust. Vet. J. 65:68.

Shigaki, F., J.P. Schmidt, P.J. Kleinman, A.N. Sharpley, and A.L. Allen. 2009. Nitrogen fate in drainage ditches of the coastal plain after dredging. J. Environ. Qual. 38:2449-2457.

Simonovic, S.P., and R.W. Carson. 2003. Flooding in the Red River basin – lessons from post flood activities. Natural Hazards. 28:345-365.

Souris-Red-Rainy River Basins Commission. 1972. The combined report – type I framework study. Vol. 1, 216 p.

Sterk, G., L. Herrmann, and A. Bationo. 1996. Wind-blown nutrient transport and soil productivity changes in southwest Niger. Land Degradation & Development 7:325-335.

Stoner, J.D., D.L. Lorenz, G.J. Wiche, and R.M. Goldstein. 1993. Red River of the North basin, Minnesota, North Dakota, and South Dakota. Water Resour. Bull. 29:575-615.

Swenson, L. 2010. Personal communication.

Tabatabai, M.A. 1982. Sulfur. p. 501-538. *In* Page, A.L. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Taebi, A., and R.L. Droste. 2004a. First flush pollution load of urban stormwater runoff. J. Environ. Eng. Sci. 3:301-309.

Taebi, A., and R.L. Droste. 2004b. Pollution loads in urban runoff and sanitary wastewater. Sci. Tot. Environ. 327:175-184.

Thompson, M.L., F.X.M. Casey, E. Kahn, H. Hakk, G.L. Larsen, and T.M. DeSutter. 2009. Occurrence and pathways of manure-borne 17ß-estadiol in Vadose zone water. Chemosphere 76:472-479.

Tockner, K., and J.A. Stanford. 2002. Riverine flood plains: present state and future trends. Environ. Cons. 29(3): 308-330.

Todhunter, P.E. 1998. Flood hazard in the Red River Valley: A case study of Grand Forks flood of 1997. North Dakota Quarterly 65:254-275.

Todhunter, P.E. 2001. A hydroclimatological analysis of the Red River of the North snowmelt flood catastrophe of 1997. J. Am. Water Resour. Assoc. 37:1263-1278.

Toft, G., and E. Baatrup. 2001. Sexual characteristics are altered by 4-tert-octylphenol and 17ß-estradiol in adult male guppy. Ecotoxicol. Environ. Safety 46:76-84.

Tornes, L.H., and M.E. Brigham. 1995. Pesticide Amounts are Small in Streams in the Red River of the North Basin, 1993-94: U.S. Geological Survey Open-File Report 95-283.

Tsihrintzis, V.A., and R. Hamid. 1997. Modeling and management of urban stormwater runoff quality: A review. Water Resour. Manage. 11:137-164.Tian, J.R., and P.J. Zhou. 2007. Phosphorus fractions of floodplain sediments and phosphorus exchange on the sediment-water interface in the lower reaches of the Han River in China. Ecol. Eng. 30:264-270.

US Army Corp of Engineers. 2010. Flood risk management: Fargo-Moorhead metro, North Dakota and Minnesota [Online]. Available at <http://www.mvp.usace.army.mil/fl_damage_reduct/default.asp?pageid=1455> (verified 11 February 2011).

USDA National Agricultural Statistics Service (NASS). 2010. North Dakota county data, 2008 Quick Stats, crops [Online]. Available at http://www.nass.usda.gov/QuickStats/PullData_US_CNTY.jsp [cited 8 June 2010]. USDA-NASS, Washington, DC.

USDA-Natural Resources Conservation Service (NRCS). 1996. Plant material for saline-alkaline soils [Online]. Available at <ftp://ftp-fc.sc.egov.usda.gov/MT/www/technical/plants/PMC_Tech_Note_MT26.pdf> [cited 20 Mar 2011].

USDA-NRCS. 2002. Web Soil Survey [Online]. Available at <https://soilseries.sc.egov.usda.gov/OSD_Docs/C/CASHEL.html> [cited 11 Dec 2010].

USDA-NRI. 2009. National Resources Inventory-2007 NRI. Available at <http://www.nrcs.usda.gov/technical/nri/2007/nri07erosion.html> [cited 12 March 2011]. USDA-NRCS, Washington, DC. 17 Dec. 2009.

US-Environmental Protection Agency (EPA). 1990. National water quality inventory – 1988 report to Congress. Office of Program Operations, Water Planning Division, US Environmental Protection Agency, Washington, DC.

USEPA. 1993a. Method 140.4. Chloride-automated flow injection analysis [Online]. Available at <http://www.epa.gov.glnpo/lmmb/methods/method140.pdf> [cited 16 June 2010].

USEPA. 1993b. Method 350.1. Determination of Ammonia Nitrogen by semi-automated colorimetry [Online]. Available at <http://www.epa.gov/waterscience/methods/method/files/350_1.pdf> [cited 16 June 2010].

USEPA. 1993c. Method 353.2. Determination of nitrate-nitrite nitrogen by automated colorimetry [Online]. Available at <http://www.epa.gov/waterscience/methods/method/files/353_2.pdf> [cited 16 June 2010].

USEPA. 1993d. Method 365.1. Determination of phosphorus by semi-automated colorimetry [Online]. Available at <http://www.epa.gov/waterscience/methods/method/files/365_1.pdf> [cited 16 June 2010].

USEPA. 1993e. Method 375.2. Determination of sulfate by automated colorimetry [Online]. Available at

<http://www.epa.gov/waterscience/methods/method/files/375_2.pdf> [cited 16 June 2010].

USPEA. 1996a. Method 5035. Closed-system purge-and-trap and extraction for volatile organics in soil and waste samples [Online]. Available at <http://www.epa.gov/wast/hazard/testmethods/sw846/pdfs/5035.pdf> [cited 16 June 2010].

USEPA. 1996b. Method 8260B. Volatile organic compounds by gas chromatography/mass spectrometry (GC/MS) [Online]. Available at <http://www.epa.gov/waste/hazard/testmethods/sw846/pdfs/8260b.pdf> [cited 16 June 2010].

USEPA. 2000. National water quality inventory (EPA-841-R-00-001). United States Environmental Protection Agency, Washington, DC.

USEPA. 2007a. Method 3550C. Ultrasonic extraction [Online]. Available at <http://www.epa.gov/epawaste/hazard/testmethods/sw846/pdfs/3550c.pdf> [cited 16 June 2010].

USEPA. 2007b. Method 8270D. Semivolatile organic compounds by gas chromatography/mass spectrometry (GC/MS) [Online]. Available at <http://www.epa.gov/epawaste/hazard/testmethods/sw846/pdfs/8270d.pdf> [cited 16 June 2010].

USEPA. 2009a. Method 7473: Mercury in solids and solutions by thermal decomposition, amalgamation, and atomic adsorption spectrophotometry [Online]. Available at <http://www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/7473.pdf> [cited 9 June 2010].

USEPA. 2009b. The great waters program: second report to Congress – executive summary [Online]. Available at <http://www.epa.gov/oar/oaqps/gr8water/2ndrpt/execsumm.html> [cited 20 Mar 2011].

USGS. 2008. Kansas Water Science Center: Flood definitions [Online]. Available at <http://ks.water.usgs.gov/waterwatch/flood/definition.html> [cited 20 Mar 2011].

USGS. 2009. Data files for the Red River at Fargo, ND [Online]. Available at <http://www.fargoflood. Dreamhosters.com/level2009/data.cgi> Verified 11 February 2011.

USGS. 2010a. Mineral resources and on-line spatial data: national geochemical database [Online]. Available at <http://mrdata.usgs.gov/geochemistry/ngs.html> Verified 10 March 2011.

USGS. 2010b. Red River of the North at Fargo, ND [Online]. Available at <http://nd.water.usgs.gov/floodtracking/charts/05054000_09020104.html> Verified 11 February 2011.

US Department of Homeland Security – FEMA. 2003. Do you live in a floodplain? [Online]. Available at <http://www.fema.gov/news/newsrelease.fema?id=3866> [cited 12 Mar 2011].

US Department of Homeland Security – FEMA. 2010. Definitions [Online]. Available at <http://www.fema.gov/business/nfip/19def2.shtm#F> [cited 12 Mar 2011].

van den Brink, F.W.B., G. Van Der Velde, A.J. Buijse, and A.G. Klink. 1996. Biodiversity in the Lower Rhine and Meuse river-floodplains: Its significance for ecological river management. Aquatic Ecology 30:129-149.

Vaze, J., and F.H.S. Chiew. 2002. Experimental study of pollutant accumulation on an urban road surface. Urban Water 4:379-389.

Van Metre, P.C., and B. J. Mahler. 2010. Contribution of PAHs from coal-tar pavement sealcoat and other sources to 40 U.S. lakes. Sci. Tot. Environ. 409:334-344.

Voutsa, D., A. Grimanis, and C. Samara. 1996. Trace elements in vegetables grown in an industrial area in relation to soil and air particulate matter. Environ. Pollut. 94:325-335.

Walling, D.E., P.N. Owens, J. Carter, G.J.L. Leeks, S. Lewis, A.A. Meharg, and J. Wright. 2003. Storage of sediment-associated nutrients and contaminants in river channel and floodplain systems. Applied Geochemistry. 18:195-220.

Table 9. Concentration data for all water variables at two locations during the spring 2009 Red River of the North flood at Fargo, North Dakota and Moorhead, Minnesota.

Location	Day of Year (DOY)	Sediment (g)	PO_4	SO_4	Cl^- (mg L^{-1})	NO_3-N	NH_4-N	EC (ds m^{-1})	pH	E1 field concentration (ng L^{-1})	E2 field concentration (ng L^{-1})	DRO (μg L^{-1})	GRO (μg L^{-1})
52nd Ave S	83	0.01	0.04	54.8	8.3	0.35	0.07	0.19	7.5	0	1.5	92.7	0
52nd Ave S	84	0.01	0.03	51.2	7.0	0.24	0.02	0.18	7.5	0	0.30	87.5	0
52nd Ave S	85	0.01	0.05	48.3	7.7	0.21	0.01	0.17	7.5	0	0	64.5	0
52nd Ave S	86	0.01	0.27	29.7	6.4	0.25	0.00	0.16	7.6	0	0.30	0	0
52nd Ave S	89	0.01	0.07	53.4	8.1	0.36	0.02	0.19	7.7	0	0	0	0
52nd Ave S	91	0.01	0.11	95.6	12.2	0.39	0.06	0.24	7.7	0	0	0	0
52nd Ave S	93	0.01	0.12	119	10.7	0.41	0.04	0.27	7.7	0	0	0	0
52nd Ave S	98	0.01	0.13	145	12.5	0.48	0.08	0.38	7.9	0	0	0	0
52nd Ave S	105	0.01	0.08	106	10.0	0.28	0.03	0.34	7.8	0	0	0	0
52nd Ave S	112	0.01	0.09	163	13.2	0.18	0.03	0.40	7.9	0	0	0	0
52nd Ave S	119	0.01	0.01	186	13.1	0.10	0.01	0.48	8.1	0	0	0	0
52nd Ave S	126	0.01	0.06	210	18.0	0.18	0.03	0.61	8.2	0	0.40	0	0
40th Ave N	83	0.01	0.15	63.3	10.3	0.44	0.05	0.22	7.5	0	0.80	91.2	0
40th Ave N	84	0.01	0.10	52.3	8.1	0.36	0.03	0.19	7.5	0	1.2	91.2	0
40th Ave N	85	0.01	0.03	50.4	7.7	0.12	0.02	0.18	7.5	0	0.50	108	0
40th Ave N	86	0.01	0.04	48.4	7.9	0.29	0.01	0.18	7.5	0	0	0	0
40th Ave N	89	0.01	0.08	49.0	8.0	0.34	0.01	0.19	7.6	0	0.10	40.4	0
40th Ave N	91	0.01	0.10	77.8	9.3	0.37	0.04	0.22	7.7	0	0	0	0
40th Ave N	93	0.01	0.11	105	11.3	0.40	0.08	0.25	7.7	0	0	0	0
40th Ave N	98	0.01	0.12	140	12.8	0.59	0.09	0.38	7.8	0	0	0	0
40th Ave N	105	0.01	0.07	93.7	9.1	0.20	0.01	0.31	7.8	0	0	0	0
40th Ave N	112	0.01	0.10	164	13.1	0.19	0.06	0.43	7.8	0	0.40	64.2	0
40th Ave N	119	0.01	0.01	184	13.7	0.11	0.04	0.47	8.1	0	0	0	0
40th Ave N	126	0.01	0.07	218	18.6	0.19	0.04	0.61	8.2	0	0	0	0

Table 10. Data for all variables for sediment (SED) and soil (SOIL) (0-10cm) from location A along the Red River of the North near Fargo, North Dakota.

Location	Type	Set	Dry Sed ($g\ m^{-2}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	CEC ($cmol_{(+)}\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	Inorganic C ($g\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Organic N ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
A	SED	1	2021			1.28	7.23	32.14	49.74	39.84	9.90	4215	4105.12	109.38	0.51
A	SED	1	2492			1.32	7.17	31.96	51.99	42.39	9.60	4077	3965.53	110.55	0.92
A	SED	1	3740	468	532	1.04	7.16	32.86	56.09	47.29	8.80	4256	4120.52	133.55	1.94
A	SED	1	1523			0.80	7.13	32.06	53.47	43.87	9.60	4091	3954.09	136.61	0.30
A	SED	1	1780			0.62	7.15	31.91	54.43	45.23	9.20	4577	4473.34	103.34	0.32
A	SED	1	3787	505	495	0.70	7.1	32.47	55.56	47.36	8.20	4487	4356.23	129.43	1.34
A	SED	1	2965			1.28	7.11	29.78	53.77	44.47	9.30	4519	4379.14	138.21	1.65
A	SED	1	3416	528	472	1.01	7.14	30.87	57.81	49.41	8.40	4748	4579.70	165.60	2.70
A	SED	1	3249			0.98	7.16	30.67	53.76	44.56	9.20	4481	4356.93	121.94	2.14
A	SED	1	3202			0.93	7.14	29.83	54.7	45.90	8.80	4583	4438.97	142.39	1.64
A	SED	1	3977	471	529	0.85	7.2	29.61	60.79	52.39	8.40	4927	4771.92	152.83	2.25
A	SED	1	3755	515	485	0.97	7.21	29.27	58.21	49.21	9.00	4590	4448.50	140.57	0.93
A	SED	1	1187			1.11	7.17	29.89	54.78	46.08	8.70	4443	4311.92	128.79	2.29
A	SED	1	3602			0.88	7.31	29.21	53.01	44.31	8.70	4502	4379.68	121.35	0.98
A	SED	1	2540			0.92	7.3	28.78	51.8	42.20	9.60	4167	4041.43	125.06	0.50
A	SED	1	4102			1.07	7.16	30.46	59.47	51.37	8.10	4707	4590.44	114.53	2.03
A	SED	1	985			0.84	7.23	29.92	54.62	46.17	8.45	4507	4397.15	107.70	2.15
A	SOIL	1				0.82	7.13	34.91	57.8	53.40	4.40	5701	5657.88	10.71	32.41
A	SOIL	1				0.60	7.14	34.54	61.14	56.54	4.60	5807	5786.25	10.85	9.91
A	SOIL	1				0.81	7.11	33.68	57.65	52.75	4.90	5755	5701.05	12.84	41.12
A	SOIL	1				0.80	7.2	32.21	57.09	51.69	5.40	5271	5231.80	9.57	29.63
A	SOIL	1				0.76	7.27	32.62	53.14	46.94	6.20	5101	5054.40	13.76	32.84
A	SOIL	1				0.77	7.19	32.03	53.75	47.45	6.30	5341	5307.82	7.51	25.67
A	SOIL	1				0.70	7.2	31.65	53.8	47.40	6.40	4944	4911.68	8.91	23.42
A	SOIL	1				0.57	7.3	31.78	56.54	50.34	6.20	5433	5392.92	17.73	22.35
A	SOIL	1				0.72	7.28	32.97	49.77	43.67	6.10	4781	4746.65	8.68	25.68
A	SOIL	1				0.70	7.21	33.94	58.23	52.83	5.40	5787	5738.65	11.09	37.26
A	SOIL	1		370	630	0.71	7.24	32.92	52.77	47.27	5.50	4841	4823.13	8.85	9.02
A	SOIL	1		392	608	0.75	7.26	32.87	53.46	47.96	5.50	5103	5064.73	8.30	29.97
A	SOIL	1				0.65	7.24	33.99	52.46	47.76	4.70	5148	5104.65	8.01	35.34
A	SOIL	1				0.75	7.24	34.54	53.61	49.51	4.10	5267	5231.03	8.66	27.31
A	SOIL	1		418	582	0.89	7.1	34.84	52.87	49.27	3.60	5029	4979.43	14.17	35.40
A	SOIL	1		421	579	0.86	7.1	33.99	52.67	48.37	4.30	5350	5255.19	51.92	42.89
A	SOIL	1		431	569	0.79	7.29	32.29	46.51	41.91	4.60	4792	4751.73	13.99	26.28

Table 10 (continued)

Location	Type	Set	Olsen P (mg kg^{-1})	Water Soluble P (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	DRO (µg g^{-1})	As	B	Ba	Bi	Cd	Co	Cr	Cu	Ga
							mg kg^{-1}								
A	SED	1	44.10	3.03	2546.17	22.2									
A	SED	1	50.77	2.60	3414.27	43.5									
A	SED	1	39.09	4.83	2024.04	39	6.9	16.0	172	0.3	0.5	9.4	31.0	24.7	5.0
A	SED	1	46.20	3.74	3186.41										
A	SED	1	49.61	4.24	3121.89										
A	SED	1	37.71	2.92	2022.69		6.6	19.0	183	0.2	0.6	9.8	27.0	26.0	4.0
A	SED	1	40.27	3.44	2170.49										
A	SED	1	38.72	4.42	2184.47										
A	SED	1	48.33	4.32	2018.19		7.0	16.0	186	0.2	0.7	9.8	31.0	26.0	5.0
A	SED	1	41.26	4.35	3056.77										
A	SED	1	43.59	4.76	2196.62		6.7	16.0	170	0.2	0.6	9.8	27.0	25.9	5.0
A	SED	1	19.69	3.34	2056.15		6.6	16.0	175	0.2	0.7	95.0	40.0	26.6	5.0
A	SED	1	20.31	4.88	2243.26										
A	SED	1	29.19	4.48	1868.95										
A	SED	1	16.78	2.82	2247.77										
A	SED	1	20.65	3.85	1998.95										
A	SED	1	16.78	3.44	3007.91										
A	SOIL	1	21.62	8.27	565.55	0									
A	SOIL	1	25.48	7.43	718.94	0									
A	SOIL	1	26.95	8.03	559.91	5.52									
A	SOIL	1	25.74	6.68	442.67										
A	SOIL	1	20.03	6.32	672.38										
A	SOIL	1	23.28	7.91	400.27										
A	SOIL	1	18.71	11.23	439.69										
A	SOIL	1	21.71	9.13	815.42										
A	SOIL	1	20.32	4.52	442.94										
A	SOIL	1	25.22	7.75	466.93										
A	SOIL	1	19.32	7.35	479.47		7.8	16.0	180	0.3	0.7	10.9	27.0	28.5	5.0
A	SOIL	1	33.96	6.53	315.35		7.9	17.0	179	0.3	0.7	10.4	34.0	27.7	5.0
A	SOIL	1	30.35	9.08	413.22										
A	SOIL	1	32.90	6.72	225.04										
A	SOIL	1	27.70	7.21	658.86		7.4	19.0	189	0.2	0.6	10.8	28.0	27.4	5.0
A	SOIL	1	31.67	3.81	506.07		7.6	18.0	170	0.2	0.8	11.1	35.0	27.0	5.0
A	SOIL	1	28.35	3.71	401.82		7.9	16.0	180	0.3	0.6	10.4	27.0	25.3	5.0

Table 10 (continued)

Location	Type	Set	Hg (ng g^{-1})	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Ti	U	V	Zn
				mg kg^{-1}											
A	SED	1	52.09												
A	SED	1	50.89												
A	SED	1	54.19	19.0	815	0.7	26.4	14.2	0.3	3.2	58.0	0.3	1.7	51.0	94.0
A	SED	1	47.06												
A	SED	1	59.70												
A	SED	1	50.04	20.0	725	0.5	27.8	14.2	0.3	3.4	55.0	0.3	1.7	51.0	90.0
A	SED	1	46.30												
A	SED	1	57.18												
A	SED	1	49.28	20.0	817	0.7	27.4	13.8	0.3	3.5	60.0	0.3	1.6	53.0	94.0
A	SED	1	43.07												
A	SED	1	38.40	18.0	795	0.6	25.8	13.8	0.3	3.2	56.0	0.3	1.6	51.0	92.0
A	SED	1	46.43	19.0	806	0.4	27.6	14.0	0.3	3.4	56.0	0.3	1.6	50.0	98.0
A	SED	1	52.59												
A	SED	1	39.51												
A	SED	1	41.61												
A	SED	1	41.23												
A	SED	1	45.69												
A	SOIL	1	65.88												
A	SOIL	1	58.60												
A	SOIL	1	69.16												
A	SOIL	1	67.88												
A	SOIL	1	65.69												
A	SOIL	1	65.34												
A	SOIL	1	55.15												
A	SOIL	1	64.12												
A	SOIL	1	66.37												
A	SOIL	1	63.87												
A	SOIL	1	61.11	20.0	995	0.4	31.7	53.1	1.0	3.2	41.0	0.3	1.3	52.0	97.0
A	SOIL	1	59.82	20.0	979	0.7	29.7	56.8	0.5	3.2	41.0	0.3	1.3	54.0	99.0
A	SOIL	1	47.32												
A	SOIL	1	50.65												
A	SOIL	1	39.42	21.0	894	0.5	31.1	17.3	0.3	3.2	40.0	0.3	1.3	54.0	98.0
A	SOIL	1	47.98	21.0	952	0.9	28.9	41.2	0.3	3.2	42.0	0.3	1.3	55.0	96.0
A	SOIL	1	47.11	21.0	918	0.4	29.1	17.5	0.3	3.4	41.0	0.3	1.2	54.0	92.0

Table 10 (continued)

Location	Type	Set	Dry Sed ($g\ m^{-2}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	CEC ($cmol_{(+)}\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	Inorganic C ($g\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Organic N ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
A	SED	2	7991			1.04	7.25	24.76	47.99	34.69	13.30	3496	3396.49	98.91	0.60
A	SED	2	7520			0.99	7.27	25.88	51.56	38.56	13.00	4165	4045.03	119.33	0.65
A	SED	2	7119			0.88	7.35	24.34	45.62	32.22	13.40	3333	3229.89	102.64	0.47
A	SED	2	6536			1.16	7.26	25.93	53.09	39.99	13.10	4399	4295.34	102.20	1.47
A	SED	2	6057			1.10	7.26	25.13	47.28	34.08	13.20	4003	3891.29	111.16	0.55
A	SED	2	5735			1.05	7.27	24.22	49.25	35.95	13.30	3643	3534.94	107.66	0.40
A	SED	2	5418			1.02	7.35	25.53	49.87	36.27	13.60	3810	3694.95	113.05	2.00
A	SED	2	6860			1.02	7.26	25.50	51	37.30	13.70	3962	3863.56	96.62	1.82
A	SED	2	5835			0.98	7.27	27.83	57.8	44.40	13.40	4796	4683.49	108.91	3.60
A	SED	2	8300			0.86	7.26	27.37	52.89	38.99	13.90	4346	4223.45	121.00	1.56
A	SED	2	7115	467	533	0.99	7.26	25.48	52.92	39.02	13.90	4329	4212.51	114.03	2.46
A	SED	2	4906			0.96	7.26	24.76	49.48	35.48	14.00	3825	3715.10	107.97	1.93
A	SED	2	6517	467	533	1.08	7.3	26.22	52.21	38.21	14.00	4072	3921.96	148.15	1.89
A	SED	2	6742			1.07	7.2	25.08	47.91	34.11	13.80	3661	3525.61	133.90	1.49
A	SED	2	4504	467	533	1.03	7.26	24.21	44.41	30.71	13.70	3849	3733.26	114.49	1.25
A	SED	2	6669	477	523	0.99	7.19	24.25	46.23	32.53	13.70	3690	3578.92	109.78	1.29
A	SED	2	6664	467	523	1.03	7.14	19.54	47.95	34.50	13.45	3634	3514.72	117.89	1.39
A	SOIL	2				0.59	7.28	31.72	48.45	40.85	7.60	4306	4279.50	5.94	20.56
A	SOIL	2				0.76	7.19	31.03	46.97	38.97	8.00	4470	4444.33	5.29	20.38
A	SOIL	2				0.68	7.17	31.27	48.59	41.19	7.40	4445	4419.86	5.42	19.73
A	SOIL	2				0.72	7.2	31.14	47.08	39.98	7.10	4273	4255.53	8.50	8.96
A	SOIL	2				0.74	7.15	31.49	46.7	38.80	7.90	4062	4031.59	7.23	23.18
A	SOIL	2				0.77	7.17	30.53	44	36.70	7.30	4062	4033.69	6.84	21.47
A	SOIL	2				0.80	7.04	31.26	46.08	39.08	7.00	4029	4004.49	7.57	16.94
A	SOIL	2		408	592	0.77	7.05	31.41	46.58	39.68	6.90	4380	4354.79	6.74	18.47
A	SOIL	2				0.55	7.05	26.52	47.33	40.63	6.70	4518	4491.07	6.96	19.97
A	SOIL	2				0.77	7.3	30.69	47.53	40.43	7.10	4537	4501.46	9.45	26.10
A	SOIL	2		380	620	0.69	7.3	31.16	49.84	42.24	7.60	4582	4557.38	8.89	15.73
A	SOIL	2				0.79	7.28	30.67	48.55	40.85	7.70	4598	4557.23	8.59	32.18
A	SOIL	2				0.71	7.31	30.25	48.89	41.59	7.30	4507	4470.45	8.98	27.57
A	SOIL	2		402	598	0.54	7.28	30.75	47.02	39.32	7.70	4305	4279.82	10.09	15.09
A	SOIL	2		397	603	0.67	7.33	30.07	44.95	38.25	6.70	4332	4304.04	7.41	20.55
A	SOIL	2				0.62	7.35	30.19	46.99	39.89	7.10	4491	4475.05	8.02	7.94
A	SOIL	2		367	633	0.76	7.3	30.23	48.45	40.95	7.50	4477	4442.95	9.24	24.81

Table 10 (continued)

Location	Type	Set	Olsen P (mg kg^{-1})	Water Soluble P (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	DRO (µg g^{-1})	As	B	Ba	Bi	Cd	Co	Cr	Cu	Ga
							mg kg^{-1}								
A	SED	2	30.80	3.99	1503.86	40.3									
A	SED	2	29.43	3.49	1781.50	55									
A	SED	2	31.45	2.48	1712.74	52.4									
A	SED	2	30.66	3.57	1739.21										
A	SED	2	31.80	3.52	1521.55										
A	SED	2	29.39	2.72	1551.96										
A	SED	2	30.36	3.75	1784.33										
A	SED	2	28.76	3.64	2147.26										
A	SED	2	36.59	2.67	3156.23										
A	SED	2	38.83	3.97	2091.88										
A	SED	2	36.60	3.63	1949.47		7.3	16.0	181	0.2	0.7	9.9	31.0	24.4	5.0
A	SED	2	34.81	2.80	2066.29										
A	SED	2	34.93	2.74	3338.34		6.7	15.0	175	0.2	0.5	9.5	27.0	24.5	5.0
A	SED	2	32.25	2.25	2750.00										
A	SED	2	31.14	3.16	2099.67		6.4	18.0	173	0.2	0.6	9.7	31.0	22.6	5.0
A	SED	2	35.82	2.84	2058.96		6.8	15.0	184	0.2	0.5	10.1	27.0	24.3	5.0
A	SED	2	31.64	3.18	2819.61		6.7	16.0	182	0.2	0.6	10.1	30.0	23.2	4.0
A	SOIL	2	30.27	4.24	476.59	4.08									
A	SOIL	2	36.55	4.03	448.40	0									
A	SOIL	2	31.28	5.63	425.45	0									
A	SOIL	2	31.51	3.61	416.78										
A	SOIL	2	25.46	4.73	373.82										
A	SOIL	2	28.42	2.95	447.23										
A	SOIL	2	19.59	5.09	439.94										
A	SOIL	2	23.85	4.72	484.85		6.9	19.0	182	0.3	0.6	10.4	30.0	27.3	5.0
A	SOIL	2	25.73	5.33	360.40										
A	SOIL	2	21.46	5.33	574.09										
A	SOIL	2	22.95	4.27	489.55		6.6	19.0	185	0.3	0.7	10.8	44.0	27.0	5.0
A	SOIL	2	20.57	3.81	566.74										
A	SOIL	2	23.05	3.62	344.03										
A	SOIL	2	24.89	4.24	442.77		6.4	22.0	1.82	0.2	0.6	10.2	27.0	24.6	5.0
A	SOIL	2	17.30	4.51	361.06		6.2	17.0	181	0.2	0.6	10.2	31.0	25.8	4.0
A	SOIL	2	20.87	5.75	388.27										
A	SOIL	2	19.49	3.71	460.40		6.5	19.0	182	0.2	0.5	10.4	27.0	25.9	5.0

Table 10 (continued)

Location	Type	Set	Hg ($ng\ g^{-1}$)	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Ti	U	V	Zn
				mg kg^{-1}											
A	SED	2	54.85												
A	SED	2	43.94												
A	SED	2	51.74												
A	SED	2	39.67												
A	SED	2	42.13												
A	SED	2	35.52												
A	SED	2	49.51												
A	SED	2	37.09												
A	SED	2	46.27												
A	SED	2	39.03												
A	SED	2	38.78	20.0	844	0.8	26.8	12.8	0.3	3.4	56.0	0.3	1.6	52.0	88.0
A	SED	2	42.15												
A	SED	2	39.95	19.0	765	0.6	26.8	12.6	0.3	3.4	56.0	0.3	1.5	51.0	88.0
A	SED	2	39.23												
A	SED	2	40.12	19.0	806	0.7	26.4	12.7	0.3	3.3	57.0	0.3	1.6	49.0	83.0
A	SED	2	39.99	20.0	833	0.5	27.9	13.0	0.3	3.6	57.0	0.3	1.6	52.0	85.0
A	SED	2	49.18	19.0	872	0.8	26.6	12.9	0.3	3.5	57.0	0.3	1.6	47.0	87.0
A	SOIL	2	52.38												
A	SOIL	2	52.14												
A	SOIL	2	49.37												
A	SOIL	2	53.40												
A	SOIL	2	47.93												
A	SOIL	2	48.45												
A	SOIL	2	43.44												
A	SOIL	2	63.83	20.0	936	0.4	30.2	20.4	0.3	3.5	46.0	0.3	1.4	53.0	104
A	SOIL	2	56.39												
A	SOIL	2	46.94												
A	SOIL	2	45.37	21.0	965	1.3	29.0	16.8	0.3	3.5	48.0	0.3	1.4	56.0	99.0
A	SOIL	2	57.91												
A	SOIL	2	47.19												
A	SOIL	2	46.93	20.0	875	0.4	27.3	16.5	0.3	3.2	45.0	0.3	1.4	52.0	90.0
A	SOIL	2	45.64	20.0	842	0.7	26.5	16.8	0.3	3.2	42.0	0.3	1.4	51.0	87.0
A	SOIL	2	44.99												
A	SOIL	2	52.77	20.0	910	0.4	27.4	17.0	0.3	3.3	46.0	0.3	1.4	50.0	92.0

Table 10 (continued)

Location	Type	Set	Dry Sed ($g\ m^{-2}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	CEC ($cmol_{(+)}\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	Inorganic C ($g\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Organic N ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
A	SED	3	6972			1.13	7.16	22.71	45.51	34.71	10.80	3375	3319.27	52.63	3.10
A	SED	3	8761			1.05	7.3	23.05	41.12	30.92	10.20	2654	2595.82	55.44	2.74
A	SED	3	8332			1.17	7.35	23.63	40.7	30.20	10.50	2818	2757.67	58.86	1.48
A	SED	3	9815			1.02	7.36	21.74	41.45	30.75	10.70	2899	2837.47	57.69	3.84
A	SED	3	7928			1.10	7.4	21.42	39.12	28.32	10.80	2701	2634.23	65.51	1.27
A	SED	3	9581			1.18	7.43	22.75	40.8	29.80	11.00	2765	2701.20	61.55	2.25
A	SED	3	9625			0.87	7.42	22.10	38.56	27.96	10.60	2508	2453.50	51.85	2.65
A	SED	3	9283			1.33	7.39	22.69	39.29	29.39	9.90	2648	2602.45	39.85	5.69
A	SED	3	7327			1.46	7.43	22.78	38.09	29.19	8.90	2424	2366.75	55.74	1.51
A	SED	3	5734			1.09	7.48	22.57	41.49	31.99	9.50	2926	2888.51	32.72	4.78
A	SED	3	8521			1.14	7.46	22.16	37.74	27.84	9.90	2467	2420.52	44.75	1.73
A	SED	3	9551	437	563	1.29	7.45	22.36	39.12	28.62	10.50	2397	2349.47	42.18	5.36
A	SED	3	7942	437	563	0.98	7.43	21.10	35.95	25.55	10.40	2691	2640.10	48.12	2.78
A	SED	3	7240			1.24	7.38	0.19	43.54	32.44	11.10	3429	3382.73	41.55	4.72
A	SED	3	7852	447	553	1.15	7.4	22.43	38.62	27.42	11.20	2550	2494.17	52.79	3.04
A	SED	3	10682	447	553	0.78	7.46	23.72	40.67	29.47	11.20	2712	2644.47	64.38	3.15
A	SED	3	7312	437	563	1.39	7.42	22.96	38.91	27.11	11.80	2591	2536.84	52.09	2.07
A	SOIL	3				0.50	7.57	22.92	40.15	27.75	12.40	2844	2823.64	6.55	13.81
A	SOIL	3				0.60	7.55	22.94	41.25	29.15	12.10	3224	3201.91	6.51	15.58
A	SOIL	3				0.74	7.56	26.92	38.86	26.66	12.20	3177	3152.16	7.94	16.91
A	SOIL	3				0.62	7.56	28.20	42.15	29.65	12.50	3442	3420.95	6.48	14.56
A	SOIL	3				0.64	7.58	26.69	40.34	28.14	12.20	3152	3131.03	6.04	14.93
A	SOIL	3				0.57	7.54	27.03	41.43	29.53	11.90	3304	3283.33	6.71	13.96
A	SOIL	3		410	590	0.61	7.54	27.32	41.87	29.77	12.10	3150	3127.78	6.24	15.98
A	SOIL	3				0.62	7.57	27.34	40.28	27.98	12.30	3074	3055.42	4.73	13.85
A	SOIL	3				0.46	7.5	27.21	42.63	30.03	12.60	3545	3522.54	5.54	16.92
A	SOIL	3				0.42	7.47	27.55	41.98	29.68	12.30	3267	3245.00	6.41	15.59
A	SOIL	3		413	587	0.42	7.47	27.13	43.12	30.52	12.60	3549	3527.51	5.79	15.70
A	SOIL	3				0.48	7.5	27.24	41.33	28.43	12.90	3354	3335.16	4.37	14.47
A	SOIL	3				0.59	7.57	24.80	41.14	28.44	12.70	3315	3293.13	5.12	16.75
A	SOIL	3				0.63	7.58	26.56	40.61	27.41	13.20	3016	2996.25	5.90	13.85
A	SOIL	3		423	577	0.65	7.57	26.47	41.85	28.65	13.20	3393	3368.82	5.97	18.21
A	SOIL	3		421	579	0.46	7.48	27.30	43.58	30.58	13.00	3167	3144.08	6.18	16.74
A	SOIL	3		423	577	0.77	7.47	25.53	41.72	28.32	13.40	3300	3271.24	7.35	21.42

Table 10 (continued)

Location	Type	Set	Olsen P (mg kg^{-1})	Water Soluble P (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	DRO (µg g^{-1})	As	B	Ba	Bi	Cd	Co	Cr	Cu	Ga
											mg kg^{-1}				
A	SED	3	16.41	1.82	5171.46	21.3									
A	SED	3	20.73	1.93	4893.66	16.6									
A	SED	3	17.66	2.47	3556.61	16.3									
A	SED	3	20.35	1.97	3794.28										
A	SED	3	14.43	2.28	3332.17										
A	SED	3	13.40	1.84	4316.44										
A	SED	3	37.67	2.19	3275.58										
A	SED	3	35.08	2.20	4341.76										
A	SED	3	32.28	1.91	4697.78										
A	SED	3	33.25	2.40	4523.93										
A	SED	3	35.35	2.10	3250.75										
A	SED	3	31.25	2.60	3881.62		7.2	16.0	173	0.2	0.5	9.9	30.0	21.7	4.0
A	SED	3	28.28	1.39	3507.37		6.4	15.0	168	0.2	0.5	9.3	24.0	21.8	4.0
A	SED	3	32.93	1.74	5341.28										
A	SED	3	27.16	1.40	4768.16		6.6	14.0	173	0.2	0.6	9.8	30.0	22.5	4.0
A	SED	3	28.87	1.82	3058.29		7.0	14.0	174	0.2	0.5	10.4	26.0	25.3	4.0
A	SED	3	33.75	2.43	4700.01		7.0	15.0	167	0.2	0.4	10.6	29.0	21.4	4.0
A	SOIL	3	28.88	3.45	352.22	0									
A	SOIL	3	29.53	3.47	359.92	0									
A	SOIL	3	29.57	2.32	458.05	0									
A	SOIL	3	30.52	2.54	324.80										
A	SOIL	3	29.74	3.01	353.55										
A	SOIL	3	24.99	2.92	314.98										
A	SOIL	3	29.42	3.29	375.60		6.2	15.0	180	0.3	5.0	10.4	25.0	23.5	4.0
A	SOIL	3	29.76	4.64	324.80										
A	SOIL	3	23.12	4.74	456.35										
A	SOIL	3	27.53	4.31	426.55										
A	SOIL	3	25.37	5.48	285.38		5.5	14.0	165	0.2	0.6	9.8	26.0	22.7	4.0
A	SOIL	3	22.50	5.39	339.56										
A	SOIL	3	25.58	5.51	335.91										
A	SOIL	3	24.10	4.19	365.72										
A	SOIL	3	29.06	3.29	375.39		6.1	14.0	174	0.2	0.5	9.8	23.0	22.7	4.0
A	SOIL	3	19.33	3.61	354.37		59.0	14.0	168	0.2	0.5	10.0	28.0	24.6	4.0
A	SOIL	3	17.94	2.81	624.72		5.3	16.0	170	0.2	0.4	9.6	23.0	23.7	4.0

Table 10 (continued)

Location	Type	Set	Hg (ng g^{-1})	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Ti	U	V	Zn
				mg kg^{-1}											
A	SED	3	42.24												
A	SED	3	41.10												
A	SED	3	43.95												
A	SED	3	42.64												
A	SED	3	40.89												
A	SED	3	39.60												
A	SED	3	39.23												
A	SED	3	42.86												
A	SED	3	42.42												
A	SED	3	51.57												
A	SED	3	46.54												
A	SED	3	49.78	19.0	850	0.7	25.8	12.5	0.3	3.6	58.0	0.3	1.6	48.0	72.0
A	SED	3	59.90	18.0	718	0.4	24.5	11.9	0.3	3.2	54.0	0.2	1.4	48.0	78.0
A	SED	3	56.43												
A	SED	3	45.86	18.0	785	0.8	26.5	11.7	0.3	3.2	58.0	0.3	1.5	45.0	72.0
A	SED	3	49.95	19.0	826	0.5	28.2	12.6	0.3	3.7	58.0	0.3	1.5	48.0	79.0
A	SED	3	41.72	18.0	883	0.8	27.4	11.9	0.3	3.2	56.0	0.3	1.5	47.0	77.0
A	SOIL	3	49.34												
A	SOIL	3	47.73												
A	SOIL	3	47.24												
A	SOIL	3	47.35												
A	SOIL	3	44.38												
A	SOIL	3	51.34												
A	SOIL	3	49.42	19.0	850	0.5	28.1	13.2	0.3	3.5	51.0	0.3	1.4	50.0	86.0
A	SOIL	3	48.73												
A	SOIL	3	44.29												
A	SOIL	3	47.35												
A	SOIL	3	55.16	18.0	785	0.8	26.6	12.5	0.3	3.1	50.0	0.2	1.3	41.0	79.0
A	SOIL	3	53.63												
A	SOIL	3	53.56												
A	SOIL	3	45.60												
A	SOIL	3	50.71	18.0	815	0.5	26.5	12.7	0.3	3.3	51.0	0.3	1.4	43.0	85.0
A	SOIL	3	49.28	19.0	767	0.8	28.0	13.2	0.3	3.3	53.0	0.3	1.3	43.0	88.0
A	SOIL	3	49.01	19.0	694	0.5	26.0	14.4	0.3	3.6	51.0	0.3	1.5	47.0	82.0

APPENDIX C

Table 11. Data for all variables for sediment (SED) and soil (SOIL) (0-10cm) from location B along the Red River of the North near Fargo, North Dakota.

Location	Type	Set	Dry Sed ($g\ m^{-2}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	CEC ($cmol_{(+)}\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	Inorganic C ($g\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Organic N ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
B	SED	1	1570			1.15	7.27	27.43	57.98	46.08	11.90	3274	3221.95	50.98	1.07
B	SED	1	4572			0.90	7.28	27.69	59.08	48.48	10.60	3561	3489.77	70.68	0.55
B	SED	1	2571			0.87	7.21	28.51	61.08	49.28	11.80	3705	3625.27	78.96	0.78
B	SED	1	5147			0.82	7.28	26.00	57.95	46.05	11.90	3604	3533.80	69.13	1.08
B	SED	1	5153			1.03	7.19	24.49	53.46	40.66	12.80	3140	3089.91	48.05	2.04
B	SED	1	2918			0.95	7.22	26.72	60.84	48.74	12.10	3739	3674.14	63.99	0.87
B	SED	1	5063			0.91	7.26	26.90	68.11	56.01	12.10	4148	4068.71	78.59	0.69
B	SED	1	5157			1.12	7.22	26.90	64.02	51.82	12.20	3308	3246.93	60.34	0.73
B	SED	1	3399			0.78	7.35	26.99	62.5	51.00	11.50	4572	4514.92	56.00	1.07
B	SED	1	9079			1.00	7.26	24.82	57.08	44.58	12.50	3215	3163.64	50.76	0.59
B	SED	1	7299	394	606	0.97	7.25	23.45	50.69	37.89	12.80	3023	2968.54	54.19	0.27
B	SED	1	4683			1.03	7.26	22.13	53.43	40.43	13.00	3204	3159.84	43.47	0.69
B	SED	1	6878	389	611	1.14	7.26	21.93	50.77	37.37	13.40	2617	2570.65	45.39	0.97
B	SED	1	6320	355	645	1.11	7.27	21.98	47.41	33.71	13.70	2388	2354.72	32.92	0.36
B	SED	1	2428			0.93	7.35	22.81	49.36	35.36	14.00	2727	2689.70	36.46	0.84
B	SED	1	5487	368	632	1.04	7.31	22.09	58.54	44.84	13.70	3148	3110.21	36.58	1.21
B	SED	1	6512	420	580	0.92	7.4	23.43	56.4	43.05	13.35	3079	3039.37	39.07	0.57
B	SOIL	1				0.64	7.39	32.86	60.92	52.22	8.70	4832	4808.83	3.33	19.85
B	SOIL	1				0.61	7.37	29.39	53.25	43.25	10.00	4183	4160.89	3.42	18.69
B	SOIL	1				0.69	7.33	29.89	55.08	44.88	10.20	4054	4017.82	6.76	29.42
B	SOIL	1				0.62	7.34	29.60	54.02	43.92	10.10	4147	4123.33	3.94	19.73
B	SOIL	1				0.74	7.32	30.46	66.02	55.82	10.20	4542	4523.86	5.77	12.37
B	SOIL	1				0.58	7.34	29.19	55.66	45.86	9.80	4314	4290.82	3.99	19.19
B	SOIL	1				0.70	7.29	29.76	64.71	54.71	10.00	4783	4747.11	6.84	29.06
B	SOIL	1				0.73	7.27	30.75	63.3	51.90	11.40	4977	4939.72	6.46	30.82
B	SOIL	1				0.71	7.25	31.35	57.97	48.57	9.40	4688	4656.41	6.77	24.83
B	SOIL	1				0.68	7.26	29.77	58.61	47.71	10.90	4585	4556.94	4.80	23.26
B	SOIL	1				0.66	7.31	29.55	63.74	52.54	11.20	4786	4758.98	7.22	19.80
B	SOIL	1		346	654	0.64	7.31	29.68	59.55	48.95	10.60	4634	4611.26	4.63	18.11
B	SOIL	1				0.75	7.32	28.70	57.53	46.53	11.00	4381	4347.70	4.74	28.56
B	SOIL	1		359	641	0.60	7.36	28.34	56.29	44.79	11.50	4524	4503.75	4.93	15.32
B	SOIL	1		346	654	0.75	7.27	28.27	58.82	47.72	11.10	4542	4502.86	7.23	31.92
B	SOIL	1		353	647	0.59	7.32	28.07	52.3	41.70	10.60	4340	4322.10	4.00	13.90
B	SOIL	1		348	652	0.65	7.28	28.27	64.81	53.66	11.15	4927	4899.02	5.59	22.39

Table 11 (continued)

Location	Type	Set	Olsen P (mg kg^{-1})	Water Soluble P (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	DRO (µg g^{-1})	As	B	Ba	Bi	Cd	Co	Cr	Cu	Ga
							mg kg^{-1}								
B	SED	1	28.26	2.98	5489.62	51.2									
B	SED	1	27.23	4.24	2841.88	48.4									
B	SED	1	29.55	5.21	3022.22	47.4									
B	SED	1	27.95	5.14	3387.45										
B	SED	1	25.96	1.72	4408.61										
B	SED	1	23.87	4.90	3830.50										
B	SED	1	31.63	3.36	2918.47										
B	SED	1	27.07	1.65	3581.98										
B	SED	1	27.35	4.40	1209.84										
B	SED	1	20.70	1.79	3199.46										
B	SED	1	21.72	2.43	4626.33		7.4	15.0	186	0.2	0.5	9.3	28.0	21.8	4.0
B	SED	1	25.77	2.84	3829.04										
B	SED	1	20.12	1.30	4330.17		7.5	15.0	186	0.3	0.4	9.7	24.0	23.2	3.0
B	SED	1	19.63	1.11	4457.35		6.7	16.0	186	0.3	0.5	9.1	31.0	20.9	3.0
B	SED	1	27.28	2.46	3627.85										
B	SED	1	23.59	1.82	1767.60		6.9	18.0	191	0.2	0.4	8.9	24.0	21.8	4.0
B	SED	1	22.00	1.88	3339.38		7.2	15.0	195	0.2	0.5	9.3	39.0	22.4	3.0
B	SOIL	1	10.88	1.71	362.53	14.6									
B	SOIL	1	6.95	0.76	243.33	11.2									
B	SOIL	1	8.06	0.66	309.48	10.4									
B	SOIL	1	6.42	0.85	325.04										
B	SOIL	1	9.85	2.43	842.54										
B	SOIL	1	6.92	1.29	262.45										
B	SOIL	1	11.31	2.34	404.17										
B	SOIL	1	11.60	2.54	388.75										
B	SOIL	1	10.83	2.12	439.29										
B	SOIL	1	13.19	3.78	486.38										
B	SOIL	1	13.17	2.31	437.57										
B	SOIL	1	11.14	1.58	578.36		6.4	18.0	204	0.3	0.5	9.0	22.0	23.6	3.0
B	SOIL	1	13.77	2.31	658.96										
B	SOIL	1	10.33	1.19	259.08		6.3	16.0	203	0.2	0.6	9.1	40.0	22.3	3.0
B	SOIL	1	11.52	2.04	445.85		6.5	17.0	210	0.2	0.5	9.4	23.0	22.4	4.0
B	SOIL	1	6.54	0.80	208.19		6.9	17.0	2.03	0.3	0.5	9.1	32.0	22.1	4.0
B	SOIL	1	12.70	2.25	302.77		6.3	16.0	210	0.3	0.5	9.0	21.0	23.6	3.0

Table 11 (continued)

Location	Type	Set	Hg (ng g^{-1})	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Ti	U	V	Zn
				mg kg^{-1}											
B	SED	1	59.09												
B	SED	1	51.89												
B	SED	1	55.24												
B	SED	1	57.35												
B	SED	1	57.18												
B	SED	1	53.71												
B	SED	1	53.84												
B	SED	1	59.47												
B	SED	1	62.86												
B	SED	1	63.04												
B	SED	1	66.08	17.0	765	0.9	24.5	28.0	0.4	2.9	67.0	0.2	1.5	40.0	87.0
B	SED	1	59.58												
B	SED	1	55.71	16.0	728	0.8	24.7	33.8	0.4	2.9	68.0	0.2	1.5	40.0	89.0
B	SED	1	81.18	16.0	719	1.0	23.0	29.7	0.4	2.8	65.0	0.2	1.4	40.0	85.0
B	SED	1	66.64												
B	SED	1	65.12	17.0	745	0.7	23.4	27.9	0.4	2.7	69.0	0.2	1.5	42.0	82.0
B	SED	1	82.15	16.0	732	1.7	23.7	37.1	0.4	2.6	72.0	0.2	1.4	37.0	98.0
B	SOIL	1	86.86												
B	SOIL	1	67.95												
B	SOIL	1	73.50												
B	SOIL	1	72.33												
B	SOIL	1	83.99												
B	SOIL	1	82.31												
B	SOIL	1	83.20												
B	SOIL	1	79.85												
B	SOIL	1	77.97												
B	SOIL	1	76.05												
B	SOIL	1	81.22												
B	SOIL	1	97.05	17.0	846	0.6	24.4	27.3	0.4	2.3	60.0	0.3	1.4	39.0	84.0
B	SOIL	1	74.19												
B	SOIL	1	90.93	17.0	836	1.6	23.1	25.7	0.4	2.3	57.0	0.3	1.4	38.0	81.0
B	SOIL	1	78.92	18.0	856	0.5	24.4	25.6	0.3	2.5	55.0	0.3	1.4	41.0	84.0
B	SOIL	1	78.94	18.0	873	0.9	23.9	27.2	0.3	2.6	57.0	0.3	1.4	44.0	85.0
B	SOIL	1	97.38	16.0	853	0.5	22.6	35.7	0.4	2.2	62.0	0.2	1.5	37.0	94.0

Table 11 (continued)

Location	Type	Set	Dry Sed ($g\ m^{-2}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	CEC ($cmol_{(+)}\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	Inorganic C ($g\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Organic N ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
B	SED	2	6298			1.21	7.25	23.80	45.52	32.12	13.40	2565	2540.35	23.99	0.66
B	SED	2	7232			1.55	7.25	22.18	47.47	34.27	13.20	2764	2741.26	22.04	0.71
B	SED	2	7204			1.21	7.29	22.63	47.77	34.67	13.10	3006	2982.81	22.88	0.31
B	SED	2	8463			1.21	7.36	22.60	47.06	33.86	13.20	2922	2897.47	24.14	0.40
B	SED	2	5662			1.25	7.36	20.41	40.16	26.26	13.90	2160	2142.08	17.61	0.31
B	SED	2	8929			1.20	7.37	22.74	45.82	32.32	13.50	2705	2678.57	26.03	0.39
B	SED	2	9311			0.98	7.37	21.23	42.39	28.59	13.80	2458	2436.84	20.98	0.18
B	SED	2	10273			0.96	7.35	21.42	41.58	27.58	14.00	2283	2257.65	25.24	0.11
B	SED	2	7267			1.07	7.36	21.48	40.73	27.13	13.60	2207	2182.00	24.69	0.31
B	SED	2	12935			1.15	7.38	22.91	52.01	38.31	13.70	2963	2932.86	29.56	0.58
B	SED	2	12490			0.84	7.44	22.54	42.94	29.34	13.60	2233	2207.34	25.42	0.23
B	SED	2	8126			0.92	7.42	21.25	45.27	33.57	11.70	2266	2244.53	21.21	0.26
B	SED	2	11985	428	572	1.03	7.37	22.57	42.35	28.85	13.50	2267	2244.28	22.42	0.31
B	SED	2	13820	408	592	0.91	7.37	23.27	55.05	41.35	13.70	2773	2743.85	27.22	1.93
B	SED	2	11369	400	600	0.98	7.36	22.76	48.09	35.99	12.10	2246	2213.77	30.23	2.00
B	SED	2	8198	400	600	0.88	7.36	22.69	46.4	32.60	13.80	2690	2661.33	27.00	1.68
B	SED	2	9004	418	582	1.03	7.28	23.41	53.04	39.69	13.35	3401	3370.26	29.24	1.51
B	SOIL	2				0.66	7.15	28.40	49.22	36.62	12.60	3265	3246.60	4.29	14.12
B	SOIL	2				0.66	7.21	29.97	45.56	33.16	12.40	3150	3134.51	3.46	12.03
B	SOIL	2				0.54	7.2	30.83	49.14	37.04	12.10	3570	3556.79	1.83	11.38
B	SOIL	2				0.54	7.27	30.84	44.36	32.26	12.10	3115	3100.86	3.55	10.58
B	SOIL	2				0.54	7.26	30.36	51.01	37.81	13.20	3506	3486.52	3.88	15.60
B	SOIL	2				0.61	7.26	30.22	49.62	36.72	12.90	3235	3214.25	3.58	17.17
B	SOIL	2				0.63	7.29	29.83	51.3	38.00	13.30	3478	3460.58	3.14	14.28
B	SOIL	2				0.61	7.27	29.15	49.61	35.71	13.90	3695	3676.98	3.51	14.51
B	SOIL	2				0.59	7.3	29.17	48.1	34.70	13.40	3293	3276.32	3.35	13.34
B	SOIL	2				0.58	7.32	30.08	48.61	35.21	13.40	3447	3428.94	3.33	14.73
B	SOIL	2		405	595	0.63	7.33	30.44	48.56	35.46	13.10	3146	3125.76	4.40	15.84
B	SOIL	2				0.62	7.28	31.01	48.13	35.63	12.50	3634	3616.85	3.72	13.43
B	SOIL	2		400	600	0.62	7.31	28.41	50.83	37.33	13.50	3437	3417.81	4.12	15.07
B	SOIL	2		398	602	0.62	7.34	27.64	51.8	37.90	13.90	3358	3336.76	5.03	16.21
B	SOIL	2				0.75	7.33	29.05	50.54	36.54	14.00	3324	3298.71	5.59	19.70
B	SOIL	2		395	605	0.66	7.35	26.04	50.76	36.56	14.20	3385	3364.20	3.47	17.33
B	SOIL	2		361	635	0.66	7.32	26.36	51.22	36.57	14.65	3949	3923.63	7.46	17.90

Table 11 (continued)

Location	Type	Set	Olsen P ($mg\ kg^{-1}$)	Water Soluble P ($mg\ kg^{-1}$)	SO_4^{2-} ($mg\ kg^{-1}$)	DRO ($\mu g\ g^{-1}$)	As	B	Ba	Bi	Cd	Co	Cr	Cu	Ga
							$mg\ kg^{-1}$								
B	SED	2	18.74	0.83	3028.80	29.8									
B	SED	2	22.68	0.93	4023.25	34.9									
B	SED	2	19.48	0.23	3206.91	0									
B	SED	2	17.78	0.50	3969.57										
B	SED	2	18.70	0.30	5032.20										
B	SED	2	19.02	0.10	3942.26										
B	SED	2	18.24	0.72	3296.03										
B	SED	2	17.26	0.89	3198.58										
B	SED	2	17.85	0.85	3637.88										
B	SED	2	18.53	0.93	4092.80										
B	SED	2	20.03	0.78	2082.56										
B	SED	2	16.40	0.92	2107.33										
B	SED	2	16.79	0.65	3394.93		8.0	12.0	203	0.3	0.6	10.7	28.0	24.6	3.0
B	SED	2	15.57	0.72	3178.99		8.8	15.0	206	0.3	0.6	11.3	25.0	27.7	3.0
B	SED	2	16.19	1.69	3398.50		8.6	15.0	201	0.3	0.6	10.7	32.0	26.9	4.0
B	SED	2	13.80	0.72	2088.96		7.1	16.0	194	0.2	0.4	9.3	24.0	22.2	4.0
B	SED	2	15.50	0.89	3583.47		6.5	12.0	186	0.2	0.5	8.8	26.0	21.5	3.0
B	SOIL	2	12.41	2.55	500.29	0									
B	SOIL	2	10.76	2.65	356.67	4.34									
B	SOIL	2	13.72	3.12	325.81	5.26									
B	SOIL	2	11.51	2.51	292.80										
B	SOIL	2	15.42	2.53	373.19										
B	SOIL	2	14.17	3.20	219.79										
B	SOIL	2	20.49	3.66	330.97										
B	SOIL	2	16.67	4.39	311.82										
B	SOIL	2	12.32	2.72	289.28										
B	SOIL	2	18.41	4.70	290.73										
B	SOIL	2	18.17	4.52	293.71		7.2	15.0	203	0.3	0.5	9.0	22.0	23.5	3.0
B	SOIL	2	12.71	4.99	244.55										
B	SOIL	2	20.09	5.06	292.74		6.8	16.0	204	0.2	0.5	9.2	27.0	23.0	4.0
B	SOIL	2	17.29	4.27	295.51		6.2	17.0	206	0.2	0.5	9.2	24.0	23.5	4.0
B	SOIL	2	16.96	3.45	357.91										
B	SOIL	2	17.89	4.25	273.12		5.4	15.0	211	0.3	0.5	8.5	27.0	22.8	4.0
B	SOIL	2	16.87	4.56	484.94		6.4	17.0	245	0.3	0.6	9.0	24.0	27.0	4.0

Table 11 (continued)

Location	Type	Set	Hg (ng g^{-1})	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Ti	U	V	Zn
				mg kg^{-1}											
B	SED	2	55.33												
B	SED	2	65.39												
B	SED	2	46.52												
B	SED	2	59.27												
B	SED	2	69.36												
B	SED	2	67.72												
B	SED	2	61.02												
B	SED	2	73.83												
B	SED	2	65.04												
B	SED	2	75.59												
B	SED	2	70.25												
B	SED	2	60.25												
B	SED	2	77.91	17.0	688	1.5	26.0	40.8	0.5	3.1	73.0	0.2	1.4	40.0	99.0
B	SED	2	88.87	17.0	676	0.8	27.4	43.9	0.6	3.2	71.0	0.2	1.6	43.0	107
B	SED	2	83.20	17.0	646	1.0	27.0	40.8	0.5	3.1	71.0	0.2	1.5	44.0	101
B	SED	2	70.98	17.0	649	0.06	24.5	25.8	0.4	3.2	67.0	0.3	1.5	43.0	87.0
B	SED	2	55.59	16.0	680	0.9	23.5	22.5	0.4	2.6	64.0	0.2	1.5	37.0	83.0
B	SOIL	2	72.13												
B	SOIL	2	69.97												
B	SOIL	2	67.40												
B	SOIL	2	67.27												
B	SOIL	2	74.45												
B	SOIL	2	73.11												
B	SOIL	2	65.49												
B	SOIL	2	84.12												
B	SOIL	2	76.01												
B	SOIL	2	96.20												
B	SOIL	2	79.05	17.0	845	0.5	24.2	22.8	0.3	2.7	61.0	0.3	1.5	39.0	81.0
B	SOIL	2	84.42												
B	SOIL	2	72.88	17.0	869	0.7	24.1	23.9	0.4	2.7	63.0	0.3	1.6	39.0	81.0
B	SOIL	2	79.66	17.0	854	0.5	23.9	23.0	0.3	3.0	65.0	0.3	1.5	43.0	80.0
B	SOIL	2	89.03												
B	SOIL	2	77.13	17.0	7.33	0.7	21.2	23.8	0.3	2.6	60.0	0.2	1.4	40.0	82.0
B	SOIL	2	89.50	19.0	838	0.5	25.1	32.4	0.4	2.8	78.0	0.3	1.6	45.0	100

Table 11 (continued)

Location	Type	Set	Dry Sed ($g\ m^{-2}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	CEC ($cmol_{(+)}\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	Inorganic C ($g\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Organic N ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
B	SED	3	6864			1.79	7.4	21.27	39.8	25.30	14.50	2375	2341.87	31.16	1.97
B	SED	3	8526			1.71	7.37	21.12	37.23	22.73	14.50	2025	1991.26	31.08	2.66
B	SED	3	11443			1.68	7.34	19.51	43.03	28.53	14.50	2604	2579.48	22.70	1.82
B	SED	3	9075			1.43	7.38	21.89	39.45	24.35	15.10	2289	2264.14	23.04	1.82
B	SED	3	7543			1.33	7.4	19.79	37.21	22.41	14.80	1925	1902.54	20.69	1.77
B	SED	3	11813			1.36	7.31	20.81	40.63	25.83	14.80	2289	2266.18	20.74	2.08
B	SED	3	11908	387	613	0.96	7.43	20.80	38.16	23.26	14.90	1760	1733.51	24.27	2.23
B	SED	3	1534			1.08	7.37	21.91	40.35	25.65	14.70	2094	2066.25	25.68	2.07
B	SED	3	12532			1.10	7.4	21.54	40.78	25.68	15.10	2127	2100.72	24.81	1.48
B	SED	3	10596	426	574	1.27	7.31	21.45	41.47	26.67	14.80	2484	2465.32	18.66	0.02
B	SED	3	9638			1.26	7.33	21.01	40.8	26.10	14.70	2244	2219.95	23.81	0.25
B	SED	3	11351			1.21	7.34	21.54	41.42	26.62	14.80	2092	2069.04	22.84	0.12
B	SED	3	12245			1.02	7.39	22.23	46.69	32.09	14.60	2661	2634.43	26.33	0.24
B	SED	3	13584	395	605	1.08	7.36	22.79	43.99	28.89	15.10	2459	2431.56	27.28	0.16
B	SED	3	9312			0.83	7.43	22.67	39.77	24.37	15.40	2376	2352.21	23.81	-0.02
B	SED	3	16638	418	582	1.03	7.35	22.26	43.95	28.95	15.00	2624	2594.65	29.16	0.20
B	SED	3	10888	370	630	0.79	7.42	23.08	41.25	26.35	14.90	2375	2344.63	30.52	-0.15
B	SOIL	3				0.71	7.44	26.95	46.15	32.55	13.60	3158	3141.05	2.88	14.07
B	SOIL	3				0.63	7.51	25.75	46.25	31.95	14.30	2674	2657.53	2.68	13.79
B	SOIL	3				0.69	7.47	22.69	46.56	32.46	14.10	2911	2895.22	2.46	13.32
B	SOIL	3				0.62	7.51	25.26	47.42	33.32	14.10	2925	2908.83	2.80	13.37
B	SOIL	3		420	580	0.68	7.47	24.85	47.37	32.97	14.40	2997	2976.67	2.46	17.87
B	SOIL	3		434	566	0.76	7.46	26.15	48.77	34.07	14.70	2966	2945.17	3.85	16.98
B	SOIL	3		426	574	0.67	7.49	25.43	49.3	34.70	14.60	3056	3035.32	3.52	17.16
B	SOIL	3				0.62	7.45	25.84	49.72	35.02	14.70	3133	3115.22	3.29	14.49
B	SOIL	3				0.69	7.43	26.52	46.67	31.57	15.10	2950	2930.11	3.17	16.72
B	SOIL	3				0.52	7.48	26.99	46.09	32.29	13.80	2675	2657.24	2.77	14.99
B	SOIL	3				0.63	7.44	26.19	46.98	32.68	14.30	2816	2797.08	2.57	16.35
B	SOIL	3		428	572	0.67	7.46	25.71	46.91	32.51	14.40	3003	2983.62	3.63	15.75
B	SOIL	3				0.50	7.47	27.54	46.69	33.09	13.60	3136	3121.61	2.53	11.86
B	SOIL	3				0.66	7.48	21.68	47.55	33.35	14.20	2970	2953.67	3.64	12.70
B	SOIL	3				0.55	7.44	25.55	47.31	32.31	15.00	2844	2829.74	3.18	11.08
B	SOIL	3				0.60	7.42	25.18	49.12	34.72	14.40	2925	2908.56	3.62	12.82
B	SOIL	3		413	587	0.50	7.49	25.01	45.54	31.04	14.50	2993	2977.97	3.46	11.57

Table 11 (continued)

Location	Type	Set	Olsen P (mg kg^{-1})	Water Soluble P (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	DRO (µg g^{-1})	As	B	Ba	Bi	Cd	Co	Cr	Cu	Ga
							mg kg^{-1}								
B	SED	3	17.02	0.80	9044.76	44.9									
B	SED	3	16.23	0.55	8381.38	42.9									
B	SED	3	13.18	0.38	8015.27	23.1									
B	SED	3	15.61	0.42	5627.68										
B	SED	3	18.94	0.77	5139.51										
B	SED	3	14.18	0.58	6248.88										
B	SED	3	16.04	0.84	3379.03		7.1	16.0	196	0.3	0.5	9.8	61.0	23.8	4.0
B	SED	3	13.61	0.58	3885.81										
B	SED	3	14.17	0.67	3835.68										
B	SED	3	16.49	0.60	4725.77		6.7	15.0	192	0.2	0.5	8.9	22.0	21.6	4.0
B	SED	3	15.76	0.72	5304.25										
B	SED	3	14.07	0.46	4620.38										
B	SED	3	22.56	1.06	2067.26										
B	SED	3	21.19	0.73	3320.28		6.8	15.0	189	0.2	0.5	9.6	41.0	23.0	4.0
B	SED	3	25.93	1.23	1349.39										
B	SED	3	17.67	0.59	3238.33		7.0	12.0	193	0.3	0.5	9.5	24.0	25.0	4.0
B	SED	3	17.73	0.67	1697.23		64.0	13.0	202	0.2	0.5	9.6	29.0	22.8	4.0
B	SOIL	3	21.30	2.01	449.54	4.34									
B	SOIL	3	18.45	2.49	475.93	5.12									
B	SOIL	3	15.20	1.36	448.18	0									
B	SOIL	3	16.90	2.28	359.07										
B	SOIL	3	24.07	2.78	424.80		6.0	14.0	186	0.2	0.6	9.3	24.0	23.8	4.0
B	SOIL	3	15.32	3.35	435.61		6.2	13.0	192	0.3	0.6	8.7	26.0	23.8	4.0
B	SOIL	3	26.43	3.93	593.52		6.1	16.0	195	0.3	0.6	9.6	24.0	24.1	4.0
B	SOIL	3	18.79	2.62	582.73										
B	SOIL	3	22.55	2.80	555.28										
B	SOIL	3	23.07	3.63	360.63										
B	SOIL	3	21.90	3.03	468.53										
B	SOIL	3	23.45	2.96	530.60		6.5	15.0	194	0.3	0.4	9.4	29.0	24.7	4.0
B	SOIL	3	25.59	4.51	569.51										
B	SOIL	3	22.40	3.88	518.23										
B	SOIL	3	17.77	3.05	278.55										
B	SOIL	3	24.02	3.94	469.08										
B	SOIL	3	19.94	2.56	334.06		6.6	16.0	215	0.3	0.6	9.1	22.0	25.3	4.0

Table 11 (continued)

Location	Type	Set	Hg (ng g^{-1})	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Ti	U	V	Zn
				mg kg^{-1}											
B	SED	3	58.17												
B	SED	3	55.64												
B	SED	3	81.04												
B	SED	3	58.10												
B	SED	3	71.58												
B	SED	3	54.92												
B	SED	3	51.93	18.0	688	3.1	25.0	29.7	0.5	3.1	67.0	0.3	1.5	43.0	92.
B	SED	3	72.72												
B	SED	3	65.35												
B	SED	3	52.98	18.0	772	0.5	23.1	20.9	0.5	3.1	67.0	0.2	1.5	43.0	83.0
B	SED	3	52.89												
B	SED	3	49.04												
B	SED	3	62.83												
B	SED	3	51.62	18.0	878	1.6	23.9	22.1	0.3	2.9	67.0	0.3	1.5	43.0	84.0
B	SED	3	30.17												
B	SED	3	72.25	18.0	776	0.6	26.0	26.5	0.4	3.2	70.0	0.3	1.6	43.0	95.0
B	SED	3	94.73	18.0	726	0.9	23.4	23.0	0.3	3.1	67.0	0.2	1.5	40.0	84.0
B	SOIL	3	73.86												
B	SOIL	3	84.65												
B	SOIL	3	79.86												
B	SOIL	3	69.75												
B	SOIL	3	64.43	18.0	8.15	0.4	23.7	20.8	0.3	3.1	63.0	0.3	1.5	43.0	85.0
B	SOIL	3	78.46	18.0	813	0.6	24.0	24.0	0.3	2.8	64.0	0.3	1.4	42.0	85.0
B	SOIL	3	64.96	19.0	826	0.5	24.5	21.8	0.3	3.0	64.0	0.3	1.5	44.0	89.0
B	SOIL	3	93.21												
B	SOIL	3	76.48												
B	SOIL	3	68.19												
B	SOIL	3	56.87												
B	SOIL	3	64.63	19.0	827	0.8	25.1	20.5	0.3	3.1	63.0	0.3	1.5	46.0	87.0
B	SOIL	3	73.31												
B	SOIL	3	101.70												
B	SOIL	3	67.07												
B	SOIL	3	73.91												
B	SOIL	3	78.31	19.0	865	0.3	24.6	24.5	0.3	3.2	65.0	0.3	1.4	46.0	86.0

Table 12. Data for all variables for sediment (SED) and soil (SOIL) (0-10cm) from location C along the Red River of the North near Moorhead, Minnesota.

Location	Type	Set	Dry Sed ($g\ m^{-2}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	CEC ($cmol_{(+)}\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	Inorganic C ($g\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Organic N ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
C	SED	1	2149	497	503	1.40	7.19	31.33	52.23	43.03	9.20	4239	4106.88	129.19	2.93
C	SED	1	1769	484	517	1.35	7.06	30.01	62.21	53.71	8.50	3970	3861.12	106.17	2.71
C	SED	1	1097			1.62	7.1	33.88	51.78	42.06	9.72	3963	3844.25	116.14	2.62
C	SED	1	2269	497	503	1.71	7.11	33.77	47.61	38.01	9.60	3647	3481.20	161.70	4.10
C	SED	1	2229	499	501	1.85	7.08	33.53	45.91	36.31	9.60	3702	3529.07	155.47	17.46
C	SED	1	2397			1.79	7.11	31.30	48.76	39.11	9.65	4208	4045.49	139.63	22.88
C	SED	1	2149			1.93	7.11	33.19	48.11	38.31	9.80	4122	3925.12	172.38	24.49
C	SED	1	1011			1.68	7.26	32.99	48.97	39.37	9.60	3990	3826.87	157.46	5.67
C	SED	1	3427			1.52	7.24	32.52	50.79	41.29	9.50	3862	3733.30	126.08	2.63
C	SED	1	2932			1.58	7.17	32.39	51.25	41.45	9.80	3941	3800.69	137.07	3.25
C	SED	1	2263			1.79	7.14	34.30	46.1	36.30	9.80	3507	3378.93	125.33	2.75
C	SED	1	2907			1.41	7.21	32.27	46.54	36.04	10.5	3599	3497.73	98.48	2.79
C	SED	1	1168			1.67	7.17	33.75	55.84	46.44	9.4	4148	4045.00	100.42	2.58
C	SED	1	2621	497	503	1.28	7.23	32.82	51.53	40.93	10.6	3759	3661.93	95.86	1.21
C	SED	1	2697			1.25	7.23	28.46	48.07	38.27	9.8	3636	3533.52	100.91	1.57
C	SED	1	1413			1.35	7.23	31.83	56.8	47.1	9.7	3936	3846.28	88.6	1.11
C	SED	1	2117			1.51	7.25	33.25	47.6	37.2	10.4	3522	3406.36	114.10	1.53
C	SOIL	1				0.66	7.41	32.52	40.98	36.78	4.2	3221	3188.11	15.9	16.99
C	SOIL	1				0.61	7.35	27.10	36.2	29.8	6.4	2607	2576.90	15.95	14.15
C	SOIL	1				0.75	7.29	29.18	44.29	37.58	6.71	3138	3097.83	17.76	22.41
C	SOIL	1				0.73	7.31	29.52	45.54	35.49	10.05	3374	3316.99	25.85	31.16
C	SOIL	1				0.58	7.21	29.75	49.08	38.58	10.5	3431	3362.13	29.83	39.04
C	SOIL	1				0.89	7.21	29.05	51.87	42.97	8.9	3474	3411.04	28.93	34.03
C	SOIL	1				1.04	7.17	29.07	52.21	43.21	9.0	3783	3702.49	25.63	54.88
C	SOIL	1				0.82	7.31	29.56	44.34	35.54	8.8	3268	3207.47	29.5	31.03
C	SOIL	1		420	580	0.55	7.27	31.83	44.51	38.41	6.1	3197	3156.67	20.18	20.16
C	SOIL	1				0.77	7.26	31.05	42.69	35.89	6.8	3252	3207.24	26.01	18.74
C	SOIL	1		459	542	0.86	7.23	30.47	43.49	35.69	7.8	3269	3219.25	29.84	19.91
C	SOIL	1				0.86	7.2	31.68	43.38	39.58	3.8	3400	3374.86	17.06	8.08
C	SOIL	1		412	588	0.86	7.19	32.08	49.93	43.63	6.3	3799	3744.62	26.51	27.86
C	SOIL	1				0.71	7.27	32.13	41.92	38.02	3.9	3553	3516.45	24.24	12.31
C	SOIL	1		324	676	0.54	7.27	22.47	39.11	31.91	7.2	2945	2893.01	29.77	22.21
C	SOIL	1				0.69	7.18	33.90	50.05	46.65	3.4	4022	3972.26	20.53	29.21
C	SOIL	1		399	601	0.75	7.17	29.30	42.76	38.56	4.2	3568	3520.59	23.5	23.91

Table 12 (continued)

Location	Type	Set	Olsen P (mg kg^{-1})	Water Soluble P (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	DRO (µg g^{-1})	As	B	Ba	Bi	Cd	Co	Cr	Cu	Ga
											mg kg^{-1}				
C	SED	1	30.09	5.01	4623.15	21.6	7.8	19	179	0.2	0.7	9.8	32	24.9	5
C	SED	1	31.72	6.91	4568.48	22.8									
C	SED	1	29.82	4.09	6453.2	23.2									
C	SED	1	29.09	3.87	7019.24		9.3	26	198	0.3	0.6	11.3	32	28.4	6
C	SED	1	34.39	6.15	9380.45		9.3	22	1.95	0.3	0.7	10.3	31	25.5	6
C	SED	1	29.87	5.36	9793.1		8.8	26	205	0.3	0.6	10.8	30	28.3	6
C	SED	1	36.18	6.96	8484.37										
C	SED	1	37.5	6.45	6376.22										
C	SED	1	30.1	3.27	5614.84										
C	SED	1	30.0	4.12	5707.35										
C	SED	1	25.22	3.86	7863.23										
C	SED	1	25.43	3.37	2250.0										
C	SED	1	29.21	3.72	7222.74										
C	SED	1	27.41	3.38	4963.04		8.8	26	202	0.3	0.5	9.9	31	25.7	6
C	SED	1	28.85	3.7	3128.75										
C	SED	1	26.9	4.52	5165.17										
C	SED	1	25.89	3.53	4059.45										
C	SOIL	1	9.5	3.75	210.15	0									
C	SOIL	1	12.31	3.55	208.35	0									
C	SOIL	1	16.49	4.52	349.23	0									
C	SOIL	1	14.62	4.96	273.29										
C	SOIL	1	16.01	5.59	504.81										
C	SOIL	1	18.44	6.21	493.9										
C	SOIL	1	21.53	5.67	659.0										
C	SOIL	1	24.07	6.51	313.71										
C	SOIL	1	13.45	3.04	244.67		8	21	190	0.2	0.6	10.3	28	25	5
C	SOIL	1	17.13	3.83	228.65										
C	SOIL	1	11.69	2.78	446.57		6.6	18	187	0.2	0.6	10.0	37	25	5
C	SOIL	1	15.96	3.3	944.38										
C	SOIL	1	13.52	3.91	309.71		7	17	193	0.2	0.6	10.1	28	25.6	5
C	SOIL	1	14.17	3.78	510.43										
C	SOIL	1	14.42	2.93	266.22		6.4	17	190	0.2	0.7	9.8	32	22.4	4
C	SOIL	1	16.04	4.91	265.87										
C	SOIL	1	12.79	2.88	283.68		7	18	191	0.2	0.6	10.1	25	24.9	5

Table 12 (continued)

Location	Type	Set	Hg ($ng\ g^{-1}$)	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Ti	U	V	Zn
				mg kg^{-1}											
C	SED	1	73.02	19	980	0.7	26.8	14.1	0.3	3.5	62	0.3	1.6	52	98
C	SED	1	75.64												
C	SED	1	50.07												
C	SED	1	38.59	20	934	0.6	30.4	14.4	0.4	4.5	6.8	0.3	1.7	62	110
C	SED	1	35.0	20	821	0.7	27.3	14.2	0.4	4.3	66	0.3	1.7	56	103
C	SED	1	58.7	21	878	0.6	28.6	14.1	0.4	4.3	65	0.3	1.7	61	110
C	SED	1	67.28												
C	SED	1	59.14												
C	SED	1	65.33												
C	SED	1	73.16												
C	SED	1	55.18												
C	SED	1	53.53												
C	SED	1	53.46												
C	SED	1	61.05												
C	SED	1	55.45												
C	SED	1	45.05	20	901	0.7	26.8	14.0	0.4	4.2	66	0.3	1.8	59	103
C	SED	1	55.85												
C	SOIL	1	46.21												
C	SOIL	1	38.96												
C	SOIL	1	50.5												
C	SOIL	1	58.55												
C	SOIL	1	50.24												
C	SOIL	1	55.39												
C	SOIL	1	50.23												
C	SOIL	1	54.47												
C	SOIL	1	41.81	21	876	0.5	27.3	16.7	0.4	3.8	55	0.3	1.3	54	90
C	SOIL	1	43.62												
C	SOIL	1	49.44	20	955	1.3	27.5	14.2	0.3	3.0	46	0.3	1.3	50	94
C	SOIL	1	42.1												
C	SOIL	1	47.81	20	1002	0.5	28.4	14.2	0.3	2.9	43	0.3	1.2	47	91
C	SOIL	1	41.58												
C	SOIL	1	38.68	20	999	1.0	25.5	13.6	0.2	3.0	42	0.3	1.2	44	87
C	SOIL	1	40.89												
C	SOIL	1	43.5	20	997	0.6	27.2	15.2	0.3	2.9	45	0.3	1.3	46	89

Table 12 (continued)

Location	Type	Set	Dry Sed ($g\ m^{-2}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	CEC ($cmol_{(+)}\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	Inorganic C ($g\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Organic N ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
C	SED	2	4423			1.31	7.09	27.81	42.51	29.81	12.70	2702	2631.30	69.04	1.66
C	SED	2	5906	500	500	1.61	7.09	29.63	47.36	34.56	12.80	2856	2786.71	67.41	1.89
C	SED	2	2163			1.56	7.18	29.84	39.39	26.99	12.40	2804	2737.09	65.32	1.59
C	SED	2	4077			1.31	7.21	30.63	40.64	28.74	11.90	2778	2714.72	61.85	1.43
C	SED	2	4079			1.26	7.18	30.15	42.73	30.13	12.60	2868	2802.28	63.94	1.78
C	SED	2	5895	509	491	1.25	7.24	30.49	44.7	31.50	13.20	2788	2729.08	57.28	1.63
C	SED	2	2761			1.27	7.31	30.37	40.79	28.29	12.50	2683	2623.47	58.28	1.25
C	SED	2	3195			1.21	7.28	32.01	41.41	29.01	12.40	2700	2642.08	55.35	1.73
C	SED	2	5074	493	507	1.28	7.26	31.91	57.69	43.69	14.00	3792	3715.68	74.63	1.69
C	SED	2	7419			1.29	7.23	29.49	48.82	36.42	12.40	3405	3326.97	76.71	1.31
C	SED	2	4769			1.28	7.25	32.87	43.26	31.16	12.10	3097	2999.00	96.74	1.26
C	SED	2	5254	518	482	1.32	7.25	32.91	43.06	31.16	11.90	2911	2831.38	78.92	0.70
C	SED	2	8825	503	497	1.3	7.19	30.01	47.38	35.28	12.10	3296	3229.64	64.00	2.36
C	SED	2	3268			1.39	7.22	32.58	44.26	31.76	12.50	3001	2943.30	55.37	2.33
C	SED	2	3088			1.42	7.23	27.26	46.31	34.11	12.20	3093	3029.46	61.60	1.94
C	SED	2	8212			1.2	7.33	25.5	42.35	30.15	12.20	2794	2733.47	57.99	2.54
C	SED	2	3164			1.52	7.24	23.94	45.42	33.87	11.55	3474	3386.91	85.22	1.87
C	SOIL	2				0.65	7.17	25.47	33.08	22.58	10.50	2353	2332.71	11.13	9.17
C	SOIL	2				0.63	7.16	25.84	30.09	19.69	10.40	1792	1773.68	10.70	7.62
C	SOIL	2				0.68	7.17	24.14	31.71	20.11	11.60	1946	1927.24	8.37	10.39
C	SOIL	2				0.63	7.26	25.26	31.07	19.97	11.10	1767	1749.40	9.11	8.50
C	SOIL	2		477	522	0.65	7.2	23.78	33.52	22.42	11.10	2272	2248.18	11.81	12.01
C	SOIL	2				0.77	7.24	26.29	32.78	22.38	10.40	2142	2113.26	17.09	11.65
C	SOIL	2				0.73	7.26	26.55	31.85	21.65	10.20	2330	2307.89	12.11	10.50
C	SOIL	2				0.78	7.21	25.69	38.35	28.05	10.30	2661	2634.89	11.16	14.95
C	SOIL	2		492	508	0.67	7.26	25.2	35.15	24.15	11.00	2298	2279.46	11.92	6.62
C	SOIL	2				0.79	7.35	25.23	34.63	23.43	11.20	2257	2231.60	12.33	13.07
C	SOIL	2				0.72	7.23	26.22	38.52	27.32	11.20	2577	2548.60	11.67	16.73
C	SOIL	2		462	538	0.7	7.33	24.06	38.62	27.52	11.10	2499	2472.98	16.28	9.74
C	SOIL	2				0.67	7.3	23.19	36.4	25.40	11.00	2443	2418.03	11.75	13.22
C	SOIL	2		483	517	0.83	7.3	20.07	35.82	24.92	10.90	2492	2459.52	15.60	16.89
C	SOIL	2				0.76	7.32	22.15	34.66	24.06	10.60	2415	2380.16	21.17	13.67
C	SOIL	2		482	518	0.85	7.31	25.18	34.37	23.57	10.80	2461	2424.68	21.95	14.37
C	SOIL	2				0.79	7.3	26.31	35.62	24.82	10.80	2317	2276.35	22.18	18.47

Table 12 (continued)

Location	Type	Set	Olsen P (mg kg^{-1})	Water Soluble P (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	DRO (µg g^{-1})	As	B	Ba	Bi	Cd	Co	Cr	Cu	Ga
											mg kg^{-1}				
C	SED	2	28.35	2.83	3230.86	24.1									
C	SED	2	25.83	2.45	4660.37	26.1	7.7	16	187	0.2	0.7	9.5	33	24.3	5
C	SED	2	27.26	2.84	4576.41	16.4									
C	SED	2	30.37	3.31	3421.09										
C	SED	2	21.29	2.54	5004.03										
C	SED	2	15.32	2.45	2959.02		6.5	16	191	0.2	0.5	9.7	25	25.0	5
C	SED	2	19.89	3.29	2999.47										
C	SED	2	20.48	3.61	2621.45										
C	SED	2	26.63	4.76	2397.49		7.7	19	186	0.2	0.6	10.3	29	24.8	5
C	SED	2	20.05	2.89	2793.22										
C	SED	2	23.29	2.60	2821.32										
C	SED	2	22.44	2.65	3046.26		7.4	16	185	0.3	0.5	10.0	27	25.2	5
C	SED	2	19.32	2.58	3464.90		7.1	14	174	0.3	0.6	10.0	62	22.7	4
C	SED	2	19.69	3.23	3499.89										
C	SED	2	21.35	3.98	4460.43										
C	SED	2	21.95	3.08	2741.60										
C	SED	2	19.37	2.40	5523.76										
C	SOIL	2	5.93	1.76	337.52	5.36									
C	SOIL	2	2.12	0.99	413.92	0									
C	SOIL	2	6.69	1.85	284.58										
C	SOIL	2	5.21	1.46	246.58										
C	SOIL	2	13.70	3.06	261.10		6.6	12	166	0.2	0.5	9.5	23	21.4	4
C	SOIL	2	10.12	2.09	440.15										
C	SOIL	2	10.43	2.47	366.38										
C	SOIL	2	13.84	2.58	617.58										
C	SOIL	2	11.82	3.29	438.51		7.2	13	172	0.2	0.5	10.1	36	22.0	4
C	SOIL	2	14.22	3.16	321.37										
C	SOIL	2	15.86	3.07	434.66										
C	SOIL	2	23.17	2.90	622.20		6.8	16	179	0.3	0.5	9.6	25	22.4	4
C	SOIL	2	19.26	2.63	481.11										
C	SOIL	2	19.58	2.17	534.33		6.8	14	171	0.3	0.5	9.5	27	23.0	4
C	SOIL	2	14.69	1.19	523.63										
C	SOIL	2	16.20	1.73	388.78		7.2	15	173	0.3	0.5	9.9	25	22.3	4
C	SOIL	2	14.60	1.56	527.47										

Table 12 (continued)

Location	Type	Set	Hg (ng g^{-1})	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Ti	U	V	Zn
				mg kg^{-1}											
C	SED	2	54.54												
C	SED	2	63.82	19	959	1.0	25.4	13.4	0.3	3.4	63	0.3	1.5	49	90
C	SED	2	59.73												
C	SED	2	76.19												
C	SED	2	56.80												
C	SED	2	55.16	19	805	0.5	27.0	13.6	0.3	3.2	62	0.3	1.6	47	94
C	SED	2	53.17												
C	SED	2	55.38												
C	SED	2	54.02	19	1116	0.7	27.1	13.3	0.3	3.4	66	0.3	1.6	50	109
C	SED	2	40.41												
C	SED	2	52.67												
C	SED	2	57.27	19	1030	0.5	26.8	13.9	0.3	3.5	65	0.3	1.5	50	98
C	SED	2	47.33	18	908	2.9	25.8	12.9	0.3	3.3	59	0.3	1.6	44	87
C	SED	2	53.92												
C	SED	2	46.38												
C	SED	2	56.89												
C	SED	2	45.62												
C	SOIL	2	48.03												
C	SOIL	2	43.36												
C	SOIL	2	45.16												
C	SOIL	2	48.55												
C	SOIL	2	47.34	18	869	0.5	25.6	12.8	0.2	3.2	4.8	0.3	1.3	40	79
C	SOIL	2	53.43												
C	SOIL	2	52.85												
C	SOIL	2	55.98												
C	SOIL	2	43.44	18	885	1.1	26.7	13.6	0.3	3.4	50	0.3	1.2	44	83
C	SOIL	2	59.71												
C	SOIL	2	52.93												
C	SOIL	2	60.17	18	800	0.4	25.6	13.6	0.3	3.4	52	0.3	1.4	46	85
C	SOIL	2	51.23												
C	SOIL	2	58.62	18	783	0.5	24.9	12.9	0.3	3.3	51	0.3	1.3	44	82
C	SOIL	2	52.06												
C	SOIL	2	57.20	19	840	0.4	25.9	13.3	0.3	3.6	51	0.3	1.4	47	82
C	SOIL	2	51.71												

Table 12 (continued)

Location	Type	Set	Dry Sed ($g\ m^{-2}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	EC ($dS\ m^{-1}$)	pH	CEC ($cmol_{(+)}\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	Inorganic C ($g\ kg^{-1}$)	Total N ($mg\ kg^{-1}$)	Organic N ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
C	SED	3	8487	465	535	0.82	7.38	23.21	44.34	29.54	14.80	2518	2443.37	73.37	1.26
C	SED	3	13046	506	494	0.86	7.35	24.37	39.9	25.30	14.60	2459	2391.30	66.61	1.10
C	SED	3	6739			0.89	7.36	22.60	37.95	23.45	14.50	2391	2333.01	57.27	0.72
C	SED	3	8824			0.87	7.34	23.73	41.61	27.11	14.50	2757	2701.03	54.34	1.64
C	SED	3	9783			0.92	7.36	23.85	36.09	21.59	14.50	2218	2155.98	61.15	0.87
C	SED	3	11054			0.92	7.32	22.78	41.36	25.96	15.40	2327	2261.03	64.65	1.32
C	SED	3	8743			0.87	7.36	24.81	38.83	25.33	13.50	2573	2498.26	73.40	1.34
C	SED	3	7070			0.86	7.44	23.33	42.72	26.62	16.10	2590	2527.85	61.24	0.91
C	SED	3	8106	475	525	0.80	7.37	24.15	38.95	24.15	14.80	2430	2361.85	67.06	1.09
C	SED	3	8354			0.93	7.3	24.05	38.92	24.12	14.80	2313	2237.05	75.06	0.89
C	SED	3	8130			0.88	7.33	24.10	38.76	24.36	14.40	2294	2219.38	73.46	1.16
C	SED	3	9770			0.88	7.38	24.86	37.56	23.46	14.10	2394	2320.57	72.37	1.06
C	SED	3	9831			0.87	7.34	24.53	39.53	25.83	13.70	2520	2436.31	82.64	1.05
C	SED	3	8144	469	531	0.86	7.34	25.23	39.41	25.51	13.90	2557	2483.78	72.67	0.55
C	SED	3	8205			0.89	7.36	24.46	38	24.30	13.70	2327	2257.48	68.63	0.89
C	SED	3	11697	524	476	0.97	7.34	25.06	38.36	24.86	13.50	2679	2590.27	87.46	1.27
C	SED	3	8111			0.85	7.38	25.36	38.09	24.59	13.50	2563	2488.71	73.45	0.85
C	SOIL	3		445	555	0.72	7.45	23.97	36.15	22.95	13.20	2088	2064.17	12.50	11.33
C	SOIL	3				0.55	7.48	24.23	34.9	21.50	13.40	2067	2044.61	11.61	10.78
C	SOIL	3				0.59	7.51	23.72	33.73	20.23	13.50	1851	1825.29	15.78	9.94
C	SOIL	3		489	512	0.69	7.49	23.57	34.04	20.34	13.70	1942	1918.44	14.74	8.83
C	SOIL	3				0.74	7.54	24.15	35.83	22.23	13.60	2110	2084.59	12.95	12.46
C	SOIL	3				0.69	7.58	24.51	33.02	19.42	13.60	1871	1847.84	11.79	11.37
C	SOIL	3				0.76	7.52	23.84	34.28	21.08	13.20	1814	1793.31	11.54	9.14
C	SOIL	3		515	484	0.83	7.55	24.45	34.11	20.71	13.40	1852	1825.48	13.57	12.95
C	SOIL	3				0.66	7.53	24.72	35.08	21.28	13.80	2033	2005.79	15.78	11.43
C	SOIL	3				0.72	7.58	24.63	33.39	20.19	13.20	1730	1710.14	12.05	7.81
C	SOIL	3				0.71	7.57	26.01	34.28	20.38	13.90	1926	1903.34	11.17	11.49
C	SOIL	3				0.66	7.57	24.91	35.02	22.22	12.80	2034	2013.10	12.40	8.50
C	SOIL	3				0.79	7.54	25.64	33.32	20.12	13.20	2108	2085.39	13.29	9.32
C	SOIL	3				0.73	7.6	24.40	34.71	21.31	13.40	1966	1941.13	17.59	7.28
C	SOIL	3		504	496	0.77	7.6	24.98	35.26	22.16	13.10	1855	1827.61	19.48	7.91
C	SOIL	3		523	477	0.84	7.55	25.17	35.85	22.85	13.00	1918	1883.58	24.69	9.73
C	SOIL	3				0.82	7.59	25.19	33.68	20.73	12.95	2033	2008.75	15.70	8.55

Table 12 (continued)

Location	Type	Set	Olsen P (mg kg^{-1})	Water Soluble P (mg kg^{-1})	SO_4^{2-} (mg kg^{-1})	DRO (µg g^{-1})	As	B	Ba	Bi	Cd	Co	Cr	Cu	Ga
											mg kg^{-1}				
C	SED	3	26.58	1.69	1878.63	18.2	7.6	13.0	181.0	0.2	0.6	9.7	28.0	21.0	4.0
C	SED	3	29.53	1.83	1742.57	15.1	7.6	13.0	176.0	0.2	0.5	9.8	24.0	21.3	4.0
C	SED	3	28.72	2.55	1740.50	17.9									
C	SED	3	32.49	1.71	1503.72										
C	SED	3	29.89	2.13	1472.23										
C	SED	3	24.40	1.81	2407.27										
C	SED	3	31.97	2.22	1394.19										
C	SED	3	30.52	2.11	1728.89										
C	SED	3	31.23	1.95	1671.48		8.3	15.0	183.0	0.2	0.5	10.0	28.0	22.0	4.0
C	SED	3	26.26	2.60	2007.54										
C	SED	3	26.37	2.19	1647.44										
C	SED	3	24.07	2.27	1935.23										
C	SED	3	25.91	1.54	1635.56										
C	SED	3	29.36	2.45	1607.88		8.0	15.0	181.0	0.2	0.6	9.8	26.0	21.5	4.0
C	SED	3	25.37	1.38	1645.18										
C	SED	3	28.13	1.65	1976.05		8.2	15.0	185.0	0.3	0.6	10.1	36.0	22.4	4.0
C	SED	3	23.74	2.31	1523.33										
C	SOIL	3	22.37	3.39	451.95	0	7.9	14.0	184.0	0.2	0.6	9.9	25.0	23.1	4.0
C	SOIL	3	22.75	2.85	358.09	0									
C	SOIL	3	23.75	1.90	506.64	4.79									
C	SOIL	3	24.61	2.25	389.53		8.1	14.0	186.0	0.3	0.6	10.1	28.0	22.3	4.0
C	SOIL	3	25.94	3.06	423.33										
C	SOIL	3	23.34	2.82	433.67										
C	SOIL	3	26.18	3.03	448.16										
C	SOIL	3	24.08	4.09	433.55		8.5	15.0	187.0	0.3	0.6	10.9	29.0	24.3	5.0
C	SOIL	3	25.48	3.97	401.44										
C	SOIL	3	24.22	3.80	437.72										
C	SOIL	3	27.49	4.72	412.18										
C	SOIL	3	28.51	5.29	515.12										
C	SOIL	3	23.72	5.19	410.50										
C	SOIL	3	26.03	3.48	410.19										
C	SOIL	3	28.91	2.86	449.43		8.1	16.0	186.0	0.3	0.5	10.2	31.0	22.8	5.0
C	SOIL	3	29.97	3.37	686.37		8.2	13.0	191.0	0.2	0.6	10.8	27.0	23.3	5.0
C	SOIL	3	26.58	2.26	376.90										

Table 12 (continued)

Location	Type	Set	Hg (ng g^{-1})	La	Mn	Mo	Ni	Pb	Sb	Sc	Sr	Ti	U	V	Zn
				mg kg^{-1}											
C	SED	3	50.75	17.0	993	0.7	24.2	13.6	0.3	3.1	60.0	0.3	1.5	43.0	79.0
C	SED	3	50.79	17.0	1031	0.6	24.8	12.9	0.2	3.3	60.0	0.3	1.3	44.0	81.0
C	SED	3	53.29												
C	SED	3	53.76												
C	SED	3	51.40												
C	SED	3	51.45												
C	SED	3	50.89												
C	SED	3	77.41												
C	SED	3	53.62	18.0	1115	0.6	24.9	13.2	0.3	3.5	61.0	0.3	1.4	47.0	85.0
C	SED	3	54.04												
C	SED	3	60.23												
C	SED	3	52.15												
C	SED	3	57.12												
C	SED	3	55.01	18.0	1080	0.5	25.4	12.8	0.3	3.7	61.0	0.3	1.4	48.0	86.0
C	SED	3	54.12												
C	SED	3	52.26	18.0	1149	1.1	26.4	14.3	0.3	3.5	63.0	0.3	1.4	47.0	86.0
C	SED	3	51.90												
C	SOIL	3	53.68	18.0	902	0.5	26.0	14.8	0.2	3.6	60.0	0.3	1.4	46.0	83.0
C	SOIL	3	58.72												
C	SOIL	3	49.92												
C	SOIL	3	58.58	19.0	928	0.6	27.0	13.8	0.3	3.8	59.0	0.3	1.4	47.0	84.0
C	SOIL	3	53.55												
C	SOIL	3	56.87												
C	SOIL	3	55.26												
C	SOIL	3	59.47	19.0	998	0.6	28.2	14.1	0.3	4.0	6.2	0.3	1.4	52.0	88.0
C	SOIL	3	55.93												
C	SOIL	3	62.16												
C	SOIL	3	50.80												
C	SOIL	3	56.70												
C	SOIL	3	58.05	18.0	953	0.6	26.4	13.6	0.3	4.0	64.0	0.3	1.4	51.0	85.0
C	SOIL	3	49.39	19.0	1001	0.5	27.1	14.6	0.3	3.8	62.0	0.3	1.4	47.0	87.0
C	SOIL	3	52.58												
C	SOIL	3	49.11												
C	SOIL	3	60.53												

APPENDIX E

Effects of Major Flooding on Water and Sediment Characteristics on an Urban Environment

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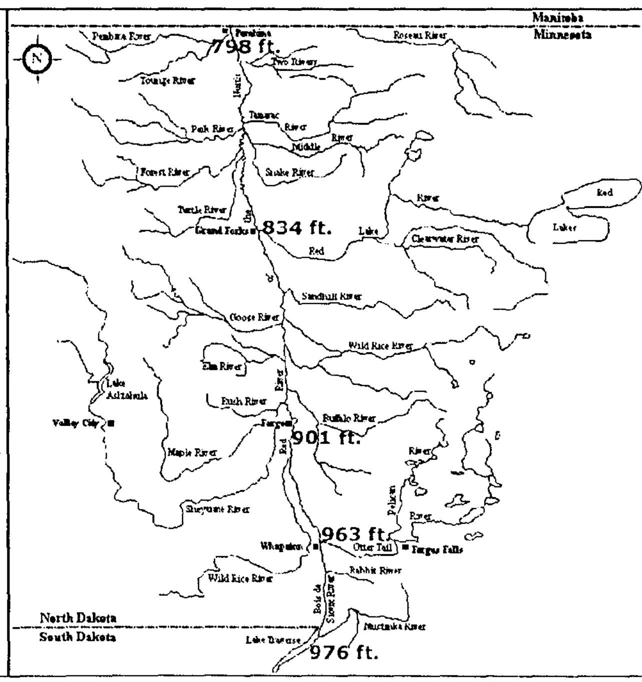
28 March 2011

Overview and Background Information

- *Brief* overview of the RR basin
- Why flooding occurs
- "positive" and "negative" aspects of floods
- My research

Factors of why RR flood

- Above normal fall precipitation
- Depth of moisture content in seasonably frozen soils
- Above normal winter snowfall
- Unfavorable melting conditions
- Rate of spring thaw
- Temporary ice dams
- Gentle slope of main channel (IJC, 2000; Macek-Rowland, 1997; Todhunter 2001)



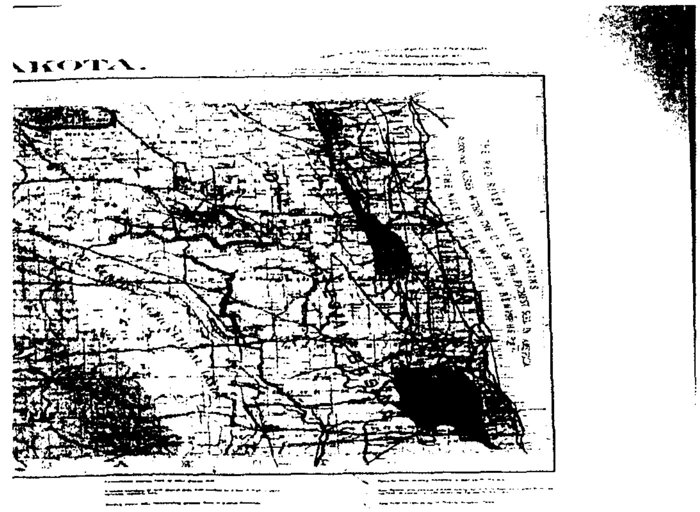
Factors of 2009 RR flood

- Received between 200 and 300 percent above normal precipitation from September 2008 – February 2009
  - 23 days of snow in December
  - Water content in snowpack up to 300 percent above normal
  - 61.5 inches of winter total snowfall (September 23, 2008 – February 6, 2009)(Fargo Forum)
- Frozen soils
- Unfavorable melting conditions (blizzards and rain)
- Rate of spring thaw
- Gentle slope of main channel

Overview of flooding – "negative" aspects

- Average annual flood damage to the F-M area exceeds $190 million (US) (US Army Corps of Engineers, 2010)
- Average annual flood damage across the US exceeds $3 billion (US) (Pielke and Downton, 2000)
- Trace elements (As, Cd, Hg, Pb, and Zn) can adversely affect the health of water bodies, degrade aquatic habitats, and affect the organisms living in these environments (Bakri et al., 2008; Bay et al., 2003; Herngren et al., 2010)
- Nutrients can degrade aquatic habitats, depreciate recreation and aesthetics, or cause algae to grow uncontrollably
- Organics and hydrocarbons can adversely affect the health of the water bodies and the organisms living in these environments (Boxall and Maltby, 1995)

Overview of flooding – “positive” aspects



Hall, C.M. 1908

Justification for this study

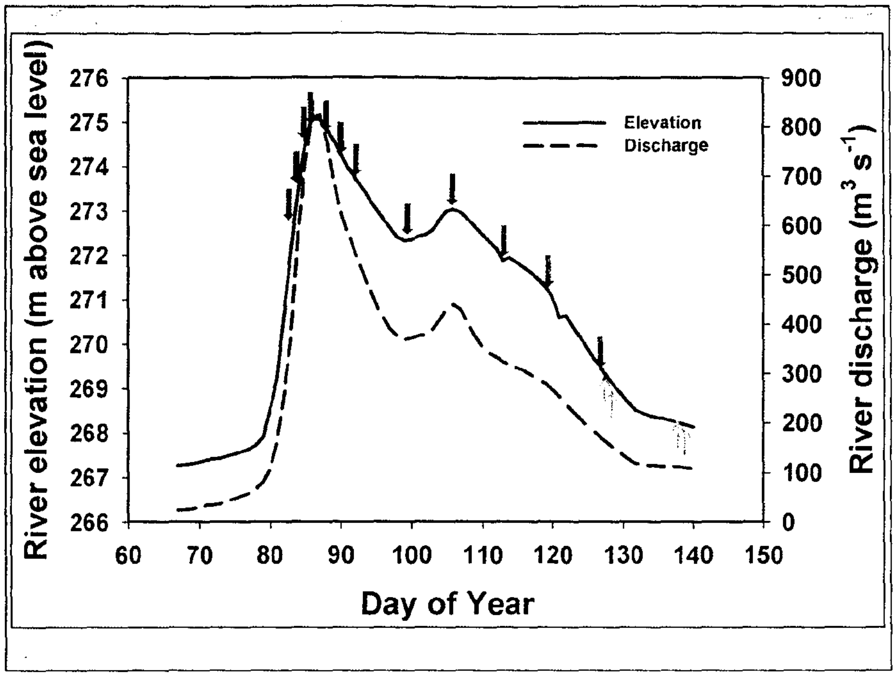
- Stories of fuel oil in basements, pesticides from garages, and chemicals from farm yards entering floodwaters
- Primarily an agricultural basin (Approximately 75 percent) (Souris-Red-Rainy River Commission, 1972)
- Urban runoff enhanced by impervious surfaces
- Flooded area is generally residential
  - 20 public and recreational lands along the banks of the RR (parks, community gardens, school campuses, and golf courses)

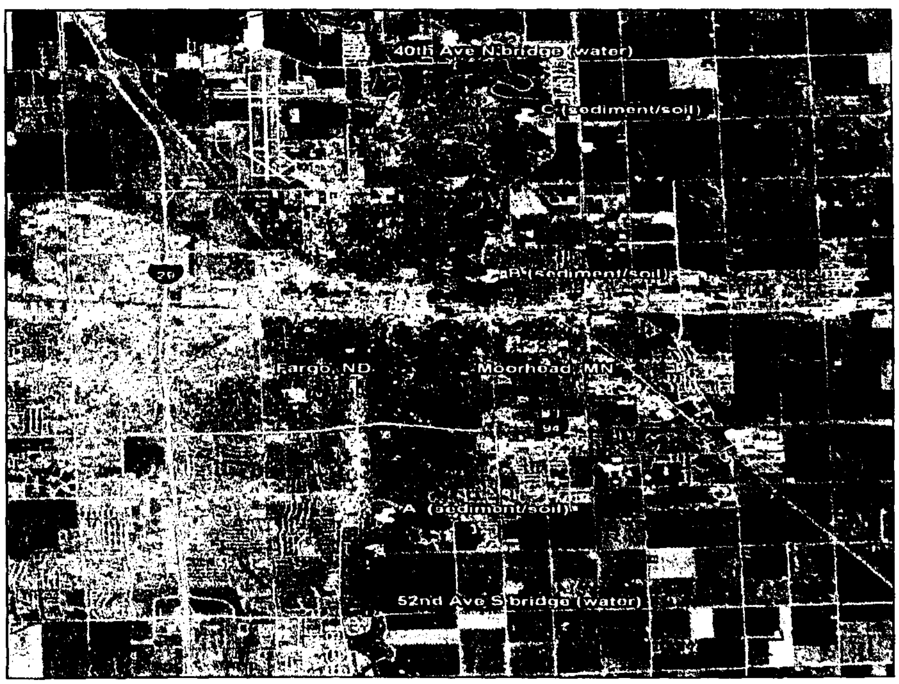
Research Question 1

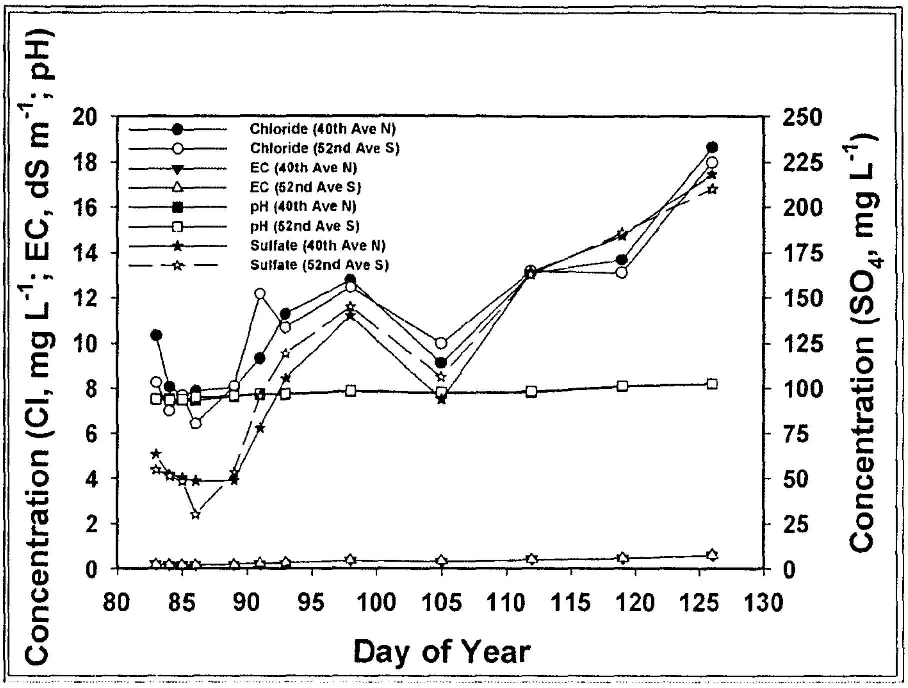
- What is the impact of a major flooding event on water quality within the Fargo-Moorhead area?

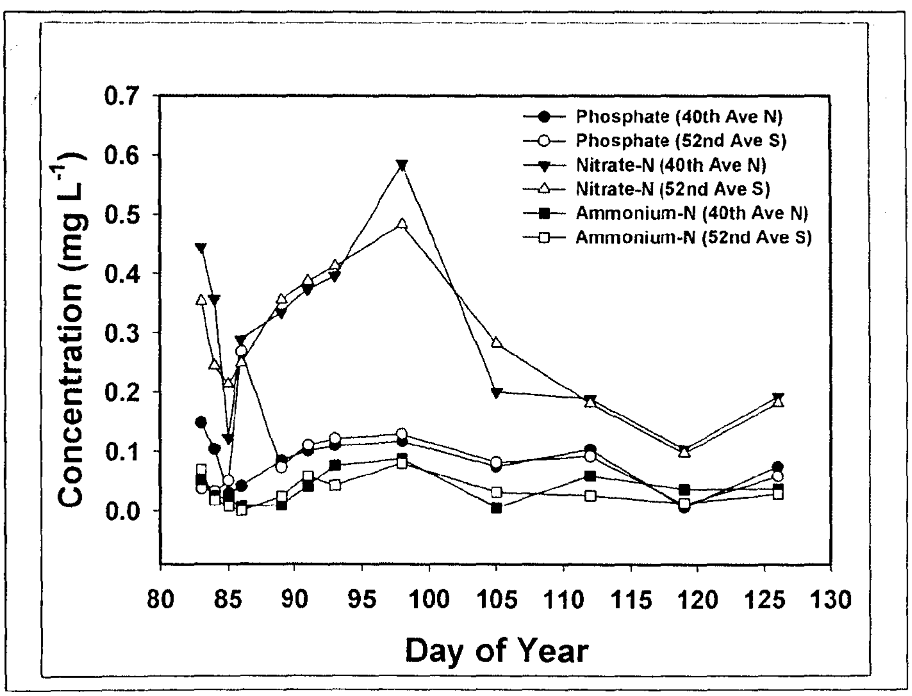
Materials and Methods

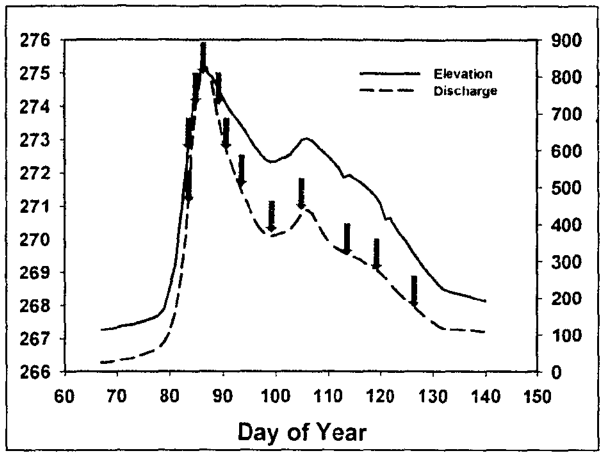
- Samples were collected at two locations (pre-, at-, and post-river crest on 7 dates)
  - 52nd Ave S (upstream) and 40th Ave N (downstream) bridges
- Parameters measured
  - Total solids (suspended plus dissolved), NO_3-N, NH_4-N, PO_4, pH, EC, SO_4, Cl, 17β-estradiol (E2), estrone (E1), diesel range organics (DRO), and gasoline range organics (GRO)


River elevation (m above sea level)
276
275
274
273
272
271
270
269
268
267
266
900
800
700
600
500
400
300
200
100
0
River discharge ($m^3 s^{-1}$)
60
70
80
90
100
110
120
130
140
150
Day of Year
Elevation
Discharge

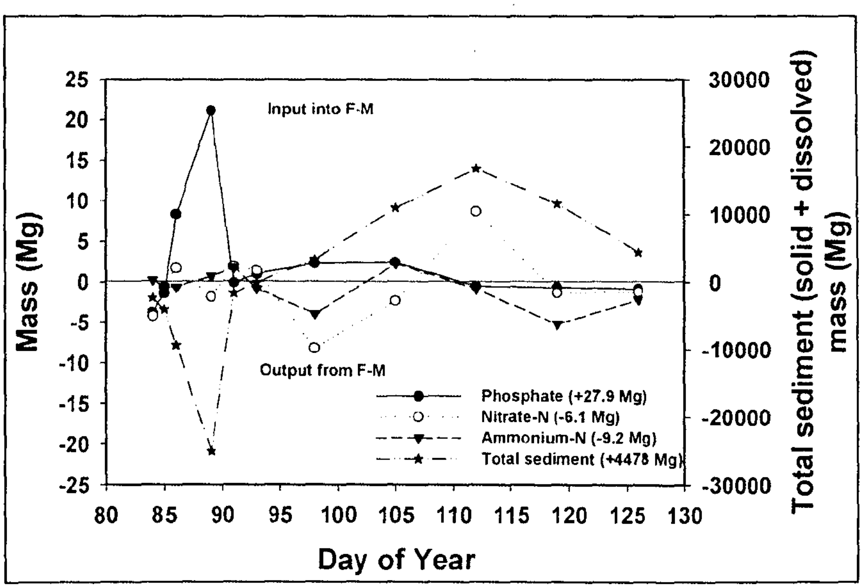

40th Ave N bridge (water)
C (sediment/soil)
B (sediment/soil)
Fargo, ND
Moorhead, MN
A (sediment/soil)
52nd Ave S bridge (water)
29
94


Chloride (40th Ave N)
Chloride (52nd Ave S)
EC (40th Ave N)
EC (52nd Ave S)
pH (40th Ave N)
pH (52nd Ave S)
Sulfate (40th Ave N)
Sulfate (52nd Ave S)
Concentration (Cl, mg L^{-1}; EC, dS m^{-1}; pH)
Concentration (SO$_4$, mg L^{-1})
Day of Year
0
2
4
6
8
10
12
14
16
18
20
0
25
50
75
100
125
150
175
200
225
250
80
85
90
95
100
105
110
115
120
125
130


Phosphate (40th Ave N)
Phosphate (52nd Ave S)
Nitrate-N (40th Ave N)
Nitrate-N (52nd Ave S)
Ammonium-N (40th Ave N)
Ammonium-N (52nd Ave S)
Concentration (mg L^{-1})
Day of Year
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
80
85
90
95
100
105
110
115
120
125
130



Mass = Concentration x discharge x elapsed time.



Water parameter concentrations

- DRO: detected in 8 of 24 samples with an average concentration of 80.0 $\mu g\ L^{-1}$
- GRO: no detection was measured in any sample
- 17β-estradiol: detected in 9 of 24 samples with an average concentration of 0.61 ng L^{-1}
- Estrtone: No detection was measured in any sample

Research Question 2

- What is the impact of a major flooding event on the quality of sediment remaining after floodwaters recede?

Materials and Methods

- Collect deposited sediment (alluvium) and base soil (0 to 10 cm below surface) from three locations within F-M. Cashel series.
- Samples were collected from three transects as floodwaters receded (n=17 samples per transect)
- Dry sediment mass, texture, carbon (total, OC, IC), nitrogen (total, organic, ammonium, and nitrate), phosphate (Olsen and water soluble), sulfate, EC, pH, DRO, GRO, total Hg, and 23 other trace metals

Statistical Methods

- ANOVA: test for differences in physical and chemical parameters of the SED between transects (1, 2, and 3)
  - Tukey-Kramer HSD: test for significance in physical and chemical parameters of the SED between transects (1, 2, and 3), then by soil type, and again by location (A, B, and C)
- Student's t-test: test for differences between soil type, then by location, and then again by transect
- Statistical results were considered significant at $p \leq 0.05$ level
- Made no attempt to compare between sites

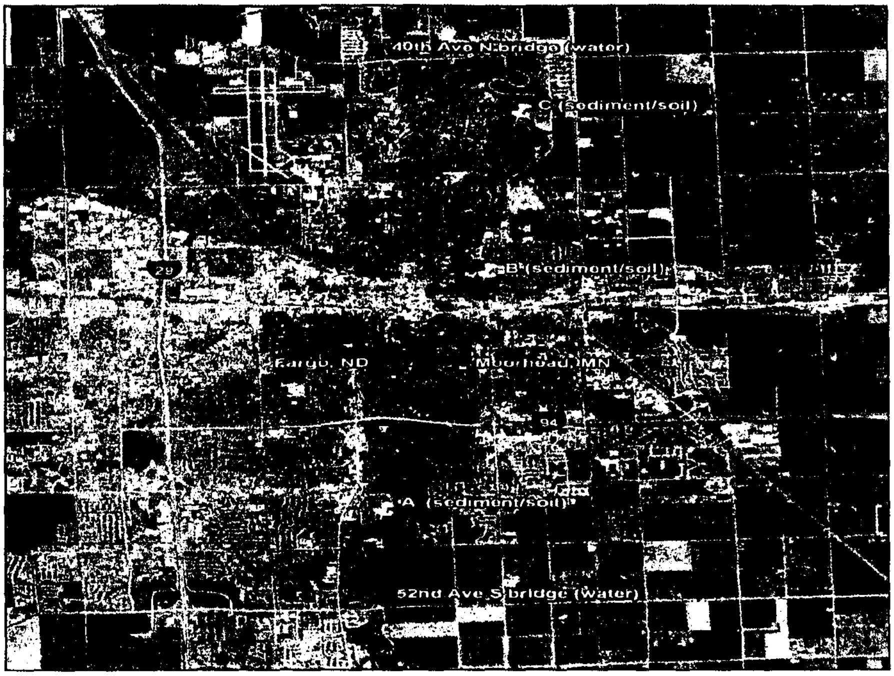
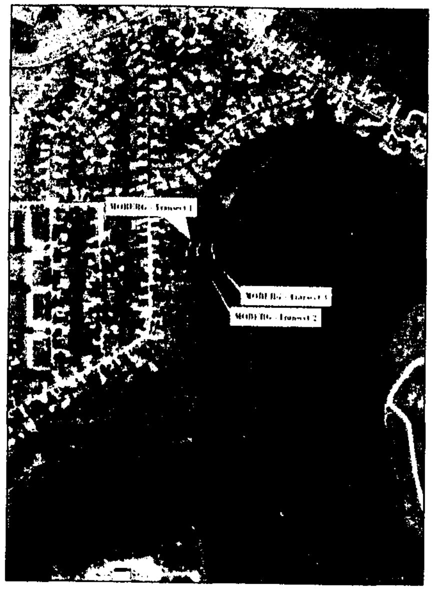


Table 1. Number of days that each location and transect was inundated by floodwaters and the number of days between submergence and sediment and soil sampling

Location	Transect	Days Inundated	Days Between Submergence and Sampling	Day of Year
A†	1	31	15	127
	2	37	9	127
	3	59	1	138
B	1	41	10	128
	2	44	10	139
	3	54	5	139
C	1	42	5	127
	2	57	1	138
	3	59	1	138

† A, B, and C indicate the upstream residential lawn, the central city park, and the downstream residential lawn, respectively



Results

- Dry sediment: 3>2>1; ranged from 2.0 to 10.3 kg m^{-2} ($p \leq 0.05$)
- EC: SED, no pattern; SED>SOIL ranged from 0.7 to 1.1 dS m^{-1} ($p \leq 0.05$)
- Total C: SED 1>2>3 ($p \leq 0.05$); no pattern between SED and SOIL; ranged from 34.5 to 59.0 g kg^{-1}
- Organic C: SED 1>2>3 ($p \leq 0.05$); no pattern between SED and SOIL; ranged from 21.2 to 49.1 g kg^{-1}
- Olsen P: SED 1>2>3; SED>SOIL; ranged from 13 to 36 mg kg^{-1} ($p \leq 0.05$)
- WSP: SED 1>2>3; SOIL>SED; ranged from 1 to 7 mg kg^{-1} ($p \leq 0.05$)

Results

- Total N: ranged from 1,750 to 4,980 mg kg^{-1}; where concentrations decreased with decreasing distance from the river channel for SED and SOIL
- Organic N: ranged from 1,730 to 4,949 mg kg^{-1}
- NH_4-N: SED>SOIL ($p \leq 0.05$); highly variable in SED, however, if differences were present, Transect 1 generally had higher concentrations; ranged from 3.1 to 128 mg kg^{-1}
- NO_3-N: SOIL>SED ($p \leq 0.05$); no pattern in SED; ranged from 0.70 to 28.6 mg kg^{-1}

Affects on NH_4-N?

Location	Transect	Days Inundated	Days Between Submergence and Sampling	Day of Year
A†	1	31	15	127
	2	37	9	127
	3	59	1	138
B	1	41	10	128
	2	44	10	139
	3	54	5	139
C	1	42	5	127
	2	57	1	138
	3	59	1	138

† A, B, and C indicate the upstream residential lawn, the central city park, and the downstream residential lawn, respectively

Organics and Trace Metals

- DRO: few detects; SED>SOIL; ranged from 0 to 49 ng g^{-1}
- GRO: no detections
- Total mercury (Hg): Locations A and B SOIL>SED ($p \leq 0.05$); ranged from 43 to 81 ng g^{-1}
- Highly variable in SED, however, if differences were present, Transect 1 generally had higher concentrations
- Highly variable between SED and SOIL, however, if differences were present, SED>SOIL

Summary

- Concentration of analytes similar before and after F-M
- All water quality parameters in the floodwater were under threshold concentrations for USEPA in surface waters
- Deposition of P in sediment within F-M, but out flux of inorganic N
- Sediment was generally enriched in carbon and nutrients
- All trace elements in sediment and soil were within range of other studies of non-contaminated soils
- Deposition of sediment is unsightly, but no parameter would be considered a contaminant (no concern of a problem)

Acknowledgements

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