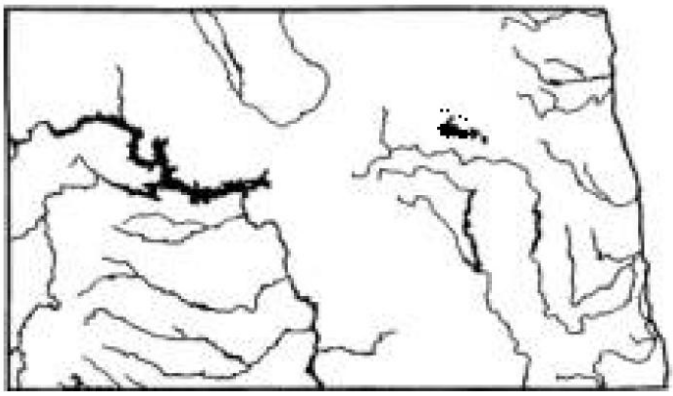

Technical Report No: ND11-01

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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, and 17ß-estradiol. 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 µg 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 2,100 to 4,200 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 µg 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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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) exceeds $190 million (US) (US Army Corps of Engineers, 2010). The RR basin is predominantly agricultural (Stoner et al., 1993) and a concern for high volumes of sediment loading into the RR because constituents attached to sediments may be harmful to 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 widespread. 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 should to 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 quality and to assess the quality of the sediment deposited in an urban environment after floodwaters recede.

BACKGROUND

In March 2009, the RR at F-M reached the highest recorded flood stage in its recorded history (275.1 m above sea level) (Figure 1) (USGS, 2010). 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, and detached fuel-oil tanks, might influence water and sediment quality.

OBJECTIVES

The objectives of this study were to:
(1) determine if the F-M area affects floodwater quality, and
(2) determine the quality of the sediment deposited in the F-M area after floodwaters recede.

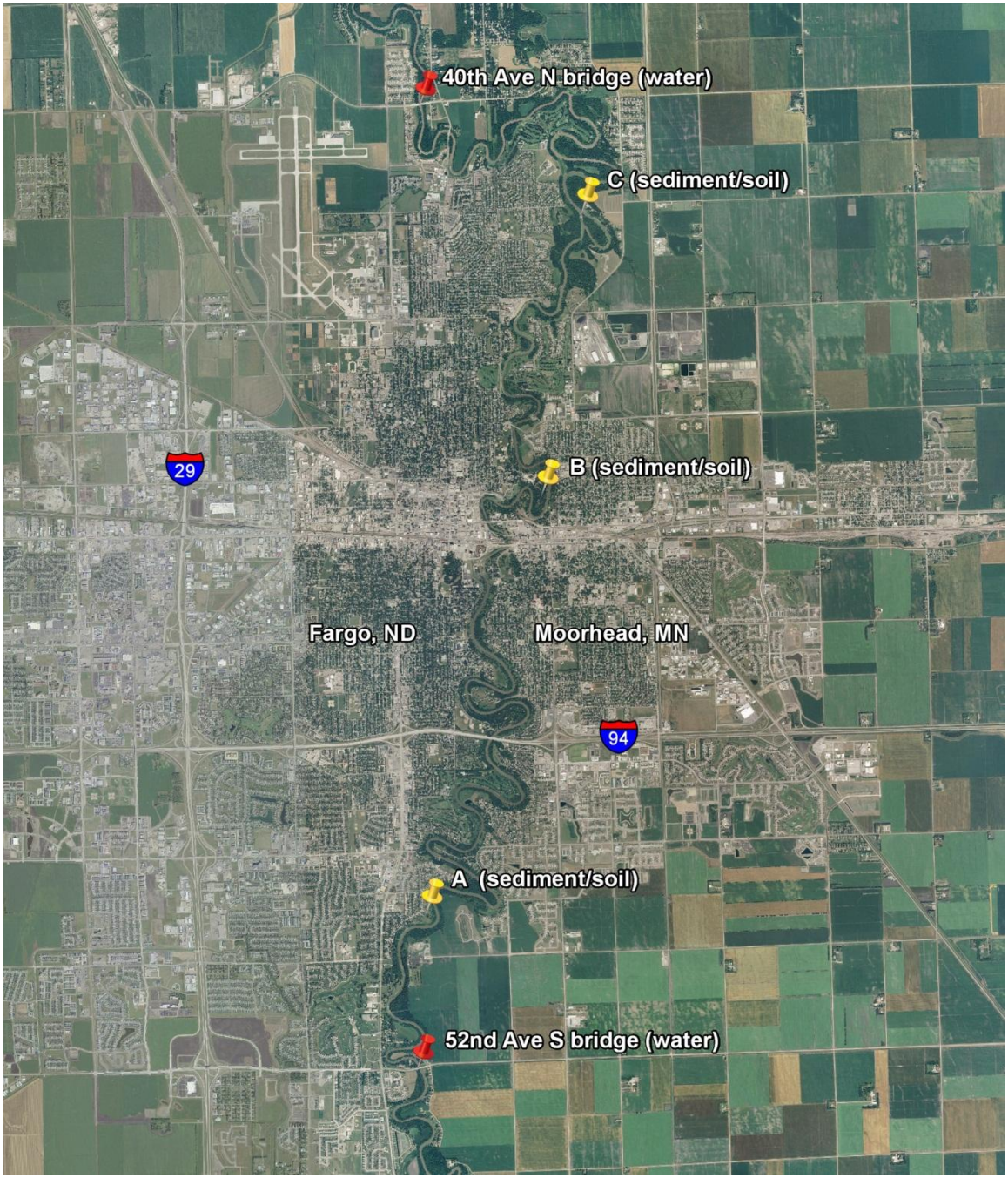
MATERIALS AND METHODS

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

1). 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.

Figure 1. Aerial map depicting water and sediment/soil sampling locations near the Red River of the North at Fargo, North Dakota and Moorhead, Minnesota.



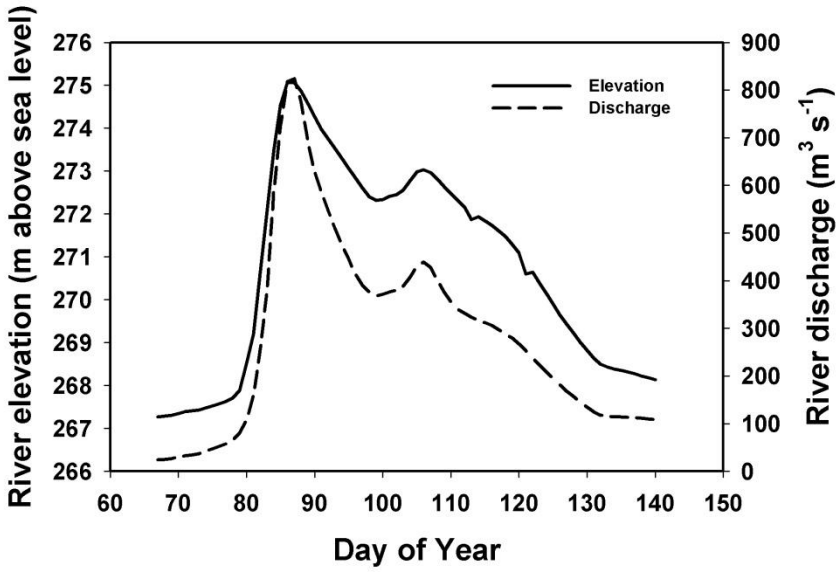
Samples for gasoline range organics (GRO) and diesel range organics (DRO) were stored in manufacturer-cleaned 500 mL glass bottles. All samples from both locations were taken

within 1 hr of each other. Water 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 (105ºC, 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, and 3550C and 8270D, respectively (USEPA, 1996a,b; 2007a,b).

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. Average mass (Mass (Mg)) of each parameter was calculated by multiplying the average concentration (Mass/Volume) by the average discharge (Volume/Time) (Figure 2) 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 locations. A gain between locations determined parameter input into F-M and a loss determined output from F-M. Samples for 17ß-estradiol and estrone were stored in 50 mL narrow-mouth high-density polyethylene (HDPE) bottles and were frozen until analysis.

Figure 2. 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).



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 1).

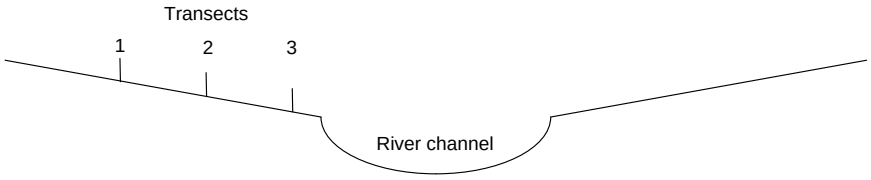
All sediment and soil samples were collected as soon as floodwaters receded to a safe level. Each location included three transects regularly parallel to the river channel at a constant elevation. Transect 1 was furthest from the river channel, Transect 2 was between Transects 1 and 3, and Transect 3 was closest to the river channel (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 25ºC 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. 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 (three replications 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 (US EPA, 2009) 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 Analysis

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 3). 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). The 40th Ave N location had higher total solids concentration in the first half of sampling but was lower in the second half (Figure 3), 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 (Figure 5).

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.

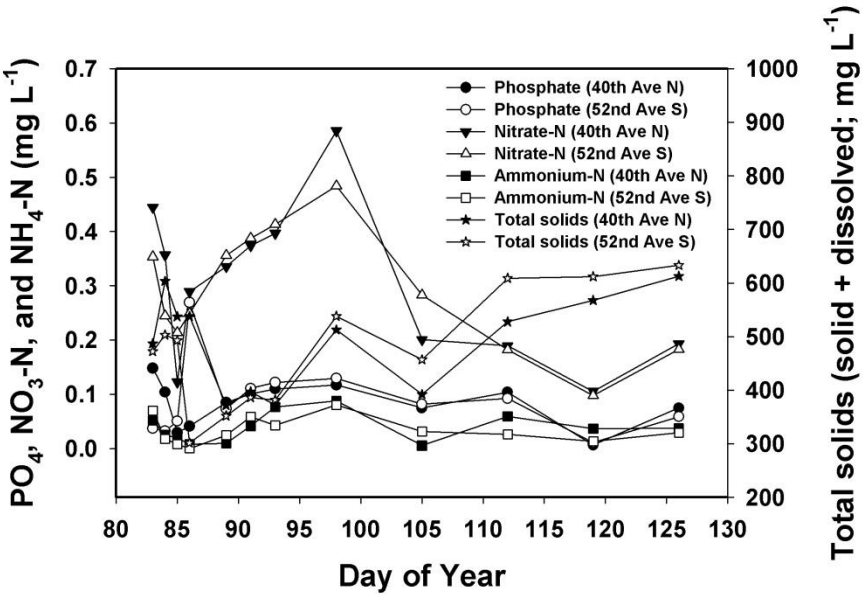
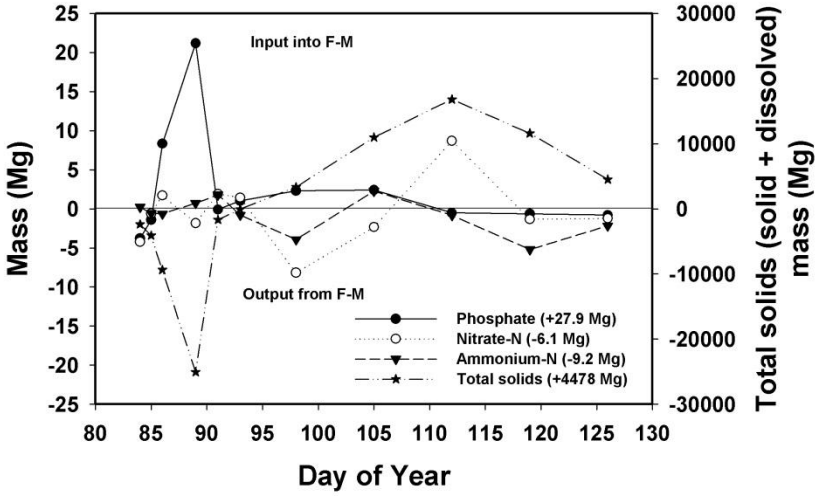


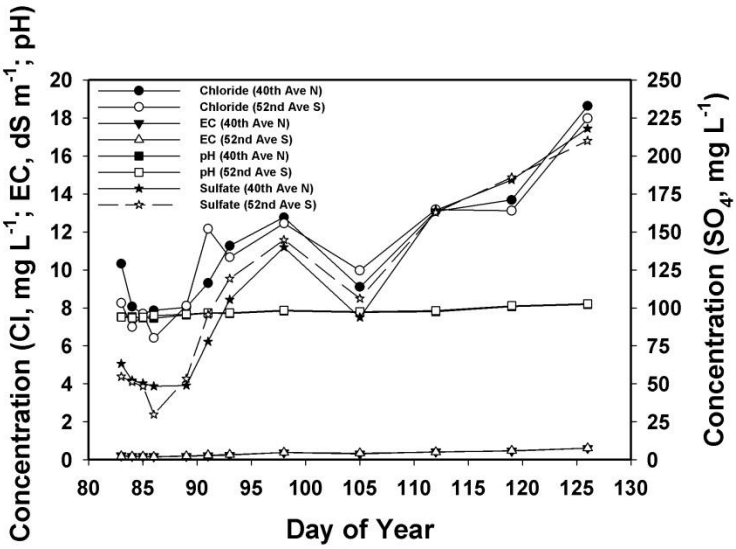
Figure 5. Mass additions to (positive numbers) and losses from (negative numbers) the Fargo, North Dakota and Moorhead, Minnesota urban area of PO_4, NO_3-N, and NH_4-N during the spring 2009 Red River of the North flood. (Note: total mass additions (+) and losses (-) are reported in the figure legend).



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 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 period of time 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 2) and PO_4 concentrations (Figure 4) at each sampling date, about 30 Mg of PO_4 were deposited within F-M (Figure 5).

The pH values averaged 7.8 between both water-sampling locations (Figure 6). Electrical conductivities of floodwater were similar between 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 harmful to the 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-estrodial (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 measured in any sample. 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 measured in any sample.

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.

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.

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}, respectively (Tables 3, 4, and 5). The sediment layer covering the riverbanks after floodwaters receded was typically less than 5 cm thick.

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.

		Transect		
Parameter	Sample	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	4220 (997)a,A	3550 (1250)a,A	2600 (670)a,B
	SOIL	4980 (1200)a	3910 (1320)a	2890 (1040)a
Organic N (mg kg^{-1})	SED	4090 (998)b,A	3430 (1250)a,A	2550 (671)a,B
	SOIL	4940 (1210)a	3880 (1320)a	2870 (1040)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†† (ug 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.

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.

		Transect		
Parameter	Sample	1†	2	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	3150 (908)b,A	2330 (854)b,B	2190 (561)a,B
	SOIL	4310 (1040)a	3060 (1040)a	2640 (892)a
Organic N (mg kg^{-1})	SED	3100 (901)b,A	2300 (854)b,B	2160 (561)a,B
	SOIL	4290 (1030)a	3040 (1040)a	2620 (892)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†† (ug 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.

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.

		Transect		
Parameter	Sample	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	3450 (1150)a,A	2850 (789)a,AB	2070 (878)a,B
	SOIL	3170 (852)b	2170 (561)b	1750 (593)a
Organic N (mg kg^{-1})	SED	3320 (852)a,A	2780 (784)a,AB	2000 (878)a,B
	SOIL	3120 (844)a	2150 (559)b	1730 (593)a
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[††] (ug 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.

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 3, 4, and 5) (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).

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 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). 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 within its banks. 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 (Chow, 1959), which in this case, would allow OC to collect near the edges of flow.

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 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 2,070 to 4,220 mg kg^{-1} and 1,750 to 4,980 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 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). Dissolution of gypsum ($CaSO_4 \cdot 2H_2O$), 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. 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, http://mrdata.usgs.gov/geochemistry/ngs.html).

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.

Parameter	Sample	Transect 1†	Transect 2	Transect 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 (µg kg^{-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)aA,	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 (μg kg^{-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 (μg kg^{-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.

CONCLUSIONS

The objectives of this study were to (i) determine if floodwater quality affects F-M area 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 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 compared to 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. 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 creating 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.

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