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Water Quality, Sediment, and Soil Characteristics near Fargo-Moorhead Urban Areas as Affected by Major Flooding of the Red River of the North

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Spring flooding of the Red River of the North (RR) is common, but little information exits on how these flood events affect water and overbank sediment quality within an urban area. With the threat of the spring 2009 flood in the RR predicted to be the largest in recorded history and the concerns about the flooding of farmsteads, outbuildings, garages, and basements, the objectives of this study, which focused on Fargo, ND, and Moorhead, MN, were to assess floodwater quality and to determine the quantity and quality of overbank sediment deposited after floodwaters recede and the quality of soil underlying sediment deposits. 17β-Estradiol was detected in 9 of 24 water samples, with an average concentration of 0.61 ng L^{-1}. Diesel-range organics were detected in 8 of 24 samples, with an average concentration of 80.0 μg L^{-1}. The deposition of sediment across locations and transects ranged from 2 to 10 kg m^{-2}, and the greatest mass deposition of chemicals was closest to the river channel. No gasoline-range organics were detected, but diesel-range organics were detected in 26 of the 27 overbank sediment samples (maximum concentration, 49.2 mg kg^{-1}). All trace elements detected in the overbank sediments were within ranges for noncontaminated sites. Although flooding has economic, social, and environmental impacts, based on the results of this study, it does not appear that flooding in the RR in F-M led to decreased quality of water, sediment, or soil compared with normal river flows or resident soil.

In March 2009, the Red River of the North (RR) at Fargo, ND, and Moorhead, MN (F-M), reached the highest flood stage in its recorded history (275.1 m above sea level) (Fig. 1) (USGS, 2010a). Much of the lower-lying areas within the F-M area were flooded for more than 10 wk. The predominant land use in the RR drainage basin is agriculture, where the main crops are corn (*Zea mays* L.), soybeans (*Glycine max*), sugar beets (*Beta vulgaris*), and wheat (*Triticum* spp.) (USDA–NASS, 2010), and approximately 19% (∼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, whose combined population is approximately 143,000 (US Census Bureau, 2011), 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) occupy lands along its banks. At least two community gardens were flooded for greater than 20 d during this flood, and a much greater number of personal gardens were likely affected. Extensive quantities of overbank sediment were deposited on this urban landscape, which were from "muddy flooding" (Boardman and Vandaele, 2010) and from river channel erosion.

The rate and magnitude of spring flooding in the RR basin hinges on various contributing factors, including (i) precipitation amounts in the previous 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, North Dakota to only 0.038 m km^{-1} at the North Dakota–Manitoba (Canada) border (International Joint Commission, 2000; Macek-Rowland, 1997; Todhunter, 2001). In 2009, these combined factors contributed to historic flood levels of the RR in F-M.

Chemicals, dissolved in water and attached to solids (mineral and organic), transported via "muddy flooding" and urban runoff from target to nontarget areas may affect water quality

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Abbreviations: CEC, cation exchange capacity; DRO, diesel-range organics; E1, estrone; E2, 17β-estradiol; EC, electrical conductivity; F-M, Fargo, ND, and Moorhead, MN; GRO, gasoline-range organics; RR, Red River of the North.

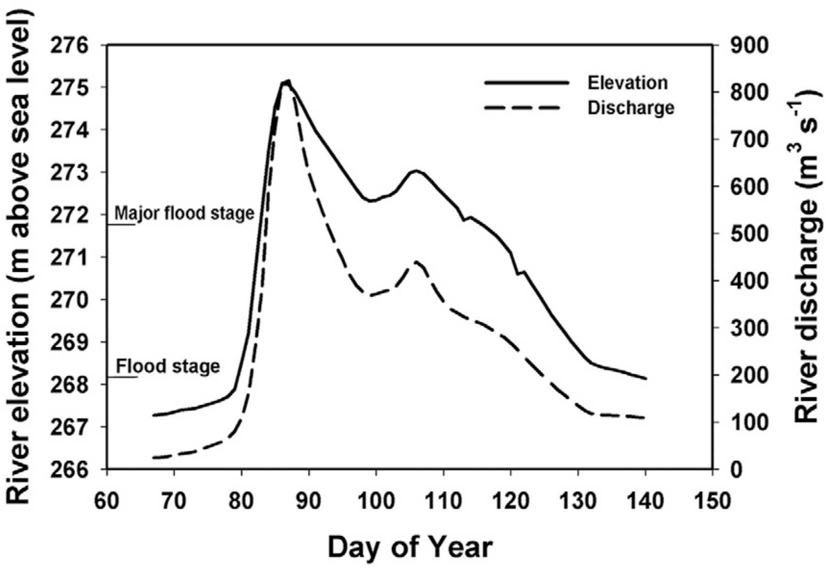

Fig. 1. 2009 Red River of the North elevation above sea level and discharge recorded at the USGS gaging station in Fargo, ND (http://fargoflood.dreamhosters.com/level2009/data.cgi).

and soil quality after floodwaters recede. Chemicals may include natural and agrichemicals (Cook, 2007; Hubbard et al., 2011; Tian and Zhou, 2007), organics (Herngren et al., 2010; Kolpin et al., 2004), and trace elements (Du Laing et al., 2008). Many of these chemicals may not negatively affect urban or rural environments; however, fruits and vegetables grown on flooded soils can uptake contaminants, affecting food safety (Kipopoulou et al., 1999; Samsoe-Peterson et al., 2002).

Although social and economic studies have been conducted in the RR with respect to flood events (Hearne, 2007; International Joint Commission, 2000; James and Korum, 2001), little information exists on the how major flooding affects urban areas in the southern RR basin. The objectives of this study were to (i) determine changes in water quality between upstream and downstream locations within the F-M area during the 2009 flooding event, (ii) to determine the quality and quantity of the overbank sediment in the F-M area after floodwaters receded, and (iii) to determine the quality of soil underlying overbank sediment deposits.

Materials and Methods

Water Sampling

Water samples from the RR were taken on day of year (DOY) 83 (24 Mar.), 84, 85, 86, 89, 91, 93, 98, 105, 112, 119, and 126 (6 May) from two locations during the spring 2009 flood to assess water quality. Location 1 was the 52nd Avenue South Bridge (−96.796789 W, 46.803362N) on the south side of F-M, which is upstream of the most populated urban areas. Location 2 was the 40th Avenue North Bridge (−96.791386 W, 46.933856 N) on the north edge and downstream of the main urban areas (Fig. 2). The river distance between these two bridges during nonflood conditions is 35.6 km, but during this flood the straight-line distance was approximately 14.5 km. Water samples (n = 1) were collected each sampling day from the center of the RR from each bridge by lowering a 2-L stainless steel beaker 0.25 m below the water surface. The beaker was flushed three times before a sample was collected for analysis. Water samples for total solids (suspended plus dissolved ions), NO_3–N, NH_4–N, PO_4, pH, electrical conductivity (EC), SO_4, and Cl were transferred by pouring and stored in plastic 500-mL bottles. Samples for 17β-estradiol (E2) and estrone (E1) were stored in 50-mL narrow-mouth, high-density polyethylene bottles and were frozen until analysis. Samples for gasoline-range organics (GRO) and diesel-range organics (DRO) were stored in 500-mL glass jars (220–0500, I-CHEM Brand Products). All samples from both locations were taken within 1 h of each other. Water pH and EC were measured using an ion probe (SensIon 378, HACH Co.). Nitrate-N and NH_4–N concentrations were measured using EPA methods 350.1 and 353.2, respectively (Keith, 1996), with flow injection (FIAlab 2500, FIAlab Instruments, Inc.). Orthophosphate concentration was determined using USEPA Method 365.1 (Keith, 1996) with flow injection (FIAlab 2500). Sulfate and chloride concentrations were determined using the EPA methods 375.2 and 140.4, respectively (Keith, 1996), with flow injection. Total solids were determined by oven-drying (105°C, 24 h) 50 mL of each sample. Each of these chemical constituents was quantified within 48 h after collection. 17β-Estradiol and E1 were quantified using LC-MS/MS in negative ion mode following the methods of Derby et al. (2011) and Thompson et al. (2009) at the USDA-ARS Biosciences Research Laboratory (Fargo, ND). Gasoline-range organics and DRO were determined by the North Dakota Department of Health (Bismarck, ND) using EPA methods 5035 and 8260B, and 3550C and 8270D, respectively (USEPA, 1996a,b; 2007a,b). Reporting limits for NO_3–N, NH_4–N, PO_4, SO_4, Cl, 17β-estradiol, E1, GRO, and DRO were 0.1, 0.01, 0.01, 2, and 1 mg L^{-1}, 0.1 and 0.1 ng L^{-1}, and 1 and 40 μg L^{-1}, respectively.

Sediment and Soil Sampling

Overbank 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 was 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 (Fig. 2). All locations were dominated by Kentucky Bluegrass (*Poa pratensis* L.), but location B did have mature Northern Hackberry (*Celtis occidentalis* ssp.), Green Ash (*Fraxinus pennsylvanica* Marsh.), and American Linden (*Tilia Americana* L.) trees within the sampling area.

All overbank sediment and soil samples were collected as soon as floodwaters receded. Each location included three transects parallel to the river channel. 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; Fig. 3). Transects at each location were measured for equal points of elevation using a rod and transit and varied in distance from each other from 20 to 60 m. Each transect was comprised of 17 sampling points of overbank sediment and underlying soil, which allowed for a distribution of samples across each transect. Sampling points were approximately

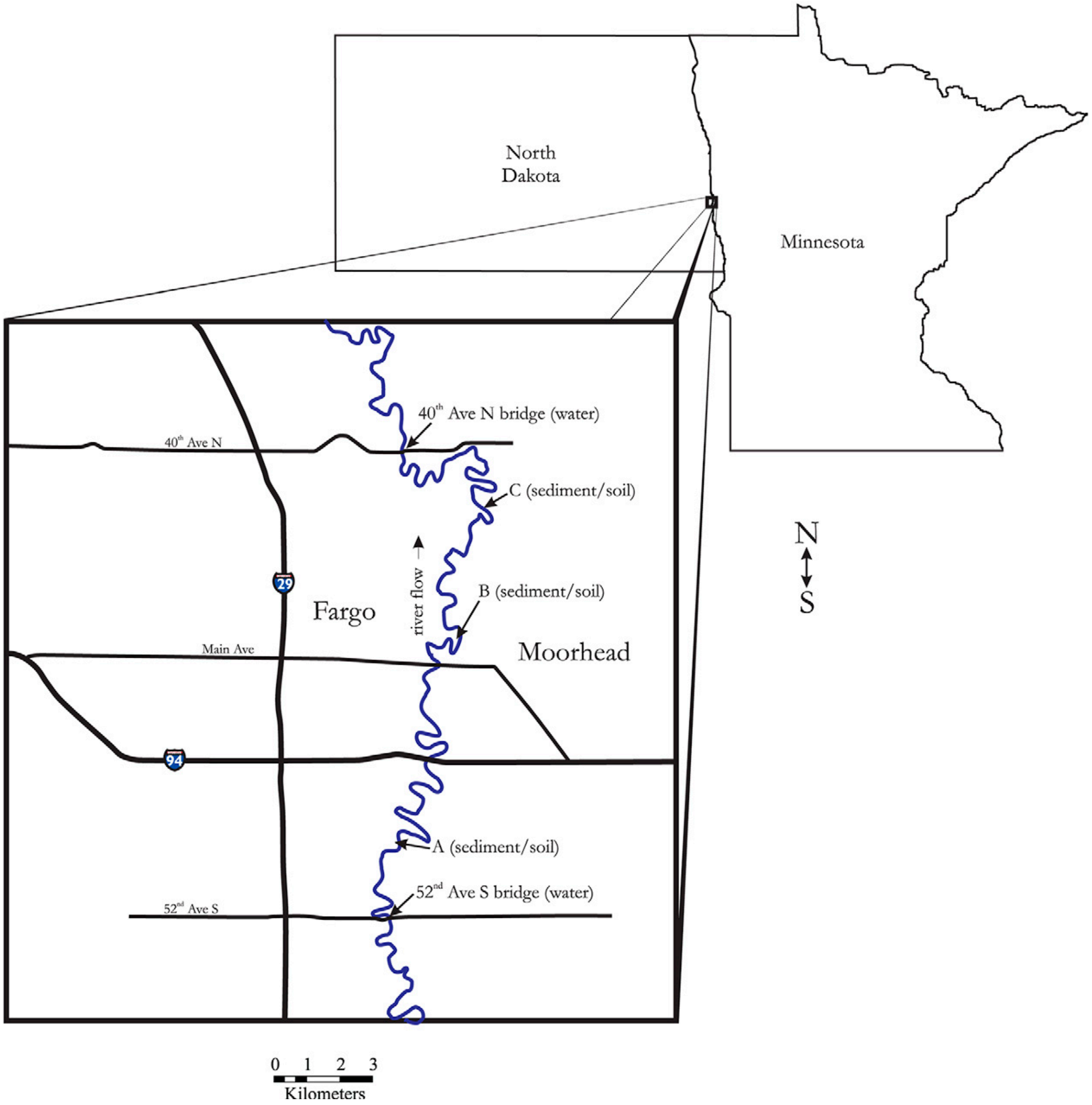

Fig. 2. Diagram depicting water and overbank sediment/soil sampling locations near the Red River of the North at Fargo, ND, and Moorhead, MN.

2 m apart from each other. None of the locations investigated here had been fertilized in the past 10 yr. Care was taken to not sample areas where water ponded after floodwaters receded.

The soil at all locations was from the Cashel series (fine, smectitic, calcareous, frigid, Aquertic Udifluvents). Overbank sediment samples were collected at each point using the middle 15-cm section of a 19-L HDPE bucket (3827, USPlastic Corp.), which had an internal area of 0.06 m^2. Cleaned plastic spatulas were used to remove the sediment, which was placed in plastic bags and put in coolers for transport. Depth of overbank sediment was determined by the presence or absence of Kentucky Bluegrass and structured soil. After overbank sediment was removed, four soil cores to a depth of 10 cm were taken from where the sediment had been removed using a stainless steel probe (3.2 cm inner diameter) and stored as noted above for the overbank sediment. All overbank sediment and soil samples were transported to North Dakota State University, Fargo, ND. Samples were weighed and subsampled for trace elements, gravimetric water was measured, and all samples were frozen within 24 h. Overbank 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 an acid-washed, chemical porcelain mortar and pestle. A 4:1 methanol/deionized water solution was used to clean all sampling equipment between samples. The bulk density of this sediment was 1000 kg m^{-3}.

Total C and N were measured by high-temperature combustion (TruSpec CHNS, LECO). Inorganic C was determined using a modified version of the pressure-calcimeter method of Sherrod et al. (2002), and organic C was determined to be the difference between total and inorganic C. Olsen-P (Olsen et al., 1954) was quantified with a flow injection analyzer. Overbank sediment and soil were analyzed for pH and EC in 1:1 soil/deionized water using ion probes (SensIon 378, HACH 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 USEPA Method 353.2 (Keith, 1996).

Table 1. Number of days that each location and transect was inundated by floodwaters and the number of days between submergence and overbank sediment and soil sampling. All samples were taken in 2009 along the Red River of the North within the city limits of Fargo, ND, and Moorhead, MN, after a major flood event.

Location†	Transect	Distance from the river channel	Elevation above sea level	Days inundated by floodwaters	Days between submergence and sampling	Day of year that sampling occurred
		m		d		
A	1	23	272.0	31	15	127
	2	53	271.2	37	9	127
	3	76	270.2	59	1	138
B	1	33	270.4	41	10	128
	2	54	268.7	44	10	139
	3	83	268.4	54	5	139
C	1	23	270.8	42	5	127
	2	45	268.2	57	1	138
	3	71	267.6	59	1	138

† A, B, and C indicate an upstream residential lawn, a centrally located city park, and a downstream residential lawn, respectively.

Total Hg was determined using a direct Hg analyzer (DMA-80, Milestone Inc.) and USEPA Method 7473 (USEPA, 2009).

Gasoline-range organics and DRO from the overbank sediment and soil were collected within 0.25 m from three randomly chosen sampling locations along each transect as defined above. Sediment samples were taken using plastic spatulas. Soil was taken using a stainless steel sampler, stored in 500-mL glass jars (220–0500, I-CHEM Brand Products), 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 overbank sediment and soil from five sampling areas from each transect with a hydrometer (ASTM 152-H Soil Hydrometer, H-B Instrument Co.) following the procedure of Gee and Bauder (1986). From these same sampling areas, 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) and quantified using inductively coupled plasma mass spectrometry. 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 (v. 8.0, SAS Institute Inc.). Student's *t* test was used to test for differences between overbank sediment and soil. Least squares means comparisons using Tukey's honestly significant difference (HSD) were used to test for differences in physical and chemical parameters of the overbank sediment between locations. Tukey's HSD was used to compare mean deposition across days of inundation, which was followed by linear regressions to investigate the relationships between length of inundation and mass deposition. All statistical analysis were conducted with $\alpha = 0.05$ and were considered significant at the $p \leq 0.05$ level.

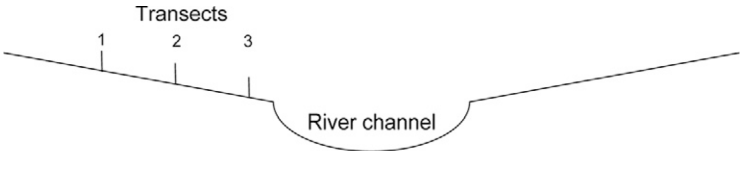

Fig. 3. Relative transect locations that were sampled after the 2009 flood in Fargo, ND, and Moorhead, MN.

Results and Discussion

Water Quality

Total solids in water samples ranged from approximately 300 to 600 mg L^{-1} (Table 2). Mean concentrations across locations and dates were similar to other samples collected within F-M from 2001 to 2008 (mostly summer months, nonflood conditions) (Ivashchenko, 2009; Ryberg, 2006). Water at the downstream location had numerically greater concentrations of total solids in the first half of sampling than in the second half (Table 2), possibly due to deposition as river discharge rates decreased (Fig. 1). Average NO_3–N concentrations in water samples during the sampling period (0.3 mg L^{-1}) were similar to or less than Ivashchenko (2009) and Ryberg (2006) (Table 2), which was not unexpected due to the dilutional effect from the high river discharge during our study (Kolpin et al., 2004). 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 (Table 2).

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 (Table 2). Although numerical differences in PO_4 between upstream and downstream F-M were not observed, Ivashchenko (2009) showed that PO_4 concentrations were generally higher downstream of the two F-M wastewater treatment plants, which are located 1.9 and 14.1 km upstream of the 40th Avenue North location (Fig. 2). Samples in the Ivashchenko (2009) study were collected over a longer time period (approximately April to October), and river discharges ranged from 21 to 113 m^3 s^{-1}, where typical base flow through F-M is approximately 50 m^3 s^{-1}. However, Ryberg (2006) reported average PO_4 concentrations from 2003 to 2005 study to be three times greater than the average concentration reported here (Table 2), which may be a result of the mean river discharge in the Ryberg study (62 m^3 s^{-1}) being approximately 12 times less than discharges reported in this study (Fig. 1).

The pH values averaged 7.8 at both water sampling locations (Table 2). Electrical conductivity values of floodwater were similar at both sampling locations but slightly increased over the flood event, which may have been due to the increases in SO_4 and Cl. Average SO_4 and Cl concentrations were approximately 105 and 11 mg L^{-1} at both locations, respectively, and both trended upward as river flow decreased (Table 2), perhaps due to decreased dilution (Kolpin et al., 2004; Ryberg, 2006). Electrical conductivity and pH values are similar to those reported in Ivashchenko (2009) and Ryberg (2006). The SO_4 results reported here were approximately 50 mg L^{-1} less than the average value reported by Ryberg (2006).

17β-Estradiol was detected in 9 of 24 water samples, with an average concentration of 0.61 ng L^{-1} and no E1 detections. Concentrations here were similar to those found by Kolpin et al. (2002), who detected E2 in 85 of 139 streams sampled across 30 states during 1999 and 2000, with concentrations ranging from 0.0 to 1.5 ng L^{-1}. The results from this study are the first known values reported for floodwaters. Concerns surrounding these hormones stem from their abilities 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., 2002). The source of 17β-estradiol may have been livestock facilities, wild animals, or wastewater treatment plants in the watershed, but its presence is more likely an indicator of anthropogenic events.

Diesel-range organics were detected in 8 of 24 samples, with an average concentration of 80.0 μg L^{-1}, whereas no GRO was found in any sample. The concentration range of DRO was 0.0 to 108 ng L^{-1} (data not shown). During a major flood in the RR in 1997, petroleum products were seen in the river after basements with fuel oil tanks and outbuildings with stored fuel and chemicals were flooded (R. Backman, personal communication, 2011). Given that much of the RR was more prepared for large-scale flooding in 2009 than in 1997, the DRO and GRO results are encouraging in that people living in the RR seemingly took measures to reduce the effects of flooding on water quality.

Sediment and Soil Characterization

The texture of the overbank sediment and soil was predominantly clay and silt and generally contained less than 10 g kg^{-1} sand-sized fractions (Table 3). 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 overbank sediment were greater than in the underlying soil, and silt concentrations were typically greater in the underlying soil. Overbank 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).

Table 2. Concentrations of PO_4, NO_3–N, NH_4–N, Cl, SO_4, and total solids and electrical conductivity and pH values from water samples taken in 2009 from upstream and downstream locations from the Red River of the North within the city limits of Fargo, ND, and Moorhead, MN, during a major flooding event.

Day of year	Location†	PO_4	NO_3–N	NH_4–N	Cl	SO_4	TS‡	EC§	pH
		mg L^{-1}						dS m^{-1}	
83	upstream	0.04	0.35	0.07	8.25	54.8	472	0.19	7.5
	downstream	0.15	0.44	0.05	10.3	63.3	487	0.22	7.5
84	upstream	0.03	0.24	0.02	6.99	51.2	503	0.18	7.5
	downstream	0.10	0.36	0.03	8.06	52.3	603	0.19	7.5
85	upstream	0.05	0.21	0.01	7.69	48.3	493	0.17	7.5
	downstream	0.03	0.12	0.02	7.69	50.4	537	0.18	7.5
86	upstream	0.27	0.25	BQL¶	6.41	29.7	301	0.16	7.6
	downstream	0.04	0.29	0.01	7.87	48.4	537	0.18	7.5
89	upstream	0.07	0.36	0.02	8.10	53.4	352	0.19	7.7
	downstream	0.08	0.34	0.01	8.02	49.0	372	0.19	7.6
91	upstream	0.11	0.39	0.06	12.2	95.6	386	0.24	7.7
	downstream	0.10	0.37	0.04	9.30	77.8	397	0.22	7.7
93	upstream	0.12	0.41	0.04	10.7	119	382	0.27	7.7
	downstream	0.11	0.40	0.08	11.3	105	372	0.25	7.7
98	upstream	0.13	0.48	0.08	12.5	144	538	0.38	7.9
	downstream	0.12	0.59	0.09	12.8	140	513	0.38	7.8
105	upstream	0.08	0.28	0.03	9.97	106	457	0.34	7.8
	downstream	0.07	0.20	0.01	9.10	93.7	392	0.31	7.8
112	upstream	0.09	0.18	0.03	13.2	162	609	0.40	7.9
	downstream	0.10	0.19	0.06	13.1	164	528	0.43	7.8
119	upstream	0.01	0.10	0.01	13.1	186	612	0.48	8.1
	downstream	0.01	0.11	0.04	13.7	184	568	0.47	8.1
126	upstream	0.06	0.18	0.03	18.0	210	633	0.61	8.2
	downstream	0.07	0.19	0.04	18.6	218	613	0.61	8.2

† The upstream location was the 52nd Avenue South Bridge (–96.796789 W, 46.803362 N) on the south side of Fargo-Moorhead (upstream of the most populated urban areas), and the downstream location was the 40th Avenue North Bridge (–96.791386 W, 46.933856 N) and downstream of the most populated urban areas within Fargo-Moorhead.

‡ Total solids (suspended plus dissolved).

§ Electrical conductivity.

¶ Below quantification limit.

Table 3. Physical and chemical parameters of overbank sediment remaining from all locations after floodwaters receded and from underlying soil where overbank sediment samples were taken. All samples were taken in 2009 along the Red River of the North within the city limits of Fargo, ND, and Moorhead, MN, after a major flooding event.

Location†	Transect‡	Sample§	Parameter¶								
			Clay	Silt	EC	pH	CEC	Organic C	Total N	Olsen P	DRO
			——— g kg^{-1} ———		dS m^{-1}		$cmol_{(+)}$ kg^{-1}	——— g kg^{-1} ———		——— mg kg^{-1} ———	
A	1	SED	497 (27)#a††	503 (27)b	1.0 (0.2)a	7.2 (0.1)a	30.7 (1.3)b	46.0 (3.3)b	4.5 (0.2)b	35.5 (12.2)a	34.9 (11.2)a
		SOIL	406 (25)b	594 (25)b	0.7 (0.1)b	7.2 (0.1)a	33.3 (1.1)a	49.1 (3.6)a	5.3 (0.3)a	25.5 (4.9)b	1.8 (3.2)b
	2	SED	469 (4.5)a	529 (5.5)b	1.0 (0.1)a	7.3 (0.1)a	25.1 (1.8)b	36.3 (3.4)b	3.9 (0.4)b	32.6 (3.0)a	49.2 (7.8)a
		SOIL	391 (17)b	609 (17)a	0.7 (0.1)b	7.2 (0.1)a	30.6 (1.2)a	40.0 (1.4)a	4.4 (0.2)a	24.9 (5.2)b	1.4 (2.4)b
	3	SED	441 (5.5)a	559 (5.5)b	1.1 (0.2)a	7.4 (0.1)b	21.2 (5.5)b	29.5 (2.2)a	2.7 (0.3)a	27.0 (8.1)a	18.1 (2.8)
		SOIL	418 (6.1)b	582 (6.1)a	0.6 (0.1)b	7.5 (0.0)‡‡a	26.4 (1.5)a	28.9 (1.1)a	3.3 (0.2)a	26.3 (3.9)a	BQL§§
B	1	SED	385 (25)a	615 (25.1)b	1.0 (0.1)a	7.3 (0.1)b	25.0 (2.3)b	44.3 (6.2)a	3.3 (0.5)b	25.3 (3.5)a	49.0 (2.0)a
		SOIL	350 (5.6)b	650 (5.6)a	0.7 (0.1)b	7.3 (0.1)a	29.6 (1.2)a	48.5 (4.3)a	4.5 (0.3)a	10.3 (2.5)b	12.1 (2.2)b
	2	SED	411 (12.1)a	589 (12.1)a	1.1 (0.2)a	7.3 (0.1)a	22.3 (0.9)b	32.7 (4.4)b	2.6 (0.4)b	17.8 (2.1)a	21.6 (18.9)a
		SOIL	392 (17.6)a	607 (15.9)a	0.6 (0.1)b	7.3 (0.1)b	29.3 (1.5)a	36.1 (1.6)a	3.4 (0.2)a	15.6 (3.0)b	3.2 (2.8)a
	3	SED	399 (23)b	601 (23)a	1.2 (0.3)a	7.4 (0.0)b	21.5 (0.98)b	26.1 (2.5)b	2.3 (0.3)a	21.0 (3.5)a	37.0 (12.1)a
		SOIL	424 (8.0)a	576 (8)b	0.6 (0.1)b	7.5 (0.0)a	25.5 (1.5)a	33.0 (1.1)a	3.0 (0.1)a	17.1 (3.4)b	3.2 (2.8)b
C	1	SED	495 (6.1)a	505 (6.5)b	1.6 (0.2)a	7.2 (0.1)b	32.4 (7.8)a	40.9 (4.7)a	3.9 (0.2)a	29.9 (3.5)a	22.3 (0.8)
		SOIL	403 (49.4)b	597 (49.1)a	0.7 (0.1)b	7.3 (0.1)a	30.0 (2.5)b	38.1 (4.3)a	3.4 (0.3)b	15.4 (3.8)b	BQL
	2	SED	505 (9.4)a	495 (9.5)b	1.3 (0.1)a	7.2 (0.1)a	24.7 (1.7)b	32.2 (4.0)a	3.0 (0.3)a	22.5 (3.9)a	22.2 (5.1)a
		SOIL	479 (11.0)b	521 (11.0)a	0.7 (0.1)b	7.3 (0.1)a	32.2 (4.0)a	23.6 (9.5)b	2.3 (0.3)b	12.8 (5.7)b	2.7 (3.8)b
	3	SED	488 (26)a	512 (26)a	0.9 (0.0)a	7.4 (0.0)b	24.1 (0.82)a	25.1 (1.7)a	2.5 (0.1)a	27.9 (2.8)a	17.0 (1.7)a
		SOIL	495 (31)a	505 (31)a	0.7 (0.1)b	7.5 (0.0)a	24.6 (0.67)a	21.2 (1.0)b	2.0 (0.1)a	25.5 (2.2)b	1.6 (2.8)b

† Locations A, B, and C are samples from an upstream residential lawn, a centrally located city park, and a downstream residential lawn, respectively.

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

§ SED, overbank sediment; SOIL, underlying soil (0–10 cm).

¶ EC, electrical conductivity; CEC, cation exchange capacity; DRO, diesel range organics.

Numbers in parentheses are SD ($n = 17$).

†† Different lowercase letters between sediment and soil within location, transect, and parameter indicate statistical difference at the $p \leq 0.05$ level as determined using Student's *t* test

‡‡ Numbers of 0.0 within the SD indicates that values are <0.05.

§§ Below quantification limit.

Electrical conductivity values were consistent across transects and averaged 1.1 and 0.7 dS m^{-1} across all overbank sediment and soil, respectively (estimated saturated paste EC of 2.5 and 1.3 dS m^{-1}, respectively, as computed from Franzen [2007]) (Table 3). At all transects, the overbank sediment had significantly greater ($p \leq 0.05$) EC than the underlying soil, which indicated that the overbank sediment characteristics were different from previous flood events or that the soluble salts in the soil had leached below the depth of 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).

The pH values across locations and transects ranged from 7.2 to 7.5 across all overbank sediment and soil (Table 3). Although some statistical differences did occur, the cumulative evidence does not indicate that the overbank sediment pH is different from the underlying soil. The pH of the overbank sediment was similar to values measured in floodwaters (Table 2). The CEC of the overbank sediment and soil across locations and transects ranged from 21.2 to 32.4 (cmol_c kg^{-1}) and from 24.6 to 33.3 (cmol_c kg^{-1}), respectively (Table 3). At locations A and B, soil CEC was significantly greater ($p \leq 0.05$) than the overbank sediment at all transects (Table 3). Although all locations were the same vegetation type (predominantly Kentucky Bluegrass) 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). The CEC values reported here for the overbank sediment are within the typical range for soils of the RR (L. Swenson, personal communication, 2010).

Organic C concentrations of the overbank sediment and soil across all locations and transects ranged from 25.1 to 46.0 g kg^{-1} and from 21.2 to 49.1 g kg^{-1}, respectively (Table 3). 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, pedon ID S08ND017-002a; USDA–NRCS National Cooperative Soil Survey, 2011). Organic C concentrations between overbank sediment and soil varied, with no discernible pattern (Table 3). Visual evidence during sampling suggested that floating organic matter was greater at higher elevations on the riverbank (transects 1 and 2 compared with transect 3). Velocities on the edges of the river are slower as a result of frictional forces compared with the higher velocities in the center of the river (Chow, 1959), which may have allowed visible OC to be deposited first further away from the main channel of flow.

Total N of the overbank sediment and soil across all locations and transects ranged from 2.3 to 4.5 g kg^{-1} and 2.0 to 5.3 g kg^{-1}, respectively. Total N concentrations decreased with decreasing distance from the river channel for overbank sediment and soil (Table 3). Of the samples collected, less than 5% of the total N was inorganic (NH_4–N + NO_3–N) (data not shown). Given the length of time between overbank sediment exposure to the atmosphere and when samples were collected (Table 1), the concentrations of inorganic N may have been due to mineralization and not to overbank sediment transport. During the 2011 F-M flood, NO_3–N concentrations in submerged-sediment samples, which were extracted immediately in the field, were significantly less ($p \leq 0.05$) than those that were air-dried and extracted (this study), and NH_4–N concentrations from field-extracted samples were not significantly different. The results from this 2011 study indicate that caution must be used when investigating overbank sediments in the RR when N speciation is the focus. Using the area of submergence at location A during this flooding event (~1650 m^2) and the average total N and dry overbank sediment deposition values across the transects (Table 4), approximately 35 kg of N was deposited on this residential property during this flooding event, which is approximately 212 kg ha^{-1}. Most of the N found in the overbank 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, much of it may be very stable.

Table 4. Least squares means comparisons of selected overbank sediment deposition parameters across transects. All samples were taken in 2009 along the Red River of the North within the city limits of Fargo, ND, and Moorhead, MN, after a major flooding event.

Parameter	Locations†		
	A	B	C
Sediment, kg m^{-2}	6.7 (0.35)‡b§	8.5 (0.32)a	3.6 (0.40)c
Organic C, g m^{-2}	220.0 (11.4)b	268.2 (10.7)a	118.7 (13.1)c
Total N, g m^{-2}	21.5 (1.0)a	21.7 (0.9)a	11.3 (1.2)b
Olsen P, mg m^{-2}	196.1 (9.5)a	157.4 (8.9)b	96.5 (10.9)c
Hg, μg m^{-2}	301.8 (25.4)b	542.5 (23.8)a	198.8 (29.2)c

† Locations A, B, and C are samples from an upstream residential lawn, a centrally located city park, and a downstream residential lawn, respectively.

‡ Numbers within parentheses are SE ($n = 51$).

§ Different letters by parameter and across rows indicate statistical difference at the $p \leq 0.05$ level by using the Tukey honestly significant difference test.

Olsen P of the overbank sediment and soil across locations and transects ranged from 17.8 to 35.5 mg kg^{-1} and from 10.3 to 26.3 mg kg^{-1}, respectively (Table 3), where the Olsen P in the overbank sediment was commonly statistically greater ($p \leq 0.05$) than in the underlying soil. The P enrichment in the overbank sediment is possibly due to P being bound to fine-grained sediment transported in runoff (Rekolainen, 1989). Using the area of submergence for location A and the information from Table 4, approximately 0.3 kg of Olsen-extractable P was deposited on this property. Phosphorus concentrations observed within a single watershed and within a single runoff event are a result of several interacting factors, including season (growing and nongrowing), tillage practices, vegetation type, and application of fertilizers (Rekolainen, 1989).

Diesel range organics within the overbank sediment and soil across locations and transects ranged from 17.0 to 49.2 mg kg^{-1} and from no detection to 12.1 mg kg^{-1}, respectively (Table 3). Overall, DRO was present in 26 out of the 27 overbank sediment samples analyzed and in 11 of the 27 soil samples (Table 3). In a DRO degradation study using soils planted with grasses and legumes, Pichtel and Liskanen (2001) determined that DRO degradation was fairly rapid, from approximately 450 to 100 μg g^{-1} in 100 d in a soil planted to grasses (calculated half-life of approximately 46 d). Therefore, the likelihood of degradation of DRO detected in the sediment to the concentrations found in the soil is high. There were no GRO detected in the overbank sediments or soils.

In general, trace element concentrations from transect 3 were not statistically different between overbank sediment and soil at all locations and were within levels for noncontaminated soils (Kabata-Pendias, 2011) (Table 5). Mercury in the overbank sediment and soil, for example, had mean concentrations of approximately 55 and 61 μg kg^{-1}, respectively,

Table 5. Trace element concentrations for overbank sediment (SED) and soil (SOIL) (0–10cm) from Transect 3, which was located closest to the river channel. All samples were taken in 2009 along the Red River of the North within the city limits of Fargo, ND, and Moorhead, MN, after a major flooding event.

Parameter	Sample†		Location‡	
		A	B	C
			mg kg^{-1}	
As	SED	6.8 (0.33)§a¶	18.3 (25.5)a	7.9 (0.33)a
	SOIL	16.4 (23.8)a	6.3 (0.26)a	8.2 (0.22)a
B	SED	14.8 (0.84)a	14.2 (1.6)a	14.2 (1.1)a
	SOIL	14.6 (0.84)a	14.8 (1.3)a	14.4 (1.1)a
Ba	SED	171 (3.2)a	194 (4.9)a	181 (3.3)b
	SOIL	171 (5.8)a	196 (11.0)a	187 (2.6)a
Bi	SED	0.20 (0.0)#a	0.24 (0.05)a	0.22 (0.04)a
	SOIL	0.22 (0.04)a	0.28 (0.04)a	0.26 (0.05)a
Cd	SED	0.50 (0.07)a	0.50 (0.0)a	0.56 (0.05)a
	SOIL	1.4 (2.0)a	0.56 (0.09)a	0.58 (0.04)a
Co	SED	10.0 (0.51)a	9.5 (0.34)a	9.9 (0.16)b
	SOIL	9.9 (0.30)a	9.2 (0.34)a	10.4 (0.44)a
Cr	SED	27.8 (2.7)a	35.4 (16.1)a	28.4 (4.6)a
	SOIL	25.0 (2.1)a	25.0 (2.6)a	28.0 (2.2)a
Cu	SED	22.5 (1.6)a	23.2 (1.3)a	21.6 (0.56)b
	SOIL	23.4 (0.79)a	24.3 (0.65)a	23.2 (0.74)a
Ga	SED	4.0 (0.0)a	4.0 (0.0)a	4.0 (0.0)b
	SOIL	4.0 (0.0)a	4.0 (0.0)a	4.6 (0.55)a
La	SED	18.4 (0.55)a	18.0 (0.0)b	17.6 (0.55)b
	SOIL	18.6 (0.55)a	18.6 (0.55)a	18.6 (0.55)a
Mn	SED	812 (63.7)a	768 (71.3)a	1070 (62.8)a
	SOIL	782 (58.5)a	668 (369)a	956 (43.3)b
Mo	SED	0.64 (0.18)a	1.3 (1.1)a	0.70 (0.23)a
	SOIL	0.62 (0.16)a	0.52 (0.19)a	0.56 (0.05)a
Ni	SED	26.5 (1.4)a	24.3 (1.2)a	25.1 (0.82)b
	SOIL	27.0 (0.95)a	24.4 (0.54)a	26.9 (0.84)a
Pb	SED	12.1 (0.40)b	24.4 (3.6)a	13.4 (0.61)a
	SOIL	13.2 (0.74)a	22.3 (1.8)a	14.2 (0.51)a
Sb	SED	0.30 (0.0)a	0.40 (0.10)a	0.28 (0.04)a
	SOIL	0.30 (0.0)a	0.30 (0.0)a	0.28 (0.04)a
Sc	SED	3.4 (0.25)a	3.1 (0.11)a	3.4 (0.23)b
	SOIL	3.4 (0.19)a	3.0 (0.15)a	3.8 (0.17)a
Sr	SED	56.8 (1.8)a	67.6 (1.3)a	61.0 (1.2)a
	SOIL	51.2 (1.1)b	63.8 (0.84)b	50.2 (1.9)a
Ti	SED	0.28 (0.0)a	0.26 (0.0)a	0.30 (0.0)a
	SOIL	0.28 (0.0)a	0.30 (0.0)a	0.30 (0.0)a
U	SED	1.5 (0.07)a	1.5 (0.04)a	1.4 (0.07)a
	SOIL	1.4 (0.08)b	1.5 (0.05)a	1.4 (0.0)a
V	SED	47.2 (1.3)a	42.4 (1.3)a	45.8 (2.2)a
	SOIL	44.8 (3.6)a	44.2 (1.8)a	48.6 (2.7)a
Zn	SED	76.8 (2.8)b	87.6 (5.5)a	83.4 (3.2)a
	SOIL	84.0 (3.5)a	86.4 (1.7)a	85.4 (2.1)a
			μg kg^{-1}	
Hg	SED	45.7 (6.0)b	60.9 (14.6)b	54.7 (6.3)a
	SOIL	49.1 (3.1)a	74.7 (11.1)a	55.4 (4.0)a

† SED, overbank sediment; SOIL, underlying soil (0–10 cm).

‡ Locations A, B, and C are samples from an upstream residential lawn, a centrally located city park, and a downstream residential lawn, respectively.

§ Numbers in parentheses represent the SD ($n = 5$).

¶ Different lowercase letters between sediment and soil within location, transect, and parameter indicate statistical difference at the $p \leq 0.05$ level as determined using Student's *t* test

Numbers of 0.0 within the SD indicates that values are <0.05.

Table 6. Mass deposition of selected parameters and days of inundation for each transect. All samples were taken in 2009 along the Red River of the North within the city limits of Fargo, ND, and Moorhead, MN, after a major flooding event.

Location†	Transect‡	Days of inundation	Dry sediment	Organic C	Total N	Olsen P	Hg
			kg m^{-2}	——— g m^{-2} ———		mg m^{-2}	μg m^{-2}
A	1	31	2.8 (1.0)§c¶	132.5 (53.6)b	12.8 (4.9)b	101.4 (46.0)b	134.4 (46.7)c
	2	37	6.5 (1.0)b	236.6 (45.4)a	25.6 (4.8)a	212.7 (42.3)a	279.7 (63.0)b
	3	59	8.4 (1.3)a	246.6 (37.7)a	22.8 (3.4)a	225.4 (75.7)a	381.2 (67.8)a
B	1	41	5.0 (2.0)b	216.9 (81.9)b	16.1 (5.8)b	120.8 (38.5)b	311.5 (145.0)b
	2	44	9.3 (2.4)a	309.2 (107.2)a	24.1 (7.1)a	164.8 (42.8)a	646.5 (259.3)a
	3	54	10.3 (3.3)a	273.2 (102.0)ab	23.9 (8.9)a	178.0 (68.0)a	628.2 (268.0)a
C	1	42	2.2 (0.7)c	86.7 (26.0)c	8.3 (2.6)c	63.7 (19.8)c	125.2 (51.7)c
	2	57	4.8 (1.9)b	157.1 (72.3)b	14.5 (6.5)b	106.7 (41.7)b	259.6 (101.2)b
	3	59	9.1 (1.6)a	227.2 (43.8)a	22.4 (4.3)a	252.6 (50.9)a	491.9 (77.3)a

† Locations A, B, and C are samples from an upstream residential lawn, a centrally located city park, and a downstream residential lawn, respectively.

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

§ Numbers in parentheses represent SD ($n = 17$).

¶ Different letters within location and across days of inundation for each parameter indicate statistical significance at the $p \leq 0.05$ level by using the Tukey honestly significant difference test.

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 μg kg^{-1}) (DeSutter et al., 2010) and are greater than a statewide survey of surface soils in North Dakota that had an average concentration of 32 μg kg^{-1} (DeSutter et al., 2009). The trace element that was generally higher than would normally be found in global surface soils was Mn (Kabata-Pendias, 2011). Manganese values across locations and transects ranged from 668 to 1070 mg kg^{-1} across all overbank sediment and soil (Table 5). Although some statistical differences did occur, the values reported here do not indicate that overbank sediment Mn is generally different from underlying soil, and the concentrations of Mn found in this study were not unexpected because the average Mn concentration in surface soils in Richland County, just south of Fargo (Cass County; upstream) is approximately 540 mg kg^{-1} (USGS, 2010b).

Overbank sediment deposition across transects was highest at location B ($p \leq 0.05$) compared with the other locations (Table 4). One reason for this might be that locations A and C were void of trees immediately upstream of the sampling area, whereas the average tree basal area at location B was 18 m^2 ha^{-1}, which would reduce stream velocity and allow gravitational forces on the suspended sediment to overcome fluid forces. Because the concentrations of selected parameters in Table 3 were similar across locations (Table 3), the increased overbank sediment deposition at location B likely increased the mass deposition of these parameters. The only exception was for Olsen P, whose mass deposition was significantly greater at location A compared with the other locations.

As days of inundation increased, the deposition of overbank sediment increased ($p \leq 0.05$) at all locations, and the thickest/deepest overbank sediment was deposited along transect 3 after 54 d of inundation (Table 6). Across all locations, days of inundation, and soil chemical parameters, transects having the longest days of inundation had the greatest respective mass deposition. Comparing the two identical days of inundation in Table 5 (i.e., 59 d from locations A and C), deposition for all parameters were very similar. The close relationship between these locations for the 59 d of inundation indicates that similar surfaces (i.e., turfgrass) would likely have similar deposition rates irrespective of their proximity from one another.

Conclusion and Environmental Significance

Major flooding has economic, social, and environmental consequences, and widespread floods in 2011 across the United States were exceptionally prominent. Given the rapid nature of many of these floods, conducting research on the impacts of flooding is commonly done after the event. Water quality parameters in this study were similar between upstream and downstream locations within F-M, and overbank sediment loading was greatest on the sampled areas closest to the river channel; these areas also tended to have the greatest deposition of the investigated chemicals. These results are timely in that little information exists regarding the quality of floodwaters, and even less information is available regarding the quality of the overbank sediment that remains after waters recede. Although overbank sediment remaining after floodwaters recede can be unsightly and cleanup efforts can be labor intensive, these sediments can provide essential plant nutrients for urban riverine ecosystems, which may include turf grass, fruits and vegetables, native grasses, shrubs and trees, and domestic horticultural plants. In addition, treating postflooding sandbags as “hazardous materials” if they had come into contact with floodwaters may not be necessary regarding the inorganic and organic chemicals investigated in this study, but infectious organisms should still be considered.

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