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Sediment Concentrations, Loads, and Particle-Size Distributions in the Red River of the North and Selected Tributaries near Fargo, North Dakota, during the 2011 Spring High-Flow Event

Scientific Investigations Report 2011–5134

U.S. Department of the Interior
U.S. Geological Survey

Cover. Confluence of a tributary with the Rush River near Prosper, North Dakota, during the 2011 spring high-flow event. (Photograph by William C. Damschen, U.S. Geological Survey).

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U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Conversion Factors and Datums

Inch/Pound to SI

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
square mile (mi^2)	259.0	hectare (ha)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton per day (ton/d)	0.9072	metric ton per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Sediment Concentrations, Loads, and Particle-Size Distributions in the Red River of the North and Selected Tributaries near Fargo, North Dakota, during the 2011 Spring High-Flow Event

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Abstract

To provide accurate and reliable information on sediment near the Fargo-Moorhead metropolitan area, the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers conducted a study in the spring (March–May) of 2010 and the spring of 2011 to examine sediment concentrations, loads, and particle-size distributions at nine selected sites in the Red River and its tributaries. Samples of suspended sediment, bed material, and bedload were collected at the nine sites at various time intervals during the high-flow events.

Suspended-sediment concentrations varied spatially during the 2011 spring high-flow event sampling period. Most tributary streams had substantially higher suspended-sediment concentrations compared to suspended-sediment concentrations in the main stem of the Red River, especially at the Sheyenne River sites. Suspended-sediment concentrations on the Red River ranged from 45 to 126 milligrams per liter near Christine, North Dakota and from 49 to 197 milligrams per liter near Fargo, North Dakota. In comparison, the suspended-sediment concentrations ranged from 239 to 1,180 milligrams per liter at the Sheyenne River above Diversion and from 199 to 1,130 milligrams per liter at the Sheyenne River below Diversion. The Buffalo River had the lowest concentrations among the sites; suspended-sediment concentrations in the Buffalo River ranged from 21 to 61 milligrams per liter. Peak measured suspended-sediment concentrations were slightly higher in 2011 at the Red River near Fargo, Sheyenne River above Diversion, and Sheyenne River below Diversion compared to measured suspended-sediment concentrations in 2010. Peak measured suspended-sediment concentrations were lower in 2011 at the Red River near Christine, Maple River, and Wild Rice River compared to measured suspended-sediment concentrations in 2010.

Total sediment loads measured during the 2011 spring high-flow event at the Red River and its tributaries near the Fargo-Moorhead metropolitan area were mainly composed of suspended sediment and were greatest at the Sheyenne River above Diversion compared to the loads at the other eight sites. The calculated total sediment load during the entire event ranged from 3,040 tons at the Lower Branch Rush River (April 7–21) to 188,000 tons at the Sheyenne River above Diversion (April 8 to May 16). The peak daily total sediment loads calculated for the 2011 spring high-flow event ranged from 825 tons per day in the Lower Branch Rush River to 13,209 tons per day in the Sheyenne River above Diversion.

More than 90 percent of the measured suspended sediment was composed of fine-grained material less than 0.062 millimeters in most of the suspended-sediment samples collected during the 2011 spring high-flow event, except for the Sheyenne River. Samples from the Sheyenne River above Diversion had 19 to 43 percent of the suspended sediment with particle sizes greater than 0.062 millimeters and the Sheyenne River below Diversion had 10 to 30 percent of the suspended sediment with particle sizes greater than 0.062 millimeters.

Most of the bedload samples had particle sizes in the 0.5 to 1 millimeter and 0.25 to 0.5 millimeter ranges from the Maple River, Wild Rice River, Rush River, Buffalo River, and Red River sites. The Rush and Lower Branch Rush Rivers also had a greater portion of larger particle sizes in the 1 to 2 millimeter range. The Sheyenne River sites had a greater portion of smaller particle sizes in the bedload in the 0.125 to 0.5 millimeter range compared to the other sites. The bed material in samples collected during the 2011 spring high-flow event demonstrated a wider distribution of particle sizes than were observed in the bedload; the coarsest material was found at the Red River near Christine and the Lower Branch Rush River and the finest material at the Sheyenne River sites.

Introduction

The Red River of the North (Red River) has exceeded the National Weather Service flood stage of 18 feet (ft) in 47 of the past 108 years for the Fargo-Moorhead metropolitan area and every year from 1993 through 2011. Flooding in the

Fargo-Moorhead metropolitan area typically occurs during the spring high-flow event in late March and early April coinciding with the annual snowmelt pattern. Current (2010–2011) flood-management activities in the Fargo-Moorhead metropolitan area such as sandbagging, levee systems, and the Sheyenne River Diversion channel have reduced the effects of flooding. Even with these activities, average annual flood damages are estimated at over $187 million (U.S. Army Corps of Engineers, 2010). As the Fargo-Moorhead metropolitan area continues to grow, future average annual flood damages are estimated at over $195 million, if no additional actions for flood management are taken to reduce flooding (U.S. Army Corps of Engineers, 2010). To reduce the flooding effects, a feasibility study was begun in the Fargo-Moorhead metropolitan area in 2008, under direction of the U.S. Army Corps of Engineers (USACE), St. Paul District, and the sponsor cities of Fargo, N. Dak., and Moorhead, Minn., to investigate measures to reduce flood risk and analyze the potential for Federal participation in implementing a flood-risk management project. The study analyzed a number of possible types of measures and alternative plans that could reduce the flood risk in the Fargo-Moorhead metropolitan area. An array of potential alternatives was considered, including nonstructural flood proofing, diversion channels, levee/floodwall systems, and flood storage. Construction of a North Dakota Diversion Channel around the Fargo-Moorhead metropolitan area was chosen from these plans for further analysis (Blanchard and others, 2011).

Natural-resource agencies were concerned about possible geomorphic effects of the proposed diversion project in the Fargo-Moorhead metropolitan area (U.S. Army Corps of Engineers, 2010). Site-specific information available on sediment transport and riverine geomorphic processes was very limited and has prohibited accurate geomorphic modeling to address those concerns. To provide accurate and reliable information on sediment transport, the U.S. Geological Survey (USGS) in cooperation with the USACE conducted a study in the spring (March–May) of 2010 (Blanchard and others, 2011) and the spring of 2011 to examine sediment concentrations, loads, and particle-size distributions in the Red River and its tributaries near the Fargo-Moorhead metropolitan area. The 2010 and 2011 spring high-flow events provided a unique opportunity to sample sites during high-flow conditions when most sediment generally is transported (Guy, 1970). The USGS collected samples of suspended sediment, bed material, and bedload at six sites during the 2010 spring high-flow event, which are described in Blanchard and others (2011), and at an additional three sites in 2011. The methods and results from the nine sites sampled in 2011 are described in this report.

Description of Study Area

The Red River begins at Wahpeton, N. Dak., at the confluence of the Otter Tail River and the Bois de Sioux River and flows north into Canada before emptying into Lake Winnipeg, Manitoba. The drainage area for the Red River Basin is about 40,200 square miles (mi^2) and encompasses parts of eastern North Dakota and northwestern Minnesota in the United States and southern Manitoba in Canada. The Red River flows through several urban areas along its path including the cities of Fargo, N. Dak.; Moorhead, Minn.; Grand Forks, N. Dak.; East Grand Forks, Minn.; and Winnipeg, Manitoba. Tributaries to the Red River near the Fargo-Moorhead metropolitan area include the Sheyenne, Maple, Wild Rice, Rush, Lower Branch Rush, and Buffalo Rivers (fig. 1).

Purpose and Scope

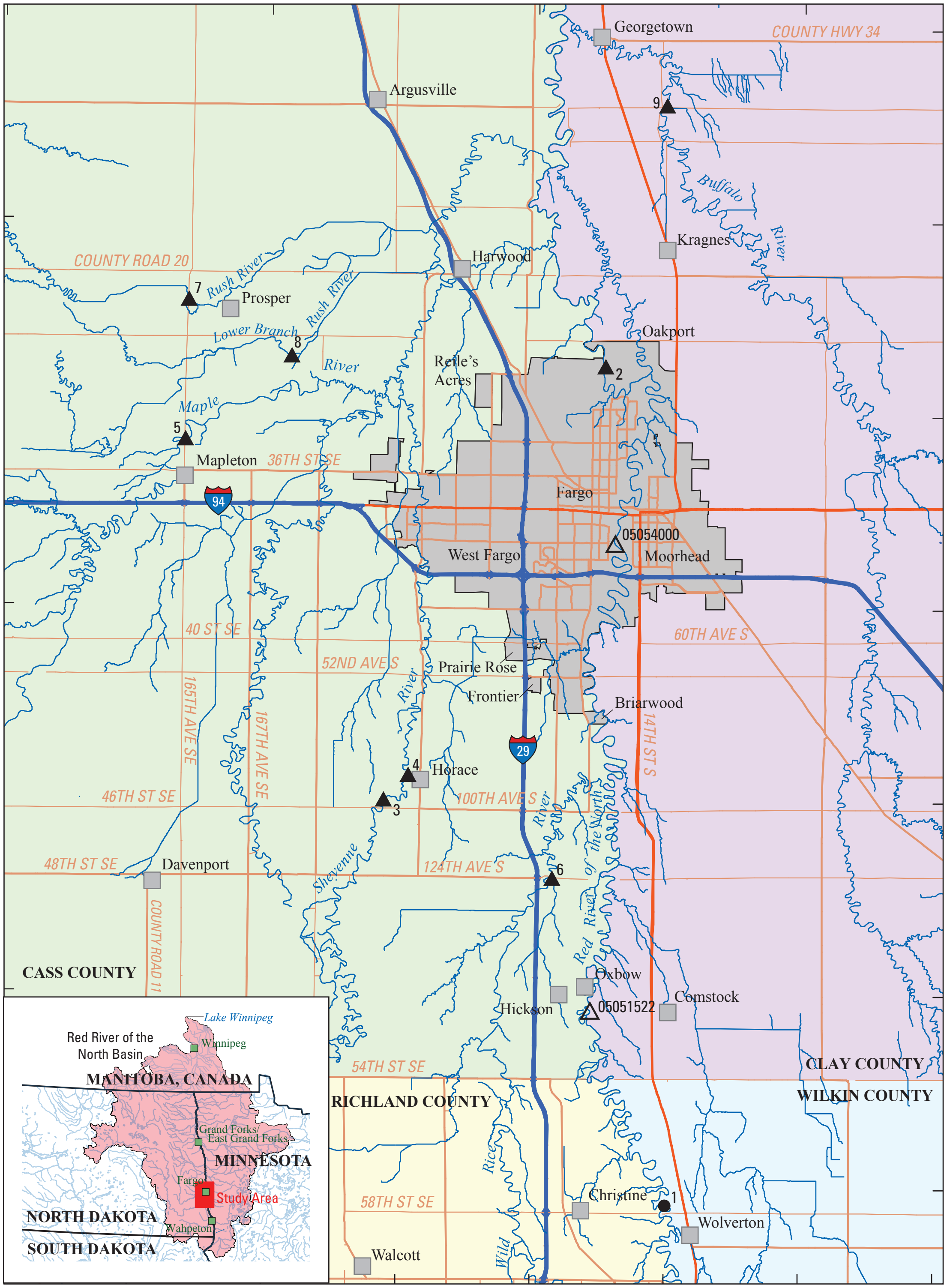
This report describes sediment concentrations, loads, and particle-size distribution during the 2011 spring high-flow event at nine selected sites in the Fargo-Moorhead metropolitan area. Sediment samples were collected from April 4, 2011 (when the spring high-flow event began and ice cover had dissipated), to May 17, 2011 (when streamflow had receded). The data from the samples provided information on transport and distribution of sediment at the nine sites. Comparisons also are discussed for six of the nine sites where data were collected during the 2010 and 2011 spring high-flow events.

Methods of Study

The following sections describe methods used for the collection and analysis of sediment samples and measurement of streamflow. Data were collected by the USGS in the general vicinity of the Fargo-Moorhead metropolitan area and included selected sites at or near USGS streamgages. A total of nine sites were sampled, including two sites on the Red River, upstream and downstream from the Fargo-Moorhead metropolitan area; two sites on the Sheyenne River, one upstream from the Sheyenne River Diversion channel and one site below the Diversion channel; and one site on the Maple River, Wild Rice River, Rush River, Lower Branch Rush River, and Buffalo River (fig. 1; table 1).

Sediment Data Collection

Samples of suspended sediment, bed material, and bedload were collected at nine sites near the Fargo-Moorhead metropolitan area at various time intervals during the 2011 spring high-flow event. Sampling began at each site as soon as ice cover or ice jamming (accumulation of broken ice) was not present at the site. In general, suspended-sediment and bed-material samples were collected every day or every 2 days during the rise and peak of the streamflow hydrograph at each site and at a less frequent interval during the recession of the streamflow hydrograph at each site. Bedload samples were collected on a less frequent basis than the suspended-sediment and bed-material samples. Sampling sites on the Red



Base from U.S. Geological Survey digital data, 1983
Albers Equal-Area Conic projection
Standard parallels 29°30'N and 45°30'N, central meridian 96°00W

0 2.5 5 MILES

0 2.5 5 KILOMETERS

EXPLANATION

- Cities
- 6 Sediment sampling site and streamgage with associated site identification number
- 05051522 Streamgage with associated U.S. Geological Survey station number
- 1 Sediment sampling sites with associated site identification number

Figure 1. Location of selected sites in the study area.

Table 1. Streamflow and sediment data-collection sites for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.

Site identification number (fig. 1)	U.S. Geological Survey station number	Site description	Abbreviated site description	Data collected
1	463421096451000	Red River of the North near Christine, N. Dak.	Red River near Christine	Sediment
05051522	05051522	Red River of the North near Hickson, N. Dak.	Red River near Hickson	Streamflow
05054000	05054000	Red River of the North at Fargo, N. Dak.	Red River at Fargo	Streamflow
2	465603096472900	Red River of the North at County Road 20 near Fargo, N. Dak.	Red River near Fargo	Streamflow, sediment
3	05059300	Sheyenne River above Diversion near Horace, N. Dak.	Sheyenne River above Diversion	Streamflow, sediment
4	05059330	Sheyenne River below Diversion at Horace, N. Dak.	Sheyenne River below Diversion	Streamflow, sediment
5	05060100	Maple River below Mapleton, N. Dak.	Maple River	Streamflow, sediment
6	464243096495100	Wild Rice River near St. Benedict, N. Dak.	Wild Rice River	Streamflow, sediment
7	05060550	Rush River near Prosper, N. Dak.	Rush River	Streamflow, sediment
8	465752096573000	Lower Branch Rush River east of Prosper, N. Dak.	Lower Branch Rush River	Streamflow, sediment
9	465839096412800	Buffalo River east of Kragnes, Minn.	Buffalo River	Streamflow, sediment

River and its tributaries were selected at locations with USGS streamgages so that sediment data could be related to streamflow data. One exception was the sediment data-collection site at the Red River near Christine, N. Dak., which was upstream from the streamgage near Hickson, N. Dak. (USGS station number 05051522) (table 1; fig. 1).

Suspended-sediment concentration (SSC) samples were collected on a frequent basis during the spring 2011 high-flow event to estimate the amount of suspended material being transported past the nine sites during the event. Depth-integrated samplers (Davis, 2005) and the equal-width increment (EWI) method (Edwards and Glysson, 1999; Blanchard and others, 2011) were used to collect samples that represent the vertical and horizontal variability of suspended sediment in the stream channels. Replicate samples were obtained for the SSC samples by removing a representative volume of water from the churn splitter concurrently with the regular sample or collecting a second sample using the same EWI method sequentially with the regular sample.

Bed-material samples were collected with every SSC sample for use in estimating the total sediment load in the channel at the nine sites. Bed-material samples were collected using either a US BMH-60 or a US BM-54 sampler, depending on depths and velocities in the stream cross section (Davis, 2005). The bed-material samples were collected at three to five locations in the stream cross section and then composited into a 1-liter (L) plastic container.

Bedload samples were collected to estimate the sediment transport near the streambed at the nine sites. Bedload samples were obtained using a cable-suspended Helley-Smith Model 8035 sampler (Davis, 2005). Bedload samples were collected at 10 to 20 equal-width sections across the stream cross section. The bedload samples were then composited in a 1-L plastic container. Sequential replicate samples were collected with the regular samples and were obtained by independently sampling the stream cross section twice for bedload.

All samples of suspended sediment, bed material, and bedload were analyzed for particle-size distribution and concentration at the USGS Iowa Water Science Center Sediment Laboratory in Iowa City, Iowa, using methods described in Guy (1969). Some suspended-sediment samples were not analyzed for a full particle-size distribution because of insufficient sediment mass present in the sample. Results from the analysis were stored in the USGS National Water Information System (NWIS) database (*http://nwis.waterdata.usgs.gov/nd/nwis/qw*).

Streamflow Data Collection

Streamflow data were collected for use with the sediment concentration data to calculate sediment loads. Stream stage was measured continuously at all the sampling sites except the Red River of the North near Christine, N. Dak. (table 1; fig. 1). The continuous stage data were used with instantaneous discharge measurements to compute the continuous streamflow from stage-discharge rating curves using methods described in Rantz and others (1982). Data for stream stage and streamflow were stored in the USGS NWIS database (*http://nwis.waterdata.usgs.gov/nd/nwis*). Computed streamflow from the streamgage at the Red River of the North near Hickson, N. Dak. (USGS station number 05051522) was used to compute loads for site 1 (Red River of the North near Christine).

Sediment Data Analysis

The relation between SSC and streamflow was examined to evaluate whether streamflow could be used to predict the sediment load. A Kendall-Sen nonparametric test was conducted to evaluate relations between SSC and streamflow using S-Plus statistical analysis software (TIBCO Software Inc., 2010; Blanchard and others, 2011). Because it is based on ranks, the correlation coefficient for the Kendall-Sen test (tau) is more resistant to outlier effects than the more commonly used Pearson's r correlation coefficient (Helsel and Hirsch, 1992). Measures of correlation between SSC and streamflow are dimensionless and scaled to be in the range of -1.0 to 1.0. A value of 0 indicates no relation between SSC and streamflow. Correlations from 0 to 1.0 (positive relation) indicated that SSC increased as streamflow increased. Correlations from 0 to -1.0 (negative relation) indicated that SSC decreased as streamflow increased. Correlations were considered significant if the probability (two-sided p-value) of rejecting a correct hypothesis (in this case, no trend) was less than or equal to 0.05. The Kendall-Sen test does not assume a normal distribution of the data and provides a linear median estimator of SSC (Sen, 1968).

Total sediment loads were estimated for each of the nine sites during the sampling period by summing the estimated suspended-sediment loads and bedloads. Daily suspended-sediment loads (sediment discharge) were estimated for the nine sites using the daily mean streamflow data and SSC data collected during the 2011 spring high-flow event using the same methods described in Blanchard and others (2011). Two methods were used to estimate the bedload at each site. The first method was to calculate bedload from the measured data, and the second method was to use a modified version of Einstein's procedure (MEP) (U.S. Bureau of Reclamation, 2010) using bed-material particle-size distribution, streamflow, velocity, channel geometry, and water temperature data. The total sediment load for the sampling period was estimated by summing the daily total sediment loads. Daily sediment loads were estimated for the sampling period at each site by using linear interpolation between the days when calculated total sediment loads were available.

Suspended-Sediment Concentration

SSC varied spatially during the 2011 spring high-flow event sampling period. Most of the tributary streams had substantially higher SSC compared to SSC in the main stem of the Red River, especially at the Sheyenne River sites (fig. 2; table 2). SSC on the Red River ranged from 45 to 126 milligrams per liter (mg/L) at site 1 (near Christine) and from 49 to 197 mg/L at site 2 (near Fargo). In comparison, the SSC ranged from 239 to 1,180 mg/L at the Sheyenne River above Diversion (site 3) and from 199 to 1,130 mg/L at the Sheyenne River below Diversion (site 4). The Maple River (site 5) had SSC ranging from 68 to 231 mg/L, the Wild Rice River (site 6) had SSC ranging from 70 to 299 mg/L, the Rush River (site 7) had SSC ranging from 72 to 401 mg/L, and the Lower Branch Rush River (site 8) had SSC ranging from 57 to 361 mg/L (fig. 2; table 2). The Buffalo River (site 9) had the lowest concentrations among the sites, with SSC ranging from 21 to 61 mg/L.

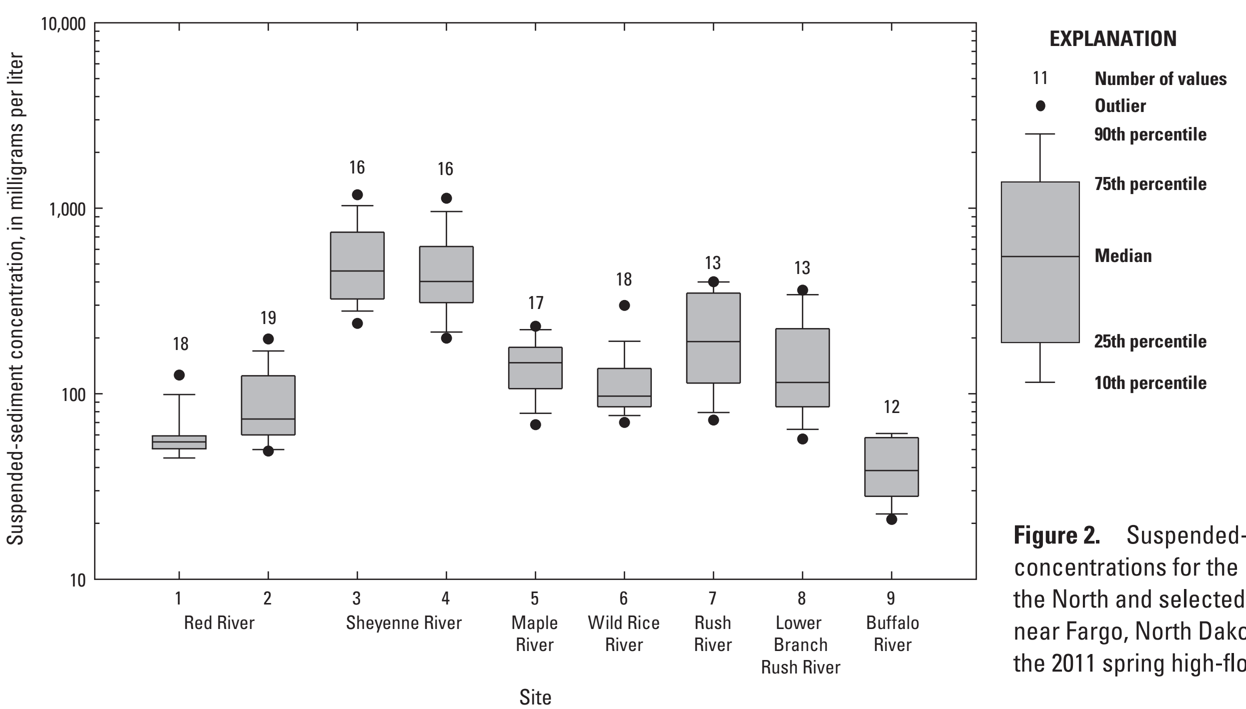


Figure 2. Suspended-sediment concentrations for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.

Table 2. Streamflow, suspended-sediment concentrations, fall diameters, and sieve diameters for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.

[ft^3/s, cubic foot per second; mg/L, milligram per liter; mm, millimeter; +, rising stage; IM, insufficient material for analysis; --, no value; -, falling stage]

Date	Stage condition	Streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Suspended-sediment fall diameter (values in percent finer than size)								Percent finer than suspended sediment sieve diameter of 0.062 mm
				0.002 mm	0.004 mm	0.008 mm	0.016 mm	0.062 mm	0.125 mm	0.250 mm	0.500 mm	
Red River of the North near Christine, N. Dak. (site 1)												
04/06/2011	+	12,700	126	IM	IM	IM	IM	99	99	99	100	--
04/07/2011	+	13,400	96	IM	IM	IM	IM	96	98	100	100	--
04/08/2011	+	13,500	71	IM	IM	IM	IM	IM	IM	IM	IM	99
04/09/2011	-	12,800	55	IM	IM	IM	IM	IM	IM	IM	IM	98
04/10/2011	-	12,100	56	IM	IM	IM	IM	IM	IM	IM	IM	99
04/11/2011	-	11,600	51	IM	IM	IM	IM	IM	IM	IM	IM	96
04/12/2011	-	11,300	60	IM	IM	IM	IM	IM	IM	IM	IM	95
04/13/2011	-	10,800	53	IM	IM	IM	IM	IM	IM	IM	IM	95
04/14/2011	-	10,300	45	IM	IM	IM	IM	IM	IM	IM	IM	98
04/15/2011	-	9,600	45	IM	IM	IM	IM	IM	IM	IM	IM	96
04/16/2011	-	9,020	57	IM	IM	IM	IM	IM	IM	IM	IM	97
04/18/2011	-	9,380	54	IM	IM	IM	IM	IM	IM	IM	IM	96
04/20/2011	-	8,130	53	IM	IM	IM	IM	IM	IM	IM	IM	96
04/22/2011	-	7,860	59	IM	IM	IM	IM	92	94	100	100	--
04/26/2011	-	7,390	59	IM	IM	IM	IM	IM	IM	IM	IM	96
05/02/2011	-	5,880	55	IM	IM	IM	IM	IM	IM	IM	IM	87
05/09/2011	-	4,280	49	IM	IM	IM	IM	IM	IM	IM	IM	89
05/17/2011	-	3,330	47	IM	IM	IM	IM	IM	IM	IM	IM	82
Red River of the North at County Road 20 near Fargo, N. Dak. (site 2)												
04/04/2011	+	6,980	197	IM	IM	IM	IM	99	100	100	100	--
04/05/2011	+	8,950	163	IM	IM	IM	IM	99	99	100	100	--
04/07/2011	+	16,100	170	73	80	85	96	98	99	100	100	--
04/08/2011	+	21,500	156	IM	IM	IM	IM	99	100	100	100	--
04/09/2011	+	23,200	125	IM	IM	IM	IM	IM	IM	IM	IM	100
04/10/2011	+	23,400	99	IM	IM	IM	IM	IM	IM	IM	IM	99
04/11/2011	-	23,100	72	IM	IM	IM	IM	IM	IM	IM	IM	98
04/12/2011	-	22,400	85	IM	IM	IM	IM	IM	IM	IM	IM	99
04/13/2011	-	21,500	60	IM	IM	IM	IM	IM	IM	IM	IM	99
04/14/2011	-	20,500	67	IM	IM	IM	IM	IM	IM	IM	IM	96
04/15/2011	-	19,500	76	IM	IM	IM	IM	IM	IM	IM	IM	97
04/16/2011	-	18,600	57	IM	IM	IM	IM	IM	IM	IM	IM	95
04/17/2011	-	17,600	50	IM	IM	IM	IM	IM	IM	IM	IM	92
04/19/2011	-	15,800	61	IM	IM	IM	IM	IM	IM	IM	IM	94
04/21/2011	-	14,700	73	IM	IM	IM	IM	IM	IM	IM	IM	99
04/25/2011	-	14,100	79	IM	IM	IM	IM	IM	IM	IM	IM	100
05/02/2011	-	11,700	56	IM	IM	IM	IM	IM	IM	IM	IM	89
05/09/2011	-	8,200	49	IM	IM	IM	IM	IM	IM	IM	IM	98
05/16/2011	-	5,460	62	IM	IM	IM	IM	IM	IM	IM	IM	97

Table 2. Streamflow, suspended-sediment concentrations, fall diameters, and sieve diameters for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; mm, millimeter; +, rising stage; IM, insufficient material for analysis; --, no value; -, falling stage]

Date	Stage condition	Streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Suspended-sediment fall diameter (values in percent finer than size)								Percent finer than suspended sediment sieve diameter of 0.062 mm
				0.002 mm	0.004 mm	0.008 mm	0.016 mm	0.062 mm	0.125 mm	0.250 mm	0.500 mm	
Sheyenne River above Diversion near Horace, N. Dak. (site 3)												
04/08/2011	+	4,150	1,180	28	28	29	44	81	92	100	100	--
04/09/2011	+	4,190	968	29	31	32	49	79	90	100	100	--
04/10/2011	+	4,250	796	37	40	47	54	78	91	100	100	--
04/11/2011	+	4,360	771	35	40	44	51	75	99	99	100	--
04/12/2011	Stable	4,400	656	34	40	41	45	71	86	100	100	--
04/13/2011	Stable	4,430	582	31	36	45	48	63	97	100	100	--
04/14/2011	Stable	4,460	534	IM	IM	IM	IM	68	83	99	100	--
04/15/2011	+	4,510	465	IM	IM	IM	IM	65	81	98	100	--
04/16/2011	+	4,550	410	IM	IM	IM	IM	68	83	99	100	--
04/18/2011	+	4,600	452	IM	IM	IM	IM	60	78	98	100	--
04/20/2011	+	4,640	355	IM	IM	IM	IM	74	86	99	100	--
04/22/2011	+	4,630	371	IM	IM	IM	IM	67	81	100	100	--
04/26/2011	+	4,670	314	IM	IM	IM	IM	66	83	100	100	--
05/03/2011	-	4,590	239	IM	IM	IM	IM	63	72	98	100	--
05/09/2011	-	4,430	296	IM	IM	IM	IM	57	77	95	100	--
05/16/2011	-	4,100	304	IM	IM	IM	IM	67	79	99	100	--
Sheyenne River below Diversion at Horace, N. Dak. (site 4)												
04/08/2011	Stable	2,060	1,130	28	38	43	57	88	95	100	100	--
04/09/2011	Stable	2,060	888	37	40	43	61	90	94	100	100	--
04/10/2011	Stable	2,060	745	40	46	53	69	89	96	99	100	--
04/11/2011	Stable	2,090	648	41	43	44	56	87	97	100	100	--
04/12/2011	Stable	2,100	483	40	45	50	55	84	93	98	100	--
04/13/2011	Stable	2,110	451	38	41	45	56	80	91	96	97	--
04/14/2011	Stable	2,120	545	IM	IM	IM	IM	71	81	87	96	--
04/15/2011	Stable	2,140	410	IM	IM	IM	IM	74	89	99	100	--
04/16/2011	Stable	2,160	395	IM	IM	IM	IM	76	92	99	100	--
04/18/2011	Stable	2,190	372	IM	IM	IM	IM	73	87	100	100	--
04/20/2011	Stable	2,220	342	IM	IM	IM	IM	79	91	100	100	--
04/22/2011	Stable	2,220	336	IM	IM	IM	IM	76	91	100	100	--
04/26/2011	Stable	2,230	264	IM	IM	IM	IM	77	91	96	100	--
05/03/2011	-	2,190	199	IM	IM	IM	IM	72	90	99	100	--
05/10/2011	-	2,100	222	IM	IM	IM	IM	75	94	100	100	--
05/16/2011	-	2,020	301	IM	IM	IM	IM	70	82	100	100	--

Table 2. Streamflow, suspended-sediment concentrations, fall diameters, and sieve diameters for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; mm, millimeter; +, rising stage; IM, insufficient material for analysis; --, no value; -, falling stage]

Date	Stage condition	Streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Suspended-sediment fall diameter (values in percent finer than size)								Percent finer than suspended sediment sieve diameter of 0.062 mm
				0.002 mm	0.004 mm	0.008 mm	0.016 mm	0.062 mm	0.125 mm	0.250 mm	0.500 mm	
Maple River below Mapleton, N. Dak. (site 5)												
04/07/2011	+	7,730	174	81	84	88	90	98	99	100	100	--
04/08/2011	-	7,180	163	IM	IM	IM	IM	IM	IM	IM	IM	99
04/09/2011	-	6,390	186	67	70	71	73	83	88	89	97	--
04/10/2011	-	5,610	182	IM	IM	IM	IM	93	97	99	100	--
04/11/2011	-	5,410	171	IM	IM	IM	IM	98	98	99	100	--
04/12/2011	-	5,260	143	IM	IM	IM	IM	IM	IM	IM	IM	98
04/13/2011	-	4,470	147	IM	IM	IM	IM	98	99	99	100	--
04/14/2011	-	4,100	219	IM	IM	IM	IM	IM	IM	IM	IM	99
04/15/2011	+	4,390	231	IM	IM	IM	IM	IM	IM	IM	IM	99
04/16/2011	+	4,620	151	IM	IM	IM	IM	IM	IM	IM	IM	97
04/17/2011	+	4,690	135	IM	IM	IM	IM	IM	IM	IM	IM	98
04/18/2011	+	4,770	108	IM	IM	IM	IM	IM	IM	IM	IM	98
04/21/2011	-	3,900	81	IM	IM	IM	IM	IM	IM	IM	IM	93
04/25/2011	-	3,660	68	IM	IM	IM	IM	IM	IM	IM	IM	94
05/02/2011	-	2,510	105	IM	IM	IM	IM	IM	IM	IM	IM	96
05/09/2011	-	1,630	116	IM	IM	IM	IM	IM	IM	IM	IM	94
05/16/2011	-	1,400	92	IM	IM	IM	IM	97	98	100	--	--
Wild Rice River near St. Benedict, N. Dak. (site 6)												
04/05/2011	+	6,000	180	IM	IM	IM	IM	IM	IM	IM	IM	98
04/07/2011	+	9,000	147	IM	IM	IM	IM	IM	IM	IM	IM	98
04/08/2011	+	9,170	121	IM	IM	IM	IM	IM	IM	IM	IM	97
04/09/2011	-	8,850	94	IM	IM	IM	IM	IM	IM	IM	IM	97
04/10/2011	-	8,570	103	IM	IM	IM	IM	IM	IM	IM	IM	97
04/11/2011	-	8,510	99	IM	IM	IM	IM	IM	IM	IM	IM	97
04/12/2011	-	8,340	94	IM	IM	IM	IM	IM	IM	IM	IM	98
04/13/2011	-	8,040	139	IM	IM	IM	IM	IM	IM	IM	IM	99
04/14/2011	-	7,530	81	IM	IM	IM	IM	IM	IM	IM	IM	95
04/15/2011	-	6,980	70	IM	IM	IM	IM	IM	IM	IM	IM	91
04/16/2011	-	6,510	77	IM	IM	IM	IM	IM	IM	IM	IM	93
04/18/2011	-	5,740	86	IM	IM	IM	IM	IM	IM	IM	IM	92
04/20/2011	-	5,180	82	IM	IM	IM	IM	IM	IM	IM	IM	93
04/22/2011	-	4,850	95	IM	IM	IM	IM	IM	IM	IM	IM	94
04/25/2011	+	5,110	88	IM	IM	IM	IM	IM	IM	IM	IM	95
05/03/2011	-	4,100	105	IM	IM	IM	IM	IM	IM	IM	IM	93
05/09/2011	-	2,850	299	IM	IM	IM	IM	IM	IM	IM	IM	98
05/17/2011	-	1,410	136	IM	IM	IM	IM	99	99	100	100	--

Table 2. Streamflow, suspended-sediment concentrations, fall diameters, and sieve diameters for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; mm, millimeter; +, rising stage; IM, insufficient material for analysis; --, no value; -, falling stage]

Date	Stage condition	Streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Suspended-sediment fall diameter (values in percent finer than size)								Percent finer than suspended sediment sieve diameter of 0.062 mm
				0.002 mm	0.004 mm	0.008 mm	0.016 mm	0.062 mm	0.125 mm	0.250 mm	0.500 mm	
Rush River near Prosper, N. Dak. (site 7)												
04/07/2011	+	950	191	67	75	77	79	91	94	99	100	--
04/08/2011	+	2,100	401	IM	IM	IM	IM	92	93	100	100	--
04/09/2011	+	2,500	399	67	74	74	78	91	95	100	100	--
04/10/2011	-	1,730	353	59	65	68	71	84	87	97	100	--
04/11/2011	-	1,680	345	IM	IM	IM	IM	94	97	99	100	--
04/12/2011	-	1,340	299	IM	IM	IM	IM	84	92	96	99	--
04/13/2011	-	912	209	IM	IM	IM	IM	98	100	100	100	--
04/14/2011	-	626	146	IM	IM	IM	IM	IM	IM	IM	IM	95
04/15/2011	-	502	134	IM	IM	IM	IM	IM	IM	IM	IM	95
04/16/2011	-	395	110	IM	IM	IM	IM	98	99	100	100	--
04/17/2011	-	404	118	IM	IM	IM	IM	91	92	97	100	--
04/19/2011	-	488	90	IM	IM	IM	IM	IM	IM	IM	IM	94
04/21/2011	-	363	72	IM	IM	IM	IM	IM	IM	IM	IM	92
Lower Branch Rush River east of Prosper, N. Dak. (site 8)												
04/07/2011	+	1,060	288	71	78	86	88	--	--	--	--	99
04/08/2011	+	1,770	160	IM	IM	IM	IM	IM	IM	IM	IM	99
04/09/2011	-	1,480	82	IM	IM	IM	IM	IM	IM	IM	IM	97
04/10/2011	-	1,040	88	IM	IM	IM	IM	87	91	95	100	--
04/11/2011	-	860	127	IM	IM	IM	IM	IM	IM	IM	IM	100
04/12/2011	-	480	75	IM	IM	IM	IM	IM	IM	IM	IM	96
04/13/2011	-	339	103	IM	IM	IM	IM	IM	IM	IM	IM	98
04/14/2011	-	243	361	73	79	86	87	--	--	--	--	99
04/15/2011	-	90	314	IM	IM	IM	IM	IM	IM	IM	IM	100
04/16/2011	-	27	95	IM	IM	IM	IM	IM	IM	IM	IM	92
04/17/2011	-	51	131	IM	IM	IM	IM	IM	IM	IM	IM	99
04/19/2011	-	84	57	IM	IM	IM	IM	IM	IM	IM	IM	100
04/21/2011	-	24	115	IM	IM	IM	IM	IM	IM	IM	IM	96
Buffalo River east of Kragnes, Minn. (site 9)												
04/06/2011	+	6,360	61	IM	IM	IM	IM	IM	IM	IM	IM	97
04/07/2011	-	5,690	61	IM	IM	IM	IM	IM	IM	IM	IM	96
04/08/2011	-	4,900	59	IM	IM	IM	IM	IM	IM	IM	IM	96
04/09/2011	-	4,100	28	IM	IM	IM	IM	IM	IM	IM	IM	90
04/10/2011	-	3,500	28	IM	IM	IM	IM	IM	IM	IM	IM	86
04/11/2011	-	3,700	41	IM	IM	IM	IM	IM	IM	IM	IM	98
04/12/2011	-	3,750	36	IM	IM	IM	IM	IM	IM	IM	IM	96
04/15/2011	-	3,420	21	IM	IM	IM	IM	IM	IM	IM	IM	80
04/17/2011	-	2,750	26	IM	IM	IM	IM	IM	IM	IM	IM	81
04/19/2011	-	2,170	32	IM	IM	IM	IM	IM	IM	IM	IM	80
04/21/2011	-	1,770	51	IM	IM	IM	IM	IM	IM	IM	IM	95
04/25/2011	-	1,450	55	IM	IM	IM	IM	IM	IM	IM	IM	96

Although the spring 2011 streamflow peak occurred considerably later than the spring 2010 peak, measured peak SSC were similar between the two events at the nine sites (fig. 3*A*; table 2). Peak measured SSCs were slightly higher in 2011 at the Red River near Fargo (site 2), Sheyenne River above Diversion (site 3), and Sheyenne River below Diversion (site 4) compared to measured SSC in 2010. Peak measured SSCs from the spring snowmelt were lower in 2011 at the Red River near Christine (site 1), Maple River (site 5), and Wild Rice River (site 6) compared to measured SSC in 2010 (Blanchard and others, 2011; table 2). However, the Wild Rice River had a peak SSC later in the sampling period in 2011 that was caused by a rainfall event that produced the highest concentration (299 mg/L) measured in 2010 and 2011. The range in SSC was greater in samples collected in 2011 than in samples from 2010 because more samples were collected on the fall in the streamflow hydrograph in 2011 (fig. 3*A*; table 2). In general, concentrations are relatively lower on the fall of the streamflow hydrograph compared to the rise and peak of the hydrograph.

Streamflow and SSC data collected during the 2011 spring high-flow event showed that the peak in SSC mainly occurred prior to the peak in streamflow among the nine sites, except at the Maple River and Lower Branch Rush River (figs. 3*A*, 3*B*). However, in most cases, the early peak in SSC could not be well defined because heavy ice flows in the channels at the sampling sites prevented samples from being collected on the early rise of the streamflow hydrograph. For example, although the samples collected at Lower Branch Rush River showed a peak in concentration after the peak in the streamflow hydrograph, the shape of the SSC curve indicated that concentrations could have been greater before sampling began (fig. 3*B*). The occurrence of peak SSC compared to the peak streamflow in 2011 contrasted with the pattern observed during the spring high-flow event in 2010 at the Red River sites (sites 1 and 2) and the Sheyenne River below Diversion (site 4). In 2010, the peak SSC occurred after the peak in the streamflow hydrograph (fig. 3*A*). The difference in the timing of the SSC compared to the streamflow peak may be related to the difference in how snowmelt occurred upstream from the sampling locations in 2011 compared to 2010. If snowmelt runoff that transports a large amount of sediment upstream from the sampling locations caused streamflow to peak earlier than the peak at the sampling location, then SSC could peak before the streamflow peak at the sampling location. If the streamflow peak in the snowmelt runoff occurred after the peak at the sampling location, the SSC could peak after the peak in streamflow at the sampling location.

The evaluation of the relation between SSC and streamflow during the 2010 and 2011 spring high-flow events indicated that only three of the nine sites demonstrated significant correlations between SSC and streamflow for the range of streamflow observed during the sampling periods (fig. 4; table 3). The relation between streamflow and sediment concentration is known to vary widely from stream to stream and within varying cross sections of the same stream (Blanchard and others, 2011). The variation and range of concentration during any snowmelt or runoff event may differ from the concentrations during other periods, even though streamflow may be identical or similar (Porterfield, 1972). Both Sheyenne River sites (sites 3 and 4) and the Rush River (site 7) had SSC data correlated to streamflow ($p<0.05$) during the sampling period. The Sheyenne River sites showed a negative correlation between SSC and streamflow, and the Rush River showed a positive correlation between SSC and streamflow (fig. 4; table 3). The lack of a significant relation between SSC and streamflow at the other six sites may be attributed to a combination of complex factors that include a high variability of SSC and the limited range of streamflow observed during snowmelt runoff (Blanchard and others, 2011). Inputs of sediment to streams are highly variable over space and time, which tends to affect the SSC and streamflow relation (Uhrich and Bragg, 2003; Guy, 1970). Studies indicate that SSC collected over a wide range of streamflow can improve the relation between SSC and streamflow (Guy, 1970; Porterfield, 1972; Tornes, 1986).

Suspended-Sediment Load, Bedload, and Total Sediment Load

Total sediment loads measured during the 2011 spring high-flow event at the Red River and its tributaries near the Fargo-Moorhead metropolitan area were mainly composed of suspended sediment and were the greatest at the Sheyenne River above Diversion (site 3) compared to the loads at the other eight sites (fig. 5). Total measured bedload for the 2011 event ranged from less than 1 ton at the Lower Branch Rush River (site 8, April 7–21) to 800 tons at the Red River near Christine (site 1, April 6 to May 17) (fig. 5). Contribution of total measured bedload during the 2011 event for each of the sites was less than 2 percent of the total sediment load calculated for each of the sites (fig. 5). The low bedload transport rates, which are proportional to streamflow and channel slope, may be attributable, in part, to low gradients in the basin, overbank flooding, and low stream velocities. At the Lower Branch Rush River (site 8), only two samples had bedload material for analysis and comparison. It was found that the stream bottom at the sampling site was lined with concrete, so very little material was available for transport in the bedload. The calculated total sediment load during the entire event ranged from 3,040 tons at the Lower Branch Rush River (site 8, April 7–21) to 188,000 tons at the Sheyenne River above Diversion (site 3, April 8 to May 16) (fig. 5).

The total event sediment loads measured during the 2011 spring high-flow event were greater than the loads measured during the 2010 spring high-flow event at the six sites that were sampled during both events (fig. 5). Total event sediment loads were approximately 60 to 75 percent greater in 2011 compared to 2010 at all the sites sampled during both events. Total event sediment loads were greater in 2011 compared to 2010 because streamflow volumes were greater in 2011.

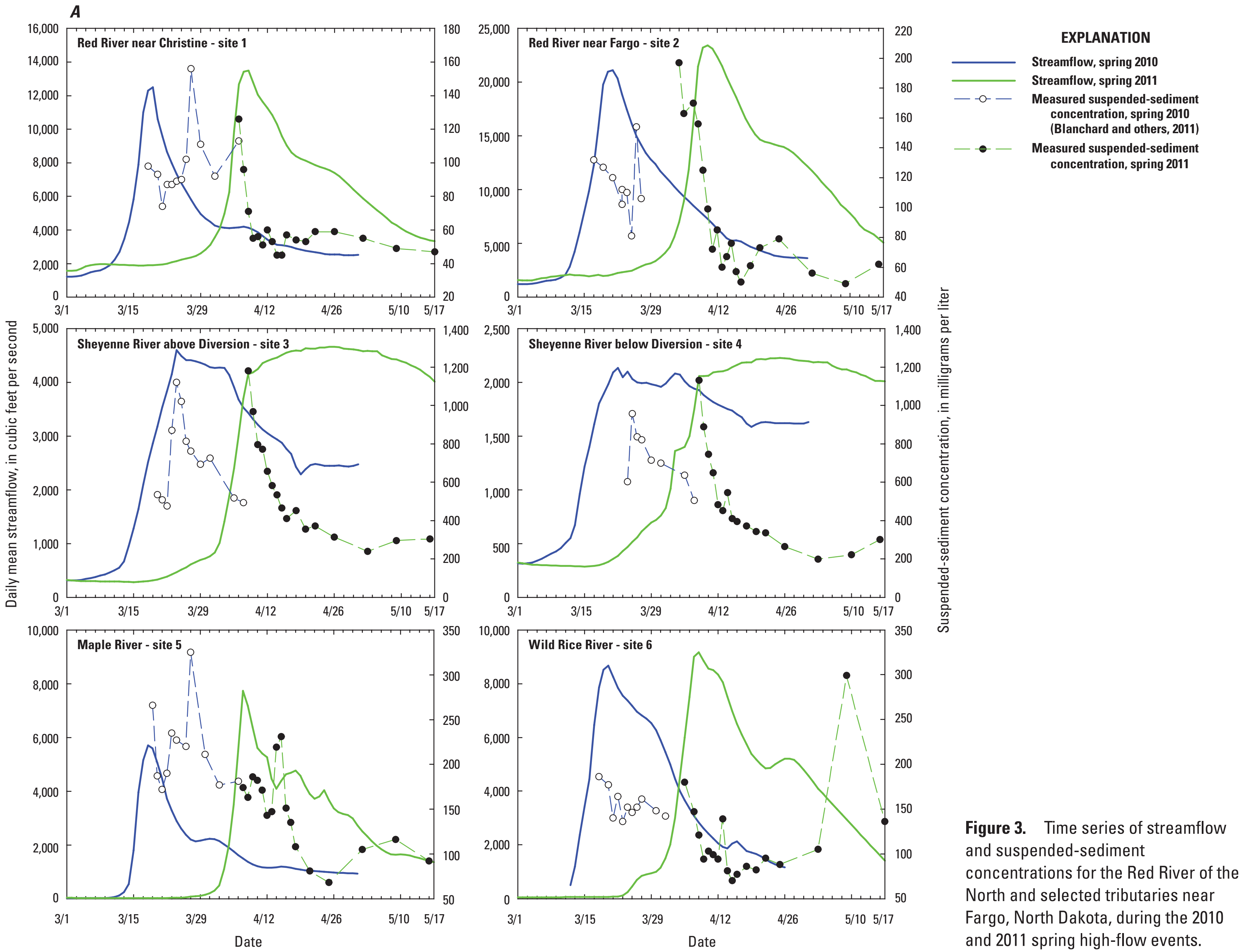


Figure 3. Time series of streamflow and suspended-sediment concentrations for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2010 and 2011 spring high-flow events.

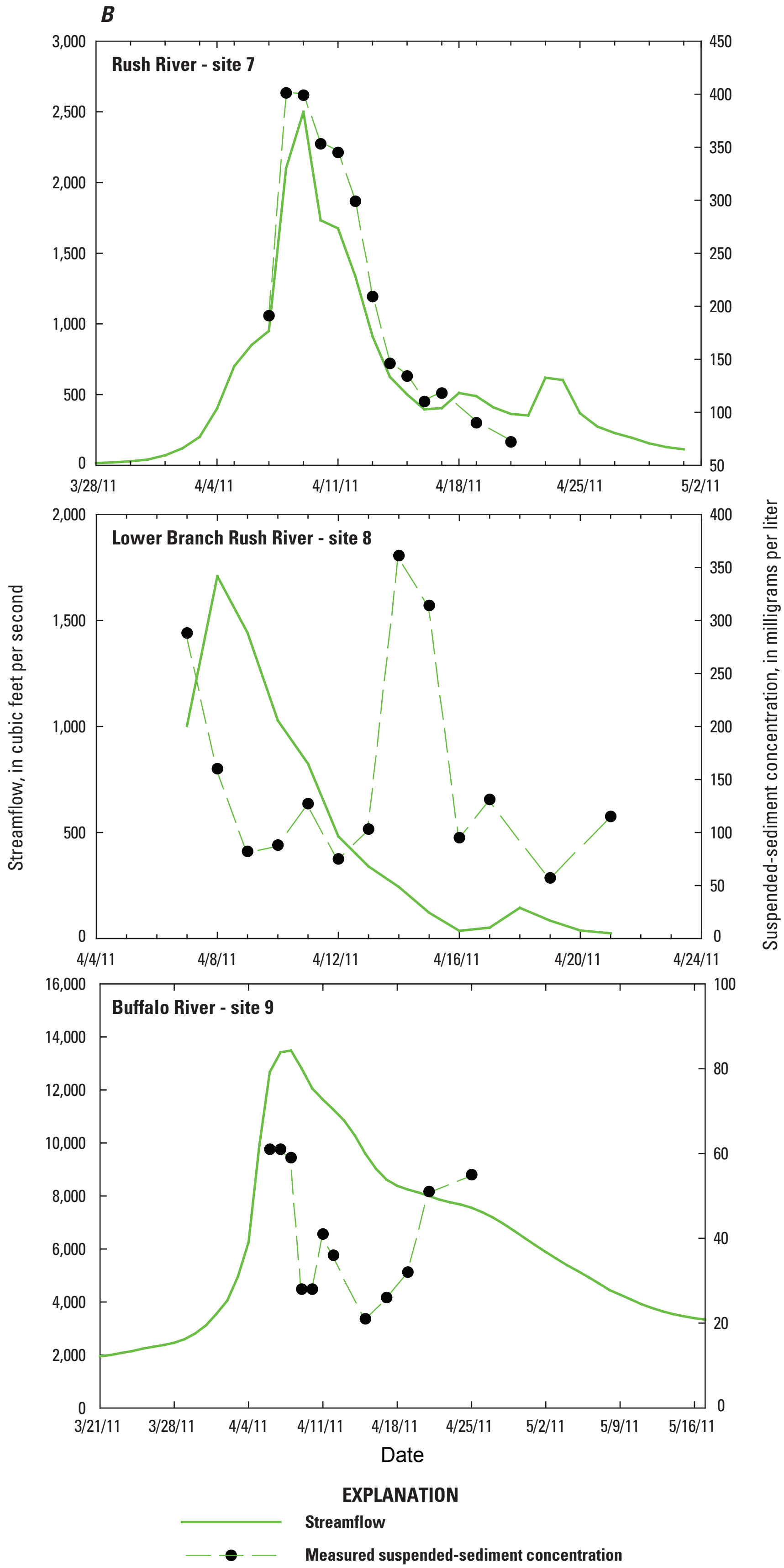


Figure 3. Time series of streamflow and suspended-sediment concentrations for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2010 and 2011 spring high-flow events.—Continued

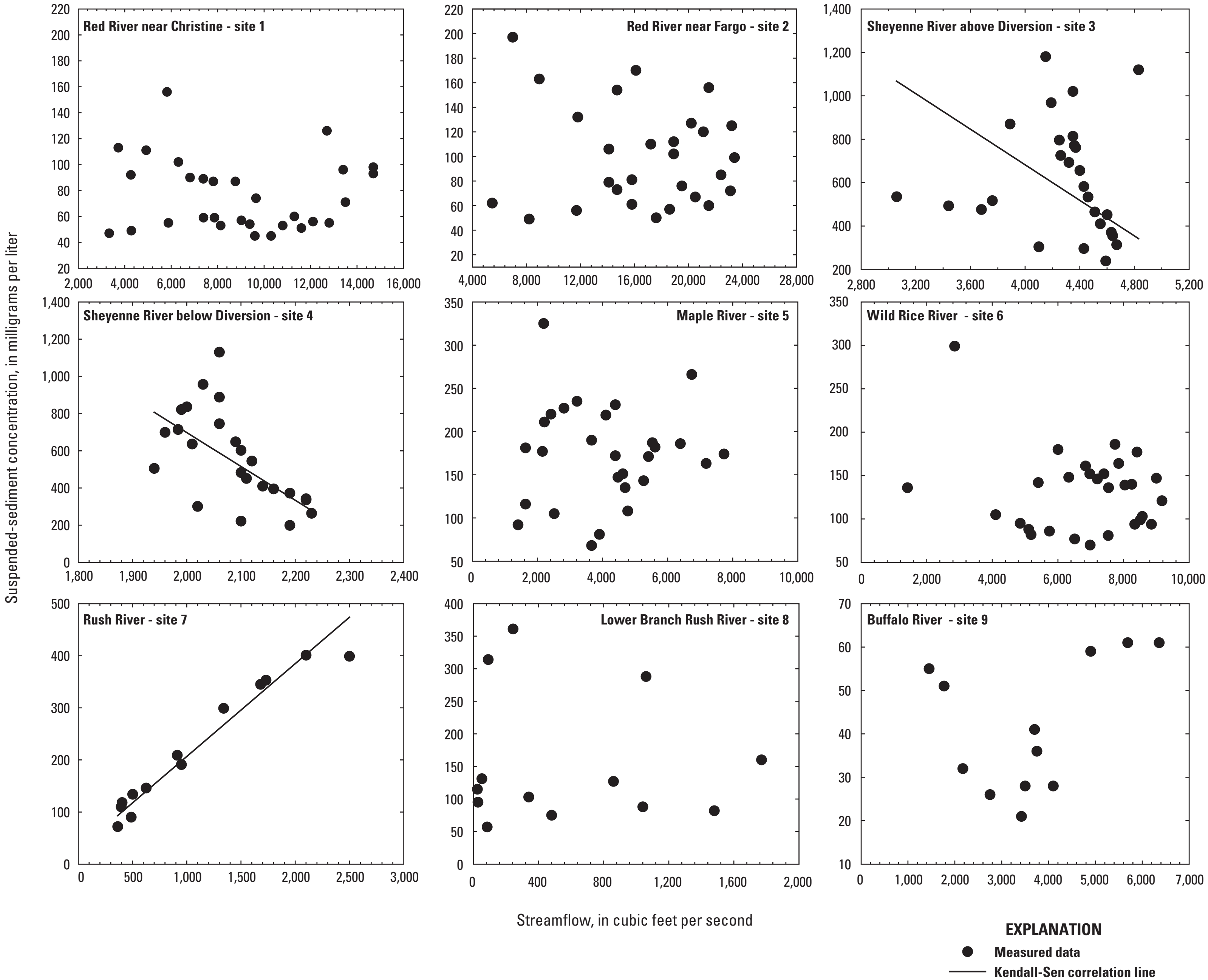


Figure 4. Relation between suspended-sediment concentration and streamflow for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2010 and 2011 spring high-flow events.

Table 3. Kendall-Sen test correlation results between suspended-sediment concentration and streamflow for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2010 and 2011 spring high-flow events.

[ft^3/s, cubic foot per second; SSC, suspended-sediment concentration; mg/L, milligrams per liter, bold P values indicates statistical significance ($p<0.05$); *, only includes data from 2011; <, less than]

Site	Tau	P	Slope	Median streamflow (ft^3/s)	Median SSC (mg/L)
Red River of the North near Christine, N. Dak. (site 1)	-0.08	0.556	-0.0008	8,890	66
Red River of the North near Fargo, N. Dak. (site 2)	.03	.859	.0005	17,400	92
Sheyenne River above Diversion near Horace, N. Dak. (site 3)	-.29	**.030**	-.4095	4,360	535
Sheyenne River below Diversion at Horace, N. Dak. (site 4)	-.48	**.001**	-1.8179	2,100	525
Maple River below Mapleton, N. Dak. (site 5)	.03	.859	.0014	4,240	176
Wild Rice River near St. Benedict, N. Dak. (site 6)	.00	1.000	.0000	7,200	136
Rush River near Prosper, N. Dak. (site 7)*	.90	**<.001**	.1781	912	191
Lower Branch Rush River east of Prosper, N. Dak. (site 8)*	.03	.951	.0107	339	115
Buffalo River east of Kragnes, Minn. (site 9)*	.27	.242	.0025	3,600	39

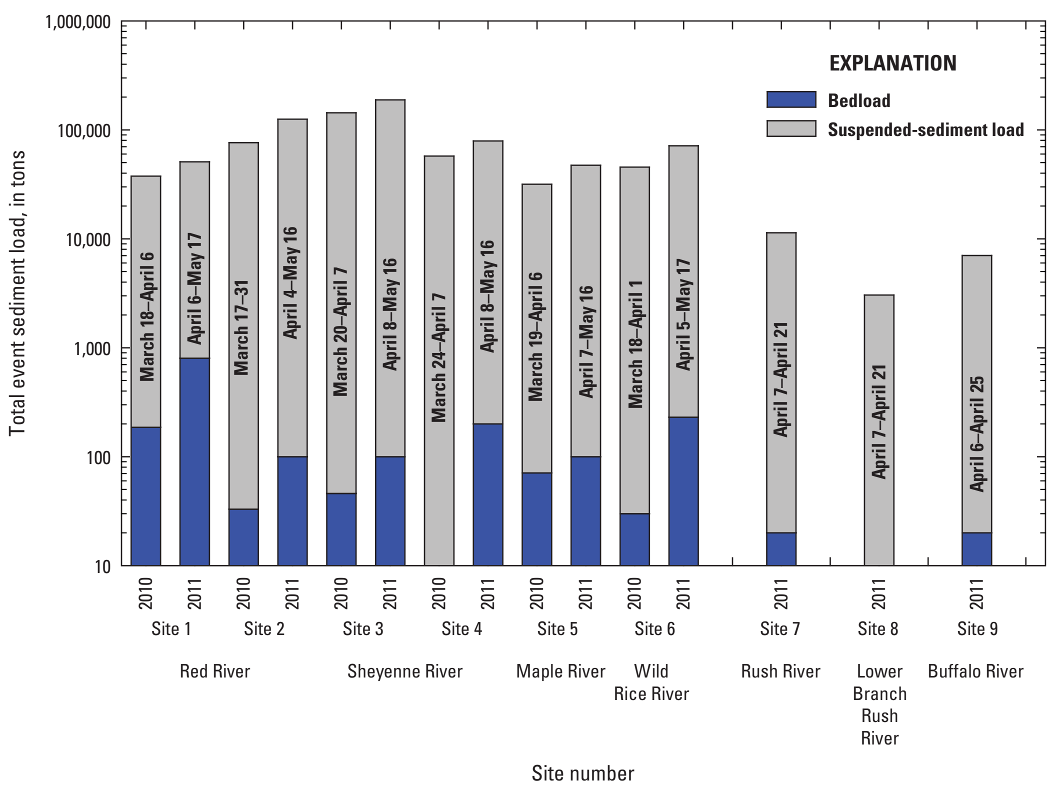


Figure 5. Estimated total event sediment loads from the 2010 and 2011 spring high-flow events for the Red River of the North and selected tributaries near Fargo, North Dakota.

Daily total sediment loads calculated for the 2011 spring high-flow event showed that the peak in sediment mainly occurred prior to or simultaneously with the peak in streamflow at the nine sites (figs. 6*A*, 6*B*). Samples could not be collected on the early rise of the streamflow hydrograph at several sites because of heavy ice flows in the channels, so the peak in sediment load prior to the streamflow peak was not well defined. In particular, the Red River near Christine (site 1), Sheyenne River above Diversion (site 3), Sheyenne River below Diversion (site 4), Maple River (site 5), Lower Branch Rush River (site 8) and the Buffalo River (site 9) had the greatest daily load during the event on the first day the sites were sampled. The peak daily sediment loads were 4,370 tons per day (tons/d), 13,209 tons/d, 6,280 tons/d, 3,653 tons/d, 825 tons/d, and 1,052 tons/d, respectively. The peak daily sediment loads were well defined at the Red River near Fargo (site 2), Wild Rice River (site 6), and Rush River (site 7). The Red River near Fargo had a peak daily sediment load of 9,093 tons/d that occurred 1 day before the streamflow peak (fig. 6*A*). The Wild Rice River had a peak daily sediment load of 3,570 tons/d that also occurred 1 day before the peak in streamflow. Two other peaks occurred at the Wild Rice River later in the event, one 6 days after the initial peak (3,020 tons/d) and another 15 days after the initial peak (2,300 tons/d). The Rush River had a daily sediment peak of 2,692 tons/d that occurred on the same day as the streamflow peak (fig. 6*B*).

Two methods for estimating bedload, described in Blanchard and others (2011), were compared to determine whether a model (MEP model) could be used to determine bedload instead of collecting bedload samples for future investigations. Numerous errors resulted from difficulties inherent with collecting bedload samples using a portable sampler. When a bedload sampler rests on the bed, the flow pattern and the bedload discharge in the vicinity of the sampler are altered to an unknown extent. The degree to which the bedload discharge is altered depends on many factors, such as stream velocity and depth, the magnitude of the bedload discharge, and the particle size of the bedload (Hubbell, 1964; Edwards and Glysson, 1999).

Similar to results from 2010 (Blanchard and others, 2011), bedload estimated from physical samples collected in the 2011 spring high-flow event and from the MEP model did not compare well (table 4). The MEP model overestimated bedload transport rates by a relatively large amount at all sites except the Red River near Christine. At the Red River near Christine, the MEP method yielded bedloads that ranged from less than the measured bedload (April 8, 14, and 22, 2011) to more than eight times the measured bedload (April 9 and 18, 2011). At the other eight sites, the MEP method yielded bedloads that were mostly one to three orders of magnitude greater than the measured bedload. These results were similar to several other studies that found the Einstein bedload function was unable to match measured bedload transport rates in certain rivers (Blanchard and others, 2011). For example, Kiat and others (2007) compared bedload samples for 122 sets of data for sand-bed rivers in Malaysia with the Einstein bedload equation and determined that it overpredicted bedload transport rates when compared to the measured values. Pires and Ribeiro (1988) also evaluated the Einstein method of estimating bedload transport in a backwater river in Brazil and found that the Einstein method of using tractive forces overestimated bedload transport. The Einstein bedload transport function is based on statistical probabilities that particles of a given size move in a uniform flow over a constant slope, which may have not occurred in the Red River and its tributaries during the study period.

Particle-Size Distribution

Particle-size information for the suspended load, bedload, and bed material of a stream are important to the design of engineering projects because the information is used in numerical modeling of sediment loads and provides insight on the stability of the stream. Samples collected during the 2011 high-flow event were analyzed for particle-size distribution if enough material was present in the samples.

Similar to the samples collected in 2010 (Blanchard and others, 2011), more than 90 percent of the measured suspended sediment in samples collected during the 2011 spring high-flow event was composed of fine-grained material (less than 0.062 mm), except for the Sheyenne River (sites 3 and 4) (table 2). Samples from the Sheyenne River above Diversion (site 3) had 19 to 43 percent of the suspended sediment with particle sizes greater than 0.062 mm and 1 to 28 percent greater than the 0.125 mm particle size. Samples from the Sheyenne River below Diversion (site 4) had 10 to 30 percent of the suspended sediment with particle sizes greater than 0.062 mm and 3 to 19 percent greater than the 0.125 mm particle size (table 2).

The bedload samples collected during the 2011 spring high-flow event demonstrated different distributions of particle sizes among the nine sites (fig. 7; table 5). For the Red River sites (sites 1 and 2) most (50 to 60 percent) of the bedload had particle sizes in the 0.5 to 1 mm and 0.25 to 0.5 mm ranges. Similarly, the Maple River, Wild Rice River, and Buffalo River also had particle size mainly ranging from 0.5 to 1 mm and 0.25 to 0.5 mm in the bed-load samples. The Rush and Lower Branch Rush Rivers (sites 7 and 8) also had a greater portion of larger particle sizes in the 1 to 2 mm range (20 to 24 percent) compared to the bedload at the other sites. The Sheyenne River sites (sites 3 and 4) had a greater portion of smaller particles in the bedload in the 0.125 to 0.5 mm range compared to the other sites (table 5; fig. 7).

The bed material in samples collected during the 2011 spring high-flow event demonstrated a wider distribution of particle sizes than were observed in the bedload; the coarsest material was found at the Red River near Christine (site 1) and the Lower Branch Rush River (site 8) and the finest material at the Sheyenne River sites (sites 3 and 4; fig. 7; table 6). The

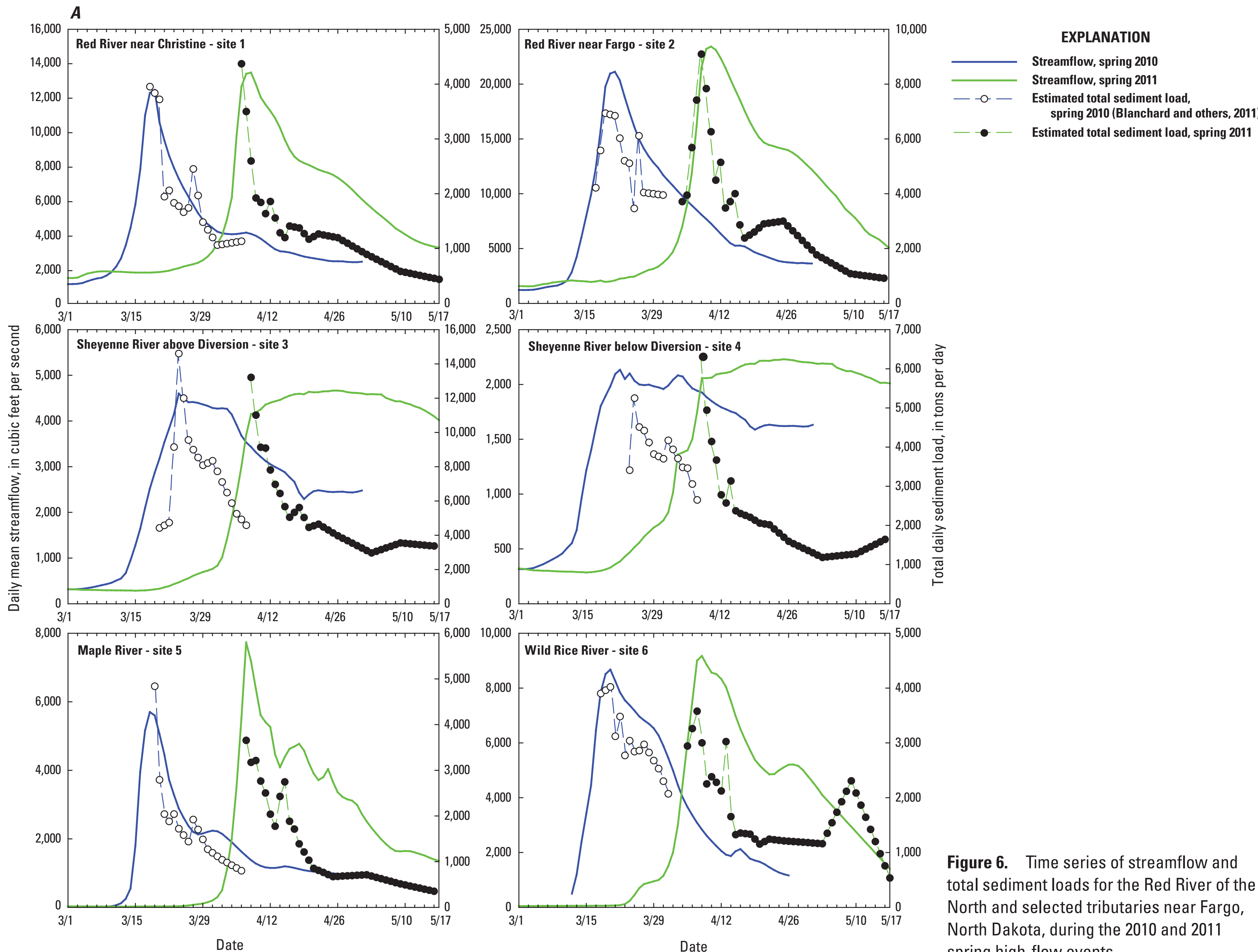


Figure 6. Time series of streamflow and total sediment loads for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2010 and 2011 spring high-flow events.

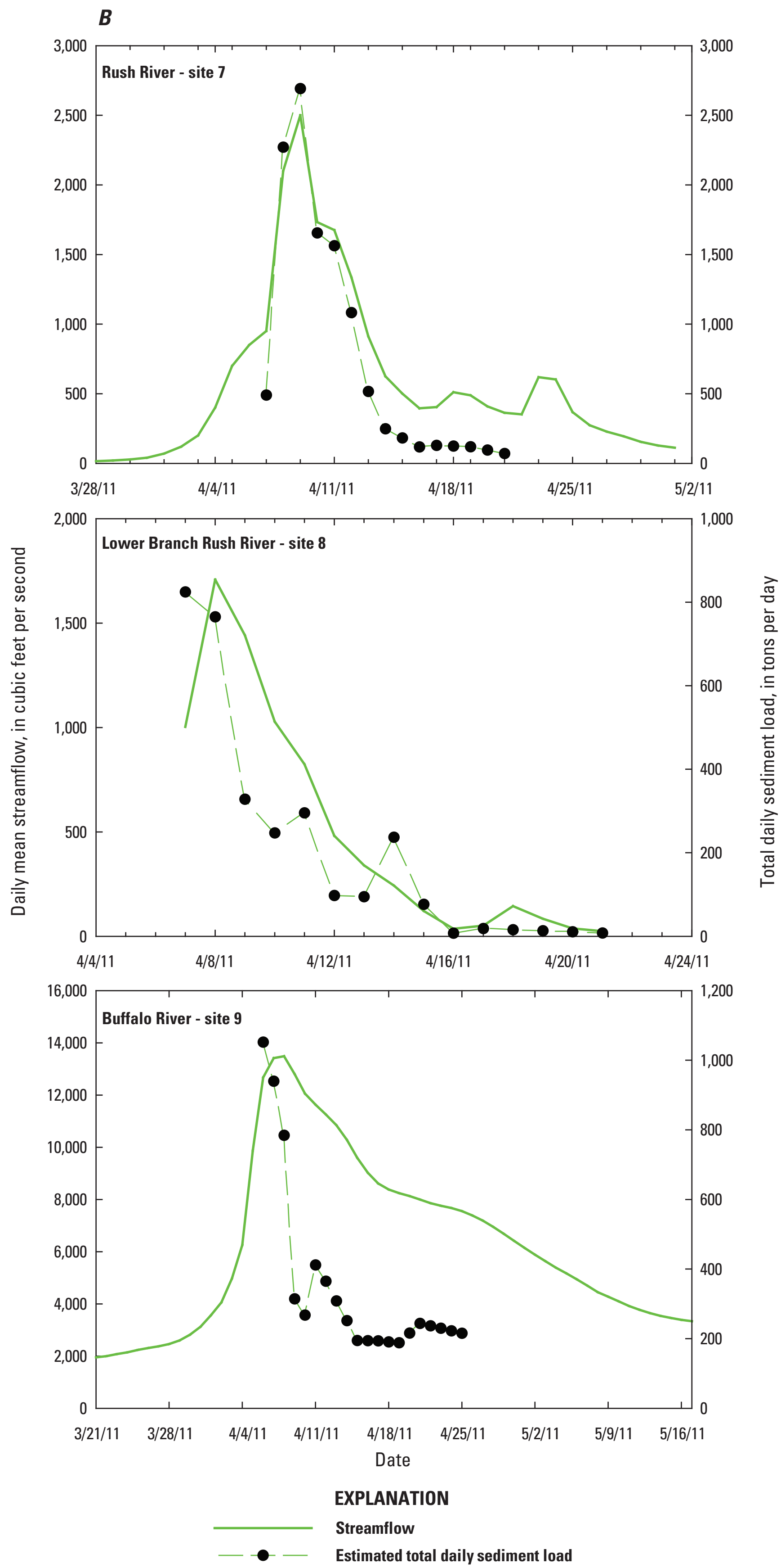


Figure 6. Time series of streamflow and total sediment loads for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2010 and 2011 spring high-flow events.—Continued

Table 4. Sediment loads for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.

[MEP, Modified Einstein Procedure; --, not calculated]

Date	Load, in tons per day				
	Suspended sediment	Measured bedload	MEP bedload	Measured total sediment	MEP total sediment
Red River of the North near Christine, N. Dak. (site 1)					
04/06/2011	4,320	50	147	4,370	4,470
04/07/2011	3,470	--	--	3,470	--
04/08/2011	2,590	6	5	2,596	2,590
04/09/2011	1,900	21	173	1,921	2,070
04/10/2011	1,830	11	47	1,840	1,880
04/11/2011	1,600	36	55	1,636	1,650
04/12/2011	1,830	27	33	1,857	1,860
04/13/2011	1,540	17	23	1,557	1,570
04/14/2011	1,250	37	34	1,287	1,290
04/15/2011	1,170	--	--	1,170	--
04/16/2011	1,390	--	--	1,390	--
04/18/2011	1,370	4	33	1,374	1,400
04/20/2011	1,160	--	--	1,160	--
04/22/2011	1,250	15	10	1,265	1,260
04/26/2011	1,180	--	--	1,180	--
05/02/2011	873	20	29	893	902
05/09/2011	566	--	--	566	--
05/17/2011	423	15	74	437	497
Mean	**1,651**	**21**	**55**	**1,665**	**1,787**
Median	**1,380**	**18**	**34**	**1,382**	**1,610**
Standard deviation	**967**	**14**	**53**	**973**	**1,006**
Red River of the North at County Road 20 near Fargo, N. Dak. (site 2)					
04/04/2011	3,710	--	--	3,710	--
04/05/2011	3,940	7	63	3,947	4,000
04/07/2011	7,390	--	--	7,390	--
04/08/2011	9,060	33	672	9,093	9,730
04/09/2011	7,830	3	190	7,833	8,020
04/10/2011	6,260	--	--	6,260	--
04/11/2011	4,490	--	--	4,490	--
04/12/2011	5,140	1	246	5,141	5,390
04/13/2011	3,480	--	--	3,480	--
04/14/2011	3,710	--	--	3,710	--
04/15/2011	4,000	--	--	4,000	--
04/16/2011	2,860	0	72	2,860	2,934
04/17/2011	2,380	--	--	2,380	--
04/19/2011	2,600	--	--	2,600	--
04/21/2011	2,900	0	--	2,900	--
04/25/2011	3,000	--	--	3,000	--
05/02/2011	1,770	0	70	1,770	1,840
05/09/2011	1,080	--	--	1,080	--
05/16/2011	914	1	35	915	949
Mean	**4,027**	**6**	**193**	**4,029**	**4,695**
Median	**3,710**	**1**	**72**	**3,710**	**4,000**
Standard deviation	**2,236**	**11**	**225**	**2,240**	**3,232**

Table 4. Sediment loads for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.—Continued

[MEP, Modified Einstein Procedure; --, not calculated]

Date	Load, in tons per day				
	Suspended sediment	Measured bedload	MEP bedload	Measured total sediment	MEP total sediment
Sheyenne River above Diversion near Horace, N. Dak. (site 3)					
04/08/2011	13,200	9	--	13,209	--
04/09/2011	11,000	1	1,300	11,001	12,200
04/10/2011	9,130	1	1,660	9,131	10,800
04/11/2011	9,080	2	774	9,082	9,850
04/12/2011	7,800	2	2,300	7,802	10,100
04/13/2011	6,960	0	1,590	6,960	8,550
04/14/2011	6,430	3	634	6,433	7,060
04/15/2011	5,660	3	453	5,663	6,120
04/16/2011	5,040	2	581	5,042	5,620
04/18/2011	5,610	2	746	5,612	6,360
04/20/2011	4,450	2	900	4,452	5,350
04/22/2011	4,640	--	--	4,640	--
04/26/2011	3,960	2	1,530	3,962	5,490
05/03/2011	2,960	1	1,580	2,961	4,540
05/09/2011	3,540	--	--	3,540	--
05/16/2011	3,360	5	1,140	3,365	4,500
Mean	**6,426**	**2**	**1,168**	**6,428**	**7,426**
Median	**5,635**	**2**	**1,140**	**5,637**	**6,360**
Standard deviation	**2,937**	**2**	**545**	**2,938**	**2,576**
Sheyenne River below Diversion at Horace, N. Dak. (site 4)					
04/08/2011	6,280	--	--	6,280	--
04/09/2011	4,940	3	450	4,943	5,390
04/10/2011	4,140	2	114	4,142	4,260
04/11/2011	3,660	8	78	3,668	3,730
04/12/2011	2,740	41	129	2,781	2,870
04/13/2011	2,570	2	0	2,572	2,550
04/14/2011	3,120	14	109	3,134	3,220
04/15/2011	2,370	1	102	2,371	2,470
04/16/2011	2,300	--	--	2,300	--
04/18/2011	2,200	7	64	2,207	2,260
04/20/2011	2,050	6	20	2,056	2,070
04/22/2011	2,010	--	--	2,010	--
04/26/2011	1,590	1	122	1,591	1,710
05/03/2011	1,180	2	123	1,182	1,300
05/10/2011	1,260	13	91	1,273	1,350
05/16/2011	1,640	0	348	1,640	1,990
Mean	**2,753**	**8**	**135**	**2,759**	**2,705**
Median	**2,335**	**3**	**109**	**2,335**	**2,470**
Standard deviation	**1,394**	**11**	**125**	**1,393**	**1,189**

Table 4. Sediment loads for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.—Continued

[MEP, Modified Einstein Procedure; --, not calculated]

Date	Load, in tons per day				
	Suspended sediment	Measured bedload	MEP bedload	Measured total sediment	MEP total sediment
Maple River below Mapleton, N. Dak. (site 5)					
04/07/2011	3,630	23	4,060	3,653	7,690
04/08/2011	3,160	--	--	3,160	--
04/09/2011	3,210	2	2,120	3,212	5,330
04/10/2011	2,760	3	1,190	2,763	3,950
04/11/2011	2,500	3	637	2,503	3,140
04/12/2011	2,030	7	721	2,037	2,750
04/13/2011	1,770	6	555	1,776	2,330
04/14/2011	2,420	7	817	2,427	3,240
04/15/2011	2,740	--	--	2,740	--
04/16/2011	1,880	--	--	1,880	--
04/17/2011	1,710	--	--	1,710	--
04/18/2011	1,390	0	310	1,390	1,700
04/21/2011	853	0	556	853	1,410
04/25/2011	672	--	--	672	--
05/02/2011	712	0	404	712	1,120
05/09/2011	511	--	--	511	--
05/16/2011	348	3	250	351	597
Mean	**1,900**	**5**	**1,056**	**1,903**	**3,023**
Median	**1,880**	**3**	**637**	**1,880**	**2,750**
Standard deviation	**1,033**	**7**	**1,125**	**1,035**	**2,060**
Wild Rice River near St. Benedict, N. Dak. (site 6)					
04/05/2011	2,920	23	59	2,943	2,980
04/07/2011	3,570	--	--	3,570	--
04/08/2011	3,000	0	164	3,000	3,160
04/09/2011	2,250	--	--	2,250	--
04/10/2011	2,380	--	--	2,380	--
04/11/2011	2,280	0	17	2,280	2,290
04/12/2011	2,120	--	--	2,120	--
04/13/2011	3,020	--	--	3,020	--
04/14/2011	1,650	--	--	1,650	--
04/15/2011	1,320	5	21	1,325	1,340
04/16/2011	1,350	--	--	1,350	--
04/18/2011	1,330	--	--	1,330	--
04/20/2011	1,150	--	--	1,150	--
04/22/2011	1,240	--	--	1,240	--
04/25/2011	1,210	--	--	1,210	--
05/03/2011	1,160	0	163	1,160	1,330
05/09/2011	2,300	--	--	2,300	--
05/17/2011	518	17	94	535	612
Mean	**1,932**	**8**	**86**	**1,934**	**1,952**
Median	**1,885**	**3**	**77**	**1,885**	**1,815**
Standard deviation	**838**	**10**	**66**	**838**	**1,019**
Rush River near Prosper, N. Dak. (site 7)					
04/07/2011	490	0	43	490	533
04/08/2011	2,270	--	--	2,270	--
04/09/2011	2,690	2	6,780	2,692	9,480

Table 4. Sediment loads for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.—Continued

[MEP, Modified Einstein Procedure; --, not calculated]

Date	Load, in tons per day				
	Suspended sediment	Measured bedload	MEP bedload	Measured total sediment	MEP total sediment
Rush River near Prosper, N. Dak. (site 7)—Continued					
04/10/2011	1,650	4	2,240	1,654	3,890
04/11/2011	1,560	3	1,250	1,563	2,820
04/12/2011	1,080	--	--	1,080	--
04/13/2011	515	1	427	516	941
04/14/2011	247	1	513	248	760
04/15/2011	181	1	136	182	318
04/16/2011	117	0	80	118	198
04/17/2011	129	--	--	129	--
04/19/2011	119	--	--	119	--
04/21/2011	71	0	328	71	399
Mean	**855**	**1**	**1,311**	**856**	**2,149**
Median	**490**	**1**	**427**	**490**	**760**
Standard deviation	**906**	**1**	**2,170**	**907**	**3,030**
Lower Branch Rush River east of Prosper, N. Dak. (site 8)					
04/07/2011	824	0	--	825	--
04/08/2011	765	--	--	765	--
04/09/2011	328	0	--	328	--
04/10/2011	247	0	--	247	--
04/11/2011	295	--	--	295	--
04/12/2011	97	--	--	97	--
04/13/2011	94	0	--	94	--
04/14/2011	237	--	--	237	--
04/15/2011	76	--	--	76	--
04/16/2011	7	--	--	7	--
04/17/2011	18	--	--	18	--
04/19/2011	13	--	--	13	--
04/21/2011	7	0	--	7	--
Mean	**231**	**0**	**--**	**231**	**--**
Median	**97**	**0**	**--**	**97**	**--**
Standard deviation	**274**	**0**	**--**	**275**	**--**
Buffalo River east of Kragnes, Minn. (site 9)					
04/06/2011	1,050	2	200	1,052	1,250
04/07/2011	937	--	--	937	--
04/08/2011	781	--	--	781	--
04/09/2011	310	4	17	314	327
04/10/2011	265	--	--	265	--
04/11/2011	410	--	--	410	--
04/12/2011	365	1	148	365	513
04/15/2011	194	1	79	195	273
04/17/2011	193	--	--	193	--
04/19/2011	187	--	--	187	--
04/21/2011	244	0	38	244	282
04/25/2011	215	--	--	215	--
Mean	**429**	**1**	**96**	**430**	**529**
Median	**287**	**1**	**79**	**289**	**327**
Standard deviation	**311**	**2**	**76**	**311**	**415**

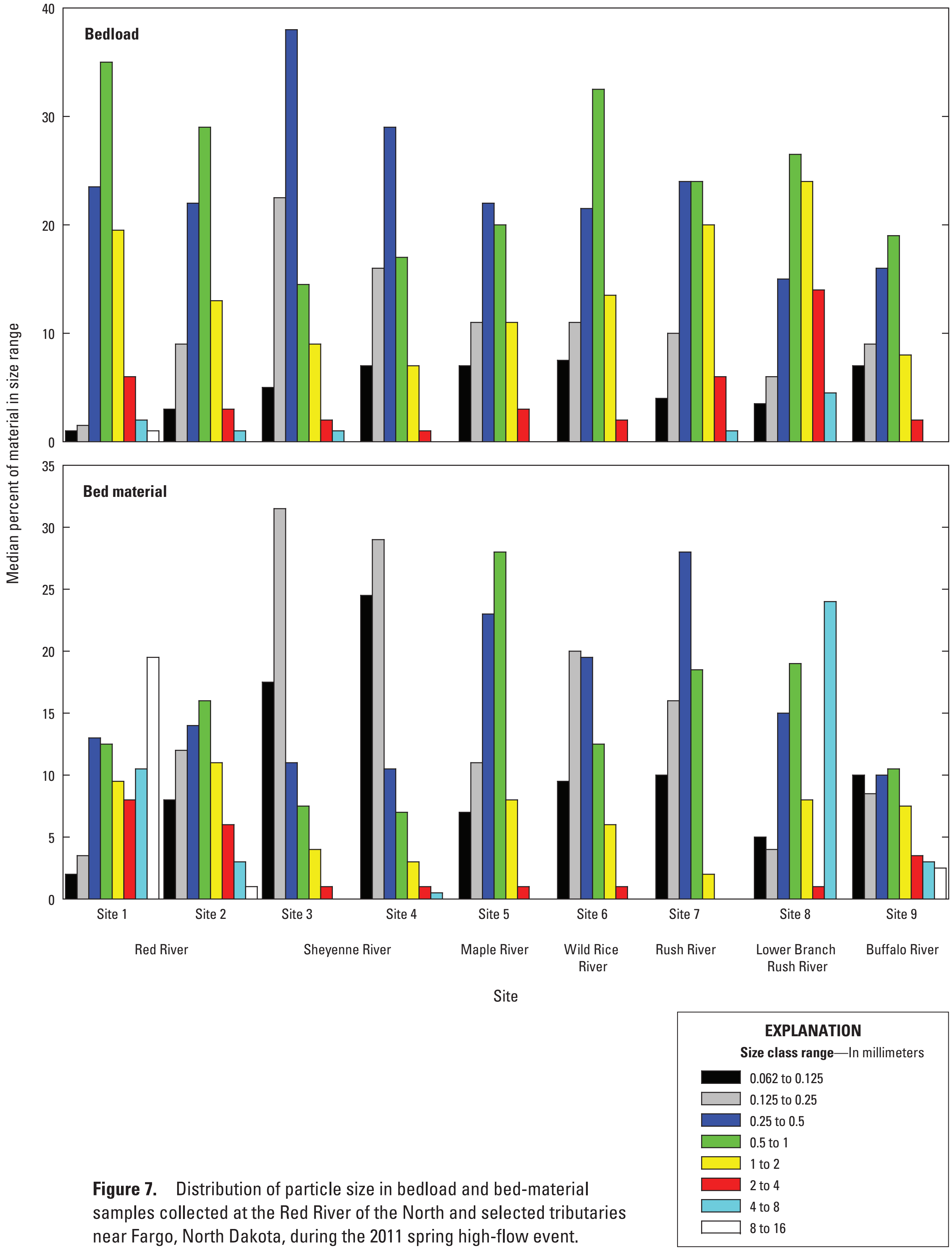


Figure 7. Distribution of particle size in bedload and bed-material samples collected at the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.

Table 5. Sieve diameters and mass of bedload samples for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.

[mm, millimeter; IM, insufficient material]

Date	Bedload-sediment fall diameter (values in percent finer than size)									Mass (grams)
	0.062 mm	0.125 mm	0.25 mm	0.5 mm	1 mm	2 mm	4 mm	8 mm	16 mm	
Red River of the North near Christine, N. Dak. (site 1)										
04/06/2011	1	1	2	32	76	92	95	96	100	2,235
04/08/2011	0	1	3	52	87	93	96	99	100	345
04/09/2011	0	1	2	19	57	86	96	99	100	1,295
04/10/2011	1	1	3	22	50	80	93	96	100	400
04/11/2011	1	1	2	37	85	96	98	99	100	1,133
04/12/2011	4	5	7	19	47	78	94	100	100	422
04/13/2011	5	7	9	30	65	86	92	93	96	268
04/14/2011	1	1	1	23	69	91	97	99	100	577
04/18/2011	0	0	1	43	86	97	99	100	100	67
04/22/2011	1	2	3	14	40	69	78	84	100	235
05/02/2011	4	8	14	39	72	90	97	99	100	310
05/17/2011	2	3	12	79	92	98	99	100	100	288
Red River of the North at County Road 20 near Fargo, N. Dak. (site 2)										
04/05/2011	4	6	12	35	68	91	98	100	100	333
04/08/2011	19	25	35	56	83	96	99	100	100	385
04/09/2011	5	7	12	34	64	78	85	95	100	32
04/12/2011	3	6	11	47	76	88	93	100	100	9
04/16/2011	14	14	43	100	100	100	100	100	100	1
04/21/2011	17	33	67	83	100	100	100	100	100	1
05/02/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM	0
05/16/2011	12	17	26	41	75	98	100	100	100	17.4
Sheyenne River above Diversion near Horace, N. Dak. (site 3)										
04/08/2011	12	28	65	84	93	97	99	100	100	330
04/09/2011	8	14	40	71	84	95	100	100	100	25
04/10/2011	8	14	39	82	95	99	100	100	100	35
04/11/2011	16	23	44	79	94	98	99	100	100	59
04/12/2011	7	12	30	70	89	98	99	100	100	58
04/13/2011	10	15	46	79	92	100	100	100	100	9
04/14/2011	2	4	9	36	64	86	94	100	100	96
04/15/2011	1	2	7	42	73	91	97	100	100	106
04/16/2011	1	2	11	61	80	91	96	100	100	49
04/18/2011	2	3	11	56	80	94	98	99	100	49
04/20/2011	2	4	14	63	87	96	99	100	100	68
04/26/2011	9	15	39	75	89	99	100	100	100	64
05/03/2011	6	11	40	81	94	99	100	100	100	32
05/16/2011	2	4	31	81	91	96	98	100	100	156
Sheyenne River below Diversion at Horace, N. Dak. (site 4)										
04/09/2011	10	17	43	78	89	96	99	100	100	84
04/10/2011	8	14	29	59	75	90	98	100	100	70
04/11/2011	19	29	45	70	93	100	100	100	100	248
04/12/2011	13	26	54	79	96	100	100	100	100	1,298
04/13/2011	6	10	18	50	78	97	100	100	100	67
04/14/2011	5	10	26	60	83	96	100	100	100	450
04/15/2011	6	10	23	62	86	100	100	100	100	16
04/18/2011	3	5	12	49	73	94	99	100	100	200
04/20/2011	4	7	12	24	60	95	100	100	100	185

Table 5. Sieve diameters and mass of bedload samples for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.—Continued

[mm, millimeter; IM, insufficient material]

Date	Bedload-sediment fall diameter (values in percent finer than size)									Mass (grams)
	0.062 mm	0.125 mm	0.25 mm	0.5 mm	1 mm	2 mm	4 mm	8 mm	16 mm	
Sheyenne River below Diversion at Horace, N. Dak. (site 4)—Continued										
04/26/2011	32	47	67	91	99	100	100	100	100	31
05/03/2011	21	32	65	94	99	100	100	100	100	43
05/10/2011	11	24	55	80	94	99	100	100	100	343
05/16/2011	24	40	66	86	92	95	95	100	100	13
Maple River below Mapleton, N. Dak. (site 5)										
04/07/2011	5	9	14	23	38	61	80	89	90	1,379
04/09/2011	13	20	31	56	87	98	100	100	100	36
04/10/2011	13	20	31	52	80	97	100	100	100	60
04/11/2011	19	28	41	63	88	97	100	100	100	69
04/12/2011	15	22	32	53	81	97	100	100	100	159
04/13/2011	2	3	5	12	27	80	96	100	100	127
04/14/2011	6	9	15	47	85	97	100	100	100	132
04/18/2011	34	49	75	91	100	100	100	100	100	10
04/21/2011	20	28	45	80	100	100	100	100	100	6
05/02/2011	18	29	56	84	100	100	100	100	100	5
05/16/2011	15	23	42	79	98	100	100	100	100	104
Wild Rice River near St. Benedict, N. Dak. (site 6)										
04/05/2011	0	15	23	35	50	71	90	96	100	1,014
04/08/2011	3	4	9	26	66	96	100	100	100	23
04/11/2011	21	36	57	100	100	100	100	100	100	2
04/15/2011	2	3	6	19	52	95	100	100	100	83
05/03/2011	15	23	38	65	100	100	100	100	100	3
05/17/2011	15	22	36	62	94	100	100	100	100	446
Rush River near Prosper, N. Dak. (site 7)										
04/07/2011	5	9	17	36	59	81	94	100	100	50
04/09/2011	4	7	12	22	45	77	93	100	100	155
04/10/2011	6	11	21	40	64	87	99	100	100	366
04/11/2011	13	21	34	56	79	93	99	100	100	279
04/13/2011	11	17	30	58	85	96	99	100	100	154
04/14/2011	6	10	18	48	82	96	99	100	100	140
04/15/2011	6	10	18	42	72	92	99	100	100	99
04/16/2011	7	11	21	45	74	95	100	100	100	26
04/21/2011	13	20	35	72	96	100	100	100	100	5
Lower Branch Rush River east of Prosper, N. Dak. (site 8)										
04/07/2011	8	13	22	47	86	100	100	100	100	29
04/09/2011	5	7	10	15	29	63	91	100	100	29
04/10/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM	0
04/13/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM	0
Buffalo River east of Kragnes, Minn. (site 9)										
04/06/2011	39	47	55	71	90	97	99	100	100	66
04/09/2011	26	32	37	48	63	76	84	89	100	162
04/12/2011	37	44	53	70	92	100	100	100	100	18
04/15/2011	35	42	51	62	80	93	100	100	100	9
04/21/2011	20	24	40	76	100	100	100	100	100	3

Table 6. Sieve diameters of bed-material samples for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.

[mm, millimeter; IM, insufficient material]

Date	Bed material fall diameter (values in percent finer than size)								
	0.062 mm	0.125 mm	0.25 mm	0.5 mm	1 mm	2 mm	4 mm	8 mm	16 mm
Red River of the North near Christine, N. Dak. (site 1)									
04/06/2011	0	1	1	2	8	26	37	50	92
04/07/2011	0	1	2	37	66	74	82	92	100
04/08/2011	7	10	14	21	31	44	56	69	92
04/09/2011	1	3	5	17	32	41	48	57	82
04/10/2011	8	11	16	21	38	63	79	86	88
04/11/2011	2	3	6	34	62	71	74	79	93
04/12/2011	6	11	15	21	29	39	48	61	81
04/13/2011	5	8	12	26	36	42	48	60	91
04/14/2011	1	1	3	11	17	25	35	57	98
04/15/2011	3	5	8	43	88	96	97	98	100
04/16/2011	1	3	8	24	29	37	46	66	97
04/18/2011	1	1	3	17	46	63	71	84	96
04/20/2011	1	3	7	24	46	61	66	76	97
04/22/2011	1	2	4	22	53	64	68	78	90
04/26/2011	1	2	4	7	11	19	28	39	100
05/02/2011	2	5	9	16	23	46	85	98	100
05/09/2011	10	22	40	50	58	65	70	78	97
05/17/2011	3	13	37	54	89	99	100	100	100
Red River of the North at County Road 20 near Fargo, N. Dak. (site 2)									
04/04/2011	4	12	24	38	60	79	90	99	100
04/05/2011	1	4	14	34	65	85	94	99	100
04/07/2011	1	2	3	30	75	92	98	100	100
04/08/2011	15	32	53	65	78	89	98	100	100
04/09/2011	23	23	32	44	56	65	75	88	100
04/10/2011	6	11	22	42	58	71	81	93	100
04/11/2011	15	20	27	40	56	67	72	80	100
04/12/2011	21	29	40	54	68	79	87	92	100
04/13/2011	23	34	56	69	81	87	89	96	100
04/14/2011	26	35	53	75	92	97	98	99	100
04/15/2011	18	24	34	47	64	74	79	87	100
04/16/2011	26	34	46	60	74	81	83	85	100
04/17/2011	20	27	38	54	74	88	96	99	100
04/19/2011	35	46	60	76	92	98	100	100	100
04/21/2011	15	22	34	47	63	82	93	98	100
04/25/2011	20	26	34	43	60	86	98	100	100
05/02/2011	34	47	66	82	95	99	100	100	100
05/09/2011	40	54	74	94	99	100	100	100	100
05/16/2011	36	49	70	86	94	98	100	100	100
Sheyenne River above Diversion near Horace, N. Dak. (site 3)									
04/08/2011	21	39	63	75	90	100	100	100	100
04/09/2011	14	32	65	73	81	88	94	99	100
04/10/2011	10	31	87	94	96	99	100	100	100
04/11/2011	6	17	47	67	86	96	98	99	100
04/12/2011	30	49	68	77	91	99	100	100	100
04/13/2011	4	14	40	50	68	90	97	97	100
04/14/2011	3	14	41	51	69	91	99	100	100
04/15/2011	20	40	67	100	100	100	100	100	100
04/16/2011	3	17	74	90	95	97	99	100	100
04/18/2011	3	20	71	83	93	98	99	100	100

Table 6. Sieve diameters of bed-material samples for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.—Continued

[mm, millimeter; IM, insufficient material]

Date	Bed material fall diameter (values in percent finer than size)								
	0.062 mm	0.125 mm	0.25 mm	0.5 mm	1 mm	2 mm	4 mm	8 mm	16 mm
Sheyenne River above Diversion near Horace, N. Dak. (site 3)—Continued									
04/20/2011	8	17	75	100	100	100	100	100	100
04/22/2011	4	17	61	83	100	100	100	100	100
04/26/2011	32	67	92	97	100	100	100	100	100
05/03/2011	3	17	59	67	74	94	99	100	100
05/09/2011	24	48	61	64	68	71	73	81	100
05/16/2011	11	33	80	92	94	95	96	96	100
Sheyenne River below Diversion at Horace, N. Dak. (site 4)									
04/08/2011	2	7	81	98	99	100	100	100	100
04/09/2011	19	49	76	77	78	80	81	82	82
04/10/2011	9	22	50	69	84	93	97	99	100
04/11/2011	5	15	39	68	83	91	95	98	100
04/12/2011	14	40	82	92	98	100	100	100	100
04/13/2011	12	31	59	82	92	95	96	97	97
04/14/2011	24	49	77	85	91	94	95	97	100
04/15/2011	16	45	68	77	91	99	100	100	100
04/16/2011	23	51	73	85	93	95	95	95	95
04/18/2011	20	47	79	89	96	99	100	100	100
04/20/2011	27	51	81	92	99	100	100	100	100
04/22/2011	25	40	53	61	71	85	98	100	100
04/26/2011	20	44	82	95	98	99	100	100	100
05/03/2011	7	44	89	93	94	96	97	99	100
05/10/2011	3	25	67	81	92	97	100	100	100
05/16/2011	9	36	79	88	94	98	99	100	100
Maple River below Mapleton, N. Dak. (site 5)									
04/07/2011	25	34	44	55	71	89	98	100	100
04/08/2011	3	18	32	49	80	98	100	100	100
04/09/2011	30	41	52	65	82	96	100	100	100
04/10/2011	19	28	40	61	93	99	100	100	100
04/11/2011	9	14	21	35	63	92	99	100	100
04/12/2011	10	15	22	53	91	99	100	100	100
04/13/2011	13	19	28	61	92	99	100	100	100
04/14/2011	11	17	26	60	94	100	100	100	100
04/15/2011	16	23	34	65	91	98	99	100	100
04/16/2011	16	25	37	60	86	98	99	100	100
04/17/2011	10	15	24	57	87	98	100	100	100
04/18/2011	6	9	15	40	71	92	99	100	100
04/21/2011	23	35	57	87	98	100	100	100	100
04/25/2011	2	3	5	11	40	79	95	97	100
05/02/2011	31	44	59	78	90	98	100	100	100
05/09/2011	33	50	72	86	97	100	100	100	100
05/16/2011	6	9	22	75	96	100	100	100	100
Wild Rice River near St. Benedict, N. Dak. (site 6)									
04/05/2011	21	29	43	61	82	97	99	100	100
04/07/2011	19	28	47	67	82	96	99	100	100
04/08/2011	7	10	15	25	45	74	93	96	100
04/09/2011	21	34	54	75	93	99	100	100	100
04/10/2011	2	4	8	13	18	27	38	59	83
04/11/2011	1	2	3	4	7	14	24	48	96
04/12/2011	6	9	13	21	30	39	45	57	79
04/13/2011	29	42	66	85	97	100	100	100	100
04/14/2011	28	40	63	83	96	100	100	100	100

Table 6. Sieve diameters of bed-material samples for the Red River of the North and selected tributaries near Fargo, North Dakota, during the 2011 spring high-flow event.—Continued

[mm, millimeter; IM, insufficient material]

Date	Bed material fall diameter (values in percent finer than size)								
	0.062 mm	0.125 mm	0.25 mm	0.5 mm	1 mm	2 mm	4 mm	8 mm	16 mm
Wild Rice River near St. Benedict, N. Dak. (site 6)—Continued									
04/13/2011	29	42	66	85	97	100	100	100	100
04/14/2011	28	40	63	83	96	100	100	100	100
04/15/2011	27	41	63	85	94	96	97	97	100
04/16/2011	14	22	33	46	62	76	82	91	100
04/18/2011	25	37	58	77	93	99	100	100	100
04/20/2011	28	42	62	87	99	100	100	100	100
04/22/2011	22	36	61	86	99	100	100	100	100
04/25/2011	14	14	29	43	71	100	100	100	100
05/03/2011	27	41	63	84	95	99	100	100	100
05/09/2011	20	30	60	91	96	99	100	100	100
05/17/2011	10	17	54	93	97	99	100	100	100
Rush River near Prosper, N. Dak. (site 7)									
04/08/2011	8	15	27	49	69	83	95	100	100
04/09/2011	0	2	5	10	31	73	89	97	100
04/10/2011	8	14	23	53	90	98	100	100	100
04/11/2011	23	34	51	75	100	100	100	100	100
04/12/2011	18	28	43	70	95	100	100	100	100
04/13/2011	12	21	39	84	100	100	100	100	100
04/14/2011	22	34	53	82	97	100	100	100	100
04/15/2011	18	28	45	82	99	100	100	100	100
04/16/2011	22	32	49	86	100	100	100	100	100
04/17/2011	4	13	26	52	87	100	100	100	100
04/19/2011	22	33	61	100	100	100	100	100	100
04/21/2011	75	100	100	100	100	100	100	100	100
Lower Branch Rush River east of Prosper, N. Dak. (site 8)									
04/07/2011	6	11	25	47	66	74	75	100	100
04/08/2011	3	3	7	22	48	67	76	100	100
04/09/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
04/10/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
04/11/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
04/12/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
04/13/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
04/14/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
04/15/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
04/16/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
04/17/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
04/19/2011	50	100	100	100	100	100	100	100	100
04/21/2011	IM	IM	IM	IM	IM	IM	IM	IM	IM
Buffalo River east of Kragnes, Minn. (site 9)									
04/06/2011	28	36	44	60	78	86	90	91	92
04/07/2011	28	33	38	45	55	65	71	79	94
04/08/2011	57	68	76	87	98	99	100	100	100
04/09/2011	41	48	57	74	93	99	100	100	100
04/10/2011	30	39	48	58	70	80	86	92	100
04/11/2011	42	53	59	66	76	81	84	86	87
04/12/2011	45	56	64	76	92	96	98	99	100
04/15/2011	51	61	69	79	87	90	93	96	100
04/17/2011	45	55	64	74	86	93	96	99	100
04/19/2011	32	42	52	60	67	78	88	95	100
04/21/2011	24	33	44	51	59	67	76	86	100
04/25/2011	29	40	55	62	69	79	84	88	100

bed material in samples from the Red River near Christine (site 1) had particle sizes that were distributed fairly evenly from 0.25 mm to 8 mm with the greatest portion in the 8 to 16 mm range (20 percent), which was not observed at the other sites. The Lower Branch Rush River had a large portion of particles in the 4 to 8 mm range (24 percent) compared to the other sites; however, only three samples were collected because the channel was lined with concrete and material was not available for collection. Most of the bed material from the Sheyenne River sites (53 to 56 percent) was in the 0.062 to 0.125 mm and 0.125 to 0.25 mm ranges. Generally, a greater portion of finer particle sizes were observed in the bed material compared to the bedload from the nine sites, probably because of how the two different type of samples were collected. The bed-material samples were collected from three to five locations in the cross section, including areas of low velocities, and composited into one sample. Therefore, fine-grained particles (less than 0.062 mm) deposited in the low velocity areas would compose a portion of the sample. The bed-load samples were collected at 10 to 20 locations in the cross section and composited into 1 sample. The bedload sampler depends on velocity at the surface of the streambed to move particles into the collection bag. In portions of the stream cross section that have velocities large enough to move material along the bed, fine-grained particles (less than 0.062 mm) would be in suspension and not part of the bedload. Also, the bag that the sampler uses to collect the bedload has mesh openings of 0.25 mm, so particles smaller than that size would pass through (Davis, 2005). However, if enough material clogs the mesh openings, smaller particles can adhere to the bag and get included in the sample.

Quality Assurance

Quality-assurance samples were collected for SSC and bedload during the 2011 spring high-flow event to define the variability in the laboratory analysis and reproducibility in the collection of the samples. Nine replicate samples were collected and analyzed for SSC, and nine bedload replicate samples were collected and analyzed for bedload mass (table 7). The analytical variability of SSC samples was minimal with differences less than 10 percent for all but two

Table 7. Results of quality-assurance samples for suspended-sediment concentration and bedload mass for selected samples collected during the 2011 spring high-flow event at the Red River of the North and selected tributaries near Fargo, North Dakota.

Site	Date	Sample	Replicate	Replicate type	Absolute percent difference[1]
Bedload mass (grams)					
Rush River near Prosper, N. Dak. (site 7)	04/11/2011	279	102	Sequential	93
Red River of the North near Christine, N. Dak. (site 1)	04/11/2011	1,133	905	Sequential	22
Sheyenne River below Diversion at Horace, N. Dak. (site 4)	04/12/2011	1,298	892	Sequential	37
Sheyenne River above Diversion near Horace, N. Dak. (site 3)	04/16/2011	49	24	Sequential	69
Sheyenne River below Diversion at Horace, N. Dak. (site 4)	04/18/2011	200	16	Sequential	170
Red River of the North near Christine, N. Dak. (site 1)	05/02/2011	310	354	Sequential	13
Sheyenne River below Diversion at Horace, N. Dak. (site 4)	05/03/2011	43	53	Sequential	21
Sheyenne River below Diversion at Horace, N. Dak. (site 4)	05/03/2011	43	911	Sequential	182
Sheyenne River below Diversion at Horace, N. Dak. (site 4)	05/10/2011	343	363	Sequential	5
Suspended-sediment concentration (milligrams per liter)					
Maple River below Mapleton, N. Dak. (site 5)	04/11/2011	171	162	Concurrent	5
Red River of the North at County Road 20 near Fargo, N. Dak. (site 2)	04/12/2011	85	80	Sequential	6
Red River of the North near Christine, N. Dak. (site 1)	04/16/2011	57	56	Concurrent	2
Red River of the North near Christine, N. Dak. (site 1)	04/18/2011	54	55	Sequential	2
Red River of the North near Christine, N. Dak. (site 1)	04/20/2011	53	41	Concurrent	26
Rush River near Prosper, N. Dak. (site 7)	04/21/2011	72	66	Concurrent	9
Lower Branch Rush River east of Prosper, N. Dak. (site 8)	04/21/2011	115	96	Sequential	18
Maple River below Mapleton, N. Dak. (site 5)	05/09/2011	116	119	Sequential	3
Wild Rice River near St. Benedict (site 6)	05/17/2011	136	134	Concurrent	1

[1]Calculation of absolute percent difference is: $|(x_1-x_2)/(x_1+x_2)/2|(100)$, where x_1 = sample, x_2 = sequential replicate.

samples; one concurrent sample from the Red River near Christine had a 26 percent difference, and one sequential sample from the Lower Branch Rush River had an 18 percent difference. Analytical variability was relatively large for bedload samples collected during the 2011 spring high-flow event. The differences between the samples and the replicates ranged from 5 to 182 percent. This large variation may be attributed to a combination of factors that make it difficult to accurately sample bedload using current methods. According to Edwards and Glysson (1999), placing any device, such as a bedload sampler, on or near the bed may disturb the flow pattern of the stream and, consequently, the rate of bedload movement. Moreover, the rate of bedload movement and the velocity of water close to the bed vary considerably both spatially and temporally. Because of this, any sample obtained at a given point may be extremely difficult to repeat because bed particles move intermittently according to the velocity and supply of sediment available at the specific time and point where the sample was collected.

Summary

Natural-resource agencies were concerned about possible geomorphic effects of a proposed diversion project to reduce the flood risk in the Fargo-Moorhead metropolitan area. To provide accurate and reliable information on sediment transport, the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers conducted a study in the spring (March–May) of 2010 and the spring of 2011 to examine sediment concentrations, loads, and particle-size distributions at nine selected sites in the Red River and its tributaries near the Fargo-Moorhead metropolitan area. Samples of suspended sediment, bed material, and bedload were collected at the nine sites at various time intervals during the high-flow events.

Suspended-sediment concentrations varied spatially during the 2011 spring high-flow event sampling period. Most tributary streams had substantially higher suspended-sediment concentrations compared to suspended-sediment concentrations in the main stem of the Red River, especially at the Sheyenne River sites. Suspended-sediment concentrations on the Red River ranged from 45 to 126 milligrams per liter near Christine and from 49 to 197 milligrams per liter near Fargo. In comparison, the suspended-sediment concentrations ranged from 239 to 1,180 milligrams per liter at the Sheyenne River above Diversion and from 199 to 1,130 milligrams per liter at the Sheyenne River below Diversion. The Buffalo River had the lowest concentrations among the sites; suspended-sediment concentrations in the Buffalo River ranged from 21 to 61 milligrams per liter.

Peak measured suspended-sediment concentrations were slightly higher in 2011 at the Red River near Fargo, Sheyenne River above Diversion, and Sheyenne River below Diversion compared to measured suspended-sediment concentrations in 2010. Peak measured suspended-sediment concentrations were lower in 2011 at the Red River near Christine, Maple River, and Wild Rice River compared to measured suspended-sediment concentrations in 2010. Streamflow and suspended-sediment concentration data collected during the 2011 spring high-flow event showed that the peak in suspended-sediment concentration mainly occurred prior to the peak in streamflow among the nine sites, except at the Maple River and Lower Branch Rush River.

Total sediment loads measured during the 2011 spring high-flow event at the Red River and its tributaries near the Fargo-Moorhead metropolitan area were mainly composed of suspended sediment and were greatest at the Sheyenne River above Diversion compared to the loads at the other eight sites. The calculated total sediment load during the entire event ranged from 3,040 tons at the Lower Branch Rush River (April 7–21) to 188,000 tons at the Sheyenne River above Diversion (April 8 to May 16).

Daily total sediment loads calculated for the 2011 spring high-flow event showed that the peak in sediment mainly occurred prior to or simultaneously with the peak in streamflow at the nine sites. The Red River near Christine, Sheyenne River above Diversion, Sheyenne River below Diversion, Maple River, Lower Branch Rush River, and the Buffalo River had peak daily sediment loads of 4,370 tons per day, 13,209 tons per day, 6,280 tons per day, 3,653 tons per day, 825 tons per day, and 1,052 tons per day, respectively. The Red River near Fargo had a peak daily sediment load of 9,093 tons per day, the Wild Rice River had a peak daily sediment load of 3,570 tons per day, and the Rush River had a daily sediment peak of 2,692 tons per day.

More than 90 percent of the measured suspended sediment was composed of fine-grained material (less than 0.062 millimeters) in most of the suspended-sediment samples collected during the 2011 spring high-flow event, except for the Sheyenne River. Samples from the Sheyenne River above Diversion had 19 to 43 percent of the suspended sediment with particle sizes greater than 0.062 millimeters, and the Sheyenne River below Diversion had 10 to 30 percent of the suspended sediment with particle sizes greater than 0.062 millimeters.

Bedload samples collected during the 2011 spring high-flow event demonstrated different distributions of particle sizes among the nine sites. The bedload in the Maple River, Wild Rice River, Buffalo River, and the Red River sites had particle sizes mainly ranging from 0.5 to 1 millimeter and 0.25 to 0.5 millimeter. Bedload from the Rush and Lower Branch Rush Rivers also had a greater portion of larger particle sizes in the 1 to 2 millimeter range. The Sheyenne River sites had a greater portion of smaller particle sizes in the bedload in the 0.125 to 0.5 millimeter range compared to the other sites.

The bed material in samples collected during the 2011 spring high-flow event demonstrated a wider distribution of particle sizes than were observed in the bedload; the coarsest material was found at the Red River near Christine and the Lower Branch Rush River and the finest material at the Sheyenne River sites. The bed material in samples from the Red

River near Christine had particle sizes distributed fairly evenly from 0.25 to 8 millimeters with the greatest portion in the 8 to 16 millimeter range, which was not observed at the other sites. Most of the bed material from the Sheyenne River sites was in the 0.062 to 0.125 millimeter and 0.125 to 0.25 millimeter ranges. Generally, a greater portion of finer particle sizes were observed in the bed material compared to the bedload from the nine sites, probably because of how the two different types of samples were collected.

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