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Occurrence and Transport of Nutrients in the Missouri River Basin, April through September 2011

Chapter G of
2011 Floods of the Central United States

Professional Paper 1798–G

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

Front cover. Top photograph: View of flooding from Nebraska City, Nebraska, looking east across the Missouri River, August 2, 2011. Photograph by Robert Swanson, U.S. Geological Survey (USGS).
Lower photograph: U.S. Geological Survey hydrographer collecting Missouri River flood data near Percival, Iowa, July 13, 2011 (photograph by U.S. Geological Survey).

Back cover. Center pivot irrigation system in a floodplain field near Nebraska City, Nebraska, July 2011 (photograph by U.S. Geological Survey).

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By Stephen J. Kalkhoff

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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2013

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Suggested citation:
Kalkhoff, S.J., 2013, Occurrence and transport of nutrients in the Missouri River Basin, April through September 2011: U.S. Geological Professional Paper 1798–G, 23 p., http://pubs.usgs.gov/pp/1798g/.

“This Flood is Different”*

The character of the 2011 Missouri River flood in the lower part of the basin was different from other floods during the last 30 years. Floods on the lower Missouri River generally are characterized as muddy from erosion of soils. In contrast to the historic flood of 1993, much of the Missouri River floodwater downstream of Sioux City, Iowa originated from snowmelt and rainfall in the upper and middle parts of the basin. Runoff from this area of predominantly forest, prairie, and wheat farming is “cleaner water” with smaller amounts of suspended sediment and dissolved and particulate nutrients. Flood water in 2011 contained less sediment and dissolved nitrate than in the 1993 floodwater. First hand observations made by long-time U.S. Geological Survey hydrologic technician, Joe Gorman, and reported by David Hendee in the Omaha World Herald describe the character of the 2011 Missouri River flood.

Joe Gorman can smell and see the difference in the Missouri River.

“It’s reservoir water,” he said.

Not floodwater from a thunderstorm deluge, the kind of storm that erodes Corn Belt cropland and fills rivers with muddy waves that carry the faint smell of fertilizer and pesticides.

“This flood is clear, clean and wide,” Gorman said.

“Normally, we get a lot of sand in the Missouri River,” Gorman said. “We’re not getting a lot.”

“The river’s going to be up for a long time,” he said. “That’s the thing about this one. Most other floods hit a peak and drop slowly. This is just going to be up.”

*Quoted and reproduced from July 11, 2011 Omaha World Herald; used with permission.
Background photo from U.S. Corps of Engineers.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
hectare meter (hm)	8.107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per day (m^3/d)	35.31	cubic foot per day (ft^3/d)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
	Mass	
megagram (Mg)	1.102	ton, short (2,000 lb)

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

°F=(1.8×°C)+32

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Occurrence and Transport of Nutrients in the Missouri River Basin, April through September 2011

By Stephen J. Kalkhoff

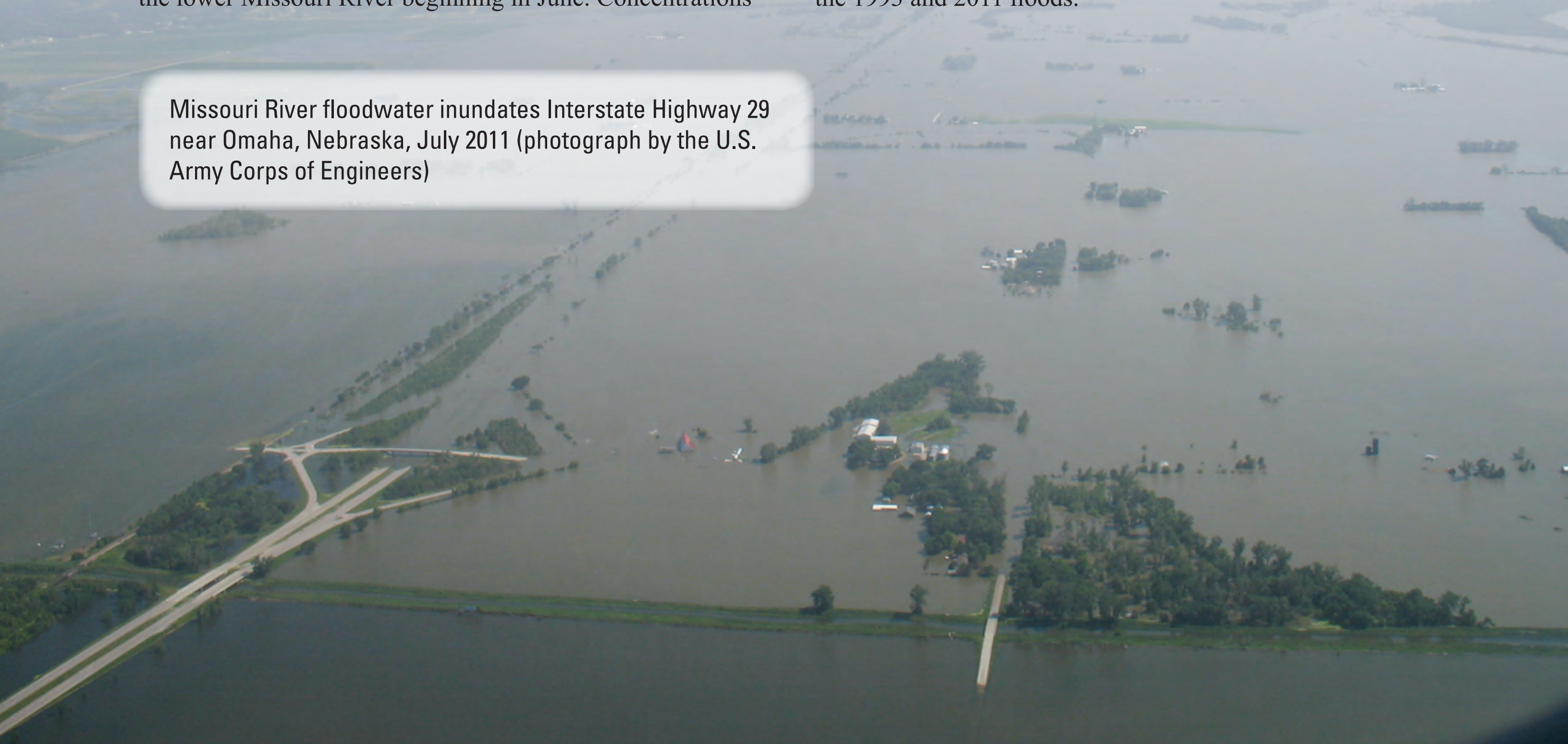
Abstract

Heavy snow and early spring rainfall generated substantial amounts of runoff and flooding in the upper part of the Missouri River Basin in 2011. Spring runoff in the upper and middle parts of the basin exceeded the storage capacity of the Missouri River reservoirs and unprecedented amounts of water were released into the lower parts of the basin resulting in record floods from June through September on the Missouri River in Iowa and Nebraska and extending into Kansas and Missouri. Runoff from the Missouri River Basin in April through September 2011 was 8,440,000 hectare meters (68,400,000 acre feet) and was only exceeded during flooding in 1993 when runoff was 11,200,000 hectare meters (90,700,000 acre feet).

Nitrate and total phosphorus concentrations in the Missouri River and selected tributaries in April through September, 2011 generally were within the expected range of concentrations measured during the last 30 years. Substantial discharge from the upper and middle parts of the Missouri River Basin resulted in nitrate concentrations decreasing in the lower Missouri River beginning in June. Concentrations of nitrate in water entering the Mississippi River from the Missouri River were less in 2011 than in 1993, but total phosphorus concentrations entering the Mississippi River were substantially greater in 2011 than in 1993.

The Missouri River transported an estimated 79,600 megagrams of nitrate and 38,000 megagrams of total phosphorus to the Mississippi River from April through September 2011. The nitrate flux in 2011 was less than 20 percent of the combined total from the Upper Mississippi and Missouri River Basins. In contrast, the total phosphorus flux of 38,000 megagrams from the Missouri River constituted about 39 percent of the combined total from the Upper Mississippi and Missouri River Basins during April through September 2011.

Substantially more nitrate but less total phosphorus was transported from the Missouri River Basin during the historic 1993 than during the 2011 flood. Greater runoff from the lower part of the basin contributed to the greater nitrate transport in 1993. In addition to the differing amounts of runoff and the source of flood waters, changes in land use, and management practices are additional factors that may have contributed to the difference in nitrate and total phosphorus flux between the 1993 and 2011 floods.



Missouri River floodwater inundates Interstate Highway 29 near Omaha, Nebraska, July 2011 (photograph by the U.S. Army Corps of Engineers)

Introduction

Snowmelt during the late winter and early spring and rainfall in spring and early summer resulted in runoff that produced high-flow and flooding conditions in the Missouri River Basin from April through September 2011, hereafter referred to as the “2011 flood.” Floods reached record levels (Holmes and others, 2013) in May and June in many rivers and streams in the upper part of the basin. Water then discharged to the Missouri River and flowed into flood control reservoirs in the middle section of the basin. Reservoirs in the Dakotas rapidly filled requiring release of water downstream in record volumes (U.S. Army Corps of Engineers, 2012). The runoff from the basin upstream from the reservoirs was the greatest amount observed since the reservoirs were constructed leading to the largest flooding along parts of the Missouri since the time the reservoirs were built. Record flooding occurred downstream from reservoirs in Iowa and Nebraska and extended into Kansas and Missouri. Because streamflow in many lower Missouri River Basin tributaries was at normal levels, the flood peak was attenuated by the time water reached the Mississippi River. April rainfall in the lower part of the Missouri River Basin was produced as part of the weather system that dropped heavy rain in the Upper Mississippi and Ohio Basins that resulted in major flooding in the lower Mississippi River (Vining and others, 2013; Holmes and others, 2013). These early spring rains generated substantial amounts of streamflow but not record floods in the lower Missouri River.

Intense rains can produce substantial runoff that carries large quantities of dissolved and suspended material into nearby rivers and streams. The amount of dissolved and suspended material transported is dependent on its availability. Snowmelt also may produce runoff but may not transport as large a quantity of material because soils generally are still frozen. Soils that do not have vegetation and have been tilled for farming or altered for urban uses can contribute substantial amounts of dissolved nitrogen and total phosphorus (Brown and others, 2011a). Runoff and overbank flow associated with high-flow and flooding conditions in the Missouri River basins had the potential to transport substantial amounts of nitrogen and phosphorus from April through September 2011.

Major floods in the Missouri River Basin generally have occurred in the spring as a result of snowmelt and or rainfall and during the summer as a result of intense widespread rains. A notable major spring flood occurred in 1952. Heavy accumulation of snow during the winter of 1951–52 in the Dakotas and eastern Montana resulted in major flooding in April of 1952 from the Dakotas to the mouth of the Missouri River (Wells, 1955). The Missouri River flood plain was completely inundated from Sioux City, Iowa to the mouth of the Kansas River. Downstream from Kansas City, Missouri flood waters breached some levees and flooded farmland (Wells, 1955). The maximum streamflow during this event was 11,200 m^3/s (396,000 ft^3/s) on April 18 at Omaha, Nebraska and 10,400 m^3/s (368,000 ft^3/s) on April 28 near the mouth of the Missouri River at Hermann, Mo.

The summer flood of 1993 was generated from intensive and persistent rains (Wahl and others, 1993) that fell in mid-June to early August in the eastern Dakotas, Iowa, Nebraska, Kansas, and Missouri on already saturated soils. Runoff from North and South Dakota was attenuated by storage in the reservoirs. Downstream in Nebraska, Kansas, and Missouri, streamflow in both the Missouri River and its major tributaries peaked at annual flood probabilities that ranged from 1 to 2 percent (recurrence intervals that ranged from 50 to more than 100 years) (Parrett and others, 1993). The peak streamflow in the Missouri River increased from 2,044 m^3/s (72,200 ft^3/s) at Sioux City, Iowa to 3,260 m^3/s (115,000 ft^3/s) on July 10 at Omaha, Nebr. to 9,500 m^3/s (335,000 ft^3/s) on July 26 at St. Joseph, Mo. to 21,200 m^3/s (750,000 ft^3/s) on July 31 near the mouth at Hermann, Mo. (Parrett and others, 1993; U.S. Geological Survey, 2012).

Transport of nitrogen and phosphorus during flood conditions in the Missouri River Basin has not been extensively documented. Water quality samples were not collected in the Missouri River Basin during the 1951 and 1952 floods, but were collected during the 1993 flood. Results of the 1993 sampling were used by Goolsby and others (1993) to describe nitrate concentrations during flooding in the Missouri River at Hermann, Mo. Although transport of nutrients during flood conditions has not been extensively described, water quality during normal streamflow and high streamflow conditions has been more frequently documented. Yearly transport of several nitrogen and phosphorus species have been calculated since the 1980s for the Missouri River at Yankton, South Dakota; Omaha, Nebr.; and Hermann, Mo., and several large tributaries that include the Platte River in Nebraska, and the Grand and Osage Rivers in Missouri (Aulenbach and others, 2007). Nutrient trends at several Missouri River Basin sites have been described by Sprague and others (2006, 2011). Battaglin and others (2010) indicated that transport of nitrate from the Missouri River in spring (April-June) decreased from an average of more than 20,000 Mg/month (megagrams per month) during 1980–1996 to about 11,000 Mg/month during 2002–06. Total phosphorus (TP) flux from the Missouri River averaged 3,860 Mg/month during spring from 1980–96 and 5,360 Mg/month from 2001–05. A SPARROW model was developed (Brown and others, 2011a) to relate nutrient flux to sources and factors affecting transport in the Missouri River Basin. The water quality in the Yellowstone River (Miller and others, 2005), South Platte River (Litke and Kimbrough, 1998), and the Central Nebraska basins (Frenzel and others, 1998), important tributaries of the Missouri River, were studied in the 1990s. Collection of water quality data from rivers is ongoing in Wyoming and Montana (Clark, 2012), Iowa (Garrett, 2012), and Missouri (Barr, 2012).

An understanding of the magnitude and timing of nutrient transport in Missouri River basins is important to determine effect of climatic and land use factors on nutrient input into the Gulf of Mexico. An understanding of transport during floods may be particularly important because a large proportion of the nutrients transported in rivers and streams commonly occur during floods.

Purpose and Scope

The purpose of this report is to describe the concentration and loads of nitrogen and phosphorus in the Missouri River and selected tributaries from April through September 2011. Differences in the timing of flooding from the upper, middle, and lower parts of the basin are summarized and are used as the basis for discussion of the spatial and temporal differences in nitrate and total phosphorus concentrations. Input and loss of nitrogen and phosphorus downstream will be identified. Finally, concentrations and loads during the 2011 flood will be compared to those of the 1993 Missouri River flood.

Data on the two most prevalent nitrogen and phosphorus species in rivers and streams in the Missouri River Basin, nitrate plus nitrite nitrogen (hereafter referred to as nitrate) and total phosphorus (TP), that were collected in 2011 as part of U.S. Geological Survey (USGS) Federal projects and USGS cooperative water projects were used for analysis. Long-term data from a select group of sites on the main stem of the Missouri and several major tributaries are used in models to estimate monthly and yearly flux of nitrogen and phosphorus. These fluxes are used to document nutrient transport in the Missouri River during the 2011 flood conditions. Some long-term sites had data from the 1970s, but samples were not consistently collected at all these sites until 1980. Thus the period 1980–2010 was selected to ensure a consistent dataset at the long-term sites. Most available data were from the lower part of the Missouri River Basin, which limited the discussion of nutrient occurrence and transport in the upper and middle part of the basin.

Hydrologic Setting and Methodology

Study Area

Description of the Missouri River Basin

The Missouri River Basin is located in north central United States and is the largest tributary to the Mississippi River (fig. 1). The Missouri River originates in Montana and flows more than 3,700 kilometers (km) to its confluence with the Mississippi River near St. Louis, Mo. The Missouri River Basin encompasses an area of 1,353,300 square kilometers (km^2) that comprises 43.1 percent of the entire Mississippi-Atchafalaya River Basin (MARB) but only contributes about 12 percent of the average annual streamflow discharged from the MARB (Aulenbach and others, 2007). Major tributaries of the Missouri River include the Yellowstone River and its tributary, the Powder River, in Montana and Wyoming; the James, Big Sioux, and Cheyenne Rivers in the Dakotas; the Platte River in Colorado, Nebraska, and Wyoming; and the Kansas River in Kansas. Additional tributaries include the Little Sioux, Boyer, and Nishnabotna Rivers that drain western Iowa, the Grand River that drains parts of northern Missouri, and the Osage River that drains parts of central and western Missouri.

The hydrology of the Missouri River Basin has been altered for flood control, irrigation, and navigation resulting in highly regulated flow in parts of the basin. Pegg and Pierce (2002) divided the Missouri River Basin into three major hydrologic zones based on the type and degree of channel alteration (fig. 1). The zones include an upper zone that includes the uppermost of the six major main-stem Missouri River reservoirs, a middle zone with short free-flowing reaches between reservoirs, and a lower zone downstream from the main-stem reservoirs, which is entirely channelized except for the reach between Yankton, South Dakota and Sioux City, Iowa (Pegg and Pierce, 2002). The upper part of the basin is about 147,600 km^2 (57,000 mi^2), which includes the Fort Peck Reservoir and many of the unchannelized headwaters streams of the Missouri River and the Yellowstone River and its tributaries including the Powder and Bighorn Rivers. The upper basin ends approximately to the Montana–North Dakota border. The middle part of the Missouri River Basin includes five major reservoirs (Garrison, Oahe, Big Bend, Fort Randall, and Gavins Point) on the main stem and extends from eastern Montana through North and South Dakota. The six reservoirs have the capacity to store more than 20,000 cubic hectare meters (hm^3) or 16,000,000 acre feet. The area of the upper and middle parts of the basin is 836,000 km^2. The channelized lower part of the Missouri River Basin extends from Sioux City, Iowa to the mouth at St. Louis, Mo. and includes about 537,000 km^2.

Land use in the Missouri River Basin is diverse; ranging from extensively altered urban, to intensively cropped farmland, to open prairie, and to forested areas. Much of the upper part of the basin is undeveloped or is rangeland or shrubland (Sprague and others, 2006; Brown and others, 2011a). Cropped areas used primarily for the production of wheat (Donner and others, 2004) are more prevalent in the northern part of the upper basin. Much of the middle part of the basin is grassland and forest. Corn and soybeans are grown in the area generally east of the Missouri River (Donner and others, 2004). The lower part of the Missouri River Basin is much more intensively farmed than the upper and middle parts. Corn and soybeans are the primary crops in Iowa and in the Platte River Basin in Nebraska. A smaller proportion of the land in northern Missouri (Donner and others, 2004) is used to grow corn and soybeans. Wheat is the main crop grown in much of the Kansas River Basin.

Nutrient input into the Missouri River Basin corresponds with the cropping patterns. Nitrogen input from farm fertilizer is greatest in the corn and soybean producing areas in the middle part of the basin in Iowa and the lower part of the basin in Nebraska (Brown and others, 2011b; Donner and others, 2004). Phosphorus application is more widespread in both corn and wheat producing areas of the basin (Brown

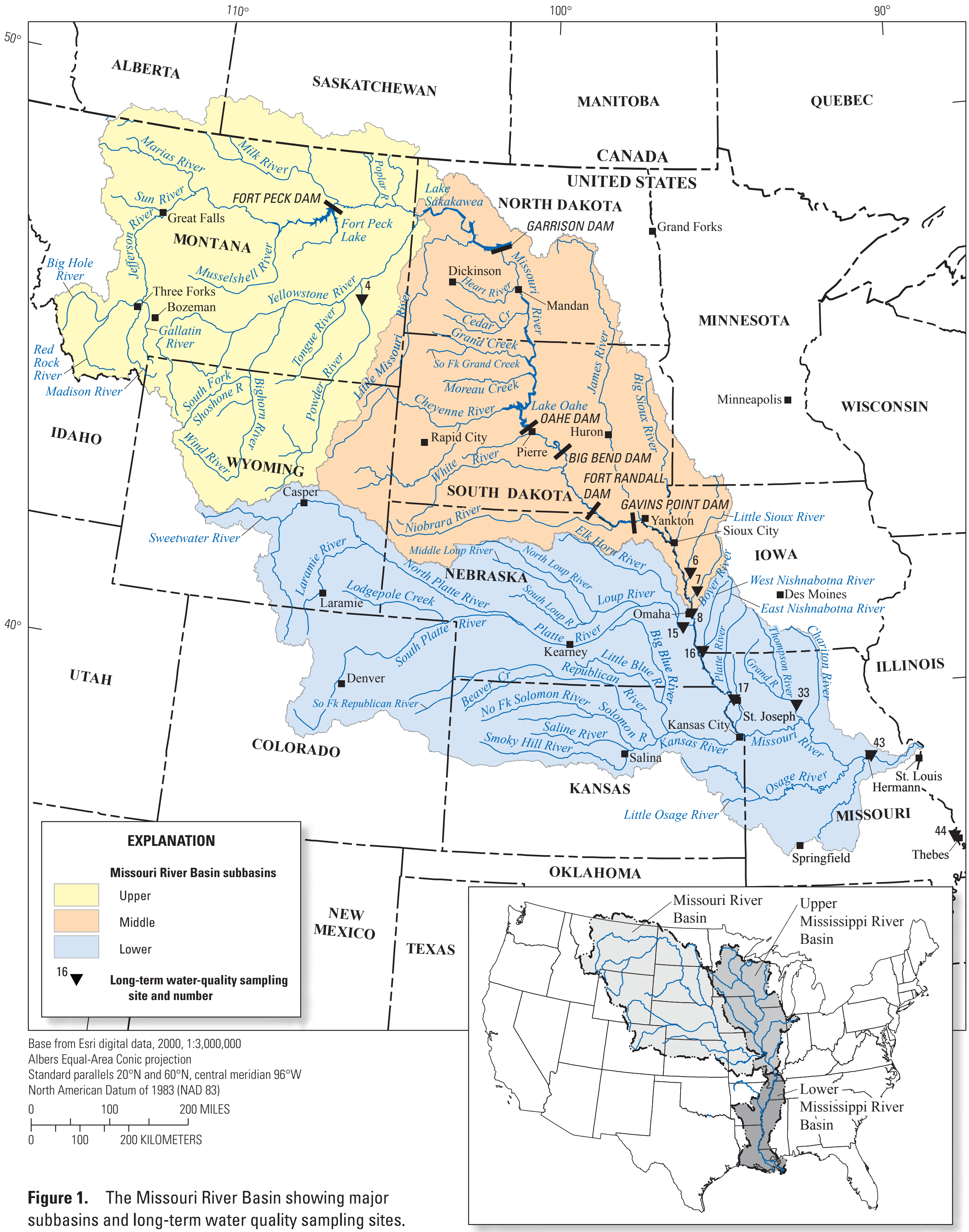


Figure 1. The Missouri River Basin showing major subbasins and long-term water quality sampling sites.

and others, 2011b). Hydrologic modeling has identified larger stream channels as another substantial source of phosphorus (Brown and others, 2011a). Point sources of nutrient input are centered in the major urban areas that include Denver, Colo., Omaha, Nebr., and Kansas City, Mo. Point source nutrient input from smaller cities and towns are most common in the Iowa and eastern Nebraska parts of the basin (Brown and others, 2011b).

Hydrologic Conditions

Flood conditions in the Missouri River Basin during 2011 were generated by a combination of snowmelt and rainfall in the upper part of the basin from late winter through summer and by large amounts of rainfall in the lower part of the basin during spring. Daily mean discharge from the Missouri River Basin since the early 1950s, when the main-stem reservoirs were completed, averages more than 2,500 m^3/s (U.S. Geological Survey, 2012). The daily mean discharge to the Mississippi River in 2011 (3,880 m^3/s) was substantially greater than the average but was only about 73 percent of the maximum yearly daily mean discharge (5,300 m^3/s) in 1993.

Large amounts of snow in the mountains and plains of the upper Missouri River Basin and heavy rains in spring and summer resulted in substantially greater than normal runoff in the upper and middle parts of the basin in 2011. Streamflow in rivers and streams in Wyoming, Montana, and the Dakotas peaked at values that consistently ranked in the top 10 peak streamflow for the period of record at individual streamgages; with most being in the top 5 peak streamflow (Holmes and others, 2013). Streamflow in the Powder River (fig. 2*A*) was typical of many rivers in the upper part of the basin. Streamflow in May was substantially greater than normal because of heavy rains at a time when the snow was beginning to melt in the mountain headwaters. Streamflow in the Powder River decreased through June and July but was still greater than normal. Runoff entering the Missouri River and the main-stem reservoirs was from two to three times normal beginning in late winter and extending through late summer (U.S. Army Corps of Engineers, 2012). Runoff upstream from Sioux City, Iowa during May through July was 5,770,000 hm (46,800,000 ac-ft, which is almost three times the storage capacity (2,010,000 hm or 16,300,000 ac-ft) of the six main-stem reservoirs (U.S. Army Corps of Engineers, 2012).

In order to avoid uncontrolled releases from the reservoirs, unprecedented amounts of water were released from May through September that resulted in record flooding along the Missouri River from Yankton to downstream from St. Joseph, Mo. Daily maximum streamflow (for the period since completion of the reservoirs in 1952) in the Missouri River was recorded at Omaha, Nebr. from May 21 to October 2, 2011 (fig. 2*B*). Daily mean streamflow exceeded 5,000 m^3/s from mid-June to early August. Downstream at St. Joseph, Mo., the Missouri River was at or above flood stage from mid-April through September (U.S. Geological Survey, 2011) . In addition to the water released from the reservoirs, a large increase in tributary flow between Omaha, Nebr., and St. Joseph, Mo. contributed to streamflow that exceeded 7,000 m^3/s at St. Joseph from June 28 to July 10, 2012. The Missouri River was above flood stage at Hermann, Mo. from June and into September (fig. 2*C*), but did not reach record levels during this period recorded during 1993 (U.S. Geological Survey, 2011).

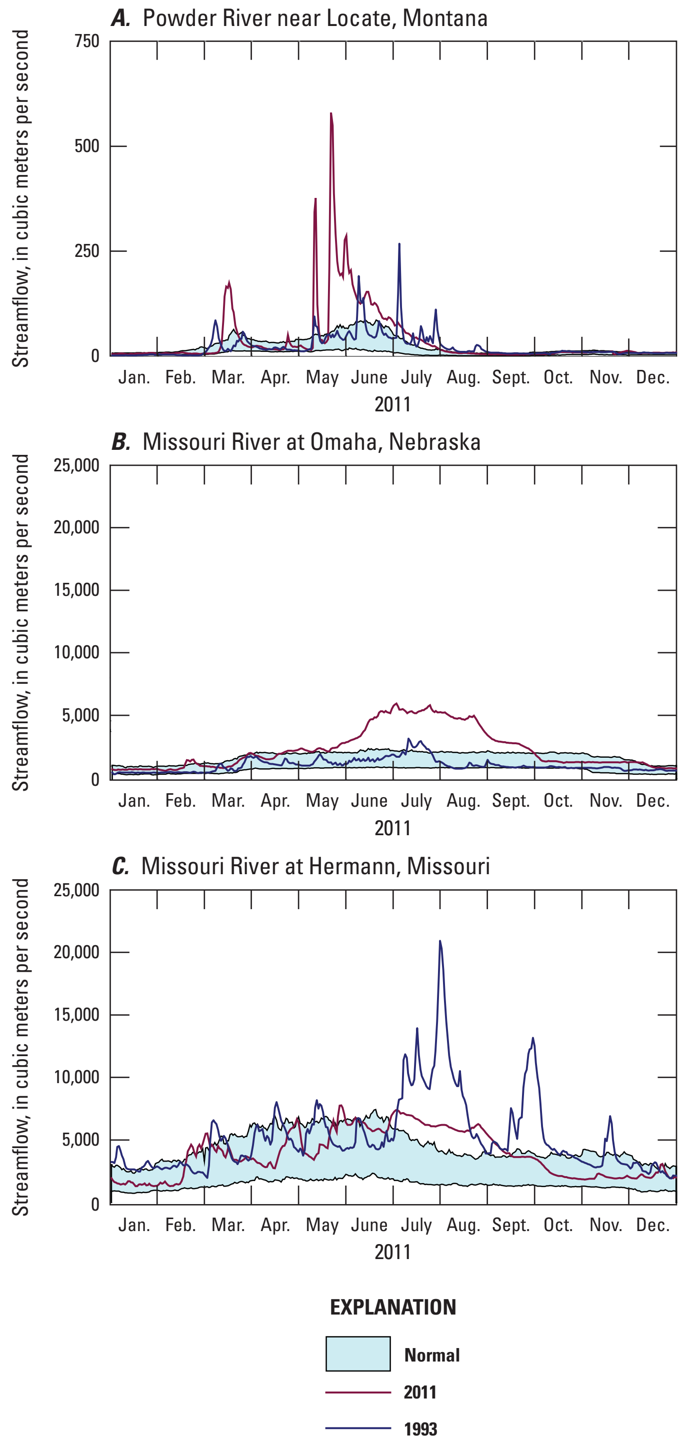


Figure 2. Normal streamflow at selected sites in the Missouri River Basin in relation to streamflow during 1993 and 2011.

The predominant source of water flowing into the Mississippi River from the Missouri River changed from late winter through spring and summer. During late winter through May more than one-half the total discharge originated from the lower part of the Missouri River Basin (table 1). In April and May, about 40 percent of the streamflow originated from about 18 percent of the basin downstream from St. Joseph. The maximum daily mean discharge of 7,760 m^3/s (274,000 ft^3/s) from the Missouri River at Hermann, Mo. in 2011 occurred on May 28 (fig. 2*C*). High flow on May 28 that partially resulted from rainfall runoff from the weather system that dropped large amounts in the lower Mississippi and Ohio River Basins (Vining and others, 2013) contributed to historic flooding on the lower Mississippi River (Holmes and others, 2013). After decreasing through most of June, streamflow in the Missouri River at Hermann, Mo. again increased from about 5,550 m^3/s (196,000 ft^3/s) (fig. 2*C*) in late June to about 7,400 m^3/s (261,000 ft^3/s) in early July reflecting flood discharges from the upper and middle parts of the basin. Consistent discharge greater than 5,000 m^3/s upstream from Omaha, Nebr. and generally decreasing discharge downstream from Omaha, Nebr. beginning in June and extending through August resulted in 70 or more percent of the streamflow entering the Mississippi River from the Missouri River originating from the upper and middle parts of the basin (table 1). During July when reservoir discharge peaked, 77 percent of the Missouri River streamflow originated upstream from Sioux City, Iowa. A disproportionately large part of the streamflow from the Missouri River Basin, measured at Hermann, Mo., (table 1) originated from the Iowa and Nebraska tributaries between Sioux City and Omaha, Nebr. during July, August, and September.

Runoff from the entire Missouri River Basin in April through September 2011 was the second greatest during the last 30 years. Runoff during this period was 8,440,000 hm (68,400,000 ac-ft) and was only exceeded 11,200,000 hm (90,700,000 ac-ft) during high streamflow and flooding in 1993 (Southard, 1995). Runoff from the upper and middle parts of the basin (measured at Sioux City, Iowa) during water year 2011 was the greatest since the beginning of record in 1929 (Holmes and others, 2013).

Data Selection

Water samples were collected by the USGS throughout the Missouri River Basin (U.S. Geological Survey, 2001). Data included in this report were selected based on the use of standardized collection and analytical methods, availability of monthly samples collected through the spring and summer of 2011, and the availability of long-term streamflow and water quality data. Data were selected from samples that were collected using methods that adequately represent the conditions in the river. River sites with a minimum of monthly data from April through September were selected (table 2) to document concentrations throughout the spring and summer high streamflow and flood conditions. A subset of 9 sites (fig. 1) that had long-term water quality and continuous streamflow data previous to 1993 were selected to model nitrate and TP flux. Sites with data previous to 1993 were selected to allow comparison of transport in 2011 with transport during the 1993 flood on the Missouri River. Data collected from the Mississippi River at Thebes, Illinois were used to quantify the effect of the Missouri River nutrient transport on the Mississippi River.

Sampling and Analytical Methods

Representative samples were collected from flowing sections of rivers using isokinetic, depth-integrating equal-width-increment (EWI) methods (U.S. Geological Survey, 2006). Water from the 10 or more vertical increments was composited for each sample. Because of safety and the difficulty in accessing flooded overbank areas, less than 10 verticals were occasionally sampled. Samples for nitrate analysis were filtered by pumping the composited water through a 0.45-micrometer

Table 1. Contribution to Missouri River discharge from selected areas in 1993 and 2011.

Subbasin	Area contributing discharge	Percent of the area of the Missouri River Basin	Year	Percent of the total discharge from the Missouri River					
				April	May	June	July	August	September
Upper and middle	Upstream from Sioux City, Iowa	60.2	1993	14.4	16.8	20.3	13.0	7.9	10.6
			2011	43.4	45.0	69.7	77.0	71.3	62.7
	Sioux City, Iowa to Omaha, Nebraska	1.6	1993	9.1	6.6	11.3	7.9	3.8	3.9
			2011	3.7	2.7	1.6	5.4	8.5	6.4
Lower	Omaha, Nebraska to St. Joseph, Missouri	19.8	1993	14.0	17.0	12.7	31.0	12.2	13.4
			2011	13.6	12.1	4.2	16.6	11.5	13.9
	St. Joseph, Missouri to Hermann, Missouri	18.4	1993	62.5	59.6	55.6	48.1	76.1	72.1
			2011	39.4	40.2	24.5	1.0	8.7	17.0

Table 2. Average nitrate plus nitrite nitrogen and total phosphorus concentrations at selected sites in the Missouri River Basin, April through September 2011.

[m³/s, cubic meters per second; mg/L, milligrams per liter; --, no data]

Map number (fig. 4)	Site identification number	Site name	Number of samples	Sampled streamflow (m^3/s)	Nitrate plus nitrite, as nitrogen (mg/L)	Total phosphorus (mg/L)
		Upper and middle Missouri River Basins				
1	06306300	Tongue River at State Line near Decker, Montana	8	47.3	0.15	0.12
2	06324500	Powder River at Moorhead, Montana	12	35.2	0.13	0.51
3	06325500	Little Powder River near Broadus, Montana	6	4.66	0.01	0.16
4	06326500	Powder River near Locate, Montana	6	37.4	0.08	0.47
5	06426500	Belle Fourche River below Moorcroft, Wyoming	6	0.88	0.88	--
6	06607500	Little Sioux River near Turin, Iowa	7	116	6.41	0.42
7	06609500	Boyer River at Logan, Iowa	7	24.0	6.83	0.96
8	06610000	Missouri River at Omaha, Nebraska	7	2,960	1.32	0.39
		Lower Missouri River Basin				
9	06713500	Cherry Creek at Denver, Colorado	18	1.13	1.59	0.15
10	06714000	South Platte River at Denver, Colorado	12	--	1.68	0.60
11	06741530	Big Thompson River at I-25 near Loveland, Colorado	6	2.85	2.01	0.51
12	06800500	Elkhorn River at Waterloo, Nebraska	14	102	3.57	0.77
13	06803525	Salt Creek below Stevens Creek near Waverly, Nebraska	6	31.4	3.54	1.12
14	06805000	Salt Creek near Ashland, Nebraska (downstream from Lincoln)	5	--	2.65	0.96
15	06805500	Platte River at Louisville, Nebraska	16	444	1.02	0.68
16	06810000	Nishnabotna River above Hamburg, Iowa	7	67.2	6.35	0.84
17	06818000	Missouri River at St. Joseph, Missouri	6	4,530	0.99	0.37
18	06893390	Indian Creek at State Line Road Leawood, Kansas	7	0.71	3.90	1.07
19	06893620	Rock Creek at Kentucky Road in Independence, Missouri	5	0.05	0.85	0.83
20	06893820	Little Blue River at Lees Summit Road in Independence, Missouri	5	1.27	0.35	0.40
21	06893830	Adair Creek at Independence, Missouri	5	0.02	0.17	0.18
22	06893890	East Fork Little Blue River near Blue Springs, Missouri	5	0.33	0.30	0.24
23	06893970	Spring Branch Creek at Holke Road in Independence, Missouri	5	0.04	0.51	1.06
24	06894000	Little Blue River near Lake City, Missouri	5	1.29	0.40	0.91
25	06894100	Missouri River at Sibley, Missouri	6	4,390	1.05	0.45
26	06899580	No Creek near Dunlap, Missouri	6	0.06	0.08	0.15
27	06900050	Medicine Creek near Laredo, Missouri	7	20.3	0.62	0.51
28	06900100	Little Medicine Creek near Harris, Missouri	6	0.17	0.21	0.07
29	06900640	Muddy Creek near Chula, Missouri	7	4.24	0.76	0.40
30	06900900	Locust Creek near Unionville, Missouri	6	0.34	0.13	0.08
31	06901250	Little East Locust Creek near Browning, Missouri	7	0.97	0.26	0.23
32	06901500	Locust Creek near Linneus, Missouri	7	18.2	0.59	0.36
33	06902000	Grand River near Sumner, Missouri	6	91.20	0.67	0.43
34	06902995	Hickory Branch near Mendon, Missouri	7	0.60	1.74	0.23
35	06905725	Mussel Fork near Mystic, Missouri	6	0.13	0.69	0.23
36	06907300	Lamine River near Pilot Grove, Missouri	6	34.7	0.64	0.28
37	06918600	Little Sac River near Walnut Grove, Missouri	6	0.39	0.79	0.09
38	06919500	Cedar Creek near Pleasant View, Missouri	6	3.17	0.25	0.06
39	06921070	Pomme de Terre River near Polk, Missouri	6	3.35	0.12	0.05
40	06921720	Big Creek near Blairstown, Missouri	6	1.62	0.32	0.17
41	06930450	Big Piney River at Devils Elbow, Missouri	6	140	0.27	0.03
42	06930800	Gasconade River above Jerome, Missouri	6	85.3	0.36	0.03
43	06934500	Missouri River at Hermann, Missouri	12	5,390	0.95	0.45
		Upper Mississippi River Basin				
44	07022000	Mississippi River at Thebes, Illinois	7	16,200	2.46	0.36

(µm) pore-size disposable capsule filter (Wilde and others, 2004) and were preserved by acidifying to a pH less than 2.0 with sulfuric acid. Sample bottles for TP analysis were filled with unfiltered composited water (Wilde and others, 2004). Samples were then chilled for shipment to the U.S. Geological Survey National Water Quality laboratory in Denver, Colorado. Nitrate and TP concentrations were analyzed using methods described by Fishman (1993).

Data Analysis

The Wilcoxon rank-sum test (Helsel and Hirsch, 1992) was used to compare differences between nitrate and TP concentrations in samples collected during 2011 and those collected previously at the long-term sites (fig. 1). The Wilcoxon rank-sum test tests data from two independent groups and does not make assumptions on how the data are distributed. (Helsel and Hirsch, 1992).

Daily nitrate and TP concentrations were estimated using two models (WRTDS and interpolation). Previously, concentration and flux estimates were modeled on selected Missouri River sites using the Load Estimator (LOADEST) regression model (Runkel and others, 2004; Aulenbach and others, 2007). Recently, analysis has indicated that although the LOADEST model provides adequate flux estimates at many sites, estimates at a substantial number can be positively biased by 25 percent or more (Stenback and others, 2011). One alternative model (WRTDS) that uses weighted regressions of concentrations on time, discharge, and season also was used to estimate nitrate and TP concentrations (Hirsch and others, 2010) at sites on tributaries to the Missouri River that had more than 20 years of periodic sampling data. Daily flux estimates were calculated using the daily estimated concentrations and the measured daily mean discharge.

The WRTDS model uses data over a period of years to estimate concentration on a particular day and because nitrate and TP concentrations during the 2011 flood were different (see discussion in the following sections) from previous high streamflow and flood periods, accuracy of model estimations may be less. Also, WRTDS estimates are dependent on a well-defined relation between constituent concentrations and streamflow. The relation between nitrate concentrations and streamflow in the Missouri River downstream from the large main-stem reservoirs is variable depending on the source of water in the river. Flow is regulated from the reservoirs to compensate for tributary inflow, decreasing when tributary inflow is great and increasing when inflow is small. Thus streamflow in the lower Missouri River may originate from different source areas with their associated differences in nitrate concentrations. Variable sources of water in the Missouri River at Omaha, Nebr. and downstream result in nitrate and TP concentrations that have little relation to streamflow. The poor relation for nitrate and TP results in less accurate WRTDS estimates of concentration and flux when compared to observed concentrations and flux.

A second estimation model that does not rely on streamflow, the interpolation method, was used to estimate daily nitrate and TP concentrations in the Missouri River at sites at Omaha, Nebr.; St. Joseph, Mo., and Hermann, Mo. Sampled concentrations were linearly interpolated between samples through time to estimate daily concentrations. As with the WRTDS model, daily flux estimates were calculated using the daily estimated concentrations and the measured daily mean discharge. The interpolation model was used because streamflow and constituent concentration at the large Missouri River sites do not fluctuate as rapidly as in the smaller tributary sites.

Flux data from the LOADEST model are commonly used to estimate transport of nutrients in the Mississippi River Basin (Aulenbach and others, 2007) and, if available, are presented in this report for ready comparison to other reports describing flood transport in the lower Mississippi River. Unless otherwise stated, discussion of nitrate and TP flux in this report is based on the WRTDS and interpolation estimates.

Overall, the difference between the WRTDS modeled and observed daily concentration and flux was less than 10 percent (table 3). Estimated concentration and flux that were in close agreement with the observed values were generated by the WRTDS model even when the concentration discharge relation was not linear at sites similar to that on the Nishnabotna River (fig. 3*A*). The difference in modeled nitrate concentration and flux compared to observed values was less than plus or minus 10 percent at five of seven sites. The difference in modeled total phosphorus concentration and flux was less than plus or minus 10 percent at all five sites where long-term data were available (table 3). An exception to the good agreement between modeled and observed nitrate concentration and flux was at the Powder River near Locate, Montana and at the Platte River at Louisville, Nebr.

The poor relation between nitrate concentrations and streamflow in the Powder River near Locate, Montana (fig. 3*B*) resulted in a WRTDS model concentration and flux estimate that was on average 15 or more percent greater than observed values. The Powder River watershed is an area characterized by low intensity land use that is mainly grassland, shrubland, and forests that contribute limited natural inputs of nitrogen from precipitation and mineralization of organic material (Sprague and others, 2007). Detectable nitrate concentrations occur consistently only when streamflow exceeds 1 m^3/s and are consistently in the range from 0.1 to 2.0 milligrams per liter (mg/L) irrespective of the streamflow when streamflow ranges from 1 to more than 100 m^3/s (fig. 3*B*). A large number of samples from the Platte River at Louisville, Nebr. with nitrate concentrations less than the detection limit also resulted in greater than 10 percent error between observed and modeled nitrate concentrations and fluxes (table 3).

Table 3. Comparison between modeled weighted regressions of concentrations on time, discharge, and season (WRTDS) and observed nitrate nitrogen and total phosphorus concentrations and flux, 1980–2012.

[Negative difference indicates modeled value is less than observed value; mg/L, milligrams per liter; kg/d; kilograms per day]

Map number (fig. 1)	Site identification number	Site name	Number of samples	Average observed concentration (mg/L)	Average modeled concentration (mg/L)	Difference between modeled and observed concentration (percent)	Average observed flux (kg/d)	Average modeled flux (kg/d)	Difference between modeled and observed flux (percent)
		Nitrate							
4	06326500	Powder River near Locate, Montana	260	0.29	0.33	15.01	451	522	15.57
6	06607500	Little Sioux near Turin, Iowa	129	6.18	6.28	1.63	49,900	54,100	8.42
7	06609500	Boyer River at Logan, Iowa	188	6.86	6.66	-2.83	7,320	7,170	-2.05
15	06805500	Platte River at Louisville, Nebraska	456	1.24	1.38	11.00	33,900	38,700	14.16
16	06810000	Nishnabotna River above Hamburg, Iowa	185	5.00	4.76	-4.89	36,800	36,200	-1.63
33	06902000	Grand River near Sumner, Missouri	354	0.68	0.69	1.97	11,300	11,200	-0.88
44	07022000	Mississippi River at Thebes, Illinois	388	2.42	2.38	-1.80	1,750,000	1,740,000	-0.57
		Total phosphorus							
4	06326500	Powder River near Locate, Montana	254	0.848	0.812	-4.24	1,930	2,000	3.63
15	06805500	Platte River at Louisville, Nebraska	475	0.622	0.614	-1.29	19,500	19,300	-1.03
16	06810000	Nishnabotna River above Hamburg, Iowa	169	0.742	0.708	-4.61	10,800	10,900	0.93
33	06902000	Grand River near Sumner, Missouri	337	0.343	0.344	0.17	9,520	9,730	2.21
44	07022000	Mississippi River at Thebes, Illinois	435	0.323	0.322	-0.57	235,000	233,000	-0.85

Missouri River levee overflow near Brownsville, Missouri, July 2011 (photograph by U.S. Geological Survey).

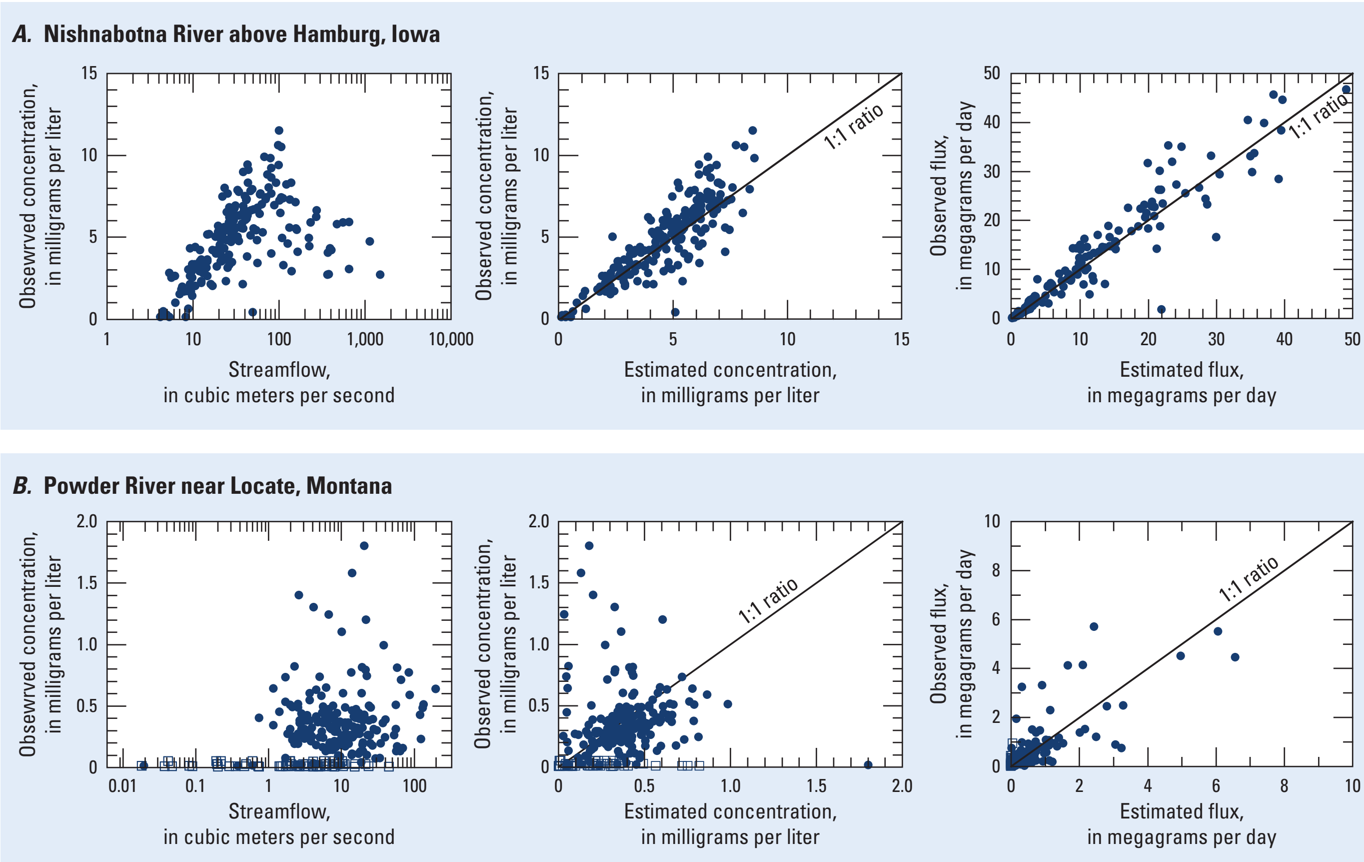


Figure 3. Relation between weighted regressions of concentrations on time, discharge, and season (WRTDS) modeled daily flux and daily observed flux at selected long-term sampling sites in the Missouri River Basin, 1980–2012.

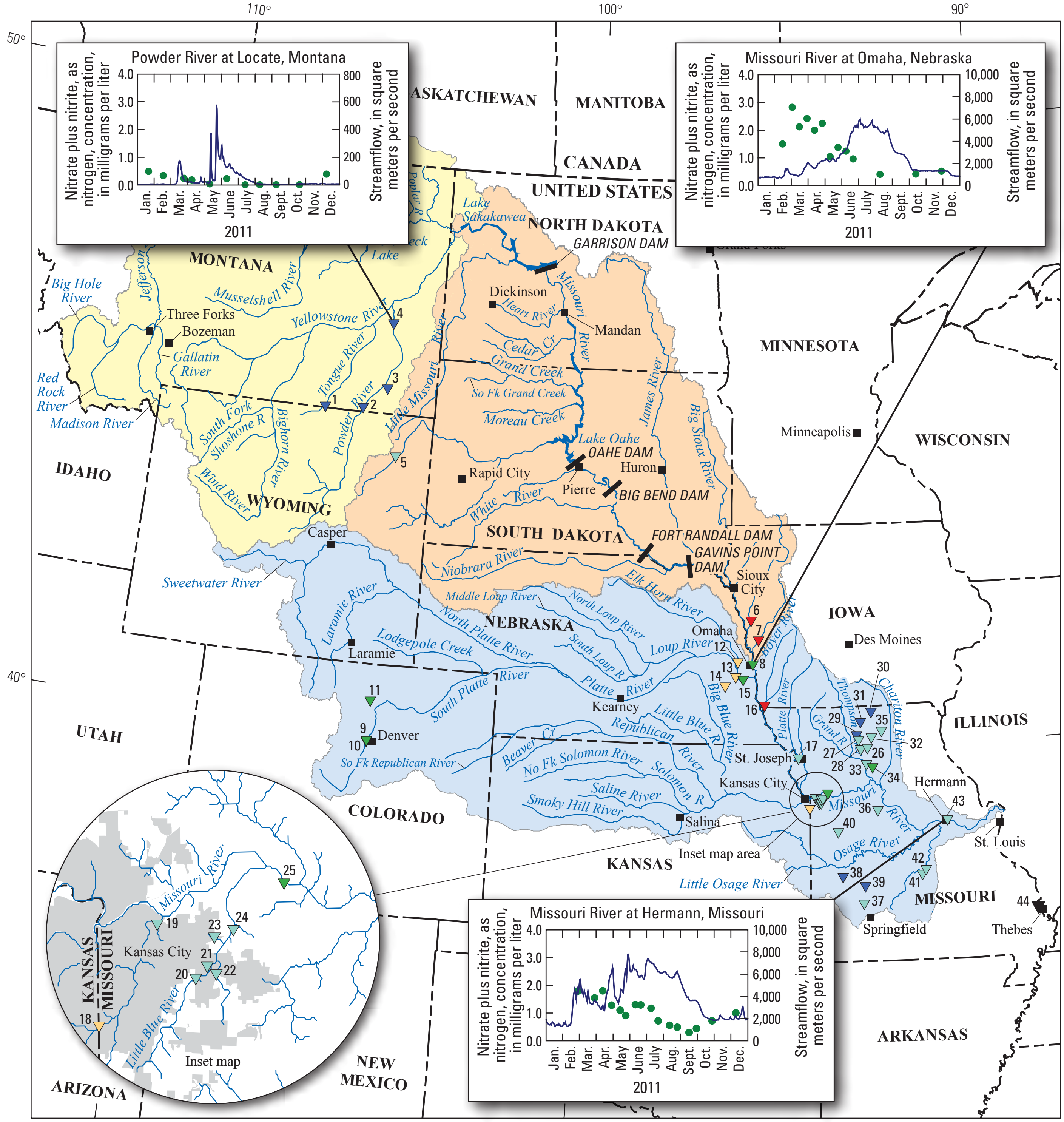
Occurrence of Nutrients in the Missouri River Basin, April through September 2011

Nitrate and TP concentrations in the Missouri River and selected tributaries in 2011 generally were within the range of concentrations measured during the last 30 years. Concentrations in the lower Missouri River decreased in June as the dominant source of water in the river changed from being higher-nutrient water from the lower part of the basin to lower nutrient water from the middle and upper part of the basin. Variability in concentrations was observed in different parts of the Missouri River Basin that may be attributed to timing of flood flows and land use practices. Substantial differences in the timing and concentrations in 2011 were seen in relation to those in 1993 when regional flooding also occurred.

Nitrate

Spatial Variability in Nitrate Concentrations

Data from samples collected in 2011 from rivers in the upper and middle parts of the Missouri River Basin suggest that flood waters that eventually entered the flood control reservoirs contained lower than normal concentrations of nitrogen. For example, nitrate concentrations in the Powder River near Locate, Mont. (fig. 4) during April through September 2011 averaged 0.08 mg/L. This was significantly ($P<0.05$) less than the April through September average (0.31 mg/L) for the 1980–2010 period (table 4). Average nitrate concentrations in other upper Missouri River Basin rivers were less than 0.25 mg/L during spring and summer of 2011 (fig. 4).



Base from Esri digital data, 2000, 1:3,000,000
Albers Equal-Area Conic projection
Standard parallels 20°N and 60°N, central meridian 96°W
North American Datum of 1983 (NAD 83)

0 100 200 MILES
0 100 200 KILOMETERS

EXPLANATION

Missouri River Basin subbasins
- Upper
- Middle
- Lower

37 ▽ **Water-quality sampling site and number**

Nitrate plus nitrite, as nitrogen, concentration, in milligrams per liter
- 0.25 or less
- More than 0.25 to 1.00
- More than 1.00 to 2.50
- More than 2.50 to 5.00
- More than 5.00

Figure 4. Average and seasonal (insets) nitrate plus nitrite nitrogen concentrations at selected sites in the Missouri River Basin, April through September 2011.

Table 4. Average concentrations of nitrate plus nitrite nitrogen and total phosphorus during April through September 2011 in relation to historical concentrations.

[Concentrations in milligrams per liter; bold values indicate a significant (P<0.05) difference between concentrations in 2011 and previous period of record]

Map number (fig. 1)	Site identification number	Site name	Period of record	Number of samples	Nitrate		Total phosphorus	
					mean	median	mean	median
4	06326500	Powder River near Locate, Montana	1980–2010	124	**0.31**	**0.18**	1.32	0.30
			2011	6	**0.08**	**0.02**	0.47	0.34
6	06607500	Little Sioux River near Turin, Iowa	2004–2010	46	6.41	6.60	0.61	0.42
			2011	7	6.41	6.21	0.42	0.48
7	06609500	Boyer River at Logan, Iowa	1990–2010	56	6.99	7.09	1.43	0.69
			2011	7	6.83	6.63	0.96	0.55
8	06610000	Missouri River at Omaha, Nebraska	1980–2010	124	1.63	1.42	0.48	0.28
			2011	7	1.32	1.24	0.39	0.37
15	06805500	Platte River at Louisville, Nebraska	1980–2010	294	1.01	0.95	0.74	0.51
			2011	16	1.02	0.89	0.68	0.56
16	06810000	Nishnabotna River above Hamburg, Iowa	1980–2010	86	5.34	5.39	0.93	0.57
			2011	7	6.35	6.41	0.84	0.54
17	06818000	Missouri River at St. Joseph, Missouri	1980–2010	146	1.54	1.40	0.43	0.30
			2011	6	0.99	0.96	0.37	0.30
33	06902000	Grand River near Sumner, Missouri	1980–2010	161	0.65	0.38	0.45	0.25
			2011	6	0.67	0.41	0.43	0.27
42	06930800	Gasconade River above Jerome, Missouri	1980–2010	130	0.23	0.20	0.04	0.03
			2011	6	0.36	0.32	0.03	0.03
43	06934500	Missouri River at Hermann, Missouri	1980–2010	260	**1.43**	**1.40**	**0.42**	**0.32**
			2011	12	**0.95**	**1.01**	**0.45**	**0.46**

The greatest average nitrate concentrations during April through September 2011 were observed in Missouri River tributaries that drained agricultural areas in Iowa and Nebraska. Average concentrations of more than 5.0 mg/L occurred in the Little Sioux, Boyer, and Nishnabotna Rivers that drain parts of western Iowa and were more than 1.0 mg/L in the Platte River that drains much of Nebraska. Average nitrate concentrations were more than 1.0 mg/L at sites in the South Platte River in Colorado that drain urban and agricultural areas. Average nitrate concentrations in 2011 were more than 2.5 mg/L at a site on Elkhorn River and a site on Salt Creek; two streams that drain agricultural areas in eastern Nebraska. Nitrate concentrations in the Iowa and Nebraska agricultural streams in 2011 were not significantly different (P<0.05) than average concentrations during the 1980–2010 period (table 4).

In the lower part of the Missouri River Basin, average nitrate concentrations were generally less than in the intensively farmed areas of Iowa and Nebraska. With a couple exceptions, average nitrate concentrations were less than 1.0 mg/L (fig. 4). Indian Creek in urban Kansas City that contributed less than 1.0 m^3/s to the Missouri River had an average nitrate concentration of 3.9 mg/L (fig. 4, table 2).

Although flood conditions prevailed and much of the water in the Missouri River originated from the upper and middle parts of the basin during a large part of the April through September period, nitrate concentrations in the main stem of the Missouri River also reflected tributary concentrations in the lower basin. Average nitrate concentrations in the Missouri River decreased slightly as flow moved downstream from Omaha, Nebr. to Hermann, Mo. Inflow of water from the Platte River (average 1.0 mg/L), Grand River (average of 0.67 mg/L), the Gasconade River (average of 0.36 mg/L) and tributaries with low average nitrate concentrations (table 2) possibly diluted floodwater in the Missouri River downstream from Omaha, Nebr. Nitrate concentrations in the Missouri River at Omaha, Nebr. and St. Joseph, Mo. during the flood were typical of concentrations measured during the last 30 years (table 4) but the average nitrate concentration at Hermann, Mo. was significantly less (P<0.05) in 2011 than in samples collected from 1980–2010.

Temporal Variability in Nitrate Concentrations

Nitrate concentrations varied through the spring and summer in the Missouri River in relation to snowmelt and rainfall in the upper part of the basin and varied in relation to the major source of water in the lower part of the basin. A combination of snowmelt and heavy rains caused substantial increase in the streamflow in the Powder River in May. A sample collected from early June as the streamflow was decreasing contained 0.23 mg/L nitrate (fig. 4). This was an increase from the sample collected before the May flood. Nitrate concentrations decreased to less than the minimum reporting level of 0.008 mg/L for the remainder of the summer.

Nitrate concentrations typically were greater than 2.0 mg/L in the Missouri River at Omaha, Nebr. downstream from the main-stem reservoirs in late winter and early spring when from 25 to 40 percent of the water originated from inflow downstream from St. Joseph, Mo. (table 1). Concentrations then decreased to less than 1.0 mg/L (fig. 4) as streamflow increased in July when 70 percent or more of the water (table 1) in the Missouri River originated from the upper and middle parts of the Missouri River Basin. Nitrate concentrations continued to decrease during the remainder of the summer as most of the water in the Missouri River continued to originate from discharge from major flood control reservoirs in the Dakotas and Montana upstream from Sioux City, Iowa (table 1).

Phosphorus

Total phosphorus concentrations were variable across the Missouri River Basin and unlike average nitrate concentrations whose smallest concentrations were in the upper part of the basin, the smallest average TP concentrations were in small streams in the lower part of the basin during 2011.

Spatial Variability in Total Phosphorus Concentrations

Flood waters that entered the Missouri River main-stem reservoirs in 2011 from the upper part of the basin had TP concentrations that were typical of those measured during the last 30 years. For example, the average TP in the Powder River during the flood period was 0.47 mg/L, which was less than the average for the 1980–2010 period (table 4). However, the median concentrations (table 4) for these two time periods were nearly the same indicating that throughout the last 30 years TP concentrations were more variable than in 2011 but that on average there was no significant difference. The range in April through September 2011 TP average concentration at other upper and middle Missouri River sites (0.12 to 0.96 mg/L) bracketed that from the Powder River (table 2).

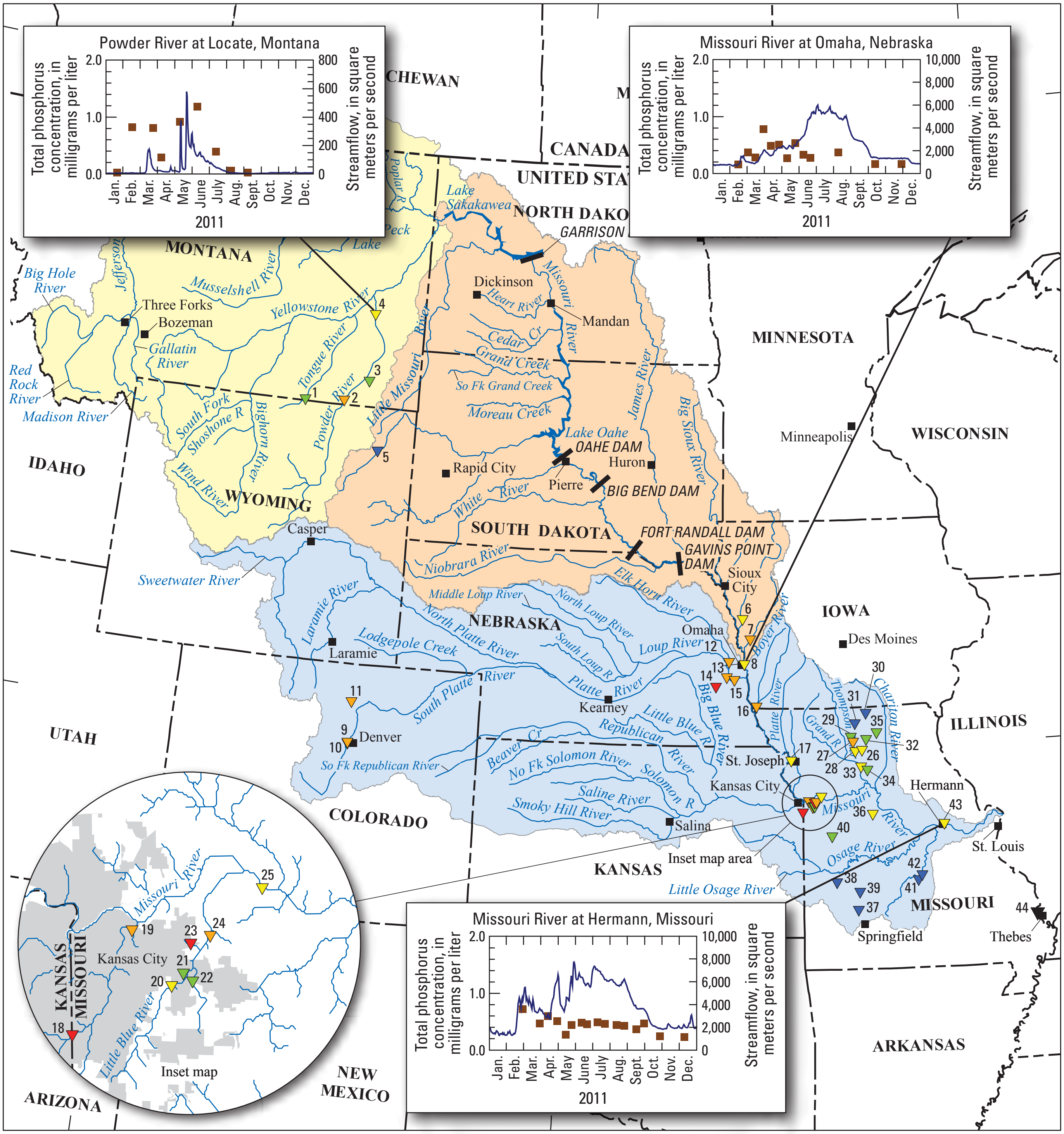
In the lower Missouri River Basin, average TP concentrations in the Iowa and Nebraska agricultural rivers (sites 12, 15, and 16) generally were more than 0.5 mg/L and exceeded 1.0 mg/L in three small (average streamflow less than 1.0 m^3/s) urban streams during the flood (table 2) . The average TP concentration was 1.12 mg/L in Salt Creek (site 13) downstream from Lincoln, Nebr., 1.07 mg/L in Indian Creek (site 18) in Kansas City, Mo., and 1.06 mg/L in Spring Branch Creek (site 23) in Independence, Mo. The smallest average TP concentrations (0.10 mg/L or less) were measured in the more heavily forested Osage River Basin (sites 37–39) in southern and central Missouri (table 2). A number of other small Missouri streams had average TP concentrations that were slightly greater, in the 0.10–0.25 mg/L range (fig. 5).

Inflow from the tributaries did not substantially change the average TP in the main stem of the Missouri River downstream from the major reservoirs in 2011. Average concentrations increased slightly from 0.39 mg/L at Omaha, Nebr. to 0.45 mg/L at Hermann, Mo., however this was not a significant ($P>0.05$) increase. The average TP concentrations in the Platte (0.68 mg/L) and Nishnabotna Rivers (0.84 mg/L) that drain agricultural areas in Iowa and Nebraska were greater than the average concentration in the Missouri River at Omaha, but average concentrations were less than in large tributaries that drain less intensively farmed areas in Missouri (site 33 on the Grand River (0.43 mg/L) and site 42 on the Gasconade River (0.03 mg/L).

Temporal Variability in Total Phosphorus Concentrations

In contrast to nitrate, TP concentrations from April through September 2011 in the Powder River near Locate, Mont. were not significantly ($P>0.05$) different than those measured during the last 30 years. TP concentrations increased during periods of increased streamflow and were from about 0.90 to 1.2 mg/L during May and early June (fig. 5). Concentrations decreased to 0.02 mg/L as streamflow decreased through the remainder of the water year.

TP concentrations varied temporally but the temporal trend was not uniform throughout the Missouri River Basin. TP concentrations in the Powder River in the upper part of the basin increased with increasing streamflow whereas concentrations in the main stem of the Missouri River in the lower part of the basin generally decreased as streamflow increased during the summer. TP concentrations in the Powder River were 0.91 and 1.18 mg/L during two runoff events in May and June. Sampled concentrations decreased as streamflow decreased the next 3 months to 0.03 mg/L in September. In contrast, TP concentrations in the main stem of the Missouri River downstream from the reservoirs at Omaha, Nebr. and Hermann, Mo. decreased to less than 0.5 mg/L during flooding and high streamflow conditions in June through August. During the high streamflow and flooding when much of the water (70 to 77 percent) in the Missouri River at Omaha and Hermann originated from the upper and middle parts of the basin, TP concentrations were relatively stable; generally varying by less than 0.1 mg/L (fig. 5).



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Albers Equal-Area Conic projection
Standard parallels 20°N and 60°N,
central meridian 96°W
North American Datum of 1983 (NAD 83)

0 100 200 MILES

0 100 200 KILOMETERS

EXPLANATION

Missouri River Basin subbasins

- Upper
- Middle
- Lower

37 ▽ **Water-quality sampling site and number**

Total phosphorus concentration, in milligrams per liter

- 0.10 or less
- More than 0.10 to 0.25
- More than 0.25 to 5.0
- More than 5.0 to 1.0
- More than 1.0

Figure 5. Average and seasonal (insets) total phosphorus concentrations at selected sites in the Missouri River Basin from April through September 2011.

Transport of Nutrients in the Missouri River Basin, April through September 2011

Nutrient Flux to the Mississippi River

High streamflow including flooding conditions resulted in the transport of an estimated 86,800 (LOADEST) to 79,600 (interpolated) Mg of nitrate to the Mississippi River from the Missouri River Basin during the 2011 flood (measured at Hermann, Mo., site 43). This represents less than 20 percent of the nitrate transported (table 5) in the Mississippi River at Thebes, Ill. Nitrate transport was greatest in June when an estimated 18,200 (LOADEST) to 20,000 (interpolated) Mg were transported from the Missouri River to the Mississippi River (table 6).

In addition, from 48,000 (LOADEST) to about 38,000 (WRTDS) Mg of phosphorus were estimated to have entered the Mississippi River during this period (table 5). Input from the Missouri River was a major source of phosphorus to the lower Mississippi as more than 39 percent of that transported from April through September 2011 in the Mississippi River at Thebes originated from the Missouri River Basin. Phosphorus transport peaked 1 month later than nitrate in July, when about 11,200 Mg (LOADEST) to 8,340 Mg (interpolated) entered the Mississippi River (table 6). Peak monthly phosphorus transport corresponded to peak monthly average stream streamflow in the Missouri River at Hermann, Mo.

Runoff from the Missouri River from April through September 2011 was the second greatest since 1980, but the nitrate flux (79,600 Mg) was substantially less than during the 1993 flood (165,000 Mg). This may be partially due to the increased amount of water in the Missouri River that originated from the middle and upper parts of the basin that have less intensive agriculture and urban areas than the lower basin that was a greater source of water in 1993. Transport of TP from the Missouri River Basin during the 2011 flood (37,900 Mg) exceeded that in the 1993 flood (24,000 Mg).

Temporal Change in Flux to the Mississippi River

Nitrate and TP transport to the Mississippi River from the Missouri River during the flood increased monthly from April through midsummer before decreasing in September. The nitrate flux in the Missouri River at Hermann Mo. increased from an estimated 16,200 Mg in April to about 20,000 Mg in June before decreasing through the remainder of the summer to about 3,900 Mg in September (table 6). Although the flux decreased from June through the remainder of the summer, the proportion of nitrate in the Mississippi River at Thebes, Ill.

Table 5. Nitrate and total phosphorus transport in spring and summer (April through September) during the 1993 and 2011 flood years at selected sites in the Missouri River Basin.

[Flux in megagrams: WRTDS, data from Weighted Regressions on Time, Discharge, and Season and interpolation models; LOADEST data from USGS, 2011; --, no data; NA, samples not available to estimate transport]

Map number (fig. 1)	Site name	1993				2011			
		Nitrate nitrogen		Total phosphorus		Nitrate nitrogen		Total phosphorus	
		WRTDS	LOADEST	WRTDS	LOADEST	WRTDS	LOADEST	WRTDS	LOADEST
4	Powder River near Locate, Montana	247	--	2,130	--	605	--	1,130	--
8	Missouri River at Omaha, Nebraska	NA	--	NA	--	48,700	60,400	19,400	21,100
15	Platte River at Louisville, Nebraska	12,800	23,400	8,000	6,580	7,500	6,740	5,270	4,680
16	Nishnabotna River above Hamburg, Iowa	15,900	--	2,330	--	6,790	--	804	--
17	Missouri River at St. Joseph, Missouri	84,800	--	23,000	--	64,700	--	25,900	--
33	Grand River near Sumner, Missouri	3,680	6,520	6,740	4,690	2,100	1,360	2,690	3,180
43	Missouri River at Hermann, Missouri	165,000	269,000	24,000	26,300	79,600	86,800	37,900	47,500
44	Mississippi River at Thebes, Illinois	863,000	770,000	99,400	86,000	483,000	484,000	96,200	96,500

Table 6. Monthly nitrate and total phosphorus flux at selected sites in the Missouri River basin, April through September 2011.

[Monthly flux in megagrams; m^3/s, cubic meters per second; WRTDS, data from Weighted Regressions on Time, Discharge, and Season and interpolation models; LOADEST data from USGS, 2011; --, no data; NA, longterm data not available to model flux]

Map number (fig. 1)	Site name	Month	Monthly mean discharge (m^3/s)	Nitrate nitrogen		Total phosphorus	
				WRTDS	LOADEST	WRTDS	LOADEST
4	Powder River near Locate, Montana	April	21.3	15	--	37	--
		May	157	480	--	685	--
		June	128	104	--	334	--
		July	43.2	6.7	--	69	--
		August	7.2	0.2	--	3	--
		September	3.9	0.1	--	1	--
6	Little Sioux near Turin, Iowa	April	106	1,870	--	NA	--
		May	117	2,290	--	NA	--
		June	191	3,610	--	NA	--
		July	192	3,400	--	NA	--
		August	48.8	653	--	NA	--
		September	15.2	94	--	NA	--
7	Boyer River at Logan, Iowa	April	16.4	300	--	NA	--
		May	22.5	429	--	NA	--
		June	36.7	633	--	NA	--
		July	23.5	443	--	NA	--
		August	13.9	248	--	NA	--
		September	7.9	125	--	NA	--
8	Missouri River at Omaha, Nebraska	April	1,930	10,600	11,500	2,580	2,390
		May	2,420	8,440	11,700	2,620	3,110
		June	4,380	11,800	13,400	3,400	4,670
		July	5,480	9,740	11,500	4,720	4,870
		August	4,710	5,200	9,700	4,290	3,890
		September	2,780	2,920	5,600	1,800	2,130
15	Platte River at Louisville, Nebraska	April	389	1,830	2,100	733	567
		May	453	1,830	1,540	1,130	945
		June	585	1,930	1,530	1,580	1,440
		July	462	1,160	944	1,100	1,040
		August	270	418	358	453	429
		September	215	320	263	271	263
16	Nishnabotna River above Hamburg, Iowa	April	50.9	799	--	76	--
		May	71.4	1,280	--	139	--
		June	129	2,170	--	323	--
		July	81.1	1,380	--	155	--
		August	55.2	776	--	81	--
		September	32.2	381	--	29	--

Table 6. Monthly nitrate and total phosphorus flux at selected sites in the Missouri River basin, April through September 2011.—Continued

[Monthly flux in megagrams; m^3/s, cubic meters per second; WRTDS, data from Weighted Regressions on Time, Discharge, and Season and interpolation models; LOADEST data from USGS, 2011; --, no data; NA, longterm data not available to model flux]

Map number (fig. 1)	Site name	Month	Monthly mean discharge (m^3/s)	Nitrate nitrogen		Total phosphorus	
				WRTDS	LOADEST	WRTDS	LOADEST
17	Missouri River at St. Joseph, Missouri	April	2,490	12,200	--	2,950	--
		May	3,040	10,100	--	3,110	--
		June	4,640	15,700	--	6,890	--
		July	6,580	17,200	--	7,470	--
		August	5,380	6,510	--	3,470	--
		September	3,340	2,950	--	2,020	--
33	Grand River near Sumner, Missouri	April	230	724	681	614	527
		May	276	698	420	1,170	1,350
		June	225	389	210	787	1,150
		July	62.3	60	35	90	112
		August	33.2	12	9	27	33
		September	11.4	3	1	6	4
43	Missouri River at Herman, Missouri	April	4,100	16,200	14,500	5,710	5,290
		May	5,080	14,400	17,400	5,410	7,550
		June	6,150	20,000	18,200	7,420	9,590
		July	6,640	16,600	17,600	8,340	11,200
		August	5,900	8,500	12,500	6,860	9,140
		September	4,020	3,900	6,620	4,200	4,770
44	Mississippi River at Thebes, Illinois	April	14,000	95,200	104,000	17,300	17,000
		May	16,700	122,000	121,000	21,800	21,300
		June	16,400	111,000	102,000	20,700	20,400
		July	14,400	86,300	80,000	18,400	18,300
		August	10,600	49,000	50,800	12,200	13,000
		September	6,360	20,200	26,600	5,760	6,500

originating from the Missouri River remained relatively constant at 17 to about 19 percent as streamflow in both the Missouri and Mississippi Rivers decreased.

The estimated monthly TP flux transported from the Missouri River Basin ranged from about 5,700 Mg in April to about 8,340 Mg in July during the middle of the summer. The TP flux then decreased to about 4,200 Mg in September as streamflow receded (table 6). In contrast to the relatively small proportion of nitrate originating from the Missouri River Basin during the flood, a large proportion (from about 25 to more than 70 percent) of the monthly TP transported in the Mississippi River at Thebes, Ill. originated from the Missouri River Basin.

Spatial Variability in Flux

The Missouri River Basin is a large and hydrologically diverse basin and thus not all areas contribute nutrients equally at all times. Much of the nitrate in the Missouri River originated upstream from Omaha, Nebr. in April preceding the flood, through June, July, and August during the flooding caused by release from the reservoirs, and into September when reservoir releases were reduced. Sufficient data were not available to readily identify the sources of nitrate in the upper and middle sections of the Missouri River, but data from a tributary (Powder River in Montana) indicate that the greatest nitrate flux occurred during May and June when streamflow was the greatest (table 6).

Table 7. Contribution of selected areas to the total Missouri River nitrate and total phosphorus flux, April through September 2011.

Subbasin	Area	Percent of the area of the Missouri River Basin	Percent of the total flux from the Missouri River Basin					
			April	May	June	July	August	September
Nitrate plus nitrite, as nitrogen (WRTDS estimate)								
Upper and middle	Boyer and Little Sioux River Basins	0.8	13.4	18.9	21.2	23.2	10.6	5.6
	Upstream from Omaha, Nebraska less Boyer and Little Sioux River Basins	61	51.9	39.7	37.5	35.6	50.6	69.3
Lower	Omaha, Nebraska to St. Joseph, Missouri	19.8	10.2	11.5	19.6	45.2	15.4	0.8
	St. Joseph, Missouri to Hermann, Missouri	18.4	24.6	29.9	21.7	[1]-4.0	23.4	24.2
Total phosphorus (WRTDS estimate)								
Upper and middle	Upstream from Omaha, Nebraska	61.8	47.2	47.1	59.4	52.9	49.4	45.8
Lower	Omaha, Nebraska to St. Joseph, Missouri	19.8	30.3	25.4	17.4	24.9	24.8	30.1
	St. Joseph, Missouri to Hermann, Missouri	18.4	22.4	27.5	23.2	22.3	25.8	24.0

[1]Negative contribution may be due to deposition during overbank flow or to error in model estimations. Sufficient data are not available to determine the cause of the negative contribution.

The nutrient flux likely attenuated as water flowed through the major Missouri River main-stem reservoirs in the middle part of the basin. A mass balance model estimated that just two of the reservoirs, Lake Oahe and Lake Sakakawea, normally retain approximately 18 percent of the total nitrogen and 24 percent of the TP that would have been transported to the Mississippi River (Brown and others, 2011a). The retention of nutrients during the flood is unclear because the amount of water moving through the reservoirs was much greater than normal, resulting in decreased residence time of the water and decreased nutrient storage time. Although the rate is not known, some nutrients were probably retained in the main-stem reservoirs. A combination of low nitrate concentrations in water flowing into reservoirs and reservoir retention can result in low-levels of nitrate and TP in the Missouri River flowing into the lower part of the basin.

The overall contribution of nitrate from the individual parts (subbasins) in the Missouri River Basin was generally proportional to the subbasin area. The 61.8 percent of the Missouri River Basin upstream from Omaha, Nebr. contributed about 61.2 percent of the nitrate flux during the flood (table 7). However a disproportionate flux of nitrate originated downstream from the main-stem reservoirs from agricultural areas in western Iowa and eastern Nebraska (represented by the Boyer and Little Sioux Rivers, sites 6 and 7). Although the total area for the two river basins is less than 1 percent of the Missouri River Basin drainage area, 17.7 percent of the nitrate transported in the Missouri River originated in the Boyer and Little Sioux River Basins (table 6). An estimated 38.8 percent of the nitrate originated from the lower part of the Missouri River Basin downstream from Omaha, Nebr. during the flood (table 7).

During the Missouri River flood of 2011, nearly as much TP originated from the 517,000 km^2 lower part of the Missouri River Basin downstream from Omaha, Nebr. as originated from the 836,000 km^2 upper and middle parts of the Missouri River Basin upstream from Omaha, Nebr. (table 7). About 49 percent of the total phosphorus transported to the Mississippi River during the 2011 flood originated from the lower part of the Missouri River Basin. However, a disproportionately large total phosphorus flux (31.7 percent of the TP from 18.4 percent of the basin) originated in the basin downstream from St. Joseph, Mo.

Discussion

Runoff of more than 8,440,000 hm (68,400,000 ac-ft) from the Missouri River Basin resulted in substantial flooding in part of the basin from April through September 2011. Based on flux estimates from models, the runoff transported an estimated 79,600 to 86,800 Mg of nitrate and 37,900 to 47,500 Mg of TP that originated from areas of the basin contributing the largest proportion of the water. During May and June 2011, nitrate transported from the Missouri River Basin, measured at Hermann, Mo., accounted for less than 20 percent (table 5) and TP transported from the Missouri River Basins accounted for between a quarter and a third of these nutrients transported from the upper Mississippi River Basin during the peak flooding in the lower Mississippi River Basin.

Runoff from the Missouri River Basin during the 2011 flood was the second greatest since 1980 but the amount of nitrate transported in 2011 was substantially less and the amount of TP was greater than the amounts in 1993 during historic basin flooding.

Occurrence and Transport in Relation to Flooding on the Lower Mississippi River

The amount of nitrate transported to the Mississippi River from the Missouri River Basin in April through September 2011 constituted only a small portion of the nitrate transported to the lower Mississippi River Basin. During the 2011 flood, the Missouri River contributed 79,600 Mg of the 483,000 Mg (16.4 percent) of the nitrate transported in the Mississippi River at Thebes, Ill. (table 5). The remainder originated from the more agricultural and urbanized upper Mississippi River Basin. In May, the Missouri River Basin contributed about 12 percent of the nitrate transported in the Mississippi River at Thebes, Ill. (table 6). The greatest monthly nitrate flux from the Missouri River (18,200 Mg; LOADEST estimate) occurred in June when flooding began on the lower Missouri River and when flooding was receding on the lower Mississippi River (Holmes and others, 2013) .

During the high streamflow and flooding on the Missouri River from April through August, the Missouri River contributed from about 8,500 to 20,000 Mg of nitrate per month (table 6) to the Mississippi River. In contrast to the relatively small contribution of nitrate to the Mississippi River, the Missouri River contributed from 35 to 73 percent of the monthly TP being transported from the upper Mississippi River. An estimated (LOADEST) monthly TP flux from the Missouri River ranged from about 5,290 Mg in April to about 11,200 Mg in July during the middle of the flood period on the lower Missouri River. The TP flux then decreased during August and September as flood conditions receded. As with nitrate, the maximum TP flux from the Missouri River Basin occurred after peak flooding (Holmes and others, 2013) on the lower Mississippi River.

Source of Nutrients during the Missouri River Flood in 2011

The Missouri River Basin is large with a diversity of climatic conditions and land use that affect the availability and transport of nutrients to the Missouri River. This diversity was evident in April through September 2011 when areas in the lower part of the basin received greater than normal rainfall and had a large percentage of developed land contributing disproportionately more nitrate and TP to the Missouri River (table 7). Agricultural and urban areas were important sources of nitrate, but row-crop areas in Iowa and Nebraska appeared to be the source of greater amounts of nitrate than the agricultural areas used to grow wheat in the Dakotas and Montana (table 7). Less developed areas of shrubland and forests, mainly in the upper and middle parts of the basin, with heavy rainfall that contributed much of the flood water during June through August contributed proportionally less of the nitrate and TP that was transported to the Mississippi River. Areas that contributed substantial nitrate and TP to the Missouri River flood flow were similar to those previously predicted as important source areas using a Missouri River Basin model (Brown and others, 2011a).

Occurrence and Transport in 2011 in Relation to 1993

Major regional flooding in the Missouri River Basin is rarely the result of precipitation throughout the basin, but because of its size major regional flooding is generally the result of much greater than normal snowfall or rainfall or both in parts of the basin. Snowmelt and rainfall runoff in Wyoming, Montana, and the Dakotas in the upper and middle parts of the basin (table 1) generated flooding on the Missouri River in 2011. In contrast, rainfall runoff in the lower part of the basin in Kansas, Missouri, and parts of Iowa and Nebraska (table 1) was the major source of flood water in 1993.

As would be expected, the concentrations and flux of nutrients differ between flood events because of differences in land use in the areas contributing most of the discharge to the Missouri River. Large amounts of dissolved and particulate nutrients were transported during both the 1993 and 2011 Missouri River floods but substantial differences were determined in nitrate and total phosphorus concentrations and flux. In 1993, most of the flow leaving the Missouri River Basin originated from the lower part of the basin (table 1), an area with potentially greater availability of nitrogen because of more row crop agriculture and urban areas than in the upper and middle parts of the basin. In 2011, streamflow was less than in 1993 but rather than originating in the lower part of the basin, most streamflow originated from the upper and middle parts of the basins. The less developed upper and middle parts of the basin with larger prairie and forested areas and less intensively cropped agricultural areas may have a limited availability of nitrogen for transport to rivers and streams.

Concentrations of nitrate in water entering the Mississippi River from the Missouri River were less in 2011 than in 1993. Nitrate concentrations in the Missouri River at Hermann, Mo. were consistently within the range of 1.2 to 1.4 mg/L during peak flooding in July and August 1993 but decreased from 1.2 mg/L in early July to less than 0.5 mg/L at the end of August in 2011 (fig. 6) . Morris and others (2013) also found that nitrate concentrations in the Missouri River at Hermann, Mo. in 2011 were less than in 2010 when much of the water originated from the lower part of the basin. In contrast, total phosphorus concentrations entering the Mississippi River were substantially greater in 2011 than in 1993. Total phosphorus concentrations ranged from 0.14 to 0.22 mg/L in the Missouri River at Hermann, Mo. in 1993 and were 0.37 to

0.48 mg/L in July and August 2011 (fig. 6). These results are in contrast to Morris and others (2013) findings that total phosphorus concentrations in the Missouri River at Hermann, Mo. were greater when most of the water originated from the lower part of the Missouri River Basin.

A combination of greater streamflow and concentrations resulted in the transport of substantially more nitrate from the Missouri River Basin to the Mississippi River in 1993 than in 2011. The April through September nitrate flux (165,000 Mg) in 1993 during record streamflow was 84,400 Mg more than the 2011 flux (79,600 Mg) (table 5) when the second greatest streamflow occurred. In 1993, most of the streamflow leaving the Missouri River Basin originated from the lower part of the basin (table 1), an area with potentially greater availability of nitrogen because of more row crop agriculture and urban areas than in the upper and middle parts of the basin. In 2011, streamflow was less than in 1993, but rather than originating in the lower part of the basin, most streamflow during April through September 2011 originated from the upper and middle parts of the basin. The less developed upper and middle parts of the basin with larger prairie and forested areas and less intensively cropped agricultural areas may have a limited availability of nitrogen for transport to rivers and streams. In addition, a small part of the nitrogen transported in the Missouri River may be retained or degraded (Brown and others, 2011a) in the major reservoirs in the middle part of the basin.

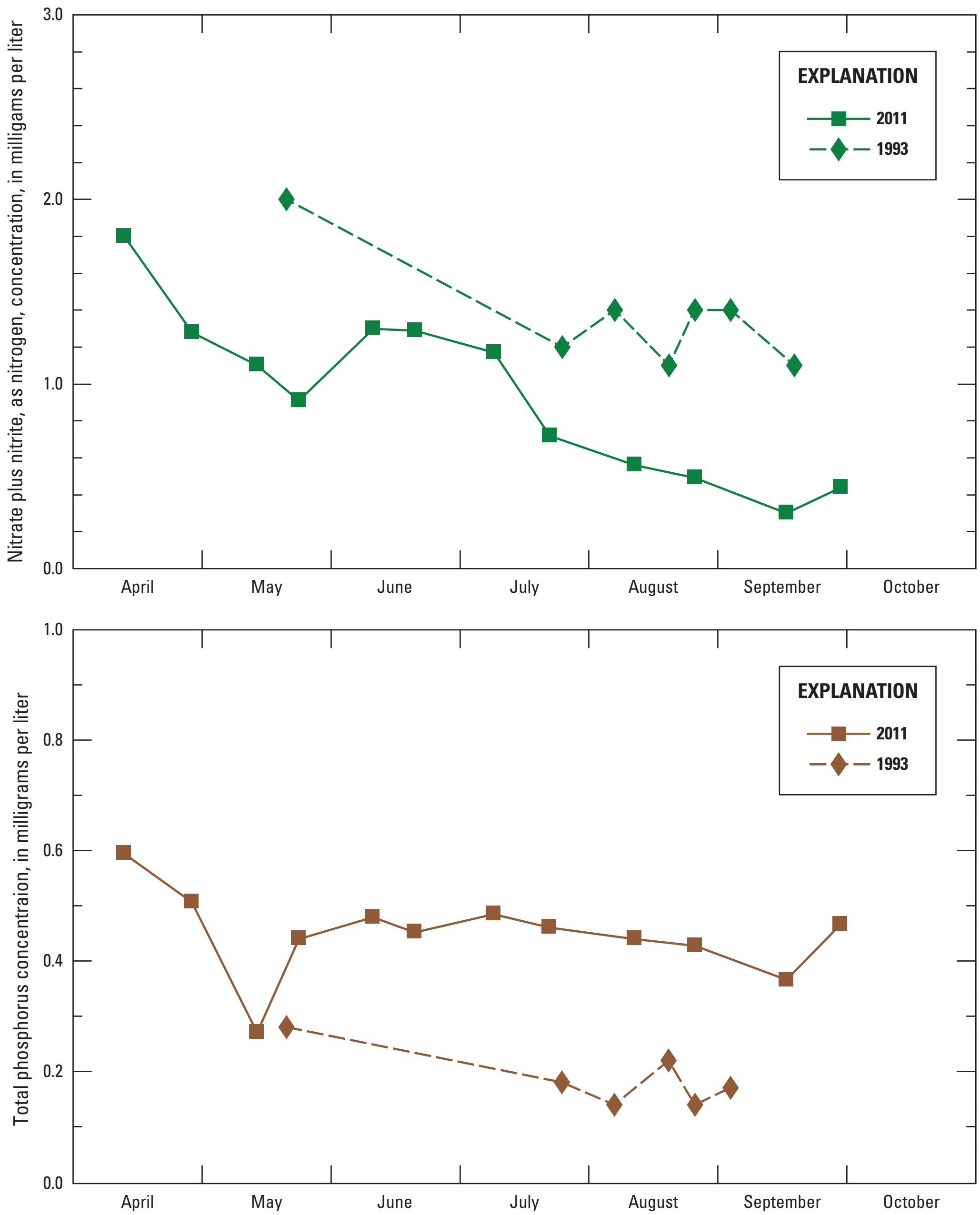

Figure 6. Nitrate and total phosphorus concentrations in the Missouri River at Hermann, Missouri in 1993 and 2011.

Contrasting with the nitrate flux, TP flux from the Missouri River to the Mississippi River was greater during the 2011 flood than in the 1993 flood. The April through September TP flux in 2011 was 37,900 Mg, 19,900 Mg greater than the 1993 flux (table 5). Phosphorus is naturally occurring in the soils and rocks in the upper parts of the Missouri River Basin and are eroded and transported by streams to the Missouri River. The 1980 to 2010 average TP concentration (1.32 mg/L) at a site on the Powder River in the upper Missouri River Basin was greater than all but one other long-term sites (table 4). Water chemistry data were not available to adequately evaluate TP transport from the upper and middle parts of the Missouri River Basin, but a model developed by Brown and others (2011a) suggest that the main-stem reservoirs retain a large part of the TP that originates from the upper and middle parts of the Missouri River Basin.

Although differing amounts of runoff and a differing source of flood waters contributed to the difference in nitrate and TP transport from the Missouri River Basin between the 1993 and 2011 floods, changes in land use and management practices also may be a contributing factor. Overall concentrations of nitrate in the Missouri River at Hermann, Mo. have decreased significantly from 1993 to 2003 (Sprague and others, 2006) indicating that, on average, there may be less nitrate available for transport throughout the Missouri River Basin since 1993. Sprague and others (2011) also indicated that when normalized for streamflow, nitrate concentrations in the Missouri River at Hermann, Mo. have increased little throughout time when streamflow is 5,000 m^3/s or greater. The nitrate trend reflects the smaller nitrate flux in the 2011 flood in relation to the flux in the 1993 flood. In contrast to the smaller nitrate flux in 2011 than in 1993, the TP flux was greater in 2011 than in 1993. TP concentrations in water leaving the Missouri River Basin have increased significantly from 1993 to 2003 (Sprague and others, 2006). The larger TP flux during the 2011 flood than during the 1993 flood also reflect the increasing TP concentration trend in the Missouri River at Hermann, Mo.

Summary

Heavy snow and early spring rainfall generated substantial amounts of runoff and flooding in the upper part of the Missouri River Basin in 2011. Spring runoff in the upper and middle parts of the basin exceeded the storage capacity of the Missouri River reservoirs and unprecedented amounts of water were released into the lower part of the basin resulting in record floods from June through September on the Missouri River from Gavins Point Dam downstream in Iowa and Nebraska and extended into Kansas and Missouri. Runoff from the Missouri River Basin in April through September 2011 was 8,440,000 hectare meters (68,400,000 acre feet) and was only exceeded during flooding in 1993 when runoff was 11,200,000 hectare meters (90,700,000 acre feet).

Nitrate and total phosphorus concentrations in the Missouri River and selected tributaries in April through September, 2011 generally were within the range of concentrations observed during the last 30 years. Substantial discharge from the upper and middle parts of the Missouri River Basin resulted in nitrate concentrations decreasing in the lower Missouri River beginning in June. Concentrations of nitrate in water entering the Mississippi River from the Missouri River were less in 2011 than during previous flooding in 1993, but total phosphorus concentrations entering the Mississippi River were substantially greater in 2011 than in 1993.

The Missouri River transported an estimated 79,600 megagrams of nitrate and 38,000 megagrams of total phosphorus to the Mississippi River from April through September 2011. The nitrate flux in 2011 was less than 20 percent of the combined total from the Upper Mississippi and Missouri River Basins. In contrast, the total phosphorus flux of 38,000 megagrams from the Missouri River constituted about 39 percent of the combined total from the Upper Mississippi and Missouri River Basins during April through September 2011.

Substantially more nitrate but less total phosphorus was transported from the Missouri River Basin during the historic 1993 than during the 2011 flood. Greater runoff from the lower part of the basin contributed to the greater nitrate transport in 1993. In addition to the differing amounts of runoff and the source of flood waters, changes in land use and management practices are additional factors that may have contributed to the difference in nitrate and total phosphorus flux between the 1993 and 2011 floods.

Floodwater flowing through a break in the levee near Percival, Iowa, August 2011 (photograph by U.S. Geological Survey).

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Damage to floodplain habitat caused by floodwater flowing through the breach in the Missouri Rver levee near Rulo, Nebraska, August 12, 2011 (photograph by U.S. Geological Survey).

Extensive flooding in the Missouri River floodplain, July 2011 (photograph by U.S. Army Corps of Engineers).

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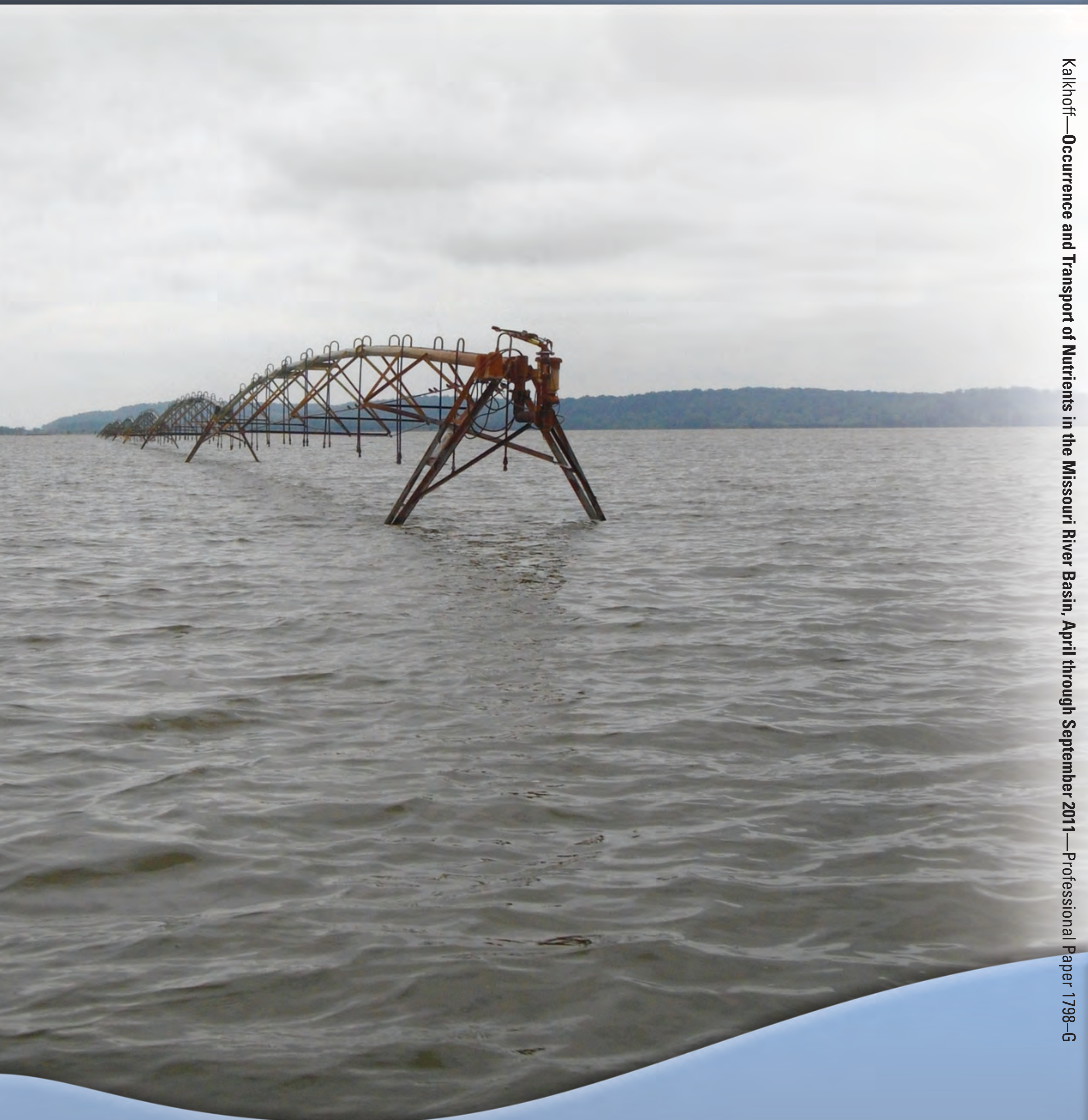

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