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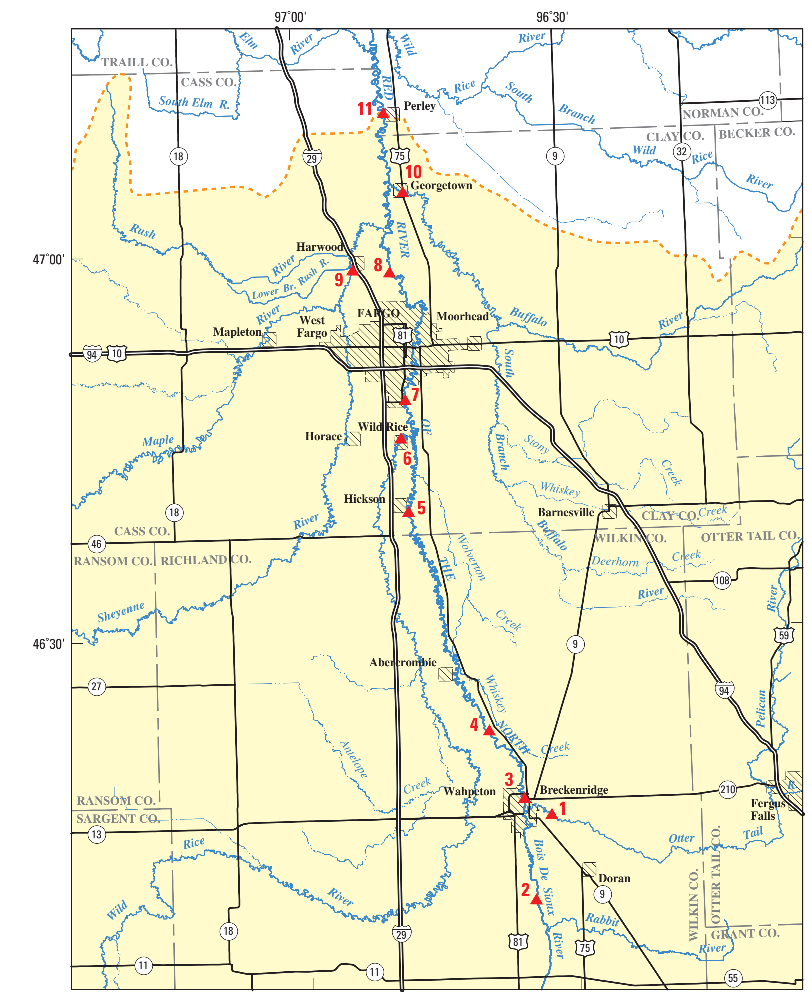
Constituent Loads and Flow-Weighted Average Concentrations for Major Subbasins of the Upper Red River of the North Basin, 1997-99



Scientific Investigations Report 2004–5200

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

Sether, Berkas, and Vecchia—**Constituent Loads and Flow-Weighted Average Concentrations for Major Subbasins of the Upper Red River of the North Basin, 1997-99**—Scientific Investigations Report 2004–5200

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Constituent Loads and Flow-Weighted Average Concentrations for Major Subbasins of the Upper Red River of the North Basin, 1997-99

By Bradley A. Sether, W. R. Berkas, and A. V. Vecchia

In cooperation with the North Dakota Department of Health, Minnesota Pollution Control Agency, Red River Joint Water Resource Board, and Red River Watershed Management Board

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Constituent Loads and Flow-Weighted Average Concentrations for Major Subbasins of the Upper Red River of the North Basin, 1997-99

By Bradley A. Sether, W. R. Berkas, and A. V. Vecchia

Abstract

Data were collected at 11 water-quality sampling sites in the upper Red River of the North (Red River) Basin from May 1997 through September 1999 to describe the water-quality characteristics of the upper Red River and to estimate constituent loads and flow-weighted average concentrations for major tributaries of the Red River upstream from the bridge crossing the Red River at Perley, Minn. Samples collected from the sites were analyzed for 5-day biochemical oxygen demand, bacteria, dissolved solids, nutrients, and suspended sediment.

Concentration data indicated the median concentrations for most constituents and sampling sites during the study period were less than existing North Dakota and Minnesota standards or guidelines. However, more than 25 percent of the samples for the Red River at Perley, Minn., site had fecal coliform concentrations that were greater than 200 colonies per 100 milliliters, indicating an abundance of pathogens in the upper Red River Basin. Although total nitrite plus nitrate concentrations generally increased in a downstream direction, the median concentrations for all sites were less than the North Dakota suggested guideline of 1.0 milligram per liter. Total and dissolved phosphorus concentrations also generally increased in a downstream direction, but, for those constituents, the median concentrations for most sampling sites exceeded the North Dakota suggested guideline of 0.1 milligram per liter.

For dissolved solids, nutrients, and suspended sediments, a relation between constituent concentration and streamflow was determined using the data collected during the study period. The relation was determined by a multiple regression model in which concentration was the dependent variable and streamflow was the primary explanatory variable. The regression model was used to compute unbiased estimates of annual loads for each constituent and for each of eight primary water-quality sampling sites and to compute the degree of uncertainty associated with each estimated annual load. The estimated annual loads for the eight primary sites then were used to estimate annual loads for five intervening reaches in the study area. Results were used as a screening tool to identify which subbasins contributed a disproportionate amount of pollutants to the Red River. To compare the relative water quality of the different subbasins, an estimated flow-weighted average (FWA) concentration was computed from the estimated average annual load and the average annual streamflow for each subbasin.

The 5-day biochemical oxygen demands in the upper Red River Basin were fairly small, and medians ranged from 1 to 3 milligrams per liter. The largest estimated FWA concentration for dissolved solids (about 630 milligrams per liter) was for the Bois de Sioux River near Doran, Minn., site. The Otter Tail River above Breckenridge, Minn., site had the smallest estimated FWA concentration (about 240 milligrams per liter). The estimated FWA concentrations for dissolved solids for the main-stem sites ranged from about 300 to 500 milligrams per liter and generally increased in a downstream direction.

The estimated FWA concentrations for total nitrite plus nitrate for the main-stem sites increased from about 0.2 milligram per liter for the Red River below Wahpeton, N. Dak., site to about 0.9 milligram per liter for the Red River at Perley, Minn., site. Much of the increase probably resulted from flows from the tributary sites and intervening reaches, excluding the Otter Tail River above Breckenridge, Minn., site. However, uncertainty in the estimated concentrations prevented any reliable conclusions regarding which sites or reaches contributed most to the increase.

The estimated FWA concentrations for total ammonia for the main-stem sites increased from about 0.05 milligram per liter for the Red River above Fargo, N. Dak., site to about 0.15 milligram per liter for the Red River near Harwood, N. Dak., site. The increase resulted from a decrease in flows in the Red River above Fargo, N. Dak., to the Red River near Harwood, N. Dak., intervening reach and the large load for that reach.

The estimated FWA concentrations for total organic nitrogen for the main-stem sites were relatively constant and ranged from about 0.5 to 0.7 milligram per liter. The relatively constant concentrations were in sharp contrast to the total nitrite plus

nitrate concentrations, which increased about fivefold between the Red River below Wahpeton, N. Dak., site and the Red River at Perley, Minn., site.

The Red River near Harwood, N. Dak., to the Red River at Perley, Minn., intervening reach had the largest estimated FWA concentration for total nitrogen (about 2.9 milligrams per liter), but the estimate was highly uncertain. The Otter Tail River above Breckenridge, Minn., site had the smallest concentration (about 0.6 milligram per liter). The estimated FWA concentrations for total nitrogen for the main-stem sites increased from about 0.9 milligram per liter for the Red River at Hickson, N. Dak., site to about 1.6 milligrams per liter for the Red River at Perley, Minn., site.

The Sheyenne River at Harwood, N. Dak., site had the largest estimated FWA concentration for total phosphorus (about 0.5 milligram per liter). The Otter Tail River above Breckenridge, Minn., site had the smallest concentration (about 0.1 milligram per liter). The estimated FWA concentrations for total phosphorus for the main-stem sites increased from about 0.15 milligram per liter for the Red River below Wahpeton, N. Dak., site to about 0.35 milligram per liter for the Red River at Perley, Minn., site.

The estimated FWA concentrations for suspended sediment for the main-stem sites increased from about 50 milligrams per liter for the Red River below Wahpeton, N. Dak., site to about 300 milligrams per liter for the Red River at Perley, Minn., site. Much of the increase occurred as a result of the large yield of suspended sediment from the Red River below Wahpeton, N. Dak., to the Red River at Hickson, N. Dak., intervening reach.

Introduction

The Red River of the North (hereinafter referred to as the Red River) (fig. 1) meanders northward for 394 miles, nearly double the straight-line distance, from its origin to the United States-Canada border. The river has been identified by North Dakota and Minnesota environmental officials as a river for which instream water-quality problems related to properties and constituents such as dissolved oxygen, dissolved solids, nutrients, ammonia, and sediment need to be assessed. The Red River Basin encompasses areas of rich agricultural land, wetlands, prairies, and forests, and nutrients from both point and nonpoint sources have been determined to cause excessive algae growth in the river.

Point-source pollutant loading to the Red River usually is identified and controlled easily because the pollutants often enter the river through a pipe. The point-source pollutants usually enter the river from urban areas along the river and along its larger tributaries. Nonpoint-source pollutant loading to the river is more difficult to identify because the pollutants may enter the river anywhere along its length. The nonpoint-source pollutants enter the river as dissolved constituents in ground water that is discharged to the river and as dissolved or suspended material in surface runoff (Tornes and others, 1997).

To control point- and nonpoint-source pollution in the Red River, the subbasins that contribute a disproportionate amount of pollutants to the river needed to be identified. Therefore, the U.S. Geological Survey (USGS), in cooperation with the North Dakota Department of Health, the Minnesota Pollution Control Agency, the Red River Joint Water Resource Board, and the Red River Watershed Management Board, began a study to collect and analyze water-quality data for the Red River. The data were used to determine the water-quality characteristics of the Red River and to determine which subbasins contribute the largest constituent loads to the river. Results of the study can be used by water-resource management agencies to establish sound water-quality standards.

Purpose and Scope

The purpose of this report is to describe the water-quality characteristics of the upper Red River and to present estimated constituent loads and flow-weighted average (FWA) concentrations for the major subbasins of the upper Red River Basin. For this report, the upper Red River Basin is defined as the drainage area upstream from the bridge crossing the Red River at Perley, Minn. (fig. 1). Data collected from May 1997 through September 1999 at 11 water-quality sampling sites in the upper Red River Basin (fig. 1) were used to describe the water-quality characteristics and to estimate constituent loads and FWA concentrations for major tributaries of the Red River. The estimated constituent loads then were used to determine which subbasins contributed the largest loads to the river during the study period. About 20 samples were collected from each of 8 sites during the study period, and about 6 samples were collected from each of 3 additional sites (table 1). The samples were analyzed for 5-day biochemical oxygen demand, bacteria, dissolved solids, nutrients, and suspended sediment. All values given in the USGS database for May 1997 through September 1999 were used in the analysis. Therefore, the number of values used varied among sites and among constituents. For example, for site 4, the number of values used ranged from 20 for dissolved solids to 22 for total nitrite plus nitrate and total nitrogen (table 1–1 in appendix 1).

Description of Red River of the North Basin

The general physical, hydrological, and ecological setting of the Red River Basin is diverse in ways that could have a significant effect on the distribution and flow of water in the basin and, therefore, the distribution and concentration of constituents that affect water quality (Stoner and others, 1993). Continental

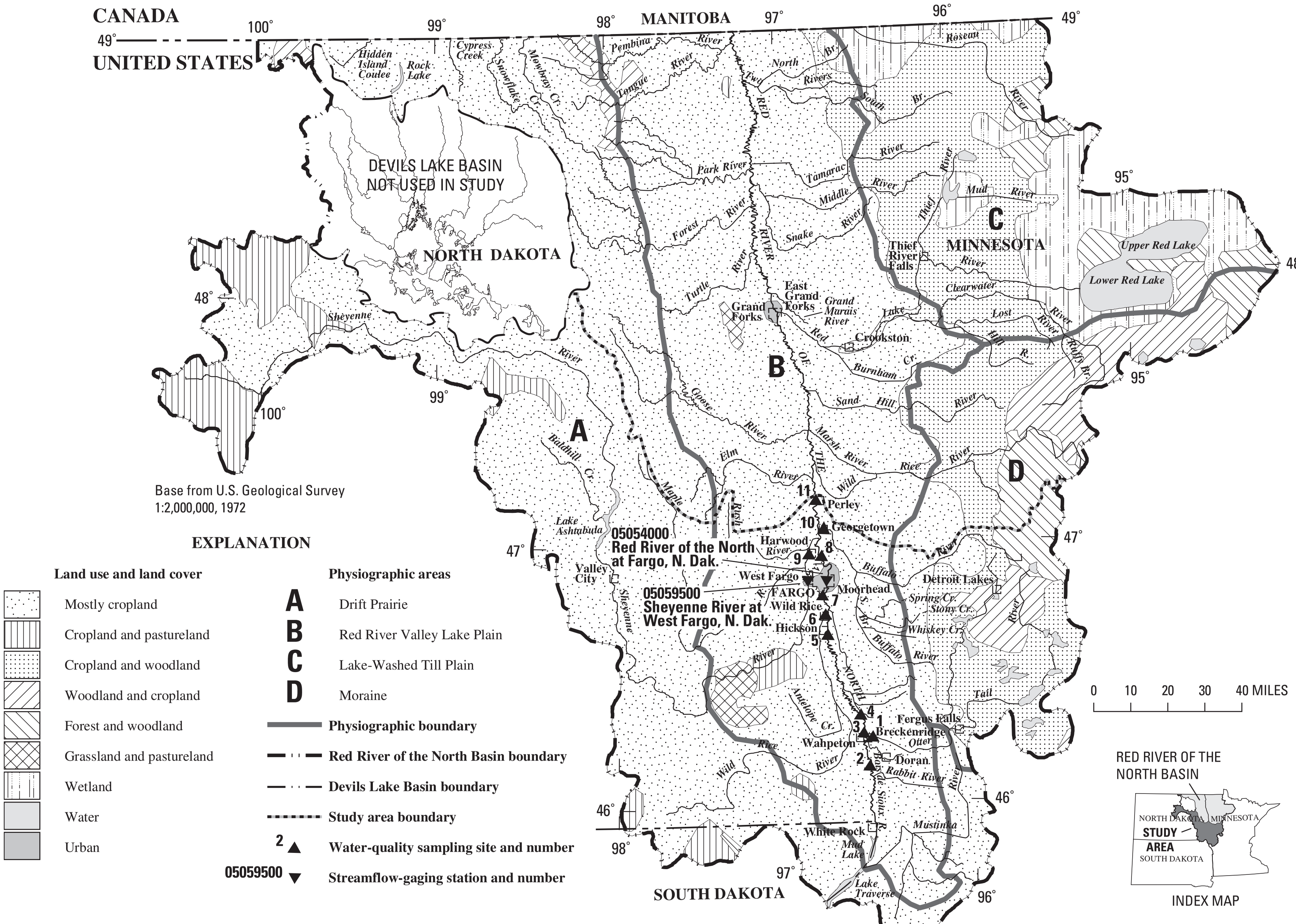

Figure 1. Location of study area, locations of water-quality sampling sites, land use and land cover, and physiographic areas in the Red River of the North Basin. [Modified from Tornes and others, 1997.]

Table 1. Water-quality sampling sites used in study.

Site number (see figure 1)	Site identification number	Site name	Period of data collection	Number of samples collected during 1997-99	Approximate contributing drainage area (square miles)
1	05046450	Otter Tail River above Breckenridge, Minn.	5-97 to 9-99	21	1,970
2	05051300	Bois de Sioux River near Doran, Minn.	5-97 to 9-99	18	1,880
3	05051505	Red River of the North at Highway 210 bridge at Wahpeton, N. Dak.	5-97 to 11-97	6	3,940
4	05051510	Red River of the North below Wahpeton, N. Dak.	5-97 to 9-99	22	4,000
5	05051522	Red River of the North at Hickson, N. Dak.	5-97 to 9-99	23	4,300
6	05053600	Wild Rice River at Wild Rice, N. Dak.	5-97 to 9-97	5	1,720
7	05053800	Red River of the North above Fargo, N. Dak.	5-97 to 9-99	24	6,800
8	05054200	Red River of the North near Harwood, N. Dak.	5-97 to 9-99	22	6,980
9	05060400	Sheyenne River at Harwood, N. Dak.	5-97 to 9-99	21	6,980
10	05062095	Buffalo River at U.S. Highway 75 in Georgetown, Minn.	5-97 to 11-97	6	1,130
11	05062150	Red River of the North at Perley, Minn.	5-97 to 9-99	22	15,100

glaciers and glacial lakes deposited 150 to 300 feet of unconsolidated material over much of the basin and shaped a landscape of flat plains near the center of the basin and gently rolling uplands, lakes, and wetlands along the margins. The Drift Prairie in the western part of the basin (fig. 1) is comprised of low, rolling hills and prairie; the Red River Valley Lake Plain in the central part of the basin is an extensive area of flat land comprised mostly of clays and silts deposited by glacial Lake Agassiz; the Lake-Washed Till Plain in the northeastern part of the basin is a relatively flat upland area and has extensive wetlands and peat deposits; and the Moraine in the southeastern part of the basin is comprised mostly of lakes and woodlands.

The upper Red River Basin, which is the focus for this study, has a drainage area of about 15,100 square miles. Major tributaries in the upper Red River Basin (and their drainage areas) are the Otter Tail River (about 1,970 square miles), the Bois de Sioux River (about 1,880 square miles), the Wild Rice River in North Dakota (about 1,720 square miles), the Sheyenne River (about 6,980 square miles), and the Buffalo River (about 1,130 square miles). Although the drainage area of the Otter Tail River subbasin ranks second in size among the drainage areas of the five major subbasins in the study area, the mean annual streamflow for the subbasin ranks first (fig. 2).

The climate of the Red River Basin is continental and ranges from dry subhumid in the west to subhumid in the east. The mean monthly temperature ranges from -1 degree Fahrenheit in January near the United States-Canada border to 73 degrees Fahrenheit in July in the southern part of the basin (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, 1982). Mean annual precipitation in the Red River Basin ranges from less than 17 inches in the west to about 26 inches in the east (fig. 2). Loss of water to evapotranspiration increases from east to west across the basin.

The population of the United States part of the Red River Basin in 2000 was 607,000, which was a 19-percent increase since 1990 (U.S. Census Bureau, 2002a, 2002b). About one-third of the population lives in Fargo, N. Dak.; West Fargo, N. Dak.; Moorhead, Minn.; Grand Forks, N. Dak.; and East Grand Forks, Minn. Water use in the Red River Basin during 1990 was about 196 million gallons. The water was used mainly for public supply and irrigation, and about 48 percent was obtained from surface-water sources. The largest cities (Fargo and Grand Forks, N. Dak., and Moorhead, Minn.) obtain most of their water from the Red River (Stoner and others, 1993).

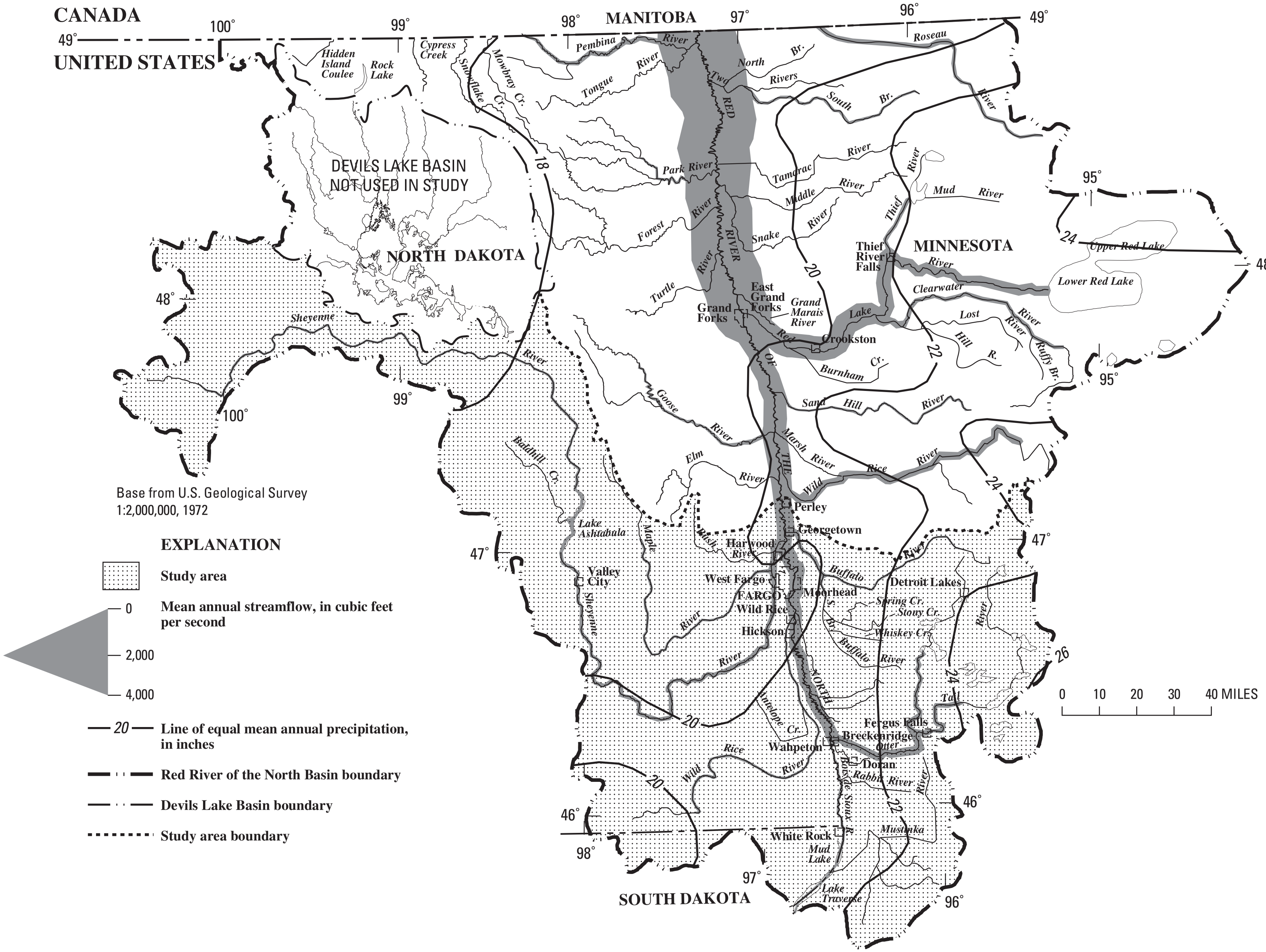

Figure 2. Mean annual precipitation and streamflow in the Red River of the North Basin. [Modified from Tornes and others, 1997.]

Streamflow in the Red River Basin varies greatly throughout the year. The largest streamflows usually occur in spring and early summer as a result of rain falling on melting snow or heavy rain falling on saturated soils. Flooding is a major problem and is aggravated by the gentle slope of the Red River and the flatness of the overbank areas. To facilitate agricultural production, an extensive system of drainage ditches has been constructed in parts of the Red River Valley Lake Plain and the Lake-Washed Till Plain to promote rapid surface drainage of clay-rich soils.

Ground water in the Red River Basin is primarily in sand and gravel aquifers near land surface or in buried glacial deposits throughout the basin. Ground water also moves toward the Red River through a regional system of bedrock and glacial-drift aquifers. Many of these bedrock and glacial-drift aquifers are connected hydraulically to streams in the basin and, therefore, affect the flow and water quality of the streams. During dry periods, ground water, in addition to water from lakes and reservoirs, is an important source of flow in many of the streams.

The fertile, black, fine-grained soils in the Red River Basin are conducive to cropland agriculture, which is the dominant land use in the basin. About 64 percent of the basin is comprised of cropland, and about 16 percent is comprised of pastureland, farmland, and local roads (data interpreted from U.S. Geological Survey, 1986; Minnesota Agricultural Statistics Service, 1991; North Dakota Agricultural Statistics Service, 1992). The remainder of the basin is comprised of grassland, forest, open water, and wetlands. Cropland is most extensive in the Red River Valley Lake Plain.

Small grains, including wheat, oats, rye, and barley, are grown throughout most of the Red River Basin. These grains often are rotated with other crops in regional patterns that are based on differences in soils, topography, and climate. Corn is grown primarily in the southern part of the basin. However, small fields in other parts of the basin also are planted in corn. Sunflowers, hay, and small grains are grown predominantly in the Drift Prairie, and sugar beets, potatoes, small grains, and soybeans are grown predominantly in the Red River Valley Lake Plain.

Study Design

Water-quality sampling sites used in this study were selected to represent major subbasins in the upper Red River Basin. Where possible, the sites were located at existing USGS streamflow-gaging stations where water-quality data previously had been collected. For this study, specific conductance, pH, air temperature, water temperature, dissolved oxygen, barometric pressure, fecal coliform, and fecal streptococci were measured in the field. Water samples were collected from each site and sent to the North Dakota Department of Health Laboratory in Bismarck, N. Dak., to be analyzed for biochemical oxygen demand, major ions, nutrients, and trace elements. An additional water sample was collected from each site and sent to the USGS Sediment Laboratory in Iowa City, Iowa, to be analyzed for suspended-sediment concentration and particle-size distribution. Initially, water samples also were collected from two sites and sent to the North Dakota Department of Health Laboratory to be analyzed for pesticides. However, after the first year of the study, the pesticide sampling schedule was re-evaluated and, because of the large number of pesticide concentrations that were less than method detection limits, the sampling frequency for pesticides was reduced. The water-quality properties and constituents analyzed for in the study described in this report are given in table 2.

Water-quality data initially were collected at 11 sites (table 1, fig. 1), but, because of changes in resources available for the study, sampling was discontinued at one tributary site [site 6 (the Wild Rice River at Wild Rice, N. Dak.)] in September 1997 and at one main-stem site [site 3 (the Red River at Highway 210 bridge at Wahpeton, N. Dak.)] and one tributary site [site 10 (the Buffalo River at U.S. Highway 75 in Georgetown, Minn.)] in November 1997 (field measurements were continued at site 3). Sample-collection timelines for the 11 sites are shown in figure 3. The three discontinued sites were chosen because loads for those sites could be estimated using loads for existing main-stem sites. Therefore, the data for the three discontinued sites were not used to estimate loads for this study and are not included in the discussion of water-quality characteristics.

Methods

Sample Collection and Analysis

Samples for August and September 1998 were collected by the North Dakota Department of Health. All other samples were collected by the USGS. All samples were collected using the equal-width increment (EWI) sampling method described by Wilde and others (1999). The EWI sampling method involves the collection of water from equally spaced widths in the stream channel using an isokinetic sampler such as a US-D77 sampler. With an isokinetic sampler, water samples are collected proportional to stream velocity. Therefore, the EWI method results in the collection of discharge-weighted samples. For this study, water samples collected with the isokinetic sampler were composited into a churn splitter. Then, aliquots of water were drawn from the churn splitter, put into bottles, and sent to the appropriate laboratory for analysis. Sediment samples were collected concurrently with the water samples but were not composited; rather, the whole-water samples were sent to the laboratory for analysis. Fecal coliform and fecal streptococci samples were collected from the river surface at the centroid of flow using a sterile bottle. A US-DH81 sampler (a hand-

Table 2. Water-quality properties and constituents for which water samples were analyzed.

Measured at time of sample collection	Determined at North Dakota Department of Health Laboratory, Bismarck, North Dakota		Determined at U.S. Geological Survey Sediment Laboratory, Iowa City, Iowa
Specific conductance	Specific conductance	Arsenic, total	Suspended-sediment concentration
pH	pH	Barium, total	Suspended sediment particle size
Air temperature	Biochemical oxygen demand, 5-day	Beryllium, total recoverable	
Water temperature	Calcium, dissolved	Boron, total recoverable	
Dissolved oxygen	Magnesium, dissolved	Cadmium, total recoverable	
Barometric pressure	Sodium, dissolved	Chromium, total recoverable	
Fecal coliform	Potassium, dissolved	Copper, total recoverable	
Fecal streptococci	Alkalinity	Iron, total recoverable	
	Sulfate, dissolved	Lead, total recoverable	
	Chloride, dissolved	Manganese, total recoverable	
	Nitrite plus nitrate, total	Nickel, total recoverable	
	Ammonia, total	Selenium, total	
	Ammonia plus organic nitrogen, total	Silver, total recoverable	
	Nitrogen, organic, total	Thallium, total recoverable	
	Nitrogen, total	Zinc, total recoverable	
	Phosphorus, total		
	Phosphorus, dissolved		
	Chlorophyll *a*		
	Chlorophyll *b*		
	Aluminum, total recoverable		
	Antimony, total		

held isokinetic sampler) or a glass bottle in a weighted basket sampler was used when samples were collected under ice and velocities were slow.

Samples were processed within 1 to 2 hours of collection. Raw water used for total analysis was drawn from the churn first. Water used for dissolved analysis was drawn last using a peristaltic pump and a 0.45-micron capsule filter. Water samples to be analyzed for biochemical oxygen demand were put into bottles and chilled. Water samples to be analyzed for total nutrients were put into bottles, preserved with sulfuric acid, and chilled, and water samples to be analyzed for dissolved nutrients were put into bottles, filtered, and chilled. Water samples to be analyzed for trace elements were put into bottles and preserved with nitric acid to a pH of 2 or less. The fecal coliform and fecal streptococci samples were processed and analyzed in the field by the USGS using the membrane-filtration procedure described by Myers and Sylvester (1997). The sediment samples were sent to the USGS Sediment Laboratory after completion of the sampling trip.

Samples analyzed by the North Dakota Department of Health Laboratory were shipped to the laboratory using next-day services. The North Dakota Department of Health Laboratory uses U.S. Environmental Protection Agency (USEPA) methods and procedures. The USGS Sediment Laboratory

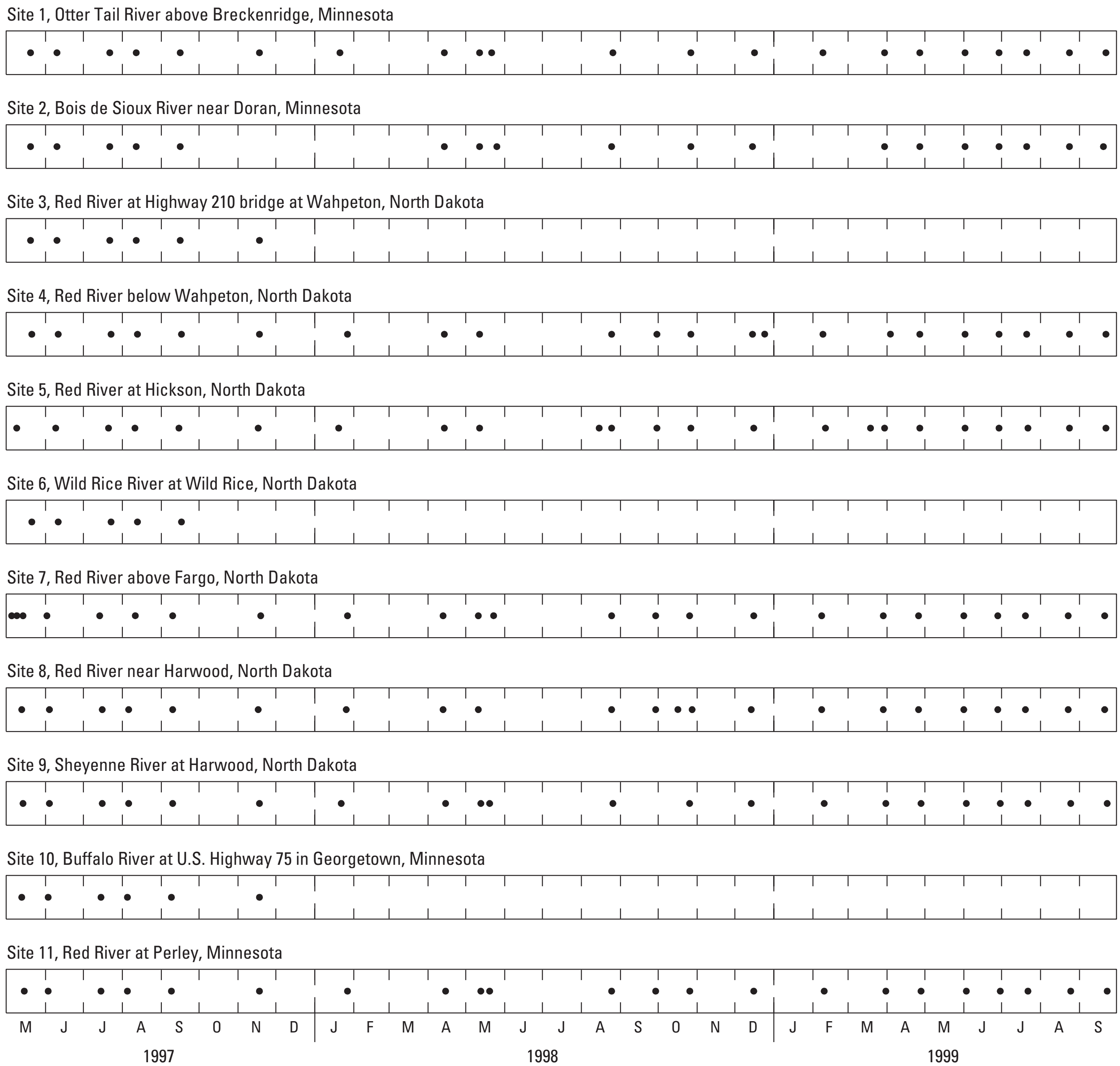

Figure 3. Sample-collection timelines for water-quality sampling sites used in study.

uses methods given by Guy (1969) and participates in a USGS quality-assurance program. External agencies and customer organizations audit the North Dakota Department of Health Laboratory to assess the laboratory analytical methods and quality-assurance/quality-control procedures. The USEPA reviews the laboratory procedures about every third year, and the Branch of Systems of the USGS reviews the laboratory procedures periodically.

A total of six replicate samples (three splits and three duplicates) were collected during the study. The quality-assurance samples were used to evaluate the precision and accuracy of the analysis of the samples collected for the study. Because of the limited resources available for the study, results from the North Dakota Department of Health laboratory and results from the USGS laboratory were not compared. Results from both laboratories may be obtained by contacting the USGS office in Bismarck, N. Dak.

Load Computation

The actual annual load for a given river cross section, constituent, and water year[1] is defined as the total mass of the constituent that is transported past the river cross section during the year. The actual annual load cannot be determined unless concentration is monitored continuously. Therefore, because concentration data were collected intermittently during this study, gaps in the data needed to be filled before the annual loads could be estimated. To fill the gaps, a relation between constituent concentration and streamflow was determined using the data collected during the study period (May 1997 through September 1999). Although constituent-concentration data were available before May 1997 for some sites, a common period of record was used for all sites to facilitate comparison of the loads. The relation was determined by a multiple regression model in which concentration was the dependent variable and streamflow was the primary explanatory variable. The regression model was determined using a program called Estimator (Cohn, Caulder, Gilroy, Zynjuk, and Summers, 1992; Cohn, Gilroy, and Baier, 1992). A seasonal factor was included in the regression model when needed.

After estimates of daily concentration were computed for each day of the year, the concentration was multiplied by daily streamflow to obtain an estimated daily load. The estimated daily loads then were summed to obtain the estimated annual load for a given water year. The difference between the estimated annual load and the actual annual load is known as the estimation error. The statistical properties of the estimation error depend on the number of concentrations used to fit the regression model, the degree of censoring of the concentrations, and the streamflow conditions during which the concentration data were collected. For this study, the estimation error was quantified by using Estimator to produce, in addition to an estimated annual load, a confidence interval within which the actual annual load was likely to plot. A more detailed description of uncertainty in the estimated annual loads is given in appendix 1.

Seasonality can have a significant effect on constituent concentrations because changing climatic conditions and human activities can affect the availability of some constituents to the aquatic environment. For example, nitrate concentrations tend to be small and ammonia concentrations tend to be large during the winter because cold conditions in the soil and the water reduce nitrifying bacteria activities. Also, nitrogen and phosphorus concentrations may be larger during the summer than during other times of the year because of rainfall runoff from fields where fertilizers have been applied. Therefore, the ability to incorporate seasonality into the regression model was an important feature of Estimator.

The ability to include censored concentrations (that is, concentrations that are less than the laboratory method detection limit) in the regression model was another important feature of Estimator. If all concentrations used to fit the regression model were greater than the detection limit, minimum-variance unbiased estimates of daily concentration were computed using the fitted model described previously. However, if some concentrations were less than the detection limit, estimates of daily concentration were computed using an adjusted maximum likelihood estimation (AMLE) procedure (Cohn, Gilroy, and Baier, 1992). The AMLE procedure produced essentially unbiased estimates even when a large percentage (as much as 80 percent) of the concentrations used to fit the regression model were censored.

The instructions for using Estimator (G. Baier, T. Cohn, and E. Gilroy, U.S. Geological Survey, written commun., 1995) state that, for efficient load estimation, at least 25 samples should be collected per year for 2 years. However, the methodology also is valid for small sample sizes provided extra care is used to fit the regression model and to verify the assumptions of the model (Tim Cohn, U.S. Geological Survey, oral commun., 2003). A small sample size, in effect, increases the standard error of the estimated annual load and, therefore, reduces the accuracy of the estimated annual load. For this study, fewer than 25 samples were collected from each site during 1997-99. However, the approximate constituent load contributed from each subbasin to the Red River could be identified for many of the constituents and sites. Therefore, the results from Estimator were used as a screening tool to identify which subbasins contributed a disproportionate amount of pollutants to the Red River. In some cases, particularly for nutrient loads for the small subbasins, the standard errors of the estimated annual loads were too large to discern differences in loads among the subbasins. However, because the Estimator program computes unbiased estimates of annual loads with the smallest possible standard error, regardless of sample size, more accurate estimates can be obtained only by increasing the sample size.

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[1]In U.S. Geological Survey reports, a water year is defined as the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends; therefore, the water year ending September 30, 1999, is called “water year 1999.”

Water-Quality Characteristics

Biochemical Oxygen Demand

A sufficient amount of dissolved oxygen is critical for maintaining the aquatic life and aesthetic quality of streams and lakes. Therefore, the determination of how organic matter affects the dissolved-oxygen concentration in a stream or lake is integral to water-quality management. The decay of organic matter in water is measured by the biochemical or chemical oxygen demand. The oxygen demand is a measure of the amount of oxygen removed from water by the metabolic requirements of oxidizable substances (Nemerow, 1974; Tchobanoglous and Schroeder, 1985).

The distribution of 5-day biochemical oxygen demand in the upper Red River Basin is shown in figure 4. The oxygen demands were fairly small, and medians ranged from 1 to 3 milligrams per liter. Site 2 (the Bois de Sioux River near Doran, Minn.) had the largest median oxygen demand.

Bacteria

Fecal indicator bacteria are used to assess the presence of waterborne disease-causing pathogens (pathogens). Indicator bacteria are used because they typically are not disease causing and they correlate well with several pathogens (Myers and Sylvester, 1997). The fecal indicator bacteria used in this study were fecal coliform and fecal streptococci. Both types of bacteria thrive in the intestines of warm-blooded animals and are present in waste from the animals. Therefore, the bacteria can

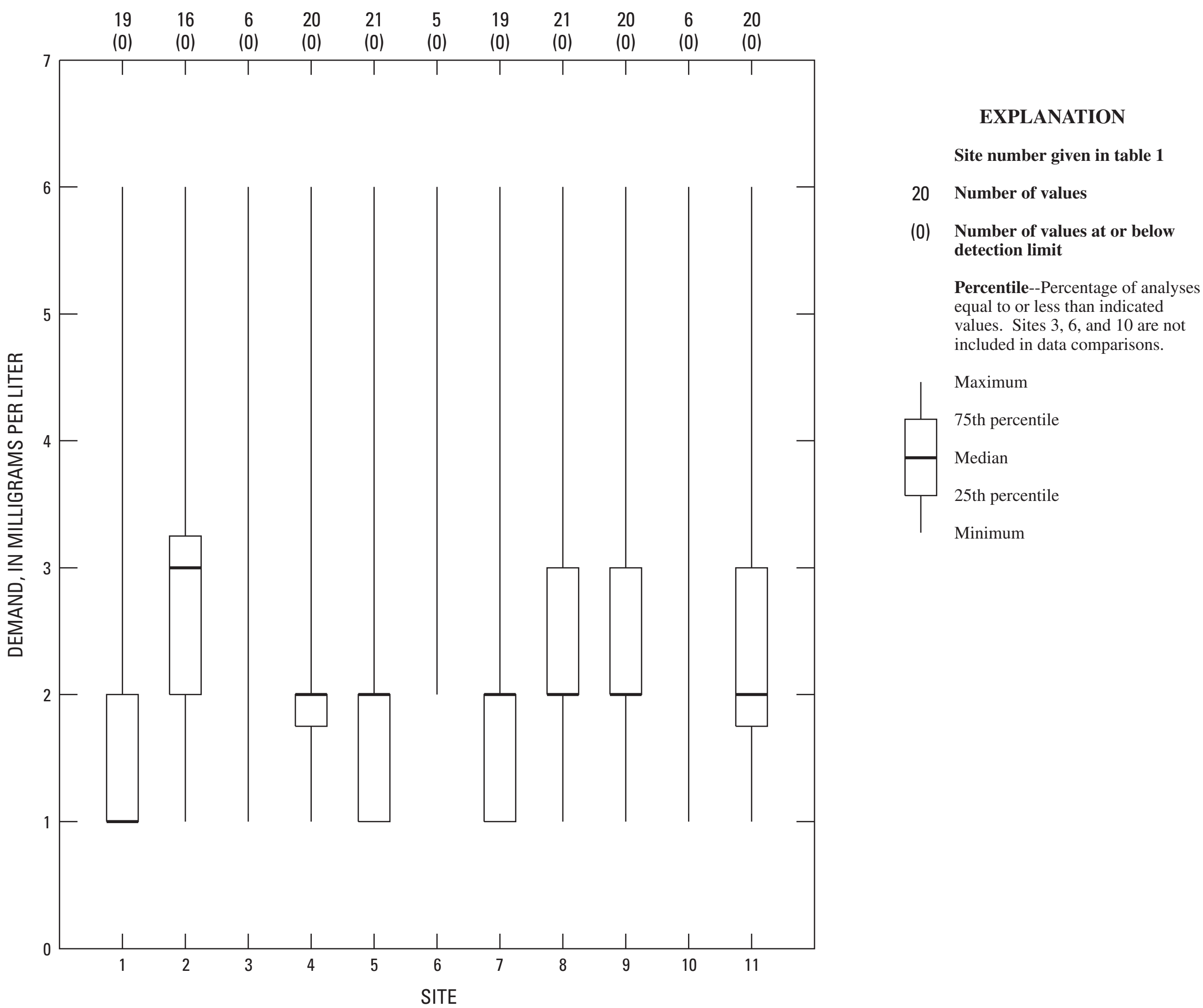

Figure 4. Distribution of 5-day biochemical oxygen demand in the upper Red River of the North Basin during May 1997 through September 1999.

be used to indicate if warm-blooded animals contribute to the contamination of a water body. The North Dakota and Minnesota water-quality standards for fecal coliform state that, for the recreational season of May 1 through September 30, the geometric mean of fecal coliform shall not exceed 200 colonies per 100 milliliters based on a minimum of five samples within a 30-day period (North Dakota Department of Health, 1991; Minnesota Pollution Control Agency, accessed July 17, 2002).

The distribution of fecal coliform in the upper Red River Basin is shown in figure 5, and the distribution of fecal streptococci is shown in figure 6. The fecal coliform and fecal streptococci concentrations varied greatly from site to site. The largest median fecal coliform concentration was for site 9 (the Sheyenne River at Harwood, N. Dak.). Site 8 (the Red River near Harwood, N. Dak.), site 9, and site 11 (the Red River at Perley, Minn.) had the largest median fecal streptococci concentrations.

Fecal coliform samples were not collected with sufficient frequency to determine if the water-quality standards were met. However, more than 50 percent of the samples for site 9 and more than 25 percent of the samples for site 2 (the Bois de Sioux River near Doran, Minn.) and site 11 had fecal coliform concentrations that were greater than 200 colonies per 100 milliliters (fig. 5). Although a few of the samples that had large concentrations were not collected during the recreational season, the concentrations that were greater than 200 colonies per 100 milliliters indicate an abundance of pathogens in the upper Red River Basin.

Dissolved Solids

Dissolved-solids concentrations in river water depend on the solubility of the rocks, the type of soil, and the amount of rainfall within a drainage basin. Large dissolved-solids concen-

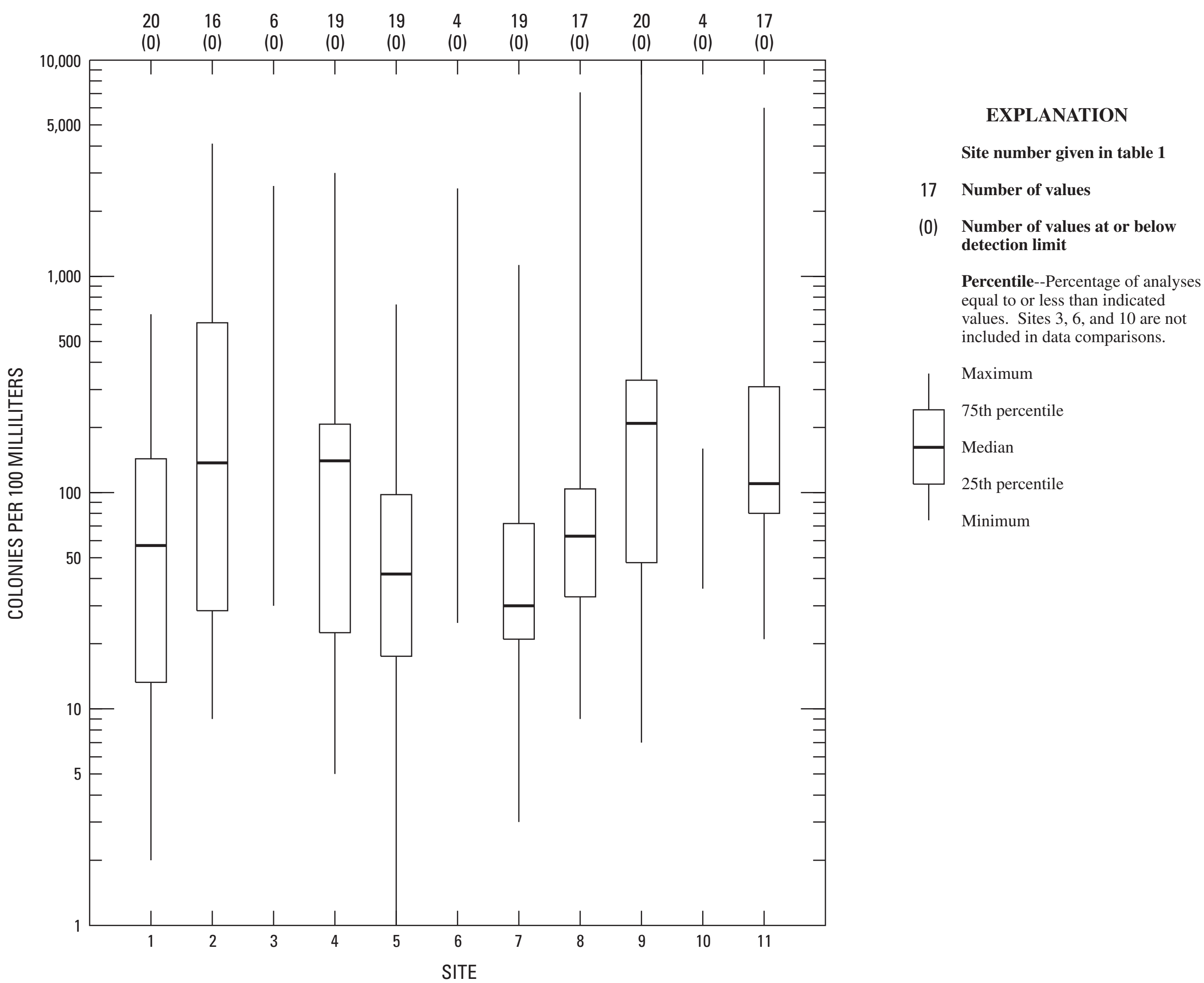

Figure 5. Distribution of fecal coliform in the upper Red River of the North Basin during May 1997 through September 1999.

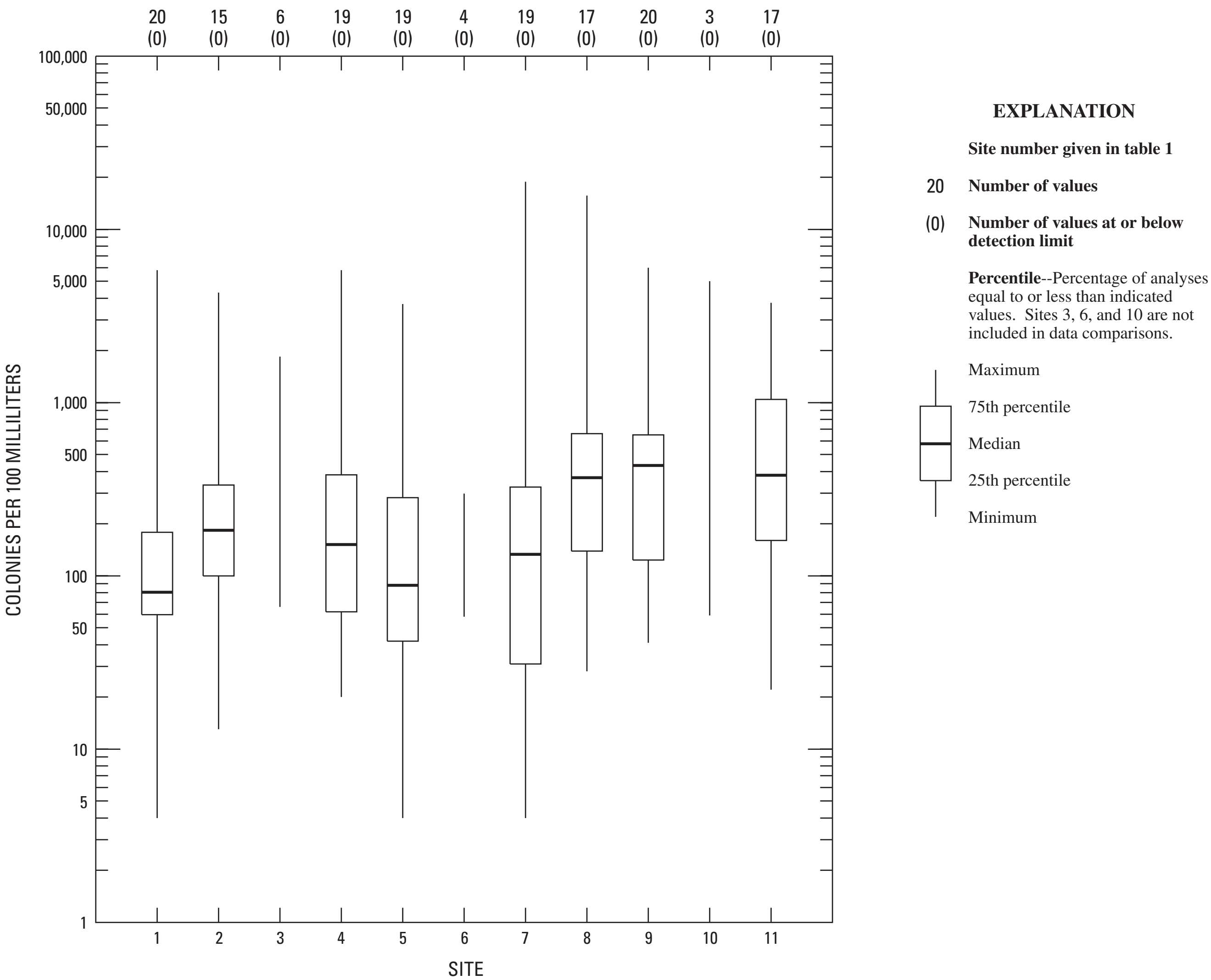

Figure 6. Distribution of fecal streptococci in the upper Red River of the North Basin during May 1997 through September 1999.

trations can be detrimental for some uses of the water. The USEPA secondary water-quality standard for dissolved solids in drinking water is 500 milligrams per liter. North Dakota has no standard for dissolved solids. The Minnesota standard for the Red River is 500 milligrams per liter (Minnesota Pollution Control Agency, accessed July 17, 2002). This standard is a nonenforceable guideline regarding cosmetic effects and aesthetic effects of drinking water.

The distribution of dissolved solids in the upper Red River Basin is shown in figure 7. The median concentrations for site 2 (the Bois de Sioux River near Doran, Minn.) and site 9 (the Sheyenne River at Harwood, N. Dak.) exceeded the USEPA secondary water-quality standard of 500 milligrams per liter. Sites 2 and 9 also had the largest dissolved-solids concentrations. No main-stem Red River sites had median concentrations that exceeded the standard. Generally, the dissolved-solids concentrations in the main stem Red River increased in a downstream direction.

Nutrients

Nutrients in streams are derived from natural sources and from many human uses of land and water resources (fig. 8). The nutrients are transported to the streams by ground-water inflow and surface runoff. Sources of nutrients include atmospheric deposition, decaying plants, animal wastes, fertilizers, septic systems, detergents, municipal and industrial wastewater, and minerals in rocks and soil. Substantially less phosphorus than nitrogen is contributed by atmospheric deposition.

In urban drainage areas, as in other drainage areas, snowmelt and a few major storms transport a large part of the annual

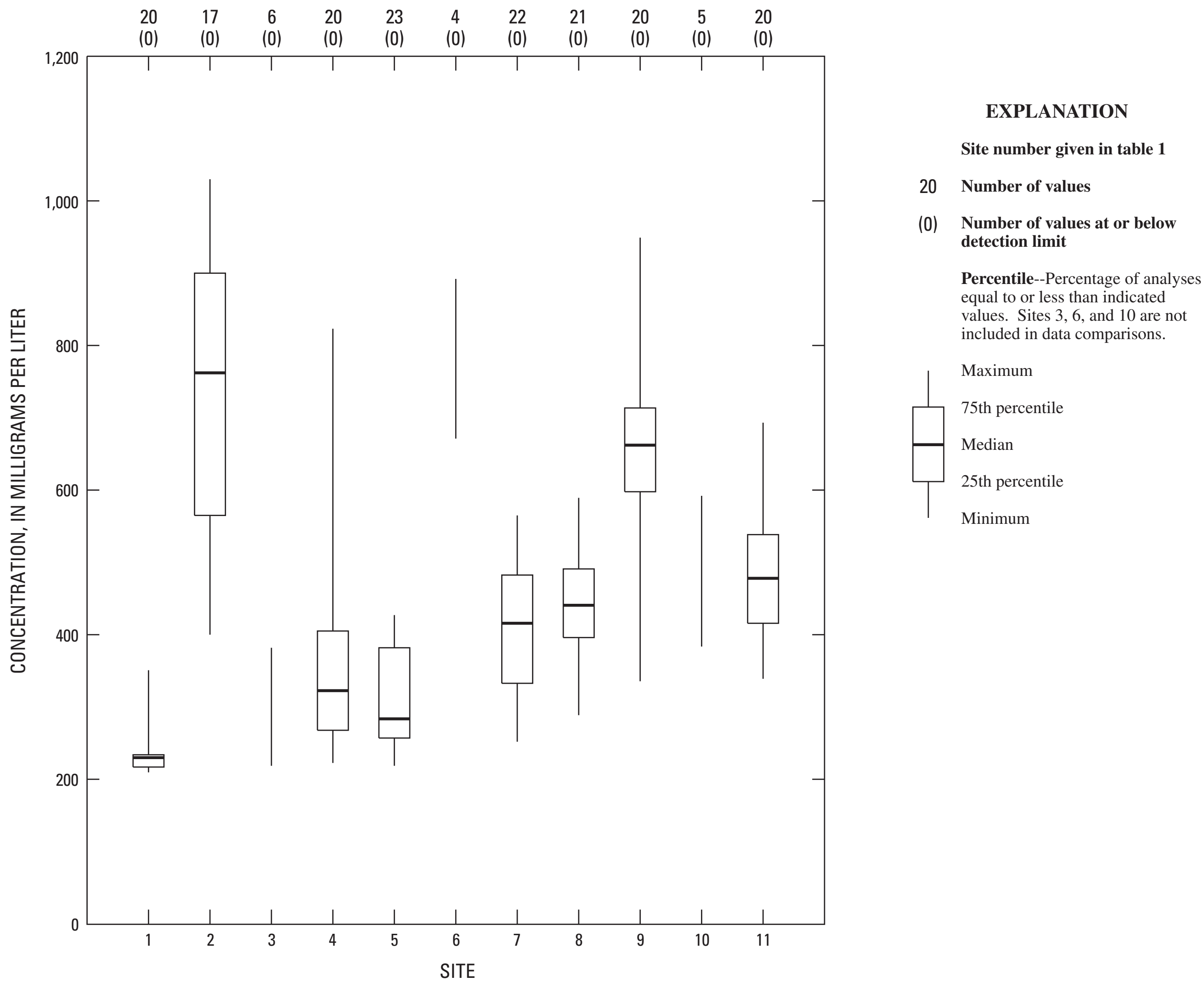

Figure 7. Distribution of dissolved solids in the upper Red River of the North Basin during May 1997 through September 1999.

nonpoint-source nutrient load to the Red River. Surface runoff is affected by the total amount of rainfall during the storm, the total contributing drainage area, the peak discharge, the runoff volume and duration, the rainfall rate, and the percentage of impervious land surface in the drainage area. Most nutrients that reach the impervious surfaces are transported to storm drains and eventually to streams by the surface runoff. Although the relative proportions of nutrients contributed from ground-water discharge and from surface runoff are not known, the contribution from surface runoff is dominant.

In agricultural areas, nutrients are contributed primarily from nonpoint sources, including animal wastes (fig. 8) and crop fertilizers (fig. 9). High flows generally contribute most of the nutrients to streams through surface runoff, erosion, transport of organic and inorganic particulates, and resuspension of streambed sediments. Low flows possibly can carry nutrients that have infiltrated to the water table and entered the ground-water-flow system. The relative proportions of nutrients contributed from ground-water discharge and from surface runoff vary depending on the local soils and geology and on the location of the agricultural area relative to the ground-water and surface-water systems.

Nitrogen

The most common forms of nitrogen are nitrate, nitrite, ammonia, and organic nitrogen. In the presence of oxygen, nitrifying bacteria will oxidize all forms of nitrogen to nitrate. The amount of ammonia and organic nitrogen in water is dependent on the population of nitrifying bacteria and the length of time the compound has been in the water. Nitrite is easily oxi-

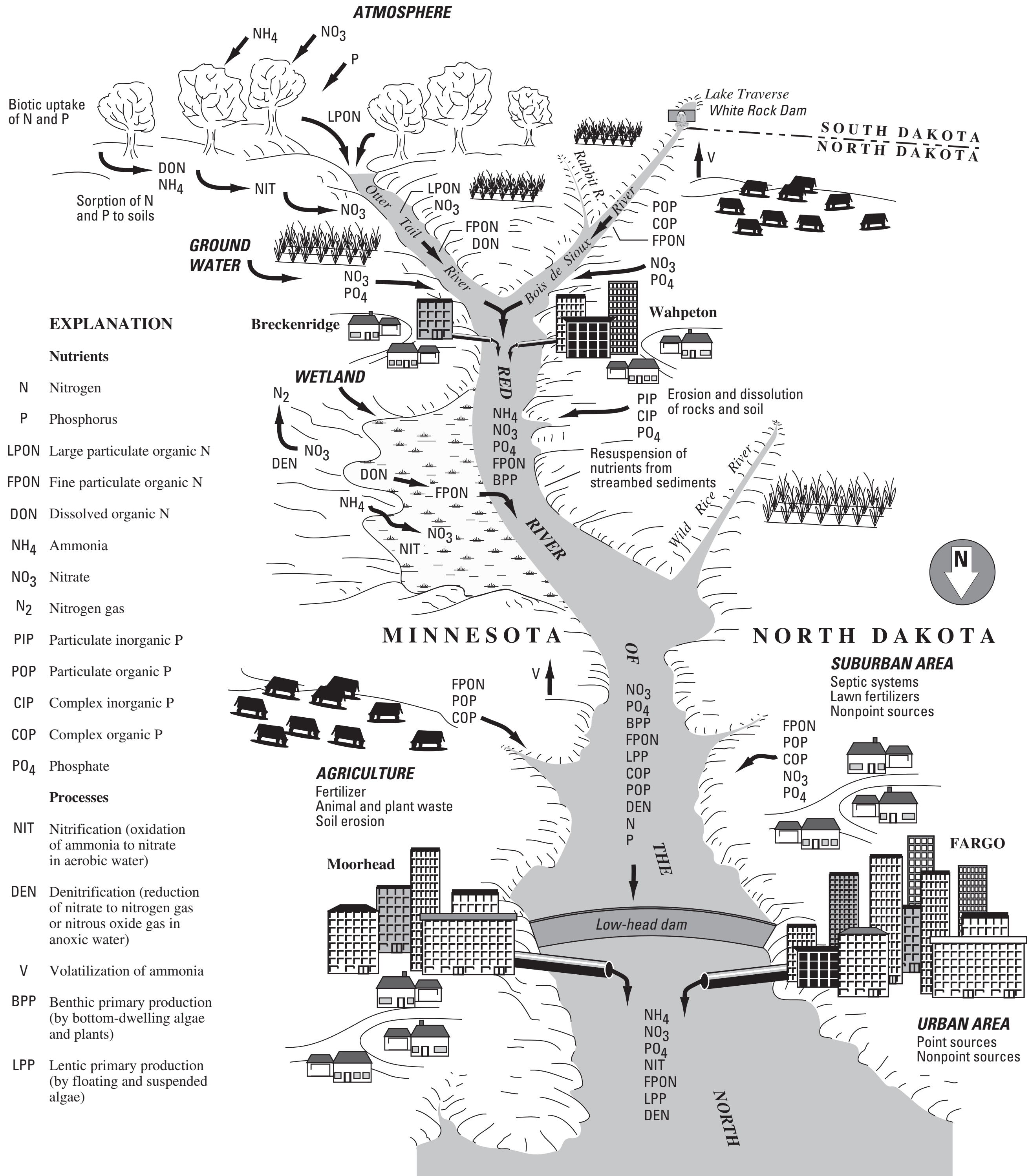

Figure 8. Movement of nutrients from subbasins of the Red River of the North Basin. [Modified from Antweiler and others, 1995.]

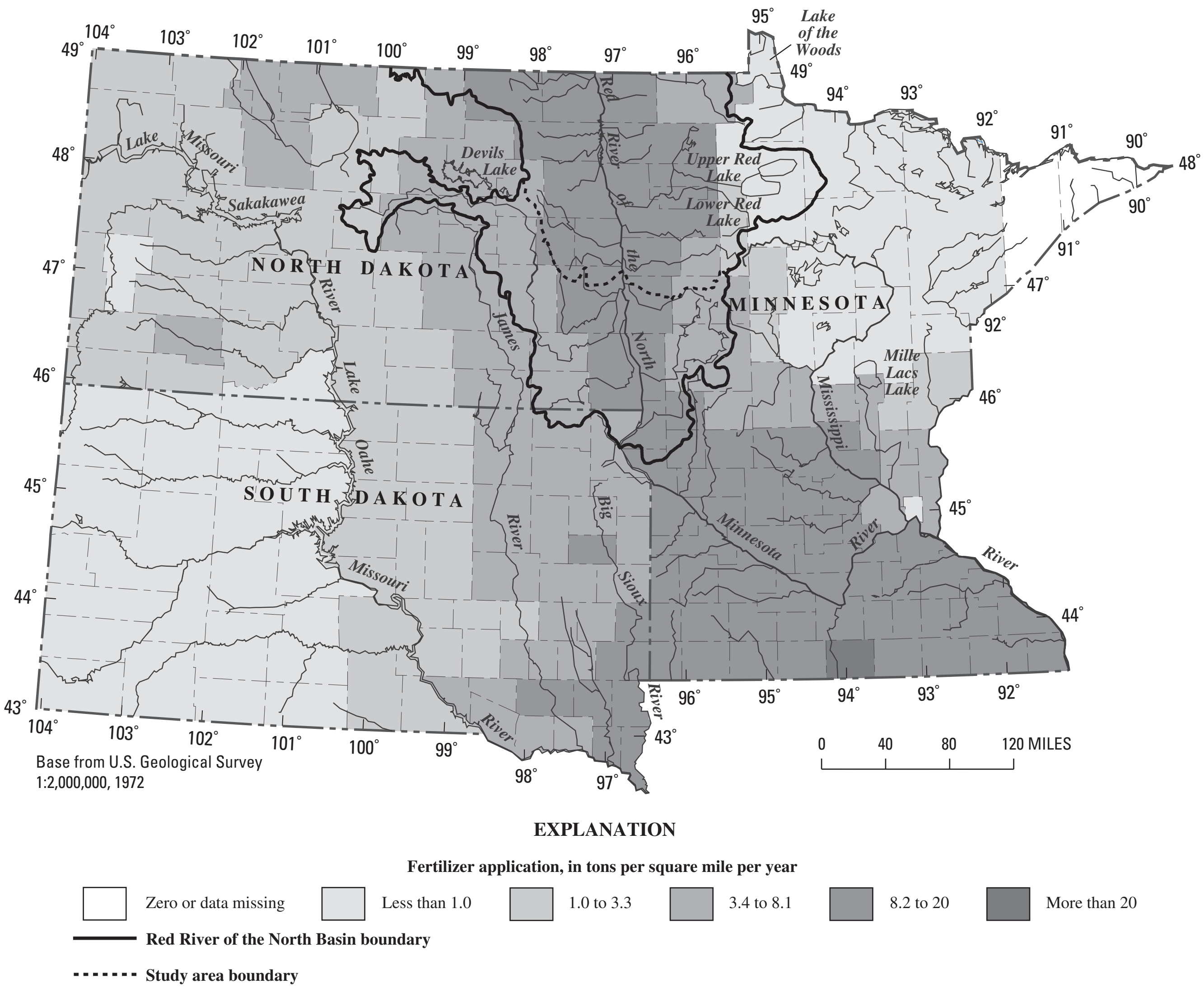

Figure 9. Nitrogen fertilizer applications by county in North Dakota, Minnesota, and South Dakota during 1991. [Modified from Antweiler and others, 1995.]

dized to nitrate, so nitrite concentrations in water generally are small.

The Red River is used by Fargo and Moorhead as a source of drinking water. The North Dakota water-quality standard for nitrate in drinking water is 10 milligrams per liter as N (North Dakota Department of Health, 1994). The Minnesota water-quality standard for nitrate in drinking water also is 10 milligrams per liter as N (Minnesota Pollution Control Agency, accessed July 17, 2002). North Dakota also has a suggested guideline for nitrate of 1.0 milligram per liter as N (North Dakota Department of Health, 1991) to reduce the potential for nuisance algal growth.

The distribution of total nitrite plus nitrate in the upper Red River Basin is shown in figure 10. The median concentrations for all sites were less than the suggested guideline for nuisance algal growth, and all concentrations were less than the standards for drinking water. The largest median concentration was for site 11 (the Red River at Perley, Minn.). The median concentration for site 8 (the Red River near Harwood, N. Dak.) was more than twice as large as the median concentration for site 7 (the Red River above Fargo, N. Dak.). The increase between the two sites probably was a result of wastewater discharges and urban runoff. The concentrations for site 9 (the Sheyenne River at Harwood, N. Dak.) were comparable to the concentrations for site 8.

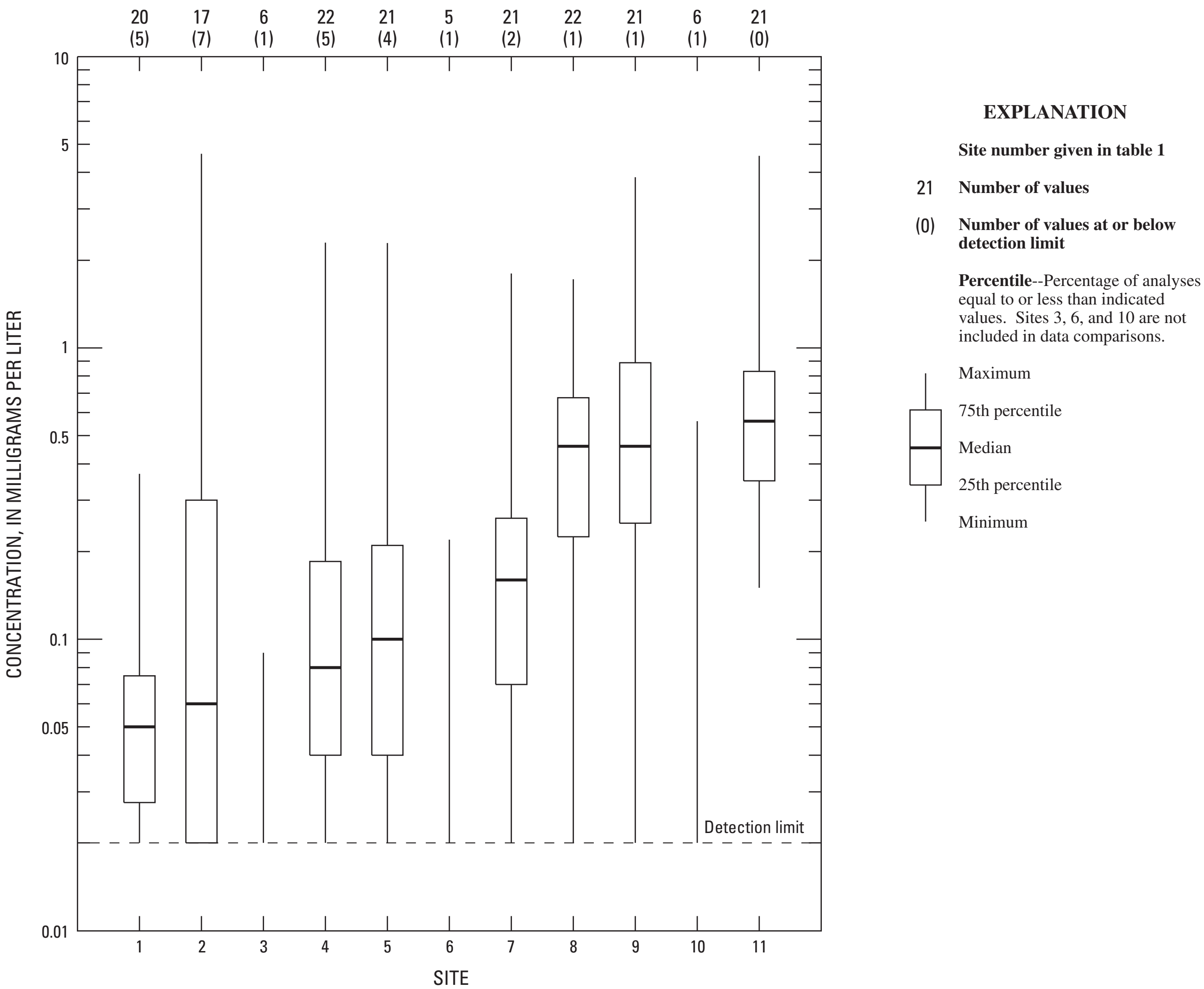

Figure 10. Distribution of total nitrite plus nitrate in the upper Red River of the North Basin during May 1997 through September 1999.

The distribution of total ammonia in the upper Red River Basin is shown in figure 11. A small fraction of the nitrogen in the upper Red River Basin was in the ammonia form. This was expected because, in the presence of oxygen and nitrifying bacteria, ammonia will be oxidized to nitrate. The largest median total ammonia concentration was for site 8. Among the tributary sites, site 2 (the Bois de Sioux River near Doran, Minn.) and site 9 had the largest median concentrations. The concentrations appeared to decrease slightly from site 4 (the Red River below Wahpeton, N. Dak.) to site 7 but then increased in a downstream direction from site 7 to site 8. The increase from site 7 to site 8 probably was a result of wastewater discharges from urban areas. Typically, wastewater discharge has large ammonia concentrations.

The distribution of total organic nitrogen in the upper Red River Basin is shown in figure 12. Much of the nitrogen comprising the total nitrogen was in the organic form. The median total organic nitrogen concentrations for all sites were greater than 0.5 milligram per liter as N. Among the tributary sites, site 2 had the largest median concentration. However, the median concentrations for the main-stem Red River sites were relatively constant, possibly indicating that much of the organic nitrogen from the tributary sites was being converted to nitrate in the main stem.

The distribution of total nitrogen in the upper Red River Basin is shown in figure 13. The smallest median concentration was for site 1 (the Otter Tail River above Breckenridge, Minn.), and the largest median concentration was for site 2. The median concentration increased substantially between site 7 and site 8. As indicated previously, the increase between the two sites probably was a result of ammonia and nitrate contributions from wastewater discharges. Generally, the total nitrogen con-

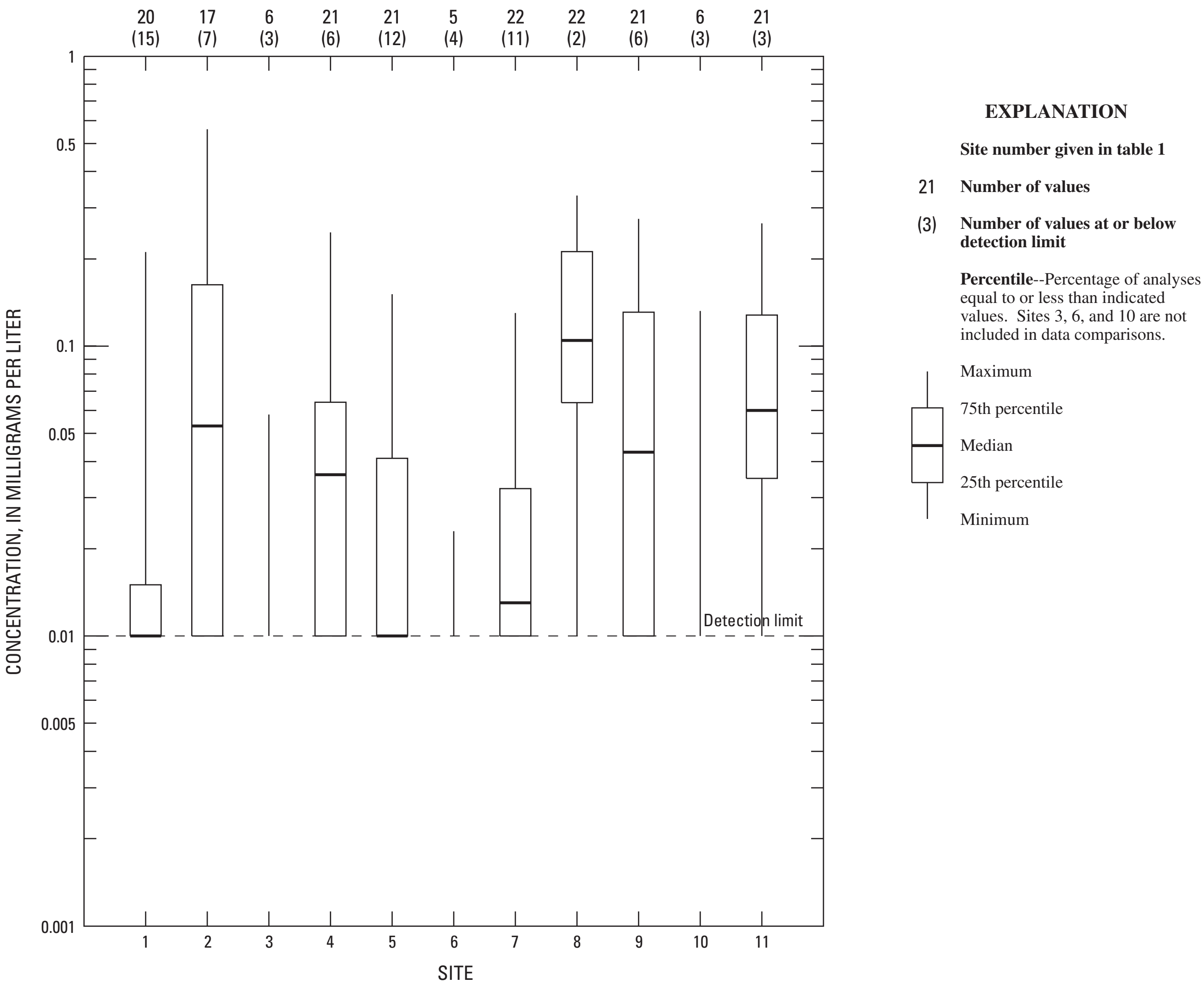

Figure 11. Distribution of total ammonia in the upper Red River of the North Basin during May 1997 through September 1999.

centrations and the median concentrations in the main stem Red River increased in a downstream direction.

Phosphorus

Phosphorus is required for plant growth and is essential for plant life. In the Red River, phosphorus is the limiting nutrient for algal growth. North Dakota has a suggested guideline for phosphorus of less than 0.1 milligram per liter as P (North Dakota Department of Health, 1991) to reduce the potential for nuisance algal growth.

The distribution of total phosphorus in the upper Red River Basin is shown in figure 14. Nearly all median concentrations exceeded the North Dakota suggested guideline of 0.1 milligram per liter. The largest median concentrations were for site 2 (the Bois de Sioux River near Doran, Minn.), site 9 (the Sheyenne River at Harwood, N. Dak.), and site 11 (the Red River at Perley, Minn.). The large concentrations for those sites may have been a result of runoff of phosphorus fertilizers from cropland. The concentrations increased from site 7 (the Red River above Fargo, N. Dak.) to site 8 (the Red River near Harwood, N. Dak.), possibly as a result of wastewater discharges and urban runoff. Wastewater discharge has large phosphorus concentrations and tends to increase phosphorus concentrations downstream from the outfall site. Generally, the total phosphorus concentrations in the Red River increased in a downstream direction.

The distribution of dissolved phosphorus in the upper Red River Basin is shown in figure 15. The largest median concentration was for site 2. The increase from site 7 to site 8 may have been a result of wastewater discharges and urban runoff.

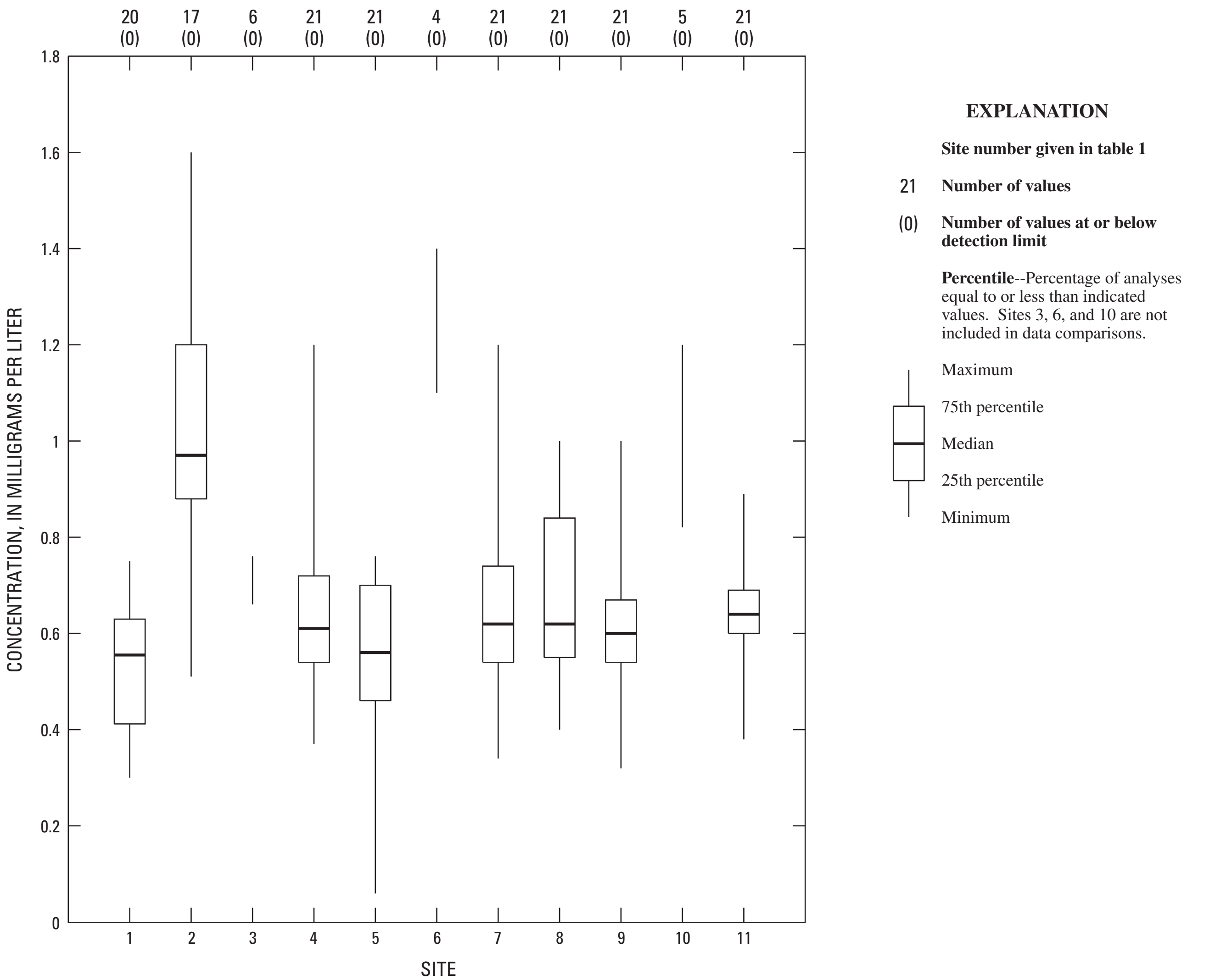

Figure 12. Distribution of total organic nitrogen in the upper Red River of the North Basin during May 1997 through September 1999.

The concentrations for site 9 were similar to the concentrations for site 8. Generally, the dissolved phosphorus concentrations increased in a downstream direction.

Dissolved phosphorus usually is considered to be that part of phosphorus that is available to plants, such as algae. Therefore, to control nuisance algal growth in streams, dissolved phosphorus concentrations should be less than 0.1 milligram per liter as P. The dissolved phosphorus concentrations for this study generally were greater than 0.1 milligram per liter as P except for site 1 (the Otter Tail River above Breckenridge, Minn.) and site 4 (the Red River below Wahpeton, N. Dak.). The fact that most of the dissolved phosphorus concentrations were greater than 0.1 milligram per liter indicates an abundant natural source of phosphorus in the basin and/or significant nonpoint sources of phosphorus from human activities.

Suspended Sediment

Sediment in surface waters may occur naturally from bank and upland soil erosion, especially during major rains and floods, or as a result of soil disturbances caused by construction and some agricultural practices. Channel modifications also can increase streambank erosion.

An increase in the amount of sediment in a stream can have adverse effects on the water quality of the stream. The sediment can carry nutrients and other constituents and, therefore, act as a transport mechanism that otherwise might not exist. Sediment transported by streams also can adversely affect aquatic ecosystems. Turbidity that results from increased suspended-sediment concentrations can reduce light penetration and, therefore, affect aquatic plants and algae, and deposition of the sediments

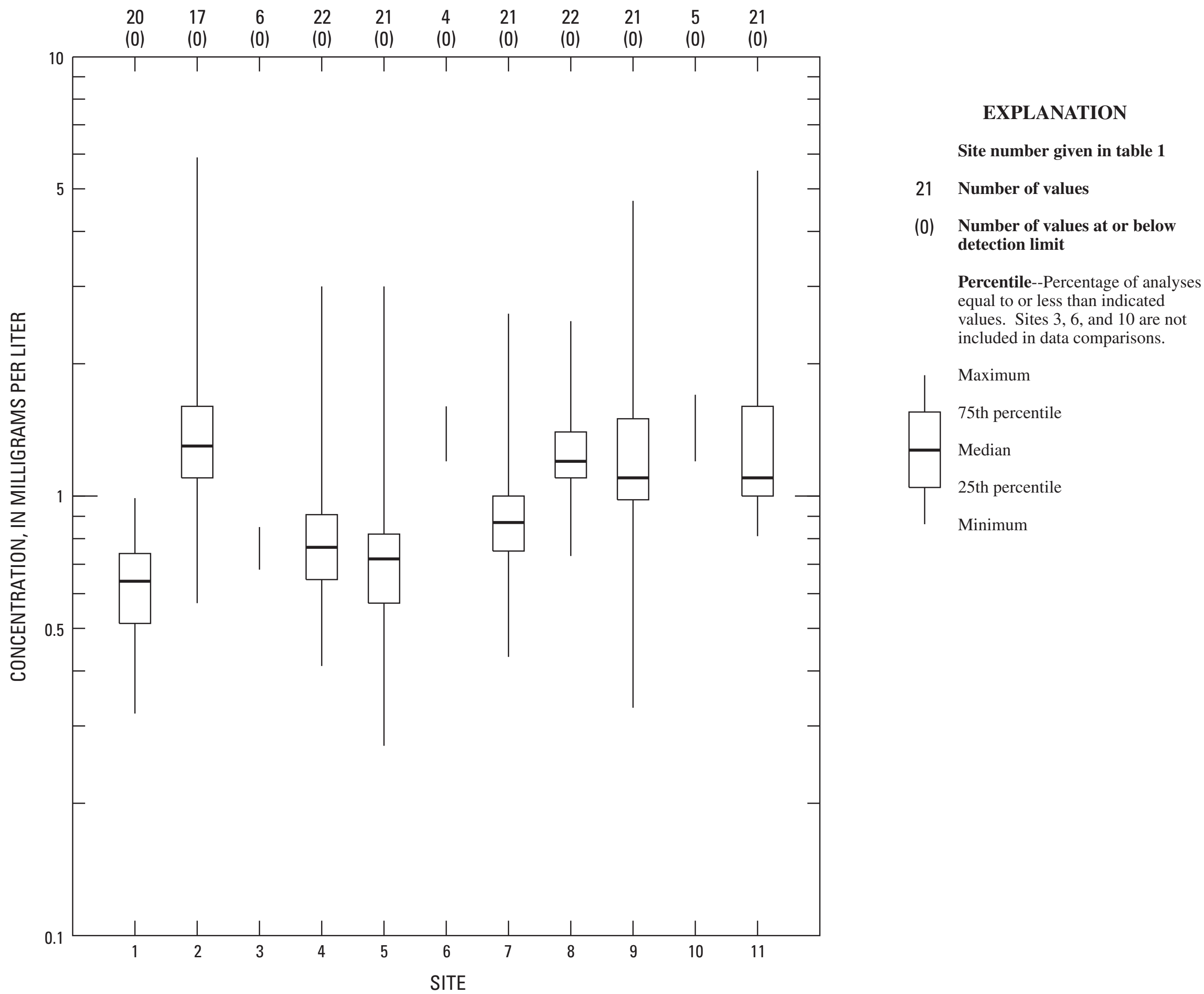

Figure 13. Distribution of total nitrogen in the upper Red River of the North Basin during May 1997 through September 1999.

possibly can change entire habitats. Nutrients, especially phosphorus, transported on sediment and deposited in the streambeds can be released and augment plant growth (Tornes and Brigham, 1994).

For this report, suspended sediment was divided into two classes, sand size (greater than 0.062 millimeter) and silt and clay size (less than 0.062 millimeter). Except for site 1 (the Otter Tail River above Breckenridge, Minn.), more than 95 percent of the suspended sediment in the streams was silt and clay.

The distribution of suspended sediment in the upper Red River Basin is shown in figure 16. The concentrations were relatively small for the upstream sites and gradually increased in a downstream direction. Site 9 (the Sheyenne River at Harwood, N. Dak.) had the largest median concentration.

Constituent Loads and Flow-Weighted Average Concentrations

Estimated annual loads were computed for eight primary water-quality sampling sites (sites 1, 2, 4, 5, 7, 8, 9, and 11) that had more than 2 years of data. The estimated annual loads for those sites then were used to compute estimated annual loads for five intervening reaches in the study area. The general methodology for computing estimated annual loads is described in the Methods section. Of the eight primary water-quality sampling sites, three [site 1 (the Otter Tail River above Breckenridge, Minn.); site 2 (the Bois de Sioux River near Doran, Minn.); and site 9 (the Sheyenne River at Harwood, N. Dak.)] are located on major tributaries of the Red River, and five [site 4 (the Red River below Wahpeton, N. Dak.); site 5 (the Red River at Hickson, N. Dak.); site 7 (the Red River above Fargo,

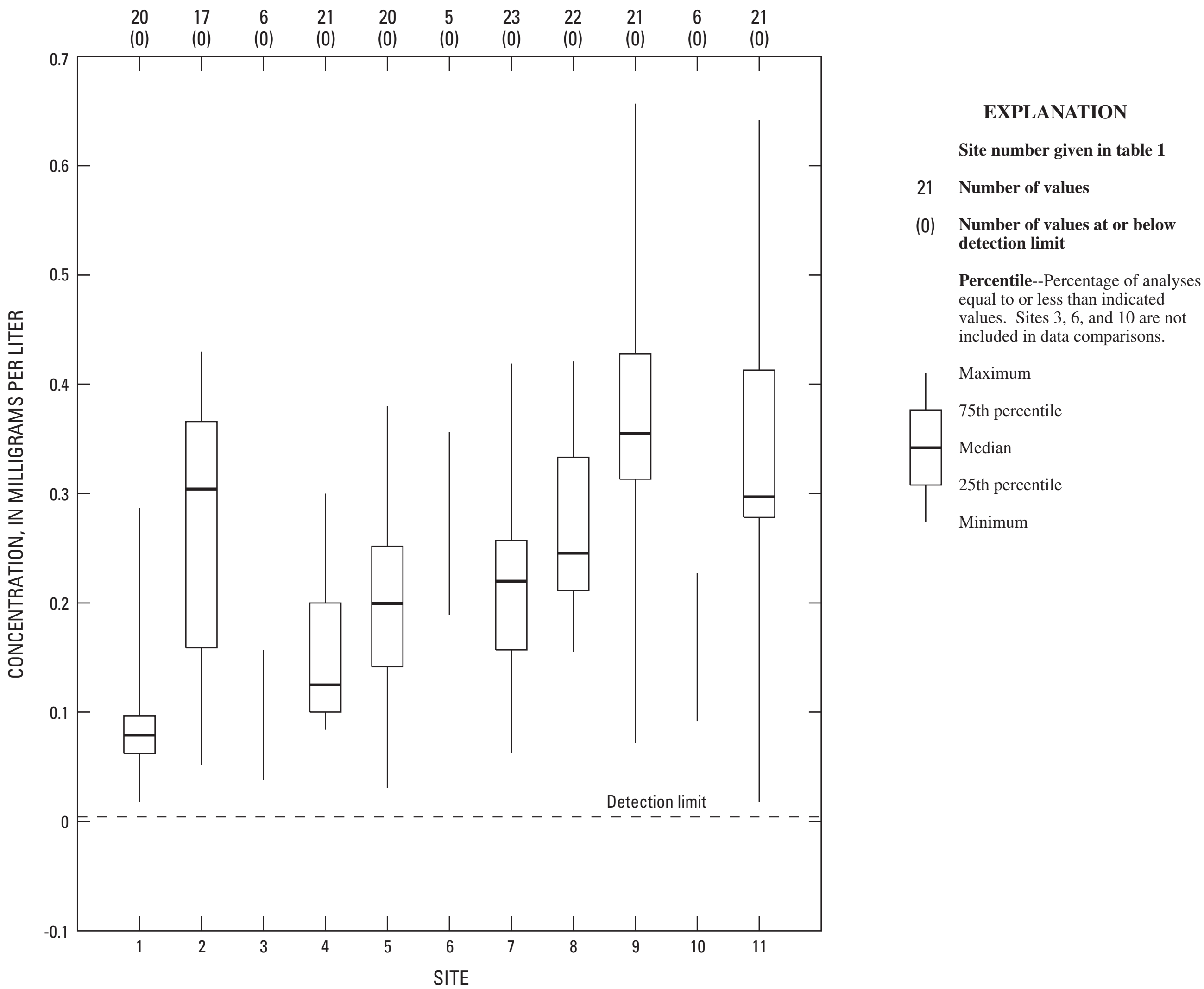

Figure 14. Distribution of total phosphorus in the upper Red River of the North Basin during May 1997 through September 1999.

N. Dak.); site 8 (the Red River near Harwood, N. Dak.); and site 11 (the Red River at Perley, Minn.)] are located on the main stem of the Red River. The subbasins for the three major tributaries and the subbasins for the five intervening reaches partitioned the study area into eight disjoint subbasins (fig. 17). Each subbasin for the intervening reaches was defined as that part of the study area that contributed runoff and/or point-source discharge to a particular intervening reach of the Red River. The first intervening reach (R1) consisted of the reach downstream from sites 1 and 2 and upstream from site 4 and included Wahpeton. The second intervening reach (R2) consisted of the reach downstream from site 4 and upstream from site 5. The third intervening reach (R3) consisted of the reach downstream from site 5 and upstream from site 7 and included the Wild Rice River. The fourth intervening reach (R4) consisted of the reach downstream from site 7 and upstream from site 8 and included Fargo. The fifth intervening reach (R5) consisted of the reach downstream from sites 8 and 9 and upstream from site 11 and included the Buffalo and Rush Rivers.

Because annual loads are largely dependent on streamflow, the streamflows for the periods of record for the Red River at Fargo, N. Dak., streamflow-gaging station [05054000; 2 miles downstream from site 7; fig. 1] and the Sheyenne River at West Fargo, N. Dak., streamflow-gaging station [05059500; 11 miles upstream from site 9; fig. 1] were used to evaluate streamflow conditions for the study period (1997-99). Streamflows for those two stations represent most of the flow for the study area. The streamflows for the two stations were much higher than normal during the study period. The annual mean streamflow for the Red River at Fargo station for the period of record (1901-99) was 657 cubic feet per second. The annual mean streamflows for water years 1997, 1998, and 1999 for that station were 2,655, 1,581, and 1,906 cubic feet per second,

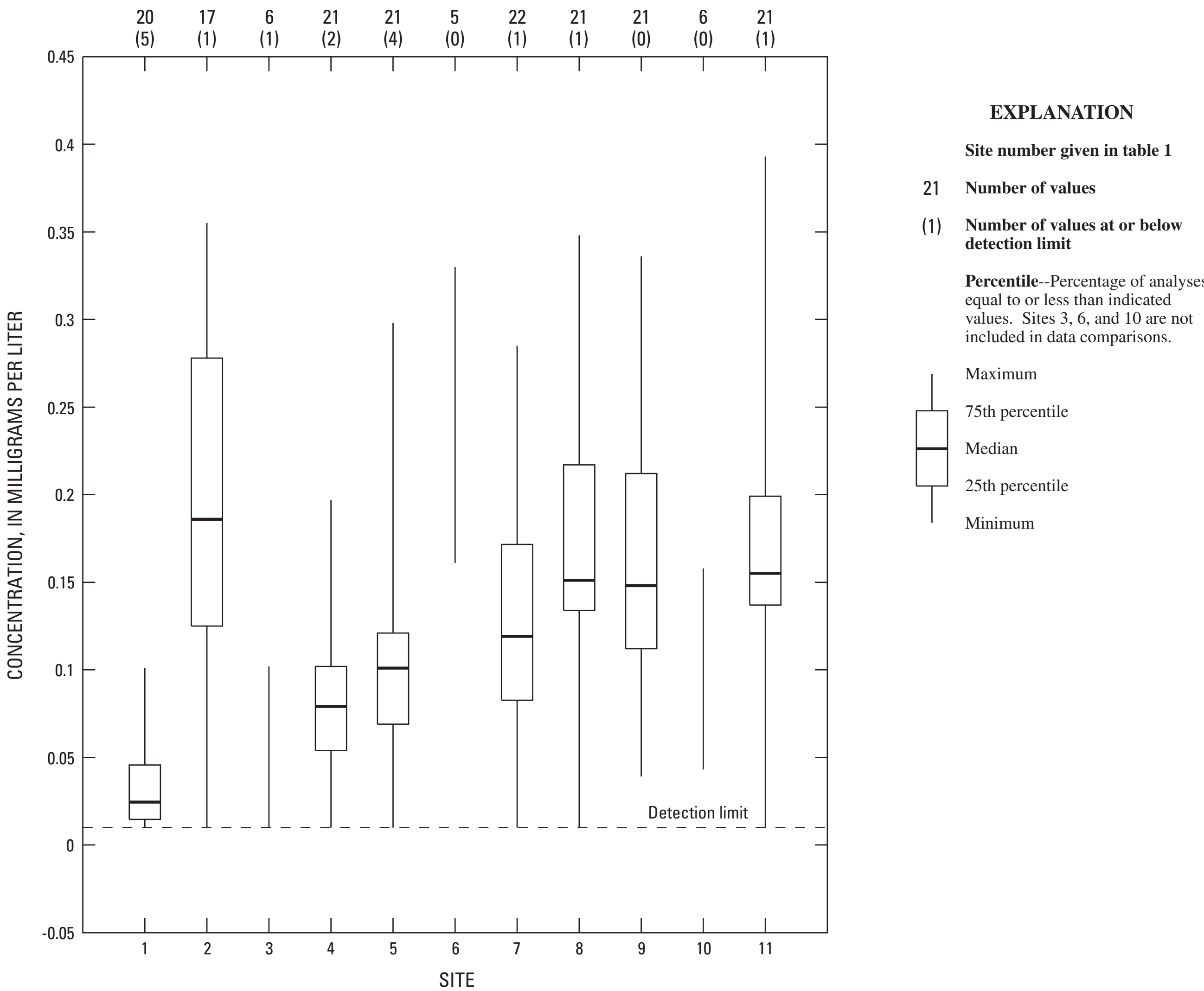

Figure 15. Distribution of dissolved phosphorus in the upper Red River of the North Basin during May 1997 through September 1999.

respectively, and were ranked as the 1st, 7th, and 4th highest streamflows on record. The annual mean streamflow for the Sheyenne River at West Fargo station for the period of record (1903-99) was 219 cubic feet per second. The annual mean streamflows for water years 1997, 1998, and 1999 for that station were 804, 478, and 787 cubic feet per second, respectively, and were ranked as the 1st, 8th, and 2nd highest streamflows on record.

The mean daily streamflows for water years 1997, 1998, and 1999 and the 25th and 75th percentiles of the historical mean daily streamflows are given in figure 18 for the Red River at Fargo station and in figure 19 for the Sheyenne River at West Fargo station. Generally, the mean daily streamflows for both stations were greater than the 75th percentiles of the historical mean daily streamflows. Therefore, the annual loads computed for this study may not be an accurate reflection of the loads for normal or dry climatic conditions. For example, those parts of the basin that had the largest loads of some constituents during 1997-99 may not necessarily have the largest loads during normal climatic conditions because the relative contribution of point sources and ground-water sources in relation to the contribution of nonpoint sources would be greater during normal climatic conditions than during the climatic conditions for 1997-99.

The annual streamflows and yields (streamflows divided by drainage areas) for each subbasin for water years 1998 and 1999 are given in table 3. Site 1 and reach R5 had the largest yields for those years, and site 2 and site 9 had the smallest yields. Reach R1 had a negative yield because of permitted water withdrawals from the Red River and natural channel losses or errors in streamflow values, and reach R4 had a negative yield because of water withdrawals for Fargo and Moor-

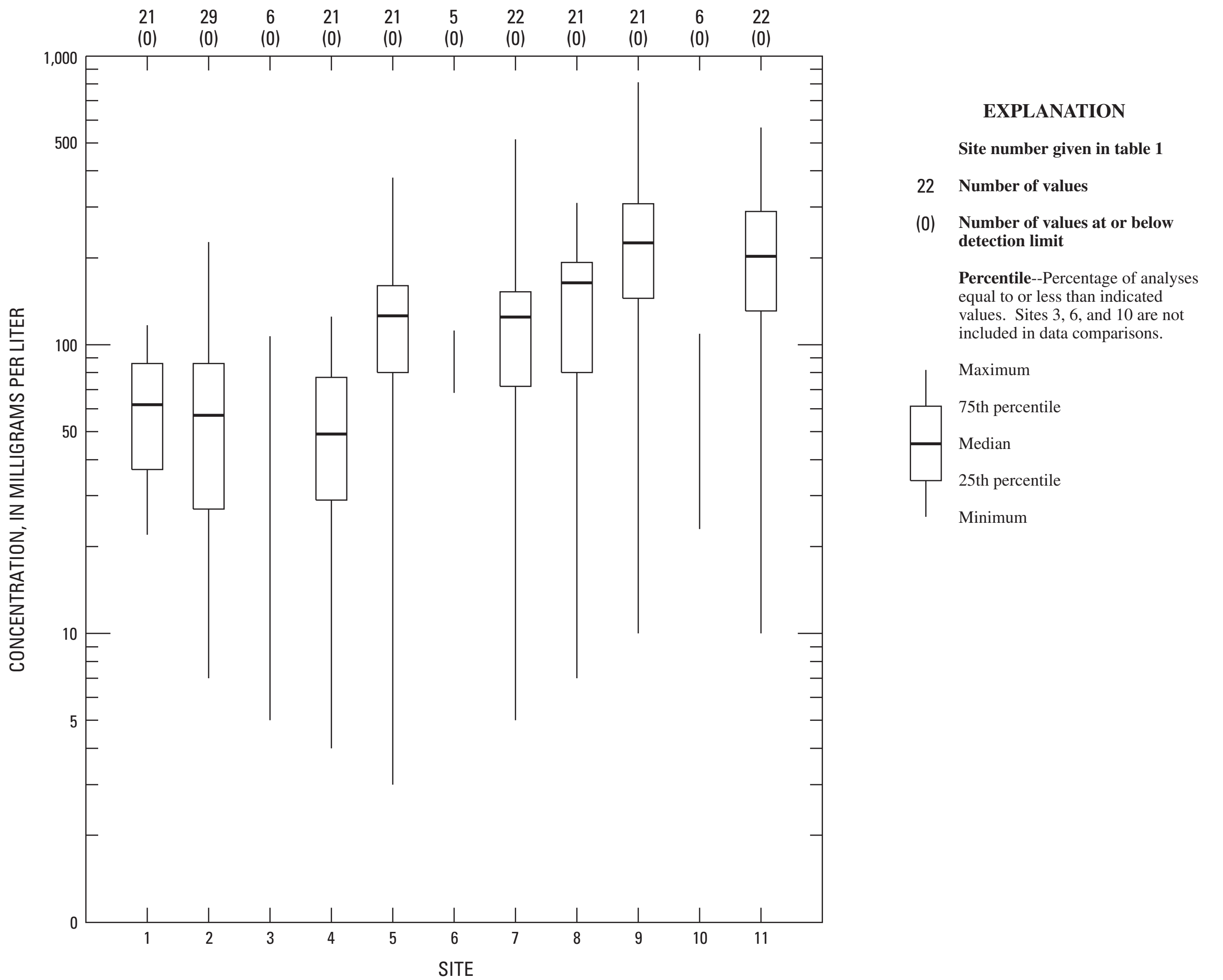

Figure 16. Distribution of suspended sediment in the upper Red River of the North Basin during May 1994 through September 1999. [Because of the small number of samples collected during the sampling period, all data given in the U.S. Geological Survey National Water Information System database for 1994-99 were used.]

head public water supplies and natural channel losses or errors in streamflow values.

The streamflows given in table 3 for reaches R1, R2, and R4 are estimates that were obtained by subtracting a large upstream value from a large downstream value. For example, the 1998 streamflow (1,300,000 acre-feet) for site 7 was subtracted from the 1998 streamflow (1,260,000 acre-feet) for site 8 to obtain the 1998 streamflow (-40,000 acre-feet) for reach R4. If the actual streamflow for site 8 for 1998 was 2 percent greater than the reported streamflow (1,285,000 acre-feet instead of 1,260,000 acre-feet) and the actual streamflow for site 7 was 2 percent less than the reported streamflow (1,274,000 acre-feet instead of 1,300,000 acre-feet), the estimated streamflow for reach R4 would be 11,000 acre-feet rather than -40,000 acre-feet. Therefore, because the estimated streamflows for reaches R1, R2, and R4 may be highly uncertain, flow-weighted average concentrations (defined later) for those reaches were not computed.

The results of the regression analysis for historical constituent concentrations and daily loads are given in table 1–1 in appendix 1, and the estimated annual loads for water years 1998 and 1999 are given in tables 1–2 through 1–9 in appendix 1. Estimator was used to compute the unbiased estimates of annual loads for each constituent and each primary water-quality sampling site and to compute the degree of uncertainty associated with each estimated annual load. The estimated annual loads for the upstream primary sites then were subtracted from the esti-

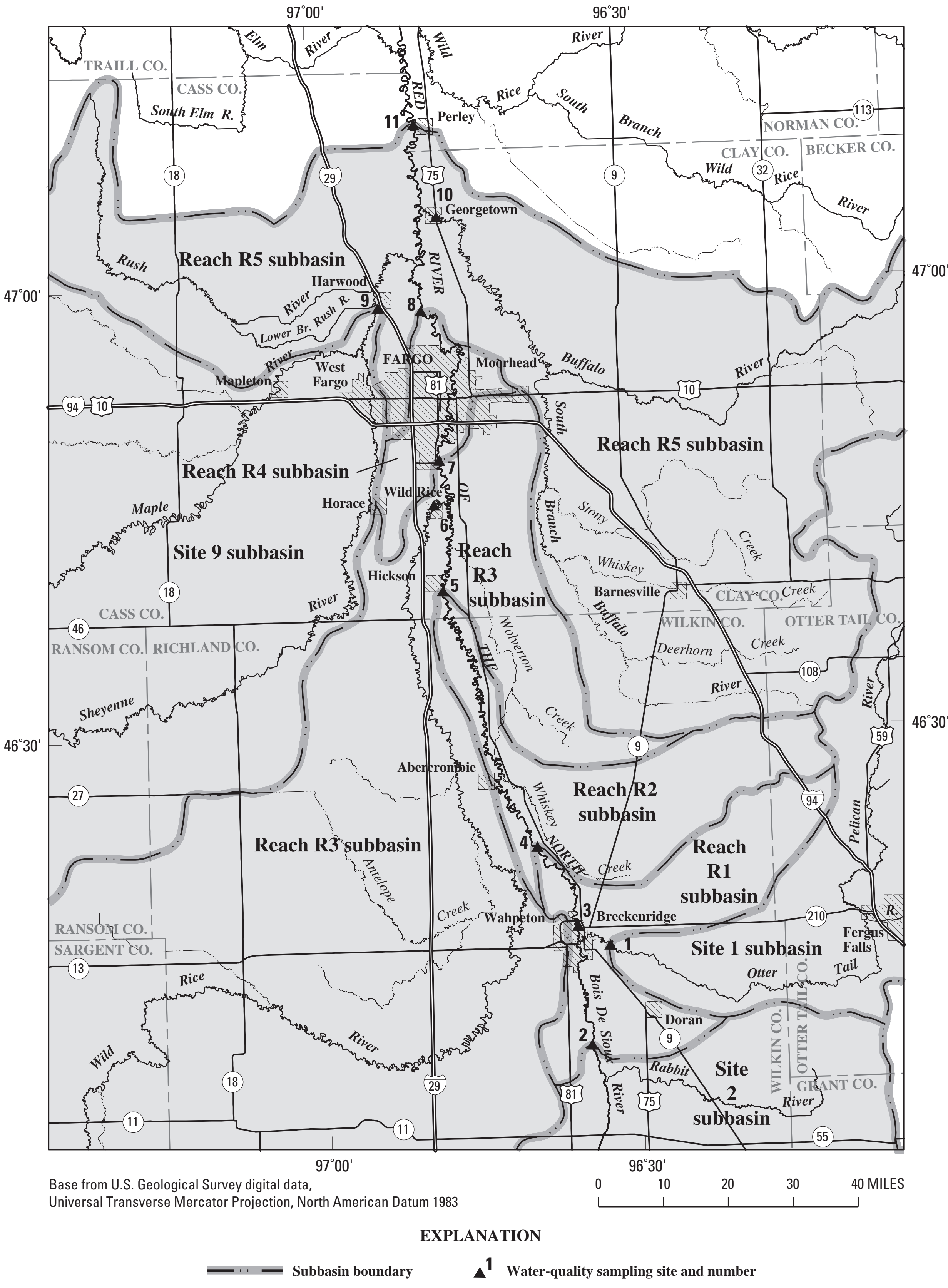

Figure 17. Disjoint subbasins used to compute estimated annual loads.

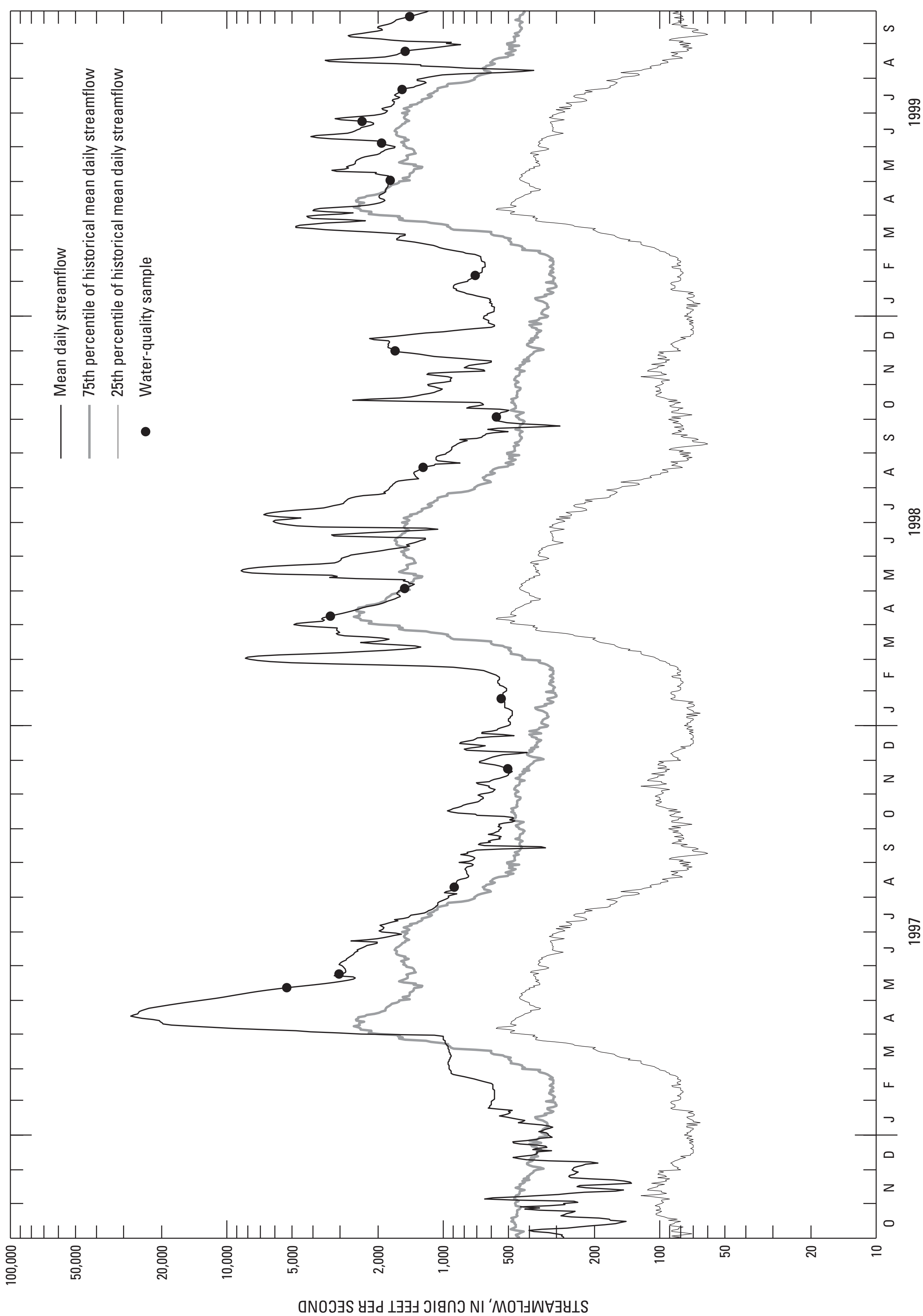

Figure 18. Mean daily streamflow for the Red River of the North at Fargo, North Dakota, streamflow-gaging station for water years 1997, 1998, and 1999.

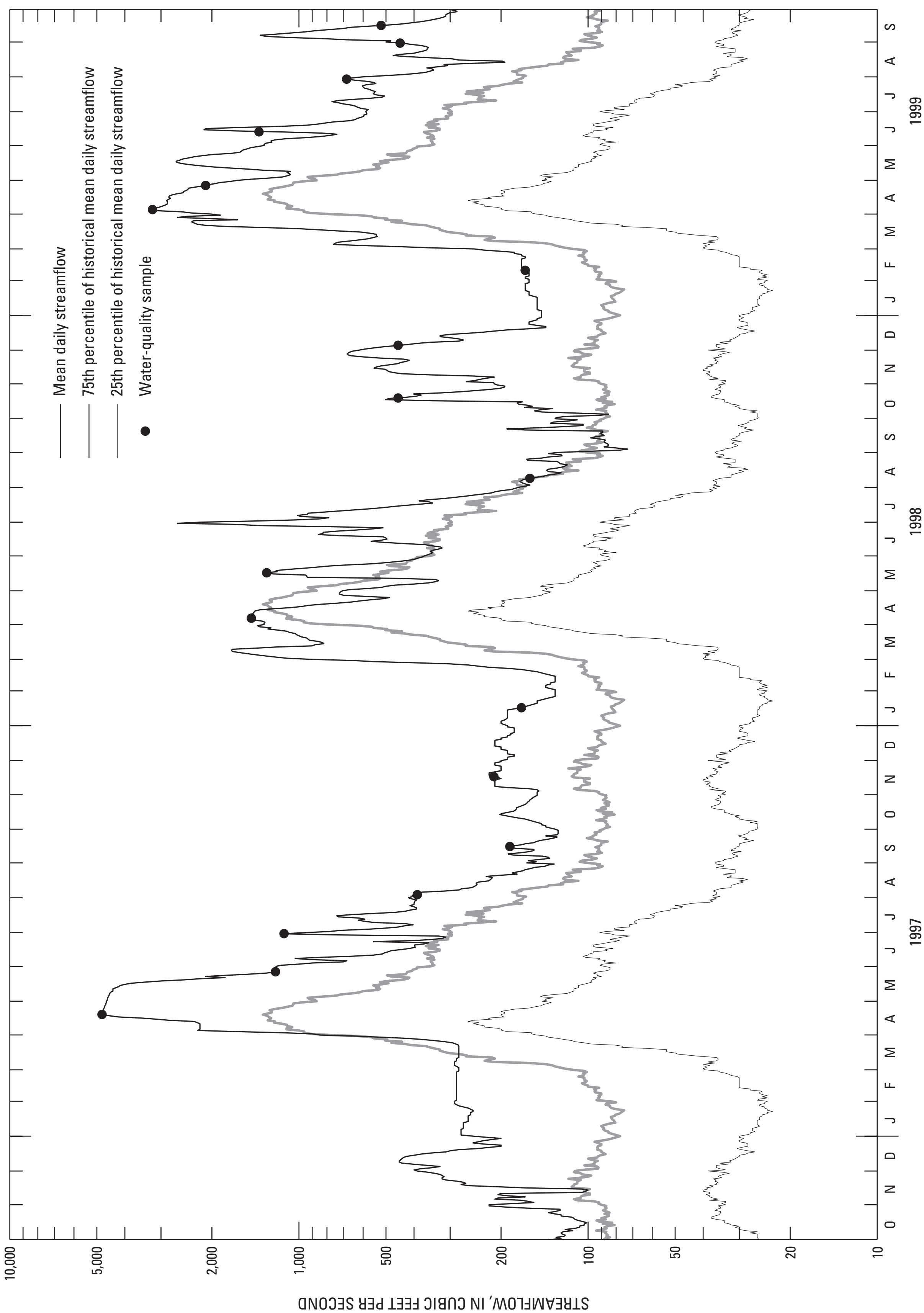

Figure 19. Mean daily streamflow for the Sheyenne River at West Fargo, North Dakota, streamflow-gaging station for water years 1997, 1998, and 1999.

Table 3. Annual streamflows and yields in the upper Red River of the North Basin for water years 1998 and 1999.

[--, indicates negative yield]

Site number or intervening reach designation (see figure 17)	Site name and reach description	Water year	Streamflow (acre-feet)	Approximate contributing drainage area (square miles)	Yield (inches)
1	Otter Tail River above Breckenridge, Minn.	1998	545,000	1,970	5.2
		1999	661,000		6.3
2	Bois de Sioux River near Doran, Minn.	1998	147,000	1,880	1.5
		1999	165,000		1.6
R1	Intervening reach downstream from the Otter Tail River above Breckenridge, Minn., and the Bois de Sioux River near Doran, Minn., and upstream from the Red River of the North below Wahpeton, N. Dak.	1998	-26,000	150	--
		1999	-23,000		--
4	Red River of the North below Wahpeton, N. Dak.	1998	666,000	4,000	3.1
		1999	803,000		3.8
R2	Intervening reach downstream from the Red River of the North below Wahpeton, N. Dak., and upstream from the Red River of the North at Hickson, N. Dak.	1998	92,000	300	5.8
		1999	24,000		1.5
5	Red River of the North at Hickson, N. Dak.	1998	758,000	4,300	3.3
		1999	827,000		3.6
R3	Intervening reach downstream from the Red River of the North at Hickson, N. Dak., and upstream from the Red River of the North above Fargo, N. Dak. (includes the Wild Rice River)	1998	542,000	2,500	4.1
		1999	313,000		2.3
7	Red River of the North above Fargo, N. Dak.	1998	1,300,000	6,800	3.4
		1999	1,140,000		3.1
R4	Intervening reach downstream from the Red River of the North above Fargo, N. Dak., and upstream from the Red River of the North near Harwood, N. Dak.	1998	-40,000	180	--
		1999	-40,000		--
8	Red River of the North near Harwood, N. Dak.	1998	1,260,000	6,980	3.4
		1999	1,100,000		3.0
9	Sheyenne River at Harwood, N. Dak.	1998	571,000	6,980	1.5
		1999	936,000		2.5
R5	Intervening reach downstream from the Red River of the North near Harwood, N. Dak., and the Sheyenne River at Harwood, N. Dak., and upstream from the Red River of the North at Perley, Minn. (includes the Buffalo and Rush Rivers)	1998	403,000	1,140	6.6
		1999	280,000		4.6
11	Red River of the North at Perley, Minn.	1998	2,230,000	15,100	2.8
		1999	2,320,000		2.9

mated annual loads for the downstream primary sites to compute the estimated annual loads for the intervening reaches.

The degree of uncertainty in the estimated annual loads depends on the variability of the concentration data, the number of samples collected, and the ability of the multiple regression model to explain the variability of the concentration data given daily streamflow and seasonality. As indicated in tables 1–2 through 1–9, the estimated annual loads for some constituent-site combinations are highly uncertain. For example, the estimation error (the difference between the estimated and actual annual loads) for total nitrite plus nitrate and ammonia may have exceeded 100 percent of the estimated annual load at most sites. The estimated annual loads for the intervening reaches are even more uncertain than the estimated annual loads for the primary sites because estimation errors for both the upstream and downstream primary sites contributed to the estimation errors for the intervening reaches. Therefore, to reduce uncertainty in the estimated annual loads, the loads for 1998 and 1999 were combined to obtain an estimated average annual load for 1998-99. The estimated average annual loads rather than the loads for the individual water years are given in tables 1–2 through 1–9 and discussed in this section.

Uncertainty is quantified in terms of the upper and lower 90-percent confidence limits for the actual annual load. The confidence limits were computed as described in appendix 1 and were interpreted using equation 1,

$$\mathrm{Prob}[L \leq \hat{L}_u] = 0.90;\ \mathrm{Prob}[L \geq \hat{L}_l] = 0.90, \tag{1}$$

where

Prob denotes probability;

L is the actual annual load, in tons per year;

$\hat{L}_u$ is the upper 90-percent confidence limit; and

$\hat{L}_l$ is the lower 90-percent confidence limit.

The upper confidence limit is useful for determining which subbasins may have contributed a large load to the Red River although the estimated annual load for the subbasin may be small. For example, if the estimated annual load of a particular constituent is 10 tons per year but the upper confidence limit is 100 tons per year, the actual annual load may be much larger than the estimated annual load. The upper confidence limit also is useful for determining which subbasins probably did not contribute a large load. For example, if the estimated annual load is 10 tons per year and the upper confidence limit is 12 tons per year, the chance that the actual annual load is less than 12 tons per year is 90 percent. In both examples, the estimated annual load is 10 tons per year but the upper confidence limit provides more information on how large the actual annual load may be.

The lower confidence limit is useful for determining which subbasins probably contributed a large load to the Red River. For example, if the estimated annual load is 100 tons per year and the lower confidence limit is 90 tons per year, the actual annual load probably is large. However, if the estimated annual load is 100 tons per year but the lower confidence limit is 10 tons per year, the actual annual load may be small. Because the confidence limits for the primary sites could not be used to directly compute confidence limits for the intervening reaches, the confidence limits for the reaches were computed as described in appendix 1.

Basins that have large loads do not necessarily have poor water quality (as indicated by large constituent concentrations). Given two basins that have similar loads but different streamflows, the basin that has the higher streamflows will have more dilution and, therefore, smaller constituent concentrations than the basin that has the lower streamflows. Therefore, to compare the relative water quality of different subbasins, an estimated FWA concentration was computed by dividing the estimated average annual load for the subbasin by the average annual streamflow and then multiplying the quotient by an appropriate conversion factor. The estimated FWA concentration was computed using equation 2,

$$\hat{C} = \left(\frac{\hat{L}}{Q}\right)735.3, \tag{2}$$

where

$\hat{C}$ is the estimated FWA concentration, in milligrams per liter;

$\hat{L}$ is the estimated average annual load, in tons per year; and

Q is the average annual streamflow, in acre-feet per year.

The FWA concentration is an overall measure of water quality in a basin and is a weighted average of daily concentrations in which the weight assigned to a given day is proportional to daily streamflow. If streamflow was constant day after day, the FWA concentration would equal the average annual concentration. However, because streamflow is not constant, the FWA concentration may not equal the average annual concentration. If concentrations tend to be larger during high flow than during low flow, the FWA concentration will be larger than the average annual concentration. If concentrations tend to be smaller during high flow than during low flow, the FWA concentration will be smaller than the average annual concentration.

Estimated annual loads and FWA concentrations for dissolved solids, nutrients, and suspended sediment are shown in figures 20 through 27 along with the 90-percent upper and lower confidence limits for the constituents. The confidence limits for the annual loads (eq. 1) were computed as described in appendix 1, and the confidence limits for the FWA concentrations were obtained by substituting the confidence limits for the loads in equation 2. Constituent loads for the main-stem

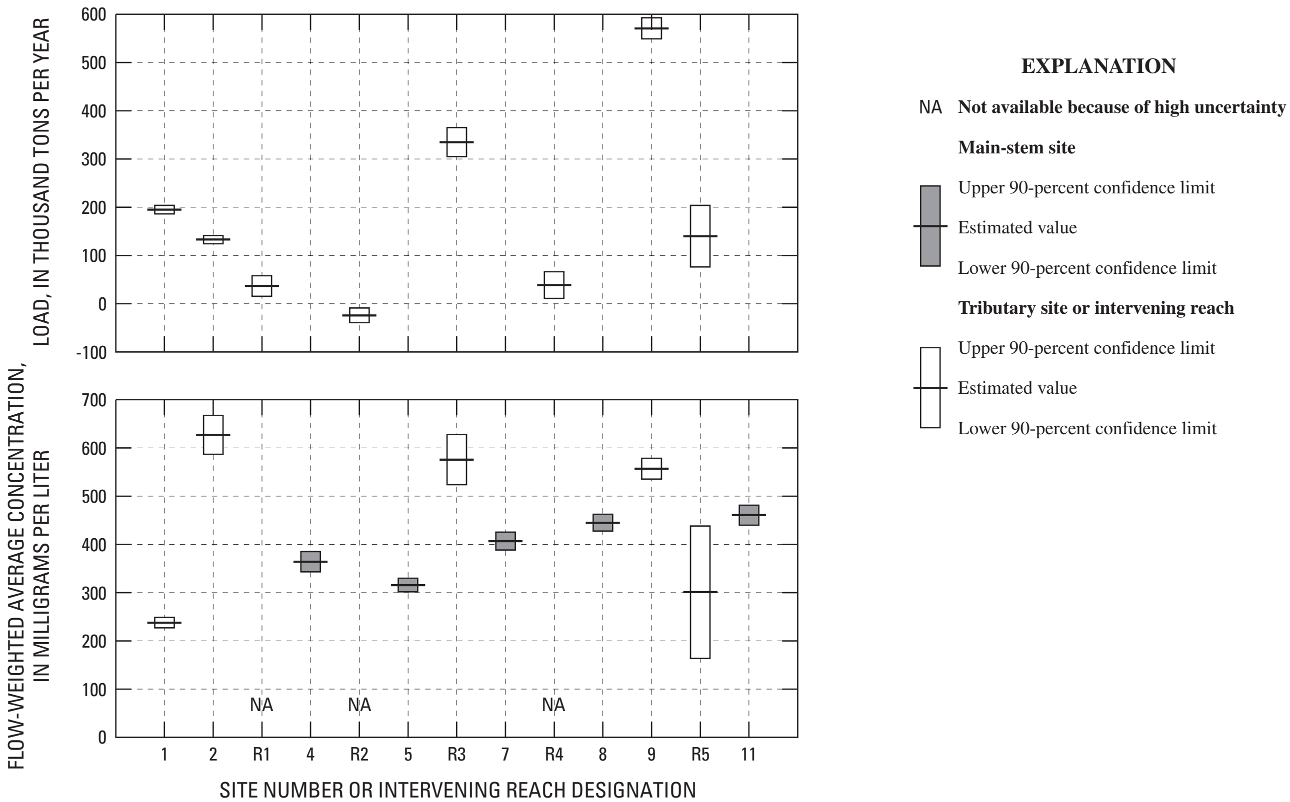

Figure 20. Estimated annual dissolved-solids loads and flow-weighted average concentrations for 1998-99 (loads not shown for main-stem sites).

sites were expected to increase in a downstream direction because the loads for the tributary sites are being accumulated. Therefore, constituent loads for the main-stem sites (sites 4, 5, 7, 8, and 11) are not shown in figures 20 through 27. Also, the FWA concentrations for reaches R1, R2, and R4 were not computed because high uncertainty in streamflows and loads for those reaches made it difficult to interpret the FWA concentrations.

Dissolved Solids

Among the tributary sites and intervening reaches, site 9 (the Sheyenne River at Harwood, N. Dak.) had the largest estimated annual dissolved-solids load (about 570,000 tons per year) (fig. 20). The load for site 9 was followed by the load (about 340,000 tons per year) for reach R3. Site 1 (the Otter Tail River above Breckenridge, Minn.), site 2 (the Bois de Sioux River near Doran, Minn.), and reach R5 also had substantial loads (between about 100,000 and 200,000 tons per year).

The largest estimated FWA concentration for dissolved solids (about 630 milligrams per liter) for the tributary sites and intervening reaches was for site 2 (fig. 20). The concentration for that site was followed by the concentration (about 580 milligrams per liter) for reach R3 and the concentration (about 560 milligrams per liter) for site 9. Site 1 had the smallest concentration (about 240 milligrams per liter). The estimated concentration for reach R5 was highly uncertain; confidence limits for that reach ranged from about 170 to 440 milligrams per liter. Although the concentrations for reaches R1 and R4 were not computed, the yields (loads per acre of drainage area) for those reaches were large compared to the yields for the tributary sites. The estimated load for reach R1 was about 30 percent of the estimated load for site 2, but the drainage area for reach R1 is only about 8 percent of the drainage area for site 2 (table 3).

The estimated FWA concentrations for dissolved solids for the main-stem sites ranged from about 300 to 500 milligrams per liter and generally increased in a downstream direction (fig. 20). Most of the increase resulted from the large concentrations for sites 2 and 9. The concentration increased substantially between site 5 (the Red River at Hickson, N. Dak.) and site 7 (the Red River above Fargo, N. Dak.) as a result of flow from reach R3 and also increased between site 7 and site 8 (the Red River near Harwood, N. Dak.). The increase in concentration between site 7 and site 8 resulted from a decrease in flow in reach R4 (table 3) and the large yield of dissolved solids from that reach. The concentration remained relatively constant from site 8 to site 11 (the Red River at Perley, Minn.) because the

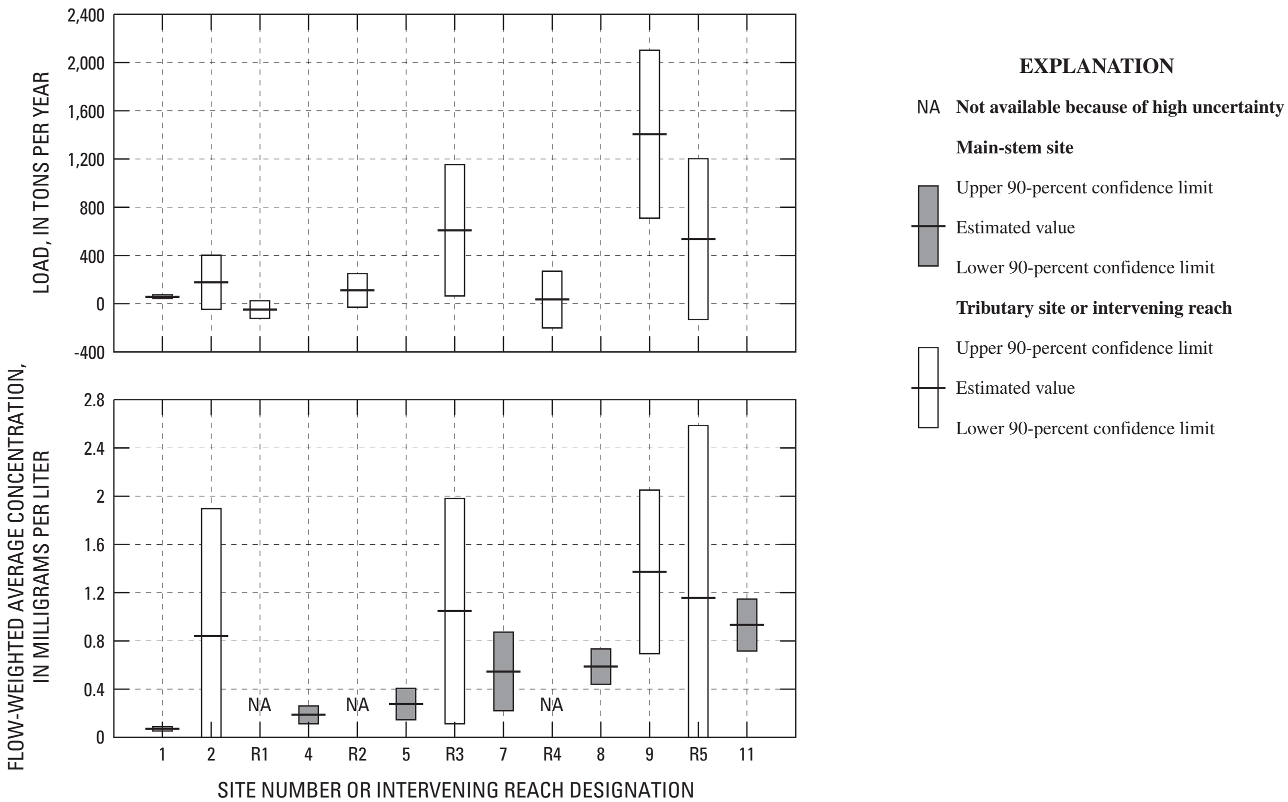

Figure 21. Estimated annual total nitrite plus nitrate loads and flow-weighted average concentrations for 1998-99 (loads not shown for main-stem sites).

large concentration for site 9 was offset by the small concentration for reach R5.

Nutrients

Nitrogen

Total Nitrite Plus Nitrate

The estimated annual total nitrite plus nitrate loads for the tributary sites and intervening reaches were highly uncertain (fig. 21). Among the tributary sites and intervening reaches, site 9 (the Sheyenne River at Harwood, N. Dak.) had the largest estimated load (about 1,400 tons per year). However, the confidence limits for that site ranged from less than 800 to more than 2,000 tons per year. The estimated load for site 9 was followed by the estimated loads (more than 500 tons per year) for reaches R3 and R5. However, the confidence limits for those reaches ranged from near zero to about 1,200 tons per year. Estimated loads for the remaining tributary sites and intervening reaches were less than 200 tons per year, and the upper confidence limits were less than 400 tons per year. The estimate (about 60 tons per year) for site 1 (the Otter Tail River above Breckenridge, Minn.) was the most precise estimate; confidence limits for that site ranged from about 40 to 80 tons per year.

The estimated FWA concentrations for total nitrite plus nitrate for the tributary sites and intervening reaches also were highly uncertain (fig. 21). Site 2 (the Bois de Sioux River near Doran, Minn.), reach R3, site 9, and reach R5 had the largest estimated concentrations (between about 0.8 and 1.4 milligrams per liter), and the upper confidence limits for those sites and reaches were greater than 1.9 milligrams per liter. However, the lower confidence limits for site 2, reach R3, and reach R5 indicated the actual FWA concentrations for that site and those reaches may be small (less than 0.2 milligram per liter). Site 1 had the smallest, and most precise, estimated FWA concentration (about 0.07 milligram per liter). Although the concentrations for reaches R2 and R4 were not computed, the yields for those reaches may have been large compared to the yields for the tributary sites; the upper confidence limits for the estimated loads for both reaches were greater than 200 tons per year. Therefore, a significant localized source of nitrate may exist in those reaches.

The estimated FWA concentrations for total nitrite plus nitrate for the main-stem sites increased from about 0.2 milli-

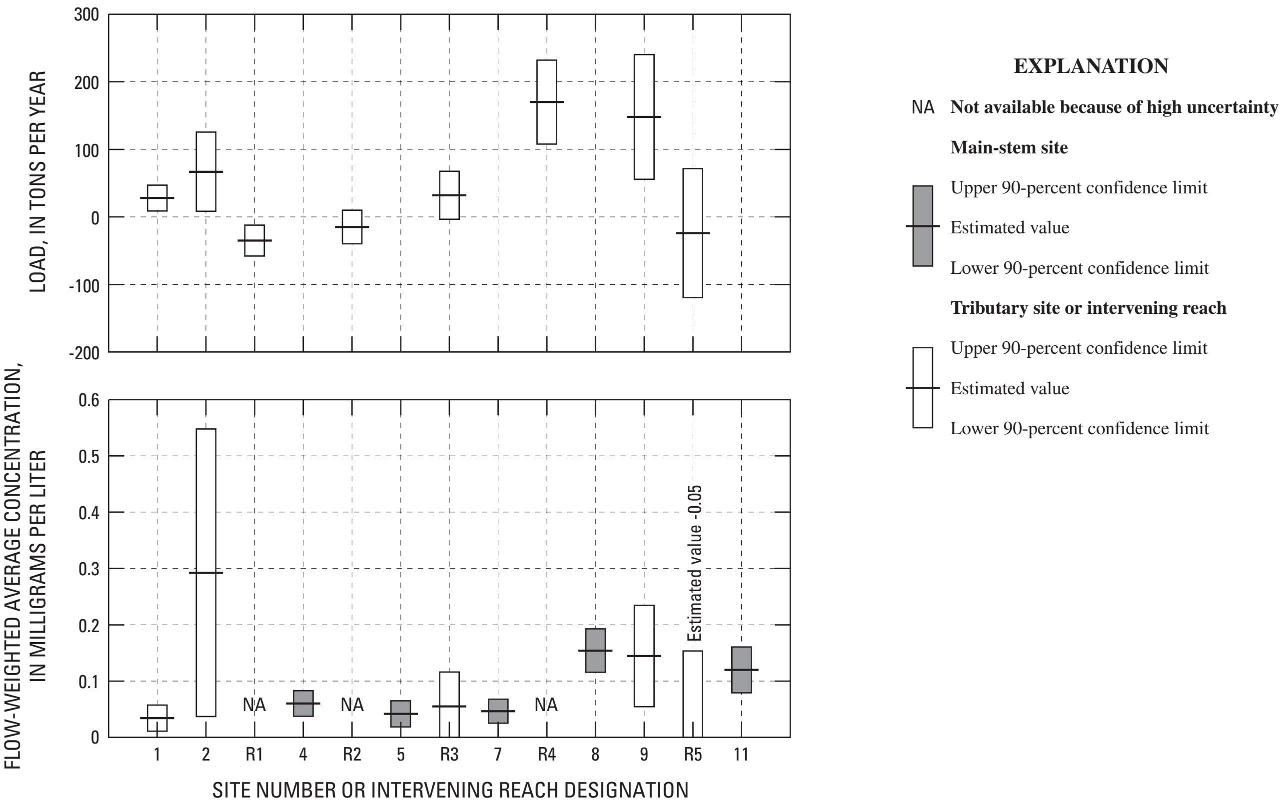

Figure 22. Estimated annual total ammonia loads and flow-weighted average concentrations for 1998-99 (loads not shown for main-stem sites).

gram per liter for site 4 (the Red River below Wahpeton, N. Dak.) to about 0.9 milligram per liter for site 11 (the Red River at Perley, Minn.) (fig. 21). Much of the increase probably resulted from flows from the tributary sites and intervening reaches, excluding site 1. However, uncertainty in the estimated concentrations prevented any reliable conclusions regarding which sites or reaches contributed most to the increase.

Total Ammonia

Among the tributary sites and intervening reaches, reach R4 had the largest estimated annual total ammonia load (about 170 tons per year) (fig. 22). The large load for reach R4, despite the small drainage area, probably resulted from wastewater discharges from urban areas. Site 9 (the Sheyenne River at Harwood, N. Dak.) had a large estimated load of about 150 tons per year. However, the confidence limits for that site ranged from about 50 to 250 tons per year. The upper confidence limit of about 120 tons per year for site 2 (the Bois de Sioux River near Doran, Minn.) indicated that site also may have had a large load. The estimated loads for reaches R1, R2, and R5 were negative, possibly indicating that ammonia was being converted to nitrate in those reaches.

The estimated FWA concentrations for total ammonia for the tributary sites and intervening reaches were highly uncertain (fig. 22). Site 2 had the largest estimated concentration (about 0.3 milligram per liter), but the confidence limits for that site ranged from about 0.04 to 0.55 milligram per liter. Site 9 had the next largest estimated concentration (about 0.15 milligram per liter), and the confidence limits for that site ranged from about 0.05 to 0.23 milligram per liter. The upper confidence limits for reaches R3 and R5 were greater than 0.1 milligram per liter, indicating those reaches may have had large concentrations. However, the lower confidence limits for both reaches were negative. Although the concentration for reach R4 was not computed, the yield for that reach was much larger than the yields for the tributary sites or the remaining intervening reaches.

The estimated FWA concentrations for total ammonia for the main-stem sites increased from about 0.05 milligram per liter for site 7 (the Red River above Fargo, N. Dak.) to about 0.15 milligram per liter for site 8 (the Red River near Harwood, N. Dak.) (fig. 22). The threefold increase from site 7 to site 8 resulted from a decrease in flows in reach R4 and the large load for that reach. The concentration decreased between site 8 and site 11 (the Red River at Perley, Minn.), possibly because of the

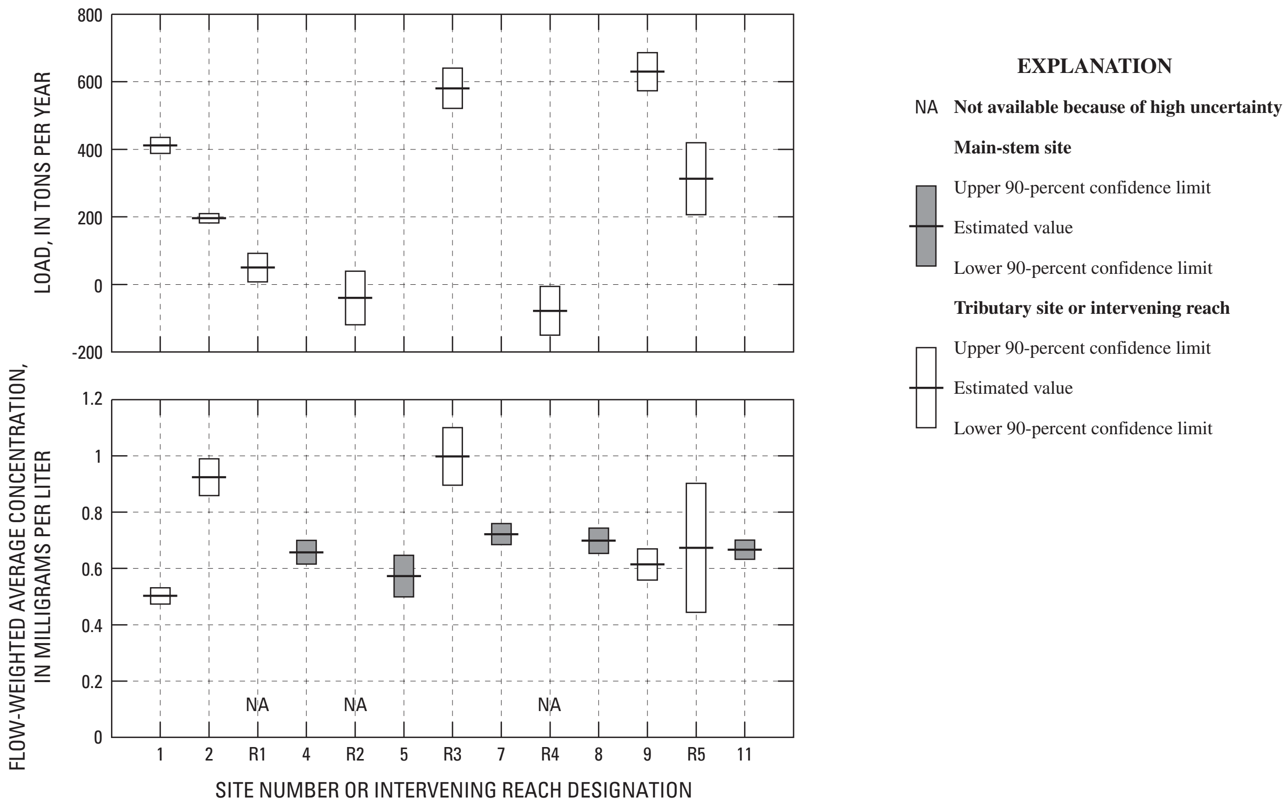

Figure 23. Estimated annual total organic nitrogen loads and flow-weighted average concentrations for 1998-99 (loads not shown for main-stem sites).

small concentration for reach R5 or because ammonia was being converted to nitrate in that reach.

Total Organic Nitrogen

Among the tributary sites and intervening reaches, reach R3 and site 9 (the Sheyenne River at Harwood, N. Dak.) had the largest estimated annual total organic nitrogen loads (about 600 tons per year) (fig. 23). Site 1 (the Otter Tail River above Breckenridge, Minn.), site 2 (the Bois de Sioux River near Doran, Minn.), and reach R5 also had substantial loads (between about 200 and 400 tons per year). Reach R1 had a load of about 50 tons per year despite its small drainage area. Reaches R2 and R4 had negative estimated loads, possibly indicating organic nitrogen was being converted to nitrate in those reaches.

The largest estimated FWA concentration for total organic nitrogen (about 1 milligram per liter) for the tributary sites and intervening reaches was for reach R3 (fig. 23). The concentration for that reach was followed by the concentration (about 0.9 milligram per liter) for site 2. The concentrations for sites 1 and 9 (about 0.5 and 0.6 milligram per liter, respectively) were relatively small despite the large loads for those sites. The estimated concentration for reach R5 was the most uncertain; confidence limits for that reach ranged from about 0.45 to 0.9 milligram per liter. Although the concentration for reach R1 was not computed, the yield for that reach may have been large compared to the yields for the tributary sites. Therefore, a significant localized source of organic nitrogen may exist in that reach.

The estimated FWA concentrations for total organic nitrogen for the main-stem sites were relatively constant and ranged from about 0.5 to 0.7 milligram per liter (fig. 23). The relatively constant concentrations were in sharp contrast to the total nitrite plus nitrate concentrations (fig. 21), which increased about fivefold between site 4 (the Red River below Wahpeton, N. Dak.) and site 11 (the Red River at Perley, Minn.). The concentration for total organic nitrogen increased between site 5 (the Red River at Hickson, N. Dak.) and site 7 (the Red River above Fargo, N. Dak.) as a result of flow from reach R3. However, the concentration decreased slightly from site 7 to site 11.

Total Nitrogen

Among the tributary sites and intervening reaches, site 9 (the Sheyenne River at Harwood, N. Dak.) had the largest estimated annual total nitrogen load (about 1,600 tons per year) (fig. 24). The load for site 9 was followed by the load (about

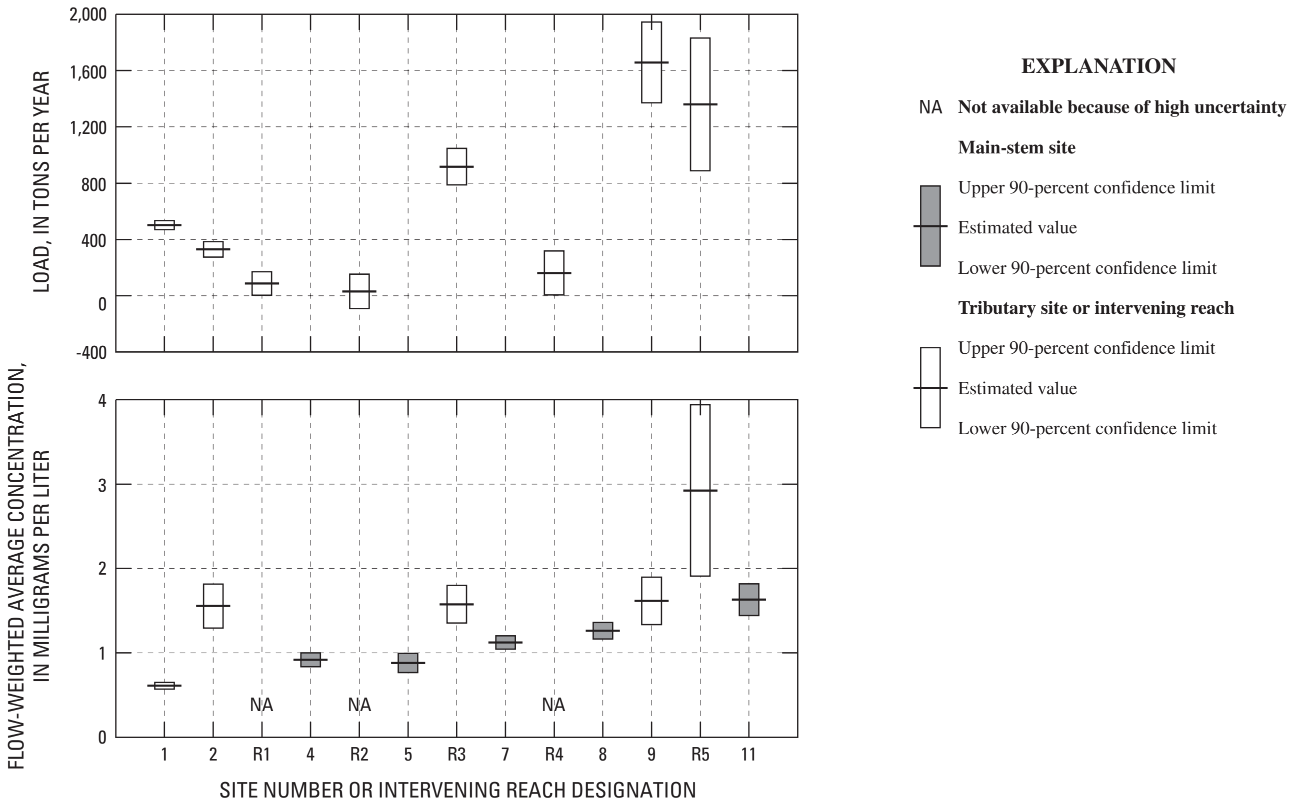

Figure 24. Estimated annual total nitrogen loads and flow-weighted average concentrations for 1998-99 (loads not shown for main-stem sites).

1,400 tons per year) for reach R5 and the load (about 900 tons per year) for reach R3. Site 1 (the Otter Tail River above Breckenridge, Minn.) and site 2 (the Bois de Sioux River near Doran, Minn.) had loads of about 500 and 300 tons per year, respectively. Reaches R1, R2, and R4 may have had substantial loads despite the small drainage areas for those reaches. For example, the upper confidence limit of about 300 tons per year for reach R4 was comparable to the estimated load for site 2.

The largest estimated FWA concentration for total nitrogen (about 2.9 milligrams per liter) was for reach R5 (fig. 24). The lower confidence limit for that reach was about 2 milligrams per liter. The estimated concentrations for site 2, reach R3, and site 9 were similar; confidence limits for those sites and that reach ranged from about 1.3 to 1.8 milligrams per liter. Site 1 had the smallest concentration (about 0.6 milligram per liter).

The estimated FWA concentrations for total nitrogen for the main-stem sites increased from about 0.9 milligram per liter for site 5 (the Red River at Hickson, N. Dak.) to about 1.6 milligrams per liter for site 11 (the Red River at Perley, Minn.) (fig. 24). Much of the increase probably resulted from the large concentrations for reach R3, site 9, and reach R5. However, the concentration also increased slightly between site 7 (the Red River above Fargo, N. Dak.) and site 8 (the Red River near Harwood, N. Dak.), indicating a large yield of total nitrogen from reach R4 also may have contributed to the increase between site 5 and site 11.

The actual load for total nitrogen consists of the sum of the actual loads for total nitrite plus nitrate, total ammonia, and total organic nitrogen. Therefore, the results for total nitrogen should be consistent with the results for those constituents. However, the sum of the estimated loads for total nitrite plus nitrate, total ammonia, and total organic nitrogen does not equal the estimated load for total nitrogen. Therefore, uncertainty in the estimated loads must be considered when determining the consistency of the results. Considering uncertainty, most (about 0.8 milligram per liter) of the approximately 1-milligram-per-liter increase in the FWA concentration for total nitrogen (from about 0.6 milligram per liter for site 1 to about 1.6 milligrams per liter for site 11) (fig. 24) probably resulted from large total nitrite plus nitrate concentrations in tributary inflows (inflows from the Bois de Sioux, Wild Rice, Sheyenne, Buffalo, and Rush Rivers) and/or localized sources of nitrate in one or more of reaches R2, R3, R4, and R5 (fig. 21). Part of the increase (about 0.1 milligram per liter) probably resulted from point sources of ammonia in reach R4 (fig. 22), and the remainder of the increase (about 0.1 milligram per liter) probably resulted

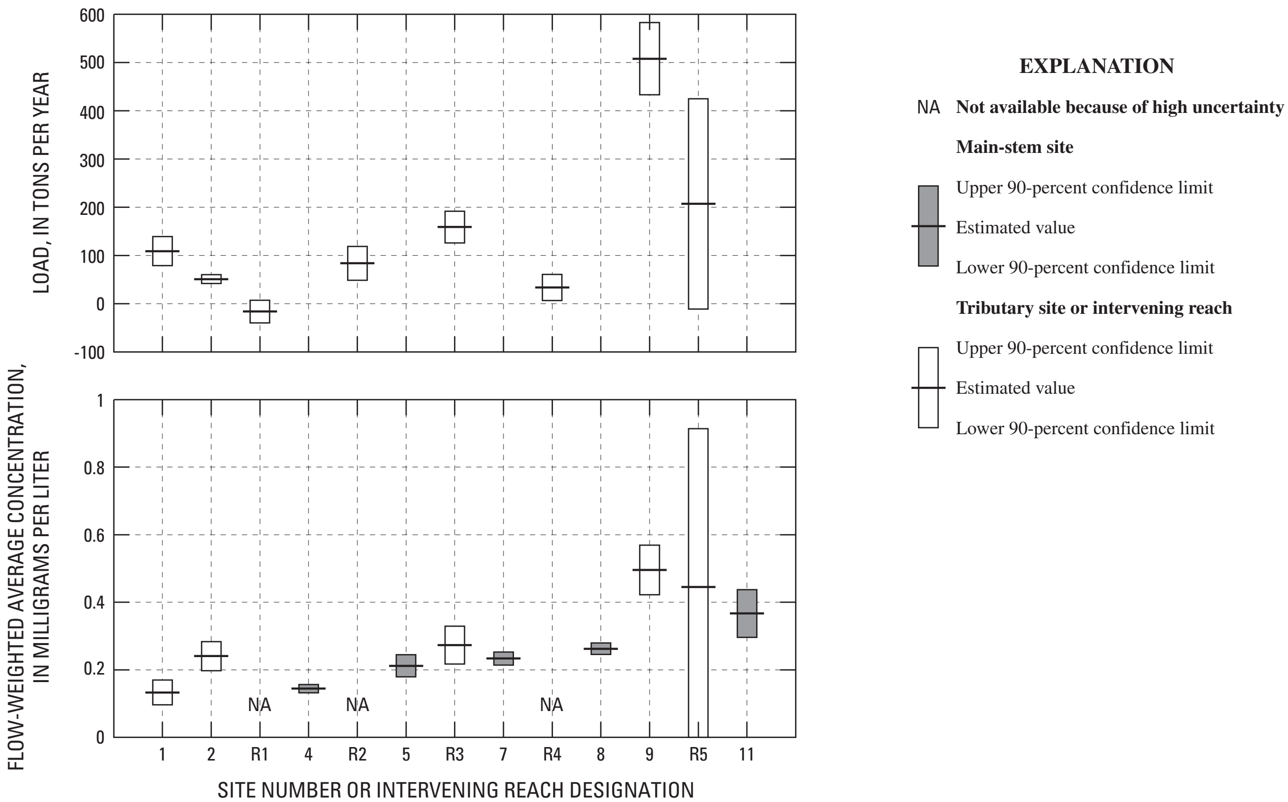

Figure 25. Estimated annual total phosphorus loads and flow-weighted average concentrations for 1998-99 (loads not shown for main-stem sites).

from large organic nitrogen concentrations in tributary inflows (primarily inflows from the Bois de Sioux and Wild Rice Rivers) and/or localized sources of organic nitrogen in reaches R1, R3, and R5 (fig. 23).

Phosphorus

Total Phosphorus

Among the tributary sites and intervening reaches, site 9 (the Sheyenne River at Harwood, N. Dak.) had the largest estimated annual total phosphorus load (about 500 tons per year) (fig. 25). Reach R5 had the next largest estimated load (about 200 tons per year), but the confidence limits for that reach ranged from near zero to more than 400 tons per year. Site 1 (the Otter Tail River above Breckenridge, Minn.), site 2 (the Bois de Sioux River near Doran, Minn.), and reach R3 also had substantial loads (between about 50 and 160 tons per year). Reach R2 had a load of about 80 tons per year, and reach R4 had a load of about 30 tons per year despite the small drainage areas for those reaches. The estimated load for reach R2 was larger than the estimated load for site 2 and comparable to the estimated load for site 1.

The largest estimated FWA concentration for total phosphorus (about 0.5 milligram per liter) for the tributary sites and intervening reaches was for site 9 (fig. 25). The estimated concentration for reach R5 was highly uncertain; confidence limits for that reach ranged from less than zero to about 0.9 milligram per liter. Site 2 and reach R3 had large concentrations of about 0.2 and 0.3 milligram per liter, respectively. Site 1 had the smallest concentration (about 0.1 milligram per liter). Although the concentrations for reaches R2 and R4 were not computed, the yields for those reaches were large compared to the yields for the tributary sites.

The estimated FWA concentrations for total phosphorus for the main-stem sites increased from about 0.15 milligram per liter for site 4 (the Red River below Wahpeton, N. Dak.) to about 0.35 milligram per liter for site 11 (the Red River at Perley, Minn.) (fig. 25). Most of the increase probably resulted from the large yield of total phosphorus from reach R2 [as indicated by the increase in concentration between site 4 and site 5 (the Red River at Hickson, N. Dak.)] and the large concentrations for site 9 and possibly reach R5 [as indicated by the increase in concentration between site 8 (the Red River near Harwood, N. Dak.) and site 11].

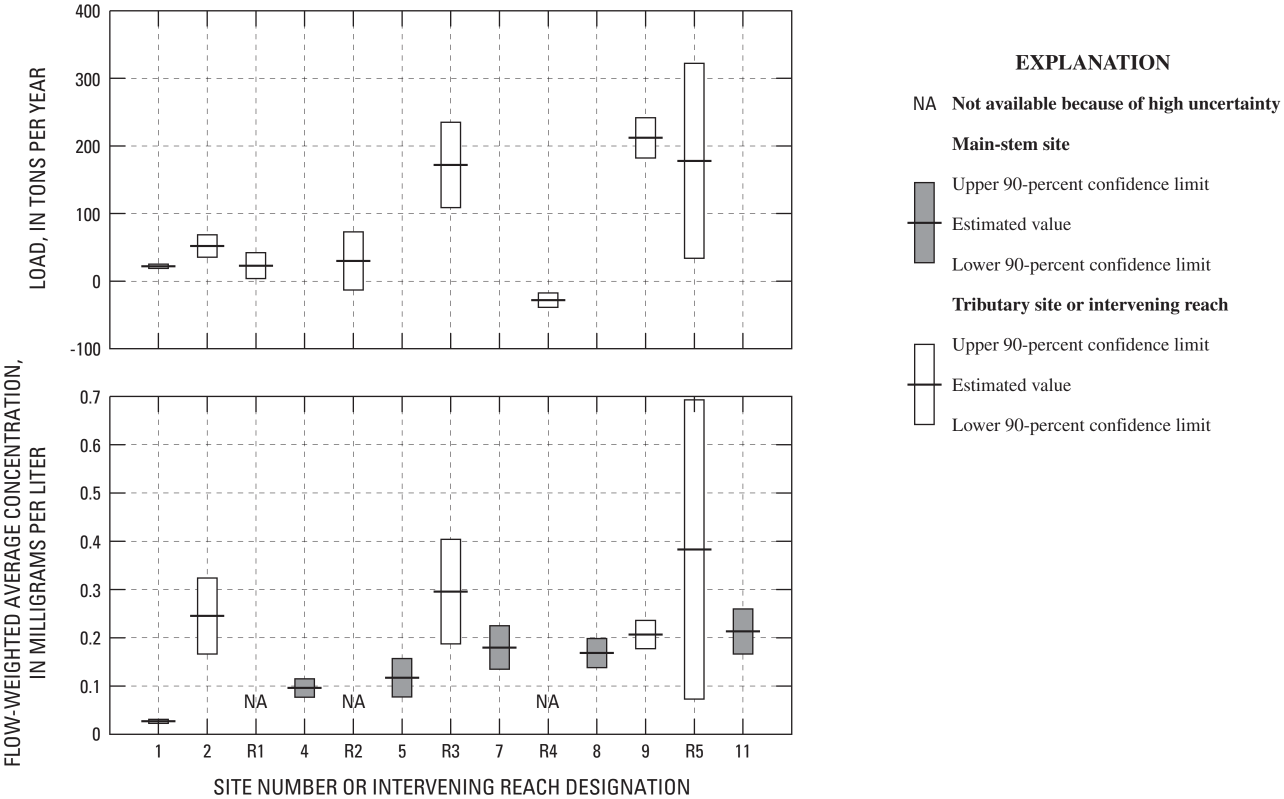

Figure 26. Estimated annual dissolved phosphorus loads and flow-weighted average concentrations for 1998-99 (loads not shown for main-stem sites).

Dissolved Phosphorus

Among the tributary sites and intervening reaches, site 9 (the Sheyenne River at Harwood, N. Dak.) had the largest estimated annual dissolved phosphorus load (about 200 tons per year) (fig. 26). The estimated load for site 9 was followed by the estimated load (about 180 tons per year) for reach R5. However, the confidence limits for reach R5 ranged from about 40 to more than 300 tons per year. The estimated load for reach R3 was about 170 tons per year. Site 1 (the Otter Tail River above Breckenridge, Minn.), site 2 (the Bois de Sioux River near Doran, Minn.), reach R1, and reach R2 also had substantial estimated loads (between about 25 and 50 tons per year). Although the lower confidence limits for reaches R1 and R2 were near zero, the loads for those reaches may have been large despite the small drainage areas.

The largest estimated FWA concentration for dissolved phosphorus (about 0.4 milligram per liter) for the tributary sites and intervening reaches was for reach R5 (fig. 26). However, the confidence limits for that reach ranged from less than 0.1 to about 0.7 milligram per liter. Site 2, reach R3, and site 9 also had large estimated concentrations (between about 0.2 and 0.3 milligram per liter). The lower confidence limits for those sites and that reach were greater than 0.16 milligram per liter. The smallest concentration (about 0.03 milligram per liter) was for site 1. Although the concentrations for reaches R1 and R2 were not computed, the yields for those reaches may have been large compared to the yields for the tributary sites.

The estimated FWA concentrations for dissolved phosphorus for the main-stem sites increased from about 0.1 milligram per liter for site 4 (the Red River below Wahpeton, N. Dak.) to about 0.2 milligram per liter for site 11 (the Red River at Perley, Minn.) (fig. 26). Most of the increase probably resulted from the large concentrations for reach R3, site 9, and possibly reach R5. A large yield from reach R2 also may have contributed to the increase, but uncertainty in the yield for that reach prevented any reliable conclusion. Reach R4 had a negative yield that may have resulted from water withdrawals from the reach or that may indicate dissolved phosphorus became attached to particulate matter and was filtered out of the sample before the dissolved phosphorus concentration was determined.

The total phosphorus load should be greater than the dissolved phosphorus load because the total phosphorus concentration is determined from whole-water samples and the dissolved phosphorus concentration is determined from filtered water samples. However, as indicated previously for total nitrogen, the estimated loads need not satisfy the same constraints as

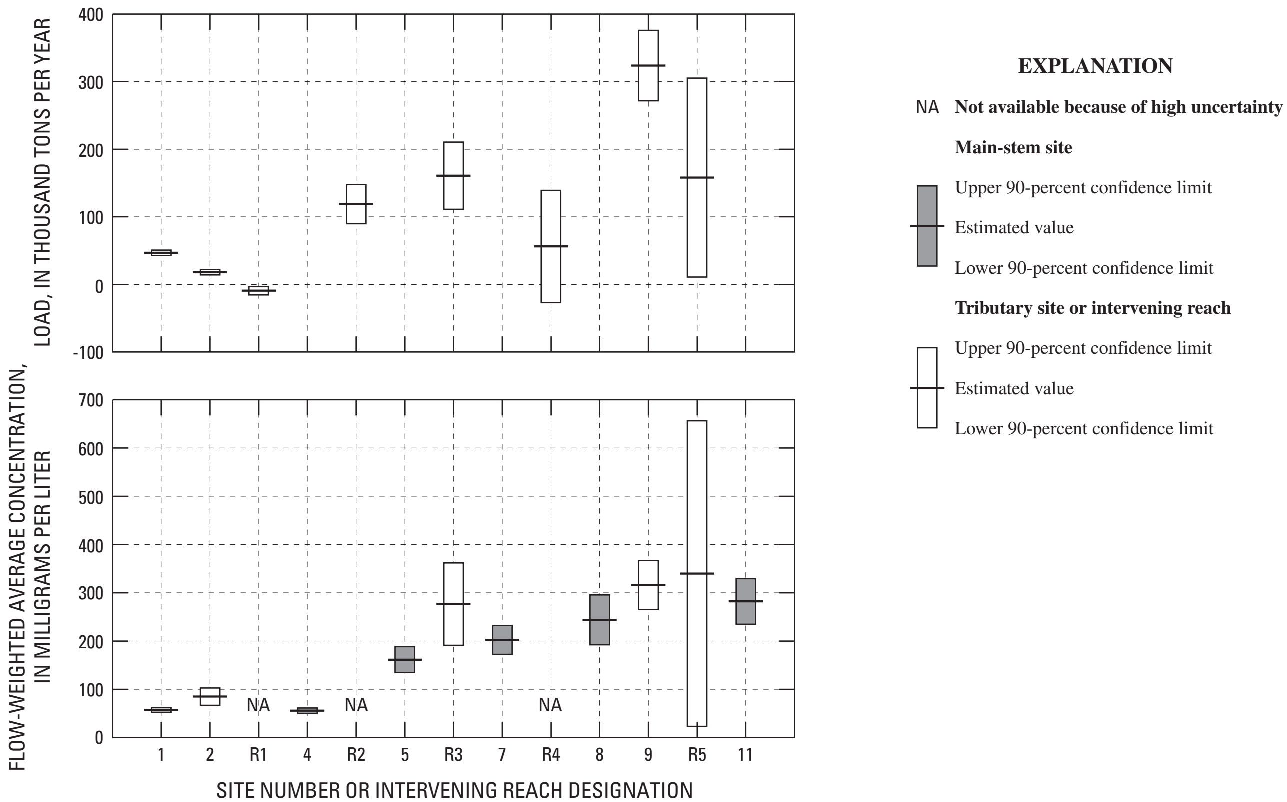

Figure 27. Estimated annual suspended-sediment loads and flow-weighted average concentrations for 1998-99 (loads not shown for main-stem sites).

the actual loads. Considering uncertainty in the estimated loads and comparing the total phosphorus loads (fig. 25) and the dissolved phosphorus loads (fig. 26), most of the total phosphorus load for site 2, reach R3, and reach R5 appears to have been in the dissolved form. However, most of the total phosphorus load for site 1, reach R4, site 9, and possibly reach R2 appears to have been in the particulate form. For reach R1, the estimated total phosphorus load was negative but the estimated dissolved phosphorus load was positive. Therefore, the results for that reach are anomalous. The apparent anomaly may reflect uncertainty because the actual loads for reach R1 were small. For reach R4, the negative estimated dissolved phosphorus load and the positive estimated total phosphorus load may indicate a large yield of phosphorus-bearing particulate matter or suspended sediment occurred in this reach and, in turn, adsorbed some of the dissolved phosphorus.

For the tributary sites and intervening reaches, the ratio of the dissolved phosphorus load to the total phosphorus load (and, therefore, the corresponding ratio of the FWA concentrations) varied considerably. Moreover, phosphorus may have been changing back and forth between the dissolved and particulate forms. For the main-stem sites, the estimated FWA concentration for dissolved phosphorus, as a percentage of the estimated FWA concentration for total phosphorus, was relatively constant at about 65 percent (the concentrations ranged from about 60 to 70 percent). Although the relatively constant ratio between dissolved and total phosphorus concentrations for the main-stem sites may have been coincidental, it also may indicate that the ratio of dissolved to total phosphorus in the main stem reached an equilibrium value of about 65 percent.

Suspended Sediment

Among the tributary sites and intervening reaches, site 9 (the Sheyenne River at Harwood, N. Dak.) had the largest estimated annual suspended-sediment load (about 320,000 tons per year) (fig. 27). Reach R3 had a large estimated load of about 160,000 tons per year, and the confidence limits for that reach ranged from about 100,000 to 200,000 tons per year. Reach R5 also had a large estimated load of about 160,000 tons per year, but the confidence limits for that reach ranged from near zero to about 300,000 tons per year. Reach R2 had a large load despite its small drainage area; the lower confidence limit of about 90,000 tons per year for that reach was larger than the estimated load for either site 1 (the Otter Tail River above Breckenridge, Minn.) or site 2 (the Bois de Sioux River near Doran, Minn.). Reach R4 had a large estimated load of about 60,000 tons per year despite its small drainage area, but the estimate for that reach was highly uncertain.

The largest estimated FWA concentration for suspended sediment (about 340 milligrams per liter) for the tributary sites and intervening reaches was for reach R5 (fig. 27). Reach R3 and site 9 had large estimated concentrations of about 280 and 320 milligrams per liter, respectively. The estimated concentration for reach R5 was highly uncertain; confidence limits for that reach ranged from about 20 to 650 milligrams per liter. Sites 1 and 2 had small concentrations (less than 100 milligrams per liter). Although the concentration for reach R2 was not computed, the yield for that reach was much larger than the yields for the tributary sites. Therefore, a significant localized source of suspended sediment probably exists in reach R2. Similarly, the yield for reach R4 may have been much larger than the yields for the tributary sites.

The estimated FWA concentrations for suspended sediment for the main-stem sites increased from about 50 milligrams per liter for site 4 (the Red River below Wahpeton, N. Dak.) to about 300 milligrams per liter for site 11 (the Red River at Perley, Minn.) (fig. 27). Much of the increase occurred between site 4 and site 5 (the Red River at Hickson, N. Dak.) as a result of the large yield of suspended sediment from reach R2. The concentration between sites 4 and 5 increased from about 50 milligrams per liter for site 4 to about 160 milligrams per liter for site 5. The concentrations continued to increase downstream from site 5 as a result of the large suspended-sediment concentrations in the tributary flows and possibly a large yield of suspended sediment from reach R4.

The patterns in the estimated loads (or FWA concentrations) for total phosphorus (fig. 25) and suspended sediment (fig. 27) were similar. Because phosphorus typically is transported with suspended sediment, the large yield of total phosphorus from reach R2 may have resulted, in part, from a large yield of suspended sediment from that reach.

Summary

Data were collected at 11 water-quality sampling sites in the upper Red River of the North (Red River) Basin from May 1997 through September 1999 to describe the water-quality characteristics of the upper Red River and to estimate constituent loads and flow-weighted average concentrations for major tributaries of the Red River. For this report, the upper Red River Basin is defined as the drainage area upstream from the bridge crossing the Red River at Perley, Minn. About 20 samples were collected from each of 8 sites during the study period, and about 6 samples were collected from each of 3 additional sites. The samples were analyzed for 5-day biochemical oxygen demand, bacteria, dissolved solids, nutrients, and suspended sediment.

For dissolved solids, nutrients, and suspended sediment, a relation between constituent concentration and streamflow was determined using the data collected during the study period. The relation was determined by a multiple regression model in which concentration was the dependent variable and streamflow was the primary explanatory variable. The regression model was determined using a program called Estimator. Estimator was used to compute unbiased estimates of annual loads for each constituent and for each of eight primary water-quality sampling sites and to compute the degree of uncertainty associated with each estimated annual load. The estimated annual loads for the eight primary sites then were used to estimate annual loads for five intervening reaches in the study area. Results from Estimator were used as a screening tool to identify which subbasins contributed a disproportionate amount of pollutants to the Red River. To compare the relative water quality of the different subbasins, an estimated flow-weighted average (FWA) concentration was computed from the estimated average annual load and the average annual streamflow for each subbasin.

The 5-day biochemical oxygen demands in the upper Red River Basin were fairly small, and medians ranged from 1 to 3 milligrams per liter. The Bois de Sioux River near Doran, Minn., site had the largest median oxygen demand.

Fecal coliform samples were not collected with sufficient frequency to determine if the North Dakota and Minnesota water-quality standards were met. However, more than 50 percent of the samples for the Sheyenne River at Harwood, N. Dak., site and more than 25 percent of the samples for the Bois de Sioux River near Doran, Minn., site and the Red River at Perley, Minn., site had fecal coliform concentrations that were greater than 200 colonies per 100 milliliters. The large concentrations indicate an abundance of pathogens in the upper Red River Basin.

The Bois de Sioux River near Doran, Minn., site and the Sheyenne River at Harwood, N. Dak., site had median dissolved-solids concentrations that exceeded the U.S. Environmental Protection Agency secondary water-quality standard of 500 milligrams per liter. However, none of the main-stem sites had median concentrations that were greater than 500 milligrams per liter. Generally, the dissolved-solids concentrations in the main stem Red River increased in a downstream direction.

Although total nitrite plus nitrate concentrations generally increased in a downstream direction, the median concentrations for all sites were less than the North Dakota suggested guideline of 1.0 milligram per liter for nuisance algal growth and all concentrations were less than the North Dakota and Minnesota water-quality standard of 10 milligrams per liter for nitrate in drinking water. The median total nitrite plus nitrate concentration for the Red River near Harwood, N. Dak., site was more than twice as large as the median concentration for the Red

River above Fargo, N. Dak., site. A small fraction of the nitrogen in the upper Red River Basin was in the ammonia form. The largest median total ammonia concentration was for the Red River near Harwood, N. Dak., site. The total ammonia concentration increased in a downstream direction from the Red River above Fargo, N. Dak., site to the Red River near Harwood, N. Dak., site, probably as a result of wastewater discharges from urban areas. The largest median total organic nitrogen concentration was for the Bois de Sioux River near Doran, Minn., site. The largest median total nitrogen concentration also was for the Bois de Sioux River near Doran, Minn., site. Generally, the median total nitrogen concentrations in the main stem Red River increased in a downstream direction.

Total and dissolved phosphorus concentrations also generally increased in a downstream direction. Nearly all median total phosphorus concentrations exceeded the North Dakota suggested guideline of 0.1 milligram per liter. The largest median total phosphorus concentrations were for the Bois de Sioux River near Doran, Minn., site, the Sheyenne River at Harwood, N. Dak., site, and the Red River at Perley, Minn., site. The largest median dissolved phosphorus concentration was for the Bois de Sioux River near Doran, Minn., site. Most of the dissolved phosphorus concentrations were greater than 0.1 milligram per liter, indicating an abundant natural source of phosphorus in the basin and/or significant nonpoint sources of phosphorus from human activities.

Except for the Otter Tail River above Breckenridge, Minn., site, more than 95 percent of the suspended sediment in streams in the upper Red River Basin was silt and clay size (less than 0.062 millimeter). Suspended-sediment concentrations were relatively small for the upstream sites and gradually increased in a downstream direction.

The Sheyenne River at Harwood, N. Dak., site and the Red River at Hickson, N. Dak., to the Red River above Fargo, N. Dak., intervening reach had the largest estimated annual dissolved-solids loads. Those subbasins also had FWA concentrations that were greater than 500 milligrams per liter. The largest estimated FWA concentration for dissolved solids (about 630 milligrams per liter) was for the Bois de Sioux River near Doran, Minn., site. The Otter Tail River above Breckenridge, Minn., site had the smallest estimated FWA concentration (about 240 milligrams per liter). The estimated FWA concentrations for dissolved solids for the main-stem sites ranged from about 300 to 500 milligrams per liter and generally increased in a downstream direction. Most of the increase resulted from the large concentrations for the Bois de Sioux River near Doran, Minn., site and the Sheyenne River at Harwood, N. Dak., site.

The estimated annual total nitrite plus nitrate loads for the tributary sites and intervening reaches were highly uncertain. The Sheyenne River at Harwood, N. Dak., site had the largest estimated load. The estimated load for that site was followed by the estimated load for the Red River at Hickson, N. Dak., to the Red River above Fargo, N. Dak., intervening reach and the Red River near Harwood, N. Dak., to the Red River at Perley, Minn., intervening reach. The estimated FWA concentrations for total nitrite plus nitrate for the main-stem sites increased from about 0.2 milligram per liter for the Red River below Wahpeton, N. Dak., site to about 0.9 milligram per liter for the Red River at Perley, Minn., site. Much of the increase probably resulted from flows from the tributary sites and intervening reaches, excluding the Otter Tail River above Breckenridge, Minn., site. However, uncertainty in the estimated concentrations prevented any reliable conclusions regarding which sites or reaches contributed most to the increase.

The Red River above Fargo, N. Dak., to the Red River near Harwood, N. Dak., intervening reach had the largest estimated annual total ammonia load. The Sheyenne River at Harwood, N. Dak., site and the Bois de Sioux River near Doran, Minn., site also had large estimated loads. The estimated FWA concentrations for total ammonia for the main-stem sites increased from about 0.05 milligram per liter for the Red River above Fargo, N. Dak., site to about 0.15 milligram per liter for the Red River near Harwood, N. Dak., site. The increase resulted from a decrease in flows in the Red River above Fargo, N. Dak., to the Red River near Harwood, N. Dak., intervening reach and the large load for that reach. The FWA concentration decreased between the Red River near Harwood, N. Dak., site and the Red River at Perley, Minn., site, possibly because of the small concentration for the Red River near Harwood, N. Dak., to the Red River at Perley, Minn., intervening reach or because ammonia was being converted to nitrate in that reach.

The Red River at Hickson, N. Dak., to the Red River above Fargo, N. Dak., intervening reach and the Sheyenne River at Harwood, N. Dak., site had the largest estimated annual total organic nitrogen loads. The Otter Tail River above Breckenridge, Minn., site, the Bois de Sioux River near Doran, Minn., site, and the Red River near Harwood, N. Dak., to the Red River at Perley, Minn., intervening reach also had substantial loads. The largest estimated FWA concentrations for total organic nitrogen were for the Red River at Hickson, N. Dak., to the Red River above Fargo, N. Dak., intervening reach and the Bois de Sioux River near Doran, Minn., site. The concentrations for the Otter Tail River above Breckenridge, Minn., site and the Sheyenne River at Harwood, N. Dak., site were relatively small. The estimated FWA concentrations for total organic nitrogen for the main-stem sites were relatively constant and ranged from about 0.5 to 0.7 milligram per liter. The relatively constant concentrations were in sharp contrast to the total nitrite plus nitrate concentrations, which increased about fivefold between the Red River below Wahpeton, N. Dak., site and the Red River at Perley, Minn., site.

The Sheyenne River at Harwood, N. Dak., site had the largest estimated annual total nitrogen load. The load for that site was followed by the load for the Red River near Harwood, N. Dak., to the Red River at Perley, Minn., intervening reach.

That reach also had the largest estimated FWA concentration for total nitrogen (about 2.9 milligrams per liter), but the estimate was highly uncertain. The Otter Tail River above Breckenridge, Minn., site had the smallest concentration (about 0.6 milligram per liter). The estimated FWA concentrations for total nitrogen for the main-stem sites increased from about 0.9 milligram per liter for the Red River at Hickson, N. Dak., site to about 1.6 milligrams per liter for the Red River at Perley, Minn., site. Much of the increase probably resulted from the large concentrations for the Red River at Hickson, N. Dak., to the Red River above Fargo, N. Dak., intervening reach, the Sheyenne River at Harwood, N. Dak., site, and the Red River near Harwood, N. Dak., to the Red River at Perley, Minn., intervening reach.

The Sheyenne River at Harwood, N. Dak., site had the largest estimated annual total phosphorus load and the largest estimated FWA concentration (about 0.5 milligram per liter). The Otter Tail River above Breckenridge, Minn., site had the smallest estimated FWA concentration (about 0.1 milligram per liter). The Red River below Wahpeton, N. Dak., to the Red River at Hickson, N. Dak., intervening reach had a total phosphorus load of about 80 tons per year despite the small drainage area for that reach. The estimated FWA concentrations for total phosphorus for the main-stem sites increased from about 0.15 milligram per liter for the Red River below Wahpeton, N. Dak., site to about 0.35 milligram per liter for the Red River at Perley, Minn., site. Most of the increase probably resulted from the large yield of total phosphorus from the Red River below Wahpeton, N. Dak., to the Red River at Hickson, N. Dak., intervening reach and the large concentrations for the Sheyenne River at Harwood, N. Dak., site.

The Sheyenne River at Harwood, N. Dak., site had the largest estimated annual dissolved phosphorus load. The Red River near Harwood, N. Dak., to the Red River at Perley, Minn., intervening reach and the Red River at Hickson, N. Dak., to the Red River above Fargo, N. Dak., intervening reach also had substantial estimated loads. Although the lower confidence limits for the Bois de Sioux River near Doran, Minn., to the Red River below Wahpeton, N. Dak., intervening reach and the Red River below Wahpeton, N. Dak., to the Red River at Hickson, N. Dak., intervening reach were near zero, the loads for those reaches may have been large despite the small drainage areas.

The Sheyenne River at Harwood, N. Dak., site had the largest estimated annual suspended-sediment load. The estimated FWA concentrations for suspended sediment for the main-stem sites increased from about 50 milligrams per liter for the Red River below Wahpeton, N. Dak., site to about 300 milligrams per liter for the Red River at Perley, Minn., site. Much of the increase occurred as a result of the large yield of suspended sediment from the Red River below Wahpeton, N. Dak., to the Red River at Hickson, N. Dak., intervening reach. Suspended-sediment concentrations continued to increase downstream from the Red River at Hickson, N. Dak., site as a result of the large suspended-sediment concentrations in the tributary flows and possibly a large yield of suspended sediment from the Red River above Fargo, N. Dak., to the Red River near Harwood, N. Dak., intervening reach.

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Appendix 1. Regression Models for Daily Concentration and Uncertainty in Estimated Annual Loads

Results of the regression analysis for historical constituent concentrations and daily loads for eight water-quality sampling sites used in this study are given in table 1–1. The estimated annual loads computed for this study depended on the relation between concentration and streamflow and on seasonality in concentration. The more variability in concentration that could be explained by streamflow and seasonality, the more accurate the estimated annual load. The natural logarithm of concentration was the dependent variable in the regression model, and the natural logarithm of daily streamflow was the explanatory variable. The explanatory variable was included whether or not the coefficient for streamflow was statistically significant. The seasonal terms (the sine and cosine variables) for 6 months and for 1 year were included only if one of the terms was significant at the 10-percent level or higher. Significant seasonality in concentration occurred for most variables and most sites.

Estimated annual loads for each constituent for water years 1998 and 1999 are given in tables 1–2 through 1–9. The Estimator program was used to compute unbiased estimates of the annual loads based on the fitted regression models for concentration and to compute the degree of uncertainty in the estimated annual loads. An adjusted maximum likelihood estimation procedure was used to account for concentrations that were censored (that is, less than the method detection limit). The degree of uncertainty in the estimated annual loads was related to the standard error of the regression for concentration and to the coefficient of variation (R^2) for daily load. For example, the standard errors of the regressions for dissolved solids and total organic nitrogen tended to be smaller than the standard errors of the regressions for the remaining constituents, and the coefficients of variation for daily loads for those constituents tended to be larger than the coefficients of variation for daily loads for the remaining constituents (table 1–1). Therefore, the degree of uncertainty for the estimated annual loads for dissolved solids and total organic nitrogen should be less than the degree of uncertainty for the estimated annual load for the remaining constituents. In contrast, the standard errors of the regressions for total nitrite plus nitrate and total ammonia tended to be larger than the standard errors of the regressions for the remaining constituents, and the coefficients of variation for daily loads for those constituents tended to be smaller than the coefficients of variation for daily loads for the remaining constituents. Therefore, the degree of uncertainty in the estimated annual loads for total nitrite plus nitrate and total ammonia should be greater than the degree of uncertainty for the estimated annual loads for the remaining constituents.

The standard errors of the estimated annual loads for each water year were computed with the Estimator program. The standard errors then were used to compute approximate confidence limits for the actual annual loads using equation 1–1:

$$\mathrm{Prob}[L > \hat{L} - Z_P SE(\hat{L})] = \mathrm{Prob}[L < \hat{L} + Z_P SE(\hat{L})] = P \qquad (1\text{–}1)$$

where

- Prob denotes probability;
- L is the actual annual load, in tons per year;
- $\hat{L}$ is the estimated annual load, in tons per year;
- Z_P is the pth percentile of a standard normal distribution;
- $SE(\hat{L})$ is the standard error of the estimated annual load; and
- P is a specified confidence limit.

Therefore, because the 90th-percentile ($Z_{0.90} = 1.285$) was used to report uncertainty for this study, the lower and upper 90-percent confidence limits for the actual annual loads were given by equation 1–2:

$$\mathrm{Prob}\left[L > \hat{L}\left(1 - \frac{1.285 SE(\hat{L})}{\hat{L}}\right)\right] = \mathrm{Prob}\left[L < \hat{L}\left(1 + \frac{1.285 SE(\hat{L})}{\hat{L}}\right)\right] = 0.90. \qquad (1\text{–}2)$$

The percents of uncertainty given in tables 1–2 through 1–9 for the estimated annual loads were used in equation 1–2 to compute the lower and upper confidence limits for the actual annual loads. The percentages given in the tables were computed using equation 1–3:

$$U(\hat{L}) = \frac{1.285 SE(\hat{L})}{\hat{L}} \times 100 \qquad (1\text{–}3)$$

where

- $U(\hat{L})$ is the uncertainty of the estimated annual load, in percent.

To reduce uncertainty in the estimated annual loads, equation 1–4,

$$\hat{L}_{1998\text{-}99} = \frac{1}{2}(\hat{L}_{1998} + \hat{L}_{1999}) \qquad (1\text{–}4)$$

where

$\hat{L}_{1998\text{-}99}$ is the estimated average annual load, in tons per year, for 1998-99;

$\hat{L}_{1998}$ is the estimated annual load, in tons per year, for 1998; and

$\hat{L}_{1999}$ is the estimated annual load, in tons per year, for 1999;

was used to obtain an estimated average annual load for 1998-99. Assuming the estimated annual loads for water years 1998 and 1999 were statistically independent, the standard error of the estimated average annual load was defined by equation 1–5:

$$SE(\hat{L}_{1998\text{-}99}) = \frac{1}{2}\sqrt{[SE(\hat{L}_{1998})]^2 + [SE(\hat{L}_{1999})]^2}. \qquad (1\text{–}5)$$

Therefore, in accordance with equation 1–3, the uncertainty of the estimated average annual load was given by equation 1–6:

$$U(\hat{L}_{1998\text{-}99}) = \frac{1.285 SE(\hat{L}_{1998\text{-}99})}{\hat{L}_{1998\text{-}99}} \text{ x } 100. \qquad (1\text{–}6)$$

Estimated annual loads for intervening reaches were obtained by subtracting estimated annual load(s) for upstream site(s) from estimated annual load(s) for downstream site(s). The approximate standard errors and the associated uncertainties in the loads for the intervening reaches therefore needed to be computed using the standard errors in the estimated annual loads for the upstream and downstream sites. To compute the standard errors and the uncertainties, assumptions needed to be made about the relation between the estimated annual loads for the upstream and downstream sites. The estimated load for an intervening reach was given by equation 1–7,

$$\hat{L}_R = \hat{L}_{DS} - \hat{L}_{US} \qquad (1\text{–}7)$$

where

$\hat{L}_R$ is the estimated load, in tons per year, for the intervening reach;

$\hat{L}_{DS}$ is the estimated load, in tons per year, for the downstream site; and

$\hat{L}_{US}$ is the estimated load, in tons per year; for the upstream site;

and the variance (the squared standard error) of the estimated annual load for the intervening reach was given by equation 1–8,

$$\text{Var}(\hat{L}_R) = \text{Var}(\hat{L}_{DS}) + \text{Var}(\hat{L}_{US}) - 2\text{Cov}(\hat{L}_{DS}, \hat{L}_{US}) \qquad (1\text{–}8)$$

where

Var (X) denotes the variance of the random variable X, and

Cov (X, Y) denotes the covariance of the random variables X and Y.

The variance could not be computed without the covariance term. However, the variance could be bounded by two extreme cases. Because the estimated annual loads for the upstream and downstream sites probably would not have a negative covariance, the largest variance was obtained by assuming the $\text{Cov}(\hat{L}_{DS}, \hat{L}_{US})$ was equal to zero. Therefore, the upper bound was given by equation 1–9:

$$\text{Var}(\hat{L}_R) \le \text{Var}(\hat{L}_{DS}) + \text{Var}(\hat{L}_{US}). \qquad (1\text{–}9)$$

The lower bound for the variance was obtained by assuming the estimated annual load for the downstream site was equal to the estimated annual load for the upstream site plus an independent incremental load, $(\hat{L}_{DS} = \hat{L}_{US} + X)$ where the $\text{Cov}(\hat{L}_{US}, X)$ was equal to zero. Therefore, the lower bound was given by equation 1–10:

$$\text{Var}(\hat{L}_R) \ge \text{Var}(\hat{L}_{DS}) - \text{Var}(\hat{L}_{US}). \qquad (1\text{–}10)$$

The uncertainty of the estimated annual load for the intervening reach was obtained by averaging equations 1–8 and 1–9; that is, with $\text{Var}(\hat{L}_R) = \text{Var}(\hat{L}_{DS})$. Therefore, the standard error of the estimated annual load for the intervening reach was assumed to equal the standard error of the estimated annual load for the downstream site as given in equation 1–11:

$$SE(\hat{L}_R) = SE(\hat{L}_{DS}). \qquad (1\text{–}11)$$

Equation 1–10 then was substituted in equation 1–3 to obtain the uncertainty of the estimated annual load for the intervening reach as given by equation 1–12:

$$U(\hat{L}_R) = \frac{1.285 SE(\hat{L}_{DS})}{\hat{L}_R} \text{ x } 100. \qquad (1\text{–}12)$$

Table 1–1. Results of regression analysis for historical constituent concentrations and daily loads.

[LF, natural logarithm of daily streamflow; S1, sine function with a period of 1 year; C1, cosine function with a period of 1 year; S2, sine function with a period of 6 months; C2, cosine function with a period of 6 months]

Site number	Site name	Number of values used in analysis	Explanatory variables included in regression model for natural logarithm of concentration and daily load	Standard error of regression	Coefficient of variation (R^2) for natural logarithm of concentration (percent)	Coefficient of variation (R^2) for natural logarithm of daily load (percent)
			Dissolved solids			
1	Otter Tail River above Breckenridge, Minn.	20	LF	0.11	4	82
2	Bois de Sioux River near Doran, Minn.	17	LF, S2, C2	.22	53	99
4	Red River of the North below Wahpeton, N. Dak.	20	LF, S1, C1	.26	35	86
5	Red River of the North at Hickson, N. Dak.	23	LF	.23	1	91
7	Red River of the North above Fargo, N. Dak.	22	LF, S2, C2	.24	10	94
8	Red River of the North near Harwood, N. Dak.	21	LF, S2, C2	.16	34	96
9	Sheyenne River at Harwood, N. Dak.	20	LF	.16	56	97
11	Red River of the North at Perley, Minn.	20	LF, S2, C2	.19	14	96
			Nitrite plus nitrate, total			
1	Otter Tail River above Breckenridge, Minn.	20	LF, S1, C1	0.95	20	15
2	Bois de Sioux River near Doran, Minn.	17	LF	2.01	31	76
4	Red River of the North below Wahpeton, N. Dak.	22	LF, S1, C1, S2, C2	1.34	17	35
5	Red River of the North at Hickson, N. Dak.	21	LF, S1, C1, S2, C2	1.54	26	41
7	Red River of the North above Fargo, N. Dak.	21	LF, S1, C1, S2, C2	1.12	43	68
8	Red River of the North near Harwood, N. Dak.	22	LF, S1, C1	.85	32	48
9	Sheyenne River at Harwood, N. Dak.	21	LF, S1, C1	1.22	32	67
11	Red River of the North at Perley, Minn.	21	LF, S1, C1	.79	16	69

Table 1–1. Results of regression analysis for historical constituent concentrations and daily loads.—Continued

[LF, natural logarithm of daily streamflow; S1, sine function with a period of 1 year; C1, cosine function with a period of 1 year; S2, sine function with a period of 6 months; C2, cosine function with a period of 6 months]

Site number	Site name	Number of values used in analysis	Explanatory variables included in regression model for natural logarithm of concentration and daily load	Standard error of regression	Coefficient of variation (R^2) for natural logarithm of concentration (percent)	Coefficient of variation (R^2) for natural logarithm of daily load (percent)
			Ammonia, total			
1	Otter Tail River above Breckenridge, Minn.	20	LF, S1, C1, S2, C2	1.39	56	56
2	Bois de Sioux River near Doran, Minn.	17	LF	1.81	42	81
4	Red River of the North below Wahpeton, N. Dak.	21	LF, S1, C1	1.30	13	20
5	Red River of the North at Hickson, N. Dak.	21	LF, S1, C1, S2, C2	1.54	33	44
7	Red River of the North above Fargo, N. Dak.	22	LF, S1, C1	1.25	37	58
8	Red River of the North near Harwood, N. Dak.	22	LF, S1, C1	.89	29	42
9	Sheyenne River at Harwood, N. Dak.	21	LF, S1, C1	1.43	24	58
11	Red River of the North at Perley, Minn.	21	LF	1.02	3	63
			Nitrogen, organic, total			
1	Otter Tail River above Breckenridge, Minn.	20	LF, S1, C1	0.29	8	43
2	Bois de Sioux River near Doran, Minn.	17	LF, S1, C1, S2, C2	.24	44	99
4	Red River of the North below Wahpeton, N. Dak.	21	LF	.30	9	81
5	Red River of the North at Hickson, N. Dak.	21	LF, S1, C1	.59	5	59
7	Red River of the North above Fargo, N. Dak.	21	LF, S1, C1	.27	48	96
8	Red River of the North near Harwood, N. Dak.	21	LF, S2, C2	.26	16	90
9	Sheyenne River at Harwood, N. Dak.	21	LF, S2, C2	.32	22	93
11	Red River of the North at Perley, Minn.	21	LF, S1, C1	.21	6	96

Table 1–1. Results of regression analysis for historical constituent concentrations and daily loads.—Continued

[LF, natural logarithm of daily streamflow; S1, sine function with a period of 1 year; C1, cosine function with a period of 1 year; S2, sine function with a period of 6 months; C2, cosine function with a period of 6 months]

Site number	Site name	Number of values used in analysis	Explanatory variables included in regression model for natural logarithm of concentration and daily load	Standard error of regression	Coefficient of variation (R^2) for natural logarithm of concentration (percent)	Coefficient of variation (R^2) for natural logarithm of daily load (percent)
			Nitrogen, total			
1	Otter Tail River above Breckenridge, Minn.	20	LF, S1, C1, S2, C2	0.30	29	52
2	Bois de Sioux River near Doran, Minn.	17	LF, S2, C2	.56	1	95
4	Red River of the North below Wahpeton, N. Dak.	22	LF, S2, C2	.42	13	71
5	Red River of the North at Hickson, N. Dak.	21	LF, S2, C2	.55	12	68
7	Red River of the North above Fargo, N. Dak.	21	LF, S1, C1	.33	63	95
8	Red River of the North near Harwood, N. Dak.	22	LF, S2, C2	.32	2	82
9	Sheyenne River at Harwood, N. Dak.	21	LF, S2, C2	.57	12	84
11	Red River of the North at Perley, Minn.	21	LF, S2, C2	.47	9	85
			Phosphorus, total			
1	Otter Tail River above Breckenridge, Minn.	20	LF, S2, C2	1.01	48	38
2	Bois de Sioux River near Doran, Minn.	17	LF, S1, C1	.62	26	93
4	Red River of the North below Wahpeton, N. Dak.	21	LF, S1, C1	.40	18	62
5	Red River of the North at Hickson, N. Dak.	20	LF, S1, C1	.65	10	59
7	Red River of the North above Fargo, N. Dak.	23	LF, S1, C1, S2, C2	.39	54	94
8	Red River of the North near Harwood, N. Dak.	22	LF, S1, C1	.27	25	87
9	Sheyenne River at Harwood, N. Dak.	21	LF, S2, C2	.43	37	92
11	Red River of the North at Perley, Minn.	21	LF, S1, C1	.73	14	68

Table 1–1. Results of regression analysis for historical constituent concentrations and daily loads.—Continued

[LF, natural logarithm of daily streamflow; S1, sine function with a period of 1 year; C1, cosine function with a period of 1 year; S2, sine function with a period of 6 months; C2, cosine function with a period of 6 months]

Site number	Site name	Number of values used in analysis	Explanatory variables included in regression model for natural logarithm of concentration and daily load	Standard error of regression	Coefficient of variation (R^2) for natural logarithm of concentration (percent)	Coefficient of variation (R^2) for natural logarithm of daily load (percent)
			Phosphorus, dissolved			
1	Otter Tail River above Breckenridge, Minn.	20	LF, S1, C1, S2, C2	0.71	49	46
2	Bois de Sioux River near Doran, Minn.	17	LF, S2, C2	.92	36	87
4	Red River of the North below Wahpeton, N. Dak.	21	LF, S2, C2	.84	14	26
5	Red River of the North at Hickson, N. Dak.	21	LF, S1, C1	1.25	2	22
7	Red River of the North above Fargo, N. Dak.	22	LF, S1, C1, S2, C2	.88	43	81
8	Red River of the North near Harwood, N. Dak.	21	LF, S1, C1	.71	19	46
9	Sheyenne River at Harwood, N. Dak.	21	LF	.45	22	89
11	Red River of the North at Perley, Minn.	21	LF, S1, C1	.74	22	66
			Suspended sediment			
1	Otter Tail River above Breckenridge, Minn.	21	LF, S1, C1, S2, C2	0.37	58	68
2	Bois de Sioux River near Doran, Minn.	[1]29	LF, S1, C1	.69	38	92
4	Red River of the North below Wahpeton, N. Dak.	21	LF, S1, C1, S2, C2	.47	81	90
5	Red River of the North at Hickson, N. Dak.	21	LF, S1, C1, S2, C2	.61	83	90
7	Red River of the North above Fargo, N. Dak.	22	LF, S1, C1, S2, C2	.49	84	94
8	Red River of the North near Harwood, N. Dak.	21	LF, S1, C1	.66	70	85
9	Sheyenne River at Harwood, N. Dak.	21	LF, S1, C1, S1, S2	.50	81	95
11	Red River of the North at Perley, Minn.	22	LF, S1, C1	.60	72	90

[1]Because of the small number of samples collected during the sampling period, all data given in the database for 1994-99 were used.

Table 1–2. Estimated annual dissolved-solids loads and flow-weighted average concentrations for the upper Red River of the North Basin.

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (thousand tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
1	Otter Tail River above Breckenridge, Minn.	1998	177	10	239
		1999	212	10	235
		1998-99	195	7	237
2	Bois de Sioux River near Doran, Minn.	1998	123	14	612
		1999	143	13	639
		1998-99	133	10	626
R1	Intervening reach downstream from the Otter Tail River above Breckenridge, Minn., and the Bois de Sioux River near Doran, Minn., and upstream from the Red River of the North below Wahpeton, N. Dak.	1998	17	--	--
		1999	57	--	--
		1998-99	37	89	--
4	Red River of the North below Wahpeton, N. Dak.	1998	316	12	349
		1999	412	13	378
		1998-99	364	9	365
R2	Intervening reach downstream from the Red River of the North below Wahpeton, N. Dak., and upstream from the Red River of the North at Hickson, N. Dak.	1998	9	--	--
		1999	-57	--	--
		1998-99	-24	99	--
5	Red River of the North at Hickson, N. Dak.	1998	325	10	315
		1999	355	10	316
		1998-99	340	7	316
R3	Intervening reach downstream from the Red River of the North at Hickson, N. Dak., and upstream from the Red River of the North above Fargo, N. Dak. (includes the Wild Rice River)	1998	384	--	520
		1999	285	--	671
		1998-99	335	14	575
7	Red River of the North above Fargo, N. Dak.	1998	709	11	401
		1999	640	10	413
		1998-99	675	7	407
R4	Intervening reach downstream from the Red River of the North above Fargo, N. Dak., and upstream from the Red River of the North near Harwood, N. Dak.	1998	53	--	--
		1999	25	--	--
		1998-99	39	110	--
8	Red River of the North near Harwood, N. Dak.	1998	762	10	445
		1999	666	7	445
		1998-99	714	6	445
9	Sheyenne River at Harwood, N. Dak.	1998	456	8	588
		1999	686	9	539
		1998-99	571	6	557
R5	Intervening reach downstream from the Red River of the North near Harwood, N. Dak., and the Sheyenne River at Harwood, N. Dak., and upstream from the Red River of the North at Perley, Minn. (includes the Buffalo and Rush Rivers)	1998	171	--	311
		1999	109	--	287
		1998-99	140	71	301

Table 1–2. Estimated annual dissolved-solids loads and flow-weighted average concentrations for the upper Red River of the North Basin.—Continued

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (thousand tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
11	Red River of the North at Perley, Minn.	1998	1,389	10	458
		1999	1,461	9	463
		1998-99	1,425	7	461

[1]Because of rounding, the numbers given for 1998-99 may not equal the average of the numbers given for water years 1998 and 1999.

Table 1–3. Estimated annual total nitrite plus nitrate loads and flow-weighted average concentrations for the upper Red River of the North Basin.

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
1	Otter Tail River above Breckenridge, Minn.	1998	52	63	0.07
		1999	64	55	.07
		1998-99	58	41	.07
2	Bois de Sioux River near Doran, Minn.	1998	179	283	.89
		1999	176	274	.79
		1998-99	178	196	.84
R1	Intervening reach downstream from the Otter Tail River above Breckenridge, Minn., and the Bois de Sioux River near Doran, Minn., and upstream from the Red River of the North below Wahpeton, N. Dak.	1998	-61	--	--
		1999	-35	--	--
		1998-99	-48	238	--
4	Red River of the North below Wahpeton, N. Dak.	1998	170	92	.19
		1999	205	82	.19
		1998-99	187	61	.19
R2	Intervening reach downstream from the Red River of the North below Wahpeton, N. Dak., and upstream from the Red River of the North at Hickson, N. Dak.	1998	112	--	--
		1999	109	--	--
		1998-99	111	196	--
5	Red River of the North at Hickson, N. Dak.	1998	282	106	.27
		1999	314	100	.28
		1998-99	298	73	.28
R3	Intervening reach downstream from the Red River of the North at Hickson, N. Dak., and upstream from the Red River of the North above Fargo, N. Dak. (includes the Wild Rice River)	1998	997	--	1.35
		1999	221	--	.52
		1998-99	609	139	1.05
7	Red River of the North above Fargo, N. Dak.	1998	1,278	129	.72
		1999	535	72	.34
		1998-99	907	-93	.55
R4	Intervening reach downstream from the Red River of the North above Fargo, N. Dak., and upstream from the Red River of the North near Harwood, N. Dak.	1998	-300	--	--
		1999	369	--	--
		1998-99	35	1,050	--
8	Red River of the North near Harwood, N. Dak.	1998	979	61	.57
		1999	904	49	.60
		1998-99	942	39	.59
9	Sheyenne River at Harwood, N. Dak.	1998	1,125	102	1.45
		1999	1,687	109	1.33
		1998-99	1,406	77	1.37
R5	Intervening reach downstream from the Red River of the North near Harwood, N. Dak., and the Sheyenne River at Harwood, N. Dak., and upstream from the Red River of the North at Perley, Minn. (includes the Buffalo and Rush Rivers)	1998	752	--	1.37
		1999	321	--	.84
		1998-99	537	193	1.15

Table 1–3. Estimated annual total nitrite plus nitrate loads and flow-weighted average concentrations for the upper Red River of the North Basin.—Continued

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
11	Red River of the North at Perley, Minn.	1998	2,855	53	0.94
		1999	2,912	48	.92
		1998-99	2,884	36	.93

[1]Because of rounding, the numbers given for 1998-99 may not equal the average of the numbers given for water years 1998 and 1999.

Table 1–4. Estimated annual total ammonia loads and flow-weighted average concentrations for the upper Red River of the North Basin.

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
1	Otter Tail River above Breckenridge, Minn.	1998	35	153	0.05
		1999	21	120	.02
		1998-99	28	106	.03
2	Bois de Sioux River near Doran, Minn.	1998	68	198	.34
		1999	66	187	.29
		1998-99	67	136	.32
R1	Intervening reach downstream from the Otter Tail River above Breckenridge, Minn., and the Bois de Sioux River near Doran, Minn., and upstream from the Red River of the North below Wahpeton, N. Dak.	1998	-45	--	--
		1999	-25	--	--
		1998-99	-35	101	--
4	Red River of the North below Wahpeton, N. Dak.	1998	58	84	.06
		1999	62	83	.06
		1998-99	60	59	.06
R2	Intervening reach downstream from the Red River of the North below Wahpeton, N. Dak., and upstream from the Red River of the North at Hickson, N. Dak.	1998	-15	--	--
		1999	-14	--	--
		1998-99	-15	258	--
5	Red River of the North at Hickson, N. Dak.	1998	43	125	.04
		1999	47	118	.04
		1998-99	45	86	.04
R3	Intervening reach downstream from the Red River of the North at Hickson, N. Dak., and upstream from the Red River of the North above Fargo, N. Dak. (includes the Wild Rice River)	1998	44	--	.06
		1999	20	--	.05
		1998-99	32	173	.05
7	Red River of the North above Fargo, N. Dak.	1998	87	107	.05
		1999	67	88	.04
		1998-99	77	72	.05
R4	Intervening reach downstream from the Red River of the North above Fargo, N. Dak., and upstream from the Red River of the North near Harwood, N. Dak.	1998	166	--	--
		1999	173	--	--
		1998-99	170	57	--
8	Red River of the North near Harwood, N. Dak.	1998	253	59	.15
		1999	240	50	.16
		1998-99	247	39	.15
9	Sheyenne River at Harwood, N. Dak.	1998	120	130	.15
		1999	176	136	.14
		1998-99	148	97	.15
R5	Intervening reach downstream from the Red River of the North near Harwood, N. Dak., and the Sheyenne River at Harwood, N. Dak., and upstream from the Red River of the North at Perley, Minn. (includes the Buffalo and Rush Rivers)	1998	-9	--	-.02
		1999	-40	--	-.10
		1998-99	-24	619	-.05

Table 1–4. Estimated annual total ammonia loads and flow-weighted average concentrations for the upper Red River of the North Basin.—Continued

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
11	Red River of the North at Perley, Minn.	1998	364	78	0.12
		1999	377	72	.12
		1998-99	371	53	.12

[1]Because of rounding, the numbers given for 1998-99 may not equal the average of the numbers given for water years 1998 and 1999.

Table 1–5. Estimated annual total organic nitrogen loads and flow-weighted average concentrations for the upper Red River of the North Basin.

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
1	Otter Tail River above Breckenridge, Minn.	1998	379	14	0.51
		1999	444	12	.49
		1998-99	412	9	.50
2	Bois de Sioux River near Doran, Minn.	1998	182	16	.91
		1999	209	14	.93
		1998-99	196	11	.92
R1	Intervening reach downstream from the Otter Tail River above Breckenridge, Minn., and the Bois de Sioux River near Doran, Minn., and upstream from the Red River of the North below Wahpeton, N. Dak.	1998	26	--	--
		1999	73	--	--
		1998-99	50	132	--
4	Red River of the North below Wahpeton, N. Dak.	1998	588	13	.65
		1999	727	14	.66
		1998-99	657	10	.66
R2	Intervening reach downstream from the Red River of the North below Wahpeton, N. Dak., and upstream from the Red River of the North at Hickson, N. Dak.	1998	-2	--	--
		1999	-77	--	--
		1998-99	-40	308	--
5	Red River of the North at Hickson, N. Dak.	1998	585	30	.57
		1999	649	28	.58
		1998-99	617	20	.57
R3	Intervening reach downstream from the Red River of the North at Hickson, N. Dak., and upstream from the Red River of the North above Fargo, N. Dak. (includes the Wild Rice River)	1998	747	--	1.01
		1999	414	--	.97
		1998-99	581	16	1.00
7	Red River of the North above Fargo, N. Dak.	1998	1,333	12	.75
		1999	1,064	11	.69
		1998-99	1,198	8	.72
R4	Intervening reach downstream from the Red River of the North above Fargo, N. Dak., and upstream from the Red River of the North near Harwood, N. Dak.	1998	-118	--	--
		1999	-37	--	--
		1998-99	-78	144	--
8	Red River of the North near Harwood, N. Dak.	1998	1,225	16	.71
		1999	1,026	11	.69
		1998-99	1,121	10	.70
9	Sheyenne River at Harwood, N. Dak.	1998	480	17	.62
		1999	781	20	.61
		1998-99	630	14	.61
R5	Intervening reach downstream from the Red River of the North near Harwood, N. Dak., and the Sheyenne River at Harwood, N. Dak., and upstream from the Red River of the North at Perley, Minn. (includes the Buffalo and Rush Rivers)	1998	314	--	.57
		1999	311	--	.82
		1998-99	313	53	.67

Table 1–5. Estimated annual total organic nitrogen loads and flow-weighted average concentrations for the upper Red River of the North Basin.—Continued

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
11	Red River of the North at Perley, Minn.	1998	2,009	12	0.66
		1999	2,118	11	.67
		1998-99	2,063	8	.67

[1]Because of rounding, the numbers given for 1998-99 may not equal the average of the numbers given for water years 1998 and 1999.

Table 1–6. Estimated annual total nitrogen loads and flow-weighted average concentrations for the upper Red River of the North Basin.

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
1	Otter Tail River above Breckenridge, Minn.	1998	473	16	0.64
		1999	530	13	.59
		1998-99	502	10	.61
2	Bois de Sioux River near Doran, Minn.	1998	310	39	1.56
		1999	348	35	1.55
		1998-99	330	26	1.55
R1	Intervening reach downstream from the Otter Tail River above Breckenridge, Minn., and the Bois de Sioux River near Doran, Minn., and upstream from the Red River of the North below Wahpeton, N. Dak.	1998	32	--	--
		1999	142	--	--
		1998-99	87	148	--
4	Red River of the North below Wahpeton, N. Dak.	1998	816	19	.90
		1999	1,021	20	.93
		1998-99	918	14	.92
R2	Intervening reach downstream from the Red River of the North below Wahpeton, N. Dak., and upstream from the Red River of the North at Hickson, N. Dak.	1998	101	--	--
		1999	-40	--	--
		1998-99	31	612	--
5S	Red River of the North at Hickson, N. Dak.	1998	917	30	.89
		1999	981	26	.87
		1998-99	949	20	.88
R3	Intervening reach downstream from the Red River of the North at Hickson, N. Dak., and upstream from the Red River of the North above Fargo, N. Dak. (includes the Wild Rice River)	1998	1,212	--	1.64
		1999	622	--	1.46
		1998-99	917	22	1.58
7	Red River of the North above Fargo, N. Dak.	1998	2,129	16	1.20
		1999	1,603	13	1.03
		1998-99	1,866	11	1.12
R4	Intervening reach downstream from the Red River of the North above Fargo, N. Dak., and upstream from the Red River of the North near Harwood, N. Dak.	1998	12	--	--
		1999	311	--	--
		1998-99	162	150	--
8	Red River of the North near Harwood, N. Dak.	1998	2,141	18	1.25
		1999	1,914	14	1.28
		1998-99	2,027	12	1.26
9	Sheyenne River at Harwood, N. Dak.	1998	1,207	33	1.55
		1999	2,107	38	1.65
		1998-99	1,658	27	1.62
R5	Intervening reach downstream from the Red River of the North near Harwood, N. Dak., and the Sheyenne River at Harwood, N. Dak., and upstream from the Red River of the North at Perley, Minn. (includes the Buffalo and Rush Rivers)	1998	1,574	--	2.87
		1999	1,149	--	3.02
		1998-99	1,360	54	2.93

Table 1–6. Estimated annual total nitrogen loads and flow-weighted average concentrations for the upper Red River of the North Basin.—Continued

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
11	Red River of the North at Perley, Minn.	1998	4,922	27	1.62
		1999	5,170	24	1.64
		1998-99	5,045	18	1.63

[1]Because of rounding, the numbers given for 1998-99 may not equal the average of the numbers given for water years 1998 and 1999.

Table 1–7. Estimated annual total phosphorus loads and flow-weighted average concentrations for the upper Red River of the North Basin.

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
1	Otter Tail River above Breckenridge, Minn.	1998	110	64	0.15
		1999	109	58	.12
		1998-99	109	43	.13
2	Bois de Sioux River near Doran, Minn.	1998	42	40	.21
		1999	59	40	.27
		1998-99	51	28	.24
R1	Intervening reach downstream from the Otter Tail River above Breckenridge, Minn., and the Bois de Sioux River near Doran, Minn., and upstream from the Red River of the North below Wahpeton, N. Dak.	1998	-15	--	--
		1999	-7	--	--
		1998-99	-16	28	--
4	Red River of the North below Wahpeton, N. Dak.	1998	127	18	.14
		1999	161	19	.15
		1998-99	144	13	.14
R2	Intervening reach downstream from the Red River of the North below Wahpeton, N. Dak., and upstream from the Red River of the North at Hickson, N. Dak.	1998	91	--	--
		1999	77	--	--
		1998-99	84	65	--
5	Red River of the North at Hickson, N. Dak.	1998	218	35	.21
		1999	238	33	.21
		1998-99	228	24	.21
R3	Intervening reach downstream from the Red River of the North at Hickson, N. Dak., and upstream from the Red River of the North above Fargo, N. Dak. (includes the Wild Rice River)	1998	216	--	.29
		1999	101	--	.24
		1998-99	159	32	.27
7	Red River of the North above Fargo, N. Dak.	1998	434	19	.25
		1999	340	15	.22
		1998-99	387	13	.23
R4	Intervening reach downstream from the Red River of the North above Fargo, N. Dak., and upstream from the Red River of the North near Harwood, N. Dak.	1998	13	--	--
		1999	54	--	--
		1998-99	34	124	--
8	Red River of the North near Harwood, N. Dak.	1998	448	16	.26
		1999	394	12	.26
		1998-99	421	10	.26
9	Sheyenne River at Harwood, N. Dak.	1998	373	31	.48
		1999	643	32	.50
		1998-99	508	23	.50
R5	Intervening reach downstream from the Red River of the North near Harwood, N. Dak., and the Sheyenne River at Harwood, N. Dak., and upstream from the Red River of the North at Perley, Minn. (includes the Buffalo and Rush Rivers)	1998	282	--	.51
		1999	132	--	.35
		1998-99	207	164	.45

Table 1–7. Estimated annual total phosphorus loads and flow-weighted average concentrations for the upper Red River of the North Basin.—Continued

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
11	Red River of the North at Perley, Minn.	1998	1,102	43	0.36
		1999	1,169	41	.37
		1998-99	1,135	30	.37

[1]Because of rounding, the numbers given for 1998-99 may not equal the average of the numbers given for water years 1998 and 1999.

Table 1–8. Estimated annual dissolved phosphorus loads and flow-weighted average concentrations for the upper Red River of the North Basin.

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
1	Otter Tail River above Breckenridge, Minn.	1998	20	34	0.03
		1999	23	33	.03
		1998-99	22	23	.03
2	Bois de Sioux River near Doran, Minn.	1998	50	76	.25
		1999	54	67	.24
		1998-99	52	50	.24
R1	Intervening reach downstream from the Otter Tail River above Breckenridge, Minn., and the Bois de Sioux River near Doran, Minn., and upstream from the Red River of the North below Wahpeton, N. Dak.	1998	19	--	--
		1999	26	--	--
		1998-99	23	129	--
4	Red River of the North below Wahpeton, N. Dak.	1998	88	42	.10
		1999	104	44	.09
		1998-99	96	31	.10
R2	Intervening reach downstream from the Red River of the North below Wahpeton, N. Dak., and upstream from the Red River of the North at Hickson, N. Dak.	1998	29	--	--
		1999	31	--	--
		1998-99	30	223	--
5	Red River of the North at Hickson, N. Dak.	1998	117	75	.11
		1999	134	74	.12
		1998-99	126	53	.12
R3	Intervening reach downstream from the Red River of the North at Hickson, N. Dak., and upstream from the Red River of the North above Fargo, N. Dak. (includes the Wild Rice River)	1998	239	--	.32
		1999	105	--	.25
		1998-99	172	57	.30
7	Red River of the North above Fargo, N. Dak.	1998	371	58	.21
		1999	225	40	.14
		1998-99	298	39	.18
R4	Intervening reach downstream from the Red River of the North above Fargo, N. Dak., and upstream from the Red River of the North near Harwood, N. Dak.	1998	-95	--	--
		1999	39	--	--
		1998-99	-28	59	--
8	Red River of the North near Harwood, N. Dak.	1998	276	42	.16
		1999	263	36	.18
		1998-99	270	28	.17
9	Sheyenne River at Harwood, N. Dak.	1998	152	26	.20
		1999	271	31	.21
		1998-99	212	22	.21
R5	Intervening reach downstream from the Red River of the North near Harwood, N. Dak., and the Sheyenne River at Harwood, N. Dak., and upstream from the Red River of the North at Perley, Minn. (includes the Buffalo and Rush Rivers)	1998	191	--	.35
		1999	165	--	.43
		1998-99	178	126	.38

Table 1–8. Estimated annual dissolved phosphorus loads and flow-weighted average concentrations for the upper Red River of the North Basin.—Continued

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
11	Red River of the North at Perley, Minn.	1998	618	48	0.20
		1999	700	48	.22
		1998-99	659	34	.21

[1]Because of rounding, the numbers given for 1998-99 may not equal the average of the numbers given for water years 1998 and 1999.

Table 1–9. Estimated annual suspended-sediment loads and flow-weighted average concentrations for the upper Red River of the North Basin.

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (thousand tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
1	Otter Tail River above Breckenridge, Minn.	1998	49	23	66
		1999	45	15	50
		1998-99	47	13	57
2	Bois de Sioux River near Doran, Minn.	1998	16	45	82
		1999	20	48	89
		1998-99	18	33	85
R1	Intervening reach downstream from the Otter Tail River above Breckenridge, Minn., and the Bois de Sioux River near Doran, Minn., and upstream from the Red River of the North below Wahpeton, N. Dak.	1998	-15	--	--
		1999	-3	--	--
		1998-99	-9	101	--
4	Red River of the North below Wahpeton, N. Dak.	1998	50	24	55
		1999	61	25	56
		1998-99	56	17	56
R2	Intervening reach downstream from the Red River of the North below Wahpeton, N. Dak., and upstream from the Red River of the North at Hickson, N. Dak.	1998	119	--	--
		1999	118	--	--
		1998-99	119	38	--
5	Red River of the North at Hickson, N. Dak.	1998	169	39	164
		1999	180	34	160
		1998-99	174	26	162
R3	Intervening reach downstream from the Red River of the North at Hickson, N. Dak., and upstream from the Red River of the North above Fargo, N. Dak. (includes the Wild Rice River)	1998	262	--	356
		1999	60	--	140
		1998-99	161	48	277
7	Red River of the North above Fargo, N. Dak.	1998	431	40	244
		1999	239	26	154
		1998-99	335	23	202
R4	Intervening reach downstream from the Red River of the North above Fargo, N. Dak., and upstream from the Red River of the North near Harwood, N. Dak.	1998	71	--	--
		1999	42	--	--
		1998-99	56	230	--
8	Red River of the North near Harwood, N. Dak.	1998	502	56	293
		1999	281	36	188
		1998-99	391	33	244
9	Sheyenne River at Harwood, N. Dak.	1998	188	32	243
		1999	460	39	361
		1998-99	324	25	316
R5	Intervening reach downstream from the Red River of the North near Harwood, N. Dak., and the Sheyenne River at Harwood, N. Dak., and upstream from the Red River of the North at Perley, Minn. (includes the Buffalo and Rush Rivers)	1998	278	--	507
		1999	38	--	98
		1998-99	158	145	339

Table 1–9. Estimated annual suspended-sediment loads and flow-weighted average concentrations for the upper Red River of the North Basin.—Continued

Site number or intervening reach designation	Site name or intervening reach designation	Water year	Load (thousand tons per year)[1]	Uncertainty (percent)[1]	Flow-weighted average concentration (milligrams per liter)
11	Red River of the North at Perley, Minn.	1998	968	42	319
		1999	778	32	247
		1998-99	873	26	282

[1]Because of rounding, the numbers given for 1998-99 may not equal the average of the numbers given for water years 1998 and 1999.