Prepared in cooperation with the North Dakota Department of Health, Minnesota Pollution Control Agency, City of Fargo, City of Moorhead, City of Grand Forks, and City of East Grand Forks

Continuous Water-Quality Monitoring and Regression Analysis to Estimate Constituent Concentrations and Loads in the Red River of the North at Fargo and Grand Forks, North Dakota, 2003–12

Scientific Investigations Report 2014–5064

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

Cover photograph: Red River of the North upstream from Fargo, North Dakota (photograph by Rochelle Nustad, U.S. Geological Survey, 2012)

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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Suggested citation:
Galloway, J.M., 2014, Continuous water-quality monitoring and regression analysis to estimate constituent concentrations and loads in the Red River of the North at Fargo and Grand Forks, North Dakota, 2003–12: U.S. Geological Survey Scientific Investigations Report 2014–5064, 37 p., *http://dx.doi.org/10.3133/sir20145064*.

ISSN 2328-0328 (online)

Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square miles (mi^2)	2.590	square kilometers (km^2)
cubic inch (in^3)	0.01639	liter (L)
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pounds per day (lbs/d)	0.4536	kilograms per day (kg/d)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day (Mg/d)
ton per day per square mile [$(ton/d)/mi^2$]	0.3503	megagram per day per square kilometer [$(Mg/d)/km^2$]
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per year (ton/yr)	0.9072	metric ton per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

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

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

Altitude, as used in this report, refers to distance above the vertical datum.

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

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

Continuous Water-Quality Monitoring and Regression Analysis to Estimate Constituent Concentrations and Loads in the Red River of the North at Fargo and Grand Forks, North Dakota, 2003–12

By Joel M. Galloway

Abstract

The Red River of the North (hereafter referred to as "Red River") Basin is an important hydrologic region where water is a valuable resource for the region's economy. Continuous water-quality monitors have been operated by the U.S. Geological Survey, in cooperation with the North Dakota Department of Health, Minnesota Pollution Control Agency, City of Fargo, City of Moorhead, City of Grand Forks, and City of East Grand Forks at the Red River at Fargo, North Dakota, from 2003 through 2012 and at Grand Forks, N.Dak., from 2007 through 2012. The purpose of the monitoring was to provide a better understanding of the water-quality dynamics of the Red River and provide a way to track changes in water quality. Regression equations were developed that can be used to estimate concentrations and loads for dissolved solids, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended sediment using explanatory variables such as streamflow, specific conductance, and turbidity.

Specific conductance was determined to be a significant explanatory variable for estimating dissolved solids concentrations at the Red River at Fargo and Grand Forks. The regression equations provided good relations between dissolved solid concentrations and specific conductance for the Red River at Fargo and at Grand Forks, with adjusted coefficients of determination of 0.99 and 0.98, respectively. Specific conductance, log-transformed streamflow, and a seasonal component were statistically significant explanatory variables for estimating sulfate in the Red River at Fargo and Grand Forks. Regression equations provided good relations between sulfate concentrations and the explanatory variables, with adjusted coefficients of determination of 0.94 and 0.89, respectively.

For the Red River at Fargo and Grand Forks, specific conductance, streamflow, and a seasonal component were statistically significant explanatory variables for estimating chloride. For the Red River at Grand Forks, a time component also was a statistically significant explanatory variable for estimating chloride. The regression equations for chloride at the Red River at Fargo provided a fair relation between chloride concentrations and the explanatory variables, with an adjusted coefficient of determination of 0.66 and the equation for the Red River at Grand Forks provided a relatively good relation between chloride concentrations and the explanatory variables, with an adjusted coefficient of determination of 0.77.

Turbidity and streamflow were statistically significant explanatory variables for estimating nitrate plus nitrite concentrations at the Red River at Fargo and turbidity was the only statistically significant explanatory variable for estimating nitrate plus nitrite concentrations at Grand Forks. The regression equation for the Red River at Fargo provided a relatively poor relation between nitrate plus nitrite concentrations, turbidity, and streamflow, with an adjusted coefficient of determination of 0.46. The regression equation for the Red River at Grand Forks provided a fair relation between nitrate plus nitrite concentrations and turbidity, with an adjusted coefficient of determination of 0.73. Some of the variability that was not explained by the equations might be attributed to different sources contributing nitrates to the stream at different times. Turbidity, streamflow, and a seasonal component were statistically significant explanatory variables for estimating total phosphorus at the Red River at Fargo and Grand Forks. The regression equation for the Red River at Fargo provided a relatively fair relation between total phosphorus concentrations, turbidity, streamflow, and season, with an adjusted coefficient of determination of 0.74. The regression equation for the Red River at Grand Forks provided a good relation between total phosphorus concentrations, turbidity, streamflow, and season, with an adjusted coefficient of determination of 0.87.

For the Red River at Fargo, turbidity and streamflow were statistically significant explanatory variables for estimating suspended-sediment concentrations. For the Red River at Grand Forks, turbidity was the only statistically significant explanatory variable for estimating suspended-sediment concentration. The regression equation at the Red River at Fargo provided a good relation between suspended-sediment concentration, turbidity, and streamflow, with an adjusted coefficient of determination of 0.95. The regression equation

for the Red River at Grand Forks provided a good relation between suspended-sediment concentration and turbidity, with an adjusted coefficient of determination of 0.96.

Introduction

The Red River of the North (hereafter referred to as “Red River”) Basin is an important hydrologic region where water is a valuable resource for the region’s economy, and the quality of the Red River is of international concern. The Red River begins at Wahpeton, North Dakota, at the confluence of the Otter Tail River and the Bois de Sioux River, and flows north into Canada before emptying into Lake Winnipeg, Manitoba (fig. 1). The drainage area for the Red River Basin is about 45,000 square miles (mi^2) (excluding the Assiniboine River in Canada) and encompasses parts of eastern North Dakota, northeastern South Dakota, and northwestern Minnesota in the United States, and southern Manitoba in Canada (Canadian part of basin not shown on fig. 1). The Red River flows through several urban areas along its path, including the cities of Fargo, N. Dak.; Moorhead, Minnesota; Grand Forks, N. Dak.; East Grand Forks, Minn.; and Winnipeg, Manitoba.

Water-quality issues in the Red River Basin are related to nonpoint and point sources of pollution. Urban runoff, treated municipal waste, and treated industrial waste can contain nutrients that are discharged into the river. About 81 percent of the land area in the Red River Basin in the United States is agricultural (Stoner and others, 1998), and runoff from pasture and cropland can transport nutrients and sediment into the river. Recently, nutrient loading into Lake Winnipeg has become a primary concern in the Red River Basin because of its declining water quality (Environment Canada and Manitoba Water Stewardship, 2011). Also, the effects of discharging water from Devils Lake into the Sheyenne River, a tributary to the Red River, on the water quality in the Red River has recently become a concern, particularly related to concentrations of sulfate and dissolved solids (Vecchia, 2011).

The U.S. Geological Survey (USGS), in cooperation with the North Dakota Department of Health (NDDH), Minnesota Pollution Control Agency, City of Fargo, City of Moorhead, City of Grand Forks, and City of East Grand Forks, has operated continuous water-quality monitors at the Red River at Fargo, N.Dak. (USGS streamgage 05054000), from 2003 through 2012 and at Grand Forks, N.Dak. (USGS streamgage 05082500) from 2007 through 2012. The monitors continuously record water temperature, dissolved oxygen (DO), specific conductance (SC), pH, and turbidity. The purpose of the continuous water-quality monitoring was to provide a better understanding of the water-quality dynamics of the Red River and provide a way to track changes in water quality. Also, previous studies have indicated that the water-quality physical properties recorded by the monitors and streamflow computed at the streamgages can be used as surrogates to estimate concentrations and loads for other water-quality constituents such as dissolved solids (DS), sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended sediment (Christensen and others, 2000; Christensen, 2001; Ryberg, 2006, 2007). This information is important to North Dakota and Minnesota as well as Canada in assessing efforts to improve water quality in the upper Red River Basin. Real-time continuous information also could be used to assist the cities of Fargo, Moorhead, Grand Forks, and East Grand Forks in managing drinking water and wastewater operations. Finally, real-time continuous estimates of constituent concentrations that are based on surrogates could more accurately estimate loads for comparison to total maximum daily loads (TMDLs). A TMDL is a calculation of the maximum amount of a constituent that a water body can receive and still meet water-quality standards (U.S. Environmental Protection Agency, 2006). Ryberg (2006) developed regression equations for estimating constituent concentrations and loads based on surrogate measurements at Fargo for data collected from 2003 to 2005. Many more discrete water-quality samples have been collected at Fargo since 2005 and an additional 7 years of continuous water-quality monitoring has been completed. With the additional data collected over a wider range of hydrologic conditions, there was a need to update the regression equations developed by Ryberg (2006) with the additional data. Although continuous and discrete water-quality data have been collected at Grand Forks since 2007, regression equations have not yet been developed.

Purpose and Scope

The purpose of this report is to describe the development and results of regression analysis of water-quality constituents for the Red River at Fargo and Grand Forks, N. Dak., using discrete water-quality data and continuously recorded streamflow and water-quality data collected from 2003 through 2012 at the two sites. Regression equations were developed that can be used to estimate concentrations and loads for DS, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended sediment using explanatory variables such as streamflow, SC, and turbidity.

Methods

Regression analyses were done to estimate concentrations and loads for DS, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended sediment at two sites on the Red River at Fargo and Grand Forks. The analyses included the use of streamflow data, continuously recorded water-quality data, and discrete water-quality sample data collected from 2003 through 2012. This section describes the methods used in the data collection and for the development of regression equations for estimating constituent concentrations and loads.

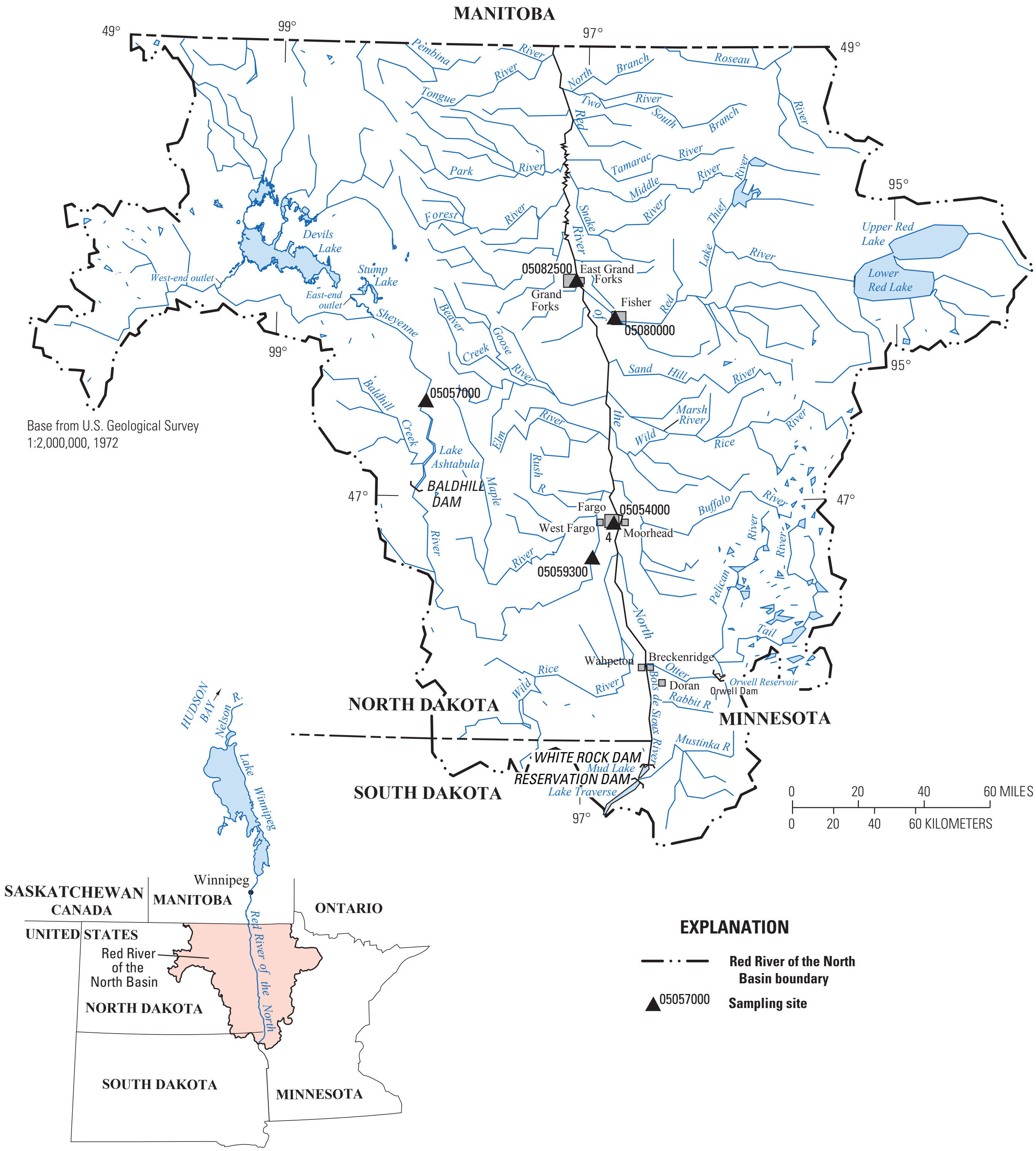


Figure 1. Site locations in the Red River of the North Basin.

Streamflow Monitoring

Instantaneous streamflow measurements were made and stream stage was continuously recorded at the Red River at Fargo (USGS streamgage 05054000) and at Grand Forks (USGS streamgage 05082500). The continuous stream stage data were used with the instantaneous streamflow measurements to compute the continuous streamflow from stage-discharge rating curves using methods described in Rantz and others (1982a and 1982b). Data for stream stage and streamflow are stored in the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2013a). Computed daily mean streamflow was used in the regression analyses described in this report.

Continuous Water-Quality Monitoring

Continuous monitoring of SC, pH, water temperature, turbidity, and DO on the Red River began in 2003 at Fargo and in 2007 at Grand Forks. The continuous water-quality monitors used for measuring the various water-quality properties at the two sites were maintained and calibrated using protocols described in Wagner and others (2006). The monitors collect data at a single point at a set depth in the stream near the riverbank. The protocols used for the computation and quality assurance of the continuous data also are described in Wagner and others (2006). The water-quality data are stored in the USGS NWIS database (U.S. Geological Survey, 2013a).

Discrete Water-Quality Sampling

Discrete water-quality samples were collected for various purposes at the Red River at Fargo and Grand Forks. Most of the samples from the two sites were collected as part of the North Dakota Department of Health's (NDDH) Ambient Water-Quality Network (Galloway and others, 2012). Samples were analyzed for major ions (including DS, sulfate, and chloride), nutrients (including nitrate plus nitrite and total phosphorus), trace metals, total suspended solids, total and dissolved organic carbon, and fecal indicator bacteria by the NDDH Laboratory in Bismarck, N. Dak., using published methods (North Dakota Department of Health, 2003b) and quality assurance procedures (North Dakota Department of Health, 2003a) . Samples also were collected for suspended-sediment concentration (SSC). Suspended-sediment samples were analyzed by the USGS Iowa Water Science Center sediment laboratory in Iowa City, Iowa, using techniques described in Guy (1969). During the collection of water-quality samples, physical properties of water also were measured, including SC, pH, water temperature, turbidity, and DO. Samples generally were collected eight times per year in March, April, May (2 samples), June, July, August, and October. Samples and physical properties were collected and processed using techniques described in U.S. Geological Survey (variously dated). Additional suspended-sediment samples were collected in 2012 at Fargo as part of a separate sediment collection program. Techniques used for the sediment data collection and analysis are described in Blanchard and others (2011) and Galloway and Nustad (2012).

Samples used for the regression analysis were collected over a large range in streamflow conditions (fig. 2 and table 1). Samples were collected at streamflows ranging from 104 to 18,900 cubic feet per second (ft^3/s) at Fargo and from 389 to 59,900 ft^3/s at Grand Forks (table 1). Samples were analyzed for different constituents at different periods from 2003 through 2007. For example, at Grand Forks, samples only were collected for the analysis of major ions such as sulfate and chloride from 2003 to 2007 (fig. 2). In 2007, nutrient analyses were added (nitrate plus nitrite and total phosphorus), and by the beginning of 2008, suspended-sediment analyses were included (fig. 2). The discrete water-quality data are stored in the USGS NWIS database (U.S. Geological Survey, 2013a).

Quality assurance data, including equipment blank samples, replicate samples, and cross section measurements, routinely were collected for the Ambient Water-Quality Network. Field equipment blank samples indicated adequate quality control in the equipment cleaning and processing with no occurrences of contamination for DS, sulfate, chloride, nitrate plus nitrite, and total phosphorus.

Replicate samples indicated good repeatability in samples collected for the Ambient Water-Quality Network. Percent differences relative to the mean (RPD_M) were calculated for environmental and replicate samples (or measurements) using the following equation:

$$RPD_M=|(a-b)/(a+b/2) * 100| \quad (1)$$

where

a is the routine environmental sample concentration (or measurement), and

b is the quality-control sample concentration (or measurement).

The median percent difference between regular and replicate samples was less than 1 percent for DS, chloride, and sulfate (15 samples); less than 2 percent for nitrate plus nitrite and total phosphorus (11 samples); and 12 percent for SSC (4 samples).

Specific conductance and turbidity were collected at multiple locations within the cross sections of the Red River at Grand Forks to describe variability related to mixing characteristics of the river as a quality-control measurement. Percent differences were calculated using the point measurements from the water-quality monitor and the mean of values measured at multiple locations along a cross section to quantify the variability.

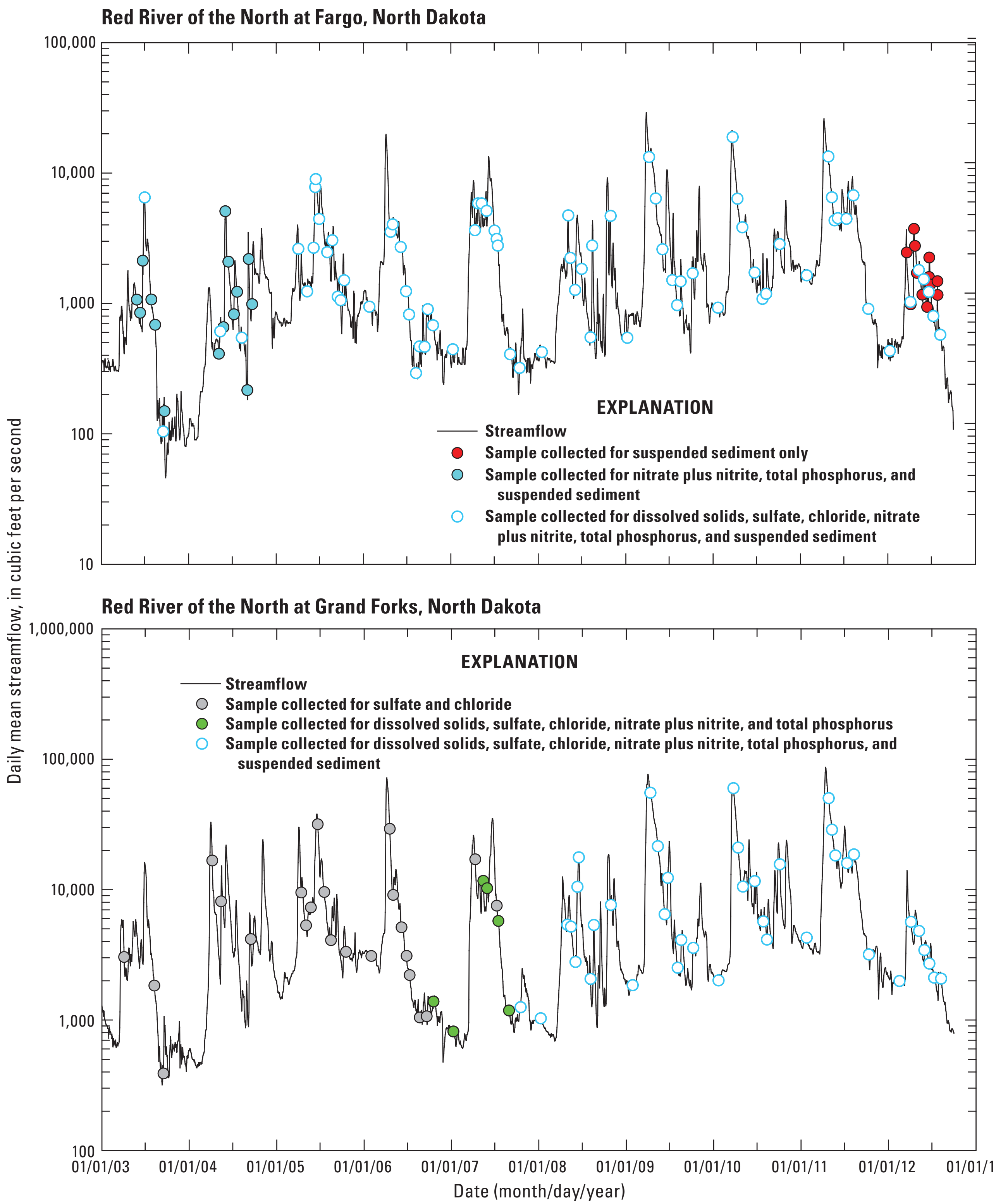


Figure 2. Daily mean streamflow and samples collected at the Red River of the North at Fargo (U.S. Geological Survey streamgage 05054000) and at Grand Forks, N.Dak. (USGS streamgage 05082500), 2003–12.

Table 1. Summary statistics for water-quality physical properties and constituents in discrete samples collected at the Red River of the North at Fargo (USGS streamgage 05054000) and at Grand Forks, North Dakota (USGS streamgage 05082500), 2003–12.

[USGS, U.S. Geological Survey; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter; ºC, degrees Celsius; —, no data; FNU, formazin nephelometric units; mg/L, milligrams per liter; N, nitrogen; <, less than; P, phosphorus]

Constituent or physical property (USGS parameter code)	Units	Descriptive statistics						
		Number of samples	Minimum	Maximum	Mean	25th percentile	50th percentile (median)	75th percentile
Red River of the North at Fargo, North Dakota								
Streamflow (00060)	ft³/s	107	104	18,900	2,600	875	1,510	3,330
Specific conductance (00095)	µS/cm at 25 °C	107	312	1,140	732	612	736	852
pH (00400)	standard units	125	7.3	8.8	—	8.0	8.1	8.3
Water temperature (00010)	°C	156	-0.1	27.3	16.9	12.9	19.3	23.2
Turbidity (63680)	FNU	95	1	810	102	41	69	100
Dissolved oxygen (00300)	mg/L	124	4.7	13.0	8.0	6.8	7.7	9.2
Dissolved solids (70301)	mg/L	76	211	670	459	383	474	538
Sulfate (00945)	mg/L	76	48	341	172	110	167	237
Chloride (00940)	mg/L	76	6.5	45.5	17.2	13.8	16.0	19.2
Nitrate plus nitrite (00631 and 00630)	mg/L as N	92	<0.03	2.14	0.39	0.11	0.25	0.42
Total phosphorus (00665)	mg/L as P	92	0.07	1.28	0.24	0.14	0.19	0.30
Suspended sediment (80154)	mg/L	101	3	1,160	169	71	111	208
Red River of the North at Grand Forks, North Dakota								
Streamflow (00060)	ft³/s	70	389	59,900	9,900	2,730	5,330	11,600
Specific conductance (00095)	µS/cm at 25 °C	70	326	959	688	623	710	769
pH (00400)	standard units	70	7.4	8.7	—	7.9	8.1	8.3
Water temperature (00010)	°C	88	-0.1	27.6	13.9	6.6	15.6	21.8
Turbidity (63680)	FNU	44	3	660	110	53	80	130
Dissolved oxygen (00300)	mg/L	66	5.0	13.4	8.8	7.3	8.9	10.4
Dissolved solids (70301)	mg/L	69	208	614	432	394	441	485
Sulfate (00945)	mg/L	69	45	278	145	115	144	174
Chloride (00940)	mg/L	69	7.0	30.0	15.5	12.9	15.1	18.8
Nitrate plus nitrite (00631 and 00630)	mg/L as N	47	<0.03	3.15	0.68	0.28	0.45	0.82
Total phosphorus (00665)	mg/L as P	47	0.08	0.68	0.24	0.16	0.21	0.30
Suspended sediment (80154)	mg/L	40	4	1,110	181	92	166	206

Regression Analysis

The methods used for the regression analysis described in this report are similar to the methods used by and described in Ryberg (2006, 2007). Regression equations previously were developed for selected water-quality constituents at the Red River at Fargo (Ryberg, 2006) and for several sites on the Sheyenne River, a tributary to the Red River (Ryberg, 2007). Similar measures for evaluating regression equations, including mean square error, standard deviation, and the adjusted coefficient of determination (R_a^2) were used in this report.

Standard deviation, *s*, is the positive square root of the mean square error (*MSE*), a common measure of variability in regression equations. Standard deviation is calculated as follows:

$$s = \sqrt{MSE} = \sqrt{\frac{SSE}{n-p}} \quad (2)$$

where

SSE is the error sum of squares (Helsel and Hirsch, 1995),

n is the number of observations used to develop the regression equation, and

p is the number of parameters estimated in the regression equation.

The standard deviation, like *MSE*, is an indicator of the variability of the probability distributions of the response, or explanatory, variable; however, the standard deviation is in the same units as the response variable, milligrams per liter for example, whereas *MSE* is in squared milligrams per liter. Therefore, the standard deviation is easier to interpret in relation to the response variable.

R^2, the coefficient of determination, is calculated as follows:

$$R^2 = 1 - \frac{SSE}{SS_y} \quad (3)$$

where

SSE is the error sum of squares, and

SS_y is the sums of squares for the response variables *y*, or total sums of squares (Helsel and Hirsch, 1995).

R^2 is a number, 0 through 1, that when multiplied by 100 is interpreted as the percentage of the variability in the response variable explained by the explanatory variables and the regression equation. Generally, the higher the R^2, the better the regression equation; however, this does not guarantee the regression equation is useful (Neter and others, 1996). For example, if estimates require extrapolation outside the observed response variables, the regression equation may not provide accurate estimates. Also, R^2 increases with the number of explanatory variables in the regression model, so R_a^2 was determined, which allows for the comparison of models that have differing numbers of explanatory variables by penalizing models that have additional coefficients (Helsel and Hirsch, 1995).

As an indicator of the ability of the regression relations to estimate constituent concentrations, the measured concentrations were compared to the concentrations estimated by the regression relations by calculating percentage differences relevant to the measured concentration (*RPD*s) using the following equation:

$$RPD = \left|\frac{B - A}{A} * 100\right| \quad (4)$$

where

B is the constituent concentration estimated from the regression equation, and

A is the measured constituent concentration.

A is assumed to be correct and the *RPD* is the relative difference of *B* from *A*, expressed as a percentage.

Potential surrogate physical properties, or explanatory variables, included streamflow, SC, pH, water temperature, turbidity, DO, and variables related to time. These variables included *t*, cos $\left(\frac{2j\pi t}{365}\right)$ and sin $\left(\frac{2j\pi t}{365}\right)$, where *t* is the Julian date referenced from January 1, 2002; *j* is an integer 1 through 3; cos is the cosine function; and sin is the sine function. An increase in *j* decreases the period of the cos and sin functions. Larger *j* values may be used to model behavior that has multiple cycles per year (Helsel and Hirsch, 1995). A model may include two or more cos/sin pairs with different periods. This may indicate two different seasonal processes that affect the response variable. In selection of a regression model, cos/sin terms were required to be used in pairs. For example, if cos $\left(\frac{2\pi t}{365}\right)$ was a statistically significant explanatory variable, the corresponding sin term, sin $\left(\frac{2\pi t}{365}\right)$, was included in the model. Including pairs of cos/sin terms may result in models where one member of the pair is significant and the other is not; however, using only one member of the cos/sin pair forces an arbitrary phase shift rather than a phase shift determined by the data (Helsel and Hirsch, 1995).

Multiple linear regression was used by experimenting with combinations of the explanatory variables to find the best regression model for estimating a particular constituent. Potential models with relatively high R_a^2 and low standard deviation were further examined using standard diagnostics for regression (Neter and others, 1996). The most common problems in the diagnostic residual plots were non-normality and heteroscedasticity, or nonconstant variance, both violations of the assumptions underlying parametric regression. Transformations of the response variable (constituent concentrations) often are effective fixes for both of these problems, which are often found together (Neter and others, 1996). In some cases, logarithmic transformations of the explanatory and response variables resulted in residuals that were approximately normally distributed. An explanatory variable was considered statistically significant and selected for regression relations if the *p*-value (attained significance level) for the variable was less than 0.05. Samples with residuals more than 3 standard deviations from zero generally were removed from the dataset used for development of the regression equations. For estimated concentrations computed from the regression equations, 90-percent confidence intervals also were computed for each estimated value using methods described in Helsel and Hirsch (1995).

Load Estimation

Daily load is the total mass of a constituent that is transported past a site in 1 day. Estimated daily constituent loads were calculated by multiplying estimated constituent concentrations, in milligrams per liter by the daily mean streamflow, in cubic feet per second, and multiplying by the conversion factor (5.39) to express the loads in pounds per day (lbs/d). Estimated annual loads were computed by accumulating the estimated daily loads in a given year and dividing by 2,000 to get loads in tons (short tons) per year (tons/yr). For days when values for continuous water-quality data such as SC and turbidity (explanatory variables) were missing, and therefore, constituent concentrations (response variable) could not be estimated, linear interpolation was used to estimate daily concentrations and loads so 365 days of values could be used to estimate annual loads.

For regression relations developed in terms of a logarithmically transformed constituent concentration, retransformation to the original units can cause an underestimation of chemical loads when adding individual load estimates during a long period of time (Christensen, 2001). Multiplying the calculated load by a bias correction factor (*BCF*; Duan, 1983) corrects for this underestimation. Calculation of the *BCF* is shown in the following equation:

$$BCF = \frac{\sum_{i=1}^{n} 10^{e_i}}{n} \quad (5)$$

where

e_i is the regression residual, in log units; and

n is the number of samples used to develop the regression relation.

Continuous Water Quality

Water quality has been monitored continuously on the Red River at Fargo (USGS streamgage 05054000) from June 2003 to October 2012 and at Grand Forks (USGS streamgage 05082500) from April 2007 to October 2012. During that time, a large range of hydrologic conditions have been monitored on the Red River. The daily mean streamflow ranged from 46 to 29,100 ft^3/s (2003–12) at Fargo, and from 690 to 86,800 ft^3/s (2007–12) at Grand Forks (fig. 2 and table 2). With the wide range of hydrologic conditions, a wide range of water-quality conditions have also been recorded at the two sites (figs. 3 and 4; table 2).

The solubility of DO is affected by water temperature and atmospheric pressure. The DO solubility increases with colder water, whereas warmer water holds less amounts of DO, and solubility increases with increasing atmospheric pressure and decreases with decreasing atmospheric pressure. DO is important in chemical reactions in water and in the life cycles of aquatic organisms (Hem, 1985). Sources of DO in surface waters primarily are atmospheric reaeration and photosynthetic activity of aquatic plants. DO is consumed by the respiration of aquatic plants, ammonia nitrification, and the decomposition of organic matter in a stream (Hem, 1985). At the Red River of North at Fargo, DO ranged from 2.9 to 16.2 milligrams per liter (mg/L) and generally was highest in the winter (November-February) when water temperatures were lower, and lowest in late summer (July–October) when temperatures were higher (fig. 3 and table 2).

Electrical conductivity is a measure of the capacity of water to conduct an electrical current and is a function of the types and quantities of dissolved substances in water (Hem, 1985). As concentrations of dissolved ions increase, conductivity of the water increases. Specific conductance is the conductivity expressed in units of microsiemens per centimeter at 25 degrees Celsius. The SC at Red River at Fargo ranged from 245 to 1,230 microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C), and generally was highest in early winter and lowest in late summer (fig. 3 and table 2). The pattern is unusual because the highest streamflow generally occurs in the spring (March–June) and early summer at Fargo from snowmelt and rainfall runoff, which should usually yield lower SC values because of dilution. The streamflow usually is lowest in the late summer and winter, so SC should be highest (less dilution) during this time. The pattern indicates that streamflow regulation and inflows from upstream tributaries might be affecting the SC at Fargo. Releases from Lake Traverse, located upstream on the Bois de Sioux River, and mixing from the Otter Tail River (fig. 1), may be affecting the SC at Fargo. The mean SC from discrete samples in the Bois de Sioux River near Doran, Minn., from June 2003 to October 2012 was 1,333 µS/cm at 25 °C (Mike Ell, North Dakota Department of Health, written commun., 2013) compared to a mean SC of 732 µS/cm at 25 °C from discrete samples collected at Fargo for the same period (table 1). Although quantifying the effects of Lake Traverse and the Otter Tail River is beyond the scope of this report, it does seem that the SC and other water-quality constituents at Fargo likely are affected by regulation to some degree.

The pH of an aqueous solution is controlled by interrelated chemical reactions that produce or consume hydrogen ions (Hem, 1985). Many reactions that occur in natural water among solutes (solid or gaseous) or other liquid species involve hydrogen ions, and, therefore, affect the pH. For example, the reaction of carbon dioxide (CO_2) with water is one of the most important in controlling the pH in natural water systems (Hem, 1985). Values for pH varied from 7.0 to 8.9, and generally were highest in late summer and lowest in the spring at Fargo (fig. 3 and table 2).

Turbidity is an expression of the optical properties of water that cause light rays to be scattered and absorbed (Gray and Glysson, 2003). Turbidity of water is caused by the

Table 2. Summary statistics for continuous streamflow and water-quality data at the Red River of the North at Fargo (USGS streamgage 05054000) and at Grand Forks, North Dakota (USGS streamgage 05082500), 2003–12.

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; FNU, formazin nephelometric units; <, less than; mg/L, milligrams per liter]

Physical property	Units	Daily minimum	Daily maximum	Mean daily
Red River of the North at Fargo, North Dakota (June 2003 to October 2012)				
Daily mean streamflow	ft^3/s	46	29,100	2,140
Specific conductance	µS/cm at 25 °C	245	1,230	765
pH	standard units	7.0	8.9	[1]8.1
Water temperature	°C	-0.3	11.2	30.9
Turbidity	FNU	<1	1,100	45
Dissolved oxygen	mg/L	2.9	16.2	10.2
Red River of the North at Grand Forks, North Dakota (April 2007 to October 2012)				
Daily mean streamflow	ft^3/s	690	86,800	8,180
Specific conductance	µS/cm at 25 °C	271	1,550	757
pH	standard units	7.5	8.9	[1]8.2
Water temperature	°C	0.0	28.8	11.1
Turbidity	FNU	1	960	75
Dissolved oxygen	mg/L	3.9	16.3	9.5

[1]Median of daily median values. Daily mean values are not computed for pH.

presence of suspended inorganic matter such as clay and silt; suspended and dissolved organic matter such as plankton, microscopic organisms, small terrestrial organic material, and organic acids; and water color. Turbidity at the Red River at Fargo generally was highest in the spring and summer months when more rainfall runoff occurs, washing material from the landscape into the stream, and lowest in the winter when there is ice cover and little material transported into the stream. Turbidity ranged from less than 1 to 1,100 formazin nephelometric units (FNU) (table 2). The lowest values of turbidity occurred in January and February of 2008 and the highest values occurred in June 2004 and June 2008 (fig. 3).

For most constituents, the Red River at Grand Forks had similar patterns in water quality compared to the water quality at Fargo. DO ranged from 3.9 to 16.3 mg/L, and generally was highest in the winter (November–February) when water temperatures were lower, and lowest in late summer (July–October) when temperatures were higher (fig. 4 and table 2).

SC generally was highest in the winter when streamflow was relatively low and, unlike the Red River at Fargo, lowest in the spring when streamflow was relatively high (more dilution of dissolved material) from snowmelt and rainfall runoff. SC ranged from 271 to 1,550 µS/cm at 25 °C (fig. 4 and table 2). The highest values of SC occurred in August through October 2012, likely related to the influence of releases from outlets from Devils Lake (fig 1). Devils Lake water generally has relatively higher concentrations of sulfate and DS because it is a closed basin. To reduce the effects of flooding in the Devils Lake Basin that has occurred during the last 20 years, and to prevent a spill through the natural spillway, the State of North Dakota has constructed outlets to discharge water from Devils Lake into the Sheyenne River, a tributary of the Red River. Releases from Devils Lake have been occurring since 2007 from an outlet on the west end of the lake (Vecchia, 2011); however, the effect of Devils Lake releases on SC on the Red River at Grand Forks became evident in the summer of 2012 due to a combination of factors—an increased percentage of streamflow comprised of water originating from Devils Lake at the Red River at Grand Forks and higher SC in the Devils Lake water, mainly from high sulfate and DS concentrations. With the addition of an east-end outlet in 2012, the total discharge capacity from Devils Lake (west-end outlet combined with the east-end outlet) increased from 250 to 600 ft^3/s in June of 2012. Both outlets discharge to the Sheyenne River above Lake Ashtabula Reservoir, a tributary to the Red River, which enters downstream from Fargo (fig. 1). The mean streamflow for the Red River at Grand Forks for the first 9 months of 2012 was 2,910 ft^3/s, which was substantially lower than annual means from 2007 through 2011 (U.S. Geological Survey, 2013b). The monthly mean streamflows for August and October 2012 were the lowest compared to the same months from 2007 through 2011. In April and May 2012, the discharge from the west-end outlet comprised approximately 50 percent of the streamflow in the Sheyenne River above Lake Ashtabula Reservoir (fig. 1) (North Dakota State Water Commission, 2013). The discharge from the combined outlets comprised approximately 97 to 100 percent of the streamflow in the Sheyenne River above Lake Ashtabula from

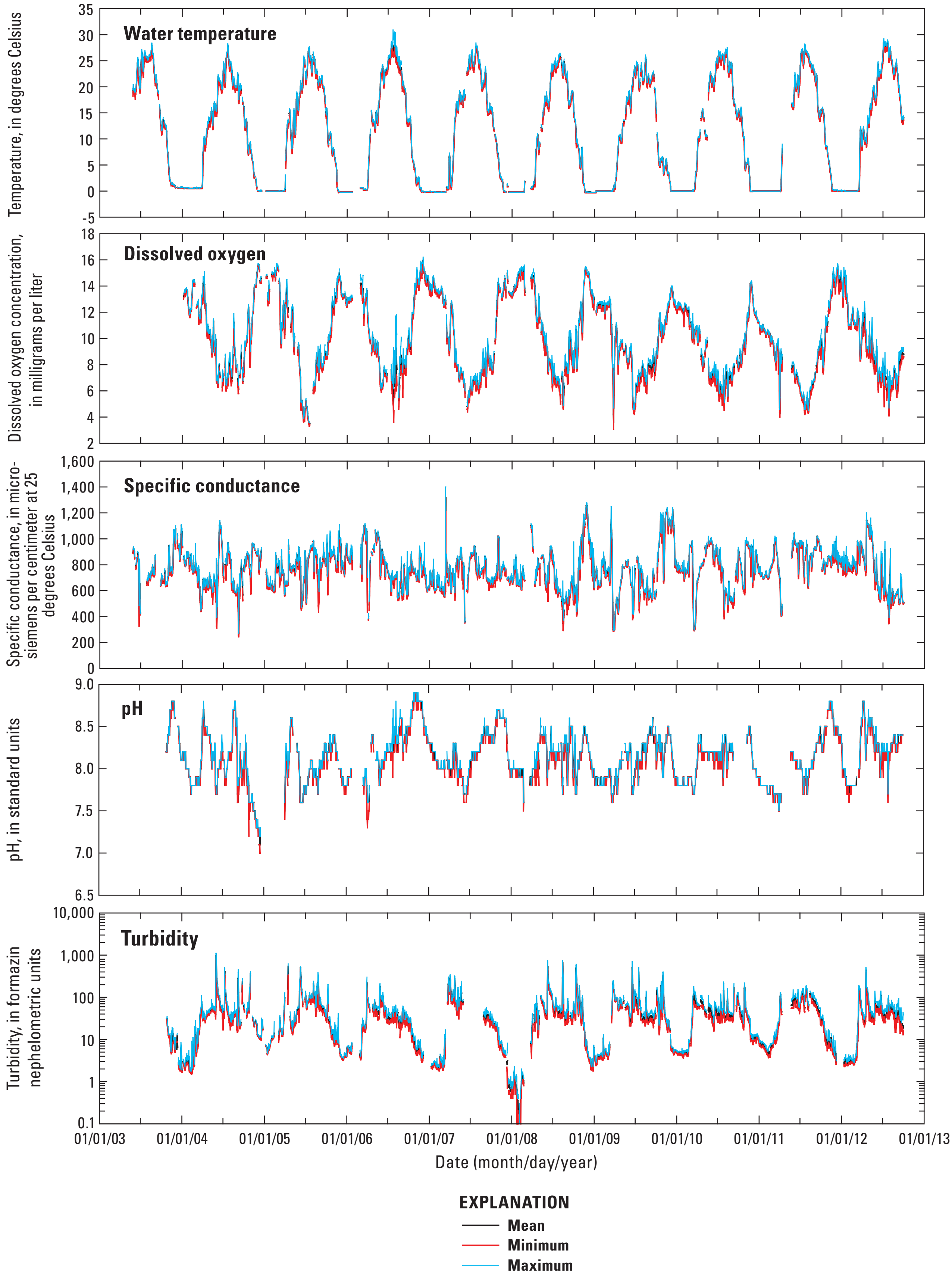


Figure 3. Daily water temperature, dissolved oxygen, specific conductance, pH, and turbidity for the Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000) from June 2003 to October 2012.

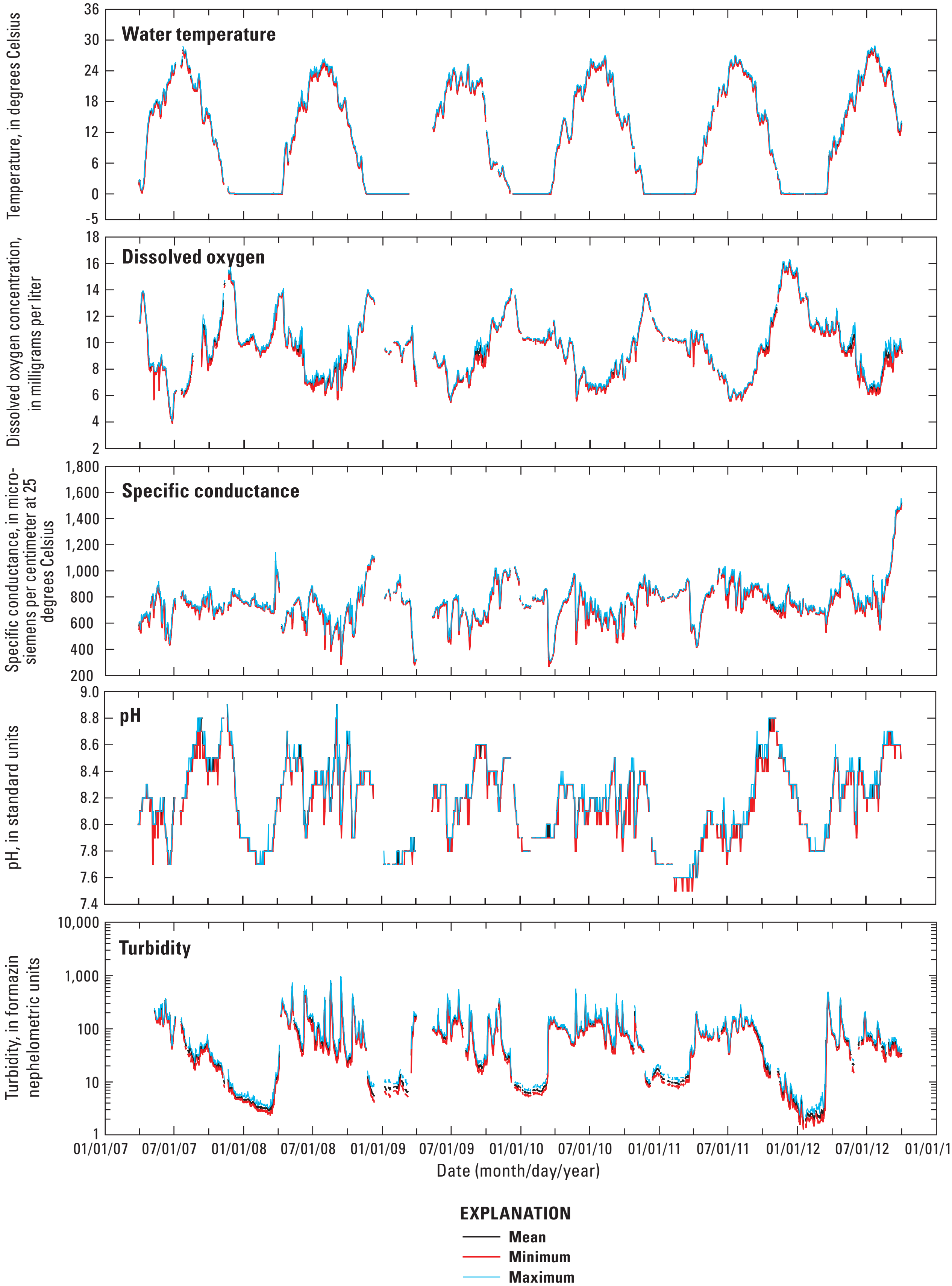


Figure 4. Daily water temperature, dissolved oxygen, specific conductance, pH, and turbidity for the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500) from April 2007 to October 2012.

July through September 2012, and the streamflow from the Sheyenne River comprised approximately 24, 33, and 60 percent of the streamflow, on average, in the Red River at Grand Forks in July, August, and September, respectively. Also, discharge water from the west-end outlet had an average SC of 1,883 µS/cm at 25 °C (April to November 2012), mainly from high concentrations of sulfate and DS with average concentrations of 570 mg/L and 1,303 mg/L, respectively (Mitchell Weier, North Dakota State Water Commission, written commun., 2012). Discharge water from the east-end outlet had an average SC of 2,977 µS/cm at 25 °C (July to November 2012), with average concentrations of sulfate and DS of 1,014 mg/L and 2,152 mg/L, respectively (Mitchell Weier, North Dakota State Water Commission, written commun., 2012). The Sheyenne River upstream from the two outlets had an average SC of 1,746 µS/cm at 25°C (April to November 2012), with average concentrations of sulfate and DS of 461 mg/L and 1,203 mg/L, respectively. At the Sheyenne River near Cooperstown, N.Dak. (USGS streamgage 05057000; fig. 1), located downstream from both outlets, SC rose from 799 mS/cm at 25 °C on March 14, 2012, to 2,540 µS/cm at 25°C on October 1, 2012 (U.S. Geological Survey, 2013a). SC started increasing from 1,120 µS/cm at 25 °C on August 17, 2012 to 2,000 µS/cm at 25°C on October 1, 2012, farther downstream at the Sheyenne River above Diversion near Horace, N.Dak. (USGS streamgage 05059300; fig. 1) (U.S. Geological Survey, 2013a). Even farther downstream, at the Red River at Grand Forks, the SC increased from 549 µS/cm at 25 °C on August 4 to 1,520 µS/cm at 25 °C on October 1, 2012. In October 2012, the higher percentage of water originating from Devils Lake in the streamflow at the Red River at Grand Forks, combined with higher SC (from higher sulfate and DS concentrations) in the Devils Lake water, resulted in the highest SC recorded at Grand Forks during the operation of the monitor (fig. 4).

Values for pH at Grand Forks ranged from 7.5 to 8.9, and generally were highest in late summer and early winter and lowest in the late winter and early spring. The lowest values for pH were recorded from February through March 2011 (fig. 4 and table 2).

Similar to Fargo, turbidity at Grand Forks generally was highest in the spring and summer months when more rainfall runoff occurs, washing material from the landscape into the stream, and lowest in the winter when there is ice cover and little material transported into the stream. Turbidity ranged from 1 to 960 FNU (table 2). The lowest values of turbidity occurred in December 2011 through March of 2012 and the highest values occurred in September 2008 (fig. 4).

A situation unique to the Red River at Grand Forks site is the location of the monitor in relation to the Red Lake River, and how that tributary affects the water quality in the cross section where the monitor is located and water-quality samples are collected. The monitor is located on the downstream side of the Sorlie Bridge (not shown on fig. 1), which is approximately 0.44 miles downstream from where the Red Lake River enters the Red River (fig. 1). To determine how well the single-point measurement from the monitor represents the conditions in the river as a whole and how mixing of the two rivers could affect water-quality constituents at the site, a cross-section survey of physical property data was collected on the downstream side of the Sorlie Bridge at various times of the year and under various hydrologic conditions. The results of surveys of SC and turbidity at the Sorlie Bridge are presented in table 3.

To demonstrate the effects of the Red Lake River on the specific conductance and turbidity in the cross section, figures 5 and 6 show the results of four cross-section surveys on selected dates when the ranges in the measurements were relatively large and under different hydrologic conditions. For SC, the pattern of lower values along the right bank of the cross section (looking downstream) from Red Lake River water progressing to higher values along the left bank as mixing occurs with the Red River was especially evident from the data on April 11 and May 12, 2009, during relatively higher streamflow conditions (fig. 5). The same pattern was evident in the turbidity data, with lower turbidity water from the Red Lake River flowing on the right bank, progressing to higher turbidity water closer to the left bank as mixing of the Red River and the Red Lake River occurs in the cross section (fig. 6).

By comparing the range in measurements to the streamflow in the Red Lake River, it is evident that the Red Lake River has an effect on the water quality in the cross section (fig. 7). The range in measurements of SC and turbidity in the cross section generally increased with increased streamflow in the Red Lake River (fig. 7). The largest range in measurements occurred from April through June when the streamflow generally was greater in the Red Lake River (table 3). Comparison between the single-point measurement from the monitor located in the middle of the cross section to mean values of SC and turbidity in the cross section, indicates that most of the time the single-point measurement from the monitor represents conditions in the river as a whole (table 3). The percent differences for SC between the monitor and the mean of the measurements in the cross section ranged from 0 to 3 percent (table 3). The percent differences for turbidity between the monitor and the mean of the measurements in the cross section were greater than those for SC, ranging from 0 to 47 percent (table 3). Measurements of turbidity generally are more highly variable because it is measuring the optical properties of dissolved and suspended matter in the water.

Regression Analysis Results

Relations between constituents of concern and surrogate physical properties were examined, and a regression equation was developed for each constituent using one or more surrogate variables. The regression equation, standard deviation, R_a^2, and median RPD for each site and constituent are listed in table 4. Each constituent and the associated regression equations are described for each site in this section.

Table 3. Summary of measurements of specific conductance and turbidity made in the cross section at the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), and comparisons to data recorded by the continuous monitor.

[ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; FNU, formazin nephelometric units; --, no data]

Dates (month/day/year)	Daily mean streamflow for the Red Lake River, in ft³/s	Percent of flow in the Red River of the North composed by the Red Lake River	Specific conductance, in µS/cm at 25 °C					Turbidity, in FNU				
			Number of measurements in cross section	Mean of cross section measurements	Range in measurements in cross section	Value from continuous monitor	Percent difference between cross section mean and monitor value	Number of measurements in cross section	Mean of cross section measurements	Range in measurements in cross section	Value from continuous monitor	Percent difference between cross section mean and monitor value
04/10/2007	1,750	9	10	623	95	622	0	0	--	--	--	--
05/14/2007	669	5	10	781	19	778	0	10	180	10	180	0
05/30/2007	1,150	10	10	592	15	592	0	10	251	40	270	7
07/09/2007	1,510	17	10	774	95	--	--	0	--	--	--	--
07/16/2007	1,400	20	10	799	173	--	--	10	180	50	--	--
08/29/2007	237	17	11	707	14	701	1	11	35	3.0	35	1
10/17/2007	407	25	10	715	9	701	2	10	24	2.0	22	8
01/09/2008	317	24	10	746	20	763	2	10	3.9	1.9	5	17
04/29/2008	1,510	22	33	695	90	--	--	33	97	28	--	--
05/14/2008	898	15	31	732	68	738	1	31	120	40	120	0
06/02/2008	887	24	31	697	6	690	1	31	46	8.0	49	6
06/10/2008	2,460	19	34	593	16	590	0	34	390	80	430	10
06/16/2008	3,110	15	41	556	22	550	1	41	260	100	280	7
08/04/2008	296	13	30	616	19	630	2	30	77	10	76	2
08/18/2008	335	6	31	427	11	427	0	31	660	50	750	13
10/28/2008	1,180	13	13	836	60	814	3	13	72	11	68	5
01/27/2009	280	13	11	816	17	--	--	11	2.3	1.2	--	--
04/11/2009	8,820	14	51	400	137	--	--	51	110	95	--	--
05/12/2009	2,460	10	28	660	183	--	--	28	87	66	--	--
06/10/2009	1,600	20	22	777	118	755	3	22	65	15	65	0
06/23/2009	1,270	9	22	507	14	502	1	22	260	30	270	4
08/03/2009	664	21	13	676	28	--	--	13	65	35	--	--
08/18/2009	2,740	40	13	498	50	483	3	13	150	20	190	24
10/07/2009	603	14	10	661	29	652	1	10	180	10	170	6
01/21/2010	713	26	10	731	34	732	0	10	5.1	0.5	5.9	14
03/24/2010	5,190	8	10	325	34	327	1	10	110	108	130	17
04/13/2010	1,200	5	10	684	143	678	1	10	68	55	110	47
01/24/2011	1,120	21	10	786	4	794	1	10	10	6.9	7.7	22
04/26/2011	6,760	12	11	723	264	719	1	11	66	45	87	28
08/10/2011	1,650	8	10	755	132	731	3	10	97	30	110	13
02/16/2012	4,095	67	10	703	76	--	--	10	6.8	0.9	--	--
08/08/2012	522	20	10	711	41	724	2	0	--	--	--	--

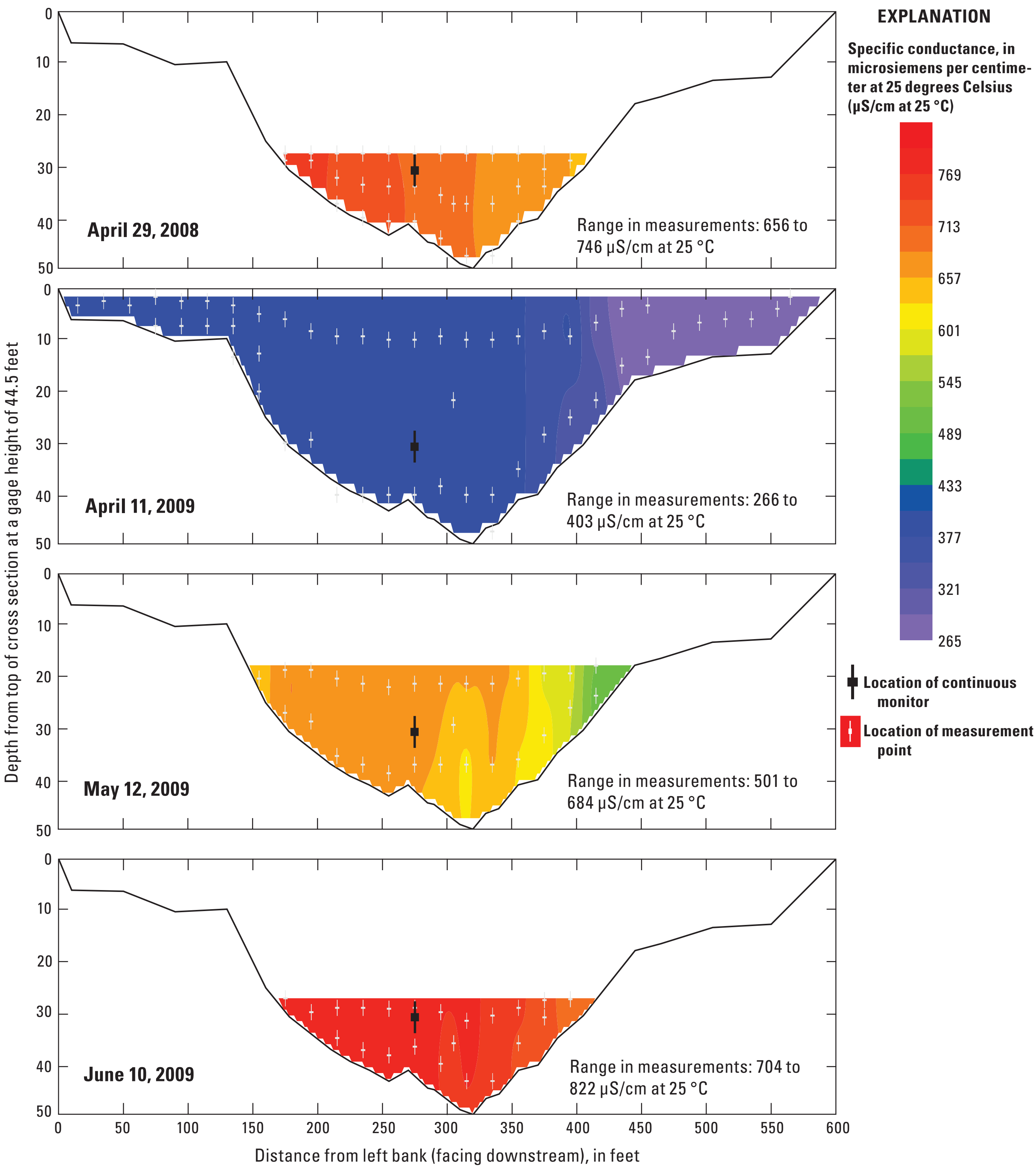


Figure 5. Distribution of specific conductance measured in the cross section at the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), on April 29, 2008 and on April 11, May 12, and June 10, 2009.

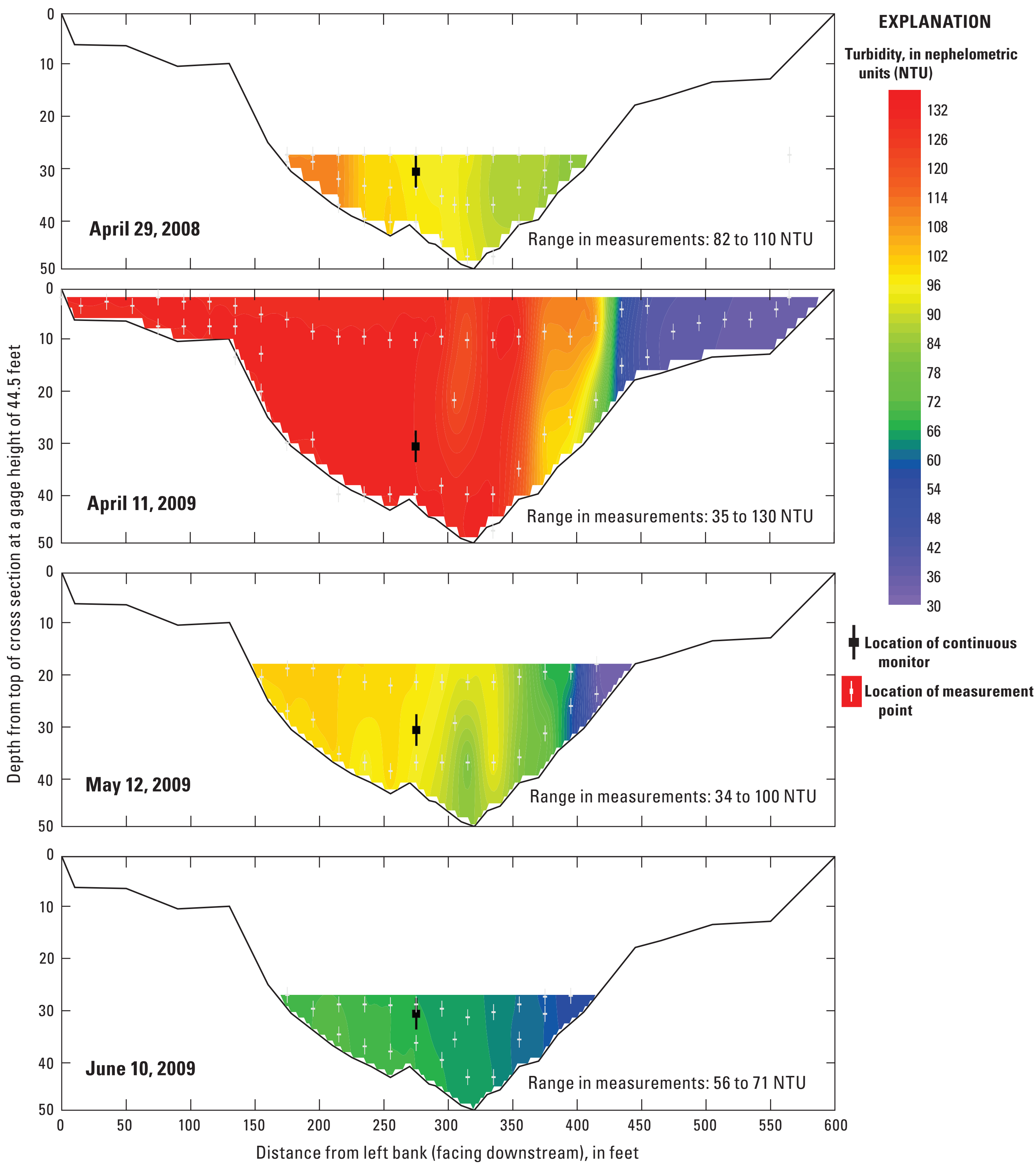


Figure 6. Distribution of turbidity measured in the cross section at the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), on April 29, 2008 and on April 11, May 12, and June 10, 2009.

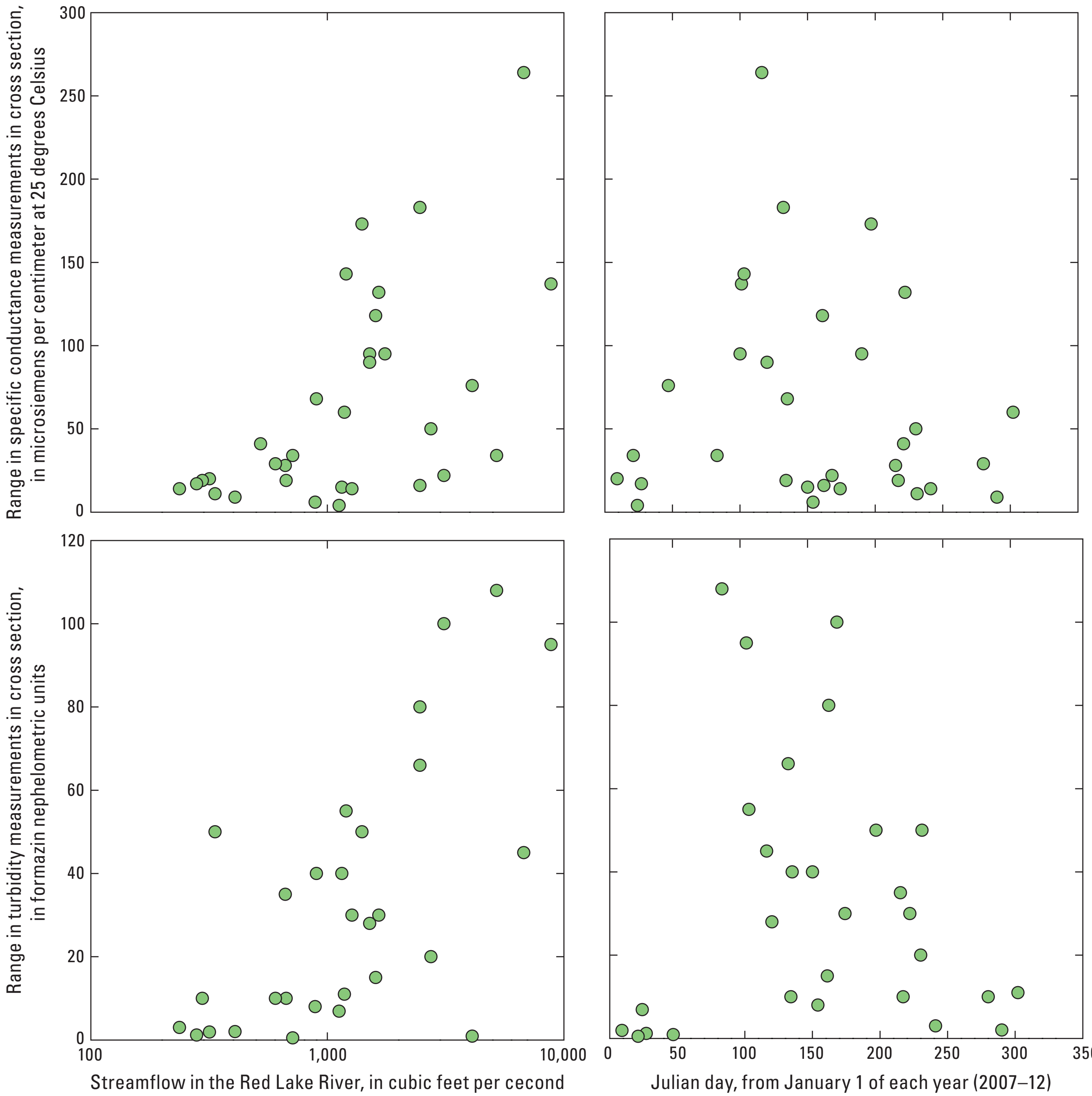


Figure 7. Comparison of the range in specific conductance and turbidity measured at the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), with daily mean streamflow in the Red Lake River measured at Fisher, Minnesota (U.S. Geological Survey streamgage 05080000).

Red River of the North at Fargo

Many influences and sources affect water-quality constituents such as DS, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended sediment in the Red River at Fargo. Influences such as urban runoff, agricultural runoff, upstream tributary contributions, and groundwater discharges can affect these constituents. Effects of influences are reflected in the significance of explanatory variables and in the ability of the developed regression equations to adequately describe the variability of the constituents. The regression equations developed for the Red River at Fargo are described in this section.

Dissolved Solids

DS in streams are composed of major ions (such as calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride) and many other constituents that are present in small quantities. The relative concentrations of the constituent components that make up DS concentrations can vary from location to location and can vary at different times of year at the same location.

SC provides a general indication of the content of dissolved material in water that is not too saline or too dilute (Hem, 1985), and was determined to be a significant explanatory variable for estimating DS concentrations at the Red River at Fargo (table 4). Similar to the results of the regression analysis in Ryberg (2006), streamflow was not determined to be a significant predictor variable. The full ranges of values measured for discrete samples collected at Fargo are shown in table 1. The range of DS concentrations used in the regression analysis (75 samples) was 211 to 670 mg/L and the range of SC for those samples was 334 to 1,060 µS/cm at 25 °C.

Estimated DS concentrations were compared to measured concentrations at Fargo (fig. 8). One sample was removed from the analysis to develop the final equation because the residual was greater than three standard deviations from zero. The regression equation (table 4) provided a good relation between DS concentrations and SC with a standard deviation of 12.20, an R_a^2 of 0.99, and an RPD of 1.3 (table 4). DS concentrations also were estimated from the continuous monitor data for the period of record (fig. 9).

Sulfate

Sulfur is naturally present in soils in the Red River Basin. Sulfur is readily oxidized to produce sulfate ions that are highly soluble (Hem, 1985). Sulfate in streams may be affected by land-use changes that can increase or decrease the

Table 4. Regression equations for estimates of dissolved solids, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended sediment at the Red River of the North at Fargo (U.S. Geological Survey streamgage 05054000) and at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2003–12.

[n, numbers of samples used to develop regression equation; R_a^2, adjusted coefficient of determination; RPD, relative percentage difference; BCF, bias correction factor; --, no data; *SC*, specific conductance; *Q*, streamflow; *t*, Julian day referenced from January 1, 2003; *Turb*, turbidity]

Constituent	n	Equation	Standard deviation	R_a^2	Median RPD	BCF
		Red River of the North at Fargo, North Dakota				
Dissolved solids (*DS*)	75	$DS = 0.655SC - 21.695$	12.20	0.99	1.3	--
Sulfate (SO_4)	75	$SO_4 = 0.426SC + 56.520\log_{10}(Q) - 7.248\cos(4\pi t/365) - 5.918\sin(4\pi t/365) - 324.158$	17.86	0.94	6.7	--
Choride (*Cl*)	69	$\log_{10}(Cl) = 0.609\log_{10}(SC) + 0.160\log_{10}(Q) - 0.0359\cos(4\pi t/365) - 0.00734\sin(4\pi t/365) - 0.0264$	0.07	0.66	9.2	1.0100
Nitrate plus nitrite (NO_3NO_2)	84	$\log_{10}(NO_3NO_2) = 0.578\log_{10}(Turb) + 0.418\log_{10}(Q) - 3.146$	0.35	0.46	51.8	1.3765
Total phosphorus (*TP*)	84	$\log_{10}(TP) = 0.468\log_{10}(Turb) + 0.217\log_{10}(Q) + 0.00881\cos(2\pi t/365) - 0.137\sin(2\pi t/365) - 2.253$	0.12	0.74	12.1	1.5743
Suspended sediment (*SSC*)	96	$\log_{10}(SSC) = 0.947\log_{10}(Turb) + 0.128\log_{10}(Q) - 0.0656$	0.10	0.95	12.7	1.0278
		Red River of the North at Grand Forks, North Dakota				
Dissolved solids (*DS*)	66	$DS = 0.642SC - 13.701$	12.49	0.98	1.7	--
Sulfate (SO_4)	65	$SO_4 = 0.353SC + 36.406\log_{10}(Q) - 11.011\cos(2\pi t/365) - 6.178\sin(2\pi t/365) - 239.31$	14.67	0.89	8.1	--
Choride (*Cl*)	64	$\log_{10}(Cl) = 0.911\log_{10}(SC) + 0.141\log_{10}(Q) - 0.0391\cos(4\pi t/365) - 0.0209\sin(4\pi t/365) - 0.0000229t - 0.928$	0.06	0.77	9.8	1.0020
Nitrate plus nitrite (NO_3NO_2)	37	$NO_3NO_2 = 0.00655Turb - 0.133$	0.32	0.73	54.2	--
Total phosphorus (*TP*)	40	$TP = 0.000859Turb + 0.0824\log_{10}(Q) + 0.0182\cos(2\pi t/365) - 0.0413\sin(2\pi t/365) - 0.181$	0.04	0.87	10.7	--
Suspended sediment (*SSC*)	35	$\log_{10}(SSC) = 0.970\log_{10}(Turb) + 0.312$	0.10	0.96	11.9	1.0272

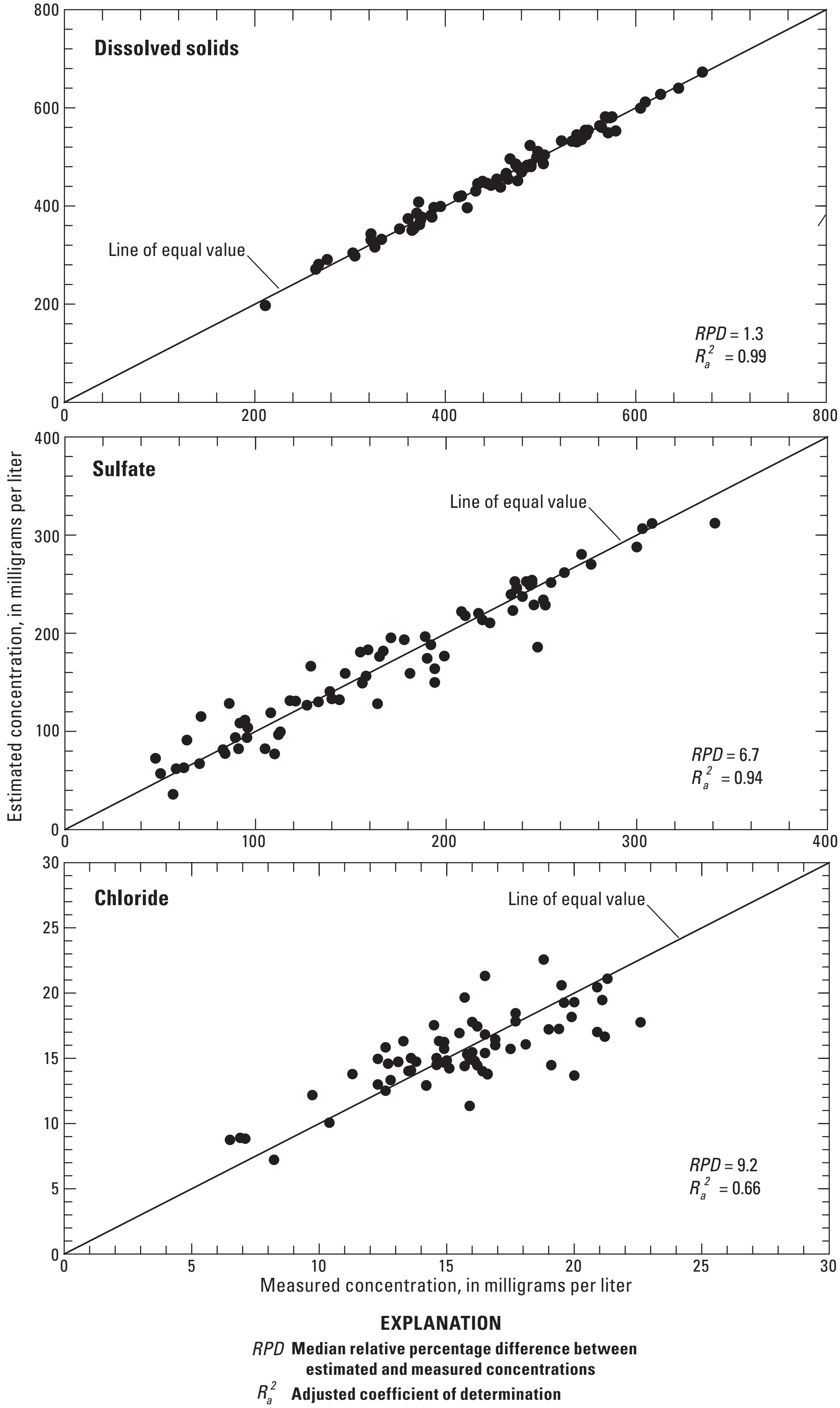


Figure 8. Comparison of measured and estimated dissolved solids, sulfate, and chloride concentrations in the Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000), 2003–12.

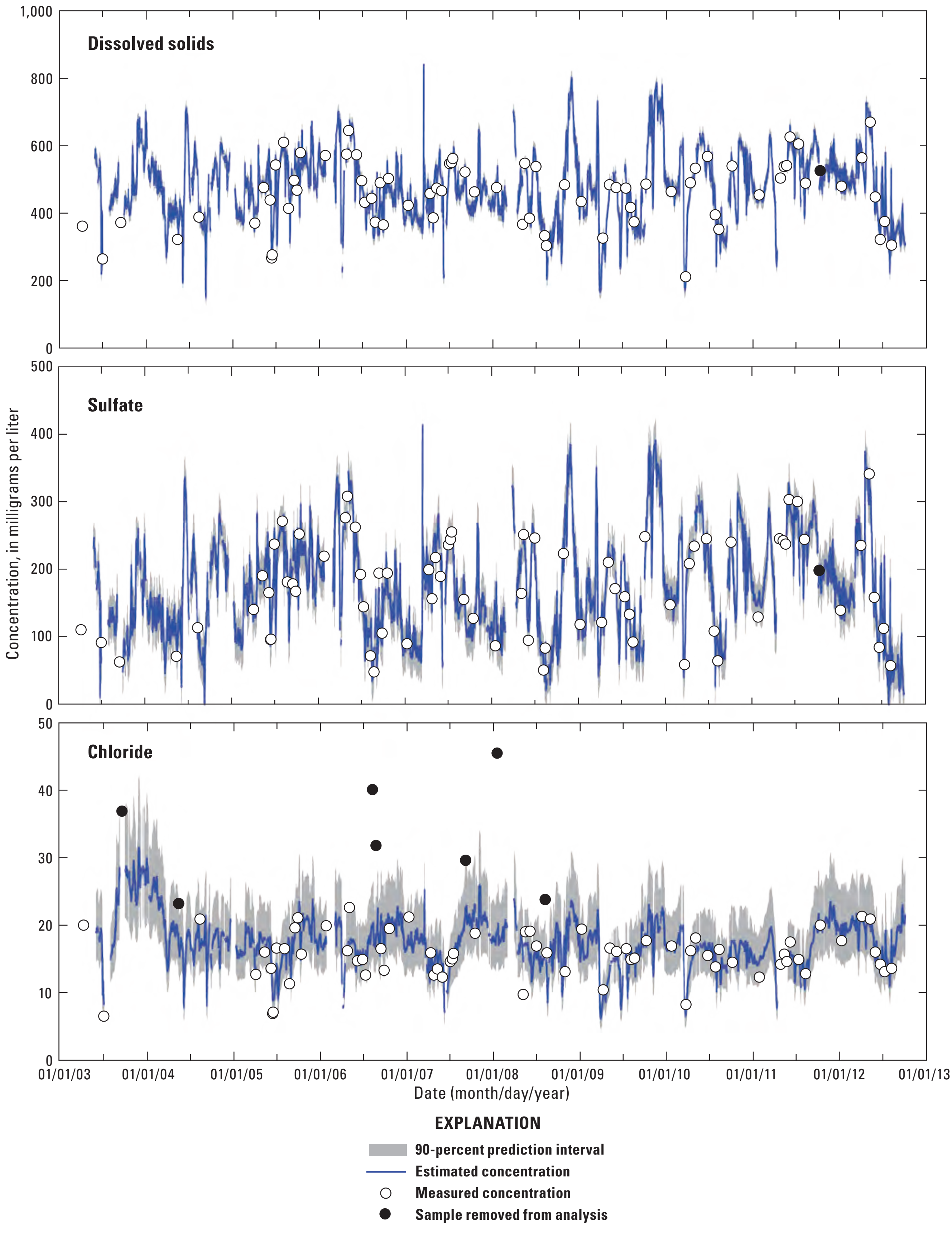


Figure 9. Estimated dissolved solids, sulfate, and chloride concentrations, 90-percent prediction intervals, and measured concentrations used in regression analyses for the Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000), 2003–12.

exposure of soils containing sulfur or sulfate-rich salts such as gypsum to surface runoff. Human sources of sulfate, such as emissions from burning fossil fuels and wastewater discharge from mining and industrial operations, also may affect sulfate concentrations in streams.

For the Red River at Fargo, SC, log-transformed streamflow, and a seasonal component were statistically significant explanatory variables for estimating sulfate (table 4). The range of sulfate concentrations used in the regression analysis (75 samples) was 48 to 341 mg/L, the range of SC was 334 to 1,060 µS/cm at 25 °C, and the range of streamflow was 104 to 18,900 ft^3/s. The full ranges of values measured for discrete samples collected at Fargo are shown in table 1.

Estimated sulfate concentrations were compared to measured concentrations at Fargo (fig. 8). One sample was removed from the analysis to develop the final equation because the residual was greater than three standard deviations from zero (fig. 9). The regression equation (table 4) provided a good relation between sulfate concentrations, SC, log-transformed streamflow, and season with a standard deviation of 17.86, an R_a^2 of 0.94, and an RPD of 6.7 (table 4). Sulfate concentrations also were estimated from the continuous monitor data for the period of record (fig. 9).

Chloride

Chloride, like sulfur, is naturally present in soils in the Red River Basin. Chloride also is highly soluble, but generally occurs in much smaller amounts in soils compared to sulfur. In contrast to other ions, most of the chloride content in streams is in the form of ionized chloride (Hem, 1985). Human activities such as roadway and driveway de-icing and industrial and municipal wastewater discharge also may introduce chloride to streams.

For the Red River at Fargo, log-transformed SC, log-transformed streamflow, and a seasonal component were statistically significant explanatory variables for estimating chloride (log-transformed) (table 4). The range of chloride concentrations used in the regression analysis (69 samples) was 6.5 to 45.5 mg/L, the range of SC was 334 to 1,060 µS/cm at 25 °C, and the range of streamflow was 104 to 18,900 ft^3/s. The full ranges of values measured for discrete samples collected at Fargo are shown in table 1.

Estimated chloride concentrations were compared to measured concentrations at Fargo (fig. 8). Seven samples were removed from the analysis to develop the final equation because the residuals were greater than three standard deviations from zero. The regression equation provided a fair relation between chloride concentrations, SC, log-transformed streamflow, and season with a standard deviation of 0.07, an R_a^2 of 0.66, and an RPD of 9.2 (table 4). Some of the variability that was not explained by the regression equation (table 4) might be attributed to the influence of releases from Lake Traverse on the Bois de Sioux River described earlier in the “Continuous Water Quality” section of this report, or from the influences of groundwater discharge, or runoff containing de-icing material from roadways in the spring during snowmelt. Chloride concentrations also were estimated from the continuous monitor data for the period of record (fig. 9).

Nitrate Plus Nitrite

Nutrient dynamics are controlled by activities in the basin and processes that occur in the stream. Wastewater-treatment plant discharge can be a major point source of nitrogen (mainly nitrate). Septic systems can act as point sources as nutrients migrate through the groundwater system into the stream. The influence of point sources usually is more evident during base-flow conditions in a stream because concentrations are less affected by dilution. Nonpoint sources of nitrogen mainly are delivered during runoff events as rainfall washes material off the landscape into the stream, resulting in greater concentrations during high-flow conditions. Some nonpoint sources of nutrients include runoff from agricultural areas, where fertilizers are applied or livestock production occurs; runoff from urban areas, where fertilizers are applied to lawns, shrubs, and trees; and from atmospheric deposition of nitrogen. Natural sources of nitrogen can include fixation of atmospheric nitrogen by plants and animals (Hem, 1985). Instream processes also can affect nutrient concentrations (Allan, 1995). Aquatic vegetation, particularly algae, depends on nitrogen and phosphorus for its food supply. Nitrate is the most stable ion of nitrogen over a wide range of conditions and is readily assimilated by algae.

For the Red River at Fargo, log-transformed turbidity and log-transformed streamflow were statistically significant explanatory variables for estimating nitrate plus nitrite concentrations (log-transformed) (table 4). The full ranges of values measured for discrete samples collected at Fargo are shown in table 1. The range of nitrate plus nitrite concentrations used in the regression analysis (84 samples) was 0.03 to 2.14 mg/L as nitrogen, the range of turbidity was 10 to 810 FNU, and the range of streamflow was 104 to 18,900 ft^3/s.

Estimated nitrate plus nitrite concentrations were compared to measured concentrations at Fargo (fig. 10). Eight samples were removed from the analysis to develop the final equation. The eight samples had associated turbidities of less than 10 FNU and were mostly collected during ice conditions in January (one was collected in June 2011). Because no samples with associated turbidities less than 10 FNU were used in developing the equation, estimated concentrations using turbidities less than 10 FNU may not be valid. The regression equation (table 4) provided a relatively poor relation between nitrate plus nitrite concentrations, log-transformed turbidity, and log-transformed streamflow, with a standard deviation of 0.35, an R_a^2 of 0.46, and an RPD of 51.8 (table 4). Some of the variability that was not explained by the regression equation might be attributed to different sources contributing nitrates to the stream at different times. Nitrate plus nitrite concentrations could increase in streams from groundwater discharge, septic systems, subsurface drainage systems, and wastewater treatment plant discharges throughout the year,

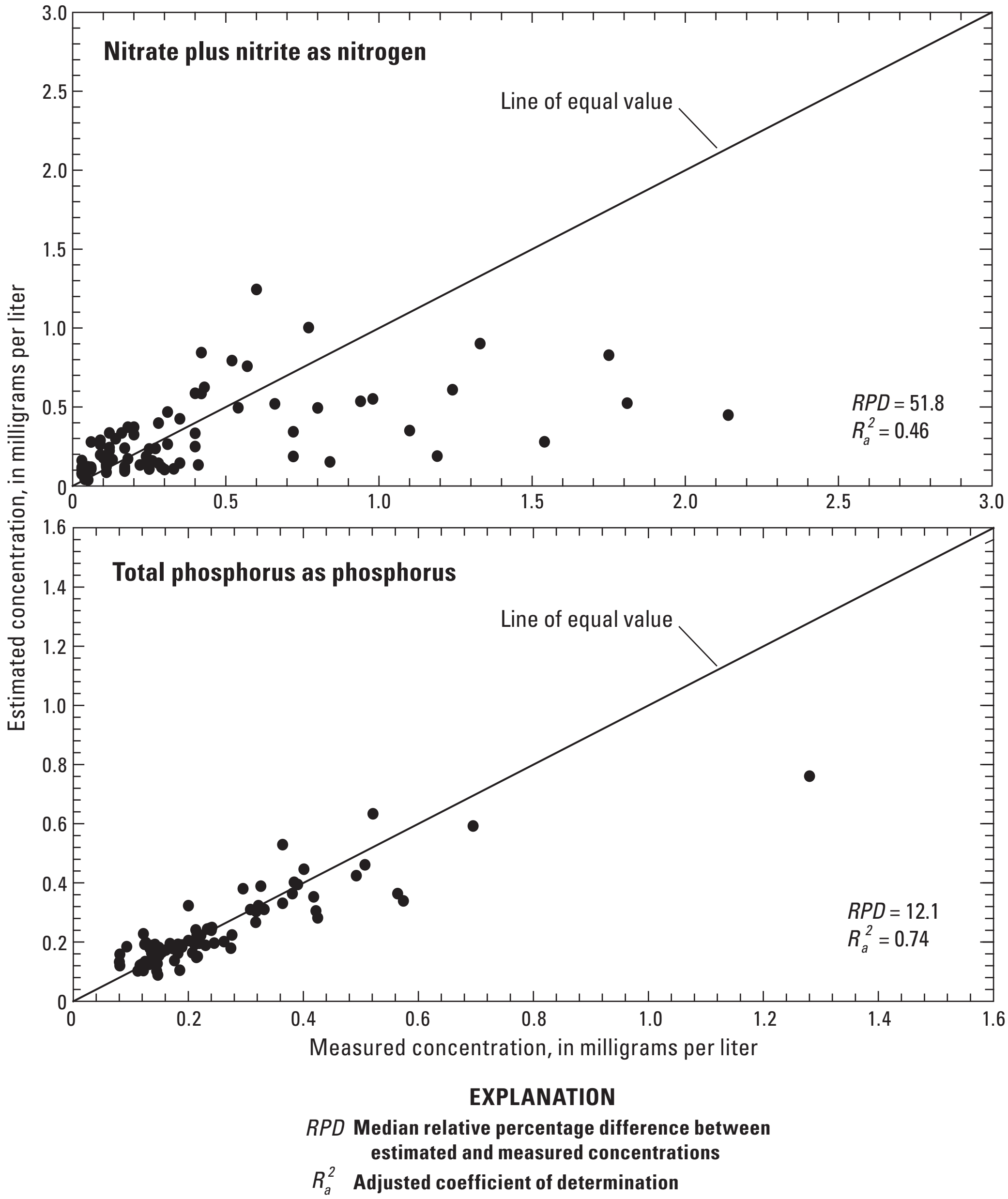


Figure 10. Comparison of measured and estimated nitrate plus nitrite and total phosphorus concentrations in the Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000), 2003–12.

and may be more evident during periods of low streamflow. Therefore, concentrations could increase although turbidity and streamflow may not. However, rainfall-runoff events may also transport nitrates to the stream, where there would be an associated increase in streamflow and turbidity. In addition, more nitrates may be available for transport at different times of the year during rainfall-runoff events based on the timing of the application of fertilizers from urban and agricultural areas, so the relation of nitrate plus nitrite, streamflow, and turbidity may widely vary even when comparing rainfall-runoff events. Nitrate plus nitrite concentrations were estimated from the continuous monitor data for the period of record (fig. 11). The wide variability can be seen from the wide 90-percent prediction interval (fig. 11) and the differences between estimated and measured concentrations (figs. 10 and 11).

Total Phosphorus

Like nitrogen, phosphorus concentrations are controlled by activities in the basin and processes that occur in the stream. Potential sources of phosphorus in streams include natural sources, animal waste, fertilizer application,

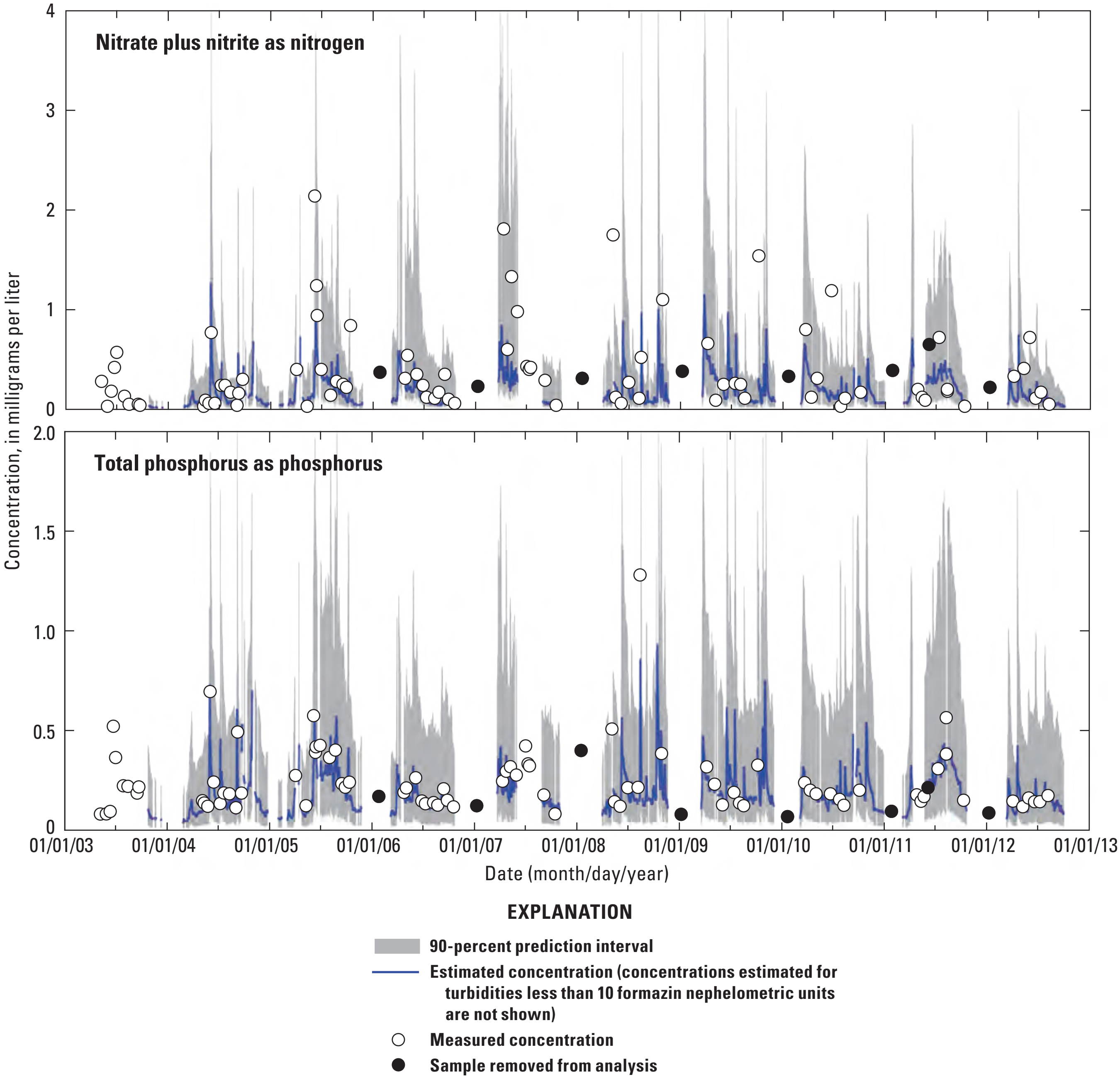
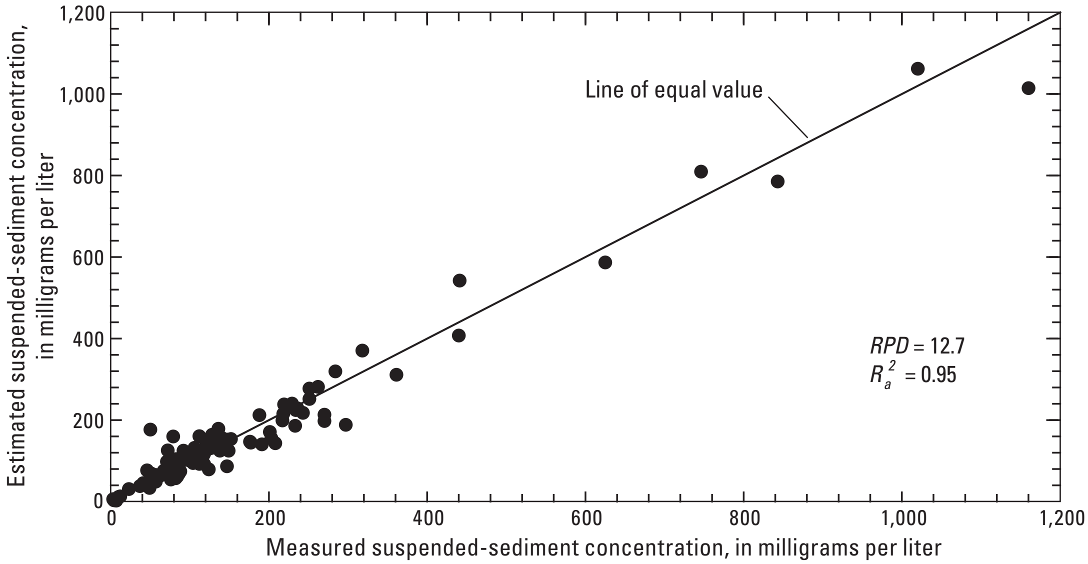


Figure 11. Estimated nitrate plus nitrite and total phosphorus concentrations, 90-percent prediction intervals, and measured concentrations used in regression analyses for the Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000), 2003–12. [Estimated concentrations for turbidities less than 10 formazin nephelometric units not shown]

wastewater-treatment plant discharge, and septic systems. Natural sources of phosphorus include phosphorus-bearing rocks or minerals in the soil and oxidation of organic matter, including soil organic matter and decaying plants and animals (Hem, 1985). Total phosphorus concentrations include inorganic phosphorus (in solution, complexed with iron or other trace elements, or adsorbed to sediment particles) and organic phosphorus.

Because phosphorus can adsorb to sediment particles that can enter a stream during runoff events, higher concentrations of total phosphorus often are associated with higher turbidity and higher streamflow. For the Red River at Fargo, log-transformed turbidity and streamflow and a seasonal component were statistically significant explanatory variables for estimating total phosphorus (log-transformed) (table 4). The range of total phosphorus concentrations used in the regression analysis (84 samples) was 0.07 to 1.28 mg/L as phosphorus, the range



EXPLANATION

RPD **Median relative percentage difference between estimated and measured concentrations**

R_a^2 **Adjusted coefficient of determination**

Figure12. Comparison of measured and estimated suspended-sediment concentrations in the Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000), 2003–12.

of turbidity was 10 to 810 FNU, and the range of streamflow was 104 to 18,900 ft^3/s. The full ranges of values measured for discrete samples collected at Fargo are shown in table 1.

Estimated total phosphorus concentrations were compared to measured concentrations at Fargo (fig. 10). Eight samples were removed from the analysis that had associated turbidities of less than 10 FNU and were mostly collected during ice conditions in January (one was collected in June 2011). Because no samples with associated turbidities less than 10 FNU were used in developing the equation, estimated concentrations using turbidities less than 10 FNU may not be valid. The regression equation (table 4) provided a relatively fair relation between total phosphorus concentrations, log-transformed turbidity, log-transformed streamflow, and season with a standard deviation of 0.12, an R_a^2 of 0.74, and an RPD of 12.1 (table 4). Total phosphorus concentrations also were estimated from the continuous monitor data for the period of record (fig. 11).

Suspended Sediment

Suspended sediment in water is the particulate matter that consists of soil and rock particles eroded from the landscape. Sediment can be transported in the water column or can settle to the streambed. The movement of suspended sediment in streams is important in the fate and transport of chemicals in the environment because the particles can sorb nutrients, trace elements, and organic compounds. Large concentrations of suspended sediment often are associated with storm-runoff events that increase streamflow, erosion, and resuspension of bed material (Guy, 1970). Activities such as row-crop agriculture, animal grazing, timber harvesting, mining, road construction and maintenance, and urbanization can cause increased sediment concentrations in streams (Guy, 1970).

Because sediment particles enter a stream or are resuspended primarily during runoff events, high concentrations of suspended sediment often are correlated with high turbidity and high streamflow. For the Red River at Fargo, log-transformed turbidity and streamflow were statistically significant explanatory variables for estimating SSC (log-transformed) (table 4). The range of SSC used in the regression analysis (96 samples) was 3 to 1,160 mg/L, the range of turbidity was 1 to 810 FNU, and the range of streamflow was 149 to 18,900 ft^3/s. The full ranges of values measured for discrete samples collected at Fargo are shown in table 1.

Estimated SSCs were compared to measured concentrations at Fargo (fig. 12). Five samples were removed from the analysis to develop the final equation because the residuals were greater than three standard deviations from zero. The regression equation (table 4) provided a good relation between SSC, log-transformed turbidity, and log-transformed streamflow, with a standard deviation of 0.10, an R_a^2 of 0.95, and an RPD of 12.7 (table 4). SSCs also were estimated from the continuous monitor data for the period of record (fig. 13).

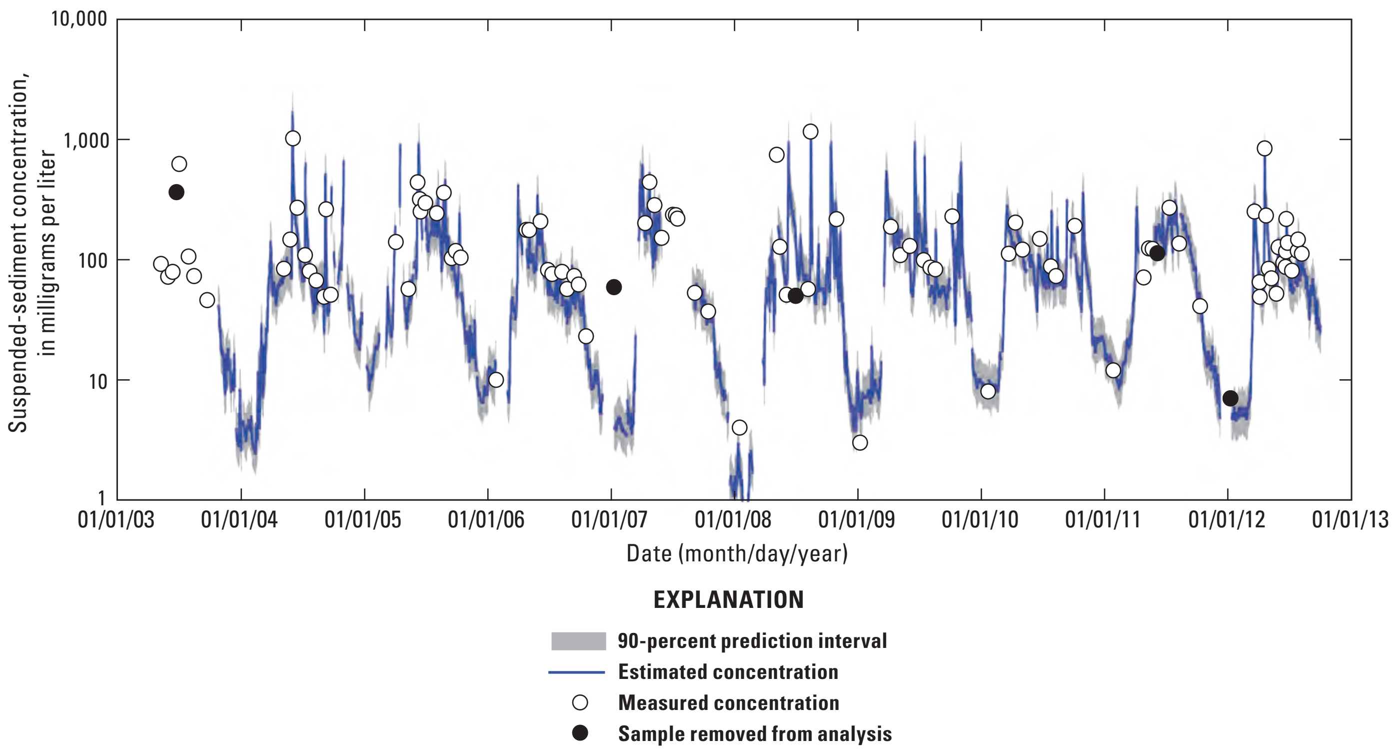


Figure 13. Estimated suspended-sediment concentrations, 90-percent prediction intervals, and measured concentrations used in regression analyses for the Red River of the North at Fargo, North Dakota (U.S. Geological Survey streamgage 05054000), 2003–12.

Red River of the North at Grand Forks

The Red River at Grand Forks represents a larger part of the Red River Basin and has different influences and sources that affect the water-quality relations compared to the site at Fargo. The site at Grand Forks has a drainage area of 26,300 mi^2, representing approximately 58 percent of the basin compared to the site at Fargo, which has a drainage area of 6,800 mi^2, representing approximately 15 percent of the Basin. The site at Grand Forks also includes the influence of the two largest tributaries in the Basin, the Sheyenne River and the Red Lake River (fig. 1). The regression equations developed for the Red River at Grand Forks are described in this section.

Dissolved Solids

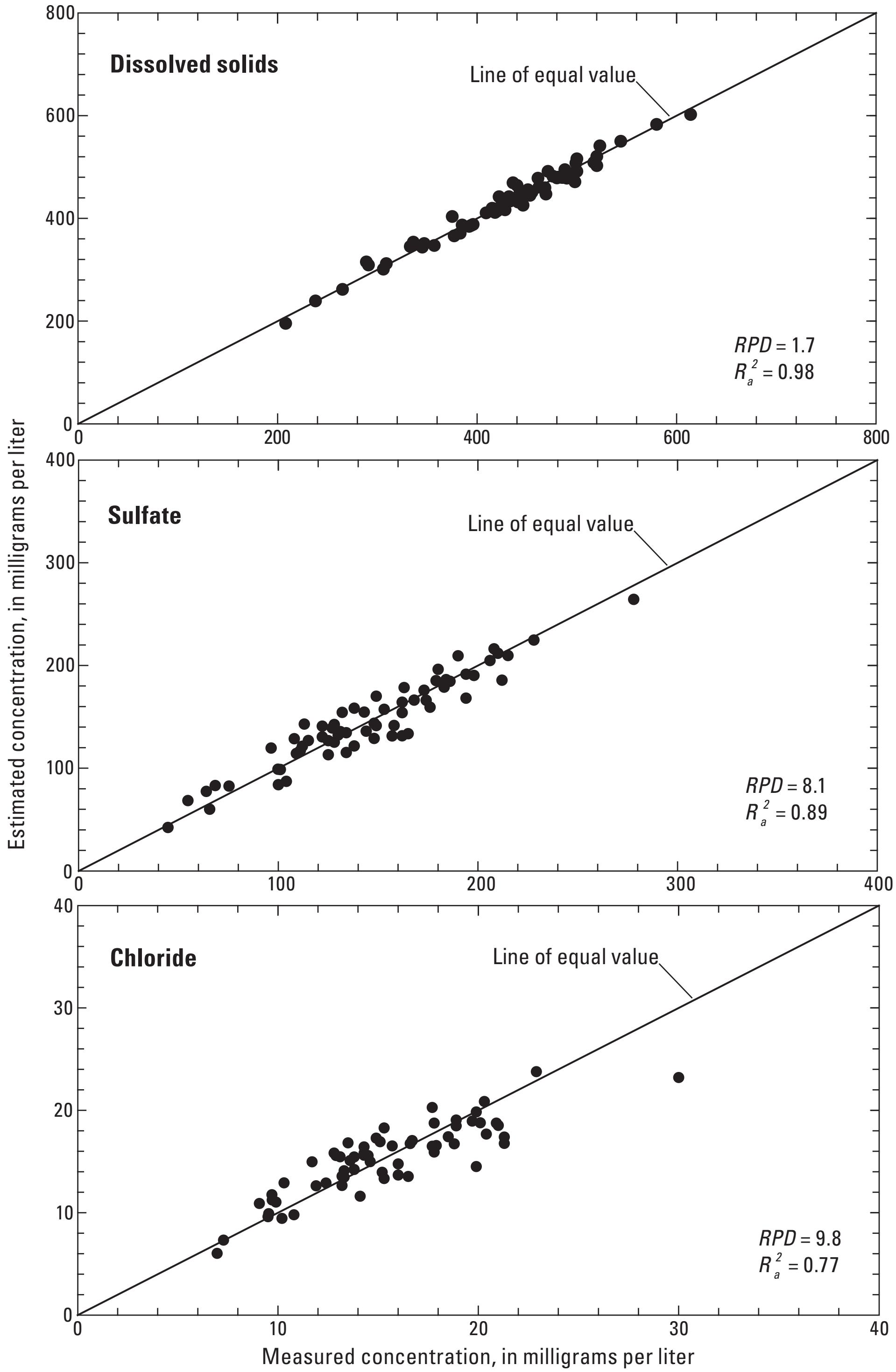
Similar to the Red River at Fargo, the SC was determined to be a significant explanatory variable for estimating DS concentrations at the Red River at Grand Forks (table 4). The full ranges of values measured for discrete samples collected at Grand Forks are shown in table 1. The range of DS concentrations used in the regression analysis (66 samples) was 208 to 614 mg/L and the range of SC was 326 to 959 µS/cm at 25 °C.

Estimated DS concentrations were compared to measured concentrations at Grand Forks (fig. 14). Three samples were removed from the analysis to develop the final equation because the residuals were greater than three standard deviations from zero. The regression equation (table 4) provided a good relation between DS concentrations and SC with a standard deviation of 12.49, an R_a^2 of 0.98, and an RPD of 1.7 (table 4). DS concentrations also were estimated from the continuous monitor data for the period of record (fig. 15). The greater variability of the measured data compared to the estimated concentrations at Grand Forks in June through August 2012 (fig. 15) likely is attributed to the influence of the Devils Lake outlets as described in the “Continuous Water Quality” section.

Sulfate

For the Red River at Grand Forks, SC, log-transformed streamflow, and a seasonal component were statistically significant explanatory variables for estimating sulfate (table 4). The full ranges of values measured for discrete samples collected at Grand Forks are shown in table 1. The range of sulfate concentrations used in the regression analysis (65 samples) was 45 to 278 mg/L, the range of SC was 326 to 959 µS/cm at 25 °C, and the range of streamflow was 389 to 59,900 ft^3/s.

Estimated sulfate concentrations were compared to measured concentrations at Grand Forks (fig. 14). Four samples were removed from the analysis to develop the final equation because the residuals were greater than three standard



EXPLANATION

RPD **Median relative percentage difference between estimated and measured concentrations**

R_a^2 **Adjusted coefficient of determination**

Figure 14. Comparison of measured and estimated dissolved solids, sulfate, and chloride concentrations in the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2003–12.

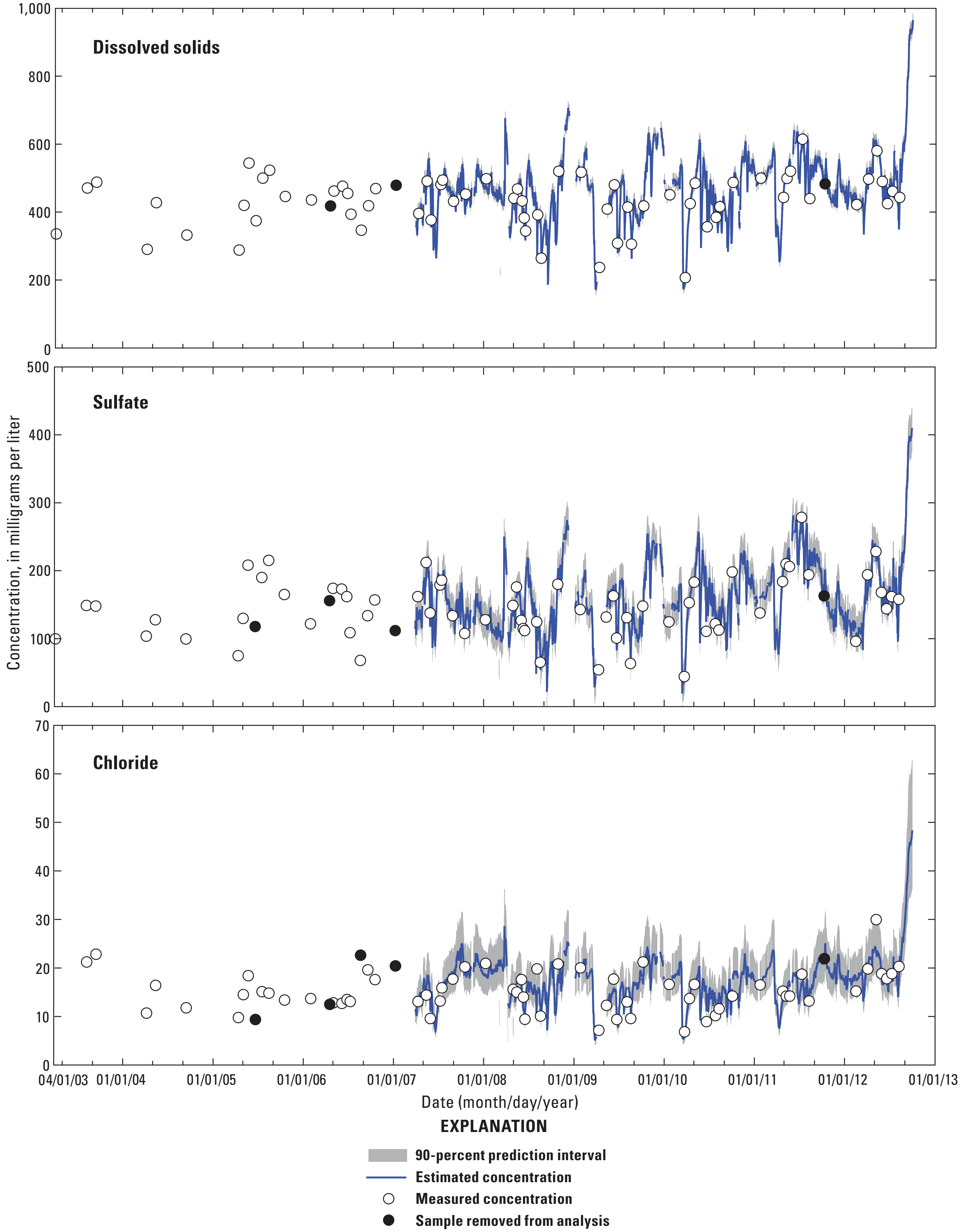


Figure 15. Estimated dissolved solids, sulfate, and chloride concentrations, 90-percent prediction intervals for 2007–12, and measured concentrations used in regression analyses from 2003–12 for the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500).

deviations from zero. The regression equation (table 4) provided a good relation between sulfate concentrations, SC, log-transformed streamflow, and season with a standard deviation of 14.67, an R_a^2 of 0.89, and an RPD of 8.1 (table 4). Sulfate concentrations also were estimated from the continuous monitor data for the period of record (fig. 15). As observed in the DS data, greater variability between measured and estimated concentrations in June through August 2012 at Grand Forks (fig. 15) likely is attributed to the influence of the Devils Lake outlets.

Chloride

For the Red River at Grand Forks, log-transformed SC, log-transformed streamflow, a seasonal component, and a time component were statistically significant explanatory variables for estimating chloride (log-transformed) (table 4). The range of chloride concentrations used in the regression analysis (64 samples) was 7.0 to 30.0 mg/L, the range of SC was 326 to 959 µS/cm at 25 °C, and the range of streamflow was 389 to 59,900 ft^3/s. The full ranges of values measured for discrete samples collected at Grand Forks are shown in table 1.

Estimated chloride concentrations were compared to measured concentrations at Grand Forks (fig. 14). Five samples were removed from the analysis to develop the final equation because the residuals were greater than three standard deviations from zero. The regression equation (table 4) provided a relatively good relation between chloride concentrations, log-transformed SC, log-transformed streamflow, season, and time with a standard deviation of 0.06, an R_a^2 of 0.77, and an RPD of 9.8 (table 4). Some of the variability that was not explained by the regression equation might be attributed to the mixing of water from the Red Lake River and from the Sheyenne River with the Red River described earlier in the “Continuous Water Quality” section. Chloride concentrations also were estimated from the continuous monitor data for the period of record (fig. 15). As observed with the DS and sulfate data, greater variability of the measured data in June through August 2012 compared to the estimated concentrations at Grand Forks (fig. 15) likely is attributed to the influence of the Devils Lake outlets as described in the “Continuous Water Quality” section.

Nitrate Plus Nitrite

For the Red River at Grand Forks, turbidity was the only statistically significant explanatory variable for estimating nitrate plus nitrite concentrations. Unlike at the Red River at Fargo, streamflow was not determined to be a significant explanatory variable and the nitrate plus nitrite concentrations were not log-transformed (table 4). The range of nitrate plus nitrite concentrations used in the regression analysis (37 samples) was less than 0.03 to 3.15 mg/L as nitrogen and the range of turbidity was 10 to 660 FNU. The full ranges of values measured for discrete samples collected at Grand Forks are shown in table 1.

Estimated nitrate plus nitrite concentrations were compared to measured concentrations at Grand Forks (fig. 16). Ten samples were removed from the analysis to develop the final equation. Five out of the 10 samples had associated turbidities of less than 10 FNU and were collected during ice conditions in January. The other five samples were removed because the residuals were greater than three standard deviations from zero. Because no samples with associated turbidities less than 10 FNU were used in developing the equation, estimated concentrations using turbidities less than 10 FNU may not be valid. The regression equation (table 4) provided a fair relation between nitrate plus nitrite concentrations and turbidity with a standard deviation of 0.32, an R_a^2 of 0.73, and an RPD of 54.2 (table 4). Similar to Fargo, some of the variability that was not explained by the regression equation (table 4) might be attributed to different sources contributing nitrates to the stream at different times of year. Nitrate plus nitrite concentrations also were estimated from the continuous monitor data for the period of record at Grand Forks (fig.17).

Total Phosphorus

Similar to the regression analysis for the Red River at Fargo, turbidity, log-transformed streamflow, and a seasonal component were statistically significant explanatory variables for estimating total phosphorus at Grand Forks (table 4). The difference in the analysis for Grand Forks was that the total phosphorus and turbidity were not log-transformed as was done at Fargo. The range of total phosphorus concentrations used in the regression analysis (40 samples) was 0.08 to 0.68 mg/L as phosphorus, the range of turbidity was 10 to 660 FNU, and the range of streamflow was 389 to 59,900 ft^3/s. The full ranges of values measured for discrete samples collected at Grand Forks are shown in table 1.

Estimated total phosphorus concentrations were compared to measured concentrations at Grand Forks (fig. 16). Seven samples were removed from the analysis to develop the final equation. Five out of the 7 samples had associated turbidities of less than 10 FNU and were collected during ice conditions in January. The other two samples were removed because the residuals were greater than three standard deviations from zero. Because no samples with associated turbidities less than 10 FNU were used in developing the equation, estimated concentrations using turbidities less than 10 FNU may not be valid. The regression equation (table 4) provided a good relation between total phosphorus concentrations, turbidity, log-transformed streamflow, and season with a standard deviation of 0.04, an R_a^2 of 0.87, and an RPD of 10.7 (table 4). Total phosphorus concentrations also were estimated from the continuous monitor data for the period of record (fig. 17).

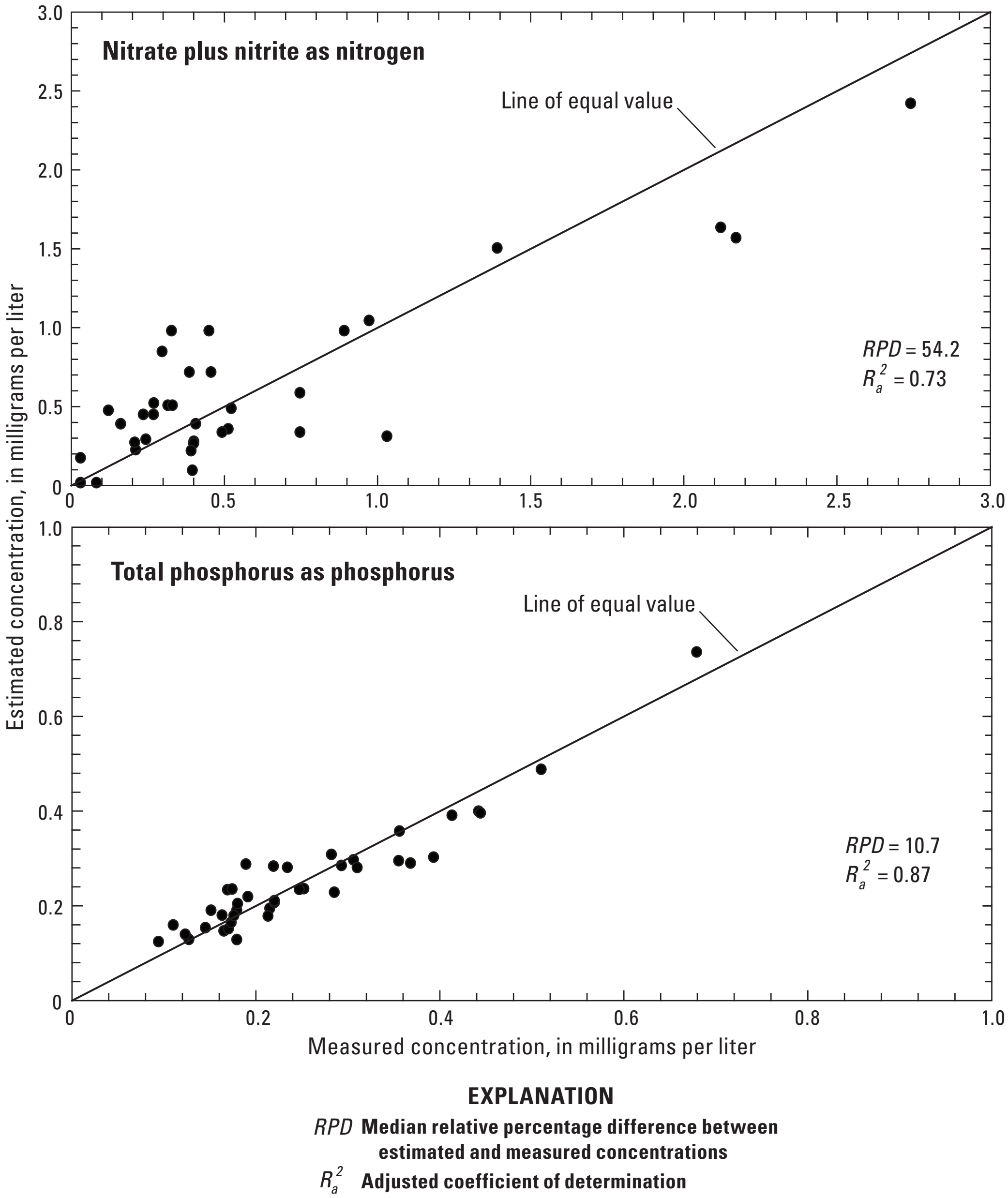


Figure 16. Comparison of measured and estimated nitrate plus nitrite and total phosphorus concentrations in the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2007–12.

Suspended Sediment

For the Red River at Grand Forks, log-transformed turbidity was the only statistically significant explanatory variables for estimating SSC (log-transformed). Unlike at the Red River at Fargo, streamflow was not determined to be a significant explanatory variable (table 4). The range of SSC used in the regression analysis (35 samples) was 4 to 1,110 mg/L and the range of turbidity was 3 to 660 FNU (table 1).

Estimated SSC were compared to measured concentrations at Grand Forks (fig. 18). Five samples were removed from the analysis to develop the final equation because the residuals were greater than three standard deviations from zero. The regression equation (table 4) provided a good relation between SSC and log-transformed turbidity with a standard deviation of 0.10, an R_a^2 of 0.96, and an RPD of 11.9 (table 4). SSCs also were estimated from the continuous monitor data for the period of record (fig. 19).

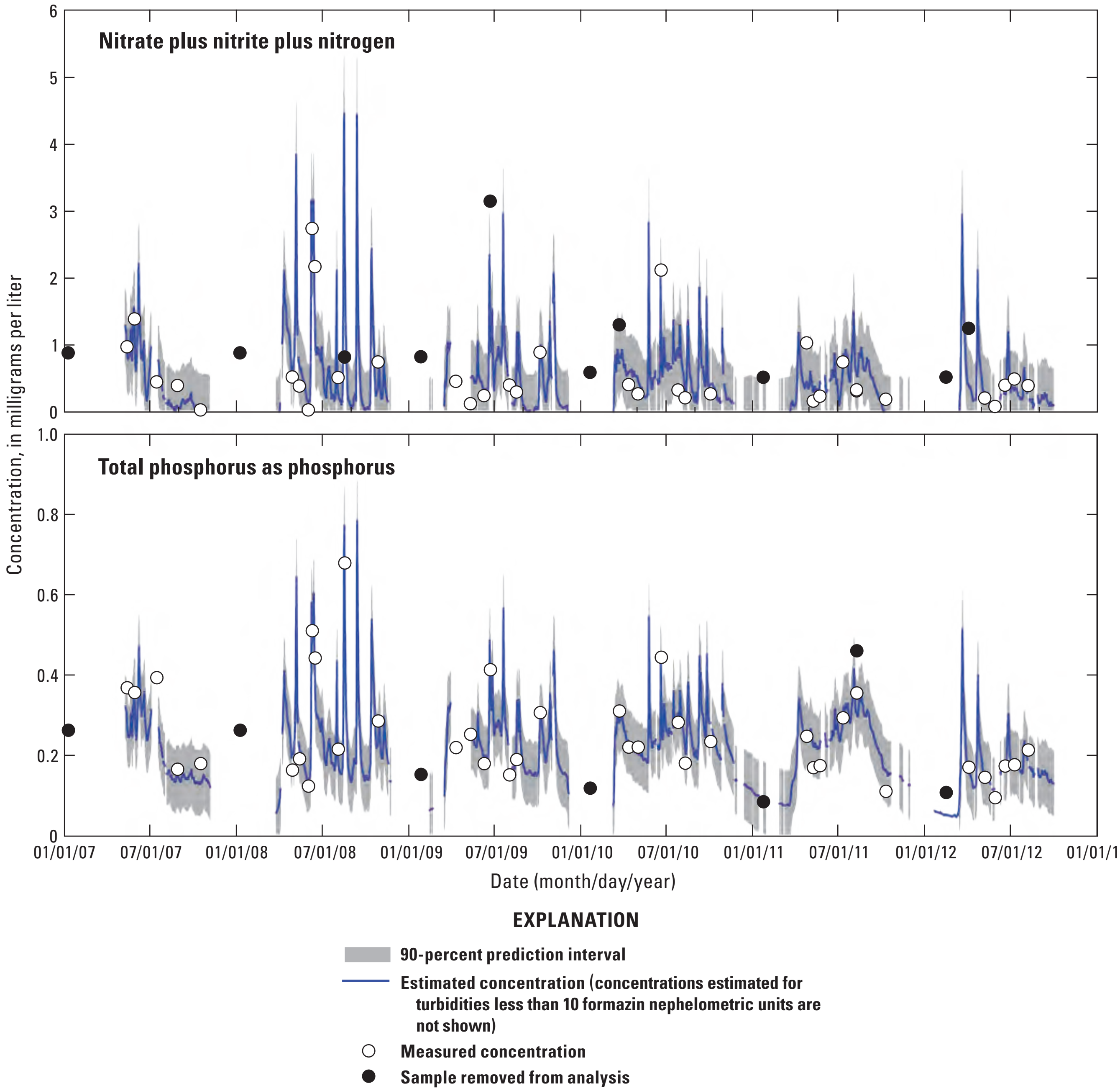
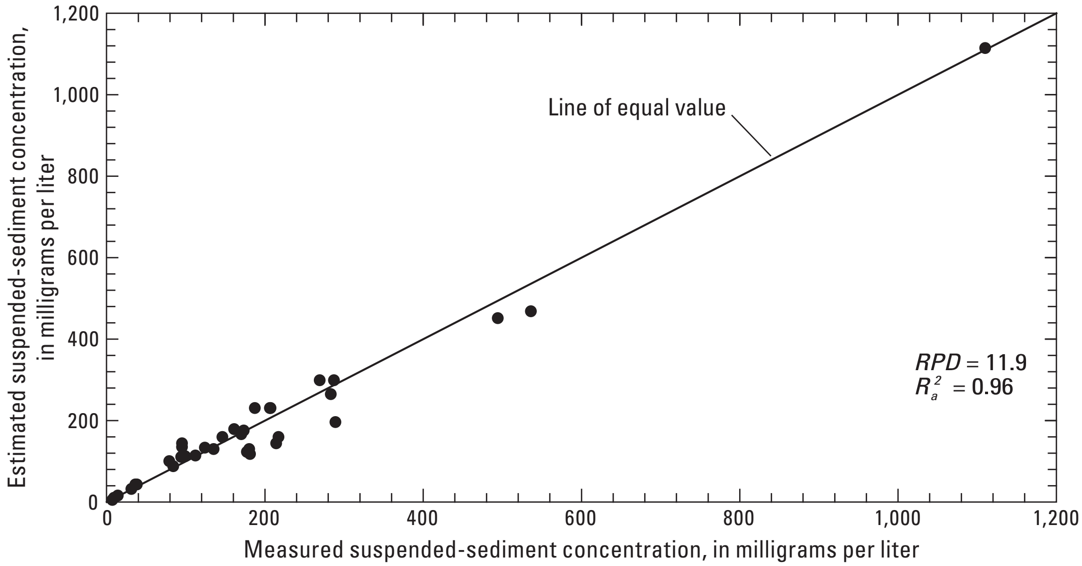


Figure 17. Estimated nitrate plus nitrite and total phosphorus concentrations, 90-percent prediction intervals, and measured concentrations used in regression analyses for the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2007–12. [Estimated concentrations for turbidities less than 10 formazin nephelometric units not shown]

Estimated Constituent Loads

Estimated annual DS, sulfate, chloride, and total phosphorus loads were greatest in 2011 and annual nitrate plus nitrite and suspended-sediment loads were greatest in 2009 at the Red River at Fargo from 2004 through 2011. Annual loads for 2012 were not included in this comparison because loads were not calculated for a full 12-month period; however, loads estimated from January to September generally were the smallest in 2012 compared to other years for that same period. The greatest loads generally were associated with the greatest annual streamflows. Annual DS loads ranged from 475,000 tons/yr (2004) to 1,840,000 tons/yr (2011) at the Red River at Fargo (table 5 and fig. 20). Annual sulfate and chloride loads ranged from 177,000 (2004) to 820,000 tons/yr (2011) and from 17,100 (2004) to 53,800 (2011) tons/yr, respectively. Annual nitrate plus nitrite and total phosphorus loads ranged from 338 (2004) to 2,100 tons/yr as nitrogen

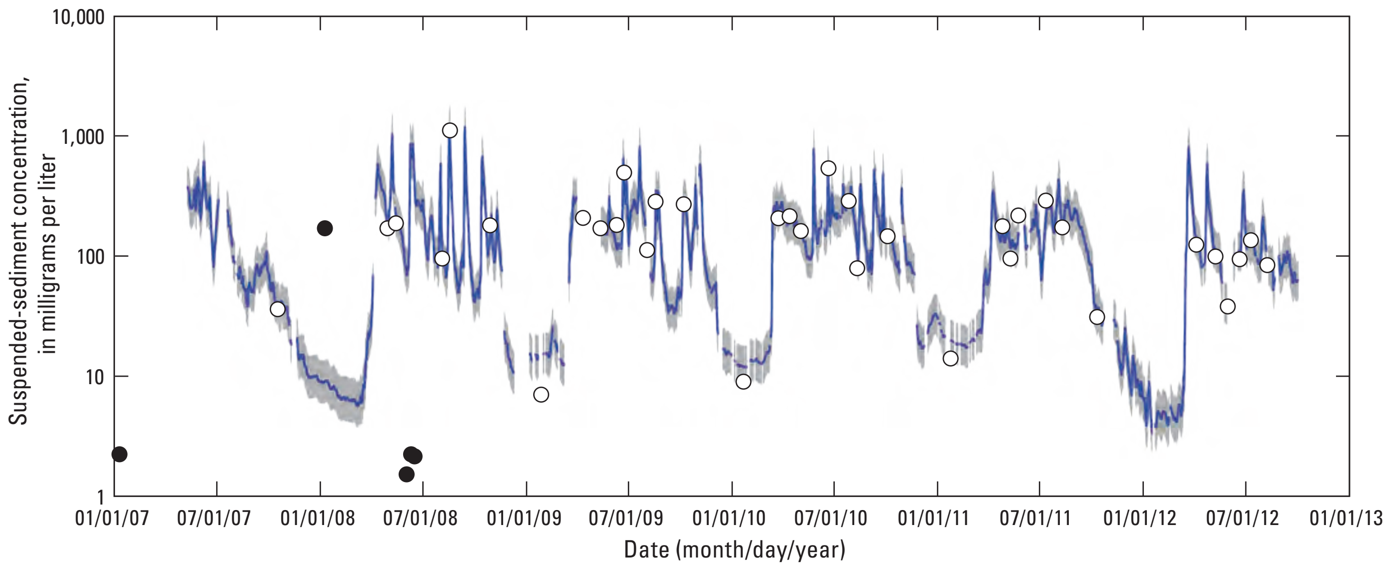


EXPLANATION

RPD **Median relative percentage difference between estimated and measured concentrations**

R_a^2 **Adjusted coefficient of determination**

Figure 18. Comparison of measured and estimated suspended-sediment concentrations in the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2003–12.



EXPLANATION

90-percent prediction interval

Estimated concentration

Measured concentration

Sample removed from analysis

Figure 19. Estimated suspended-sediment concentrations, 90-percent prediction intervals, and measured concentrations used in regression analyses for the Red River of the North at Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2007–12.

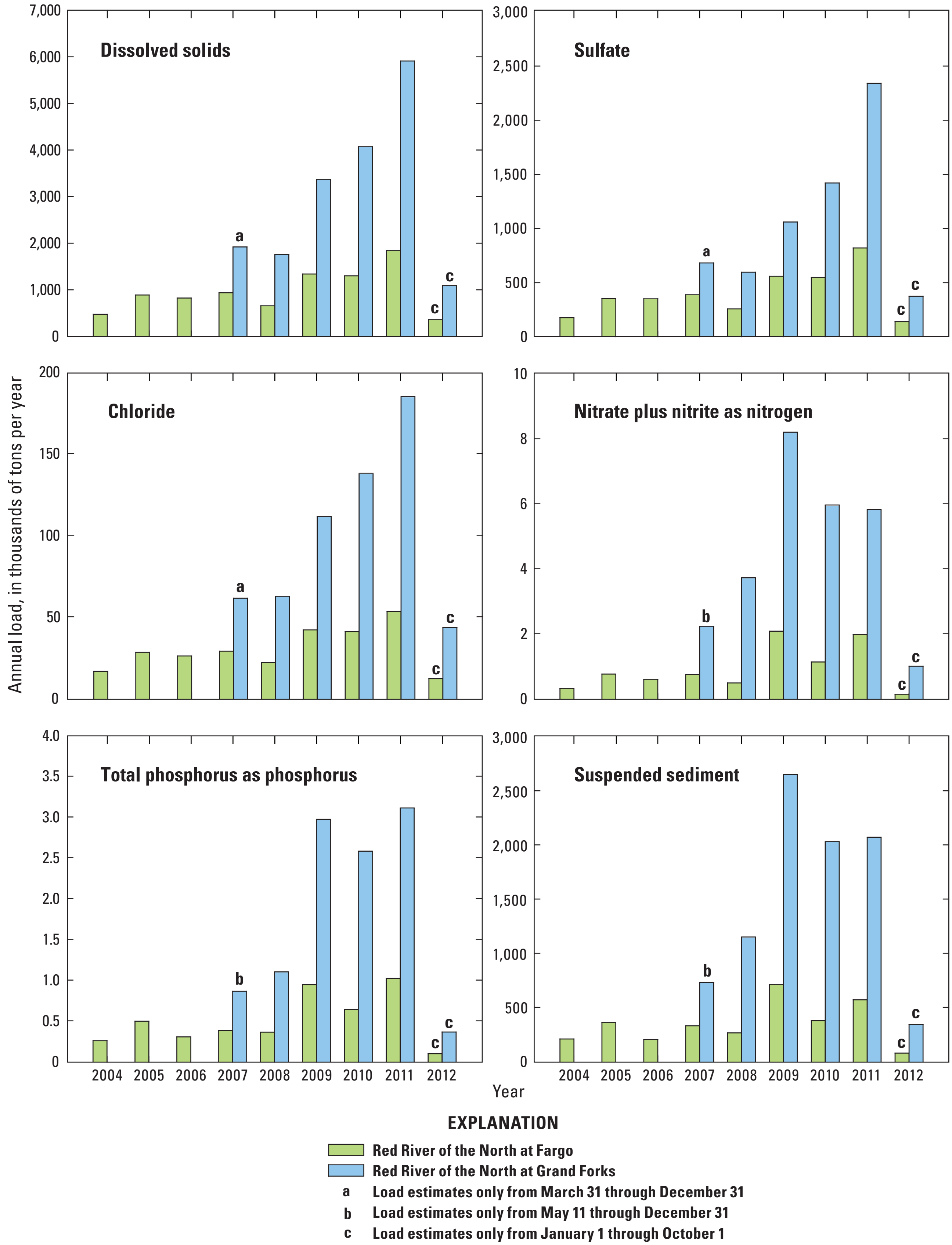


Figure 20. Estimated annual dissolved solids, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended-sediment loads in the Red River of the North at Fargo (U.S. Geological Survey streamgage 05054000) and Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2004–12.

Table 5. Estimated annual dissolved solids, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended-sediment loads in the Red River of the North at Fargo (U.S. Geological Survey streamgage 05054000) and Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2004–12.

Year	Annual load, in tons per year					
	Dissolved solids	Sulfate	Chloride	Nitrate plus nitrite as nitrogen	Total phosphorus as phosphorus	Suspended sediment
Red River of the North at Fargo, North Dakota						
2004	475,000	177,000	17,100	338	263	214,000
2005	890,000	353,000	28,800	781	503	368,000
2006	823,000	351,000	26,600	620	310	209,000
2007	939,000	388,000	29,500	766	388	336,000
2008	656,000	258,000	22,600	504	369	270,000
2009	1,340,000	559,000	42,600	2,100	950	718,000
2010	1,300,000	548,000	41,500	1,150	646	384,000
2011	1,840,000	820,000	53,800	2,000	1,020	576,000
2012	[1]360,000	[1]140,000	[1]12,700	[1]156	[1]104	[1]84,200
Red River of the North at Grand Forks, North Dakota						
2007	[2]1,920,000	[2]682,000	[2]61,900	[3]2,250	[3]869	[3]737,000
2008	1,760,000	596,000	63,200	3,720	1,100	1,150,000
2009	3,370,000	1,060,000	112,000	8,200	2,970	2,650,000
2010	4,070,000	1,420,000	138,000	5,960	2,580	2,030,000
2011	5,910,000	2,340,000	185,000	5,820	3,110	2,070,000
2012	[1]1,090,000	[1]375,000	[1]44,000	[1]1,020	[1]369	[1]348,000

[1]Load estimates only from January 1 through October 1, 2012.

[2]Load estimates only from March 31 through December 31, 2007.

[3]Load estimates only from May 11 through December 31, 2007.

(2009) and from 263 (2004) to 1,020 (2011) tons/yr as phosphorus, respectively. The annual suspended-sediment loads at Fargo ranged from 209,000 (2006) to 718,000 tons/yr (2009).

Although nitrate plus nitrite and total phosphorus concentrations were not estimated for turbidities less than 10 FNUs as described in the previous section, for the purposes of daily load calculations, concentrations were estimated for turbidities less than 10 FNUs, with the acknowledgement that those values likely had a high degree of error. However, periods of low turbidity generally coincided with periods of low streamflow, and the associated daily loads only represented a small part of the estimated annual load.

Estimated annual DS, sulfate, chloride, and total phosphorus were greatest in 2011, and nitrate plus nitrite loads and suspended-sediment loads were greatest in 2009 at the Red River at Grand Forks from 2008 through 2011 (table 5 and fig. 20). Annual loads for 2007 and 2012 were not included in this comparison because loads were not calculated for a full 12-month period; however, loads estimated from January to September generally were the smallest in 2012 compared to other years for that same period. Annual DS loads ranged from 1,760,000 (2008) to 5,910,000 tons/yr (2011) at Grand Forks and were about 3 times greater than the loads at Fargo. Annual sulfate and chloride loads ranged from 596,000 (2008) to 2,340,000 tons/yr (2011) and from 63,200 (2008) to 185,000 (2011) tons/yr, respectively. Annual nitrate plus nitrite loads ranged from 3,720 (2008) to 8,200 tons/yr as nitrogen (2009) and were about 3 to more than 7 times the annual loads estimated at Fargo. Total phosphorus loads ranged from 1,100 (2008) to 3,110 tons/yr as phosphorus (2011) and were about 3 to 4 times the annual loads estimated at Fargo. The annual suspended-sediment loads at Grand Forks ranged from 1,150,000 (2008) to 2,650,000 tons/yr (2009), approximately 4 to 5 times the estimated annual loads at Fargo. The mean annual streamflow at Grand Forks ranged from 2.4 to 3.4 times greater than the mean annual streamflow at Fargo, indicating that the greater mass of some of the constituents at Grand Forks compared to Fargo, such as nitrate plus nitrite and total phosphorus, might not be completely explained by the increased streamflow at Grand Forks. However, part of the difference between loads for nitrate plus nitrite and total phosphorus at the two sites also could be attributed to the error or uncertainty associated with the estimated concentrations at the two sites (figs. 11 and 17).

Most of the annual load was transported during spring (March and April) and early summer months (May and June),

Table 6. Mean estimated daily dissolved solids, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended-sediment daily loads in the Red River of the North at Fargo (U.S. Geological Survey streamgage 05054000) and Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2003–12.

[<, less than]

Month	Estimated mean daily loads, in pounds per day					
	Dissolved solids	Sulfate	Chloride	Nitrate plus nitrite as nitrogen	Total phosphorus as phosphorus	Suspended sediment
Red River of the North at Fargo, North Dakota (2003–12)[1]						
January	1,800,000	576,000	65,000	176	198	40,100
February	1,690,000	554,000	65,600	158	158	38,300
March	6,000,000	2,400,000	210,000	10,700	4,030	3,500,000
April	12,600,000	5,610,000	400,000	20,200	8,140	6,220,000
May	9,160,000	4,190,000	273,000	6,940	3,520	2,380,000
June	8,370,000	3,430,000	241,000	8,600	4,820	4,080,000
July	5,980,000	2,340,000	174,000	4,600	3,220	1,990,000
August	3,430,000	1,260,000	113,000	3,280	2,670	1,530,000
September	2,600,000	972,000	98,200	1,680	1,750	851,000
October	3,830,000	1,600,000	137,000	3,200	2,890	1,580,000
November	4,220,000	1,910,000	133,000	1,940	1,760	888,000
December	2,120,000	802,000	72,600	233	287	59,500
Red River of the North at Grand Forks, North Dakota (2007–12)[2]						
January	5,570,000	1,660,000	205,000	<10	875	176,000
February	5,680,000	1,720,000	219,000	<10	712	164,000
March	17,200,000	4,480,000	600,000	46,600	16,300	15,100,000
April	45,000,000	15,200,000	1,440,000	113,000	42,000	36,800,000
May	32,400,000	12,600,000	1,060,000	41,500	17,200	14,200,000
June	26,700,000	10,300,000	806,000	47,000	17,500	15,200,000
July	19,000,000	7,590,000	567,000	23,300	10,400	7,900,000
August	11,900,000	4,480,000	396,000	18,600	7,540	6,100,000
September	8,640,000	3,010,000	338,000	13,000	5,580	4,340,000
October	12,900,000	4,570,000	497,000	16,000	7,610	5,490,000
November	16,400,000	6,100,000	584,000	9,390	6,630	3,690,000
December	7,700,000	2,650,000	283,000	35	1,450	266,000

[1] Monthly loads computed for May 2003 through September 2012.

[2] Monthly loads computed for May 2007 through September 2012.

generally when streamflow was greatest in the Red River at Fargo and Grand Forks (fig. 21 and table 6). The greatest mean daily loads of DS, chloride, and sulfate occurred in April through June in the Red River at Fargo and Grand Forks. The greatest mean daily loads of nitrate plus nitrite, total phosphorus, and suspended sediment occurred in March through June at both sites (fig. 21 and table 6). The least loads occurred in the winter months of January and February for all of the constituents for which loads were estimated (fig. 21 and table 6).

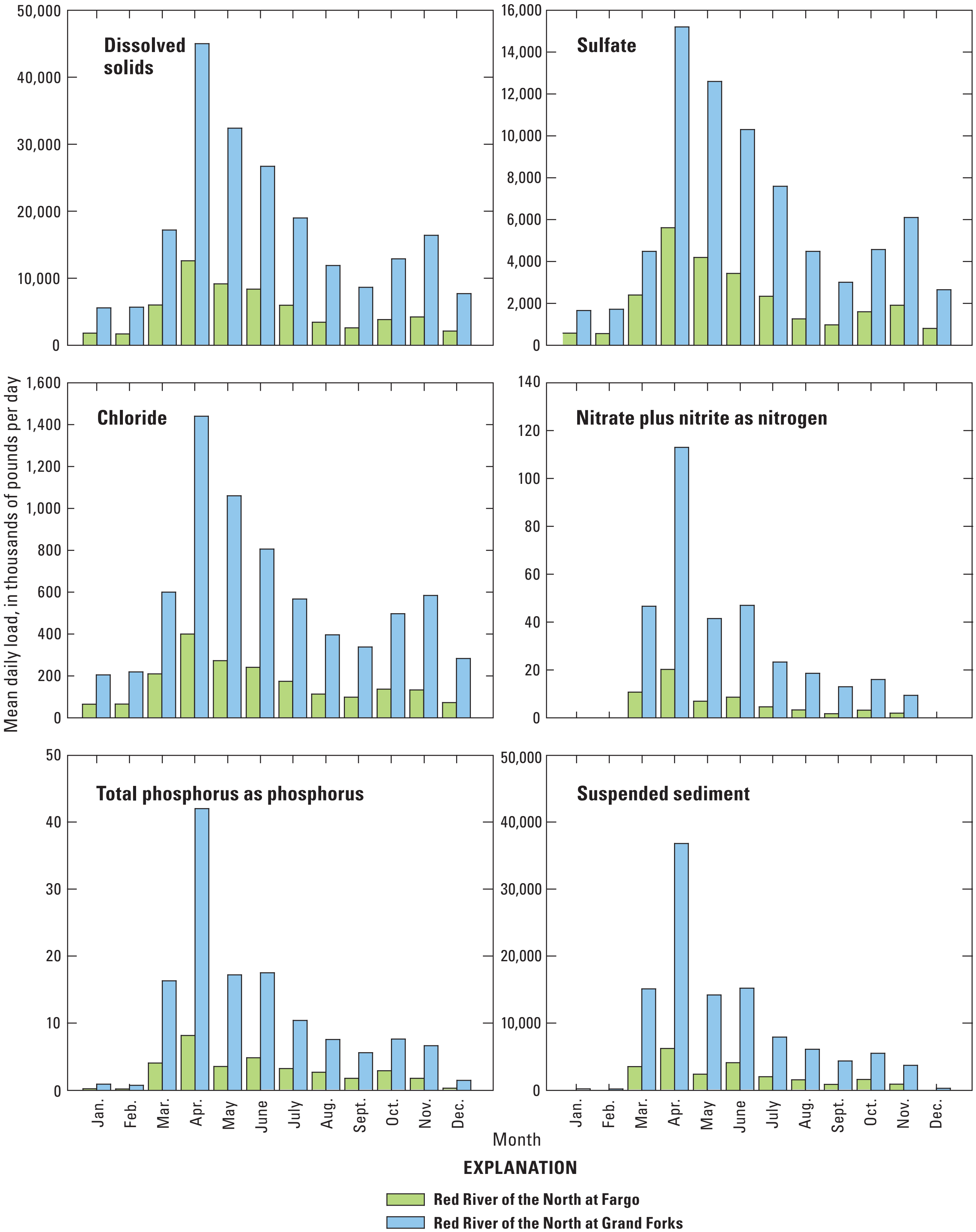


Figure 21. Mean estimated daily dissolved solids, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended-sediment loads in the Red River of the North at Fargo (U.S. Geological Survey streamgage 05054000) and Grand Forks, North Dakota (U.S. Geological Survey streamgage 05082500), 2003–12.

Summary

The Red River Basin is an important hydrologic region where water is a valuable resource for the region's economy. The U.S. Geological Survey, in cooperation with the North Dakota Department of Health, Minnesota Pollution Control Agency, City of Fargo, City of Moorhead, City of Grand Forks, and City of East Grand Forks, have operated continuous water-quality monitors at the Red River at Fargo, North Dakota, from 2003 through 2012 and at Grand Forks, N.Dak., from 2007 through 2012. The purpose of the continuous water-quality monitoring was to provide a better understanding of the water-quality dynamics of the Red River and provide a way to track changes in water quality as they occur. The purpose of this report is to describe the development and results of regression analysis of water-quality constituents for the Red River at Fargo and Grand Forks, N. Dak., using discrete water-quality data and continuously recorded streamflow and water-quality data collected from 2003 through 2012 at the two sites. Regression equations were developed that can be used to estimate concentrations and loads for dissolved solids, sulfate, chloride, nitrate plus nitrite, total phosphorus, and suspended sediment using explanatory variables such as streamflow, specific conductance, and turbidity.

Specific conductance provides a general indication of the content of dissolved material in water that is not too saline or too dilute, and was determined to be a significant explanatory variable for estimating dissolved solids concentrations at the Red River at Fargo and Grand Forks. The regression equations provided good relations between dissolved solid concentrations and specific conductance for the Red River at Fargo and at Grand Forks with adjusted coefficients of determination of 0.99 and 0.98, respectively.

Specific conductance, log-transformed streamflow, and a seasonal component were statistically significant explanatory variables for estimating sulfate in the Red River at Fargo and Grand Forks. The regression equations provided good relations between sulfate concentrations, specific conductance, streamflow, and season for the Red River at Fargo and at Grand Forks with adjusted coefficients of determination of 0.94 and 0.89, respectively.

For the Red River at Fargo and Grand Forks, specific conductance, streamflow, and a seasonal component were statistically significant explanatory variables for estimating chloride. For the Red River at Grand Forks, a time component also was a statistically significant explanatory variable for estimating chloride. The regression equation for chloride at the Red River at Fargo provided a fair relation between chloride concentrations, specific conductance, streamflow, and season with an adjusted coefficient of determination of 0.66. The equation for the Red River at Grand Forks provided a relatively good relation between chloride concentrations, specific conductance, streamflow, season, and time with an adjusted coefficient of determination of 0.77.

Nutrient dynamics are controlled by activities in the basin and processes that occur in the stream. Turbidity of water is caused by the presence of suspended and dissolved inorganic matter such as clay and silt; suspended organic matter such plankton, microscopic organisms, small terrestrial organic material, and organic acids; and water color. For the Red River at Fargo, turbidity and streamflow were statistically significant explanatory variables for estimating nitrate plus nitrite concentrations, and for the Red River at Grand Forks, turbidity was the only statistically significant explanatory variables for estimating nitrate plus nitrite concentrations. The regression equation for the Red River at Fargo provided a relatively poor relation between nitrate plus nitrite concentrations, turbidity, and streamflow, with an adjusted coefficient of determination of 0.46. The regression equation for Red River at Grand Forks provided a fair relation between nitrate plus nitrite concentrations and turbidity with an adjusted coefficient of determination of 0.73. Some of the variability that was not explained by the equations might be attributed to different sources contributing nitrates to the stream at different times. For the Red River at Fargo and Grand Forks, turbidity, streamflow, and a seasonal component were statistically significant explanatory variables for estimating total phosphorus. The regression equation for the Red River at Fargo provided a relatively fair relation between total phosphorus concentrations, turbidity, streamflow, and season with an adjusted coefficient of determination of 0.74. The regression equation for the Red River at Grand Forks provided a good relation between total phosphorus concentrations, turbidity, streamflow, and season with an adjusted coefficient of determination of 0.87.

Because sediment particles enter a stream or are resuspended primarily during runoff events, high concentrations of suspended sediment often are correlated with high turbidity and high streamflow. For the Red River at Fargo, turbidity and streamflow were statistically significant explanatory variables for estimating suspended-sediment concentrations. For the Red River at Grand Forks, turbidity was the only statistically significant explanatory variable for estimating suspended-sediment concentration. The regression equation at the Red River at Fargo provided a good relation between suspended-sediment concentration, turbidity, and streamflow, with an adjusted coefficient of determination of 0.95. The regression equation for the Red River at Grand Forks provided a good relation between suspended-sediment concentration and turbidity with an adjusted coefficient of determination of 0.96.

Estimated annual dissolved solids, sulfate, chloride, and total phophorus loads were greatest in 2011 and annual nitrate plus nitrite and suspended-sediment loads were greatest in 2009 at the Red River at Fargo from 2004 through 2011. Estimated annual dissolved solids, sulfate, chloride, and total phosphorus loads were greatest in 2011 and nitrate plus nitrate and suspended-sediment loads were greatest in 2009 at the Red River at Grand Forks from 2008 through 2011. The greatest loads generally were associated with the greatest annual streamflows. Most of the annual load was transported during spring and early summer months, generally when streamflow was greatest in the Red River at Fargo and Grand Forks.

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Publishing support provided by:
Rolla Publishing Service Center

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Joel M. Galloway—**Continuous Water-Quality Monitoring and Regression Analysis to Estimate Constituent Concentrations and Loads**—Scientific Investigations Report 2014–5064

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20145064