

Water-Quality Characteristics and Trends for Selected Sites in or near the Earth Resources Observation Systems (EROS) Data Center, South Dakota, 1973-2000

Water-Resources Investigations Report 03-4148

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

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By Kathleen M. Neitzert

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U.S. Department of the Interior

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CONVERSION FACTORS AND VERTICAL DATUM

	Multiply	By	To obtain
	acre	4,047	square meter
	acre	0.4047	hectare
	foot (ft)	0.3048	meter
	gallon (gal)	3.785	liter
	gallon (gal)	0.003785	cubic meter
	gallon per minute (gal/min)	0.06309	liter per second
	inch	2.54	centimeter
	inch	25.4	millimeter
	mile	1.609	kilometer
	square mile (mi ²)	259.0	hectare
	square mile (mi ²)	2.590	square kilometer
	troy ounce	0.031104	kilogram

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

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

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

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Water year (WY): Water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. Thus, the water year ending September 30, 2000, is called the “2000 water year.”

Water-Quality Characteristics and Trends for Selected Sites in or near the Earth Resources Observation Systems (EROS) Data Center, South Dakota, 1973-2000

By Kathleen M. Neitzert

ABSTRACT

This report presents data on water-quality samples that were collected in and near the Earth Resources Observation Systems (EROS) Data Center from 1973 through 2000. The investigation is a collaborated effort between the U.S. Geological Survey, Water Resources Discipline (WRD), and Geography (formerly National Mapping) Discipline, EROS Data Center.

A water-quality monitoring program was initiated in 1973, when the EROS Data Center was constructed, and continues at the present time (2003). Under this program, water-quality samples were collected at various sites on the EROS Data Center's property and in the surrounding area. These sites include 4 wastewater-treatment lagoons, 1 site on EROS Lake located behind the EROS Data Center, 2 stream sites near the EROS Data Center, and 9 ground-water wells surrounding the EROS Data Center. Additionally, 3 sites on EROS Lake, 7 stream sites, and 9 ground-water sites are located within the study area and have been sampled during the period covered in the report. Some of these additional sites were part of the initial water-quality monitoring conducted during and immediately after the construction of the EROS Data Center. For other sites, some special sampling (depth-profile and bottom material) has occurred at times during the sampling history; however, these sites have little water-quality data and were not used for statistical or trend analysis.

A trend-analysis program, Estimate TREND (ESTREND), was used to analyze for trends for one surface-water site, the Big Sioux River, which was the only site that had a substantial number of samples collected during an extensive period. The ESTREND trend-analysis program was used to analyze 16 constituents. Specific conductance and dissolved orthophosphate were the only constituents determined to have statistically significant trends. Results showed an increasing trend for specific conductance and a decreasing trend for dissolved orthophosphate.

Scatter plots with regression smoothing lines for selected constituents are presented for selected surface-water and ground-water sites. Regression analyses using a Lowess (Locally Weighted Scatterplot Smoothing) smoothing line for Split Rock Creek, EROS Lake, the lagoon sites, and the ground-water sites indicated variable results, with some constituents indicating an increasing or decreasing trend, some having varied results, and others indicating no change during the sampling period.

INTRODUCTION

The Earth Resources Observation Systems (EROS) Data Center is a data management, systems development, and research field center for the U.S. Geological Survey's (USGS) Geography (formerly National Mapping) Discipline. The EROS Data Center

is a large facility in a rural area, located approximately 15 mi north of Sioux Falls, South Dakota (fig. 1). As part of routine operations, the EROS Data Center stores, processes, and distributes a variety of data, including cartographic, satellite, and aircraft data. Photographic development and processing activities are integral to the operations of the EROS Data Center, and several toxic chemicals are used in these activities. As a result, the EROS Data Center has taken precautions to try to ensure that operations prevent environmental degradation and has monitored the surface water and ground water in and near the EROS Data Center to evaluate that the precautions are sufficient.

The EROS Data Center's Photographic Laboratory uses approximately 20,000 gal of water each day (U.S. Geological Survey, 2002). Chemicals used in photographic development and processing are recycled within the chemical management system by a process of first removing silver, then treating the photographic chemicals for reuse. Approximately 150 troy ounces of silver are currently collected each month from the laboratory's waste photographic processing chemistry (Daniel Wray, EROS Data Center, written commun., 2003), and 99 percent of this silver is recovered and sold. Recycling these photographic chemicals extends their life, reduces the amount of chemicals discharged through the EROS Data Center's waste-management system, and decreases chemical costs. The chemical management system has saved more than \$1 million through a reduction in chemical costs and the sale of recovered silver.

A hearing was conducted on July 10, 1973, by the U.S. Environmental Protection Agency (USEPA), and a discharge permit was granted to the EROS Data Center. The permit application requested one discrete discharge—a controlled seasonal discharge—to an unnamed intermittent stream tributary to West Pipestone Creek, a tributary of Split Rock Creek, which is a tributary of the Big Sioux River (U.S. Environmental Protection Agency, written commun., 1973). In accordance with USEPA requirements, after an in-house recycling process is completed, safe photographic processing chemicals that cannot be recycled are broken down and piped to the first of four recess ponds (lagoons). These lagoons, which are settling ponds, act as a filter to help purify the water. Effluent treatment is completed in each lagoon (assigned sequential numbers as names) in sequential order. The resulting water is discharged into EROS Lake, a 10½-acre lake located near the lagoons, where it is held until the seasonal

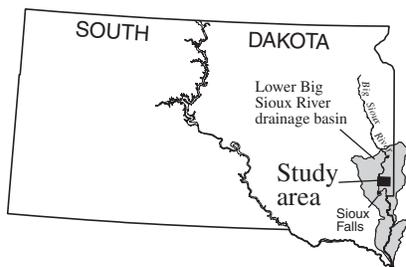
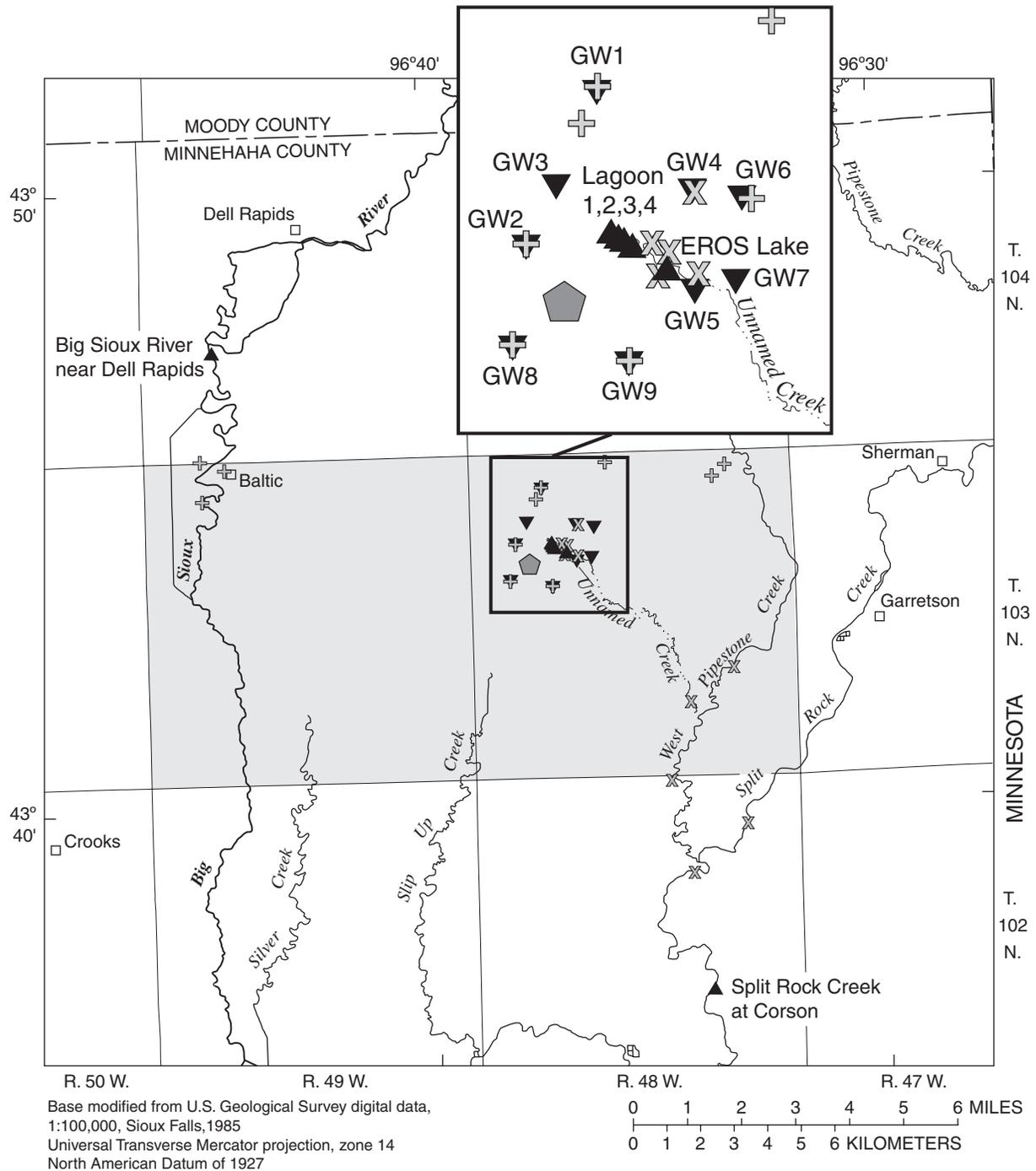
discharge occurs. This controlled seasonal discharge is adjusted to the flow rate in Split Rock Creek to minimize the effect on the environment. EROS Data Center personnel use a 90° V-notch weir to measure the discharge (Daniel Wray, EROS Data Center, written commun., 2003).

A water-quality monitoring program was initiated in 1973, when the EROS Data Center was constructed, and continues at the present time (2003). Under this program, water-quality samples are collected at various sites on the EROS Data Center property and in the surrounding area. These sites include 4 wastewater-treatment lagoons, 1 site on EROS Lake located behind the EROS Data Center, 2 stream sites near the EROS Data Center, and 9 ground-water wells surrounding the EROS Data Center. Additionally, 3 sites on EROS Lake, 7 stream sites, and 9 ground-water sites are located within the study area and have been sampled during the period covered in the report. Some of these additional sites were part of the initial water-quality monitoring conducted during and immediately after the construction of the EROS Data Center. Other sites have had some special sampling (depth-profile and bottom material) at times during the sampling history; however, all of these additional sites have little water-quality data and were not used for statistical or trend analysis. The analyzed constituents were determined by considering State and Federal water-quality standards (W.A. Radlinski, U.S. Environmental Protection Agency, written commun., 1973).

Nearly 30 years of data collected at the EROS Data Center are archived in the USGS's permanent National Water Information System's (NWIS) water-quality database (<http://waterdata.usgs.gov/nwis>), and the data collected for the study described in this report also have been published in the South Dakota District's Annual Water-Data Reports (U.S. Geological Survey, 1974-2001).

Purpose and Scope

The purpose of this report is to describe the general water-quality characteristics and trends for selected sites located in and near the EROS Data Center. The selected sites were the sites with a sufficient number of water-quality samples for statistical analysis that have been collected from 1973 through 2000. Comparisons of water quality by aquifer and comparisons of surface water and ground water by



- EXPLANATION**
- EARTH RESOURCES OBSERVATION SYSTEM STUDY AREA
 - EARTH RESOURCES OBSERVATION SYSTEM (EROS) DATA CENTER
 - Lagoon 1 SELECTED SURFACE-WATER SITES (7) AND SITE NAME (table 1)
 - SURFACE-WATER SITES INCLUDED IN REPORT TABLES BUT NOT DISCUSSED IN THE REPORT
 - GW1 SELECTED GROUND-WATER SITES (9) AND SITE NAME (table 1)
 - GROUND-WATER SITES INCLUDED IN REPORT TABLES BUT NOT DISCUSSED IN THE REPORT

Figure 1. Location of water-quality sites sampled by the U.S. Geological Survey within the Earth Resources Observation System study area, 1973-2000.

water source are presented for sites in the EROS Data Center water-quality monitoring program, and also for sites in the EROS Data Center vicinity that have sufficient water-quality data but were not part of the monitoring program.

Comparisons are made for physical properties, major-ion chemistry, nutrients, and trace elements for the surface-water and ground-water samples. This report presents spatial and temporal variations where sufficient data are available. Analytical results also are presented for 58 constituents analyzed in bottom material samples collected from three locations in EROS Lake.

Description of Study Area

The study area is located in a rural setting in Minnehaha County and includes the EROS Data Center property and surrounding areas in southeastern South Dakota (fig. 1). The study area covers a small region within the lower Big Sioux River drainage basin.

Physiography and Climate

The study area is located entirely in the Coteau des Prairies physiographic region, a plateau-like highland occupying the area between the Minnesota River-Red River Lowland to the east and the James River Lowland to the west (Koch, 1982). Land-surface altitudes within the study area range from 1,340 ft (NGVD 29) in the southeastern part to 1,630 ft (NGVD 29) in the north-central part.

The climate in the study area is subhumid with a mean annual precipitation of about 25 inches in the Big Sioux River drainage basin (Koch, 1982). Maximum precipitation occurs during the growing season with approximately 75 percent of the annual precipitation occurring between April and September. Annual cumulative snowfall averages 40 inches, generally occurring between November and March (Spuhler and others, 1971). The mean annual temperature is about 46°F (8°C), and temperature extremes commonly range from -20°F (-29°C) in the winter to near 100°F (38°C) in the summer (Ohland, 1987).

Geologic Setting

The Precambrian-age Sioux Quartzite is the oldest bedrock formation underlying the study area (Lindgren and Niehus, 1992). The altitude of the top of

the Sioux Quartzite ranges from approximately 1,300 to 1,550 ft (NGVD 29). The Sioux Quartzite is locally well-fractured and jointed crystalline rock; however, the depth and development of the fracture system is not well known (Lindgren and Niehus, 1992). The Late Cretaceous-age Split Rock Creek Formation lies in valleys in the Sioux Quartzite surface and generally consists of thick layers of siltstone, shale, and claystone (Lindgren and Niehus, 1992).

Quaternary-age glacial drift and alluvium overlies the Sioux Quartzite. The glacial drift is primarily unconsolidated sand and gravel outwash deposited by meltwater from receding glaciers (U.S. Geological Survey, 1985). Outwash deposits can be at land surface or buried by till or alluvium (Lindgren and Niehus, 1992). Till is an unsorted and unstratified mixture of glacial deposits containing clay, silt, sand, gravel, and boulders. The alluvium is composed of clay, silt, sand, and gravel that have been deposited by water.

Hydrologic Setting

The Big Sioux River flows through the western part of the study area (fig. 1) and has a drainage area of 145.9 mi² in Minnehaha County. Split Rock Creek flows through the southeast corner of the study area, and has a drainage area of 54.3 mi² in Minnehaha County. West Pipestone Creek is a tributary of Split Rock Creek that flows along the eastern edge of the study area and has a drainage area of 66.7 mi² (Lindgren and Niehus, 1992). Two smaller streams, Slip Up Creek and Silver Creek, begin in the southwestern part of the study area before joining the Big Sioux River. Several unnamed, intermittent streams develop within the study area during wet periods. Ponds within the study area include stock ponds and small intermittent ponds that develop during wet months.

Glacial Aquifers

Glacial aquifers are predominantly shallow, water-table aquifers and are primarily composed of outwash. Glacial aquifers found in the study area include the Big Sioux, Pipestone Creek, Beaver Creek, Brandon, and Slip Up Creek aquifers.

The predominant shallow aquifer in the study area is a portion of the Big Sioux aquifer, which underlies the flood plain of the Big Sioux River valley (Koch, 1982) and along the western part of the study area. The Big Sioux aquifer is composed of an alluvium-mantled

Bedrock Aquifers

outwash, which consists of silt, fine to coarse sand, and gravel. The aquifer overlies relatively impermeable glacial till. Yields from the Big Sioux aquifer can be as much as 1,000 gal/min, depending on the thickness of the aquifer (Lindgren and Niehus, 1992). Withdrawals from the Big Sioux aquifer are widely used for domestic, municipal, stock, and irrigation purposes; the city of Sioux Falls is the principal user of water withdrawn from the Big Sioux aquifer in Minnehaha County.

The Pipestone Creek aquifer generally is a shallow, water-table aquifer. One small portion of the Pipestone Creek aquifer occurs in the northeast corner of the study area, and a separate portion occurs in the eastern one-half of the study area. Yields generally are less than 100 gal/min in the Pipestone Creek aquifer; however, it can yield as much as 500 gal/min in areas where the thickness is greatest (Lindgren and Niehus, 1992). Withdrawals from the Pipestone Creek aquifer are primarily for stock watering and irrigation purposes.

The Beaver Creek aquifer occurs in a small area in the southeast portion of the study area. Yields from the Beaver Creek aquifer generally are less than 300 gal/min within the study area; however, the aquifer can yield as much as 500 gal/min in some areas (Lindgren and Niehus, 1992). Withdrawals from the Beaver Creek aquifer are primarily for stock watering and irrigation purposes.

The Brandon aquifer occurs in the southeast part of the study area between the Beaver Creek aquifer and a portion of the Big Sioux aquifer. Withdrawals from the Brandon aquifer are used primarily for municipal and domestic purposes by the city of Brandon; to a lesser extent, withdrawals also are used for stock watering and irrigation purposes.

The Valley Springs aquifer is located near the city of Valley Springs, approximately 9 mi southeast of the study area. The aquifer is under confined conditions, with the depth to the top of the aquifer ranging from 93 to 207 ft. Water from the Valley Springs aquifer is used primarily for domestic and municipal purposes by the city of Valley Springs.

Slip Up Creek aquifer, which is a minor aquifer, underlies the flood plains of Slip Up Creek located in the center of the study area. The areal extent of the sand and gravel deposits is less than 5 mi² (Lindgren and Niehus, 1992). Cumulative thickness of the Slip Up Creek aquifer generally is less than 20 ft.

The Split Rock Creek aquifer extends into southern portions of the study area. It is predominantly composed of layers of fine to coarse, well-sorted quartzose sand interbedded with layers of siltstone, shale, and claystone of the Split Rock Creek Formation (Lindgren and Niehus, 1992). Depths to the top of the aquifer range from 21 ft within the study area to 337 ft west of the study area. Although the Split Rock Creek aquifer generally is under confined conditions, water-table conditions occur south of the study area, near an observation well located in the southwest quarter of 102N49W14¹ (Lindgren and Niehus, 1992). The thickness of the sand and gravel within the study area generally ranges from 10 to 40 ft, with average cumulative thickness of about 48 ft. Recharge is likely from infiltration of precipitation that falls on Sioux Quartzite outcrops and then moves along fractures in the quartzite and into the Split Rock Creek aquifer (Lindgren and Niehus, 1992). Sioux Quartzite outcrops occur to the north, south, and west of the Split Rock Creek aquifer in southwestern Minnehaha County. The Split Rock Creek aquifer also may receive recharge from the Valley Springs aquifer. Calcium and sulfate are the predominant chemical constituents in water from the Split Rock Creek aquifer. Withdrawals are used for stock watering and domestic purposes.

The Sioux Quartzite aquifer underlies all of the study area. Locally, the aquifer is contained within well-fractured and jointed crystalline rock. It is under water-table conditions near the Sioux Quartzite outcrop areas, and under confined conditions where overlain by till or glacial aquifers in other parts of the study area (Lindgren and Niehus, 1992). Recharge to the Sioux Quartzite aquifer is by infiltration of snowmelt and precipitation, and seepage from streams (Koch, 1982). Natural discharge is by evapotranspiration and seepage to surrounding streams. Withdrawals are used for stock watering and domestic and municipal wells.

¹The well number consists of the township number, followed by "N;" the range number followed by "W;" and the section number followed by a maximum of four uppercase letters that indicate, respectively, the 160-, 40-, 10-, and 2 1/2-acre tract in which the well is located. These letters are assigned in a counterclockwise direction beginning with "A" in the northeast quarter. A serial number following the last letter is used to distinguish between wells in the same 2 1/2-acre tract.

Previous Investigations

Information about the quantity and availability of surface and ground water, the hydrologic system as it affects water availability, and the quality of surface- and ground-water supplies in Minnehaha County is presented in Lindgren and Niehus (1992). Koch (1982) describes the Big Sioux aquifer in Minnehaha County and presents a digital model to simulate varying hydrologic conditions.

Additional investigations have been completed in Minnehaha County. Bradford (1981a, 1981b) and Winter (1983) presented water-level records that were measured in the Big Sioux aquifer in Minnehaha County; Koch (1983) evaluated the response of the Big Sioux River to extreme drought conditions; Koch (1984) presented a simulated artificial recharge model for the Big Sioux aquifer; Niehus and Lindgren (1994) described the major aquifers; Ohland (1990) appraised the water resources of the Skunk Creek aquifer; and Putnam (1998) described the Split Rock Creek aquifer in Minnehaha County and presented a numerical flow model.

Acknowledgments

The author acknowledges the efforts of the EROS Data Center for helping develop and support the water-quality monitoring program, and the cooperation of residents of the study area for providing information and access concerning their private wells. The author also recognizes the hard work and dedication of the many USGS Water Resources Discipline (WRD) hydrologic technicians that collected the water-quality and streamflow data on which this report is based.

METHODS OF STUDY

A water-quality monitoring program was initiated in 1973 when the EROS Data Center was constructed. USGS WRD personnel in the South Dakota District have performed routine water-quality sampling on an annual basis for selected sites for the monitoring program. Water-quality data continue to be collected at the present time (2003), but data analyzed in the study described in this report are restricted to water years 1973 through 2000. The USGS maintained two water-quality monitoring sites during this period on streams, Split Rock Creek at Corson (station 06482610) and Big

Sioux River near Dell Rapids (station 06481000) (table 1).

The 16 sites sampled for the water-quality monitoring program (table 1) include 4 wastewater-treatment lagoons located approximately 0.1 to 0.3 mi northeast of the EROS Data Center, 1 site on EROS Lake located approximately 0.4 mi east of the EROS Data Center, 2 stream sites near the EROS Data Center, and 9 ground-water wells surrounding the EROS Data Center.

Within the study area, 19 additional sites (table 1), which include 7 stream sites, 3 sites on EROS Lake, and 9 ground-water sites, were sampled during the period covered in the report. Some of these sites were part of the initial water-quality monitoring conducted during and immediately after the construction of the EROS Data Center, whereas the remainder have been sampled for other purposes. The initial water-quality monitoring sites were analyzed to determine their suitability for a long-term monitoring project and establish which sites would be representative of various depths and completions. However, the additional sites have little water-quality data and were not used for statistical or trend analysis. Water-quality data for these sites are included in tables 15 (7 stream sites) and 16 (9 ground-water sites), available on CD-ROM at the back of this report, and are not described further. Analytical data for the bed-sediment samples for the three sites on EROS Lake are available in table 17 on the CD-ROM.

Sample Collection, Processing, and Analysis

Water-quality sampling and processing methods varied over the duration of the monitoring program. Samples were collected and processed using methods considered acceptable at the time of collection. Throughout the duration of the monitoring program, stream water-quality and suspended-sediment samples were collected using isokinetic samplers and depth- and width-integrating procedures described in Edwards and Glysson (1988). Prior to 1993, sampling procedures generally followed guidelines described in Brown and others (1970), Wells and others (1990), and Ward and Harr (1990).

In general, all water-quality sampling equipment was presoaked in a Liquinox solution, thoroughly scrubbed, rinsed with tap water, rinsed with deionized water, and finally rinsed with native water prior to collecting water-quality samples. Some of the sampling

Table 1. Site information for water-quality sites sampled in the study area

[Site type: SW, surface water. GW, ground water; EROS, Earth Resources Observation Systems Data Center; --, none]

Station name or location	Monitoring project site name (see fig. 1 for location)	Latitude	Longitude	Site type	Period of record for study
Sites used for statistical or trend analysis					
Big Sioux River near Dell Rapids, SD	Big Sioux River	434725	0964442	SW	1973-2000
Split Rock Creek at Corson, SD	Split Rock Creek	433659	0963354	SW	1973-96, 1997
EROS Lake	EROS Lake	434405	0963655	SW	1973, 1979-80, 1982-2000
Lagoon #1 at EROS Data Center	Lagoon 1	434415	0963715	SW	1979-80, 1982-2000
Lagoon #2 at EROS Data Center	Lagoon 2	434415	0963715	SW	1979-80, 1982-86
Lagoon #3 at EROS Data Center	Lagoon 3	434415	0963715	SW	1979-80, 1982-84, 1986
Lagoon #4 at EROS Data Center	Lagoon 4	434415	0963715	SW	1979, 1982-86
103N48W 5CACA2	GW1	434508	0963727	GW	1973-84, 1986-2000
103N48W 7DAC2	GW2	434414	0963803	GW	1973-79, 1981, 1983
103N48W 8BCCB2	GW3	434435	0963748	GW	1973-78
103N48W 8ADA	GW4	434432	0963642	GW	1973-82
103N48W 8DDDD	GW5	434357	0963642	GW	1973-79
103N48W 9BDCB	GW6	434429	0963618	GW	1973-80
103N48W 9CCDA	GW7	434400	0963622	GW	1973-2000
103N48W18ACA2	GW8	434339	0963811	GW	1973-79, 1981-83
103N48W17ACCC2	GW9	434332	0963715	GW	1973-82, 1984, 1986-2000
Additional sites not used for statistical or trend analysis					
EROS Lake at EROS Data Center, SD (2)	--	434405	0963656	SW	1991
EROS Lake at EROS Data Center, SD (3)	--	434408	0963658	SW	1991
EROS Lake at EROS Data Center, SD (4)	--	434409	0963655	SW	1991
Unnamed Creek near EROS Data Center	--	434433	0963640	SW	1979
Unnamed Creek East of EROS Data Center	--	434402	0963640	SW	1979
Tributary to West Pipestone Creek, SD, SW 2	SW2	434137	0963415	SW	1973
West Pipestone Creek, SD, SW 3	SW3	434210	0963316	SW	1973
West Pipestone Creek, SD, SW 4	SW4	434022	0963443	SW	1973
Split Rock Creek, SW 5	SW5	433853	0963417	SW	1973
Split Rock Creek, SW 6	SW6	433939	0963304	SW	1973
103N48W 4ABCC	--	434531	0963601	GW	1986-87
103N48W 5CACA	--	434508	0963727	GW	1981
103N48W 7DAC	--	434414	0963803	GW	1981
103N48W 8DBDB	--	434457	0963734	GW	1982
103N48W 9BDCA	--	434429	0963615	GW	1975
103N48W17ACCC	--	434332	0963715	GW	1981
103N48W18ACA	--	434339	0963811	GW	1981
103N49W 5BADA	--	434532	0964429	GW	1975-77
103N49W 5BBBB	--	434538	0964500	GW	1975

equipment, including sampling bottles, also was periodically soaked in a dilute nitric-acid solution. Although these methods were considered acceptable, they sometimes were inadequate in preventing contamination of samples for certain constituents, including dissolved aluminum, copper, lead, mercury, and zinc (Alexander and others, 1996). Beginning in about 1993, more rigorous equipment cleaning and water-quality sampling methods were implemented to prevent contamination. These methods generally followed the guidelines described in Horowitz and others (1994). All sampling equipment that would contact the native water first was soaked in a Liquinox solution, scrubbed with non-metallic brushes, rinsed with tap water, soaked in dilute hydrochloric acid, rinsed with deionized water, and finally rinsed with native water prior to collecting water-quality samples. Generally, samples

were collected by one person, and vinyl or latex gloves were worn during sample collection.

Composite wading samples generally were collected from the EROS Lake and lagoons at five locations around the perimeter of each site. The three ground-water sites currently active are sampled at yard hydrants that have been flushed for 30 minutes.

Water-quality samples for the monitoring program were analyzed for selected field-measured properties, and concentrations of major ions, nutrients, and trace elements. Analytical constituents varied over the duration of the monitoring program. Water-quality analytical constituents and properties that were used to meet the objectives of this report are presented in table 2. The USGS National Water Quality Laboratory in Denver, Colorado, performed laboratory analyses of water samples.

Table 2. Properties and constituents analyzed for in water-quality samples for the water-quality monitoring program and used for statistics and trend analyses

[$\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; mg/L , milligrams per liter; $\mu\text{g/L}$, micrograms per liter]

Field-measured property or constituent	Water-quality laboratory analytical constituents (dissolved concentration unless noted otherwise ¹)		
	Constituent		
	Major ion (mg/L)	Nutrient (mg/L)	Trace element ($\mu\text{g/L}$)
Specific conductance ($\mu\text{S/cm}$)	Solids, residue at 180 $^{\circ}\text{C}$	Nitrite, as nitrogen	Aluminum
pH (standard units)	Solids, sum of constituents	Nitrite plus nitrate, as nitrogen	Boron
Water temperature ($^{\circ}\text{C}$)	Calcium	Ammonia, as nitrogen	Chromium
Carbon dioxide (mg/L)	Magnesium	Ammonia plus organic nitrogen (total), as nitrogen	Iron
Hardness, as CaCO_3 (mg/L)	Sodium		Manganese
Noncarbonate hardness (mg/L)	Sodium, percent	Phosphorus (total)	Silver
Alkalinity (mg/L)	Sodium-adsorption ratio	Orthophosphate, as phosphorus	Zinc
	Potassium		
	Bicarbonate		
	Carbonate		
	Sulfate		
	Chloride		
	Fluoride		
	Silica		

¹Dissolved” is operationally defined as that part of a water sample that passes through a 0.45-micrometer pore-size filter; “total” is operationally defined as an unfiltered water sample.

Methods of Trend Analysis

Various methods are described in this section of the report that were used to determine trends for selected water-quality constituents. For data sets with more than 50 observations over a minimum 5-year period, the program Estimate TREND (ESTREND) was used. Scatter plots with a smoothing line were used for selected constituents that did not have sufficient data to use ESTREND.

ESTREND Trend-Analysis Program

Long-term trends in selected water-quality constituents were analyzed using both parametric and nonparametric test methods. Parametric trend tests assume that when a water-quality constituent is regressed with time, or any other independent variable, the resulting residuals are symmetrically distributed and form a bell-shaped (normal) curve. Nonparametric trend tests are utilized when the assumptions of normality and equal variances of data are not valid. Nonparametric tests compare ranks of data rather than the actual data values (Schertz and others, 1991).

The inherent variability of a data set is the primary factor responsible for the resulting loss of power when a parametric test is applied to water-quality data. This power is defined as the ability of the test to reject the null hypothesis when it is false. Other factors such as the use of censored data (values defined as “less than” the laboratory reporting limit), outliers, and data sets with multiple laboratory reporting limits also diminish the power of a parametric test to determine trends. Nonparametric tests are not subject to distributional assumptions of parametric tests (symmetry or normality) and typically are more powerful than parametric tests for data that violate normality assumptions (Helsel, 1992).

The ESTREND program incorporates statistical methods that deal with the factors that may limit power. This computerized statistical and graphical program developed by the USGS to analyze for trends in surface water, as used in this report, is described by Schertz and others (1991). Depending on the existence and quantity of censored data, three types of trend-analysis methods are utilized by ESTREND—Seasonal Kendall test for uncensored data (uncensored Seaken), Seasonal Kendall test for censored data (censored Seaken), and Tobit regression (Tobit). This report utilized each of the three types.

The Seasonal Kendall test is used to analyze water-quality data for both long-term and seasonal trends (Hirsch and others, 1982). This nonparametric method is a generalization of the Mann-Kendall test (Mann, 1945; Kendall, 1975). It is designed to remove the variability in water-quality data that may be caused by seasonality. The Seasonal Kendall test method allows the model to determine the best number of seasons to use in analyzing the trend, from 1 to 12 seasons, and data may be either flow-adjusted concentration (FAC) or raw concentration data (RCD). The FAC method reduces flow-related variability, which may decrease the power of the test. The FAC method is used for data sets that contain less than 5 percent censored data. This method has 16 flow-adjustment options available (table 3). ESTREND is used to determine the best option as defined by prediction sum of squares (PRESS) statistics (Myers, 1986) from the first 11 options. The RCD method does not use flow-adjusted data and therefore is not the preferred method; however, it is used to analyze for trends in constituents that have more than 5 percent censored data and a single laboratory reporting limit.

The Tobit parametric trend test (Cohen, 1976; Cohn, 1988) is used to analyze data sets that contain values censored at multiple laboratory reporting limits. This method does not distinguish between seasons. The Tobit method uses a maximum likelihood estimation procedure (Cohn, 1988) to estimate the parameters of a regression model relating concentration and time (Schertz and others, 1991). The Tobit method uses RCD, and therefore, the data are not flow adjusted.

Table 3. Available options for flow-adjusted models using the Seasonal Kendall test

[Lowess, Locally Weighted Scatterplot Smoothing]

None	Hyperbolic 7
Linear	Hyperbolic 8
Log	Inverse
Hyperbolic 1	Best of previous
Hyperbolic 2	Log-log
Hyperbolic 3	Lowess
Hyperbolic 4	Log-log Lowess
Hyperbolic 5	Log-flow Lowess
Hyperbolic 6	

The null hypothesis for a trend test is that there is no trend in the data over time. Results from the ESTREND program may detect trends that are increasing or decreasing over time, allowing the null hypothesis to be rejected. Failure to reject the null hypothesis does not necessarily indicate no trend in the data, but simply that the test result fails to conclude that there is trend (Schertz and others, 1991).

The test results include a calculation of a p-value to determine the statistical significance of the analysis of trend, based on a selected significance level. Trend analyses that have a p-value of 0.05 or less are considered statistically significant in this report.

Regression Using Smoothing-Line on Scatter Plots

Scatter plots are presented for selected constituents that did not have sufficient data to use ESTREND. A smoothing line, created using the Lowess (Locally Weighted Scatterplot Smoothing) method (Cleveland, 1979), is presented with the scatter plots. Lowess is a nonparametric smoothing technique that generalizes the running means, which determines a predicted value at each point by fitting a weighted linear regression, and shows where the weights decrease with distance from the point of interest. This method can depict slight changes in trend that may have occurred within a relatively small part of the period of record examined. This method does not use flow-adjusted data. The features of the Lowess regression plot are determined by: (1) the span (used to control the amount of smoothing), which was set at 0.9 for all plots because most data sets have less than 50 values and require a high level of smoothing; (2) the degree of the locally fitted polynomial, which was set as 1 degree, meaning a locally linear fit is used; and (3) the family, for which symmetric was selected because it combines local fitting with a robustness feature that guards against distortion by outliers.

WATER-QUALITY CHARACTERISTICS

Boxplots, trilinear diagrams, and statistical summaries are used to describe variability in water-quality properties and constituents at each site. Boxplots are used to graphically display the distribution of data. They provide visual summaries of the median, interquartile range, skewness, and presence or absence of disproportionate values. Trilinear diagrams show chemical analyses of water represented as percentages

of total equivalents per liter, and are useful for visually describing differences in major-ion chemistry in water (Freeze and Cherry, 1979). Statistical summaries are numeric descriptive measures that can be used to describe the center of distribution of measurements and how the measurements vary about the center of distribution.

Censored data (that is, concentrations reported as “less than” the laboratory reporting limit) exist for several constituents in the data set. When constituents with censored data had concentrations reported as “ND” or “0,” an attempt was made to determine what reporting level was in use during that time, and the concentration was assigned as “less than” that reporting level.

Some constituents had multiple laboratory reporting limits over the duration of the monitoring program. Multiple laboratory reporting limits occur for some constituents due to: (1) changes in analytical methods used during the study period; (2) changes in detection limits for a given method; and/or (3) sample dilutions for analysis. To calculate summary statistics and construct boxplots, it was necessary to select a single reporting level when multiple reporting levels exist for a constituent. For these constituents, the largest laboratory reporting limit that did not exceed a substantial number (that is, about one-half) of the reported concentrations for that constituent was selected as the study reporting level. Some constituents had a small number of censored samples that were reported as less than a given laboratory reporting limit that was unusually large in comparison to other reporting limits for the same constituent. In these cases, these censored values were excluded from the calculations of statistics and the construction of boxplots.

All concentrations that were less than the study reporting level, regardless of whether they were originally reported as “less thans,” were actual concentrations, or were assigned a “less than” value, were considered to be less than the study reporting level for the calculation of summary statistics and the construction of boxplots.

The study reporting level is shown as a line across the boxplot for constituents that had censored data, and the total number of samples with values below the study reporting level is reported below the line for each site. Censored data used for the trend plots were assigned a concentration value of one-half the value of the laboratory reporting limit. Data presented in the supplemental tables are exactly as stored in NWIS.

Selected Surface-Water Sites

Water-quality samples were collected at 17 surface-water sites within the study area. Of these sites, sufficient data were collected at 7 sites, minimal data were collected at 7 stream sites, and only bed-sediment data were collected at 3 sites on EROS Lake (table 1). The analytical results for the additional surface-water sites, excluding the three sites where only bed-sediment data were collected, are presented in table 15.

Field-Measured Properties and Constituents

A statistical summary of selected field-measured properties and constituents of surface water in the study area is given in table 4. Boxplots of the field-measured properties and constituents are presented in figure 2.

Specific conductance is a measure of the ability of water to conduct an electrical current. Values for the Big Sioux River and Split Rock Creek sites ranged from 175 to 1,900 $\mu\text{S}/\text{cm}$ (microsiemens per centimeter at 25 degrees Celsius), which generally is typical for streams in this area, and below criteria for irrigation and fish and wildlife propagation, recreation, and livestock watering (table 5). Specific-conductance values for EROS Lake ranged from 249 to 2,520 $\mu\text{S}/\text{cm}$, and also are suitable for irrigation and fish and wildlife propagation, recreation, and livestock watering.

Specific-conductance values for lagoon 1 ranged from 898 to 4,600 $\mu\text{S}/\text{cm}$. Specific-conductance values for lagoons 2, 3, and 4 ranged from 1,400 to 4,300 $\mu\text{S}/\text{cm}$.

The pH value is a measure of the hydrogen ion concentration. Values for the Big Sioux River ranged from 7.1 to 9.1, which meet the fish and wildlife propagation, recreation, and livestock-watering criterion, but the maximum value slightly exceeds the maximum beneficial-use criteria for warmwater permanent and marginal fish-life propagation (table 5). This maximum value occurred during spring runoff and does not typify the normal values. The pH values for Split Rock Creek ranged from 7.4 to 8.6 and meet the South Dakota surface-water quality criterion for fish and wildlife propagation, recreation, and livestock watering. EROS Lake had pH values that ranged from 6.6 to 9.3, which, except for one value, meet the fish and wildlife propagation, recreation, and livestock-watering criterion; one pH value exceeded the maximum beneficial-use criteria for warmwater permanent and marginal fish-life propagation. The pH values for the lagoons ranged from 6.2 to 10.1.

Water temperatures for the Big Sioux River and Split Rock Creek ranged from 0°C during winter months to 33°C. One value exceeded the maximum beneficial-use criteria for warmwater permanent and marginal fish-life propagation (table 5), and does not typify the normal maximum values. Temperatures ranged from 5.5 to 28.5°C for EROS Lake, and from 5.0 to 32.0°C in the lagoons.

Carbon dioxide is contained in the atmosphere in variable amounts and is relatively abundant in natural waters, due largely to its high coefficient of solubility (Cole, 1994). It is dissolved in the gaseous state by absorption at the water surface and utilized in photosynthesis. Rainwater, water seepage through organic soil that comes into contact with products of decomposition, and anaerobic decomposition of carbohydrates in bottom sediments may introduce gaseous carbon dioxide into surface water. Respiration and decay of aquatic organisms from within the lake and lagoons also contribute to the production of carbon dioxide. Carbon dioxide co-occurs with bicarbonate and carbonate as pH and temperatures change to sustain the dynamic balancing of ionic charges (Cole, 1994). Carbon dioxide values in the Big Sioux River ranged from 0.5 to 47.0 mg/L, which reflects the high variability of pH values; values in the Split Rock Creek ranged from 1.0 to 7.4 mg/L and reflect the low variability of pH values. Carbon dioxide values in EROS Lake ranged from 0.1 to 2.3 mg/L, whereas the lagoon values ranged from 0 to 7.8 mg/L.

Hardness is a measure of the soap-consuming capacity of water. The carbonate hardness of water includes the portion equivalent to the bicarbonate and carbonate in the water; noncarbonate hardness is the difference between total and carbonate hardness and is caused by the sulfates and chlorides of bivalent cations (Cole, 1994). Water with hardness less than 61 mg/L is considered soft; 61 to 120 mg/L, moderately hard; 121 to 180 mg/L, hard; and greater than 180 mg/L, very hard (Heath, 1983). Hardness values for the Big Sioux River and Split Rock Creek ranged from 70 to 940 mg/L, and noncarbonate hardness values ranged from 14 to 540 mg/L. EROS Lake had hardness values ranging from 110 to 400 mg/L, and noncarbonate hardness values ranged from 0 to 180 mg/L. Hardness values for the lagoon sites ranged from 280 to 480 mg/L. Noncarbonate hardness was reported for a single visit at lagoons 1, 2, and 3, and those values ranged from 190 to 420 mg/L.

Table 4. Statistical summary of water-quality results of physical properties for selected surface-water sites in the study area

[Statistics summarize alkalinity field and laboratory values, and are a combination of fixed-end point and inflection titrations. $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, Celsius; mg/L , milligrams per liter; --, not analyzed or not determined]

Property or constituent	Big Sioux River					Split Rock Creek				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance ($\mu\text{S}/\text{cm}$)	391	841	850	175	1,900	179	605	620	180	1,020
pH (standard units)	197	8.0	7.9	7.1	9.1	7	8.2	8.2	7.4	8.6
Water temperature ($^{\circ}\text{C}$)	384	10.5	9.0	0.0	29.0	221	10.5	9.5	0.0	33.0
Carbon dioxide (mg/L)	136	8.0	4.9	0.5	47	7	3.0	2.4	1.0	7.4
Hardness, as CaCO_3 (mg/L)	141	420	410	70	940	7	270	280	120	380
Noncarbonate hardness (mg/L)	101	200	190	14	540	7	71	85	23	100
Alkalinity, as CaCO_3 (mg/L)	142	222	219	51	396	7	201	204	95	276

Property or constituent	EROS Lake					Lagoon 1				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance ($\mu\text{S}/\text{cm}$)	28	1,360	1,450	249	2,520	22	1,780	1,570	898	4,600
pH (standard units)	30	8.3	8.5	6.6	9.3	22	7.3	7.4	6.2	8.3
Water temperature ($^{\circ}\text{C}$)	29	17.0	17.0	5.5	28.5	22	16.5	16.0	10.5	23.5
Carbon dioxide (mg/L)	11	1.1	0.9	0.1	2.3	8	2.6	2.2	0.2	7.1
Hardness, as CaCO_3 (mg/L)	11	290	310	110	400	8	350	340	280	410
Noncarbonate hardness (mg/L)	5	90	130	0	180	1	--	--	190	190
Alkalinity, as CaCO_3 (mg/L)	14	185	180	111	284	11	53	29	8	144

Property or constituent	Lagoon 2					Lagoon 3				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance ($\mu\text{S}/\text{cm}$)	7	2,750	2,810	1,500	4,300	6	2,520	2,520	1,400	3,680
pH (standard units)	7	8.3	8.2	6.8	10.1	6	8.2	8.3	7.3	8.9
Water temperature ($^{\circ}\text{C}$)	7	17.0	18.0	9.5	21.0	6	17.0	16.0	9.5	29.5
Carbon dioxide (mg/L)	7	1.8	0.3	0.0	5.9	6	2.5	1.3	0.1	7.3
Hardness, as CaCO_3 (mg/L)	7	360	350	330	410	6	370	360	300	480
Noncarbonate hardness (mg/L)	1	--	--	400	400	1	--	--	420	420
Alkalinity, as CaCO_3 (mg/L)	7	46	28	8	125	6	105	96	61	163

Table 4. Statistical summary of water-quality results of physical properties for selected surface-water sites in the study area—Continued

[Statistics summarize alkalinity field and laboratory values, and are a combination of fixed-end point and inflection titrations. $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, Celsius; mg/L , milligrams per liter; --, not analyzed or not determined]

Property or constituent	Lagoon 4				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance ($\mu\text{S}/\text{cm}$)	6	2,410	2,250	1,400	3,900
pH (standard units)	6	8.8	9.0	7.4	10.0
Water temperature ($^{\circ}\text{C}$)	6	20.0	20.5	5.0	32.0
Carbon dioxide (mg/L)	6	1.5	0.2	0.0	7.8
Hardness, as CaCO_3 (mg/L)	6	350	350	280	460
Noncarbonate hardness (mg/L)	0	--	--	--	--
Alkalinity, as CaCO_3 (mg/L)	6	107	102	73	160

Table 5. Surface-water quality standards for selected properties and constituents

[$\mu\text{g}/\text{L}$, micrograms per liter; mg/L , milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; >, less than; --, not applicable]

Property or constituent	Selected index values					
	National Irrigation Water-Quality Program Guidelines level of concern ¹	South Dakota beneficial-use criteria ²				
		Warmwater permanent fish-life propagation	Warmwater marginal fish-life propagation	Aquatic-life criterion, acute/chronic ($\mu\text{g}/\text{L}$)	Irrigation	Fish and wildlife propagation, recreation, livestock watering
Specific conductance ($\mu\text{S}/\text{cm}$)	--			--	³ 2,500/ ⁴ 4,375	³ 4,000/ ⁴ 7,000
pH (standard units)	--	⁵ 6.5-9.0	⁵ 6.0-9.0	--	--	⁵ 6.0-9.5
Water temperature ($^{\circ}\text{C}$)	--	27	32	--	--	--
Alkalinity, as CaCO_3 (mg/L)	--	--	--	--	--	³ 750/ ⁴ 1,313
Dissolved solids, residue on evaporation at 180°C (mg/L)	--	--	--	--	--	³ 2,500/ ⁴ 4,375
Dissolved solids, sum of constituents (mg/L)	--	--	--	--	--	³ 2,500/ ⁴ 4,375
Sodium-adsorption ratio	--	--	--	--	10	--
Nitrite plus nitrate, as nitrogen (mg/L)	--	--	--	--	--	³ 50/ ⁴ 88
Dissolved silver ($\mu\text{g}/\text{L}$)	--	--	--	⁶ 3.4/--	--	--
Dissolved zinc ($\mu\text{g}/\text{L}$)	--	--	--	⁶ 110/ ⁶ 100	--	--

¹U.S. Department of the Interior (1998); the upper value of the level of concern represents the National Irrigation Water Quality Program toxicity threshold.

²South Dakota Legislative Research Council (2001).

³30-day mean.

⁴Daily maximum.

⁵Application of this standard is dependent on specific conditions described in South Dakota Legislative Research Council (2001).

⁶Hardness-dependent criteria; value given is an example based on hardness of 100 milligrams per liter as CaCO_3 .

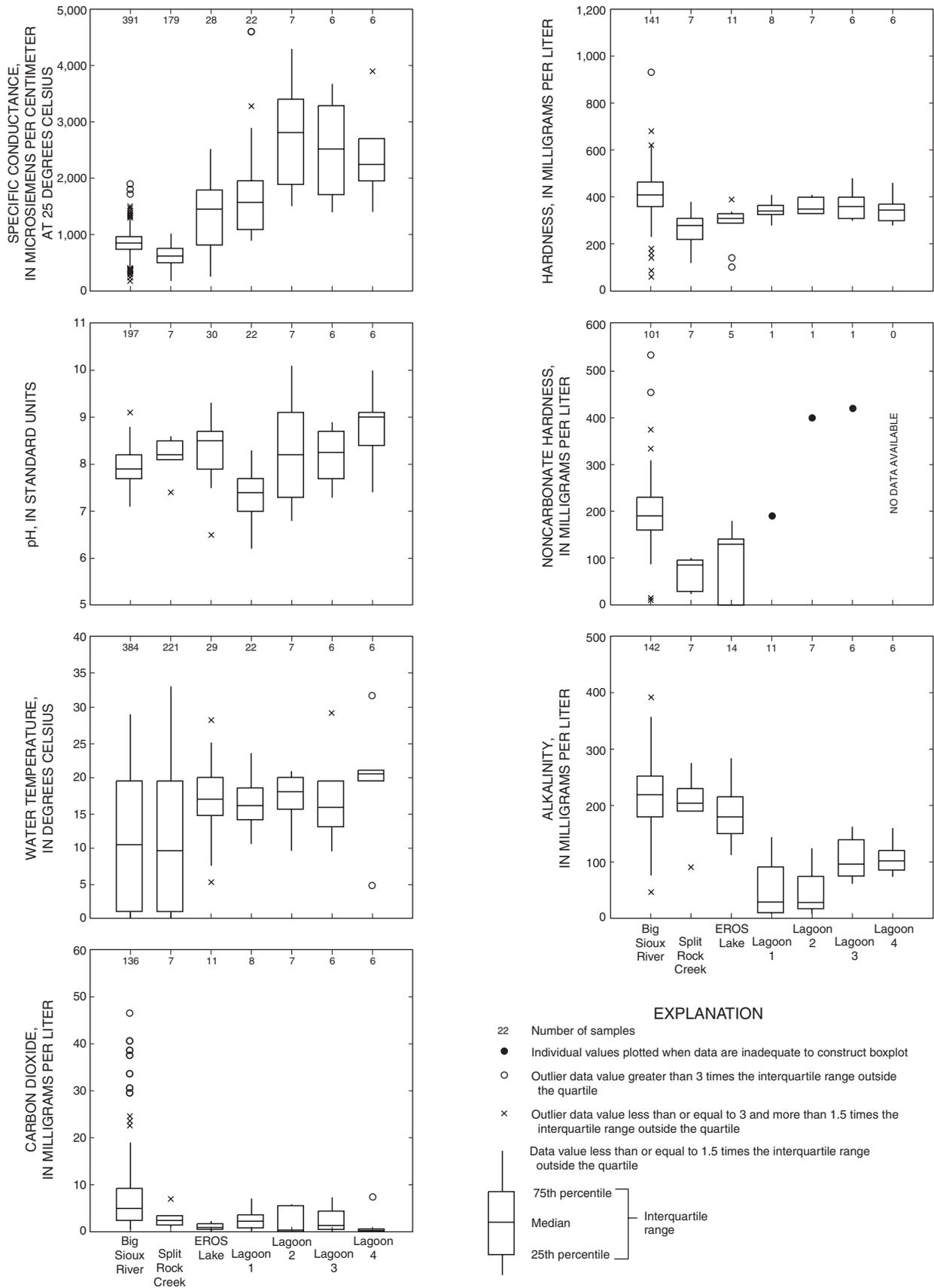


Figure 2. Boxplots of field-measured properties and constituent concentrations for selected surface-water sites in the study area.

Alkalinity is a measure of the capacity of unfiltered water to neutralize acid. It is ordinarily considered an index to the nature of the rocks within a drainage basin and to the degree to which they are weathered; increased alkalinity commonly results from carbon dioxide and water attacking sedimentary carbonate rocks and dissolving some of the carbonate to form bicarbonate solutions (Cole, 1994). The alkalinity values used for statistics and graphical representations are a combination of field and laboratory values collected during different periods of study, based on USGS standard methods at the time of collection. Alkalinity for the Big Sioux River and Split Rock Creek ranged from 51 to 396 mg/L. Alkalinity measured at EROS Lake ranged from 111 to 284 mg/L, whereas the lagoon sites had much lower alkalinity, ranging from 8 to 163 mg/L. Alkalinity for all surface-water sites were below the maximum limit for fish and wildlife propagation, recreation, and livestock-watering criterion (table 5).

Major Ions and Indicators of Major Ions

A statistical summary for selected major ions, including dissolved solids, calcium, magnesium, sodium, percent sodium, sodium-adsorption ratio, potassium, bicarbonate, carbonate, sulfate, chloride, fluoride, and silica, is given in table 6. Boxplots are presented in figure 3 for each of the major ions except carbonate.

The dissolved-solids concentration is the total of all dissolved mineral constituents and is a convenient means of comparing waters. It can be determined from the weight of the dry residue remaining after evaporation of the volatile portion of an aliquot of the water sample at 180°C, or by summing the concentrations reported for the various dissolved constituents (Hem, 1992). The dissolved-solids concentration commonly represents salinity and is classified as follows: fresh, 0 to 1,000 mg/L; slightly saline, 1,000 to 3,000 mg/L; moderately saline, 3,000 to 10,000 mg/L; very saline, 10,000 to 35,000 mg/L; and briny, more than 35,000 mg/L (Heath, 1983). Concentrations of dissolved solids, residue at 180°C, for the Big Sioux River and Split Rock Creek ranged from 126 to 1,540 mg/L (table 6, fig. 3), and the dissolved solids, sum of constituents, ranged from 98 to 1,380 mg/L. Dissolved solids, residue at 180°C, for EROS Lake ranged from 485 to

1,170 mg/L, and the concentrations of dissolved solids, sum of constituents, ranged from 137 to 1,340 mg/L. These values meet the fish and wildlife propagation, recreation, and livestock-watering daily maximum criterion (table 5).

Dissolved solids, residue at 180°C, was analyzed at lagoon 1 for 14 visits, and ranged from 606 to 1,210 mg/L; however, it was not analyzed for at the other lagoons. The dissolved solids, sum of constituents, for all four lagoon sites ranged from 720 to 2,290 mg/L.

The median concentration for major ions in the Big Sioux River generally is greater than the median concentration for major ions in Split Rock Creek. The Big Sioux River also has more variability in concentrations than Split Rock Creek. Explanations for these contrasting characteristics may be due to: (1) the large number of samples for the Big Sioux River site (76-142) compared to the Split Rock Creek site (7); (2) when the samples were collected; and/or (3) that Split Rock Creek is one of many tributaries to the Big Sioux River, and the Big Sioux River receives water from a much larger drainage area than Split Rock Creek.

EROS Lake generally has low variability in major-ion concentrations, and excluding dissolved bicarbonate, median concentrations for major ions are lower than in the lagoon sites. Concentrations of dissolved calcium, magnesium, sodium, potassium, chloride, fluoride, and sulfate generally are similar among the lagoons, with substantial overlap in distributions.

Trilinear diagrams (Piper, 1944; Maddy and others, 1990) showing proportions of major ions in water samples from selected surface-water sites are presented in figure 4. The dominant cations are calcium and magnesium in the Big Sioux River and sodium (plus potassium) in the Split Rock Creek. The dominant anions are sulfate (plus chloride) and bicarbonate in the Big Sioux River and bicarbonate and mixed in the Split Rock Creek.

Cation data for EROS Lake indicate dominance of calcium and magnesium, and anion data indicate dominance of sulfate and bicarbonate. Sodium (plus potassium) generally is the dominant cation for the four lagoons; however, bicarbonate data were not available to determine the dominant anion.

Table 6. Statistical summary of major-ion and indicators of major-ion results for selected surface-water sites in the study area
 [All values are for dissolved constituents, in milligrams per liter, except as indicated. °C, degrees Celsius; <, less than; --, not analyzed or not determined]

Constituent	Big Sioux River					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	124	0	626	594	126	1,540
Solids, sum of constituents	142	0	579	563	98	1,380
Calcium	141	0	93	90	18	210
Magnesium	141	0	45	46	6	100
Sodium	140	0	34	34	2.2	80
Sodium, percent	139	0	15	15	6	24
Sodium-adsorption ratio	140	0	0.7	0.7	0.1	1.3
Potassium	140	0	7.3	7.1	4.5	26
Bicarbonate	83	0	270	260	62	483
Carbonate	76	0	0	0	0	7
Sulfate	141	0	221	220	22	690
Chloride	141	0	30	27	4.1	260
Fluoride	141	0	0.3	0.3	0.1	1.5
Silica	142	11	10	8.7	<1.2	26

Constituent	Split Rock Creek					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	2	0	415	415	409	421
Solids, sum of constituents	7	0	354	378	166	471
Calcium	7	0	57	58	29	86
Magnesium	7	0	31	34	11	40
Sodium	7	0	23	27	7.7	28
Sodium, percent	7	0	15	16	12	17
Sodium-adsorption ratio	7	0	0.6	0.6	0.3	0.7
Potassium	7	0	5.7	5.3	3.9	8.7
Bicarbonate	7	0	238	234	116	337
Carbonate	7	0	3	0	0	13
Sulfate	7	0	87	100	27	120
Chloride	7	0	23	25	12	30
Fluoride	7	0	0.4	0.4	0.3	0.5
Silica	7	3	3.8	4.6	<1.2	7.8

Table 6. Statistical summary of major-ion and indicators of major-ion results for selected surface-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. °C, degrees Celsius; <, less than; --, not analyzed or not determined]

Constituent	EROS Lake					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	17	0	813	798	485	1,170
Solids, sum of constituents	11	0	828	850	137	1,340
Calcium	11	0	55	59	24	70
Magnesium	11	0	36	37	12	54
Sodium	11	0	178	180	8.6	320
Sodium, percent	11	0	49	56	11	63
Sodium-adsorption ratio	11	0	4.4	4.6	0.3	7.8
Potassium	11	0	17	19	3.6	28
Bicarbonate	6	0	238	248	135	319
Carbonate	6	0	4	0	0	14
Sulfate	11	0	188	200	16	330
Chloride	13	0	244	240	2.2	440
Fluoride	11	0	0.7	0.7	0.4	0.9
Silica	11	3	2.6	1.9	<1.2	5.8

Constituent	Lagoon 1					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	14	0	843	805	606	1,210
Solids, sum of constituents	8	0	1,460	1,370	720	2,290
Calcium	8	0	67	65	60	81
Magnesium	8	0	43	43	28	51
Sodium	8	0	351	355	100	630
Sodium, percent	8	0	63	67	41	77
Sodium-adsorption ratio	8	0	8.1	8.5	2.6	14.0
Potassium	8	0	35	30	22	58
Bicarbonate	3	0	83	103	35	111
Carbonate	3	0	0	0	0	0
Sulfate	8	0	411	410	240	560
Chloride	9	0	464	480	44	900
Fluoride	8	0	1.0	1.0	0.9	1.3
Silica	8	2	9.9	12	<1.2	14

Table 6. Statistical summary of major-ion and indicators of major-ion results for selected surface-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. °C, degrees Celsius; <, less than; --, not analyzed or not determined]

Constituent	Lagoon 2					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	7	0	1,580	1,680	928	2,220
Calcium	7	0	72	71	59	95
Magnesium	7	0	43	43	40	49
Sodium	7	0	394	420	170	600
Sodium, percent	7	0	66	69.3	50.3	76
Sodium-adsorption ratio	7	0	9.0	9.8	4.1	14.0
Potassium	7	0	33	30	26	44
Bicarbonate	0	0	--	--	--	--
Carbonate	0	0	--	--	--	--
Sulfate	7	0	426	440	230	530
Chloride	8	0	535	585	170	860
Fluoride	7	0	1.1	1.1	0.9	1.3
Silica	7	0	12	14	3.5	15

Constituent	Lagoon 3					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	6	0	1,480	1,550	868	1,970
Calcium	6	0	79	75	59	110
Magnesium	6	0	42	41	37	49
Sodium	6	0	362	405	170	500
Sodium, percent	6	0	64	68	52	70
Sodium-adsorption ratio	6	0	8.1	9.3	4.2	11.0
Potassium	6	0	31	29	15	47
Bicarbonate	0	0	--	--	--	--
Carbonate	0	0	--	--	--	--
Sulfate	6	0	382	355	240	530
Chloride	7	0	496	500	170	720
Fluoride	6	0	1.1	1.0	0.8	1.4
Silica	6	1	9.1	10	<1.2	16

Table 6. Statistical summary of major-ion and indicators of major-ion results for selected surface-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. °C, degrees Celsius; <, less than; --, not analyzed or not determined]

Constituent	Lagoon 4					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	6	0	1,390	1,330	884	1,990
Calcium	6	0	73	70	59	100
Magnesium	6	0	41	41	33	50
Sodium	6	0	335	340	170	490
Sodium, percent	6	0	64	67	54	69
Sodium-adsorption ratio	6	0	7.7	8.1	4.4	10.0
Potassium	6	0	31	26	21	53
Bicarbonate	0	0	--	--	--	--
Carbonate	0	0	--	--	--	--
Sulfate	6	0	370	340	310	510
Chloride	7	0	459	470	220	700
Fluoride	6	0	1.0	1.0	0.9	1.2
Silica	6	2	3.7	3.1	<1.2	11

Nutrients

Nitrogen and phosphorus are essential nutrients for plant growth. The enrichment of a surface-water body with nutrients is accompanied by a high rate of production of plant material in the water. Dense, rapidly multiplying algal growths or blooms sometimes occur in surface-water bodies that periodically receive increased concentrations of nitrogen or phosphorus. These dense growths are generally undesirable to water users and may interfere with other forms of aquatic life. A statistical summary of nutrients found in surface-water sites located within the study area is given in table 7, and boxplots are presented for selected nutrients in figure 5.

Concentrations of nitrite, as nitrogen, for the Big Sioux River, Split Rock Creek, and EROS Lake generally were low, with maximum detections of 0.08, less than the study reporting level of 0.01, and 0.01 mg/L, respectively. Lagoon 1 was the only lagoon site sampled for nitrite, as nitrogen, and concentrations were

much higher than the other surface-water sites, and ranged from 0.34 to 7.1 mg/L.

Concentrations of nitrite plus nitrate, as nitrogen, for the stream sites ranged from less than the study reporting level of 0.10 mg/L to 4.0 mg/L, and concentrations for EROS Lake ranged from less than the study reporting level of 0.10 mg/L to 1.0 mg/L. The lagoon sites 1 and 2 had similar concentrations, ranging from 0.60 to 16 mg/L, whereas the lagoon sites 3 and 4 ranged from less than the study reporting level of 0.10 mg/L to 2.8 mg/L.

Ammonia, as nitrogen, for the Big Sioux River was only sampled on a single visit and was 1.0 mg/L. Ammonia was not analyzed for at Split Rock Creek. Concentrations of ammonia for EROS Lake ranged from less than the study reporting level of 0.02 mg/L to 0.32 mg/L. Lagoon 1 had ammonia concentrations that ranged from less than the study reporting level of 0.02 mg/L to 36 mg/L. Ammonia was not sampled for at the other lagoon sites.

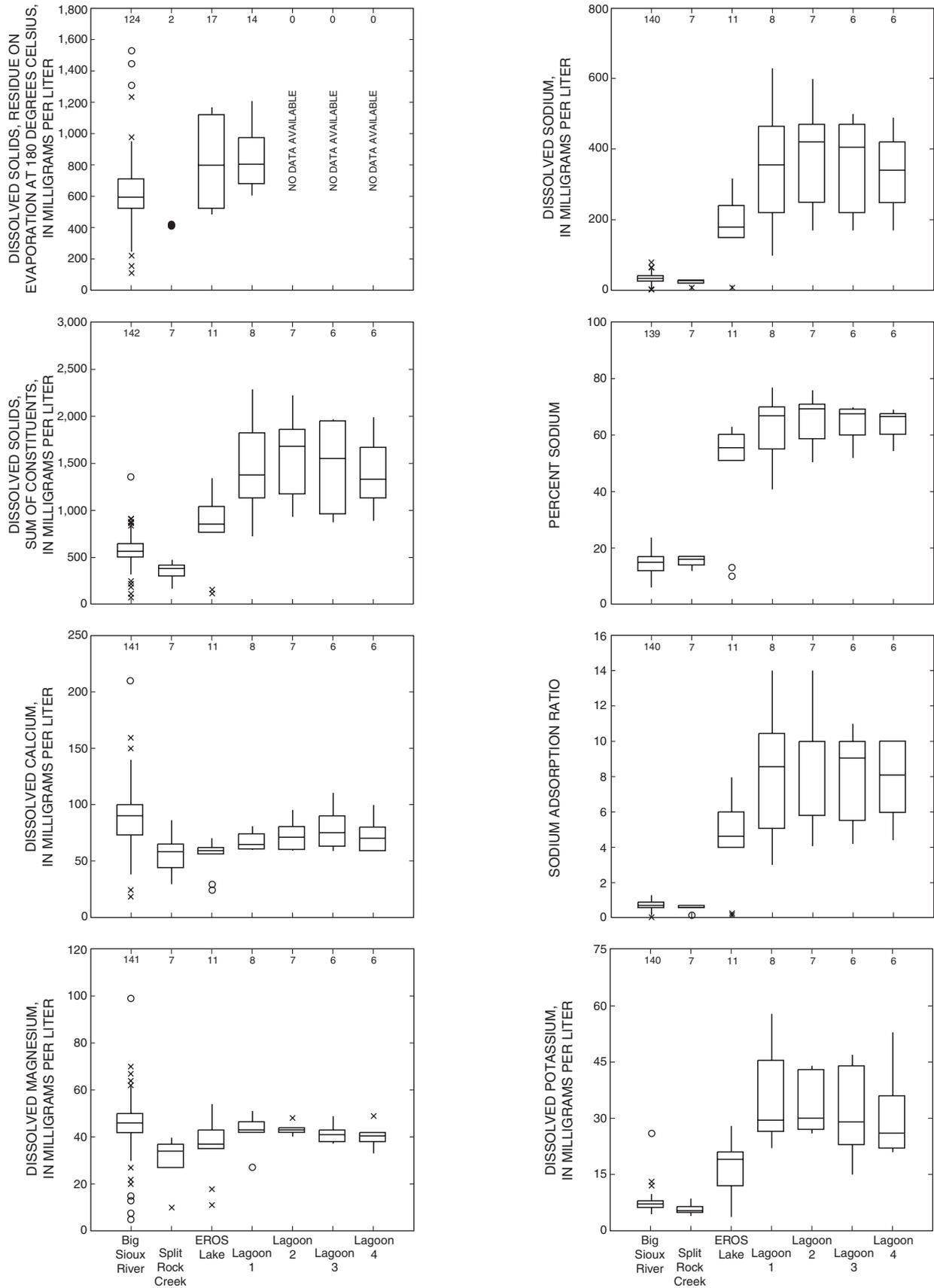
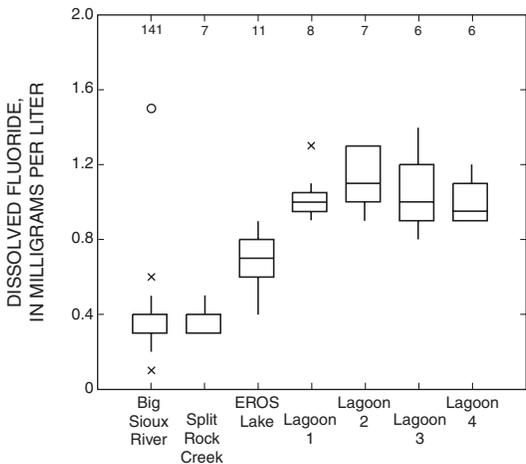
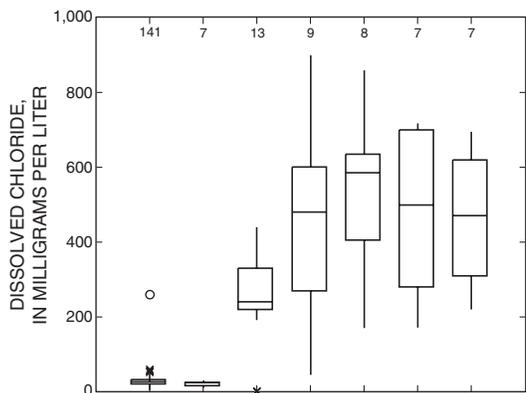
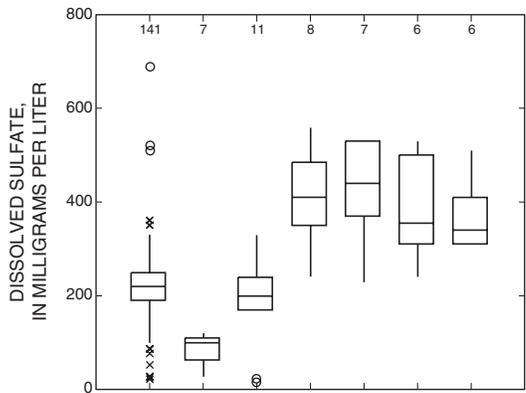
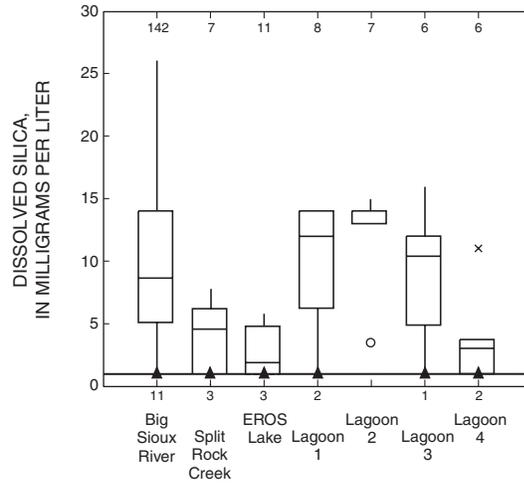
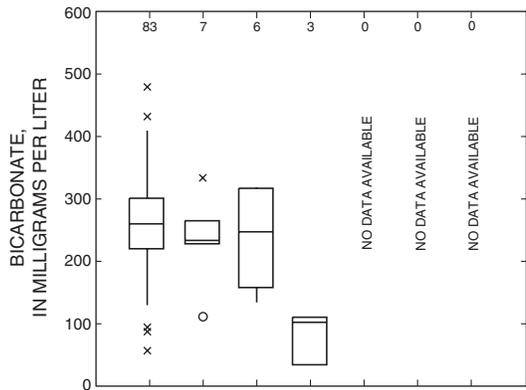


Figure 3. Boxplots of major-ion constituent concentrations for selected surface-water sites in the study area.



EXPLANATION

- 11 Number of samples
- Individual values plotted when data are inadequate to construct boxplot
- Outlier data value greater than 3 times the interquartile range outside the quartile
- × Outlier data value less than or equal to 3 and more than 1.5 times the interquartile range outside the quartile
- Data value less than or equal to 1.5 times the interquartile range outside the quartile
- 75th percentile
- Median
- 25th percentile
- Interquartile range
- ▲ Study reporting level—Triangle indicates data less than study reporting level
- 2 Number of samples with concentrations less than study reporting level

Figure 3. Boxplots of major-ion constituent concentrations for selected surface-water sites in the study area.—Continued

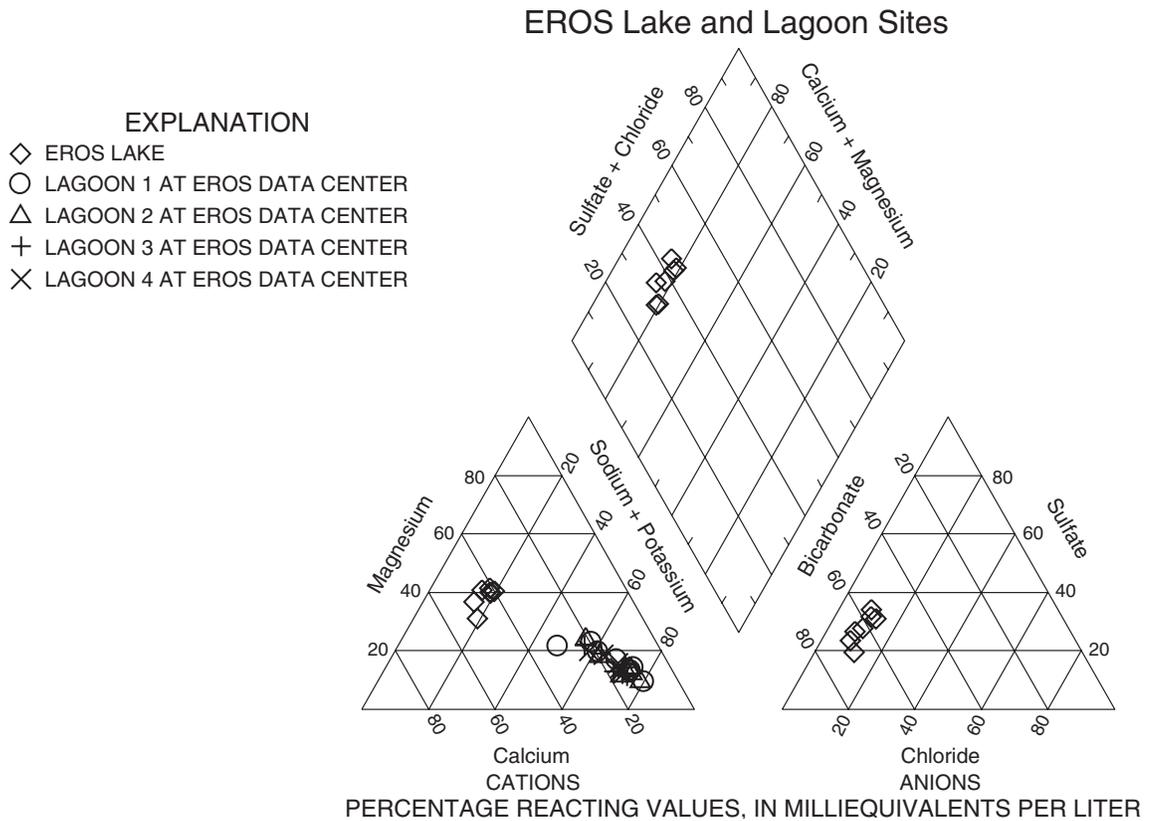
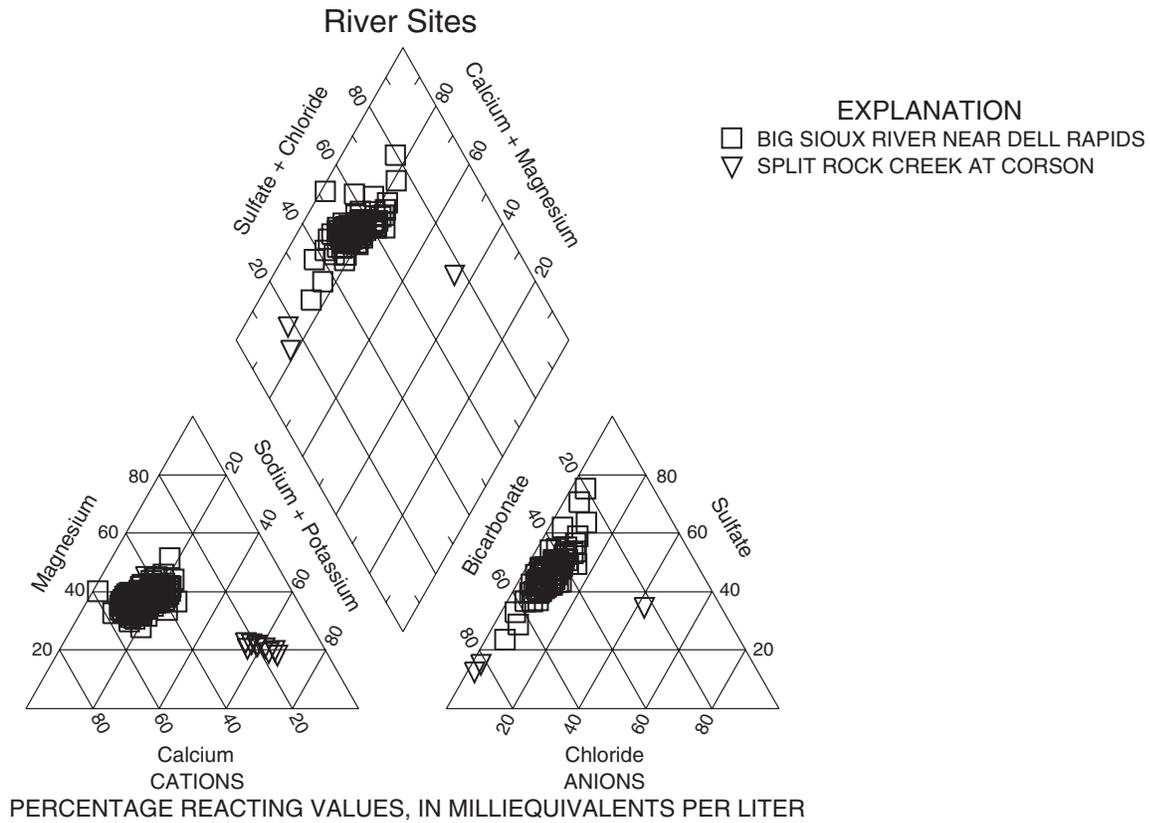


Figure 4. Trilinear diagrams (Piper, 1944) showing proportions of major ions for selected surface-water sites in the study area.

Table 7. Statistical summary of nutrient results for data for selected surface-water sites in the study area

[All values are for dissolved constituents, in milligrams per liter, except as indicated. <, less than; --, not analyzed or not determined]

Big Sioux River						
Constituent	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	12	4	0.03	0.02	<0.01	0.08
Nitrite plus nitrate, as N	138	44	0.80	0.50	<0.10	3.6
Ammonia, as N	1	0	--	--	1.0	1.0
Ammonia plus organic, total, as N	124	0	1.9	1.7	0.07	6.8
Phosphorus, total, as P	192	0	0.27	0.24	0.03	1.0
Orthophosphate, as P	132	9	0.10	0.06	<0.01	0.46

Split Rock Creek						
Constituent	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	2	2	--	--	<0.01	<0.01
Nitrite plus nitrate, as N	7	4	0.82	<0.10	<0.10	4.0
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, total, as N	2	0	1.8	1.8	1.7	1.9
Phosphorus, total, as P	4	0	0.32	0.27	0.16	0.58
Orthophosphate, as P	5	1	0.08	0.03	<0.01	0.29

EROS Lake						
Constituent	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	13	9	--	<0.01	<0.01	0.01
Nitrite plus nitrate, as N	28	22	0.14	<0.10	<0.10	1.0
Ammonia, as N	17	3	0.09	0.04	<0.02	0.32
Ammonia plus organic, total, as N	5	0	2.8	2.7	1.6	4.8
Phosphorus, total, as P	5	0	0.58	0.26	0.18	1.9
Orthophosphate, as P	13	1	0.21	0.25	<0.01	0.47

Lagoon 1						
Constituent	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	10	0	2.2	1.2	0.34	7.1
Nitrite plus nitrate, as N	22	0	6.9	5.1	0.60	16
Ammonia, as N	14	1	17	18	<0.02	36
Ammonia plus organic, total, as N	2	0	18	18	4.7	32
Phosphorus, total, as P	2	0	4.4	4.4	2.7	6.0
Orthophosphate, as P	10	0	3.5	3.6	1.5	4.9

Table 7. Statistical summary of nutrient results for data for selected surface-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. <, less than; --, not analyzed or not determined]

Constituent	Lagoon 2					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	0	0	--	--	--	--
Nitrite plus nitrate, as N	7	0	5.4	5.3	1.0	11
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, total, as N	2	0	19	19	5.1	32
Phosphorus, total, as P	2	0	3.2	3.2	2.2	4.1
Orthophosphate, as P	0	0	--	--	--	--

Constituent	Lagoon 3					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	0	0	--	--	--	--
Nitrite plus nitrate, as N	6	1	0.82	0.73	<0.10	1.7
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, total, as N	2	0	2.9	2.9	2.3	3.4
Phosphorus, total, as P	2	0	2.1	2.1	1.4	2.8
Orthophosphate, as P	0	0	--	--	--	--

Constituent	Lagoon 4					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	0	0	--	--	--	--
Nitrite plus nitrate, as N	6	2	0.88	0.58	<0.10	2.8
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, total, as N	1	0	--	--	2.1	2.1
Phosphorus, total, as P	1	0	--	--	1.2	1.2
Orthophosphate, as P	0	0	--	--	--	--

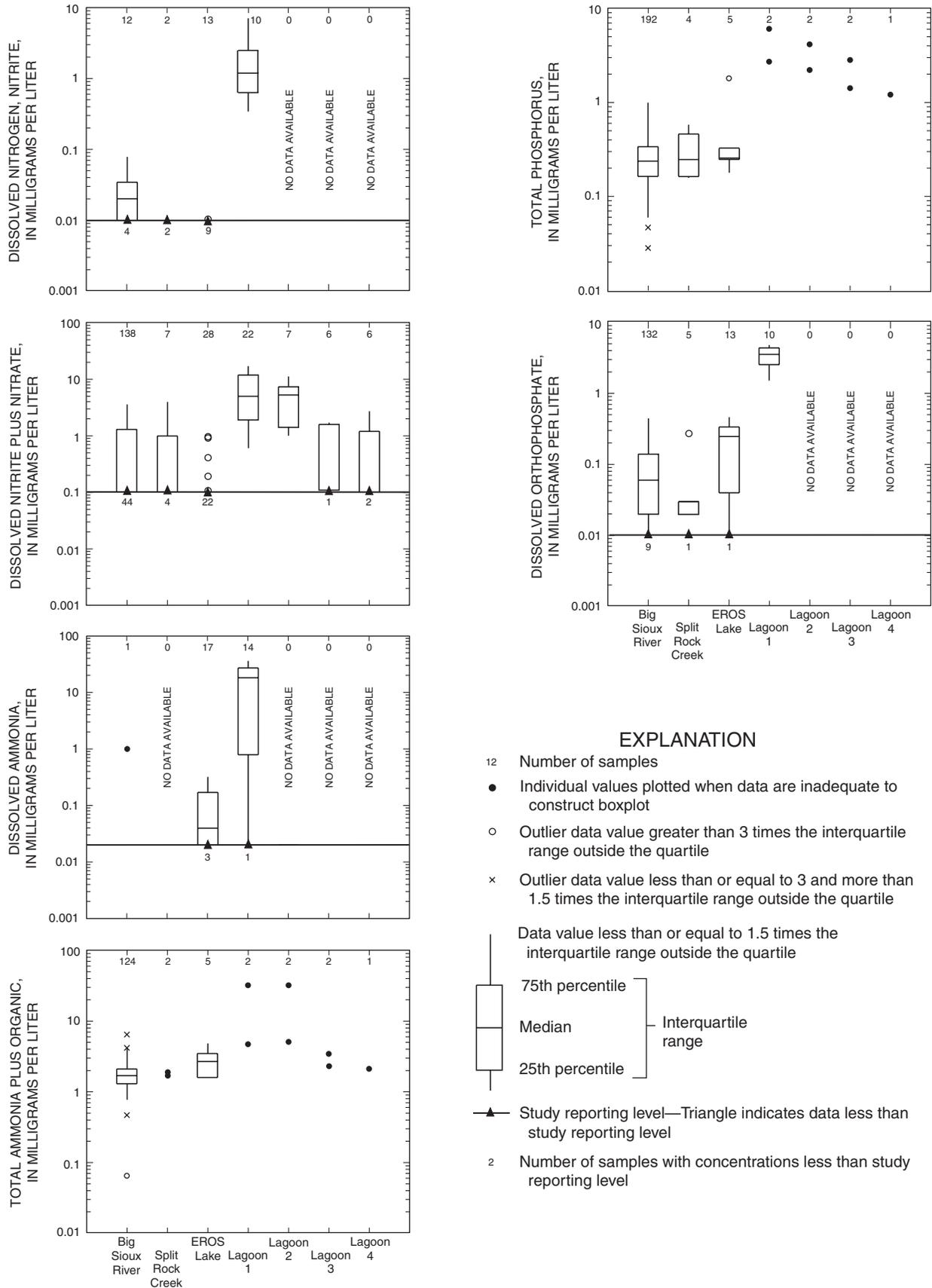


Figure 5. Boxplots of nutrient constituent concentrations for selected surface-water sites in the study area.

Concentrations of ammonia plus organic total, as nitrogen, varied widely for stream sites (table 7, fig. 5); concentrations for the Big Sioux River ranged from 0.07 to 6.8 mg/L, whereas concentrations for Split Rock Creek ranged from 1.7 to 1.9 mg/L in two samples. The concentration of ammonia plus organic total for the EROS Lake site ranged from 1.6 to 4.8 mg/L. The lagoon sites 1 and 2 had similar concentrations, ranging from 4.7 to 32 mg/L, whereas lagoon sites 3 and 4 had much lower concentrations, ranging from 2.1 to 3.4 mg/L.

Phosphorus concentrations for the stream sites ranged from 0.03 to 1.0 mg/L, whereas EROS Lake's phosphorus concentrations ranged from 0.18 to 1.9 mg/L. Lagoons 1 and 2 had similar concentrations that ranged from 2.2 to 6.0 mg/L, whereas concentrations for lagoons 3 and 4 ranged from 1.2 to 2.8 mg/L. Maximum concentrations generally decreased from lagoon 1 to lagoon 4. Orthophosphate concentrations for the stream sites ranged from less than the study reporting level of 0.01 mg/L to 0.46 mg/L, and EROS Lake concentrations ranged from less than the study reporting level of 0.01 mg/L to 0.47 mg/L. Lagoon 1 was the only lagoon site for which orthophosphate was analyzed for, and concentrations ranged from 1.5 to 4.9 mg/L.

Trace Elements

Trace elements generally are defined as elements with concentrations in natural water less than 1 mg/L (Hem, 1992). Trace elements analyzed in samples from

the various surface-water sites in the study area include dissolved concentrations for aluminum, boron, chromium, iron, manganese, silver, and zinc and are reported in micrograms per liter ($\mu\text{g/L}$). Samples were analyzed for additional trace-element constituents, but concentrations generally were below their respective study reporting levels (table 15).

A statistical summary of selected trace-element constituents in samples from selected surface-water sites located within the study area is given in table 8, and boxplots are presented in figure 6.

Only one sample from the Big Sioux River was analyzed for aluminum, which had a concentration of 800 $\mu\text{g/L}$ (table 8, fig. 6). As mentioned previously, aluminum analyses are very susceptible to contamination, and this value is questionable; however, no data exist to disregard it. Samples from Split Rock Creek were not analyzed for aluminum. Concentrations of aluminum for the EROS Lake site ranged from not detected to 60 $\mu\text{g/L}$. Concentrations of aluminum in samples from the lagoon sites ranged from less than the study reporting level of 10 $\mu\text{g/L}$ to 70 $\mu\text{g/L}$, with maximum concentrations generally decreasing from lagoon 1 to lagoon 4.

Concentrations of dissolved boron for the Big Sioux River and Split Rock Creek sites ranged from 30 to 360 $\mu\text{g/L}$. EROS Lake had dissolved boron concentrations that ranged from 70 to 1,900 $\mu\text{g/L}$, whereas concentrations for the four lagoon sites ranged from 840 to 2,500 $\mu\text{g/L}$.

Table 8. Statistical summary of water-quality results of selected trace-element constituents for selected surface-water sites in the study area

[All values are for dissolved constituents, in micrograms per liter. <, less than; --, not analyzed or not determined]

Constituent	Big Sioux River					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	1	0	--	--	800	800
Boron	129	0	130	130	30	360
Chromium	0	0	--	--	--	--
Iron	0	0	--	--	--	--
Manganese	0	0	--	--	--	--
Silver	0	0	--	--	--	--
Zinc	0	0	--	--	--	--

Table 8. Statistical summary of water-quality results of selected trace-element constituents for selected surface-water sites in the study area—Continued

[All values are for dissolved constituents, in micrograms per liter. <, less than; --, not analyzed or not determined]

Constituent	Split Rock Creek					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	0	0	--	--	--	--
Boron	4	0	78	65	60	120
Chromium	0	0	--	--	--	--
Iron	0	0	--	--	--	--
Manganese	0	0	--	--	--	--
Silver	0	0	--	--	--	--
Zinc	0	0	--	--	--	--

Constituent	EROS Lake					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	8	2	24	20	<10	60
Boron	10	0	1,300	1,500	70	1,900
Chromium	25	22	<10	<10	<10	20
Iron	10	2	72	30	<10	450
Manganese	1	0	--	--	2,200	2,200
Silver	28	28	<2	<2	<2	<2
Zinc	11	2	15	14	<3	30

Constituent	Lagoon 1					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	8	1	38	30	<10	70
Boron	8	0	1,610	1,600	980	2,300
Chromium	22	8	23	17	<10	100
Iron	9	0	1,080	750	50	2,500
Manganese	1	0	--	--	160	160
Silver	23	7	4	3	<2	18
Zinc	9	0	84	90	4	160

Table 8. Statistical summary of water-quality results of selected trace-element constituents for selected surface-water sites in the study area—Continued

[All values are for dissolved constituents, in micrograms per liter. <, less than; --, not analyzed or not determined]

Constituent	Lagoon 2					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	7	1	29	30	<10	50
Boron	7	0	1,600	1,500	940	2,300
Chromium	7	2	24	20	<10	70
Iron	8	0	550	400	29	1,900
Manganese	1	0	--	--	100	100
Silver	8	3	4	2	<2	9
Zinc	8	0	64	65	30	100

Constituent	Lagoon 3					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	6	2	18	20	<10	30
Boron	6	0	1,500	1,550	850	2,300
Chromium	6	2	18	15	<10	50
Iron	7	0	95	60	21	240
Manganese	1	0	--	--	260	260
Silver	7	7	<2	<2	<2	<2
Zinc	7	0	64	40	10	190

Constituent	Lagoon 4					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	6	1	18	20	<10	30
Boron	6	0	1,560	1,500	840	2,500
Chromium	6	4	<10	<10	<10	20
Iron	7	0	56	40	19	190
Manganese	1	0	--	--	50	50
Silver	7	6	<2	<2	<2	2
Zinc	7	0	24	25	4	50

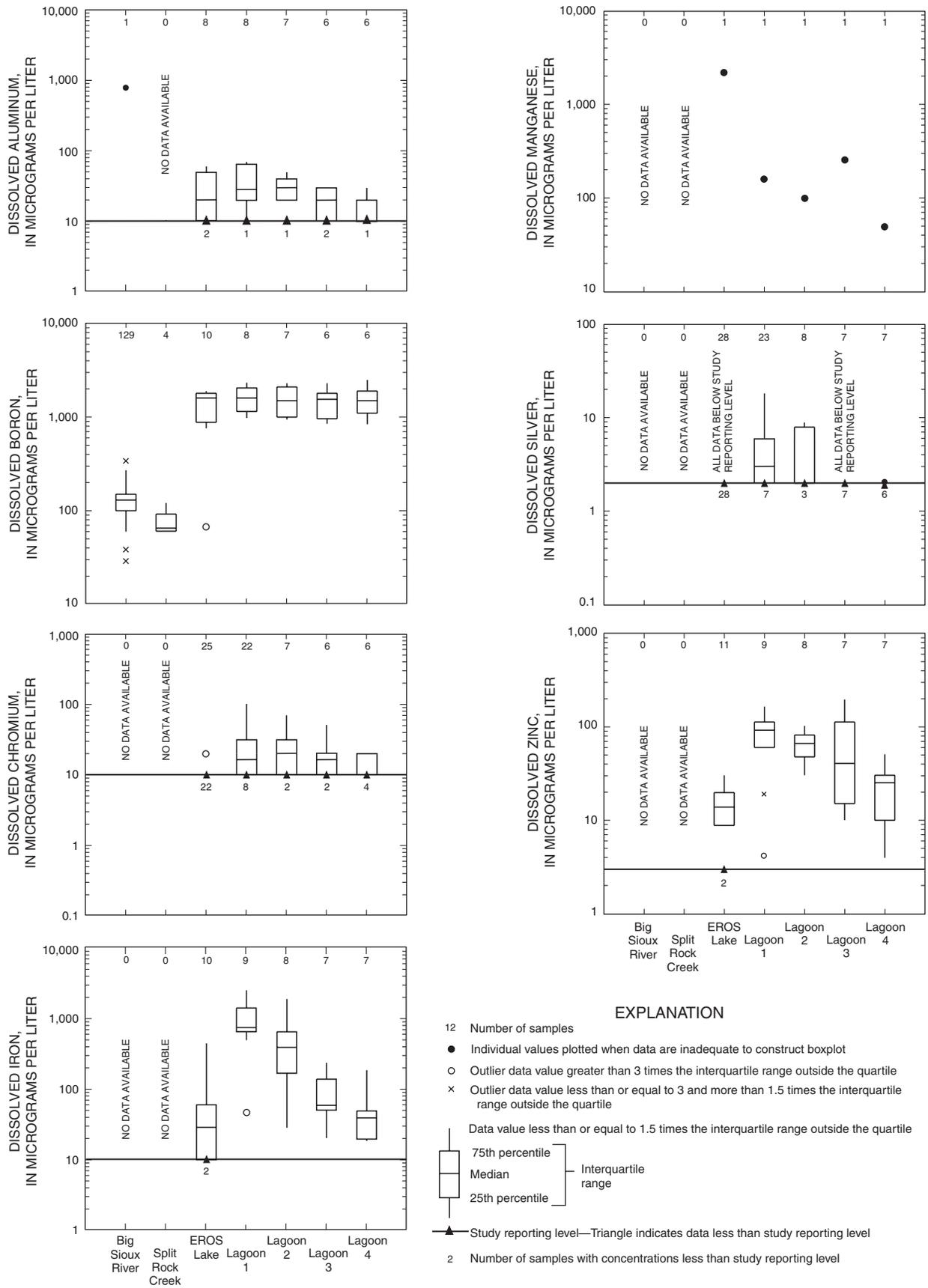


Figure 6. Boxplots of trace-element constituent concentrations for selected surface-water sites in the study area.

Samples from the stream sites were not analyzed for chromium. The EROS Lake site had dissolved chromium concentrations that ranged from less than the study reporting level of 10 µg/L to 20 µg/L. The lagoon sites had concentrations of chromium that ranged from less than the study reporting level of 10 µg/L to 100 µg/L, with maximum values generally decreasing from lagoon 1 to lagoon 4.

Samples from the stream sites were not analyzed for dissolved iron. The EROS Lake site had dissolved iron concentrations that ranged from less than the study reporting level of 10 µg/L to 450 µg/L. The lagoon sites had concentrations of dissolved iron that ranged from 19 to 2,500 µg/L, with minimum and maximum values generally decreasing from lagoon 1 to lagoon 4.

Samples from the stream sites were not analyzed for dissolved manganese. One sample from the EROS Lake site had a dissolved manganese concentration of 2,200 µg/L. One sample from each lagoon site was analyzed for dissolved manganese, and concentrations ranged from 50 to 260 µg/L.

Samples from the stream sites were not analyzed for dissolved silver. The EROS Lake site had dissolved silver concentrations that were less than the study reporting level of 2 µg/L. Concentrations of dissolved silver in samples from the lagoon sites ranged from less than the study reporting level of 2 µg/L to 18 µg/L, with maximum values generally decreasing from lagoon 1 to lagoon 4.

Dissolved zinc was not analyzed for in samples from the Big Sioux River or the Split Rock Creek sites. The EROS Lake site had dissolved zinc concentrations that ranged from less than the study reporting level of 3 µg/L to 30 µg/L, whereas concentrations of dissolved zinc in the lagoon sites ranged from 4 to 190 µg/L.

Bed Sediment

Analytical results of bottom material samples were collected within the study area at three locations in EROS Lake on July 16, 1991, and the analytical results are presented in table 17 on the CD-ROM as station name EROS Lake at EROS Data Center, SD (2), (3), and (4). Total concentrations of aluminum ranged from 4,300 to 5,700 µg/g (micrograms per gram); chromium ranged from 9 to 10 µg/g; iron ranged from 9,900 to 13,000 µg/g; and zinc ranged from 40 to 51 µg/g. Of the remaining 54 constituents analyzed for, only benzo-a-pyrene, bis(2-ethylhexyl) phthalate, di-n-butyl

phthalate, isophorone, and *n*-butylbenzyl phthalate had concentrations above their laboratory reporting limits.

Trends

The trend-analysis program ESTREND was applied to the data set; however, only one site, Big Sioux River near Dell Rapids, had sufficient data to use the program. Water-quality concentration data for 17 constituents collected at this site were analyzed to determine if trends existed using the Seasonal Kendall test for either RCD or FAC data, or the Tobit test for RCD.

The results of the trend-analysis methods for each constituent are presented in table 9. Only two constituents, specific conductance and dissolved orthophosphate, had trends that were statistically significant (table 9). Figure 7 presents two plots for each of the constituents that had statistically significant trends, a best model regression plot derived using ESTREND, and a smoothing line regression plot presenting a time-series diagram. Trend analysis, based on Seasonal Kendall FAC, showed a slightly increasing trend of 0.75 percent of the median per year in specific conductance. Trend analysis of dissolved orthophosphate showed a decreasing trend of 10.26 percent of the median per year, based on the Tobit test.

For specific conductance, ESTREND used the uncensored Seasonal Kendall test, with FAC adjustments using 12 seasons. The ESTREND output indicates the inverted model was the best model to present the statistical trend, thus, although the trend was increasing, the diagram shows the line decreasing (fig. 7). The second specific-conductance plot output by ESTREND presents the residual values over time, using a Robust MM smoothing line, which uses specialized estimates that have good robustness as properties (simultaneous high breakdown point and high efficiency when the errors are normally distributed) (Yohai, 1987).

For dissolved orthophosphate, the Tobit test, which is used to analyze data sets that contain values censored at multiple reporting limits, was used to present a regression model of deviance of values over time (fig. 7). The second dissolved orthophosphate plot presents the values with a least-squares smoothing line.

Table 9. Results of trend-analysis tests for selected surface-water constituents in samples from the Big Sioux River near Dell Rapids site[All values in milligrams per liter, except as indicated. $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; NA, not applicable]

Constituent	Trend analysis method	Beginning year	Number of years for trend analysis	Number of seasons for trend analysis	Total number of values used in trend analysis	Trend slope	Percent change	P-value	Significance of p-value
Specific conductance ($\mu\text{S}/\text{cm}$)	Uncensored	1973	27	12	271	6.5695	0.7465	0.0001	Positive
Alkalinity, as CaCO_3	Uncensored	1973	7	12	70	8.0518	2.9821	0.1249	None
Dissolved solids, sum	Uncensored	1973	12	12	125	4.7070	0.8382	0.0727	None
Nitrogen ammonia, total, as N	Uncensored	1973	7	12	75	-0.0069	-3.5448	0.1413	None
Nitrogen, organic ammonia, as N	Censored	1973	6	6	35	-0.0500	-2.9412	0.5690	None
Nitrite plus nitrate, total, as N	Censored	1973	6	12	66	-0.0100	-8.0000	0.1005	None
Nitrite plus nitrate, dissolved, as N	Tobit	1972	12	NA	141	NA	1.3846	0.7560	None
Phosphorus, total	Uncensored	1973	12	12	130	-0.0095	3.9384	0.0944	None
Phosphorus, dissolved	Uncensored	1973	12	12	120	-0.0070	-7.0197	0.0589	None
Orthophosphate, dissolved	Tobit	1972	13	NA	138	NA	-10.2553	0.0010	Negative
Arsenic, total ($\mu\text{g}/\text{L}$)	Uncensored	1974	6	12	48	-0.2281	-7.6010	0.2261	None
Boron, dissolved ($\mu\text{g}/\text{L}$)	Uncensored	1973	12	12	122	-2.6825	-2.0631	0.0544	None
Copper, total ($\mu\text{g}/\text{L}$)	Tobit	1974	6	NA	49	NA	-13.6393	0.2941	None
Lead, total ($\mu\text{g}/\text{L}$)	Tobit	1974	6	NA	52	NA	29.3396	0.2451	None
Manganese, total ($\mu\text{g}/\text{L}$)	Uncensored	1974	6	12	51	17.9709	-5.6151	0.2781	None
Zinc, total ($\mu\text{g}/\text{L}$)	Censored	1974	6	12	50	0.0000	0.0000	0.9433	None

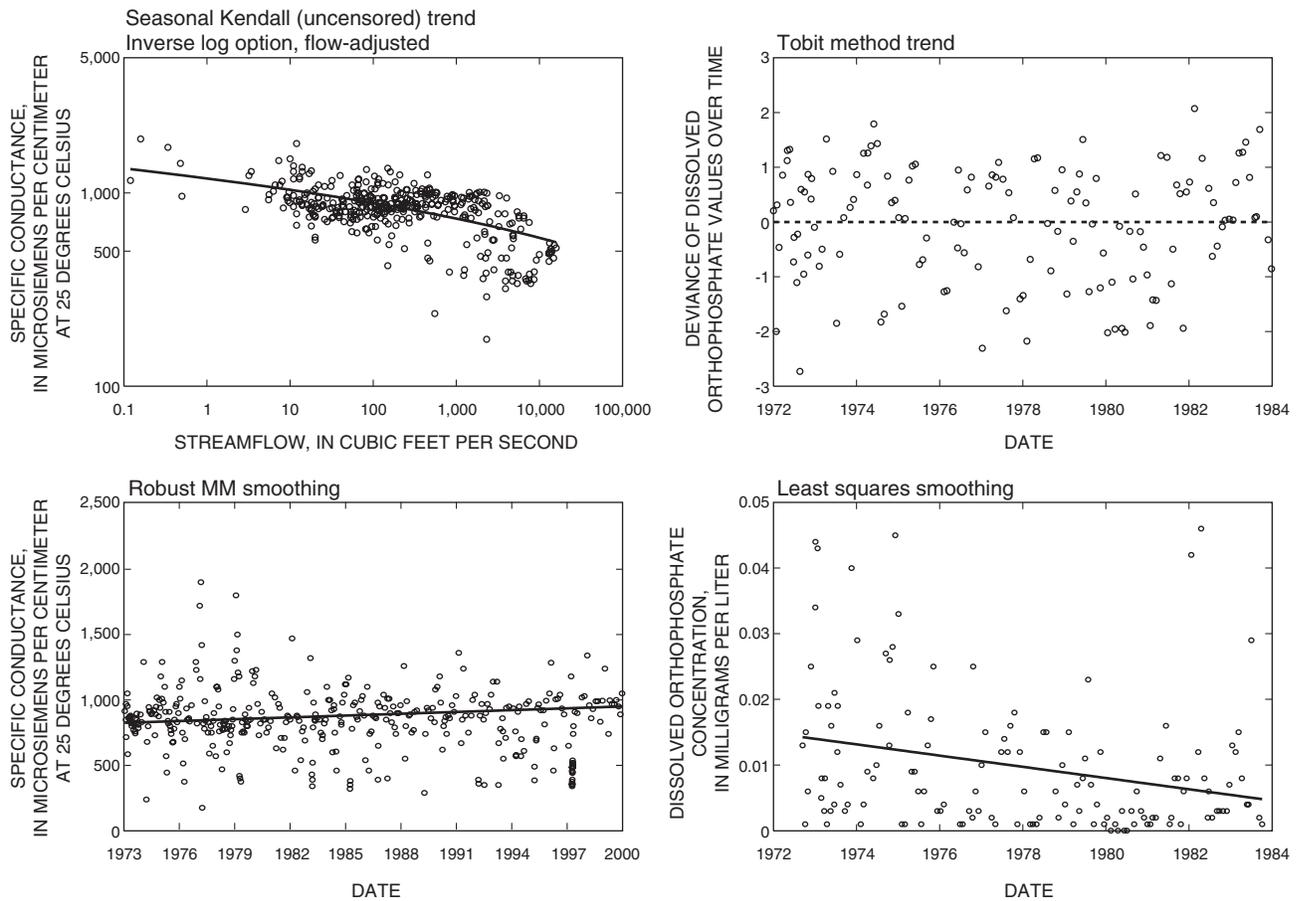


Figure 7. Trend-analysis plots showing significant trends using ESTREND in samples from the Big Sioux River near Dell Rapids.

The other surface-water sites did not have sufficient data to use ESTREND, so scatter plots with a local regression (Lowess) smoothing line are presented for selected constituents (fig. 8). This method does not use flow-adjusted data. Split Rock Creek and EROS Lake data are presented with individual plots, whereas the lagoon data are presented together on a single plot. The smoothing line displayed was created by the Lowess method (Cleveland, 1979) as discussed in the “Methods of Study” section.

Specific conductance was the only constituent that had sufficient values to present a Lowess plot for Split Rock Creek (fig. 8). The results of regression analyses for Split Rock Creek indicate decreasing specific-conductance values over time, although from 1975 to 1985, no change was evident, and the number of samples and specific-conductance values decreased after 1990. The Lowess plot for specific conductance at

EROS Lake indicates an increasing trend from 1973 to 1985 but a decreasing trend after 1990. The Lowess plot for the four lagoon sites strongly indicates a decreasing trend for all sites since 1980, when data collection began for specific conductance.

An increasing trend for alkalinity was evident at EROS Lake. The lagoon sites had varying trend results for alkalinity. The plot indicates an increasing trend for 1980 to 1984; however, there is a slight decrease after 1987, likely due to only one site (lagoon 1) being analyzed after 1987.

The trend results for dissolved solids, sum of constituents, for EROS Lake were variable because the first two samples, taken in 1973, were much lower than the subsequent samples taken during 1979 to 1986. Decreasing trends for dissolved solids, sum of constituents, is strongly indicated for the lagoon sites, both individually and as a group.

The EROS Lake regression plots indicate similar results for selected major ions, except for silica, with generally low values in 1973, and higher values from 1979 to 1986. The regression plots indicate calcium and potassium concentrations had a decreasing trend from 1979 to 1986, whereas plots for magnesium, chloride, sodium, sulfate, and fluoride generally indicate a slight increase in concentrations from 1979 to 1983, and a slight decrease from 1983 to 1986. The regression plot for dissolved silica indicates very little change from 1973 to 1986. The regression analyses of selected major-ion concentrations for the lagoon sites as a group indicate generally decreasing trends over time, especially from 1980 to 1986 for calcium, magnesium, sodium, potassium, and sulfate. Trends for chloride, fluoride, and silica had varying results, indicating both increases and decreases during the sampling period, but a decreasing trend overall.

Regression analyses for selected trace elements of aluminum, boron, and chromium strongly indicate decreasing trends for EROS Lake. Analysis of dissolved silver indicates no change during the sampling period, whereas dissolved zinc indicates variable results with no change overall for EROS Lake.

The regression analyses for the lagoon sites strongly indicate decreasing trends for dissolved boron and chromium, and a slightly increasing trend for dissolved silver. Variable increases and decreases appear evident for dissolved aluminum and zinc for the lagoon sites as a group.

Selected Ground-Water Sites

Water-quality samples were collected at 18 ground-water sites within the study area; however, sufficient data were collected at only 9 ground-water sites (table 1). The analytical results for the 18 ground-water sites are presented in table 16, but the following discussions only include data from the 9 sites with sufficient data.

Ground-water properties are aquifer dependent. Two of the selected ground-water sites (GW2 and GW4) are completed in glacial outwash (glacial aquifer), and seven of the selected ground-water sites are completed in bedrock (Sioux Quartzite aquifer). A statistical summary of the physical properties of the ground-water data, grouped by aquifer, is presented in table 10.

Table 10. Statistical summary of selected physical properties of ground-water sites, grouped by aquifer, in the study area [All values in milligrams per liter, except as indicated. $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; --, no data]

Property or constituent	Number of samples	Mean	Median	Minimum	Maximum
Glacial aquifer (glacial outwash)					
Specific conductance ($\mu\text{S}/\text{cm}$)	33	1,210	1,220	790	2,100
pH (standard units)	33	7.2	7.2	6.8	8.4
Temperature ($^{\circ}\text{C}$)	21	9.0	9	3.0	14.0
Carbon dioxide	32	84	66	2.6	208
Hardness, as CaCO_3	32	650	620	390	1,500
Noncarbonate hardness	27	100	73	13	390
Well depth (feet below land surface)	2	--	39.5	39	40
Sioux Quartzite aquifer (bedrock)					
Specific conductance ($\mu\text{S}/\text{cm}$)	162	1,270	959	681	3,520
pH (standard units)	160	7.3	7.3	5.8	8.7
Temperature ($^{\circ}\text{C}$)	94	9.5	10.0	7.5	12.0
Carbon dioxide	116	37	30	0.5	158
Hardness, as CaCO_3	118	700	520	370	1,800
Noncarbonate hardness	97	360	170	27	1,400
Well depth (feet below land surface)	7	227	165	80	465

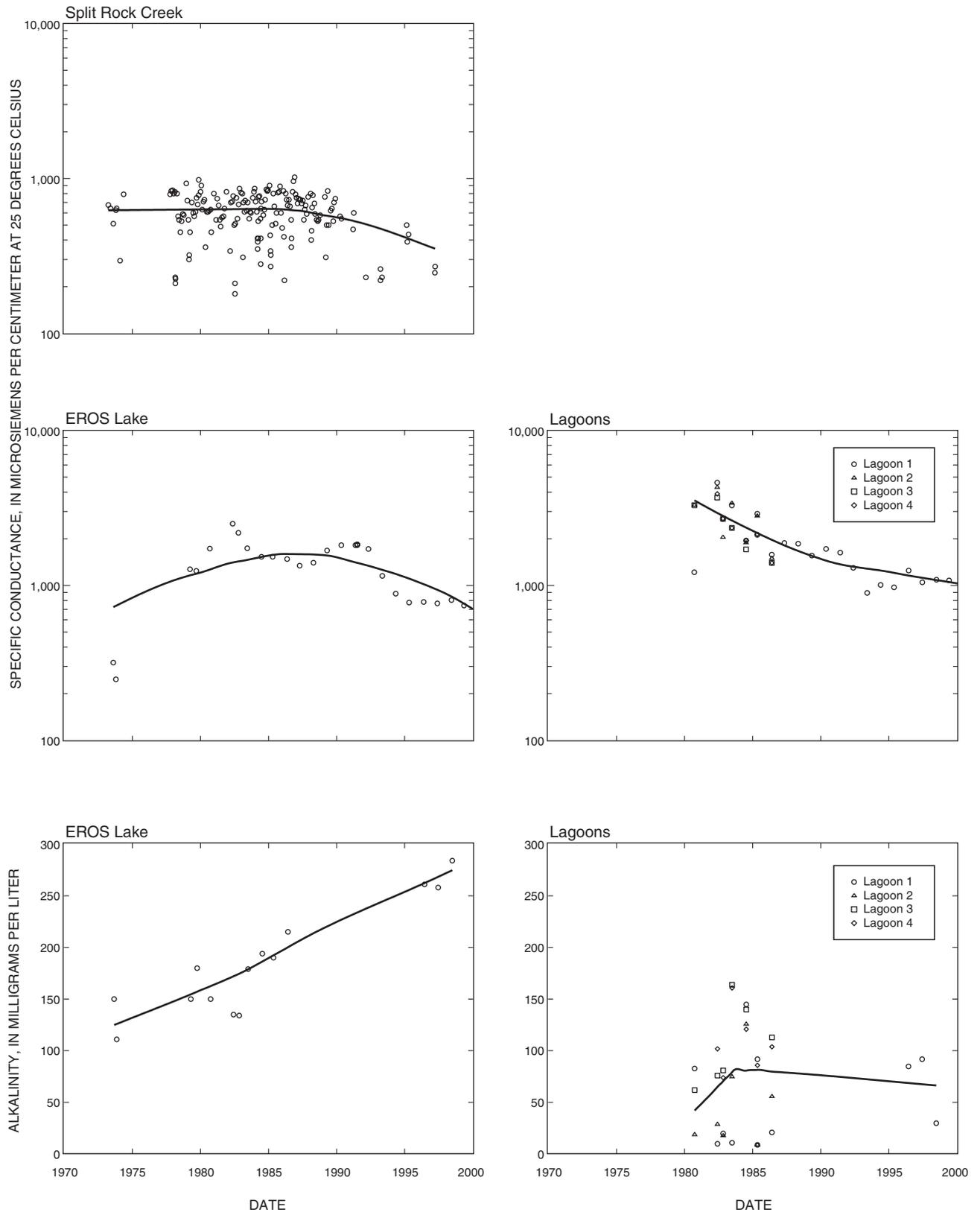


Figure 8. Local regression (Lowess) plots for constituent concentrations for selected surface-water sites in the study area.

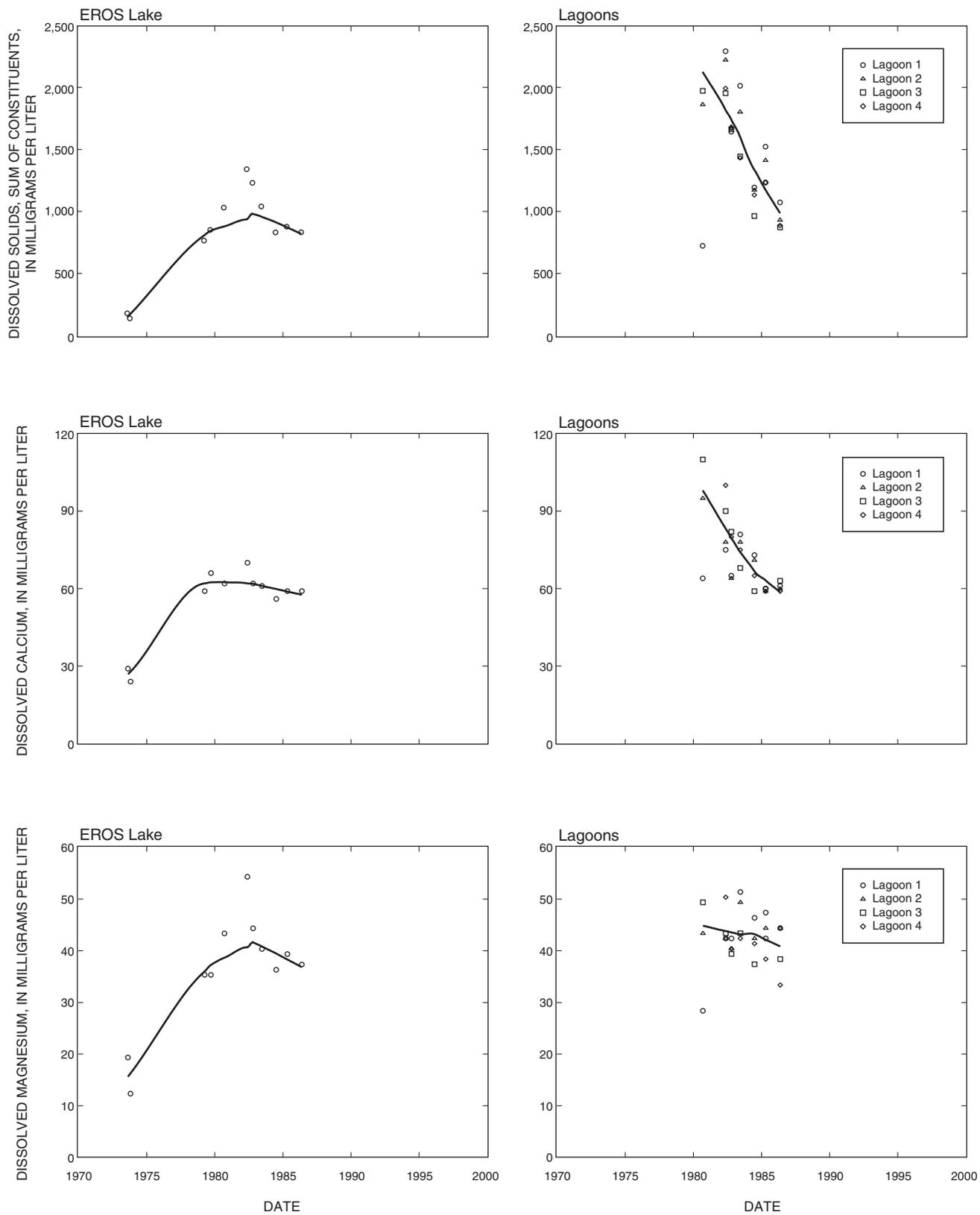


Figure 8. Local regression (Lowess) plots for constituent concentrations for selected surface-water sites in the study area.—Continued

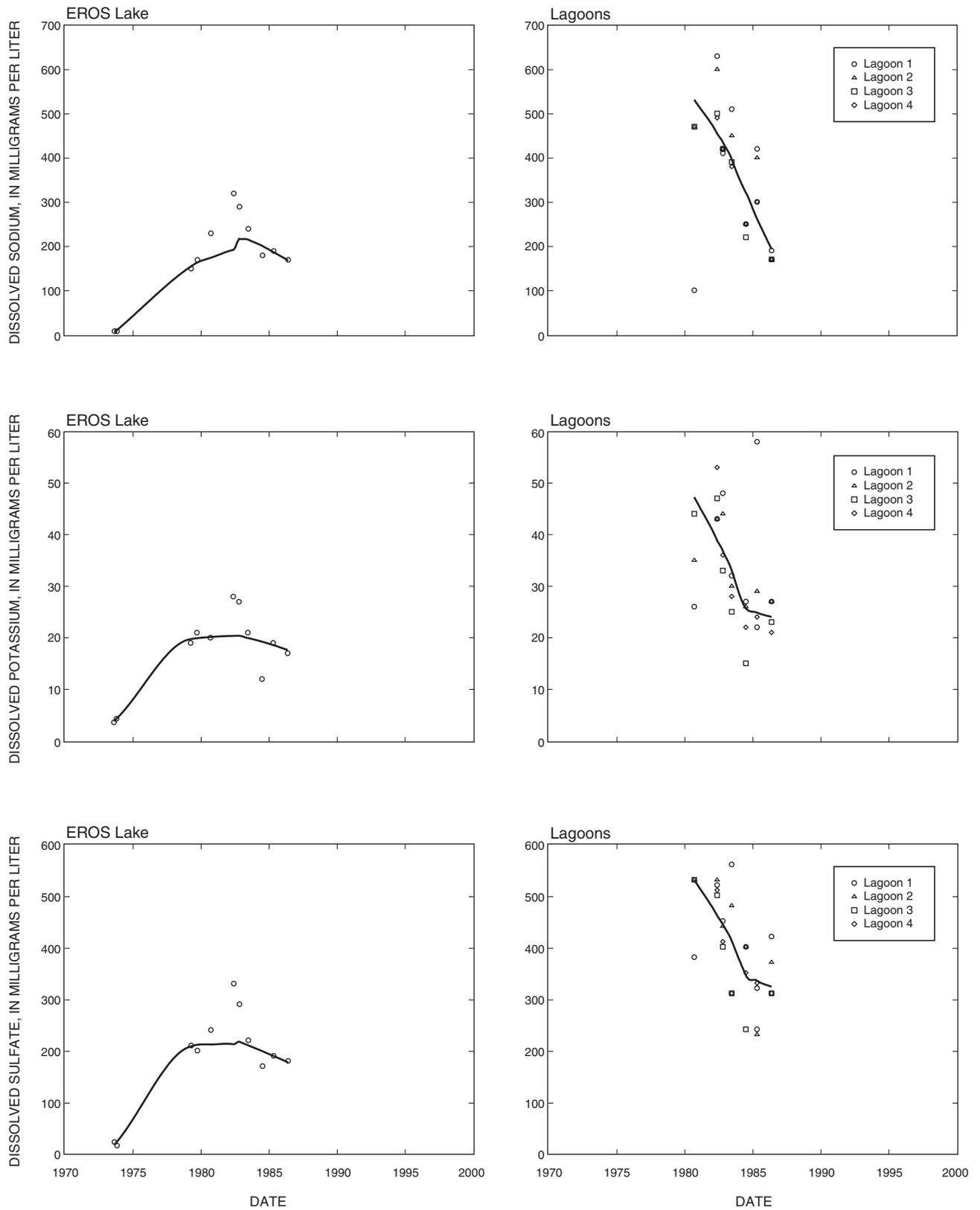


Figure 8. Local regression (Lowess) plots for constituent concentrations for selected surface-water sites in the study area.—Continued

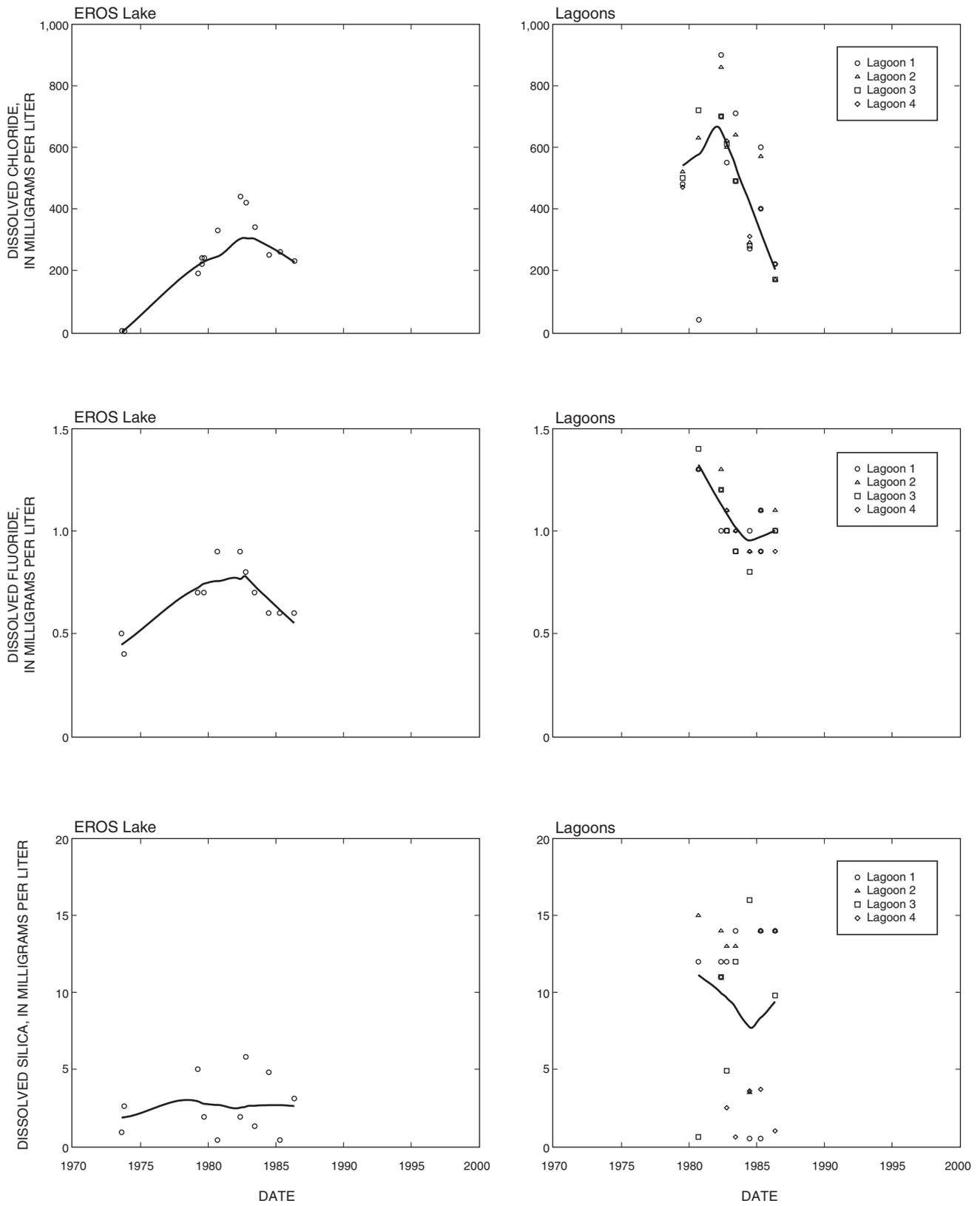


Figure 8. Local regression (Lowess) plots for constituent concentrations for selected surface-water sites in the study area.—Continued

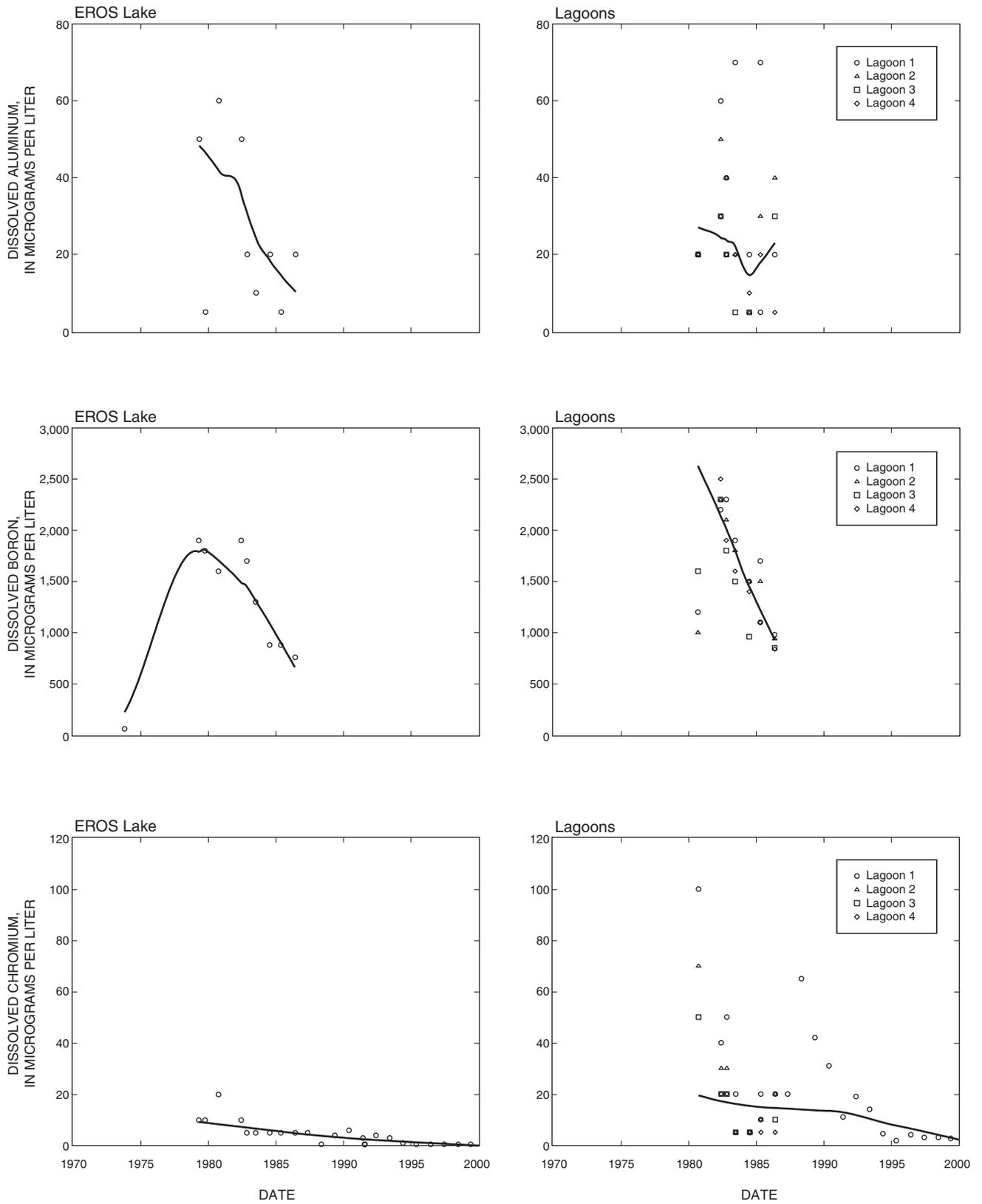


Figure 8. Local regression (Lowess) plots for constituent concentrations for selected surface-water sites in the study area.—Continued

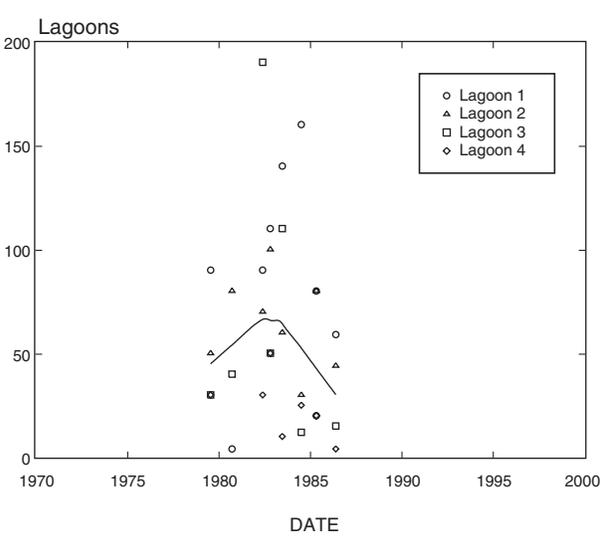
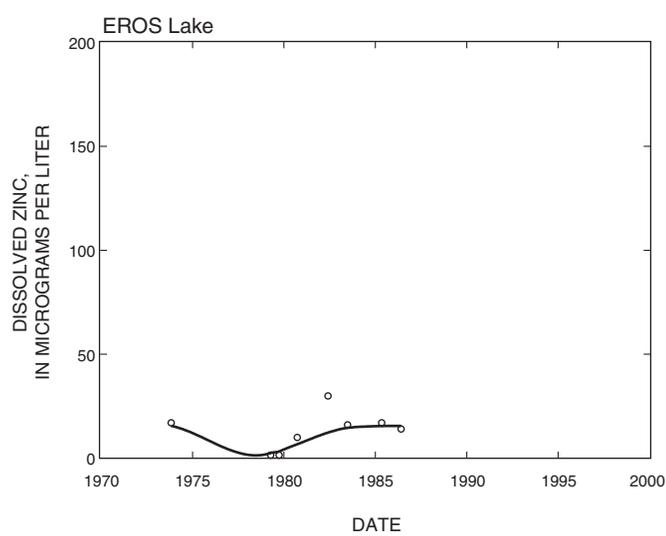
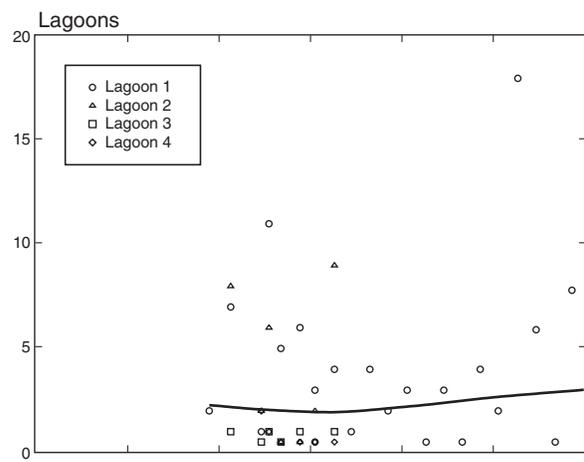
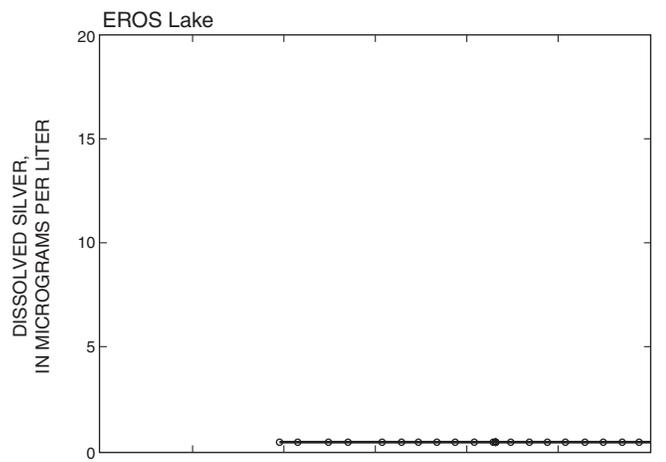


Figure 8. Local regression (Lowess) plots for constituent concentrations for selected surface-water sites in the study area.—Continued

Field-Measured Properties and Constituents

A statistical summary of the field measurements of selected physical properties for the nine ground-water sites is given in table 11. Boxplots of the selected field-measured properties and constituents for the nine ground-water sites are presented in figure 9.

Specific conductance for the selected ground-water sites ranged from 681 to 3,520 $\mu\text{S}/\text{cm}$, with the highest values and most variability measured at GW7. The pH values for the ground-water sites ranged from 5.8 to 8.7 (table 11, fig. 9).

Water seepage through organic soil that comes into contact with products of decomposition may

introduce gaseous carbon dioxide into ground water. Subterranean water rich in carbon dioxide may dissolve carbonates and bring them into solution as bicarbonates (Cole, 1994). The carbon dioxide values for ground-water sites ranged from 0.5 to 208 mg/L.

Hardness for the ground-water sites ranged from 370 to 1,800 mg/L, noncarbonate hardness ranged from 13 to 1,400 mg/L, and alkalinity ranged from 85 to 862 mg/L. Samples from GW7 had the highest hardness and noncarbonate hardness values and the most variability of these properties for the ground-water sites.

Table 11. Statistical summary of selected physical properties for selected ground-water sites in the study area

[All values in milligrams per liter, except as indicated. Statistics summarize alkalinity field and laboratory values, and are a combination of fixed-end point and inflection titrations. $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; °C, Celsius]

Property or constituent	GW1					GW2				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance ($\mu\text{S}/\text{cm}$)	35	961	920	810	1,500	14	941	915	790	1,220
pH (standard units)	35	7.3	7.3	6.3	8.3	14	7.4	7.4	7.0	8.4
Water temperature (°C)	25	9.5	9.5	8.5	11.0	10	9.0	9.0	3.0	14.0
Carbon dioxide	20	28	30	3.0	59	14	38	33	2.6	78
Hardness, as CaCO_3	20	480	460	410	690	14	500	470	390	610
Noncarbonate hardness	14	170	170	93	250	12	60	50	13	170
Alkalinity, as CaCO_3	23	313	308	290	385	14	429	415	313	530

Property or constituent	GW3					GW4				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance ($\mu\text{S}/\text{cm}$)	12	1,400	1,410	1,200	1,530	19	1,410	1,330	1,060	2,100
pH (standard units)	12	7.3	7.2	7.1	7.5	19	7.0	7.0	6.8	7.3
Water temperature (°C)	2	--	--	10.0	10.0	11	9.0	9.0	4.5	12.5
Carbon dioxide	12	33	36	18	47	18	120	113	51	208
Hardness, as CaCO_3	12	830	820	760	900	18	770	720	590	1,500
Noncarbonate hardness	12	530	530	460	600	15	130	92	36	390
Alkalinity, as CaCO_3	12	298	300	285	302	18	613	600	491	862

Table 11. Statistical summary of selected physical properties for selected ground-water sites in the study area—Continued

[All values in milligrams per liter, except as indicated. Statistics summarize alkalinity field and laboratory values, and are a combination of fixed-end point and inflection titrations. $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, Celsius]

Property or constituent	GW5					GW6				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance ($\mu\text{S}/\text{cm}$)	11	796	804	700	840	15	762	760	710	825
pH (standard units)	11	7.3	7.3	7.1	7.7	15	7.4	7.4	7.1	7.5
Water temperature ($^{\circ}\text{C}$)	3	10.0	10.0	10.0	10.0	5	10	10	8.5	10
Carbon dioxide	11	40	36	14	58	14	28	26	21	49
Hardness, as CaCO_3	11	410	410	390	430	14	384	385	370	400
Noncarbonate hardness	11	49	45	27	77	14	54	54	27	100
Alkalinity, as CaCO_3	11	364	365	350	373	14	332	340	294	343

Property or constituent	GW7					GW8				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance ($\mu\text{S}/\text{cm}$)	37	1,970	1,910	941	3,520	18	1,820	1,880	1,250	2,040
pH (standard units)	37	7.1	7.1	6.2	8.0	18	8	7.5	7.2	8.7
Water temperature ($^{\circ}\text{C}$)	27	9.5	9.5	7.5	12.0	7	9.5	9.5	8.0	10.0
Carbon dioxide	22	73	68	7.9	158	17	20	19	0.5	40
Hardness, as CaCO_3	23	1,080	1,000	710	1,800	18	1,100	1,100	610	1,200
Noncarbonate hardness	16	711	610	300	1,400	14	817	820	750	880
Alkalinity, as CaCO_3	26	423	424	300	542	17	289	320	85	327

Property or constituent	GW9				
	Number of samples	Mean	Median	Minimum	Maximum
Specific conductance ($\mu\text{S}/\text{cm}$)	34	874	880	681	1,070
pH (standard units)	34	7.3	7.3	5.8	8.2
Water temperature ($^{\circ}\text{C}$)	25	9.5	10.0	8.0	11.5
Carbon dioxide	20	28	26	4.1	40
Hardness, as CaCO_3	20	450	450	410	530
Noncarbonate hardness	16	128	125	79	180
Alkalinity, as CaCO_3	23	323	322	280	346

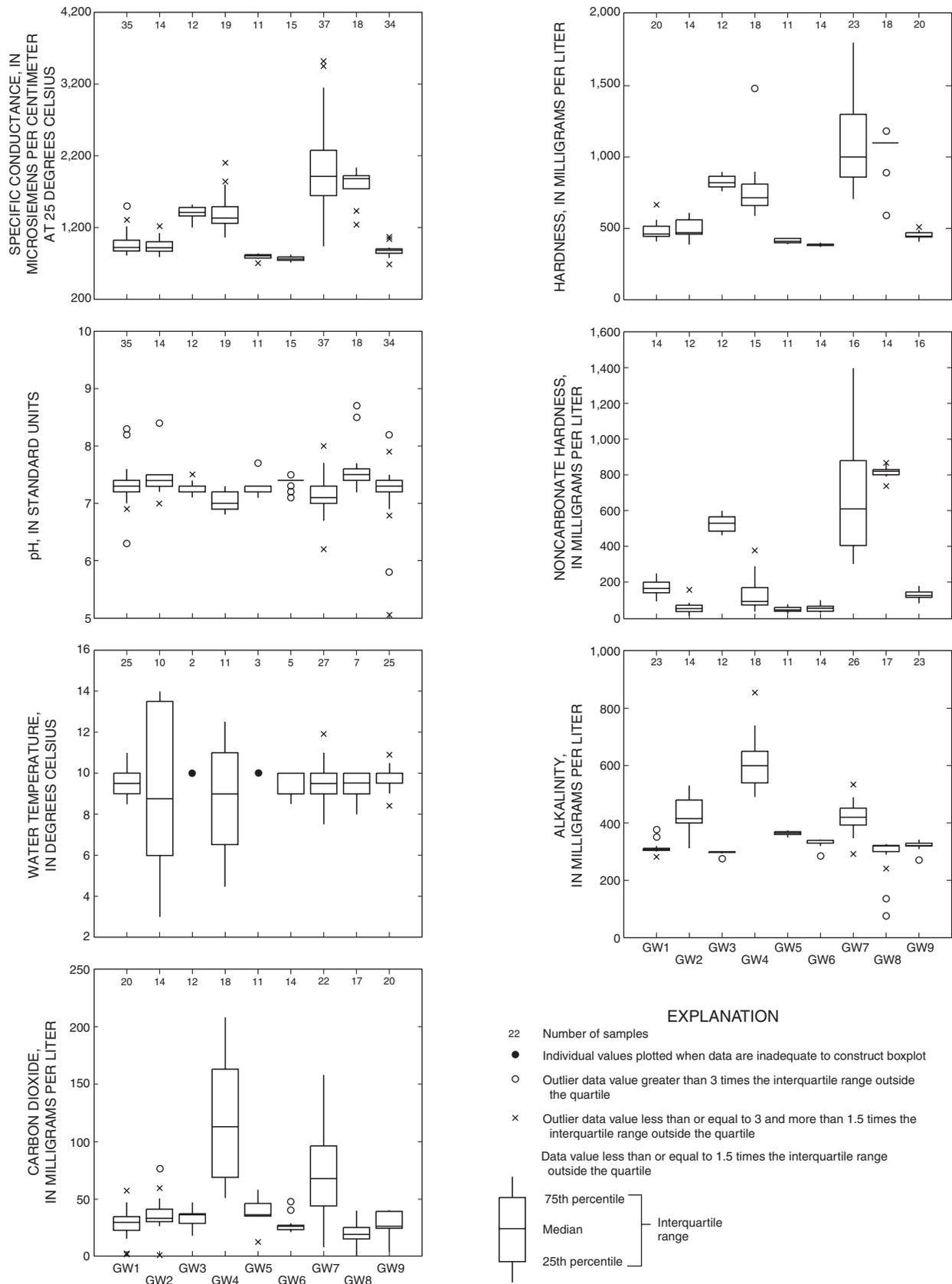


Figure 9. Boxplots of field-measured properties and constituent concentrations for selected ground-water sites in the study area.

Major Ions and Indicators of Major Ions

A statistical summary of selected major ions, including dissolved solids, calcium, magnesium, sodium, percent sodium, sodium-adsorption ratio, potassium, bicarbonate, carbonate, sulfate, chloride, fluoride, and silica, is given in table 12. Boxplots are presented in figure 10 for each of the major ions, except carbonate.

Concentrations of dissolved solids, residue at 180°C, was analyzed for at GW1, GW7, and GW9, and concentrations ranged from 527 to 1,390 mg/L. Dissolved solids, sum of constituents, was analyzed for in samples from all nine ground-water sites, and concentrations ranged from 193 to 2,530 mg/L.

Site GW7, located approximately one-third mile east of EROS Lake (fig. 1), had the highest maximum value for several of the dissolved constituents for major ions, including calcium (matching the maximum value with GW4), magnesium, sodium, and chloride. GW7 is

completed in the Sioux Quartzite aquifer, although it is relatively shallow at only 80 ft deep. GW4 also had maximum concentrations for several additional major ion constituents, including potassium, bicarbonate, and silica (matching the maximum value with GW6). GW4 is located approximately one-third mile northeast of EROS Lake and, at 39 ft deep, is completed in the glacial aquifer.

Proportions of major ions in water samples from selected ground-water sites are shown in a trilinear diagram (Piper, 1944) in figure 11. The water type in the two wells (GW2 and GW4) completed in the glacial aquifer is calcium magnesium bicarbonate. Cation data indicate predominantly calcium- and magnesium-rich water for wells completed in the Sioux Quartzite aquifer. Anion data generally indicate predominantly sulfate- and bicarbonate-rich water, with the exception of GW7, where chloride is more dominant than sulfate.

Table 12. Statistical summary of major-ion and indicators of major-ion results for data for selected ground-water sites in the study area

[All values are for dissolved constituents, in milligrams per liter, except as indicated. Bicarbonate and carbonate are a combination of fixed-end point and inflection titrations]

Constituent	GW1					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	14	0	650	639	537	801
Solids, sum of constituents	20	0	600	609	193	936
Calcium	20	0	139	140	110	160
Magnesium	20	0	33	31	11	69
Sodium	20	0	16	16	15	22
Sodium, percent	20	0	7	7	6	8
Sodium-adsorption ratio	20	0	0.3	0.3	0.3	0.4
Potassium	20	0	3.8	3.8	3.2	4.2
Bicarbonate	16	0	377	376	350	439
Carbonate	15	0	0	0	0	0
Sulfate	19	0	199	200	130	290
Chloride	19	0	4.6	1.4	0.9	61
Fluoride	19	0	0.8	0.8	0.5	0.8
Silica	20	0	24	25	18	27

Table 12. Statistical summary of major-ion and indicators of major-ion results for data for selected ground-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. Bicarbonate and carbonate are a combination of fixed-end point and inflection titrations]

Constituent	GW2					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	14	0	590	553	435	1,010
Calcium	14	0	99	93	84	130
Magnesium	14	0	60	60	28	81
Sodium	14	0	24	24	20	30
Sodium, percent	14	0	10	10	7	12
Sodium-adsorption ratio	14	0	0.5	0.5	0.4	0.6
Potassium	14	0	2.8	2.2	1.2	11
Bicarbonate	11	0	516	503	382	640
Carbonate	11	0	0	0	0	0
Sulfate	14	0	89	64	37	360
Chloride	14	0	25	20	3.5	100
Fluoride	13	0	0.9	0.9	0.6	1.0
Silica	14	0	22	23	14	28

Constituent	GW3					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	12	0	1,070	1,050	993	1,190
Calcium	12	0	220	220	200	240
Magnesium	12	0	67	67	56	73
Sodium	12	0	23	23	21	23
Sodium, percent	12	0	6	6	5	6
Sodium-adsorption ratio	12	0	0.3	0.3	0.3	0.4
Potassium	12	0	4.0	4.0	3.6	4.4
Bicarbonate	12	0	363	363	348	370
Carbonate	11	0	0	0	0	0
Sulfate	12	0	553	545	490	650
Chloride	12	0	3.4	3.4	2.8	4.1
Fluoride	12	0	0.7	0.6	0.6	0.8
Silica	12	0	17	17	16	17

Table 12. Statistical summary of major-ion and indicators of major-ion results for data for selected ground-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. Bicarbonate and carbonate are a combination of fixed-end point and inflection titrations]

Constituent	GW4					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	18	0	876	827	390	1,790
Calcium	18	0	174	165	140	340
Magnesium	18	0	81	76	59	150
Sodium	18	0	23	19	16	63
Sodium, percent	18	0	6	6	4	8
Sodium-adsorption ratio	18	0	0.4	0.3	0.3	0.7
Potassium	18	0	9.2	7.2	2.3	23
Bicarbonate	13	0	702	692	599	820
Carbonate	12	0	0	0	0	0
Sulfate	17	0	60	56	25	140
Chloride	18	0	61	53	6.7	290
Fluoride	17	0	0.5	0.5	0.4	0.6
Silica	18	0	26	26	22	30

Constituent	GW5					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	11	0	507	505	488	526
Calcium	11	0	104	100	99	110
Magnesium	11	0	37	37	35	38
Sodium	11	0	20	21	19	21
Sodium, percent	11	0	10	10	9	10
Sodium-adsorption ratio	11	0	0.4	0.4	0.4	0.5
Potassium	11	0	4.4	4.4	4.1	5.0
Bicarbonate	10	0	444	445	427	455
Carbonate	9	0	0	0	0	0
Sulfate	11	0	86	86	75	110
Chloride	11	0	5.8	5.7	4.9	7.5
Fluoride	11	0	1.3	1.3	1.1	1.3
Silica	11	0	26	26	24	28

Table 12. Statistical summary of major-ion and indicators of major-ion results for data for selected ground-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. Bicarbonate and carbonate are a combination of fixed-end point and inflection titrations]

Constituent	GW6					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	14	0	479	479	456	505
Calcium	14	0	96	97	89	100
Magnesium	14	0	35	35	34	37
Sodium	14	0	21	21	19	22
Sodium, percent	14	0	10	10	10	11
Sodium-adsorption ratio	14	0	0.5	0.5	0.4	0.5
Potassium	14	0	3.1	3.0	2.8	3.7
Bicarbonate	12	0	404	412	358	418
Carbonate	11	0	0	0	0	0
Sulfate	14	0	79	78	53	110
Chloride	15	0	3.6	3.7	2.6	4.8
Fluoride	14	0	0.7	0.7	0.5	0.8
Silica	14	0	27	28	20	30

Constituent	GW7					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	14	0	1,010	1,030	625	1,390
Solids, sum of constituents	23	0	1,410	1,340	262	2,530
Calcium	23	0	217	210	140	340
Magnesium	23	0	132	120	84	230
Sodium	23	0	47	45	28	96
Sodium, percent	23	0	9	8	6	17
Sodium-adsorption ratio	23	0	0.6	0.6	0.4	1.0
Potassium	23	0	7.0	6.9	3.9	10
Bicarbonate	16	0	544	539	460	661
Carbonate	15	0	0	0	0	0
Sulfate	22	0	143	125	81	360
Chloride	23	0	161	130	73	360
Fluoride	22	0	0.5	0.5	0.4	0.7
Silica	23	0	25	25	23	27

Table 12. Statistical summary of major-ion and indicators of major-ion results for data for selected ground-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. Bicarbonate and carbonate are a combination of fixed-end point and inflection titrations]

Constituent	GW8					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	0	0	--	--	--	--
Solids, sum of constituents	17	0	1,420	1,510	618	1,580
Calcium	18	0	288	300	130	320
Magnesium	18	0	89	91	63	98
Sodium	18	0	34	33	32	41
Sodium, percent	18	0	7	6	6	13
Sodium-adsorption ratio	18	0	0.4	0.4	0.4	0.8
Potassium	18	0	5.7	5.6	5.1	6.6
Bicarbonate	13	0	380	390	300	399
Carbonate	12	0	0	0	0	0
Sulfate	17	0	842	860	620	890
Chloride	17	0	8.2	7.6	6.8	15
Fluoride	17	0	0.4	0.4	0.2	1.0
Silica	16	0	20	22	3.7	25

Constituent	GW9					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Solids, residue at 180°C	14	0	585	589	527	601
Solids, sum of constituents	20	0	544	555	199	629
Calcium	20	0	134	130	120	160
Magnesium	20	0	28	28	25	32
Sodium	20	0	18	17	15	23
Sodium, percent	20	0	8	8	7	10
Sodium-adsorption ratio	20	0	0.4	0.4	0.3	0.5
Potassium	20	0	3.9	3.9	3.2	4.2
Bicarbonate	16	0	395	392	380	422
Carbonate	15	0	0	0	0	0
Sulfate	19	0	160	160	110	220
Chloride	19	0	1.5	1.1	0.6	3.6
Fluoride	19	0	0.5	0.4	0.3	1.4
Silica	20	0	23	23	19	26

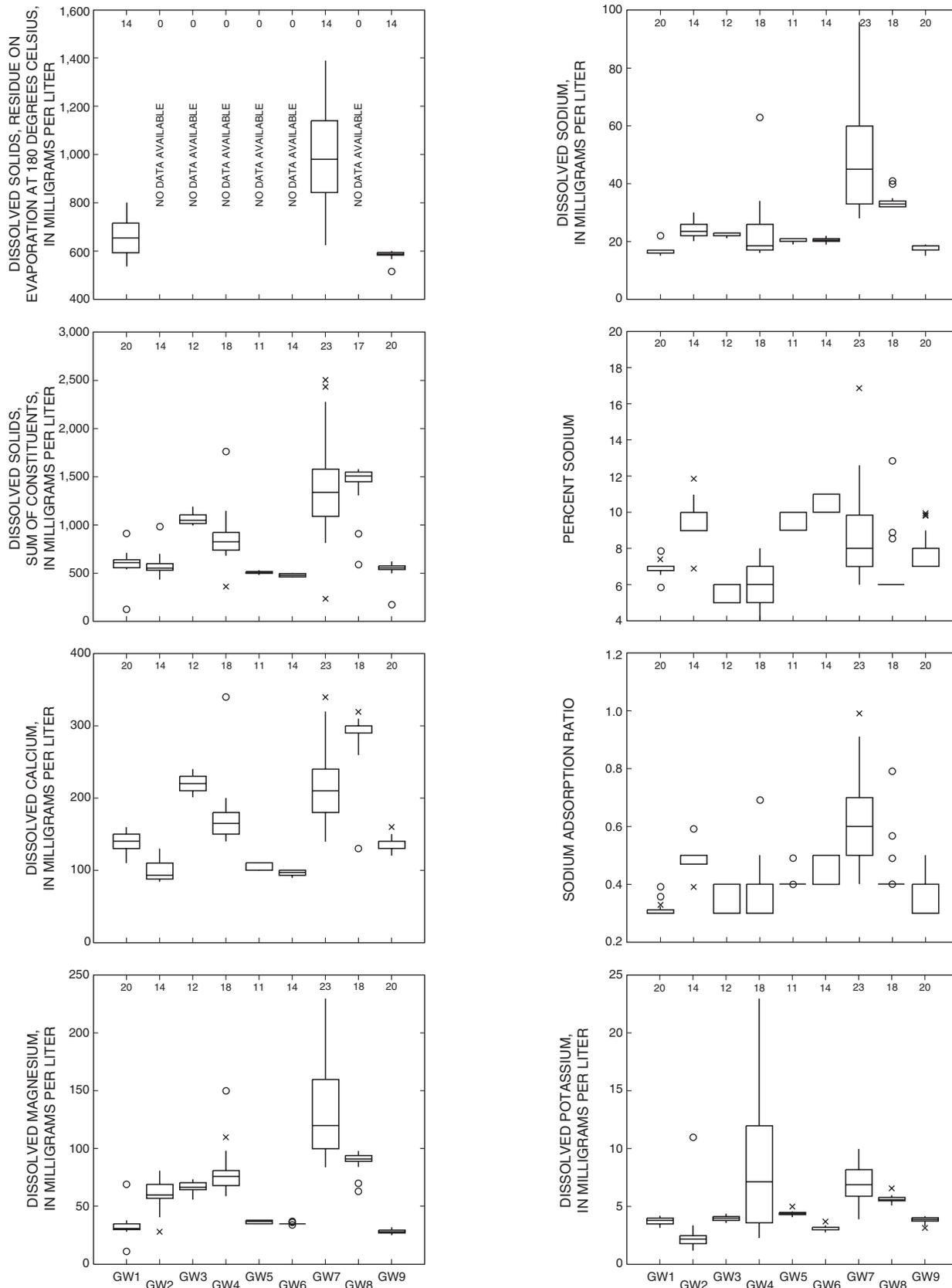
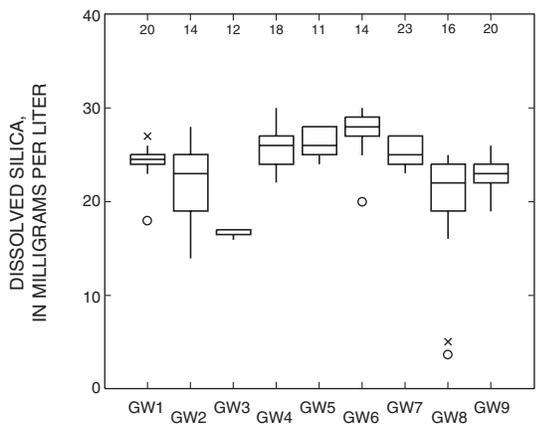
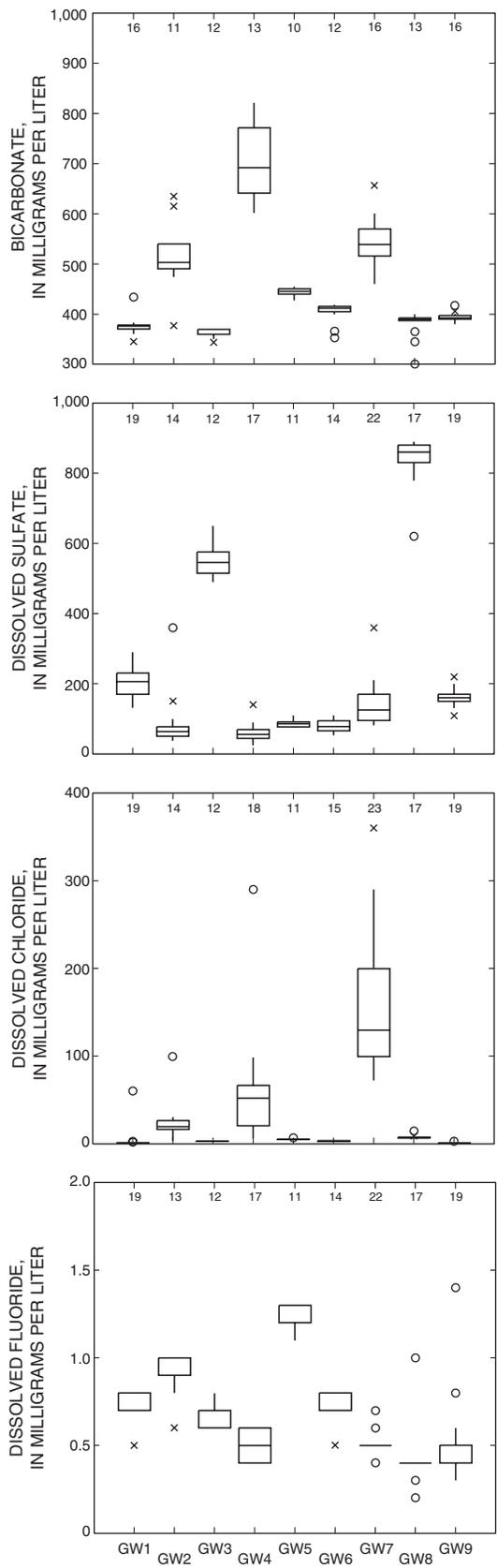


Figure 10. Boxplots of major-ion constituent concentrations for selected ground-water sites in the study area.



EXPLANATION

- 11 Number of samples
 - Outlier data value greater than 3 times the interquartile range outside the quartile
 - × Outlier data value less than or equal to 3 and more than 1.5 times the interquartile range outside the quartile
 - Data value less than or equal to 1.5 times the interquartile range outside the quartile
-
- 75th percentile
 - Median
 - 25th percentile
 - Interquartile range

Figure 10. Boxplots of major-ion constituent concentrations for selected ground-water sites in the study area.—Continued

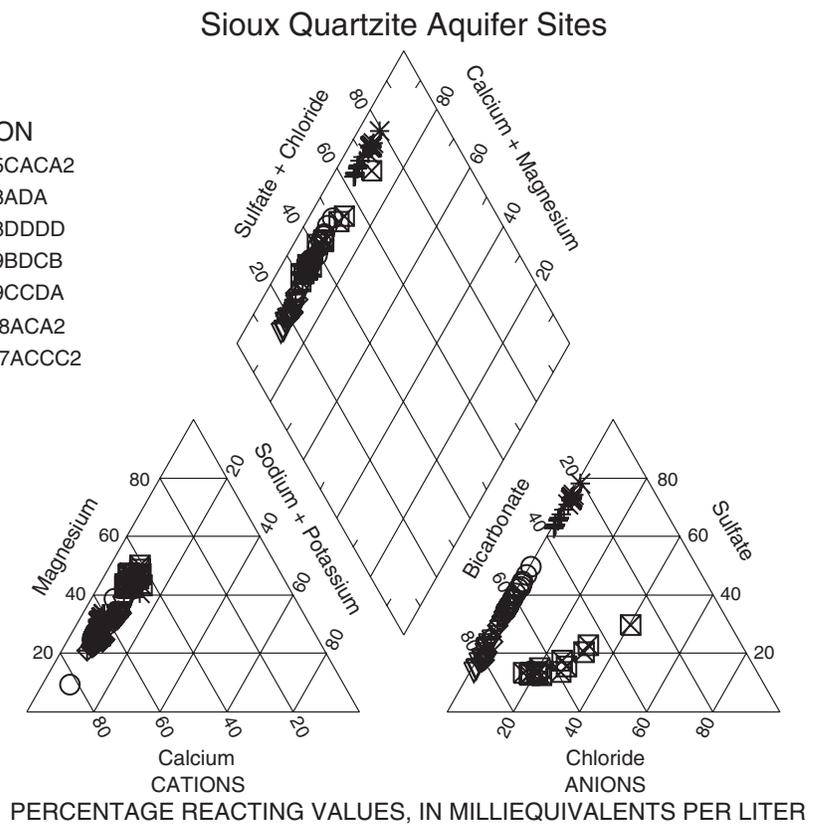
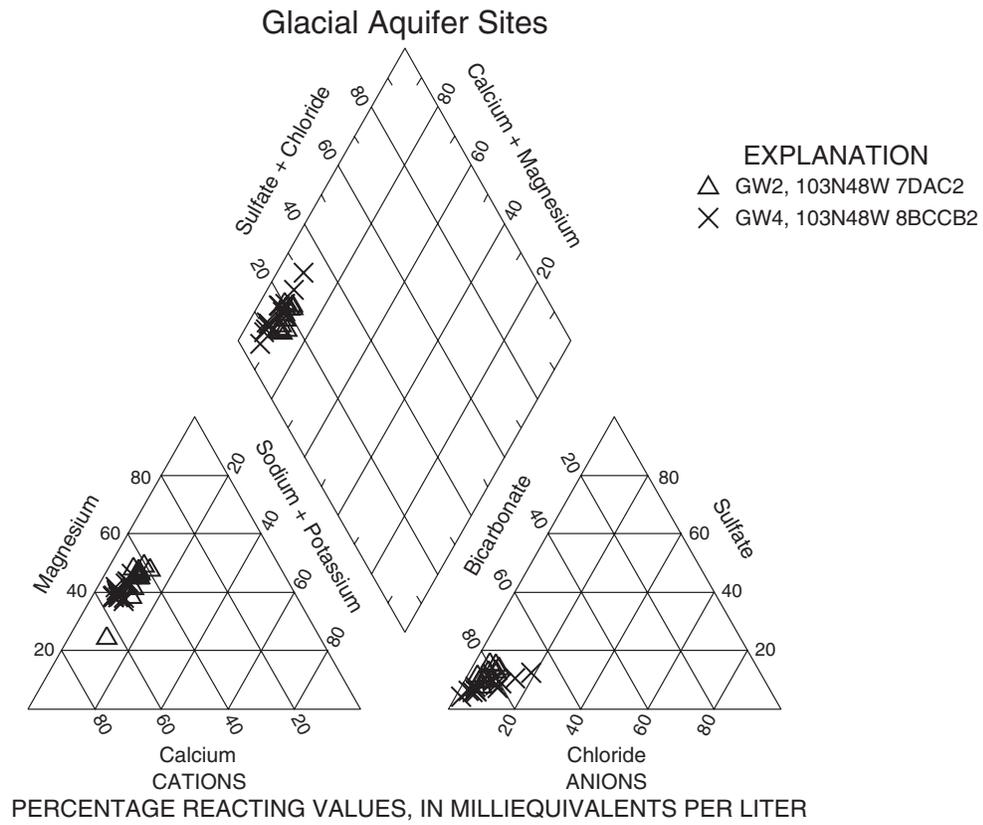


Figure 11. Trilinear diagrams (Piper, 1944) showing proportions of major ions for selected ground-water sites in the study area.

Nutrients

A statistical summary of nutrient concentrations in samples from ground-water sites located within the study area is given in table 13. Boxplots for selected nutrient constituents are presented in figure 12.

Nitrite plus nitrate, as nitrogen, was routinely sampled at each site; other constituents typically have only minimal sample results due to the requirements of the monitoring program. Nitrite plus nitrate concentrations ranged from less than the study reporting level of 0.10 mg/L to 250 mg/L (table 13, fig. 12). Concentrations in samples from GW4 and GW7 generally were greater than 10 mg/L, and exceeded the water-quality standard for drinking water (U.S. Environmental Protection Agency, 2002). The high nitrite plus nitrate concentrations at GW4 and GW7 probably reflect local contamination and not contamination from EROS

wastewater-treatment processes because concentrations measured in samples from EROS Lake were less than 1.0 mg/L. When analyzed, nitrite, as nitrogen, concentrations ranged from less than 0.01 to 0.02 mg/L.

Samples from ground-water sites that were analyzed for ammonia had concentrations that ranged from less than the study reporting level of 0.02 mg/L to 0.21 mg/L. Samples that were analyzed for ammonia plus organic, total, had concentrations that ranged from 0.02 to 9.6 mg/L.

Total phosphorus concentrations ranged from less than the study reporting level of 0.01 mg/L to 0.23 mg/L. Orthophosphate was only analyzed in three samples from the ground-water sites, and the concentrations ranged from less than the study reporting level of 0.01 mg/L to 0.07 mg/L.

Table 13. Statistical summary of nitrogen and phosphorus nutrient results for data for selected ground-water sites in the study area

[All values are for dissolved constituents, in milligrams per liter, except as indicated. <, less than; --, not analyzed or not determined]

Property or constituent	GW1					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	10	8	<0.01	<0.01	<0.01	0.01
Nitrite plus nitrate, as N	34	14	5.0	0.11	<0.10	53
Ammonia, as N	14	5	0.03	0.02	<0.02	0.10
Ammonia plus organic, as N	5	0	0.34	0.37	0.02	0.59
Phosphorus, total, as P	5	1	0.03	0.01	<0.01	0.07
Orthophosphate, as P	10	2	0.02	0.02	<0.01	0.03
Property or constituent	GW2					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	0	0	--	--	--	--
Nitrite plus nitrate, as N	14	2	1.9	1.0	<0.10	4.9
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, as N	5	0	0.53	0.48	0.33	0.83
Phosphorus, total, as P	5	2	0.03	0.01	<0.01	0.08
Orthophosphate, as P	0	0	--	--	--	--

Table 13. Statistical summary of nitrogen and phosphorus nutrient results for data for selected ground-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. <, less than; --, not analyzed or not determined]

Property or constituent	GW3					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	0	0	--	--	--	--
Nitrite plus nitrate, as N	12	9	0.11	<0.10	<0.10	0.57
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, as N	3	0	0.22	0.24	0.16	0.26
Phosphorus, total, as P	3	2	--	<0.01	<0.01	0.01
Orthophosphate, as P	0	0	--	--	--	--

Property or constituent	GW4					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	0	0	--	--	--	--
Nitrite plus nitrate, as N	17	0	22	15	0.14	67
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, as N	7	0	1.3	1.3	0.05	2.2
Phosphorus, total, as P	7	0	0.05	0.02	0.01	0.23
Orthophosphate, as P	0	0	--	--	--	--

Property or constituent	GW5					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	0	0	--	--	--	--
Nitrite plus nitrate, as N	11	7	<0.10	<0.10	<0.10	0.43
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, as N	3	0	0.33	0.33	0.25	0.40
Phosphorus, total, as P	3	1	0.01	0.01	<0.01	0.02
Orthophosphate, as P	0	0	--	--	--	--

Property or constituent	GW6					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	0	0	--	--	--	--
Nitrite plus nitrate, as N	14	0	3.2	3.2	2.0	5.3
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, as N	7	0	0.56	0.49	0.14	1.4
Phosphorus, total, as P	7	1	0.02	0.01	<0.01	0.04
Orthophosphate, as P	0	0	--	--	--	--

Table 13. Statistical summary of nitrogen and phosphorus nutrient results for data for selected ground-water sites in the study area—Continued

[All values are for dissolved constituents, in milligrams per liter, except as indicated. <, less than; --, not analyzed or not determined]

Property or constituent	GW7					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	10	8	--	<0.01	<0.01	0.02
Nitrite plus nitrate, as N	37	1	77	73	<0.10	250
Ammonia, as N	14	5	0.04	0.03	<0.02	0.18
Ammonia plus organic, as N	8	0	2.8	2.0	0.15	9.6
Phosphorus, total, as P	8	0	0.03	0.03	0.01	0.04
Orthophosphate, as P	10	0	0.02	0.03	0.01	0.04

Property or constituent	GW8					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	0	0	--	--	--	--
Nitrite plus nitrate, as N	17	11	0.13	<0.10	<0.10	0.83
Ammonia, as N	0	0	--	--	--	--
Ammonia plus organic, as N	5	0	0.70	0.62	0.52	1.1
Phosphorus, total, as P	5	0	0.04	0.05	0.02	0.06
Orthophosphate, as P	0	0	--	--	--	--

Property or constituent	GW9					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Nitrite, as N	10	9	<0.01	<0.01	<0.01	0.02
Nitrite plus nitrate, as N	32	19	0.09	<0.10	<0.10	0.33
Ammonia, as N	14	0	0.18	0.18	0.13	0.21
Ammonia plus organic, as N	7	0	0.40	0.37	0.29	0.62
Phosphorus, total, as P	7	4	0.02	<0.01	<0.01	0.08
Orthophosphate, as P	10	2	0.02	0.01	<0.01	0.07

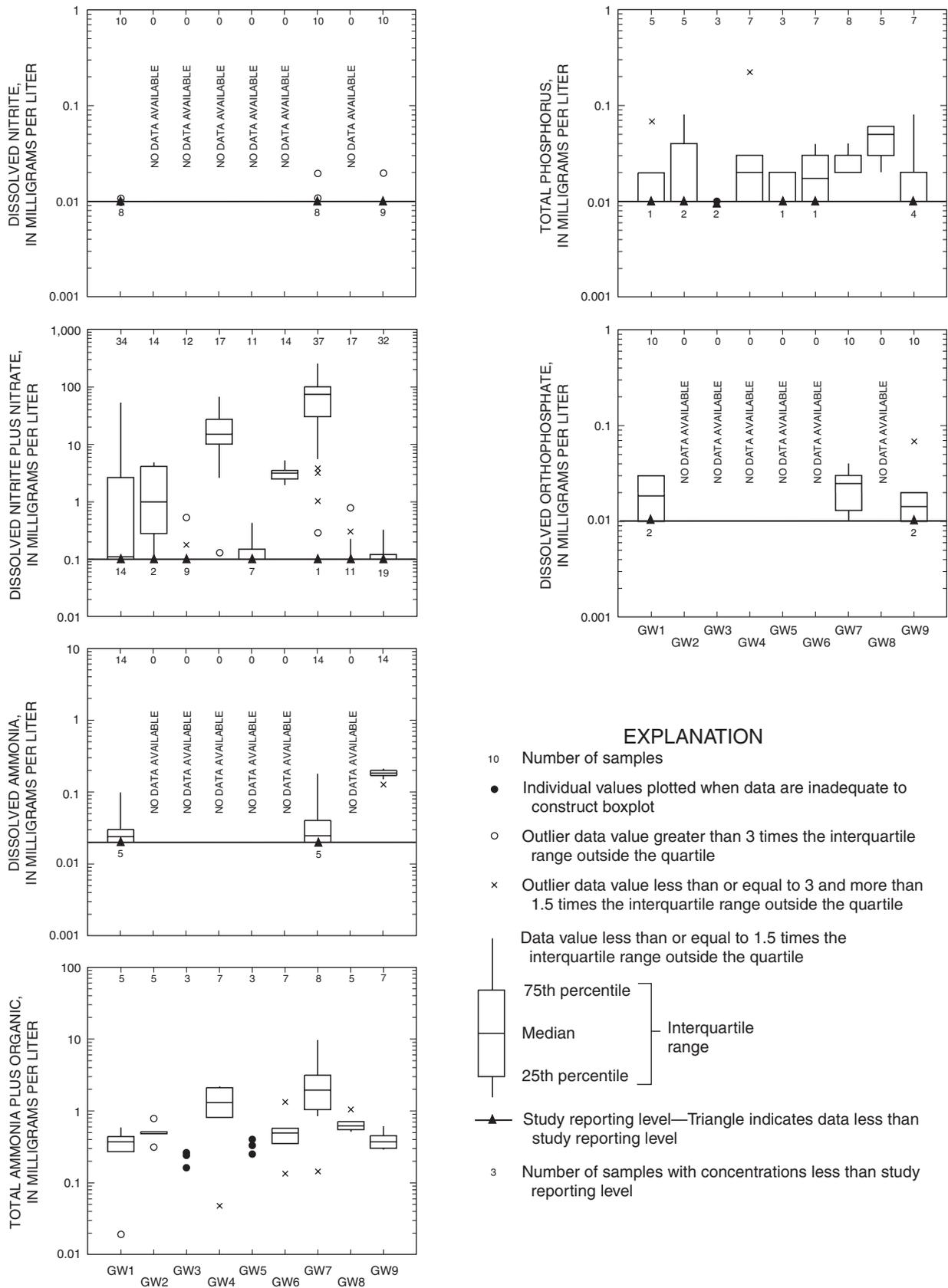


Figure 12. Boxplots of nutrient constituent concentrations for selected ground-water sites in the study area.

Trace Elements

A statistical summary of selected trace elements in samples from ground-water sites located within the study area is given in table 14. Concentrations of trace elements were highly variable among wells (table 14, fig. 13). Boxplots are presented for selected trace elements in figure 13. Many of the constituents in table 14 had a high percentage of concentrations with censored data. All dissolved silver concentrations were reported below the study reporting level of 2 µg/L, thus a boxplot is not presented for dissolved silver.

Concentrations of dissolved aluminum for ground-water sites ranged from less than the study reporting level of 10 µg/L to 230 µg/L. Concentrations of dissolved boron ranged from 10 to 1,700 µg/L. Dissolved chromium concentrations ranged from less than the study reporting level of 10 µg/L to 20 µg/L, and dissolved iron concentrations ranged from less than the study reporting level of 10 µg/L to 9,200 µg/L. Dissolved manganese concentrations ranged from less than the study reporting level of 20 µg/L to 1,700 µg/L. Concentrations of dissolved zinc ranged from less than the study reporting level of 3 µg/L to 3,000 µg/L.

Trends

The ESTREND trend-analysis program could not be used with the ground-water data set because of insufficient data. Scatter plots with a local regression (Lowess) smoothing line are presented for representative sites for selected constituents in figure 14. The graphical output shows the trend line for the selected

constituents for two representative wells, based on sampling during the period of record. GW2 was selected to represent the wells developed in the glacial aquifer because data from the other well completed in outwash of the glacial aquifer (GW4) indicated contamination. GW1 was selected to represent the wells developed in the Sioux Quartzite aquifer because it had the longest period of record other than GW7, and, furthermore, data from GW7 also indicated contamination. The smoothing line was based on the Lowess method (Cleveland, 1979), as discussed previously.

Results for the representative glacial aquifer site (GW2) indicate increasing trends for dissolved solids, calcium, magnesium, sodium, potassium, sulfate, and boron. Results indicate generally decreasing trends for chloride, fluoride, silica, and zinc. Trend results are variable but generally indicate little change during the time period analyzed for specific conductance, alkalinity, aluminum, chromium, and silver.

Trend results for the representative Sioux Quartzite aquifer site (GW1) indicate slightly increasing trends for fluoride, silica, boron, and zinc during the time period analyzed, whereas potassium, aluminum, and chromium results indicate slightly decreasing trends. Trend results are variable for sulfate. Sulfate concentrations increased from 1973 to 1978, but by 1986 had decreased to a slightly lower level than in 1973. Little or no change is evident in trend results for specific conductance, alkalinity, dissolved solids, calcium, magnesium, sodium, chloride, and silver.

Table 14. Statistical summary of water-quality results of selected trace-element constituents for selected ground-water sites in the study area

[All values are for dissolved constituents, in micrograms per liter. <, less than; --, not analyzed or not determined]

Property or constituent	GW1					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	14	2	28	20	<10	140
Boron	20	0	195	190	100	320
Chromium	26	24	<10	<10	<10	10
Iron	17	2	33	20	<10	80
Manganese	6	0	203	245	20	310
Silver	30	30	<2	<2	<2	<2
Zinc	17	0	355	90	20	2,600

Table 14. Statistical summary of water-quality results of selected trace-element constituents for selected ground-water sites in the study area—Continued

[All values are for dissolved constituents, in micrograms per liter. <, less than; --, not analyzed or not determined]

Property or constituent	GW2					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	8	1	29	20	<10	130
Boron	13	0	106	80	30	300
Chromium	6	5	6	<10	<10	10
Iron	11	1	106	50	<10	230
Manganese	4	4	<20	<20	<20	<20
Silver	11	11	<2	<2	<2	<2
Zinc	11	0	443	250	8	1,500

Property or constituent	GW3					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	7	0	36	30	20	70
Boron	11	0	302	300	250	360
Chromium	5	5	<10	<10	<10	<10
Iron	9	1	107	90	<10	410
Manganese	6	0	407	365	240	760
Silver	8	8	<2	<2	<2	<2
Zinc	8	0	330	150	30	1,600

Property or constituent	GW4					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	13	2	14	15	<10	20
Boron	17	2	219	80	<20	1,700
Chromium	10	9	6	<10	<10	10
Iron	16	0	111	70	13	280
Manganese	7	5	23	<20	<20	70
Silver	15	15	<2	<2	<2	<2
Zinc	13	1	130	20	<3	1,200

Table 14. Statistical summary of water-quality results of selected trace-element constituents for selected ground-water sites in the study area—Continued

[All values are for dissolved constituents, in micrograms per liter. <, less than; --, not analyzed or not determined]

Property or constituent	GW5					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	8	2	25	18	<10	70
Boron	10	0	209	200	150	400
Chromium	6	5	6	<10	<10	10
Iron	9	0	950	440	58	2,200
Manganese	6	1	49	48	<20	80
Silver	9	9	<2	<2	<2	<2
Zinc	9	0	1,400	1,300	160	3,000

Property or constituent	GW6					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	9	2	25	10	<10	130
Boron	13	0	98	100	50	120
Chromium	8	6	8	<10	<10	20
Iron	13	0	120	100	20	320
Manganese	7	6	<20	<20	<20	20
Silver	13	13	<2	<2	<2	<2
Zinc	13	0	140	100	20	570

Property or constituent	GW7					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	17	3	31	20	<10	230
Boron	22	0	118	70	20	980
Chromium	28	26	<10	<10	<10	10
Iron	21	1	47	40	<10	150
Manganese	7	5	<20	<20	<20	20
Silver	32	32	<2	<2	<2	<2
Zinc	21	0	164	80	20	1,300

Table 14. Statistical summary of water-quality results of selected trace-element constituents for selected ground-water sites in the study area—Continued

[All values are for dissolved constituents, in micrograms per liter. <, less than; --, not analyzed or not determined]

Property or constituent	GW8					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	12	0	31	25	10	90
Boron	16	0	464	460	270	750
Chromium	8	6	6	<10	<10	10
Iron	15	0	3,800	3,500	420	9,200
Manganese	7	0	1,400	1,500	900	1,700
Silver	12	12	<2	<2	<2	<2
Zinc	14	0	452	225	50	1,300

Property or constituent	GW9					
	Number of samples	Number of values less than study reporting level	Mean	Median	Minimum	Maximum
Aluminum	15	4	20	20	<10	40
Boron	19	0	293	290	230	360
Chromium	26	23	6	<10	<10	20
Iron	17	0	340	330	110	770
Manganese	6	0	315	325	230	380
Silver	31	31	<2	<2	<2	<2
Zinc	17	0	325	230	7	1,200

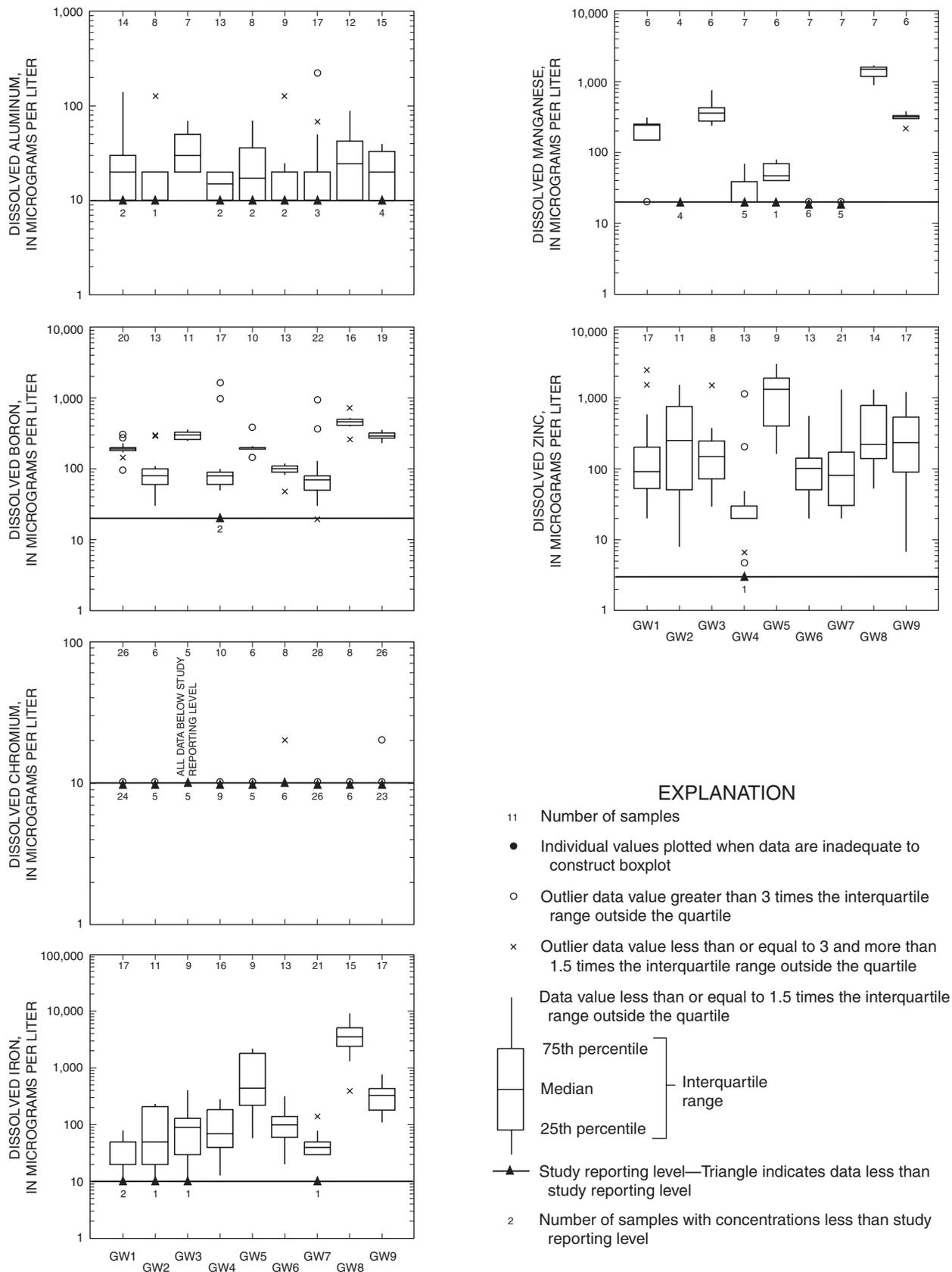


Figure 13. Boxplots of trace-element constituent concentrations for selected ground-water sites in the study area.

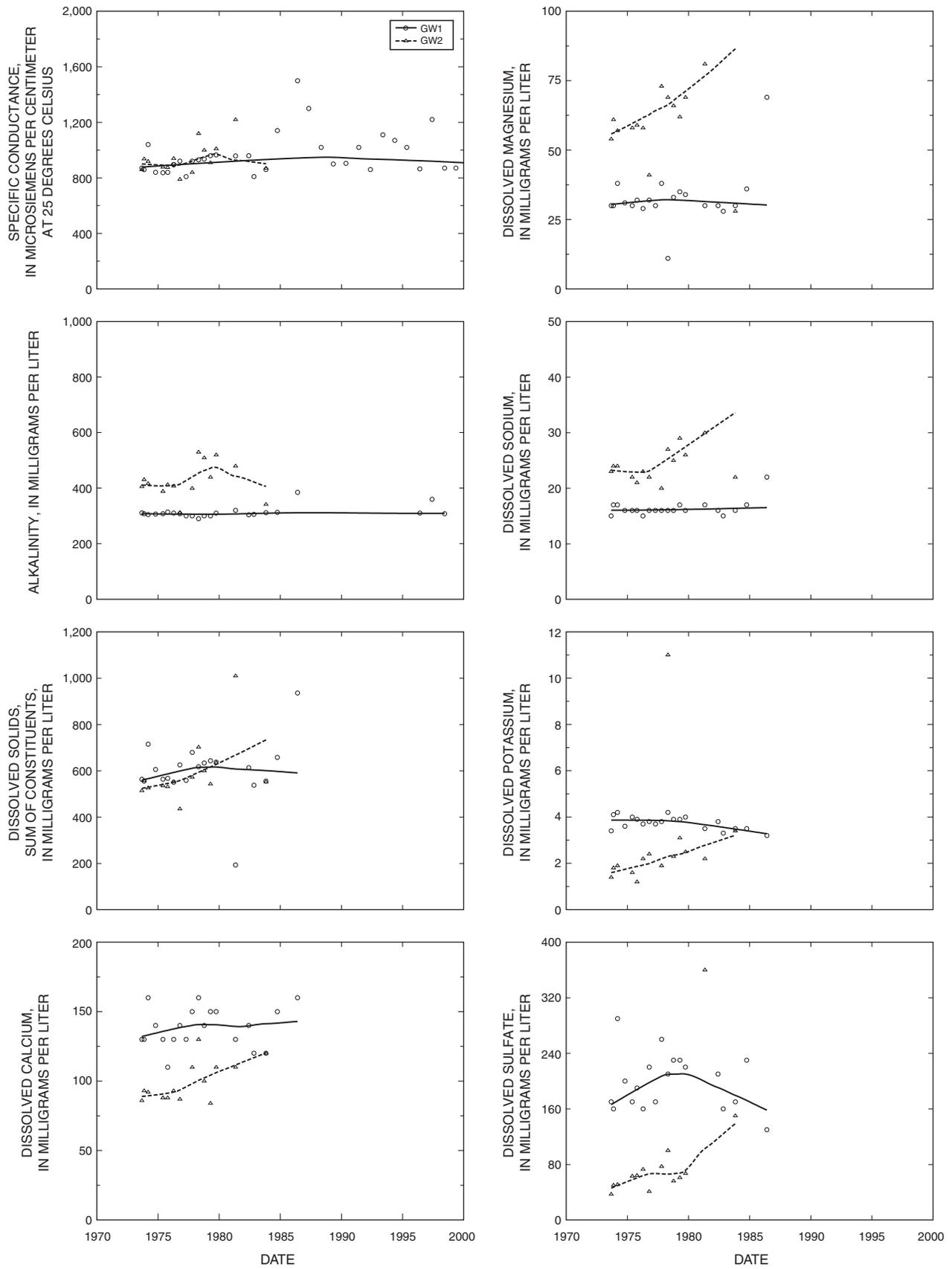


Figure 14. Local regression (Lowess) plots for selected ground-water sites in the study area.

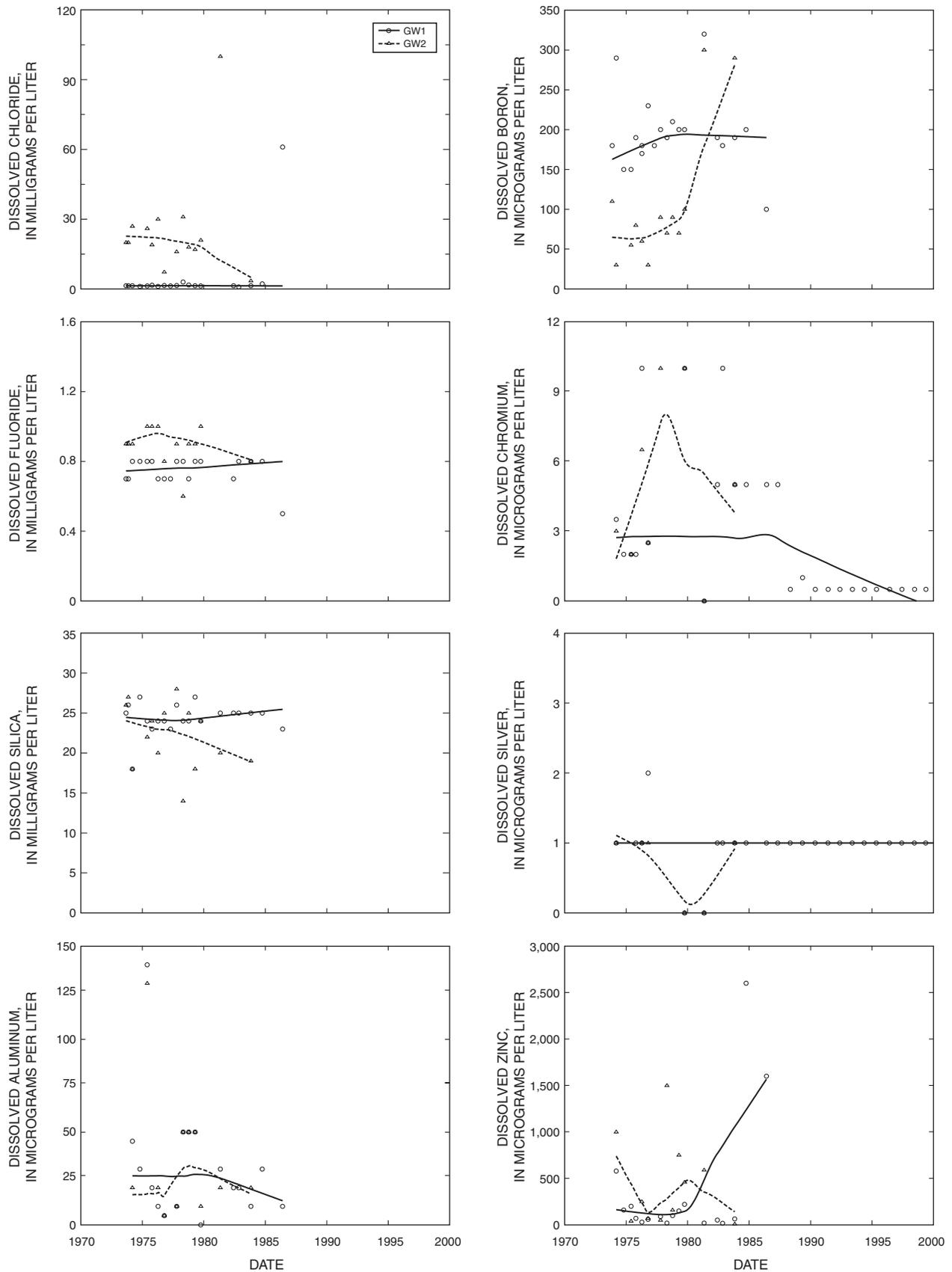


Figure 14. Local regression (Lowess) plots for selected ground-water sites in the study area.—Continued

SUMMARY

This report summarizes water-quality data that were collected from 1973 through 2000 for the Earth Resources Observation Systems (EROS) Data Center, and presents the long-term water-quality characteristics and trends. A water-quality monitoring program was initiated in 1973 as a collaborated effort between the U.S. Geological Survey, Water Resources Discipline, and Geography (formerly National Mapping) Discipline, EROS Data Center, and continues at the present time (2003). Under this program, water-quality samples were collected at various sites on EROS property and in the surrounding area.

The general water-quality characteristics and trends for selected sites within the study area were evaluated. Comparisons of surface water by water source and comparisons of water quality by aquifer are presented for selected sites in the EROS water-quality monitoring program. Comparisons were made for physical properties, major-ion chemistry, nutrient concentrations, and trace elements where sufficient data were available. Data for sites in the EROS vicinity that have water-quality data, but were not part of the EROS water-quality monitoring program, are presented on the CD-ROM in the back of this report.

Trend-analysis results for water-quality concentration data are presented, as are graphical output using Lowess regression. Results from the ESTREND trend-analysis program on Big Sioux River data showed an increasing trend of 0.75 percent of the median per year in specific conductance and a decreasing trend of 10.26 percent of the median per year for dissolved orthophosphate.

Regression analyses using a Lowess smoothing line indicated variable results for the surface-water sites, with some constituents indicating an increasing or decreasing trend, some having varied results, and others indicating no change during the time period. Results for Split Rock Creek indicated a decreasing trend for specific conductance. Results for EROS Lake indicated an increasing trend in alkalinity and a decreasing trend in aluminum, boron, and chromium. Little or no change was evident for silica and silver at EROS Lake, and although the results were variable for specific conductance and zinc, results indicated that little change has occurred over time. Results for dissolved solids, calcium, magnesium, sodium, potassium, sulfate, chloride, and fluoride indicated an increase from the initial low values in 1973, but with generally decreasing trends following 1980. Trend

analyses for the lagoon sites also indicated varied results, although no indications of increasing trends were evident. Lowess smoothing lines indicated generally decreasing trends in specific conductance, dissolved solids, calcium, magnesium, sodium, potassium, sulfate, chloride, fluoride, silica, boron, and chromium. Trend results indicated little or no change for silver in the lagoon sites. Alkalinity, aluminum, and zinc results were variable, but indicated little change during the time period analyzed.

Trend analyses for representative ground-water sites indicated mixed results. Results for the glacial aquifer site indicated increasing trends for dissolved solids, calcium, magnesium, sodium, potassium, sulfate, and boron. Results indicated generally decreasing trends for chloride, fluoride, silica, and zinc. Trend results were variable but generally indicated little change during the time period analyzed for specific conductance, alkalinity, aluminum, chromium, and silver.

Trend results for the Sioux Quartzite aquifer site indicated slightly increasing trends for fluoride, silica, boron, and zinc, whereas results for potassium, aluminum, and chromium indicated slightly decreasing trends. Little or no change was evident in trend results for specific conductance, alkalinity, dissolved solids, calcium, magnesium, sodium, chloride, and silver. Results were variable for sulfate for the Sioux Quartzite aquifer site.

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