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Water and Sediment Quality of the Lake Andes and Choteau Creek Basins, South Dakota, 1983-2000

Water-Resources Investigations Report 03-4148

U.S. Department of the Interior
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GALE A. NORTON, Secretary

U.S. Geological Survey

Charles G. Groat, Director

Rapid City, South Dakota: 2003

For additional information write to:

District Chief
U.S. Geological Survey
1608 Mt. View Road
Rapid City, SD 57702

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Building 810
Box 25286, Federal Center
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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch	2.54	centimeter
inch	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
inch per day (in/d)	2.54	centimeter per day
pound per day, avoirdupois	0.4536	kilogram per day
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
ton, short (2,000 lb)	0.9072	megagram

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

$$°F = (1.8 \times °C) + 32$$

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

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 1929); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27).

Water and Sediment Quality of the Lake Andes and Choteau Creek Basins, South Dakota, 1983-2000

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ABSTRACT

The Bureau of Reclamation has proposed construction of the Lake Andes/Wagner Irrigation Demonstration Project to investigate environmental effects of irrigation of glacial till soils substantially derived from marine shales. During 1983-2000, the U.S. Geological Survey collected hydrologic, water-quality, and sediment data in the Lake Andes and Choteau Creek Basins, and on the Missouri River upstream and downstream from Choteau Creek, to provide baseline information in support of the proposed demonstration project.

Lake Andes has a drainage area of about 230 mi^2 (square miles). Tributaries to Lake Andes are ephemeral. Water-level fluctuations in Lake Andes can be large, and the lake has been completely dry on several occasions. The outlet aqueduct from Lake Andes feeds into Garden Creek, which enters Lake Francis Case just upstream from Fort Randall Dam on the Missouri River.

For Lake Andes tributary stations, calcium, magnesium, and sodium are approximately codominant among the cations, and sulfate is the dominant anion. Dissolved-solids concentrations typically range from about 1,000 mg/L (milligrams per liter) to about 1,700 mg/L. Major-ion concentrations for Lake Andes tend to be higher than the tributaries and generally increase downstream in Lake Andes. Proportions of major ions are similar among the different lake units (with the exception of Owens Bay), with calcium, magnesium, and sodium being approximately codominant among cations, and sulfate being the dominant anion. Owens Bay is characterized by a calcium sulfate water type. Dissolved-solids concentrations for Lake Andes typically range from about 1,400 to 2,000 mg/L.

Whole-water nitrogen and phosphorus concentrations are similar among the Lake Andes tributaries, with median whole-water nitrogen concentrations ranging from about 1.6 to 2.4 mg/L, and median whole-water phosphorus concentrations ranging from about 0.5 to 0.7 mg/L. Whole-water nitrogen concentrations in Lake Andes are similar among the different units, with medians that range from about 2.4 to 4.0 mg/L. Median whole-water phosphorus concentrations for the different Lake Andes units range from 0.2 to 0.5 mg/L, and decrease downstream through Lake Andes.

Median selenium concentrations are substantially lower for Andes Creek (3 µg/L (micrograms per liter)) than for the other tributary stations (34, 18, and 7 µg/L). Median selenium concentrations for the lake stations (ranging from less than 1 to 2 µg/L) are substantially lower than tributary stations.

The pesticides 2,4-D and atrazine were the most commonly detected pesticides in Lake Andes. Median concentrations for 2,4-D for Lake Andes range from 0.07 to 0.11 µg/L; the median concentration for Owens Bay is 0.04 µg/L. Median concentrations for atrazine for Lake Andes range from 0.2 to 0.4 µg/L; the median concentration for Owens Bay is less than 0.1 µg/L. Concentrations

of both 2,4-D and atrazine are largest for the most upstream part of Lake Andes that is most influenced by tributary inflow.

Median suspended-sediment concentrations for Lake Andes tributaries range from 22 to 56 mg/L. Most of the suspended sediment transported in the Lake Andes tributaries consists of particles less than 63 μm (micrometers) in diameter. Concentrations of most constituents in bottom sediments generally had similar ranges and medians for the Lake Andes tributaries. However, Andes Creek generally had lower concentrations of several metals. For Lake Andes, medians and ranges for most constituents generally were similar among the different units. However, selenium concentrations tended to be higher in the upstream part of the lake, and generally decreased downstream. Results of vertical sediment cores collected from a single site in the South Unit of Lake Andes in October 2000 indicate that selenium loading to Lake Andes increased during the period 1952 through 2000.

Choteau Creek has a drainage area of 619 mi^2. In the upstream part of the basin, Choteau Creek is essentially ephemeral. Downstream from Wagner, Choteau Creek receives ground-water discharge providing perennial flow during most years. Choteau Creek enters the Missouri River about 28 river miles downstream from Fort Randall Dam. Choteau Creek contribution to the Missouri River relative to release from Fort Randall Dam generally is minimal.

For all of the Choteau Creek stations, calcium is dominant among the cations, and sulfate is dominant among the anions. Median dissolved-solids concentrations range from 1,180 to 1,780 mg/L. For the two Missouri River stations, calcium, magnesium, and sodium are about codominant among the cations, and bicarbonate and sulfate are about codominant among the anions. Differences in major-ion concentrations between the two Missouri River stations are negligible, with median dissolved-solids concentrations ranging from 501 to 502 mg/L.

Whole-water nitrogen concentrations for the upstream and middle stations on Choteau Creek are similar (medians of 1.9 and 2.0 mg/L), but whole-water nitrogen concentrations for the downstream station are substantially smaller (median of 1.0 mg/L). Median whole-water nitrogen concentrations for the Missouri River stations range from 0.41 to 0.42 mg/L. Median whole-water phosphorus concentrations decrease downstream on Choteau Creek, from 0.51 mg/L at the most upstream station to 0.08 mg/L at the most downstream station. Median whole-water phosphorus concentrations for the Missouri River near the mouth of Choteau Creek range from 0.01 to 0.02 mg/L.

For Choteau Creek stations, selenium concentrations are lower for the most upstream station (median concentration of 1 μg/L) than for the middle and downstream stations (median concentrations of 6 and 4 μg/L). For Missouri River stations, selenium concentrations are relatively small, with median concentrations of 2 μg/L for both stations.

Median suspended-sediment concentrations for Choteau Creek stations range from 27 to 106 mg/L. Most of the suspended sediment transported in the Lake Andes consists of particles less than 63 μm in diameter. Concentrations of most constituents in bottom sediments generally had similar ranges and medians for the Choteau Creek stations. However, concentrations of several metals show decreases in median concentrations downstream. For the Missouri River stations, median concentrations of most constituents in bottom sediments were larger for the station downstream from Choteau Creek. Several metals, including chromium, copper, titanium, and zinc have the largest increases in median concentration between the two stations. The median selenium concentration for the downstream station was about two times larger than the upstream station.

The analyses that were conducted for this report show that water-quality conditions in the basins change over seasonal and annual time periods. Results of the trend analyses also indicate that long-term changes in water quality might be occurring in the basins.

INTRODUCTION

The Bureau of Reclamation (BOR) has proposed construction of the Lake Andes/Wagner Irrigation Demonstration Project (LAWIDP) to investigate environmental effects of irrigation of glacial till soils substantially derived from marine shales and containing high levels of the trace element selenium (Bureau of Reclamation, 2000). Since 1983, the U.S. Geological Survey (USGS), in cooperation with the BOR, has been collecting water-quality data on Lake Andes, several tributaries to Lake Andes, Choteau Creek, and the Missouri River upstream and downstream from Choteau Creek. The primary purpose of this Lake Andes/Choteau Creek water-quality monitoring program has been to collect baseline water-quality data that would be useful in determining environmental effects of the proposed LAWIDP if it is constructed and implemented.

Purpose and Scope

The purpose of this report is to summarize and describe hydrologic, water-quality, and sediment-quality data collected during 1983 through 2000 as part of the Lake Andes/Choteau Creek water-quality monitoring program. Hydrologic and water-quality characteristics for 15 sampling stations are presented. The 15 sampling stations include 4 stations on tributaries to Lake Andes, 6 lake stations on Lake Andes, 3 stations on Choteau Creek, and 2 stations on the Missouri River (fig. 1). The reported results describe baseline hydrologic and water-quality conditions and trends that can be used to evaluate environmental effects of the proposed LAWIDP.

Acknowledgments

The authors recognize the hard work and dedication of the many USGS hydrologic technicians that collected the water-quality and streamflow data on which this report is based. USGS technicians who contributed to this effort include Brian Engle, Mark Freese, Kevin Guttormson, Dave Hernandez, Doug Johnson, Joel Petersen, Craig Solberg, and Doug Winter.

DESCRIPTION OF STUDY AREA

The study area consists of the Lake Andes and Choteau Creek Basins, primarily in Douglas and Charles Mix Counties of southeastern South Dakota (fig. 1). The Missouri River immediately upstream and downstream from the confluence with Choteau Creek also is included in the study area.

Climate

The climate of the study area is semiarid continental, and typified by relatively low precipitation, hot summers, cold winters, and extreme variations in both precipitation and temperatures. Climatic data collected at the South Dakota Cooperative Weather Station at Wagner (South Dakota State University, 2003) are representative of climatic conditions for the study area. Average annual temperature (1971-2000) in the study area is 49.3°F. Coldest temperatures occur in January (average monthly temperature of 20.1°F for 1971-2000), and warmest temperatures occur in July (average monthly temperature of 76.5°F for 1971-2000). Typical frost-free periods range from 140 to 160 days per year.

Average annual precipitation (1971-2000) is 25.64 inches, with about 72 percent of precipitation occurring as rainfall during the months of April through October. Annual precipitation at Wagner for the period of record is presented in figure 2. Average annual free-water-surface evaporation is about 44 inches (Farnsworth and others, 1982).

Physiography and Geology

The study area is within the Coteau du Missouri physiographic region (Flint, 1955) and the Southern Missouri Coteau Slope (Bryce and others, 1998). The area is characterized by level to rolling uplands, sloping west to the Missouri River. Wisconsin-age glaciation resulted in a surface of dead-ice moraine along the northeastern boundary of the Choteau Creek Basin, and rolling plains covered by glacial debris along the southwestern boundaries of the Lake Andes and Choteau Creek Basins (Bureau of Reclamation, 2000). Lake Andes occupies a valley eroded by glacial meltwater. The area is relatively poorly drained and there are numerous wetlands, making the area a valuable wildlife production resource. Land-surface elevations in the study area range from about 1,230 ft above NGVD of 1929 at the mouth of Choteau Creek to 1,675 ft above NGVD of 1929 at the northern basin divide of Choteau Creek.

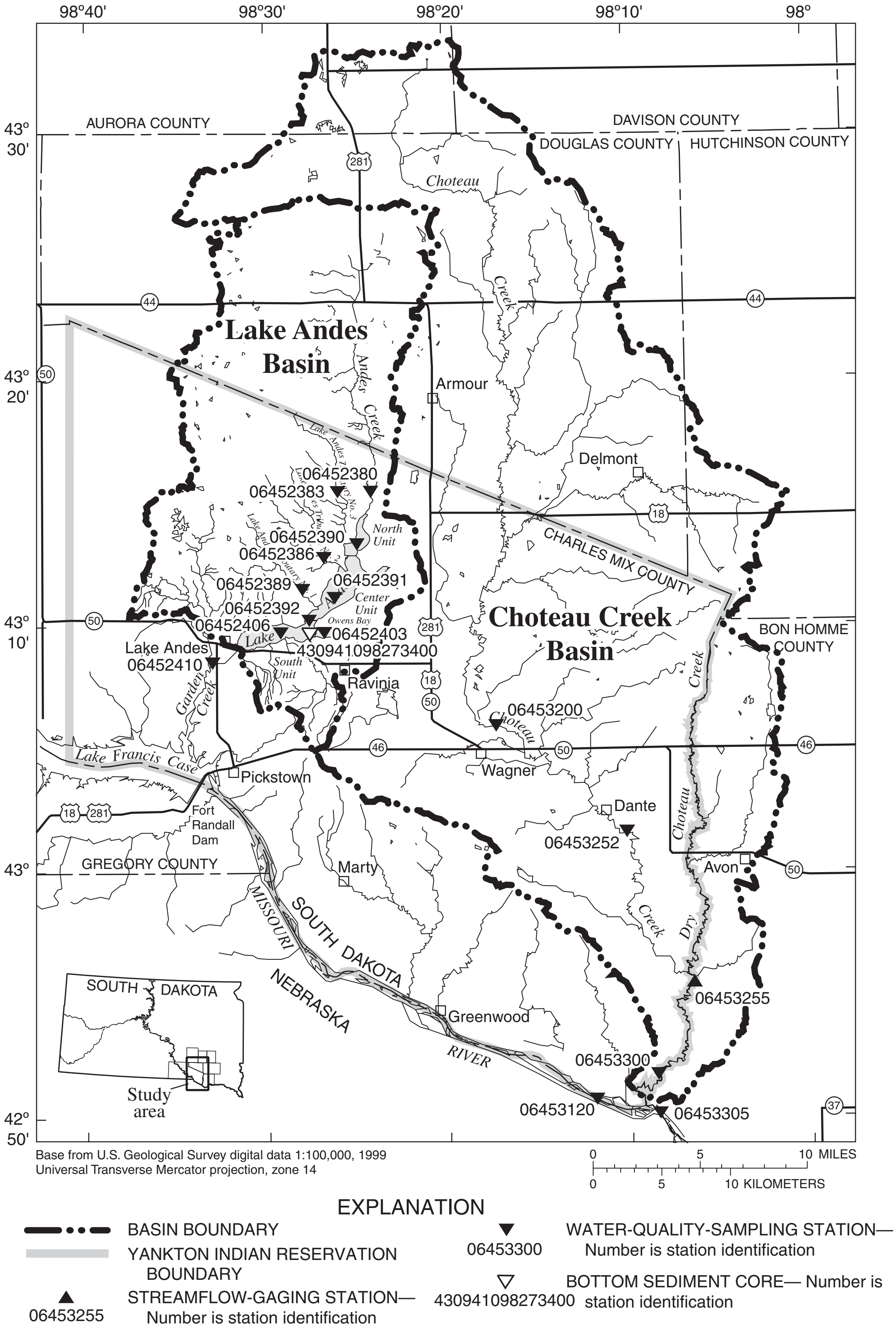


Figure 1. Location of study area and water-quality sampling and streamflow-gaging stations.

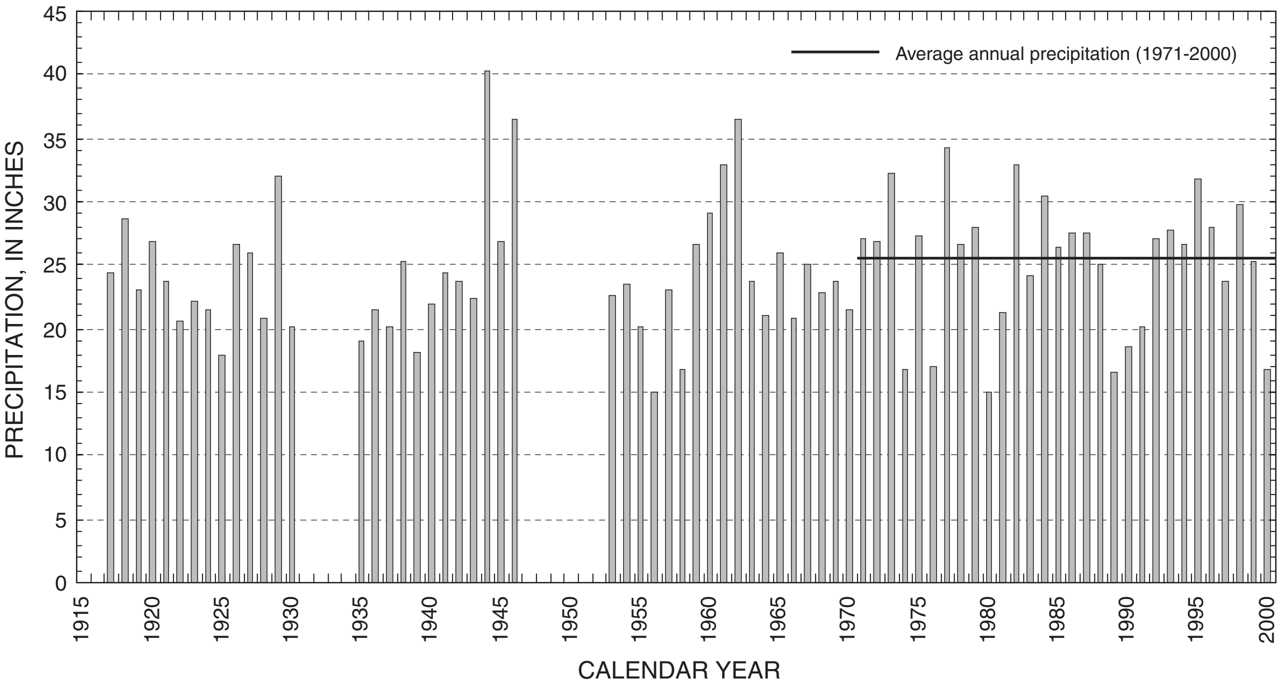


Figure 2. Annual precipitation for Wagner, South Dakota (South Dakota State University, 2003).

Glacial till deposited as ground-end and stagnation moraine dominates the surficial geology of the area (Kume, 1977). Glacial outwash occurs in patches near the Choteau Creek stream channel. Quaternary-age alluvial deposits also occur along the stream channels of Choteau Creek and parts of tributaries to Lake Andes. Cretaceous-age Pierre Shale is the uppermost bedrock unit throughout much of the Lake Andes and Choteau Creek Basins (fig. 3; Hedges, 1975). However, the Pierre Shale is absent immediately beneath most of Lake Andes. The Cretaceous-age Niobrara Marl underlies the Pierre Shale, and is the uppermost bedrock unit beneath most of Lake Andes (fig. 3).

The Pierre Shale is a light-gray to black clay shale that can be locally enriched in organic matter (Hedges, 1975; Kume, 1977). The Pierre Shale, as well as some other marine sedimentary units, can contain high concentrations of selenium (Wilson and others, 1990). Mechanisms that may have contributed to elevated selenium concentrations in these marine sedimentary units include bioaccumulation of selenium in organic matter incorporated into the shales and fallout of selenium-rich volcanic ash during formation of the shale deposits (Severson and others, 1990; Seiler and others, 1999). Typical selenium concentrations in Pierre Shale are about 2 ppm (parts per million); however, concentrations may exceed 100 ppm in some areas (National Research Council, Subcommittee on Selenium, 1983). Factors that influence selenium concentrations in the shale include concentrations of organic matter and degree of weathering of the shale (Severson and others, 1990).

The glacial till and soils derived from the till in the study area have selenium concentrations that are similar in magnitude to typical concentrations in Pierre Shale (Wilson and others, 1990). Glacial activity in eastern South Dakota eroded and reworked the preglacial shale underlying the ice mass; thus, much of the fine-grained material within the till was derived from Pierre Shale.

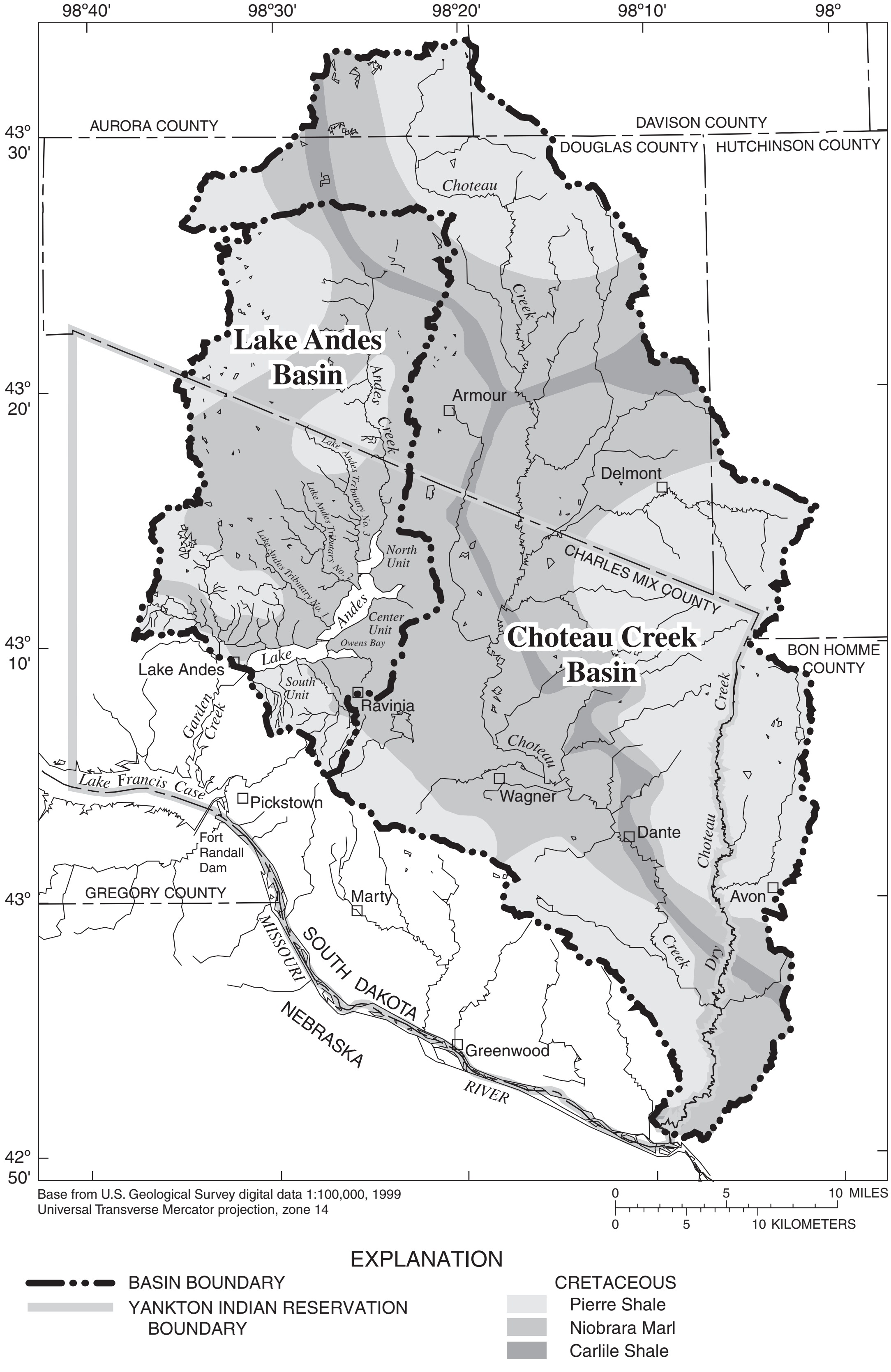


Figure 3. Location of uppermost bedrock units in the Lake Andes and Choteau Creek Basins (Hedges, 1975).

Land Use

Land use in the study area is dominated by agricultural activities, with about 97 percent of the land area being farmland (data obtained from South Dakota Agricultural Statistics Service, 2001). About 55 percent of the farmland is cropped, and the remainder consists of grazed lands, tree belts, wetlands, and farmsteads. Soybeans and corn are the dominant crops, accounting for about two-thirds of the cropland, with smaller areas planted to hay, wheat, oats, and sunflowers. Irrigation in the study area has been very limited; about 6,300 cropland acres are irrigated in the study area (Bureau of Reclamation, 2000). Of those irrigated acres, about 5,460 acres are in the Choteau Creek Basin (accounting for about 1.4 percent of the basin area), and about 840 acres are in the Lake Andes Basin (accounting for about 0.6 percent of the basin area).

Primary towns in the study area include Lake Andes and Wagner. Much of the study area lies within the Yankton Sioux Indian Reservation, and the Yankton Sioux Tribe is the single largest landholder in the study area. Tribal headquarters, housing developments, and schools are located in the town of Marty.

The Lake Andes National Wildlife Refuge lies within the study area. The Refuge was established in 1936 and initially consisted of 365 acres in the Owen's Bay area (U.S. Fish and Wildlife Service, 2001). Subsequent purchases of land have been made on a continuing basis. The meandered lake bed of Lake Andes is protected by an easement that authorizes the U.S. Fish and Wildlife Service (USFWS) to flood the lake bed and maintain a closed refuge for migratory birds and other wildlife. Public access to the lake is permitted for fishing and other recreational activities, and hunting is allowed on a portion of the meandered lake bed. In addition to the lands within the National Wildlife Refuge, the USFWS manages and protects about 75,000 acres near Lake Andes for wildlife production.

Hydrology

The major surface-water resources in the study area include Lake Andes and Choteau Creek. Numerous tributaries, such as Andes Creek, contribute inflow to Lake Andes. Flows from Choteau Creek and its tributaries contribute to flow of the Missouri River downstream from Fort Randall Dam. Streamflow characteristics of streams and tributaries within the Lake Andes and Choteau Creek Basins for which water-quality data have been collected are included in this section of the report. Long-term variability in water-surface elevations and capacities for Lake Andes also are discussed.

Lake Andes

Lake Andes (fig. 1) is a natural lake in a bedrock valley that is partly buried by ground moraine, mostly consisting of till (Kume, 1977). Over most of its area, the lake is underlain by a thick layer of till (generally greater than 50 ft in thickness), but small areas of alluvial deposits occur near the mouth of Andes Creek and other smaller tributaries on the northern part of the lake. Interaction between Lake Andes and ground water probably is negligible because of the small water-transmitting characteristics of the till.

Lake Andes, has a total drainage area of about 230 mi^2. Andes Creek, with a drainage area of 93.5 mi^2, is the primary stream contributing inflow to Lake Andes. Numerous smaller unnamed tributaries, with a combined total drainage area of about 105 mi^2 also flow into Lake Andes. Areas immediately adjacent to Lake Andes that contribute direct overland runoff account for 16.6 mi^2. Owens Bay, a large marshy area with an outlet control structure that feeds Lake Andes, has a drainage area of about 7 mi^2. The total surface area of Lake Andes (including Owens Bay) at full pool is about 8 mi^2.

Two roadway dikes separate Lake Andes into three separate units, referred to by the USFWS as the North Unit, Center Unit, and South Unit (fig. 1). Andes Creek and a large unnamed tributary, with a combined total drainage area of 124 mi^2, flow into the North Unit, which also receives overland runoff from an area of 2.74 mi^2 adjacent to the lake. The North Unit has a pool bottom of 1,429.25 ft above NGVD of 1929, and spills to the Center Unit at a water-surface elevation of 1,436.6 ft above NGVD of 1929 through a culvert in the dike (U.S. Fish and Wildlife Service, Lake Andes National Wildlife Refuge, written commun., April 2001).

In addition to inflow from the North Unit, the Center Unit receives inflow from three unnamed tributaries that range in drainage area from 1.29 to 21.3 mi^2 (combined total drainage area 31.1 mi^2). The Center Unit receives overland runoff from 11.0 mi^2. The Center Unit has a pool bottom of 1,427 ft above NGVD of 1929 and spills to the South Unit at a water-surface elevation of 1,434.71 ft above NGVD of 1929 through a culvert in the dike (U.S. Fish and Wildlife Service, Lake Andes National Wildlife Refuge, written commun., April 2001).

In addition to inflow from the Center Unit, the South Unit receives inflow from seven unnamed tributaries that range in drainage area from 1.12 to 25.4 mi^2 (combined total drainage area 42.7 mi^2) and Owens Bay (drainage area 7.54 mi^2). Owens Bay is a large marshy area that is fed by an artesian well (with a control valve) completed in the Dakota aquifer. The well that currently (2003) feeds Owens Bay was constructed in 1957 by USFWS to a depth of 927 ft below land surface (Eugene Williams, U.S. Fish and Wildlife Service, Lake Andes National Wildlife Refuge Manager, oral commun., July 2001). Owens Bay also receives surface-water inflow from two small tributaries. Owens Bay has a pool bottom of 1,436.52 ft above NGVD of 1929 and spills into the South Unit at a water-surface elevation of 1,442.12 ft above NGVD of 1929 (U.S. Fish and Wildlife Service, Lake Andes National Wildlife Refuge, written commun., April 2001). Typically, Owens Bay is isolated from Lake Andes, and only occasionally reaches an elevation where it spills into the South Unit of Lake Andes. The South Unit receives overland runoff from 2.82 mi^2. The South Unit has a pool bottom of 1,426 ft above NGVD of 1929, and spills to an outlet aqueduct at a water-surface elevation of 1,437.25 ft above NGVD of 1929. The outlet aqueduct from Lake Andes feeds into Garden Creek, which enters Lake Francis Case just upstream from Fort Randall Dam on the Missouri River.

Tributaries to Lake Andes are ephemeral and characterized by frequent periods of no flow. Uplands along the margins of the tributary basins generally are hummocky, with many depressions that retain water and do not contribute to streamflow in many years. Continuous streamflow-gaging stations have not been operated on the tributaries feeding Lake Andes. However, streamflow measurements were made during water-quality sampling trips, and those measurements have been used to estimate long-term streamflow characteristics for the four tributaries with water-quality sampling stations.

Streamflow characteristics at the locations of water-quality stations on Lake Andes tributaries are estimated by relating periodic streamflow measurements for the tributaries to gaged streamflow data at a long-term continuous streamflow-gaging station on Choteau Creek (station 06453255, Choteau Creek near Avon, period of record 1982-2003; fig. 1) using locally weighted regression (Cleveland and others, 1988). Estimates of streamflow characteristics at the mouths of those tributaries also are developed using a drainage-area adjustment procedure (Sando, 1998). Errors associated with the estimated streamflow characteristics are difficult to accurately quantify and may be substantial; however, the reported characteristics probably accurately represent the relative flow contributions of the tributaries to Lake Andes. Streamflow characteristics and results of the locally weighted regression for the four Lake Andes tributaries with water-quality stations are presented in table 1. Estimates of monthly mean streamflow of the tributaries are shown in figure 4.

Streamflow is highly variable for Lake Andes tributaries. On average, the daily mean flow will be zero or near zero on greater than 50 percent of days for all of the tributaries. When runoff events do occur, streamflow can be substantial. For water-quality sampling visits during the period 1983-2000, the maximum streamflow measurement for Andes Creek near Armour (station 06452380) was 70 ft^3/s, and four measurements exceeding 50 ft^3/s were made. Sustained streamflow generally only occurs during the months of March through July (fig. 4). However, in some years tributary inflow to Lake Andes will be essentially zero for the entire year. Largest streamflow typically occurs during April, when the combined contribution of all tributaries to Lake Andes is estimated to average about 15 ft^3/s. The combined long-term mean annual contribution of all tributaries to Lake Andes is about 5 ft^3/s.

Table 1. Results of locally weighted regression and estimated streamflow characteristics for stations on Lake Andes tributaries and Choteau Creek, water years 1983-2000

[Streamflow characteristics at sampling stations estimated from regression analysis with data from continuous streamflow-gaging station (Cleveland and others, 1988), and at the mouths from a drainage-area adjustment procedure (Sando, 1998). --, not applicable]

Location/ station name	Station identification number	Drainage area, in square miles	Latitude	Longitude	Number of concurrent streamflow measurements	R^2 of locally weighted regression	Summary statistics of daily mean flows for water years 1983-2000, in cubic feet per second								Average basin runoff, in inches per year
							Minimum	Mean	Maximum	10 percentile non-exceedance	25 percentile non-exceedance	50 percentile non-exceedance	75 percentile non-exceedance	90 percentile non-exceedance	
Stations on Tributaries to Lake Andes															
Andes Creek near Armour	06452380	92.1	431523	982408	90	0.72	0.00	3.3	79	0.00	0.02	0.05	0.87	11	0.49
Andes Creek at mouth	--	93.5	--	--	--	--	.00	3.4	80	.00	.02	.05	.88	11	.49
Lake Andes tributary no. 3 near Armour	06452383	26.5	431523	982558	78	.54	.00	.24	37	.00	.00	.02	.06	.36	.12
Tributary no. 3 at mouth	--	30.9	--	--	--	--	.00	.26	41	.00	.00	.02	.06	.40	.12
Lake Andes tributary no. 2 near Lake Andes	06452386	18.4	431243	982645	74	.67	.00	.65	45	.00	.00	.02	.09	.95	.48
Tributary no. 2 at mouth	--	21.3	--	--	--	--	.00	.71	49	.00	.00	.02	.10	1.05	.45
Lake Andes tributary no. 1 near Lake Andes	06452389	7.87	431125	982757	73	.72	.00	.15	22	.00	.00	.00	.03	.17	.25
Tributary no. 1 at mouth	--	8.49	--	--	--	--	.00	.15	23	.00	.00	.00	.03	.17	.25
Stations on Choteau Creek															
Choteau Creek near Wagner	06453200	383	430552	981715	114	.84	.00	26	1,020	.00	.00	.07	5.25	63	.93
Choteau Creek near Dante	06453252	484	430132	981003	133	.90	.00	39	1,550	.02	.07	.51	9.55	112	1.08
Choteau Creek near Avon[1]	06453255	595	425524	980621	--	--	.00	61	5,020	.57	1.70	4.50	20	134	1.39
Choteau Creek below Avon	06453300	615	425140	980825	58	.94	.17	64	5,250	2.09	3.89	7.94	25	132	1.42

[1]Continuous streamflow-gaging station used in locally weighted regressions.

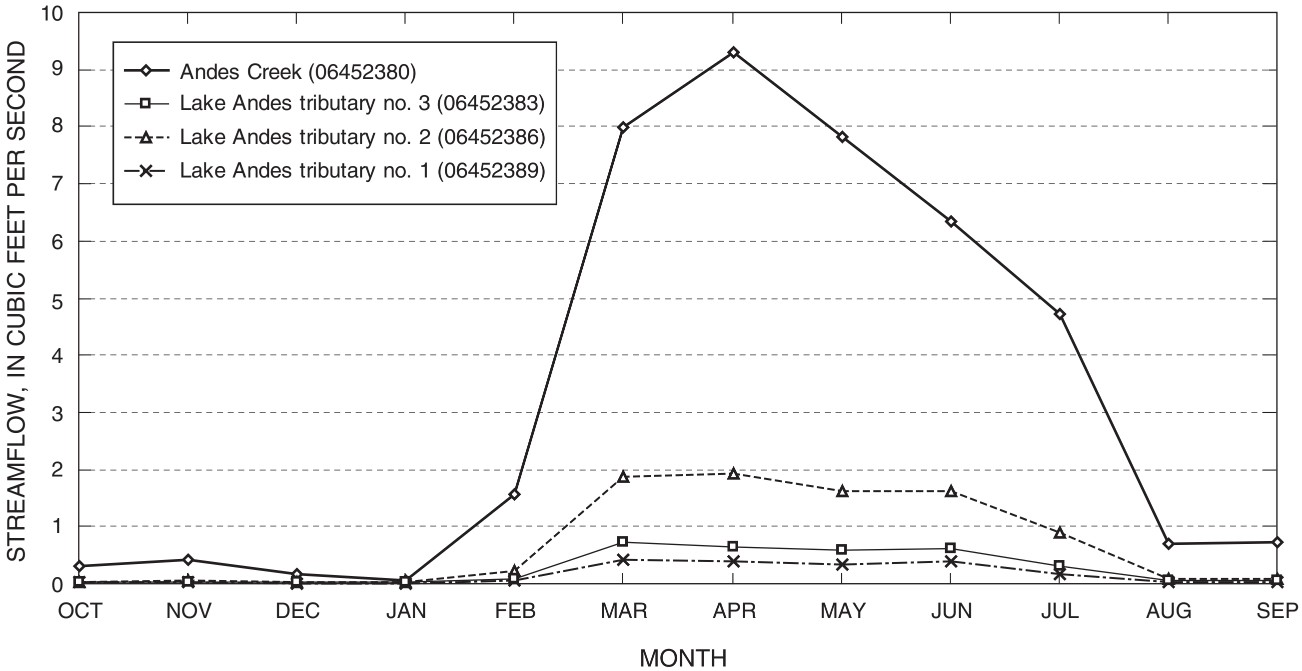


Figure 4. Estimated long-term (water years 1983-2000) monthly mean flows for tributaries to Lake Andes with water-quality stations.

USFWS collects periodic records of water-surface elevations for the North, Center, and South Units of Lake Andes, and also for Owens Bay. Estimates of volumes and surface areas for the North, Center, and South Units of Lake Andes are determined using an elevation-capacity-area table (table 2) developed by BOR in 1962 (U.S. Fish and Wildlife Service, Lake Andes National Wildlife Refuge, written commun., April 2001). No elevation-capacity-area data are available for Owens Bay. Long-term variability in water-surface elevations and capacities for Lake Andes is shown in figure 5 and somewhat reflects long-term variability in annual precipitation for Wagner, South Dakota (fig. 2).

Consistent with highly variable inflows, fluctuations in Lake Andes water levels can be large. For example, between July 15 and August 15, 1959, the terminal South Unit declined more than 2 ft, with an average drop of about 1 in/d. All units of Lake Andes were dry by August 15, 1959, and probably remained empty through the winter 1959-60. A large amount of precipitation in the spring of 1960 filled all of the units, causing the South Unit to rise more than 10 ft between the fall of 1959 and June 15, 1960. More recently, in May 1995, the South Unit rose about 5.5 ft in about 1 month in response to frequent and intense rainfall. The water level of Lake Andes has remained relatively high during the wet climatic period of the mid- to late-1990's (fig. 5). Lake Andes occasionally is completely dry. In addition to the dry periods of 1959, 1975-76, and 1981 shown in figure 5, the lake is known to have been dry in 1863, 1870, 1878, 1883, 1893-94, 1933-34, and 1939 (Bill Wilson, U.S. Fish and Wildlife Service, written commun., 1990).

USGS has been sampling Lake Andes for water quality from 1983 through 2002. During this period, Lake Andes was relatively high during 1983 to 1988. A severe drought decreased water levels from 1988 through 1992, at which time parts of the lake were almost dry. A large amount of precipitation in the spring and summer of 1993 increased lake levels dramatically, and the lake remained relatively high through 2000.

Table 2. Elevation-capacity-area table for the North, Center, and South Units of Lake Andes

[Developed using straight-line interpolation of elevation-capacity-area data determined by Bureau of Reclamation in 1962 (U.S. Fish and Wildlife Service, Lake Andes National Wildlife Refuge, written commun., April 2001)]

Elevation (feet above NGVD of 1929)	North Unit		Center Unit		South Unit	
	Capacity, (acre-feet)	Area (acres)	Capacity (acre-feet)	Area (acres)	Capacity (acre-feet)	Area (acres)
1,426.0	0	0	0	0	0	0
1,426.5	0	0	0	0	138	226
1,427.0	0	0	0	0	275	451
1,427.5	0	0	843	1,144	413	677
1,428.0	0	0	1,446	1,268	550	902
1,428.5	0	0	2,096	1,363	1,110	1,120
1,429.0	0	0	2,793	1,428	1,670	1,338
1,429.5	5	11	3,515	1,476	2,410	1,479
1,430.0	16	32	4,261	1,509	3,150	1,620
1,430.5	42	64	5,021	1,536	4,097	1,675
1,431.0	85	107	5,794	1,559	5,044	1,730
1,431.5	155	161	6,578	1,579	5,991	1,785
1,432.0	252	227	7,371	1,596	6,938	1,840
1,432.5	382	293	8,173	1,613	7,885	1,895
1,433.0	545	359	8,984	1,630	8,832	1,950
1,433.5	733	411	9,801	1,644	9,779	2,005
1,434.0	948	448	10,626	1,655	10,726	2,060
1,434.5	1,178	480	11,456	1,667	11,673	2,115
1,435.0	1,425	507	12,293	1,680	12,620	2,170
1,435.5	1,684	533	13,137	1,696	13,816	2,212
1,436.0	1,957	558	13,989	1,713	15,011	2,254
1,436.5	2,241	580	14,851	1,733	16,207	2,296
1,437.0	2,536	601	15,723	1,756	17,402	2,338
1,437.5	2,840	620	16,606	1,778	18,593	2,380
1,438.0	3,155	638	17,501	1,801	19,778	2,422
1,438.5	3,478	655	18,406	1,822	20,964	2,464
1,439.0	3,809	672	19,321	1,841	22,149	2,506
1,439.5	4,141	688	20,237	1,861	23,335	2,548
1,440.0	4,472	705	21,152	1,880	24,520	2,590
1,440.5	4,804	721	22,068	1,900	25,705	2,632
1,441.0	5,135	738	22,983	1,919	26,891	2,674
1,441.5	5,467	754	23,899	1,939	28,076	2,716
1,442.0	5,798	771	24,814	1,958	29,262	2,758

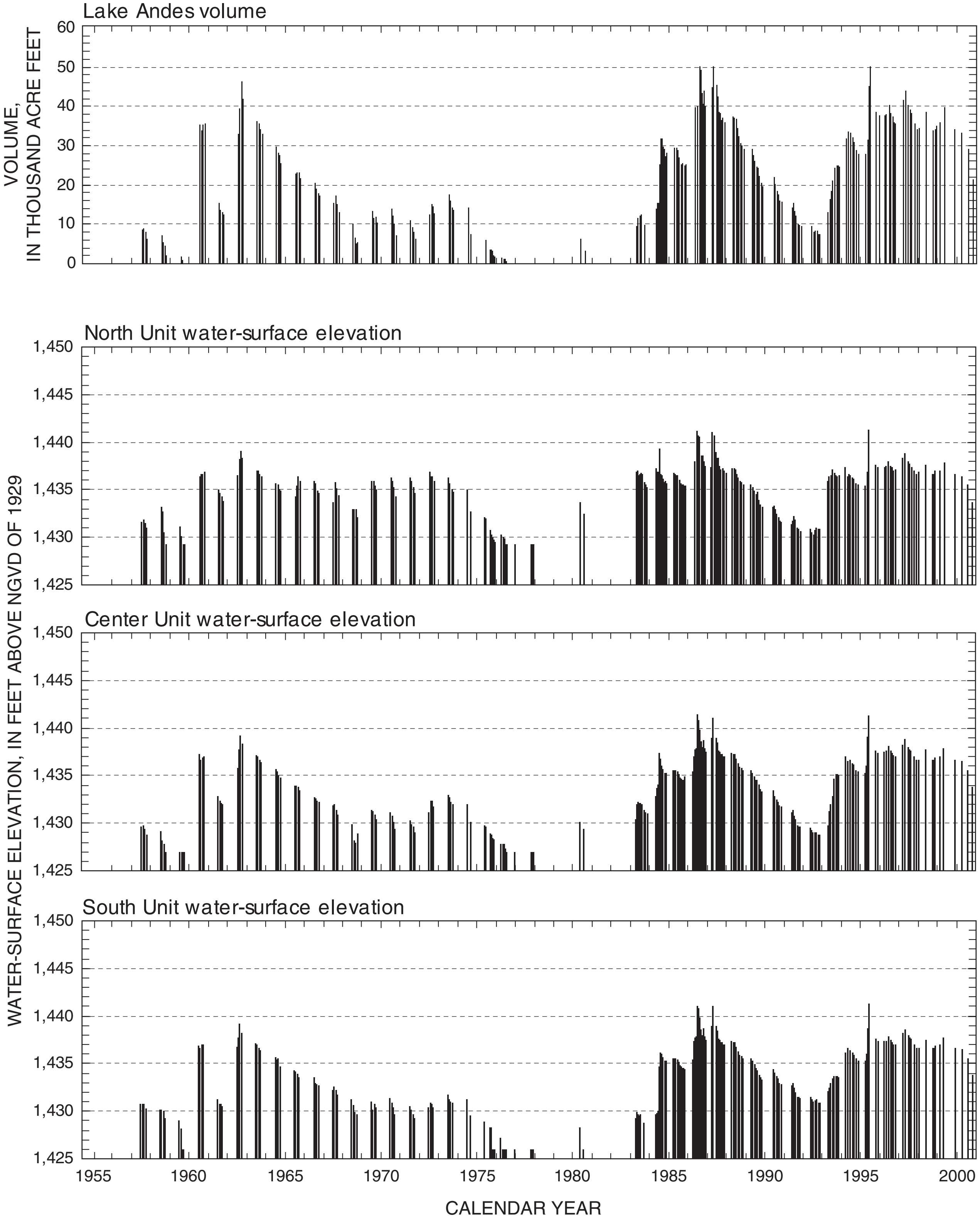


Figure 5. Long-term water-surface elevations and lake volumes for Lake Andes.

Choteau Creek

Choteau Creek has a drainage area of 619 mi^2, and although it occurs primarily in Douglas and Charles Mix Counties, parts of the basin also extend into Aurora, Bon Homme, Davison, and Hutchinson Counties. Long-term streamflow and streamflow characteristics for Choteau Creek near Avon (station 06453255; fig. 1), the only continuous streamflow-gaging station in the basin, are shown in figure 6. Streamflow data collected at the time of water-quality sampling visits were used to estimate long-term streamflow characteristics for three water-quality sampling stations on Choteau Creek (fig. 1). Streamflow characteristics at the water-quality stations were estimated by relating periodic streamflow measurements to gaged streamflow data at station 06453255 using locally weighted regression (Cleveland and others, 1988). Estimated streamflow characteristics and results of the locally weighted regression used to develop the characteristics at the three water-quality stations are listed in table 1. Estimates of long-term monthly mean streamflows for stations on Choteau Creek are shown in figure 7. Peak-flow and low-flow statistics for stations on Choteau Creek are presented in tables 3 and 4, respectively.

Upstream from the town of Wagner (represented by station 06453200, fig. 1), Choteau Creek is essentially ephemeral, and on average flows will be zero or near zero greater than 50 percent of days (table 1). There is little ground-water discharge to Choteau Creek until the channel intersects the water table of the Choteau aquifer. Downstream from Wagner (represented by stations 06453252, 06453255, and 06453300), Choteau Creek begins to receive ground-water discharge from the Choteau and Delmont aquifers (Kume, 1977), providing perennial flow during most years. Zero-flow conditions do occur during extremely dry conditions.

Highest streamflow generally occurs during March and April when snowmelt and spring rains contribute to surface runoff. Spring and summer storms can maintain substantial runoff through July, but flows generally decline markedly in late summer (fig. 7).

Choteau Creek enters the Missouri River about 28 river miles downstream from Fort Randall Dam. Long-term streamflow characteristics for the Missouri River immediately downstream from Fort Randall Dam are shown in figure 8. Choteau Creek contribution to the Missouri River relative to release from Fort Randall Dam generally is small; the median daily mean contribution of Choteau Creek to the Missouri River at the mouth of Choteau Creek is 0.019 percent. However, in about one-half of all years (based on gaging records at station 06453255, period of record 1983-2000), Choteau Creek contribution will exceed 10 percent of the Missouri River flow for short periods, typically 1 to 2 weeks. During very unusual conditions, Choteau Creek flow at its mouth can account for greater than 50 percent of the flow of the Missouri River. These conditions typically occur when releases from Fort Randall Dam are reduced to lessen flooding effects of larger downstream tributaries to the Missouri River. Even when Choteau Creek flow is high relative to release from Fort Randall Dam, the influence is limited to a relatively short reach of the Missouri River. The Keya Paha and Niobrara Rivers enter the Missouri River 3.0 and 7.2 river miles, respectively, downstream from the mouth of Choteau Creek. Inflows from Ponca Creek (drainage area about 815 mi^2; annual mean streamflow of 123 ft^3/s for period 1983-2000) and the Niobrara River (drainage area about 11,600 mi^2; annual mean streamflow 1,940 ft^3/s for period 1983-2000), generally far exceed Choteau Creek flow.

Table 3. Peak-flow magnitudes and frequencies for sites on Choteau Creek

[Characteristics for station 06453255 based on continuous streamflow records for 1982-2000. Characteristics for other stations estimated from regression analysis]

Station name and identification number	Drainage area, in square miles	Exceedance streamflow, in cubic feet per second, for specified recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
Choteau Creek near Wagner (06453200)	383	620	1,840	3,280	6,180	9,340	13,600	28,800
Choteau Creek near Dante (06453252)	484	716	2,120	3,790	7,140	10,800	15,700	33,200
Choteau Creek near Avon (06453255)	595	813	2,410	4,300	8,100	12,300	17,800	37,700
Choteau Creek below Avon (06453300)	615	830	2,460	4,390	8,270	12,500	18,200	38,500

Table 4. Low-flow characteristics for sites on Choteau Creek

[Characteristics for station 06453255 based on continuous streamflow records for 1982-2000. Characteristics for other stations estimated from regression analysis]

Station name and identification number	Drainage area, in square miles	Period	7-day non-exceedance streamflow, in cubic feet per second, for specified recurrence interval					
			2-year	5-year	10-year	25-year	50-year	100-year
Choteau Creek near Wagner (06453200)	383	Annual (April-March)	0.01	0.01	0.01	0.01	0.00	0.00
		October-November	.02	.01	.01	.01	.00	.00
		December-March	.02	.01	.01	.01	.00	.00
		April	1.4	.06	.01	.00	.00	.00
		May-September	.01	.01	.01	.01	.00	.00
Choteau Creek near Dante (06453252)	484	Annual (April-March)	.05	.02	.01	.00	.00	.00
		October-November	.11	.03	.01	.01	.00	.00
		December-March	.08	.02	.01	.01	.00	.00
		April	4.1	.18	.03	.01	.00	.00
		May-September	.1	.02	.01	.01	.00	.00
Choteau Creek near Avon (06453255)	595	Annual (April-March)	1.6	.19	.02	.00	.00	.00
		October-November	2.5	.53	.18	.05	.01	.00
		December-March	1.7	.41	.14	.04	.01	.00
		April	15	2.2	.76	.25	.10	.05
		May-September	2.2	.30	.04	.00	.00	.00
Choteau Creek below Avon (06453300)	615	Annual (April-March)	1.6	.19	.02	.00	.00	.00
		October-November	2.6	.54	.18	.05	.01	.00
		December-March	1.7	.42	.14	.04	.01	.00
		April	15	2.2	.78	.26	.10	.05
		May-September	2.2	.31	.04	.00	.00	.00

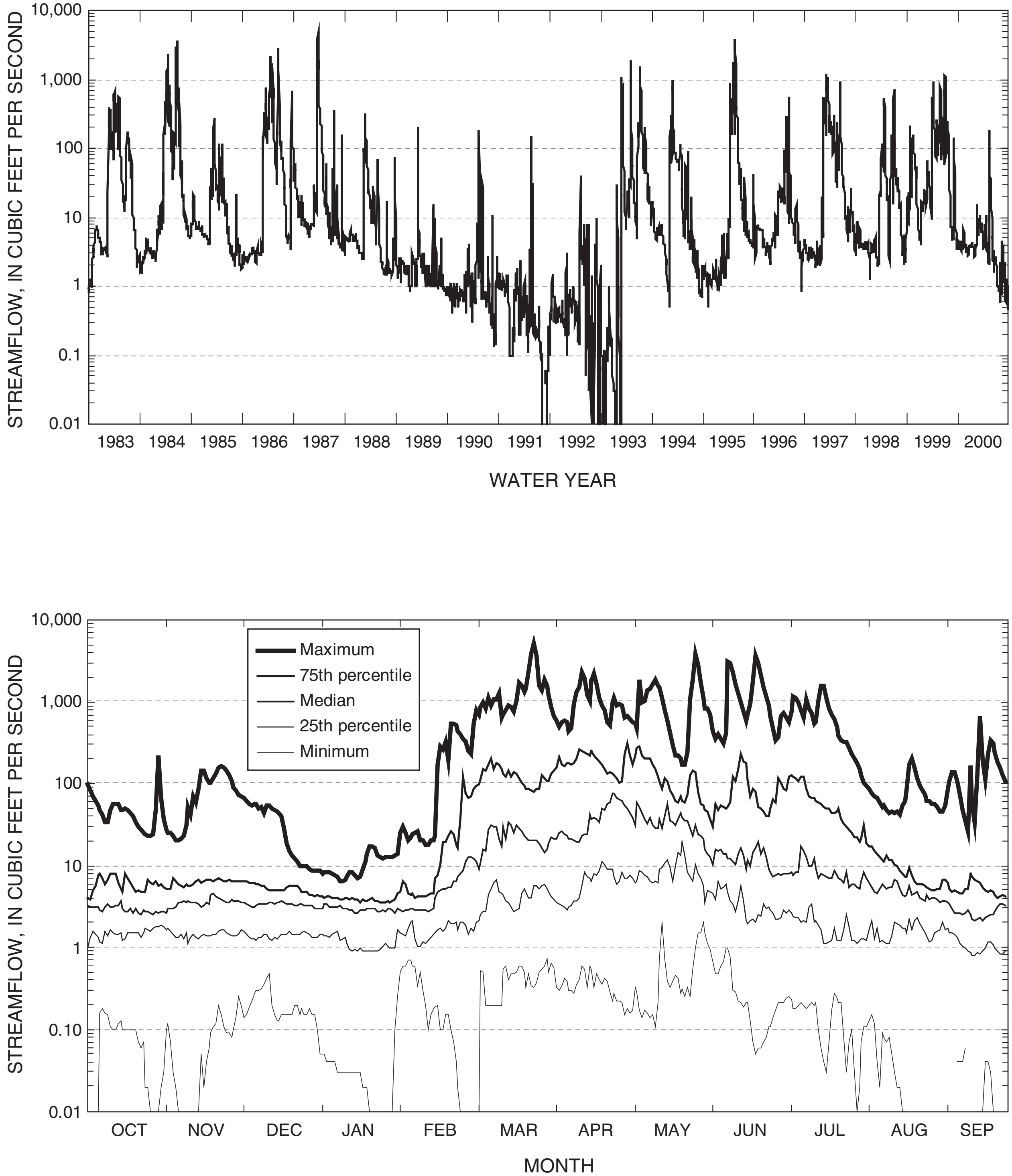


Figure 6. Long-term (water years 1983-2000) streamflow and streamflow characteristics for Choteau Creek near Avon (station 06453255).

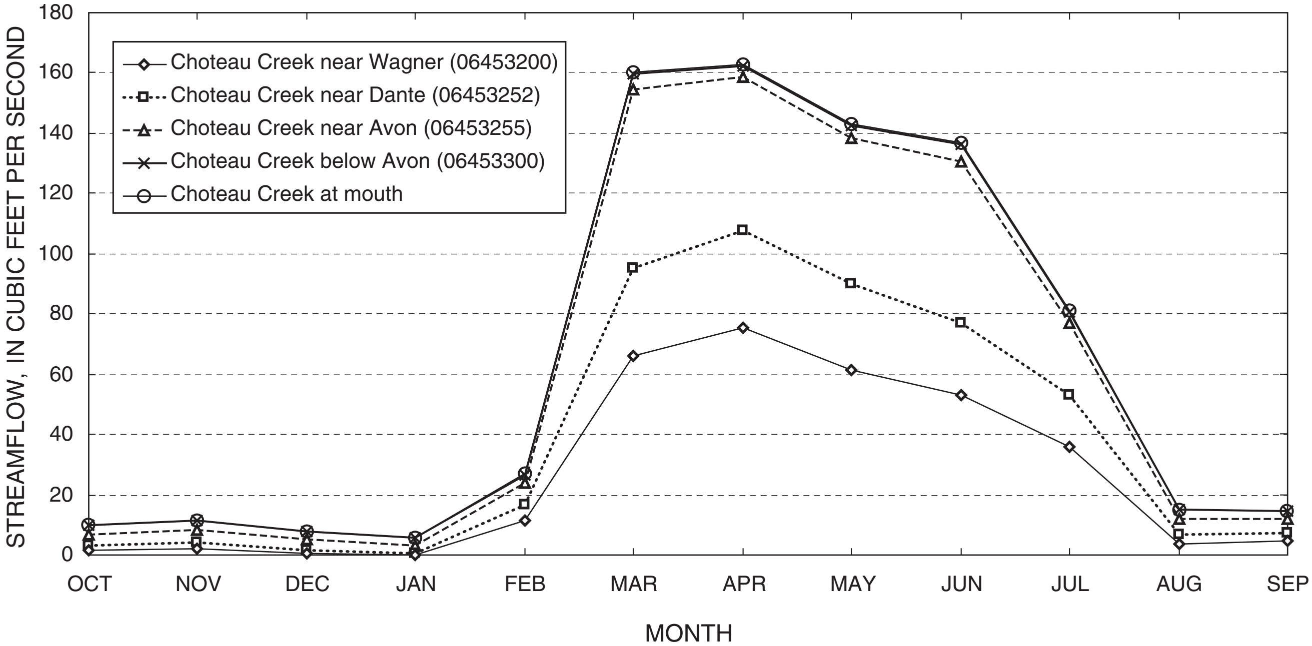


Figure 7. Estimated long-term (water years 1983-2000) monthly mean flows for stations on Choteau Creek.

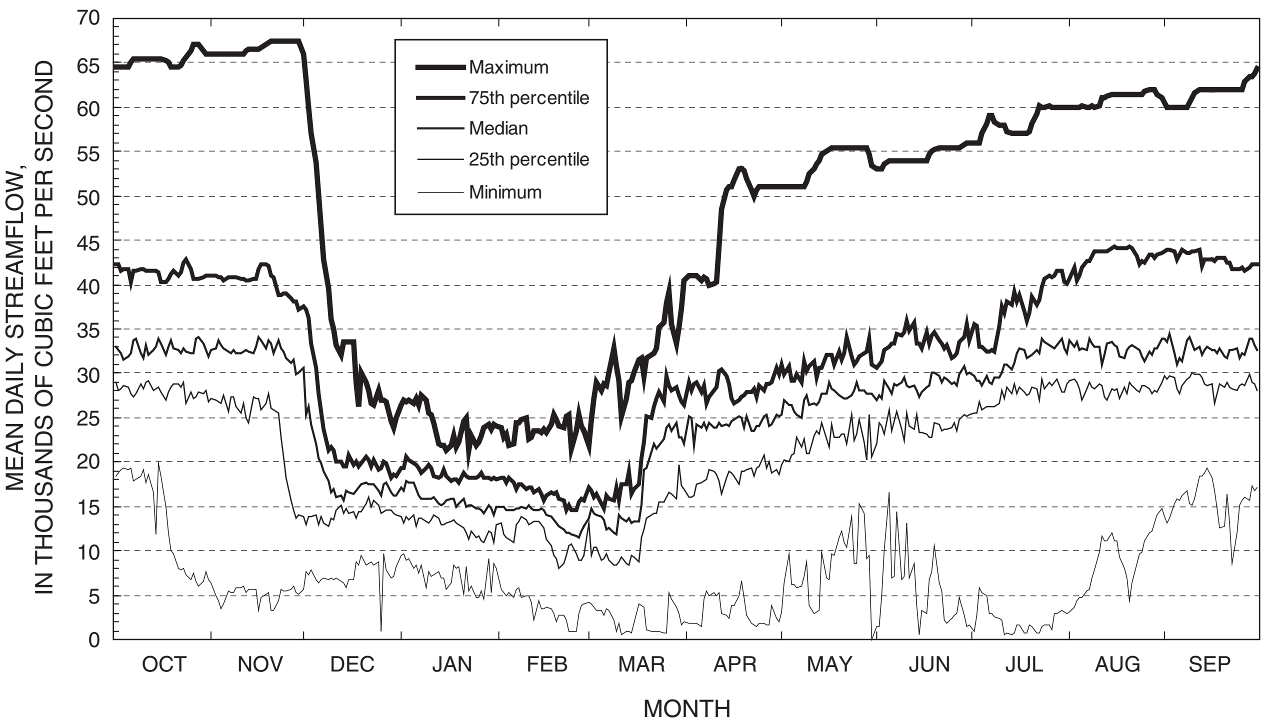


Figure 8. Long-term (water years 1967-99) streamflow characteristics for the Missouri River downstream from Fort Randall Dam (computed using dam release data for Fort Randall Dam provided by Mike Swenson, U.S. Army Corps of Engineers, written commun., April 17, 2001).

Ground Water

Ground-water resources in the Lake Andes and Choteau Creek Basins are described in detail in Kume (1977), and much of the following discussion is taken directly from that report. Ground water in the Lake Andes and Choteau Creek Basins occurs in aquifers that consist of unconsolidated surficial deposits and consolidated bedrock (fig. 9). Unconsolidated surficial deposits include preglacial stream deposits, proglacial and glacial deposits collectively termed glacial drift, and postglacial deposits that are called alluvium if deposited by water, loess if deposited by wind, and colluvium if deposited by mass wasting. The surficial aquifers in the Lake Andes and Choteau Creek Basins that were identified in Kume (1977) include the Choteau, Corsica, Geddes, and Delmont aquifers, as well as minor unnamed aquifers. The surficial aquifers overlie the bedrock formations throughout much of the Lake Andes and Choteau Creek Basins, but are absent in isolated areas where bedrock formations outcrop and in areas where only glacial till with small water-transmitting characteristics overlies the bedrock.

The two surficial aquifers that have the largest potential for interaction with surface water in the study area are the Choteau aquifer and the Delmont aquifer. The Choteau aquifer (fig. 9) consists of buried outwash and stream deposits (Kume, 1977). The outwash is composed of sand and gravel that occurs in several layers within the till. The Choteau aquifer is the largest surficial aquifer in the study area, underlying 326 mi^2, and has an average saturated thickness of about 35 ft. Recharge to the Choteau aquifer comes mostly from adjacent till and the numerous saturated lenticular outwash bodies within the till. Some recharge may also come from the Niobrara Marl where the Choteau aquifer lies directly upon the marl. Throughout most of its range, a thick layer of clayey till (generally greater than 50 ft thick) overlies the Choteau aquifer. However, downstream from Wagner, the potentiometric surface of the Choteau aquifer intercepts the Choteau Creek channel, and from that point downstream to the mouth of Choteau Creek, the Choteau aquifer typically discharges to Choteau Creek.

The Delmont aquifer (fig. 9) consists of the Delmont outwash (an extensive deposit of sand and gravel containing abundant coal, chalk, and shale fragments at or near the land surface (Stoley, 1956; Kume, 1977)) and valley fill in the drainage channels of Choteau Creek. Recharge to the Delmont aquifer is from precipitation, infiltration from Choteau Creek, and movement of water into the aquifer from the adjacent drift. North of Wagner, infiltration from Choteau Creek recharges the aquifer during times of surface runoff. South of Wagner, Choteau Creek gains water by natural ground-water discharge from the Delmont and Choteau aquifers.

The Dakota aquifer is the only bedrock aquifer that substantially affects surface-water hydrology and/or water quality in the study area, primarily as a result of a flowing well feeding Owens Bay of Lake Andes that taps the Dakota aquifer. The Dakota Formation of Upper Cretaceous age underlies the entire study area. The Dakota aquifer consists of several sandstones that are interbedded with shale in the Dakota Formation. Within the study area, the Dakota aquifer lies between about 450 ft to about 600 ft below the land surface, and the thickness of the aquifer ranges from about 100 ft to about 450 ft (Kume, 1977). Recharge to the Dakota aquifer is not well defined, but probably occurs by water migrating upward from underlying limestone bedrock formations. Discharge from the Dakota aquifer occurs mostly from flowing wells used for domestic and livestock watering purposes.

METHODS OF STUDY

Since 1983, USGS has been collecting water-quality data in the Lake Andes and Choteau Creek Basins in support of proposed BOR irrigation activities; data analyzed for this report are restricted to the period of 1983 through 2000, hereinafter referred to as "study period." Methods of study, including sample collection, processing, and analyses, quality assurance and quality control, and methods of data analyses, are discussed in this section of the report.

Sample Collection, Processing, and Analysis

Fifteen stations (including 4 stations on tributaries to Lake Andes, 6 lake stations on Lake Andes, 3 stations on Choteau Creek, and 2 stations on the Missouri River) have been sampled as part of the Lake Andes/Choteau Creek water-quality monitoring program (table 5). For an additional station (Lake Andes near Owens Bay), sediment cores were collected in October 2000, but no water-quality data were collected for that site. The sampling design, and collection and analytical methods used in the water-quality monitoring program have evolved somewhat over the duration of the program. Thus, periods of record vary between sites. Also, before 1996, water-quality

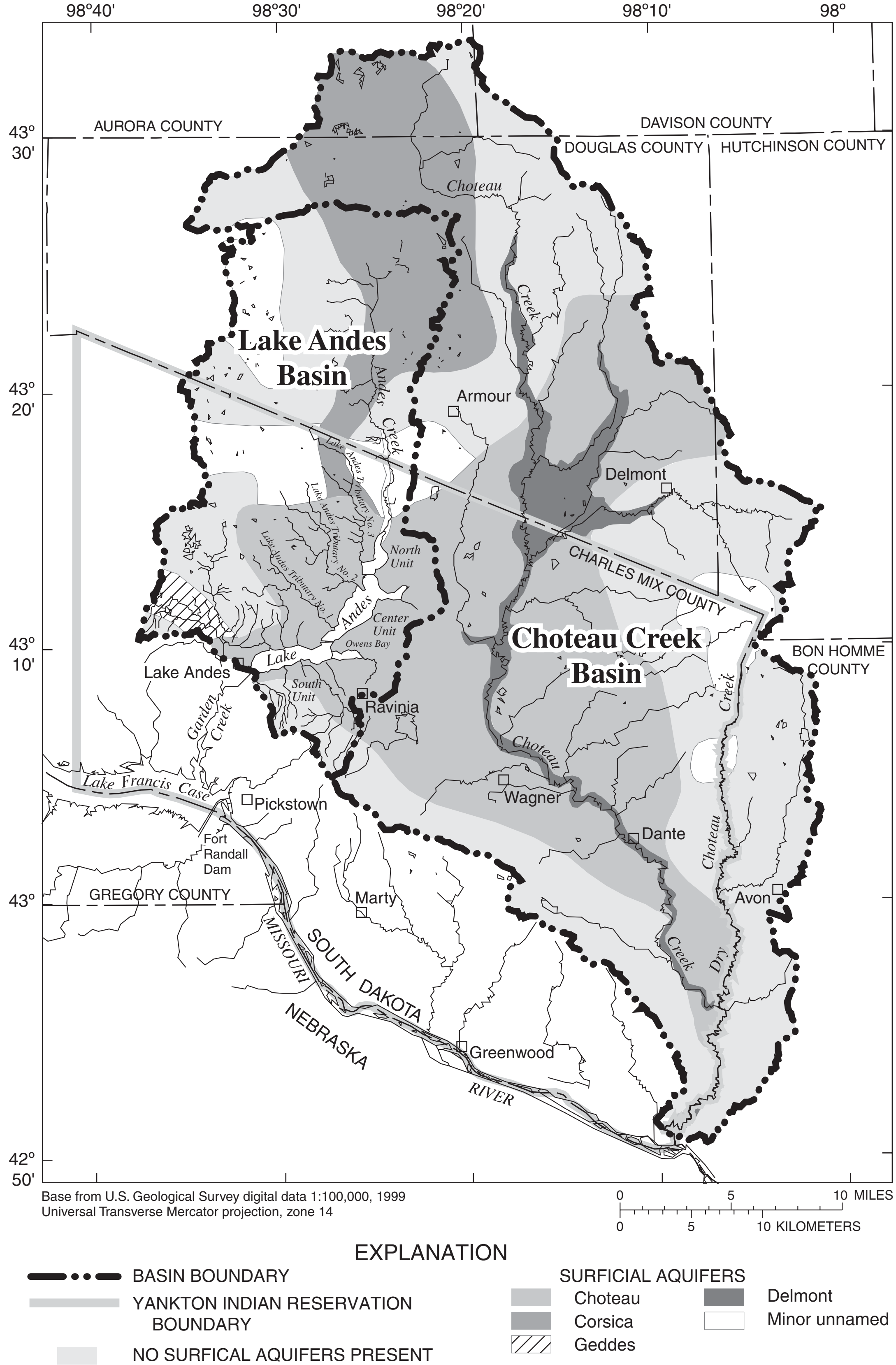


Figure 9. Location of surficial aquifers in the Lake Andes and Choteau Creek Basins (Kume, 1977; Hamilton, 1984; Lindgren and Hansen, 1990).

Table 5. Site information for water-quality stations

[--, no data]

Station identification number	Station name	Latitude	Longitude	Drainage area (square miles)	Period of record
06452380	Andes Creek near Armour	431523	982408	92.1	1984-88, 1993, 1995-2000
06452383	Lake Andes tributary no. 3 near Armour	431523	982558	26.5	1984-86, 1993, 1995-2000
06452386	Lake Andes tributary no. 2 near Lake Andes	431243	982645	18.4	1984-87, 1993, 1995-99
06452389	Lake Andes tributary no. 1 near Lake Andes	431125	982757	7.87	1984,1986, 1993, 1995-97
06452390	Lake Andes above Ravinia (represents Lake Andes North Unit)	431315	982455	--	1990-2000
06452391	Lake Andes near Ravinia (represents Lake Andes Center Unit)	431105	982610	--	1990-2000
06452392	Lake Andes near Lake Andes (represents Lake Andes Center Unit)	431010	982735	--	1983-89
430941098273400	Lake Andes near Owens Bay (represents Lake Andes South Unit)	430941	982734	--	2000
06452403	Owens Bay near Ravinia	430940	982645	--	1990-2000
06452406	Lake Andes above Lake Andes (represents Lake Andes South Unit)	430940	982910	--	1990-2000
06452410	Lake Andes below Lake Andes (represents Lake Andes South Unit)	430827	983257	--	1986-88
06453120	Missouri River above Choteau Creek, near Verdel, Nebr.	425040	981150	--	1990-2000
06453200	Choteau Creek near Wagner	430552	981715	383	1983-89, 1993-2000
06453252	Choteau Creek near Dante	430132	981003	484	1983-90, 1992-2000
06453300	Choteau Creek below Avon	425140	980825	615	1990-2000
06453305	Missouri River below Choteau Creek, near Verdel, Nebr.	425005	980820	--	1990-2000

samples for Lake Andes tributaries were collected only when the streamflow exceeded 2 ft^3/s (an arbitrary threshold for determining when the tributaries were providing substantial inflow to Lake Andes). Sampling only when streamflow exceeded 2 ft^3/s did not allow complete characterization of the water-quality regimes of the tributaries. Since 1996, samples generally have been collected whenever discernible flow existed at the time of a sampling visit.

Water-quality samples for all stations were analyzed for selected field-measured properties, and major-ion, nutrient, and trace-element constituents. Constituent analyses varied over the duration of the monitoring program. Water-quality constituents and properties with greatest relevance to the objectives of this report are presented in table 6. Laboratory analyses of water samples were performed by the USGS National Water Quality Laboratory (NWQL), Denver, Colorado. References for analytical procedures used by NWQL can be found on the World Wide Web at URL http://nwql.usgs.gov/Public/ref_list.html (accessed Apr. 29, 2003). During selected sampling visits, bottom-sediment samples were collected for all stations, and were analyzed for selected major ions, nutrients, and trace elements (table 6). During selected sampling visits, lake sampling stations were sampled and analyzed for selected pesticides (table 7). Whenever samples were collected from Lake Andes tributaries and Choteau Creek stations, suspended-sediment samples were collected and analyzed for suspended-sediment concentration and percent of fines (particles less than 62 μm (micrometer) in diameter) in the sediment sample using the methods described by Guy (1969) and Matthes and others (1991).

Water-quality sampling methods varied over the duration of the monitoring program. Samples were collected using methods considered acceptable at the time of collection. Throughout the duration of the monitoring program, stream water-quality and suspended-sediment samples have been collected using isokinetic samplers and depth- and width-integrating procedures described in Edwards and Glysson (1988). The depth- and width-integrated samples were composited into a churn splitter. Samples for whole-water analyses were withdrawn directly from the churn splitter, while samples for dissolved analyses were passed through a 0.45-μm pore-size filter. 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 equipment, including churn splitters and 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 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 (Horowitz and others, 1994). Samples generally were collected by two-person sampling teams ("clean hands/dirty hands"), and vinyl or latex gloves were worn during sample collection. All sampling equipment contacting the native water 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.

Grab samples of bottom sediment were collected following the guidelines of Edwards and Glysson (1988) and Ward and Harr (1990). At each station, samples were collected from locations where bottom sediments were dominated by fine-grained sediment. The samples were submitted to the Branch of Geochemistry Laboratory of the USGS, Geologic Division, Lakewood, Colorado, for analysis of constituents shown in table 7 using procedures described in Arbogast (1990). Prior to analysis, the samples were dried, sieved through a 2-mm (millimeter) screen, and then processed using a rigorous acid digestion to break down the rock/soil matrix, and desorb and solubilize constituents.

In October 2000, two vertical cores of bottom sediment were collected at station 430941098273400 (Lake Andes near Owens Bay; fig. 1, table 5) using a Benthos gravity corer with a 10-ft-long and 2.625-inch-diameter barrel. Each of the cores was capped in the field and transported to the USGS Huron Subdistrict office laboratory where they were kept in cold storage until processing was completed. At the laboratory, the cores were cut lengthwise, and subsamples of each core were collected at 0.15-ft intervals using cleaned plastic spatulas. Each subsample was analyzed for cesium-137 (^{137}Cs) (analysis performed by Quanterra Laboratory, Richland, Washington) and selenium and total carbon (analysis performed by the Branch of Geochemistry Laboratory of the USGS, Geologic Division, Lakewood, Colorado).

Table 6. Selected constituents and properties analyzed for in water-quality and bottom-sediment samples for the Lake Andes/Choteau Creek water-quality monitoring program

[µg/L, micrograms per liter]

Field-measured properties and constituents	Water-quality constituents (dissolved concentration, unless noted otherwise[1])	Bottom-sediment constituents (total recoverable concentration[2])	
	Constituent or property (milligrams per liter unless noted otherwise)	Major ions, nutrients, and trace elements (micrograms per gram unless noted otherwise)	
Discharge, in cubic feet per second (Lake Andes tributaries and Choteau Creek stations only)	**Major ions**	Aluminum (percent)	Mercury
	Calcium	Arsenic	Molybdenum
Barometric pressure, in millimeters of mercury	Magnesium	Barium	Neodymium
	Potassium	Beryllium	Nickel
Dissolved-oxygen concentration, in milligrams per liter	Sodium	Bismuth	Niobium
	Alkalinity (as $CaCO_3$)	Boron	Phosphorus (percent)
pH, in standard units	Chloride	Cadmium	Potassium (percent)
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	Fluoride	Calcium (percent)	Scandium
	Silica	Cerium	Selenium
Air temperature, in degrees Celsius	Sulfate	Chromium	Silver
Water temperature, in degrees Celsius	Dissolved solids	Cobalt	Sodium (percent)
Secchi disk transparency, in inches (Lake Andes lake and Missouri River stations only)	Nutrients	Copper	Strontium
	Ammonia, as nitrogen	Europium	Tantalum
	Ammonia plus organic nitrogen (whole-water[2]), as nitrogen	Gallium	Thorium
		Gold	Tin
	Nitrite, as nitrogen	Holmium	Titanium (percent)
	Nitrite plus nitrate, as nitrogen	Iron (percent)	Uranium
	Phosphorus (whole-water[2])	Lanthanum	Vanadium
	Orthophosphate, as phosphorus	Lead	Ytterbium
	Trace elements	Lithium	Yttrium
	Aluminum (µg/L)	Magnesium (percent)	Zinc
	Arsenic (µg/L)	Manganese	
	Boron (µg/L)		
	Cadmium (µg/L)		
	Chromium (µg/L)		
	Copper (µg/L)		
	Lead (µg/L)		
	Mercury (µg/L)		
	Molybdenum (µg/L)		
	Selenium (µg/L)		
	Uranium (µg/L)		
	Vanadium (µg/L)		
	Zinc (µg/L)		
	Suspended sediment		
	Concentration		
	Percent fines		

[1]"Dissolved" is operationally defined as that part of a water sample that passes through a 0.45-micrometer pore-size filter; "whole-water" is operationally defined as an unfiltered water sample.

[2]Distinction should be noted between the "total recoverable" concentrations describing bottom-sediment results and the "whole-water" or "total" concentrations describing water-quality results. Digestion procedures for bottom-sediment samples typically result in less than 95 percent of the rock/soil material being solubilized; thus, analytical results for bottom-sediment samples are termed "total recoverable" concentrations. Digestion procedures for water-quality samples typically result in greater than 95 percent of the particulate material being solubilized; thus, analytical results for water-quality samples are termed "whole-water" or "total" concentrations.

Table 7. Pesticides analyzed for in selected samples

[Whole-water analyses, in micrograms per liter]

2,4-DP	Butachlor	Disulfoton	Metolachlor	Prometryne
2,4,5-T	Butylate	Endosulfan	Metribuzin	Propachlor
2,4-D	Carbaryl	Endrin	Mirex	Propazine
Alachlor	Carbofuran	Ethion	1-Napthol	Propham
Aldicarb sulfone	3-Hydroxy carbofuran	Fonofos	Oxyamyl	Propoxur
Aldicarb sulfoxide	Carboxin	Guthion	P,P'-DDD	Silvex
Aldicarb	Chlordane	Heptachlor epoxide	P,P'-DDE	Simazine
Aldrin	Chlorpyrifos	Hexazinone	P,P'-DDT	Simetryne
Alpha BHC	Cyanazine	Lindane	Parathion	Terbacil
Ametryne	Cycloate	Malathion	PCB	Toxaphene
Atrazine	DEF	Methiocarb	PCN	Trifluralin
De-ethyl atrazine	Delta benzene hexachloride	Methomyl	PCNS	Trithion
De-isopropyl atrazine	Diazinon	Methoxychlor	Perthane	Vernolate
Beta benzene hexachloride	Dieldrin	Methylparathion	Phorate	
Bromacil	Diphenamid	Methyltrithion	Prometone	

^{137}Cs is a radioactive isotope that was distributed in the earth's atmosphere by nuclear-weapons testing, which began in about 1952 (Holmes, 1998). Following the start of testing, atmospheric concentrations of ^{137}Cs generally increased and reached a peak in about 1963 when the Nuclear Test Ban Treaty went into effect. Concentrations have declined since that time. ^{137}Cs strongly sorbs to fine-grained sediment, making it useful to age date undisturbed sediment that has been exposed to atmospheric fallout (Callender and Robbins, 1993). Based on patterns of atmospheric ^{137}Cs concentrations, the deepest subsample of a sediment core with a measurable ^{137}Cs concentration would have been deposited in about 1952. Also, the subsample of a core with the maximum ^{137}Cs concentration would have been deposited in about 1963. The top of a core would represent sediment deposition at the time of core collection. Thus, the vertical locations within the core of three discrete time periods can be identified: (1) about 1952; (2) about 1963; and (3) the time of core collection.

Selenium and total carbon concentrations also were determined in each of the core subsamples and the ^{137}Cs, selenium, and carbon results were analyzed to investigate changes in selenium loading with time. The core subsamples were analyzed for total carbon, which includes both inorganic and organic fractions, but it was assumed that the large majority of the sediment carbon in a biologically productive lake like Lake Andes is in organic form. The selenium concentrations in the core subsamples were normalized for organic carbon concentration. Selenium is a micronutrient that is present in plant and animal tissues. Changes in the trophic status of a lake can change the deposition rate of organic material to lake sediments, which also can change the deposition rate of selenium even if selenium loading to a lake is constant. Thus, in this report, selenium concentrations were normalized for organic carbon by dividing the selenium concentration by the organic carbon concentration and multiplying the result by 10.

Quality Assurance/Quality Control

Beginning in 1994, quality-control samples, including blanks and replicates, were collected to document variability in results and whether contamination was introduced during sampling and processing. Analytical results for laboratory equipment blanks and field equipment blanks are shown in tables 23 and 24 in the Supplemental Information section at the back of the report. Constituent concentrations in blank samples were either less than laboratory reporting levels, or were substantially less than concentrations found in environmental samples.

Seven sets of replicate water-quality samples were collected during 1995-2000. Results of the replicate water-quality samples and the associated primary water-quality samples are available in the annual data reports of the South Dakota District for water years 1995-2000 (U.S. Geological Survey, 1996-2001). To provide information on the precision of collection and analysis methods, the relative standard deviation (RSD) for each primary sample/replicate sample pair was calculated using the following equation:

$$RSD = \left(\frac{S}{X}\right) \times 100 \qquad (1)$$

where

RSD = the relative standard deviation, in percent;

S = the standard deviation of the primary and replicate samples; and

X = the mean of the primary and replicate samples.

For each constituent, the average RSD for all seven primary sample/replicate sample pairs was determined (table 8). Taylor (1987) specified that a typical data-quality objective is an average RSD less than 20 percent. For most constituents in this report, the average RSD's (table 8) are less than 5 percent, indicating that the precision of collection and analysis methods is very good. Average RSD's tend to be larger for some of the nutrient constituents, including ammonia, whole-water ammonia plus organic nitrogen, and whole-water phosphorus (table 8). Although analytical variability for these nutrient constituents often is larger than for most major ions and trace elements, the large average RSD's for these nutrient constituents in this report primarily result from unusually large variability between the primary and replicate samples in a single paired set. If the single large-variability primary/replicate pair is ignored, the average RSD for ammonia is less than 20 percent, for whole-water ammonia plus organic nitrogen is less than 10 percent, and for whole-water phosphorous is less than 5 percent. Thus, it is likely that the large variability for the problem set is anomalous. Generally, it can be concluded that the water-quality data collected in this report are reasonably representative of environmental conditions, and of acceptable precision to discern spatial and temporal variability in water quality.

Table 8. Average relative standard deviations for quality-control water-quality replicate samples

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius]

Constituent or property (dissolved, unless noted otherwise)	Average relative standard deviation, in percent
pH (standard units)	0.90
Specific conductance (µS/cm)	0.30
Calcium	1.53
Magnesium	0.33
Potassium	1.69
Sodium	.67
Alkalinity	.37
Chloride	1.06
Fluoride	4.04
Sulfate	.35
Silica	.66
Dissolved solids, residue on evaporation at 180°C	.37
Dissolved solids, sum of constituents	.40
Ammonia, as nitrogen	35.56
Ammonia plus organic nitrogen, whole-water	13.14
Nitrite, as nitrogen	.16
Nitrite plus nitrate, as nitrogen	.24
Orthophosphate, as phosphorus	4.26
Phosphorus, whole-water	8.78
Arsenic	.54
Selenium	6.13

Data Analysis Methods

Water-quality data collected for the monitoring program were analyzed using various methods including summary statistics and boxplots. Other analyses included calculation of daily loads and masses and determination of trends; methods for these analyses are described in the following sections.

Calculation of Summary Statistics

Summary statistics (including mean, median, minimum, and maximum) were calculated for selected water-quality properties and constituents for each sampling station using standard techniques (Inman and Conover, 1983). Boxplots showing statistical distributions of the data were constructed for selected water-quality properties and constituents for selected stations using a modification of the procedures described by Tukey (1977). The modifications involve denoting values that are greater than 1.5 times the interquartile range outside the quartile as outliers.

Censored data (that is, values that are less than the laboratory reporting level) complicated the calculation of summary statistics and construction of the boxplots. Some constituents had a small number of samples that were reported as less than a given laboratory reporting level, and that laboratory reporting level was unusually large and greater than a substantial number (that is, about one-half) of the reported concentrations for that constituent. In these cases, the “less than” samples with the unusually large laboratory reporting level were excluded from the calculation of summary statistics and construction of boxplots. Some constituents had multiple laboratory reporting levels over the duration of the monitoring program, and it was necessary to select a single reporting level for calculating summary statistics and constructing boxplots. For these constituents, the largest laboratory reporting level that did not exceed a substantial number of the reported concentrations was selected as the study reporting level. All concentrations that were less than the study reporting level, regardless of whether they were originally reported by the laboratory as “less thans” or they were reported as actual concentrations, were considered to be less than the study reporting level for the calculation of summary statistics and the construction of boxplots. After excluding data values with unusually large laboratory reporting levels and selecting a single study reporting level for a given constituent, a value of one-half the study reporting level was assigned to “less than” data values for the calculation of summary statistics and construction of boxplots.

Calculation of Loads and Masses

Daily loads of nitrogen and phosphorus transported at the Lake Andes tributary stations and the Choteau Creek stations for the days that samples were collected were calculated by:

$$L_D = C \times Q \times 5.4 \qquad (2)$$

where

L_D = daily load for a constituent, in pounds per day;

C = constituent concentration, in milligrams per liter;

Q = streamflow, in cubic feet per second; and

5.4 is a units conversion constant.

Simple linear regressions were then performed on log transformations of streamflow and load data to develop equations to estimate loads based on streamflow. Although this approach is simple and straightforward, it has been shown to be a valid and useful tool in estimating nutrient constituent loads (Cohn and others, 1992). Daily loads of nitrogen and phosphorus for 1983-2000 were estimated using the regression equations in conjunction with mean daily streamflow estimates.

Use of regression analysis on log-transformed data to estimate constituent loads based on streamflow has been shown to result in systematic bias when the results are retransformed from log units to the original arithmetic units (Koch and Smillie, 1986). To compensate for this bias, retransformed results were multiplied by a non-parametric bias-correction factor (Duan, 1983).

Masses of nitrogen and phosphorus in Lake Andes for the days that samples were collected were calculated by:

$$M = C \times V \times 0.00136 \qquad (3)$$

where

M = mass of a constituent, in tons;

C = constituent concentration, in milligrams per liter;

V = volume, in acre-feet; and

0.00136 is a units conversion constant.

Masses of nitrogen and phosphorus for all of Lake Andes were then calculated by summing the masses of the North, Center, and South Units of Lake Andes. Because Owens Bay typically is isolated from Lake Andes and only occasionally reaches an elevation where it spills into the South Unit of Lake Andes, Owens Bay was not included when calculating masses for all of Lake Andes.

Analysis of Trends

Trends in selected water-quality constituents were analyzed using a parametric time-series model that filters out interannual and seasonal variability in concentrations that result from trends and natural seasonal fluctuations in streamflow for stream stations and in lake volume for lake stations (Vecchia, 2000). Thus, the model decreases the chance of identifying natural variability as a trend and increases the chance of detecting a true trend. The model also filters out serial persistence (autocorrelation) between adjacent constituent concentration measurements that can bias estimated trends and associated significance levels. The model is fit to a set of constituent concentration and associated streamflow (or lake-volume) data using the computer program QWTREND (Skip Vecchia, U.S. Geological Survey, Bismarck, North Dakota, written commun., May 5, 2000).

The model first determines interannual and intraannual (seasonal) fluctuations in streamflow (or lake volume). A smoothing algorithm is used to separate low-frequency (annual and seasonal) variability from high-frequency variability (defined as the deviations of the recorded values from the low-frequency component). A non-linear regression of constituent concentrations on the low-frequency component of streamflow (or lake volume) then is performed to determine the low-frequency component of constituent concentrations (that is, the annual and seasonal variability in concentrations resulting from annual and seasonal variability in streamflow or lake volume). The flow-adjusted (or volume-adjusted) concentrations are obtained by subtracting the low-frequency component of constituent concentrations from the recorded data and then adding the mean of the recorded data. Flow-adjusted concentrations can be interpreted loosely as the concentrations that would have been observed if flow conditions had been uniform throughout the entire sampling period.

In addition to accounting for low-frequency variability in the streamflow and constituent-concentration data, the model also filters out complicated serial persistence that exists in the high-frequency component of constituent concentrations on a seasonal time scale. A periodic autoregressive moving-average model is calibrated to the high-frequency components of both discharge and concentration. The high-frequency component of constituent concentrations represent the time series of deviations of flow-adjusted concentrations from a fitted trend line.

The parametric time-series approach used in the model differs from more commonly used nonparametric approaches for trend analysis, such as seasonal Kendall's tau (Hirsch and Slack, 1984). Parametric tests are more powerful and flexible than nonparametric tests for detecting nonmonotonic trends and managing irregular sampling frequencies, but nonparametric tests are easier to apply and require fewer assumptions than parametric tests (Vecchia, 2000). A primary assumption of the parametric time-series model is that the streamflow and constituent-concentration data are normally distributed. Use of log transformations of these parameters in the trend-fitting process helps to ensure that this assumption is not strongly violated.

There are specific data recommendations for using the model, including at least 60 measurements made during a period of at least 15 years (the years may be nonconsecutive). Also, it is recommended that no more than 10 percent of the constituent concentrations be less than the study reporting level. Water-quality data collected by USGS in the Lake Andes and Choteau Creek Basins during the study period (1983-2000) generally do not meet all of the specified data recommendations. For this report, trend analysis was restricted to stations and constituents with at least 50 measurements made during a period of at least 10 years. Also, trend analysis was restricted to constituents determined to be of greatest relevance to water-quality issues in the Lake Andes and Choteau Creek Basins. Selected constituents included dissolved solids (sum of constituents), whole-water phosphorus, dissolved arsenic, dissolved selenium, and suspended sediment. For constituents that had some values that were less than the study reporting levels, those "less than" values were handled by assigning a value of one-half the study reporting level.

In the trend-fitting process, initial flow-adjusted (or volume-adjusted) concentrations were examined, and patterns that were apparent in the flow-adjusted (or volume-adjusted) data were noted. Step trends (Hirsch and others, 1991) and/or monotonic log-linear trends were assigned to specific periods within the sampling period. The time-series model was fit to the assigned trend patterns, and the results were examined to determine whether the model results reasonably explained variability that was apparent in the data. For the trend tests in this report, an alpha level of 0.05 was used to determine statistical significance of trends.

Because of the violation of the minimum data recommendations, the trend results for this report have a large degree of uncertainty and should be used with extreme caution. The trend results are not adequate to confidently determine the presence or absence of significant trends, but they might indicate important patterns in the data and could provide useful information for future studies of trends in the Lake Andes and Choteau Creek Basins.

WATER AND SEDIMENT QUALITY

The water and sediment quality of the Lake Andes and Choteau Creek Basins are summarized in this section of the report. Water-quality and sediment-quality data collected from the Missouri River near the mouth of Choteau Creek are included with discussions of Choteau Creek Basin. Selected water-quality criteria and index values are presented in table 9 for comparison with water-quality results.

Lake Andes Basin

In the Lake Andes Basin, water-quality data were collected at four tributary stations and six lake stations. Statistical summaries of these data are presented in table 10 for the tributary stations and in table 11 for the lake stations.

Field-Measured Properties and Constituents

Statistical distributions of selected field-measured properties and constituents for Lake Andes tributary and lake stations are shown in figure 10. Six lake stations have been sampled over the duration of the water-quality monitoring program. Four of the lake stations have consistent periods of record, while two of the lake stations have shorter periods of record that do not correspond with the other four stations. Thus, to allow consistent interpretation of differences in water quality between the lake stations, the two shorter term lake stations (stations 06452392 and 06452410) were excluded from the boxplot presentations and trend analyses of this report.

Seasonal distributions of selected field-measured properties and constituents for a single representative tributary station (06452380) and a single representative lake station (06452391) are presented in figure 11. Median dissolved-oxygen concentrations for tributaries and lake stations (tables 10 and 11, fig. 10) range from about 8 to 12 mg/L and generally exceed the South Dakota surface-water-quality minimum criterion of 5.0 mg/L for warmwater permanent fish-life propagation (table 9). Lower dissolved-oxygen conditions on Lake Andes tributaries can occur when sustained streamflow at small discharges extends into the summer months (fig. 11). Higher water temperatures (in excess of 20°C) increase growth and metabolism by aquatic organisms and deplete dissolved oxygen. Also, lower solubility of oxygen in warmer water contributes to the lower dissolved-oxygen concentrations during these periods. However, these conditions are unusual because runoff periods for Lake Andes tributaries typically are restricted to spring snowmelt and rainfall runoff, when water temperatures are low and the water is well aerated.

All lake stations occasionally have dissolved-oxygen concentrations less than the 5.0-mg/L criterion. Concentrations less than the criterion typically occur in the winter or summer (fig. 11). Low dissolved-oxygen concentrations in the winter occur when ice and snow cover on lakes restrict atmospheric exchange and prevent aeration by wind-generated turbulence. Also, restricted light penetration limits production of oxygen by photosynthesis. With little oxygen being generated, respiration by aquatic organisms consumes and depletes the available dissolved oxygen. Low dissolved-oxygen concentrations at the lake stations are less frequent during the summer because the shallow depth of the lake and frequent winds generate turbulence that disrupts thermal stratification. However, low dissolved-oxygen concentrations during the summer can occur during extended calm periods, or when algal blooms die off.

Median pH values for tributary and lake stations range from 7.8 to 8.4. Generally, the pH values are within the acceptable range for warmwater permanent fish-life propagation (tables 9-11), but all of the lake stations occasionally exceed the upper limit of 9.0. Higher pH values for the lake stations might result during periods when photosynthesis by algae consumes dissolved carbon dioxide and increases dissolved-oxygen concentrations (Wetzel, 1983).

Median specific-conductance values for Lake Andes tributary stations range from 560 to 1,710 μS/cm (microsiemens per centimeter) and are nearly always less than criteria for irrigation and fish and wildlife propagation, recreation, and livestock watering (tables 9 and 10, figs. 10 and 11). Specific-conductance values for lake stations tend to be higher than the tributary stations, with medians ranging from 1,630 to 2,560 μS/cm (table 11, figs. 10 and 11), which probably results from evaporative concentration and/or diffusive flux of solutes from bottom sediments. For lake stations, higher median specific-conductance values occur during the winter, when ice formation concentrates ions, and during the summer when evaporative concentration is largest. Lake stations routinely exceed the irrigation 30-day mean criterion, and occasionally exceed the fish and wildlife propagation, recreation, and livestock watering 30-day mean criterion (table 9). Specific-conductance values tend to increase downstream through the lake, probably due to effects of evaporative concentration.

Table 9. Selected water-quality criteria and index values

[µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; ≥, greater than or equal to; --, not applicable]

Property or constituent	Selected index values					
	National Irrigation Water-Quality Program Guidelines level of concern[1]	South Dakota surface-water quality criteria[2]				
		Warmwater permanent fish-life propagation	Warmwater marginal fish-life propagation	Aquatic-life criteria, acute/chronic	Irrigation	Fish and wildlife propagation, recreation, livestock watering
Dissolved-oxygen concentration (mg/L)	--	≥5	≥4	--	--	--
pH (standard units)	--	[3]6.5-9.0	[3]6.0-9.0	--	--	[3]6.0-9.5
Specific conductance (µS/cm)	--	--	--	--	[4]2,500/[5]4,375	[4]4,000/[5]7,000
Water temperature (°C)	--	26.7	32.2	--	--	--
Alkalinity (mg/L as $CaCO_3$)	--	--	--	--	--	[4]750/[5]1,313
Dissolved solids, residue on evaporation at 180°C (mg/L)	--	--	--	--	--	[4]2,500/[5]4,375
Dissolved solids, sum of constituents (mg/L)	--	--	--	--	--	[4]2,500/[5]4,375
Nitrite plus nitrate, as nitrogen (mg/L)	--	--	--	--	--	[4]50/[5]88
Arsenic (µg/L)	48-190	[6]0.14	[6]0.14	360/190	--	--
Selenium (µg/L)	1-2	--	--	20/5	--	--
Suspended sediment (mg/L)	--	[4,7]90/[5]158	[4,7]150/[5]263	--	--	--

[1]U.S. Department of the Interior (1998); the upper value of the level of concern represents the National Irrigation Water-Quality Program toxicity threshold.
[2]South Dakota Legislative Research Council (2001).
[3]Application of this standard is dependent on specific conditions described in South Dakota Legislative Research Council (2001).
[4]30-day mean.
[5]Daily maximum.
[6]Based on one route of exposure—ingestion of contaminated aquatic organisms only.
[7]The water-quality criterion is expressed as “Total Suspended Solids,” which is not equivalent but roughly comparable to suspended-sediment concentration.

Table 10. Statistical summaries of water-quality results for Lake Andes tributary stations

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; <, less than]

Property or constituent	06452380 (Andes Creek)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Streamflow at time of sampling (ft^3/s)	36	NA	16	5.5	<0.1	70
Oxygen, dissolved	23	NA	8.6	7.9	2.2	16.0
Oxygen, dissolved (percent saturation)	23	NA	89	85	28	164
pH (standard units)	33	NA	7.8	7.8	7.2	8.4
Specific conductance (µS/cm)	36	NA	1,480	1,400	474	3,100
Water temperature (°C)	37	NA	15.1	14.0	0.0	29.5
Calcium, dissolved	33	33	148	140	59	294
Magnesium, dissolved	33	33	65	62	21	135
Potassium, dissolved	33	33	22	22	12	47
Sodium, dissolved	33	33	82	77	27	187
Alkalinity, dissolved	33	33	213	206	83	347
Chloride, dissolved	33	33	26	25	9	52
Fluoride, dissolved	27	25	0.2	0.2	<0.1	0.2
Silica, dissolved	33	33	16	15	3	28
Sulfate, dissolved	33	33	585	500	150	1,260
Solids, dissolved, residue on evaporation at 180°C	23	23	1,250	1,100	452	2,250
Solids, dissolved, sum of constituents (calculated)	33	NA	1,070	1,010	423	2,070
Ammonia, as nitrogen, dissolved	17	13	0.09	0.03	<0.02	0.52
Ammonia plus organic nitrogen, whole-water	23	23	1.8	1.6	0.4	8.0
Nitrite plus nitrate, as nitrogen, dissolved	33	18	0.43	0.16	<0.1	2.7
Nitrite, as nitrogen, dissolved	23	10	0.02	<0.01	<0.01	0.11
Nitrogen, whole-water (calculated)	23	NA	2.2	1.7	0.85	9.3
Phosphorus, dissolved	16	16	0.56	0.44	0.14	1.8
Orthophosphate, as phosphorus, dissolved	33	33	0.52	0.42	0.09	1.5
Phosphorus, whole-water	30	30	0.64	0.56	0.16	2.1
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	23	NA	4.0	3.7	1.5	10.8
Arsenic, dissolved (µg/L)	21	21	6	5	2	12
Selenium, dissolved (µg/L)	21	20	4	3	<1	13
Suspended sediment	21	21	57	22	6	196
Percent fines	20	20	88	96	13	100

Table 10. Statistical summaries of water-quality results for Lake Andes tributary stations—Continued

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; <, less than]

Property or constituent	06452383 (Lake Andes tributary no. 3)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Streamflow at time of sampling (ft^3/s)	12	NA	4.2	1.5	0.1	31
Oxygen, dissolved	8	NA	11.2	11.4	5.6	17.0
Oxygen, dissolved (percent saturation)	8	NA	116	106	74	168
pH (standard units)	11	NA	8.0	7.9	7.8	8.4
Specific conductance (µS/cm)	12	NA	1,870	1,710	98	4,170
Water temperature (°C)	12	NA	14.1	13.6	0.0	30.0
Calcium, dissolved	11	11	196	185	70	400
Magnesium, dissolved	11	11	127	110	30	313
Potassium, dissolved	11	11	25	23	17	34
Sodium, dissolved	11	11	106	85	20	282
Alkalinity, dissolved	11	11	180	160	90	335
Chloride, dissolved	11	11	38	32	15	84
Fluoride, dissolved	9	8	0.2	0.2	<0.1	0.3
Silica, dissolved	11	11	15	15	6	22
Sulfate, dissolved	11	11	1,030	910	260	2,400
Solids, dissolved, residue on evaporation at 180°C	8	8	2,080	1,720	744	4,140
Solids, dissolved, sum of constituents (calculated)	11	NA	1,650	1,560	507	3,700
Ammonia, as nitrogen, dissolved	6	6	0.10	0.08	0.02	0.25
Ammonia plus organic nitrogen, whole-water	7	7	2.4	1.9	1.0	7.0
Nitrite plus nitrate, as nitrogen, dissolved	11	11	1.3	1.1	0.75	3.8
Nitrite, as nitrogen, dissolved	8	7	0.05	0.05	<0.01	0.14
Nitrogen, whole-water (calculated)	7	NA	3.6	3.1	1.8	8.5
Phosphorus, dissolved	5	5	0.72	0.51	0.27	1.8
Orthophosphate, as phosphorus, dissolved	11	11	0.50	0.42	0.08	1.6
Phosphorus, whole-water	10	10	0.65	0.47	0.18	2.0
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	7	NA	8.5	7.5	2.4	19.9
Arsenic, dissolved (µg/L)	7	7	5	5	3	8
Selenium, dissolved (µg/L)	7	7	39	34	11	75
Suspended sediment	8	8	37	29	14	86
Percent fines	6	6	90	96	58	99

Table 10. Statistical summaries of water-quality results for Lake Andes tributary stations—Continued

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; <, less than]

Property or constituent	06452386 (Lake Andes tributary no. 2)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Streamflow at time of sampling (ft^3/s)	12	NA	14	5.7	0.2	74
Oxygen, dissolved	9	NA	12.2	11.8	9.0	16.3
Oxygen, dissolved (percent saturation)	9	NA	109	107	0	227
pH (standard units)	12	NA	8.1	7.9	7.5	9.1
Specific conductance (µS/cm)	12	NA	1,500	1,300	780	2,640
Water temperature (°C)	12	NA	14.2	12.2	2.0	29.0
Calcium, dissolved	11	11	152	140	78	260
Magnesium, dissolved	11	11	75	52	29	156
Potassium, dissolved	11	11	24	20	16	45
Sodium, dissolved	12	12	80	56	28	174
Alkalinity, dissolved	12	12	146	142	89	234
Chloride, dissolved	12	12	33	28	11	80
Fluoride, dissolved	9	8	0.2	0.2	<0.1	0.3
Silica, dissolved	12	12	14	15	1	22
Sulfate, dissolved	12	12	676	540	200	1,350
Solids, dissolved, residue on evaporation at 180°C	9	9	1,340	1,090	510	2,350
Solids, dissolved, sum of constituents (calculated)	11	NA	1,150	893	490	2,160
Ammonia, as nitrogen, dissolved	6	6	0.25	0.25	0.04	0.48
Ammonia plus organic nitrogen, whole-water	8	8	2.3	2.0	1.3	3.8
Nitrite plus nitrate, as nitrogen, dissolved	12	12	2.0	1.2	0.28	6.4
Nitrite, as nitrogen, dissolved	9	8	0.14	0.07	<0.01	0.57
Nitrogen, whole-water (calculated)	8	NA	4.2	3.8	1.7	10.2
Phosphorus, dissolved	6	6	0.27	0.23	0.04	0.54
Orthophosphate, as phosphorus, dissolved	12	11	0.40	0.40	<0.01	0.88
Phosphorus, whole-water	11	11	0.62	0.70	0.10	1.1
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	8	NA	8.1	6.4	4.6	16.8
Arsenic, dissolved (µg/L)	8	8	5	5	2	8
Selenium, dissolved (µg/L)	8	8	20	18	2	45
Suspended sediment	8	8	72	56	23	178
Percent fines	8	8	98	99	92	100

Table 10. Statistical summaries of water-quality results for Lake Andes tributary stations—Continued

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. ft^3/s, cubic feet per second; μS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; μg/L, micrograms per liter; NA, not applicable; <, less than]

Property or constituent	06452389 (Lake Andes tributary no. 1)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Streamflow at time of sampling (ft^3/s)	6	NA	4.4	1.8	<0.1	19
Oxygen, dissolved	4	NA	10.1	10.3	9.1	10.6
Oxygen, dissolved (percent saturation)	4	NA	102	99	90	121
pH (standard units)	6	NA	7.8	7.9	7.5	8.0
Specific conductance (μS/cm)	7	NA	907	560	140	2,340
Water temperature (°C)	7	NA	13.2	12.6	7.0	26.5
Calcium, dissolved	6	6	100	53	16	280
Magnesium, dissolved	6	6	44	21	4	130
Potassium, dissolved	6	6	22	25	7	30
Sodium, dissolved	6	6	33	14	3	100
Alkalinity, dissolved	6	6	125	110	54	260
Chloride, dissolved	6	6	14	10	1	33
Fluoride, dissolved	4	2	<0.1	<0.1	<0.1	0.2
Silica, dissolved	6	6	17	19	8	22
Sulfate, dissolved	6	6	381	155	24	1,200
Solids, dissolved, residue on evaporation at 180°C	4	4	986	765	352	2,060
Solids, dissolved, sum of constituents (calculated)	6	NA	689	365	98	1,950
Ammonia, as nitrogen, dissolved	2	2	0.06	0.06	0.02	0.09
Ammonia plus organic nitrogen, whole-water	4	4	2.0	2.2	1.2	2.5
Nitrite plus nitrate, as nitrogen, dissolved	6	5	1.2	0.82	<0.1	4.3
Nitrite, as nitrogen, dissolved	4	3	0.03	0.02	<0.01	0.06
Nitrogen, whole-water (calculated)	4	NA	2.5	2.4	1.9	3.5
Phosphorus, dissolved	4	4	0.46	0.43	0.28	0.68
Orthophosphate, as phosphorus, dissolved	6	6	0.34	0.25	0.20	0.64
Phosphorus, whole-water	5	5	0.49	0.60	0.25	0.71
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	4	NA	6.0	5.8	4.8	7.4
Arsenic, dissolved (μg/L)	3	3	4	3	2	6
Selenium, dissolved (μg/L)	3	3	6	7	5	7
Suspended sediment	4	4	46	49	8	78
Percent fines	3	3	95	98	88	99

[1]"Number of detections" refers to number of samples that had concentrations larger than the study reporting level.

[2]When calculating mean values for constituents with censored data (that is, having some concentrations reported as less than the study reporting level), a value of one-half the study reporting level was assigned to the samples reported as less thans.

Table 11. Statistical summaries of water-quality results for Lake Andes stations

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; <, less than; --, no data]

Constituent	06452390 (North Unit)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Water depth at sampling location (feet)	49	NA	5.2	6.6	0.2	13.1
Secchi disk transparency (inches)	44	NA	18.7	13.6	1.2	81.6
Oxygen, dissolved	57	NA	10.7	10.3	0.1	23.0
Oxygen, dissolved (percent saturation)	56	NA	105	102	1	182
pH (standard units)	58	NA	8.4	8.4	6.6	9.5
Specific conductance (µS/cm)	59	NA	2,710	1,790	750	11,800
Water temperature (°C)	58	NA	12.7	10.6	0.0	26.0
Calcium, dissolved	57	57	208	150	64	810
Magnesium, dissolved	57	57	134	89	25	760
Potassium, dissolved	57	56	54	36	<0.1	240
Sodium, dissolved	57	57	194	114	33	1,100
Alkalinity, dissolved	57	57	185	183	83	354
Chloride, dissolved	57	57	97	51	15	640
Fluoride, dissolved	57	56	0.3	0.3	<0.1	1.0
Silica, dissolved	57	56	12	11	<0.1	38
Sulfate, dissolved	57	57	1,240	746	230	7,100
Solids, dissolved, residue on evaporation at 180°C	57	57	2,230	1,430	526	13,500
Solids, dissolved, sum of constituents (calculated)	56	NA	2,060	1,350	474	10,900
Ammonia, as nitrogen, dissolved	57	45	0.27	0.06	<0.02	3.1
Ammonia plus organic nitrogen, whole-water	29	29	3.9	3.6	1.6	10
Nitrite plus nitrate, as nitrogen, dissolved	57	8	0.13	<0.1	<0.1	0.96
Nitrite, as nitrogen, dissolved	57	20	0.01	<0.01	<0.01	0.17
Nitrogen, whole-water (calculated)	29	29	4.0	3.8	1.6	10.0
Phosphorus, dissolved	0	NA	--	--	--	--
Orthophosphate, as phosphorus, dissolved	57	52	0.31	0.17	<0.01	1.5
Phosphorus, whole-water	57	57	0.8	0.6	0.0	7.0
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	29	NA	8.9	8.3	2.8	14.9
Arsenic, dissolved (µg/L)	55	55	9	8	1	32
Selenium, dissolved (µg/L)	50	29	3	1	<1	14

Table 11. Statistical summaries of water-quality results for Lake Andes stations—Continued

Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; <, less than; --, no data]

Constituent	06452391 (Center Unit)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Water depth at sampling location (feet)	45	NA	6.6	7.5	0.7	13.1
Secchi disk transparency (inches)	43	NA	16.1	12.6	2.4	63.6
Oxygen, dissolved	57	NA	11.8	10.4	0.1	31.1
Oxygen, dissolved (percent saturation)	56	NA	114	104	0	269
pH (standard units)	58	NA	8.4	8.3	7.4	9.7
Specific conductance (µS/cm)	58	NA	2,770	2,120	1,360	12,500
Water temperature (°C)	57	NA	13.1	11.5	0.0	26.5
Calcium, dissolved	58	58	201	160	104	560
Magnesium, dissolved	58	58	139	97	56	840
Potassium, dissolved	58	58	76	54	3.0	330
Sodium, dissolved	58	58	201	144	70	1300
Alkalinity, dissolved	58	58	143	132	73	478
Chloride, dissolved	58	58	140	91	48	890
Fluoride, dissolved	58	58	0.4	0.4	0.2	1.1
Silica, dissolved	58	55	12	12	<0.1	32
Sulfate, dissolved	58	58	1,260	869	510	5,400
Solids, dissolved, residue on evaporation at 180°C	58	58	2,270	1,640	1,010	11,100
Solids, dissolved, sum of constituents (calculated)	58	NA	2,120	1,580	922	9,640
Ammonia, as nitrogen, dissolved	58	49	0.93	0.09	<0.02	22
Ammonia plus organic nitrogen, whole-water	29	29	3.8	3.8	2.0	6.3
Nitrite plus nitrate, as nitrogen, dissolved	58	10	0.10	<0.1	<0.1	1.4
Nitrite, as nitrogen, dissolved	58	17	0.02	<0.01	<0.01	0.36
Nitrogen, whole-water (calculated)	29	29	3.9	3.9	2.1	6.4
Phosphorus, dissolved	0	NA	--	--	--	--
Orthophosphate, as phosphorus, dissolved	58	38	0.12	0.03	<0.01	0.73
Phosphorus, whole-water	58	58	0.49	0.39	0.13	2.1
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	29	NA	14.3	13.1	4.9	26.9
Arsenic, dissolved (µg/L)	56	53	9	8	<1	20
Selenium, dissolved (µg/L)	52	16	1	<1	<1	3

Table 11. Statistical summaries of water-quality results for Lake Andes stations—Continued

Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; <, less than; --, no data]

Constituent	06452392 (Center Unit)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Water depth at sampling location (feet)	0	NA	--	--	--	--
Secchi disk transparency (inches)	0	NA	--	--	--	--
Oxygen, dissolved	17	NA	10.2	10.0	0.8	20.0
Oxygen, dissolved (percent saturation)	16	NA	86	96	6	134
pH (standard units)	54	NA	8.2	8.3	7.4	9.1
Specific conductance (µS/cm)	55	NA	1,760	1,630	900	3,300
Water temperature (°C)	58	NA	13.6	12.0	0.0	29.0
Calcium, dissolved	56	56	199	190	120	370
Magnesium, dissolved	56	56	68	63	23	130
Potassium, dissolved	56	56	55	52	21.0	130
Sodium, dissolved	55	55	81	76	23	180
Alkalinity, dissolved	56	56	177	177	76	335
Chloride, dissolved	56	56	58	52	15	130
Fluoride, dissolved	49	49	0.6	0.6	0.3	1.5
Silica, dissolved	56	56	18	19	0.2	32
Sulfate, dissolved	56	56	749	705	360	1,500
Solids, dissolved, residue on evaporation at 180°C	17	17	1,550	1,490	1,140	2,550
Solids, dissolved, sum of constituents (calculated)	56	NA	1,330	1,250	616	2,600
Ammonia, as nitrogen, dissolved	10	10	0.20	0.08	0.05	0.50
Ammonia plus organic nitrogen, whole-water	37	37	2.5	2.3	1.4	11
Nitrite plus nitrate, as nitrogen, dissolved	56	11	0.09	<0.1	<0.1	0.55
Nitrite, as nitrogen, dissolved	17	4	<0.01	<0.01	<0.01	0.04
Nitrogen, whole-water (calculated)	37	37	2.6	2.4	1.4	11.1
Phosphorus, dissolved	0	NA	--	--	--	--
Orthophosphate, as phosphorus, dissolved	54	52	0.40	0.25	<0.01	2.50
Phosphorus, whole-water	50	50	0.60	0.53	0.08	2.6
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	37	NA	5.1	4.0	1.6	18.1
Arsenic, dissolved (µg/L)	5	5	4	4	3	5
Selenium, dissolved (µg/L)	5	0	<1	<1	<1	<1

Table 11. Statistical summaries of water-quality results for Lake Andes stations—Continued

Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; <, less than; --, no data]

Constituent	06452403 (Owens Bay)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Water depth at sampling location (feet)	45	NA	2.0	1.6	0.3	6.6
Secchi disk transparency (inches)	41	NA	16.8	14.4	3.6	51.6
Oxygen, dissolved	58	NA	10.6	10.8	0.9	23.4
Oxygen, dissolved (percent saturation)	56	NA	105	107	9	181
pH (standard units)	57	NA	8.1	8.0	6.3	9.8
Specific conductance (µS/cm)	60	NA	2,870	2,520	337	8,370
Water temperature (°C)	57	NA	14.3	12.3	0.0	32.5
Calcium, dissolved	58	58	351	307	28	1160
Magnesium, dissolved	58	58	102	82	9	381
Potassium, dissolved	58	57	36	35	<0.1	76
Sodium, dissolved	58	58	174	140	18	635
Alkalinity, dissolved	57	57	121	116	30	273
Chloride, dissolved	58	58	220	172	22	802
Fluoride, dissolved	58	58	2.2	2.0	0.4	4.8
Silica, dissolved	58	57	12	11	<0.1	43
Sulfate, dissolved	58	58	1,290	1,050	85	4,650
Solids, dissolved, residue on evaporation at 180°C	58	58	2,400	1,940	212	8,480
Solids, dissolved, sum of constituents (calculated)	56	NA	2,240	1,880	186	7,670
Ammonia, as nitrogen, dissolved	58	50	0.46	0.08	<0.02	7.4
Ammonia plus organic nitrogen, whole-water	29	29	3.3	2.3	0.72	13
Nitrite plus nitrate, as nitrogen, dissolved	58	5	0.07	<0.1	<0.1	0.47
Nitrite, as nitrogen, dissolved	58	14	<0.01	<0.01	<0.01	0.06
Nitrogen, whole-water (calculated)	29	29	3.3	2.4	0.82	13.1
Phosphorus, dissolved	0	NA	--	--	--	--
Orthophosphate, as phosphorus, dissolved	58	26	0.03	<0.01	<0.01	0.29
Phosphorus, whole-water	58	58	0.23	0.14	0.03	1.8
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	29	NA	13.8	14.1	5.4	27.6
Arsenic, dissolved (µg/L)	56	45	4	2	<1	17
Selenium, dissolved (µg/L)	55	6	<1	<1	<1	5

Table 11. Statistical summaries of water-quality results for Lake Andes stations—Continued

Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; <, less than; --, no data]

Constituent	06452406 (South Unit)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Water depth at sampling location (feet)	46	NA	6.9	6.6	1.6	13.1
Secchi disk transparency (inches)	46	NA	14.7	12.3	2.4	32.4
Oxygen, dissolved	58	NA	11.2	10.8	0.9	25.2
Oxygen, dissolved (percent saturation)	56	NA	109	108	7	214
pH (standard units)	58	NA	8.3	8.3	7.2	9.0
Specific conductance (µS/cm)	58	NA	2,960	2,560	1,420	15,200
Water temperature (°C)	58	NA	13.3	11.6	0.3	26.3
Calcium, dissolved	57	57	251	230	105	520
Magnesium, dissolved	57	57	129	120	66	240
Potassium, dissolved	57	56	70	60	<0.1	140
Sodium, dissolved	57	57	171	153	83	340
Alkalinity, dissolved	57	57	109	111	54	182
Chloride, dissolved	57	57	137	130	55	310
Fluoride, dissolved	57	57	0.7	0.6	0.4	1.3
Silica, dissolved	57	56	12	11	<0.1	28
Sulfate, dissolved	57	57	1,300	1,130	572	2,700
Solids, dissolved, residue on evaporation at 180°C	57	57	2,280	1,990	815	4,830
Solids, dissolved, sum of constituents (calculated)	56	NA	2,140	1,940	982	4,300
Ammonia, as nitrogen, dissolved	57	50	0.42	0.09	<0.02	2.3
Ammonia plus organic nitrogen, whole-water	29	29	4.0	3.9	2.5	5.8
Nitrite plus nitrate, as nitrogen, dissolved	57	12	0.07	<0.1	<0.1	0.19
Nitrite, as nitrogen, dissolved	57	19	<0.01	<0.01	<0.01	0.07
Nitrogen, whole-water (calculated)	29	29	4.0	4.0	2.6	5.9
Phosphorus, dissolved	0	NA	--	--	--	--
Orthophosphate, as phosphorus, dissolved	57	27	0.02	<0.01	<0.01	0.08
Phosphorus, whole-water	57	57	0.26	0.23	0.07	0.89
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	29	NA	21.4	21.9	11.7	42.2
Arsenic, dissolved (µg/L)	55	55	7	6	1	19
Selenium, dissolved (µg/L)	51	12	<1	<1	<1	2

Table 11. Statistical summaries of water-quality results for Lake Andes stations—Continued

Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; <, less than; --, no data]

Constituent	06452410 (South Unit)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Water depth at sampling location (feet)	0	NA	--	--	--	--
Secchi disk transparency (inches)	0	NA	--	--	--	--
Oxygen, dissolved	21	NA	8.3	8.2	2.6	16.0
Oxygen, dissolved (percent saturation)	20	NA	86	86	34	152
pH (standard units)	22	NA	8.1	8.1	7.1	8.8
Specific conductance (µS/cm)	22	NA	1,770	1,640	1,120	2,700
Water temperature (°C)	22	NA	15.3	15.5	1.0	26.5
Calcium, dissolved	21	21	211	200	130	390
Magnesium, dissolved	21	21	69	57	49	120
Potassium, dissolved	21	21	34	33	2.7	55
Sodium, dissolved	21	21	73	69	56	120
Alkalinity, dissolved	19	19	176	182	33	277
Chloride, dissolved	21	21	48	48	27	85
Fluoride, dissolved	3	3	0.4	0.5	0.2	0.6
Silica, dissolved	20	20	13	13	1.9	33
Sulfate, dissolved	21	21	783	670	510	1,500
Solids, dissolved, residue on evaporation at 180°C	21	21	1,440	1,300	938	2,570
Solids, dissolved, sum of constituents (calculated)	21	NA	1,340	1,210	883	2,320
Ammonia, as nitrogen, dissolved	3	3	0.13	0.15	0.08	0.15
Ammonia plus organic nitrogen, whole-water	0	NA	--	--	--	--
Nitrite plus nitrate, as nitrogen, dissolved	21	10	0.57	<0.1	<0.1	3.6
Nitrite, as nitrogen, dissolved	21	9	0.02	<0.01	<0.01	0.15
Nitrogen, whole-water (calculated)	0	NA	--	--	--	--
Phosphorus, dissolved	0	NA	--	--	--	--
Orthophosphate, as phosphorus, dissolved	21	21	0.17	0.15	0.02	0.61
Phosphorus, whole-water	7	7	0.43	0.36	0.04	0.92
Whole-water nitrogen/whole-water phosphorus ratio (percent; calculated)	0	NA	--	--	--	--
Arsenic, dissolved (µg/L)	18	18	5	4	2	12
Selenium, dissolved (µg/L)	18	15	9	2	<1	60

[1]"Number of detections" refers to number of samples that had concentrations larger than the study reporting level.

[2]When calculating mean values for constituents with censored data (that is, having some concentrations reported as less than the study reporting level), a value of one-half the study reporting level was assigned to the samples reported as less thans.

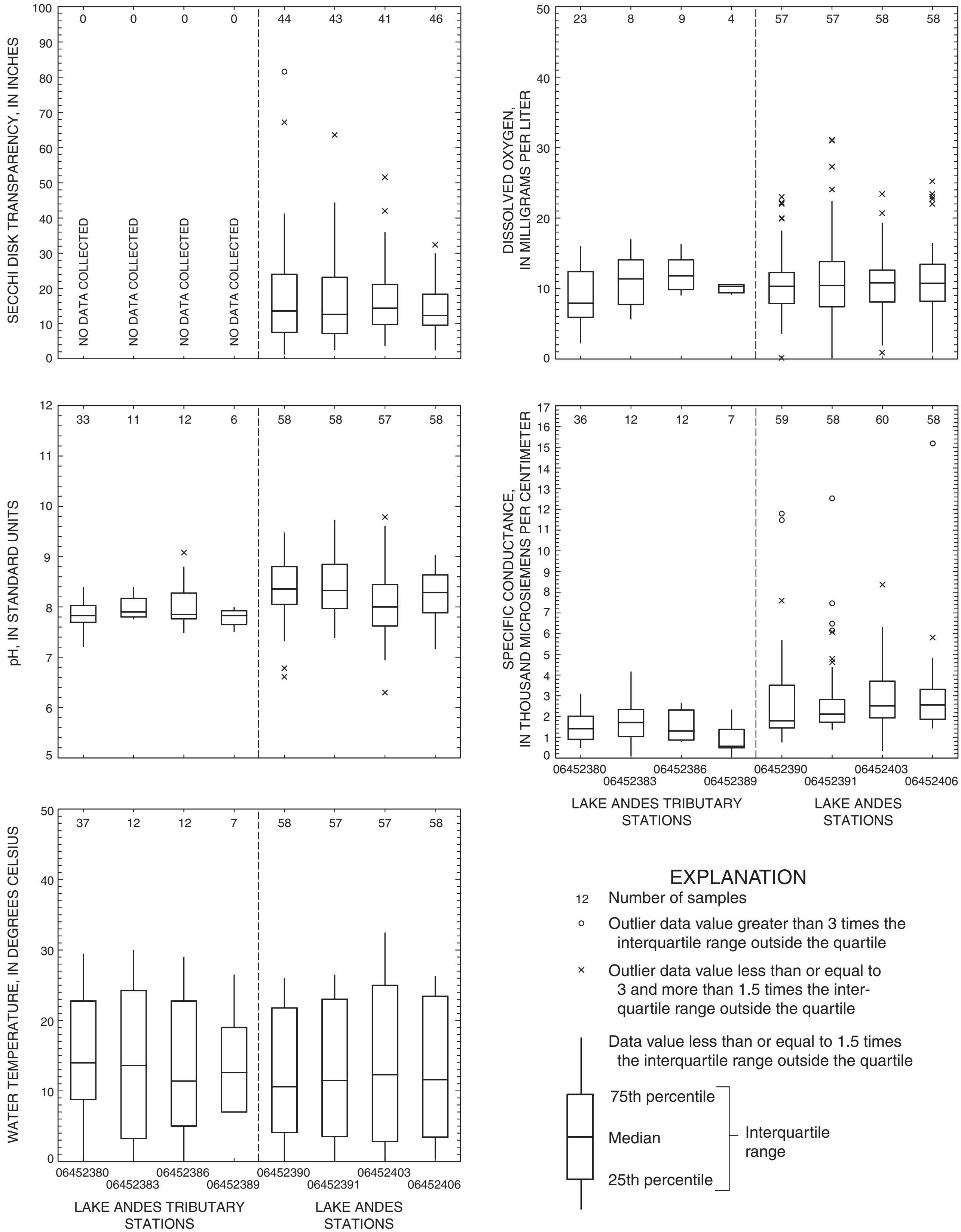


Figure 10. Boxplots of selected field-measured properties and constituents for selected stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

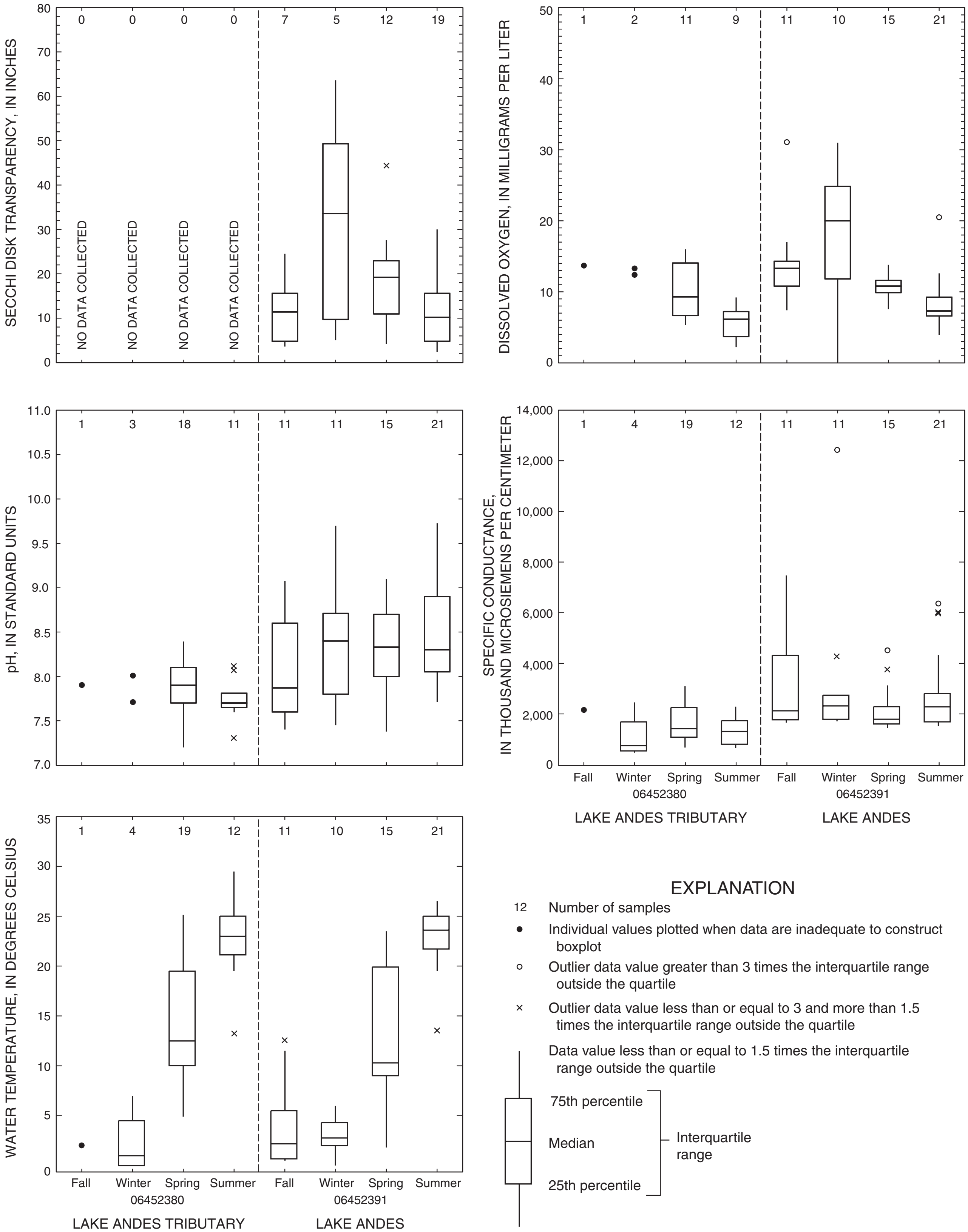


Figure 11. Boxplots showing seasonal distributions of selected field-measured properties and constituents for selected representative tributary and lake stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

Water temperatures at the various stations are similar, and are typical of shallow northern temperate water bodies (Sando and Lent, 1995) (tables 10 and 11, figs. 10 and 11). Water temperatures for lake stations only rarely exceed the warmwater permanent fish-life propagation criterion (table 9).

Major Ions

Statistical distributions of major ions for Lake Andes tributary and lake stations are shown in figure 12. Stiff diagrams (Stiff, 1951) showing average proportions of major ions for tributaries and lake stations are shown in figure 13. Seasonal distributions of major-ion constituents for a single representative tributary station (06452380) and a single representative lake station (06452391) are presented in figure 14.

Concentrations of major ions in water samples from tributary stations generally are similar (figs. 12 and 13); however, concentrations generally are lower for station 06452389 than the other three tributaries. Station 06452389 has the smallest drainage area, and flows less frequently than the other tributaries, generally only during very wet periods of either intense or extended-duration rainfall. Thus, water at this station typically has had only limited contact with geologic materials. For all of the tributary stations, calcium, magnesium, and sodium are approximately codominant among the cations, and sulfate is the dominant anion. Median dissolved-solids concentrations range from 765 to 1,560 mg/L. Dissolved-solids concentrations for tributaries only infrequently exceed the fish and wildlife propagation, recreation, and livestock watering 30-day mean criterion (table 9).

Major-ion concentrations for lake stations tend to be higher than tributary stations, probably due to evaporative concentration and/or diffusive flux of solutes from lake-bottom sediments. Concentrations of all major ions, with the exception of alkalinity (an index of bicarbonate concentration) and silica, increase upstream to downstream from the North Unit (station 06452390) to the Center Unit (station 06452391) to the South Unit (station 06452406). This pattern also probably results from evaporative concentration and/or diffusive flux of solutes from lake-bottom sediments. The decrease in alkalinity from upstream to downstream in Lake Andes probably results from precipitation of calcite as the lake water becomes more concentrated and as pH increases when photosynthetic activity is intense. Silica concentrations at the lake stations tend to be similar, and generally are less than tributary stations, probably caused by uptake and cycling of silica by diatom populations. Silica concentrations in Lake Andes show a distinct seasonal pattern (fig. 14), with concentrations being lower during the spring when diatom activity typically peaks (Wetzel, 1983).

For Owens Bay (station 06452403), concentrations of some major ions, including calcium, potassium, chloride, and fluoride, differ from patterns of the other lake stations. Owens Bay primarily is fed by a flowing well regulated by a control valve and completed in the Dakota aquifer, and major-ion chemistry in Owens Bay is very similar to typical water in the Dakota aquifer in Charles Mix and Douglas Counties (based on average concentrations for between 23-27 samples collected from the Dakota aquifer in Charles Mix and Douglas Counties; Kume, 1977) (fig. 13).

Proportions of major ions are similar for the lake stations (with the exception of Owens Bay), with calcium, magnesium, and sodium being approximately codominant among cations, and sulfate being the dominant anion (fig. 13). Owens Bay is characterized by a calcium sulfate water type. Dissolved-solids concentrations for lake stations typically range from about 1,400 to 2,000 mg/L, and fairly commonly exceed the fish and wildlife propagation, recreation, and livestock watering 30-day mean criterion, and rarely exceed the daily maximum criterion (table 9, fig. 12).

Dissolved-solids concentrations and volume-adjusted trends for Lake Andes stations are presented in figure 15. Results of trend analyses should be used with extreme caution. As previously noted, the total length of the data records generally did not meet recommended minimum data requirements for trend analysis (Vecchia, 2000). Thus, trend results cannot be used to confidently determine the presence or absence of significant trends. However, the trend analyses might indicate important patterns in the data, and could provide useful information for future studies of trends in the Lake Andes and Choteau Creek Basins.

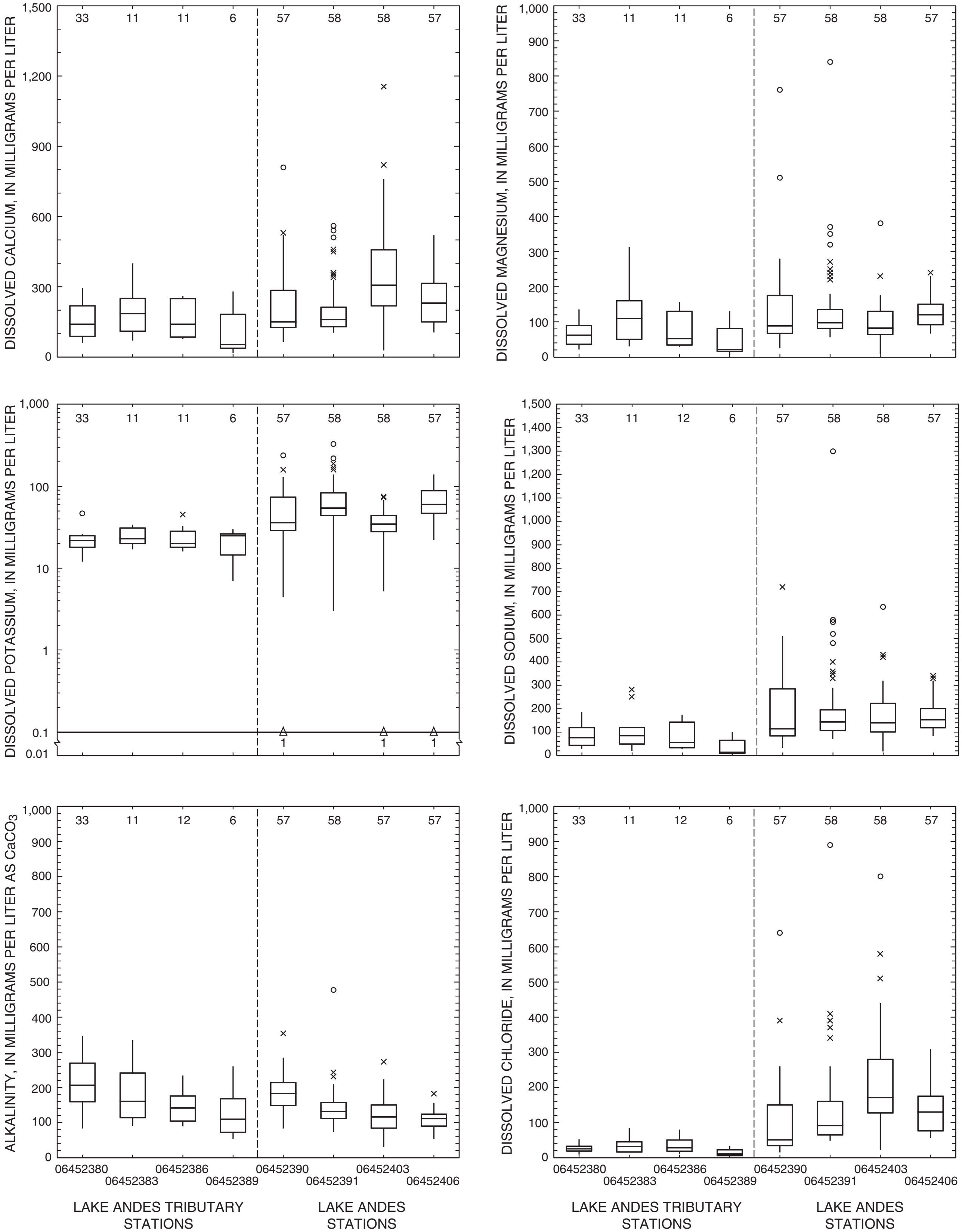


Figure 12. Boxplots of major-ion constituents for selected stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

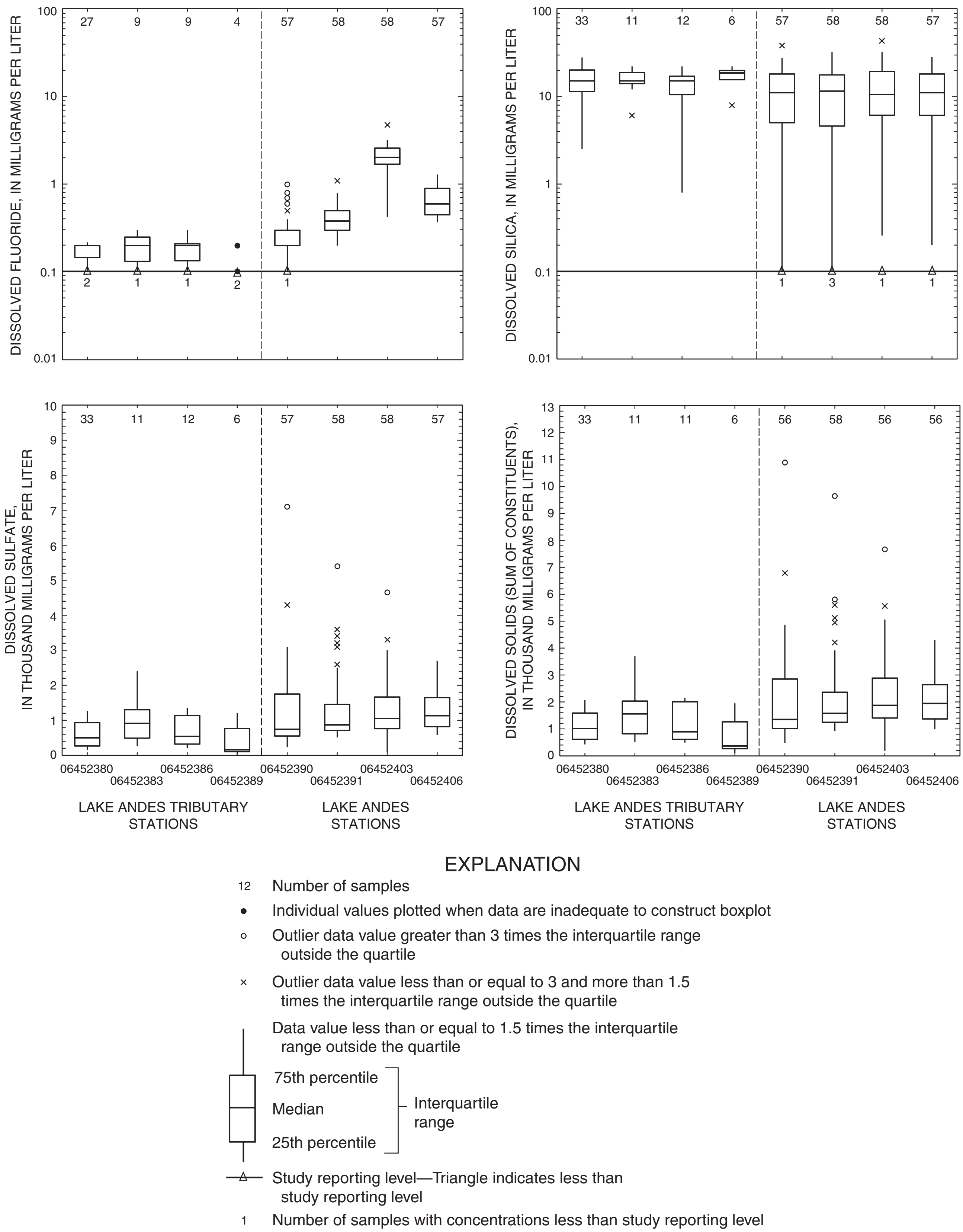


Figure 12. Boxplots of major-ion constituents for selected stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).—Continued

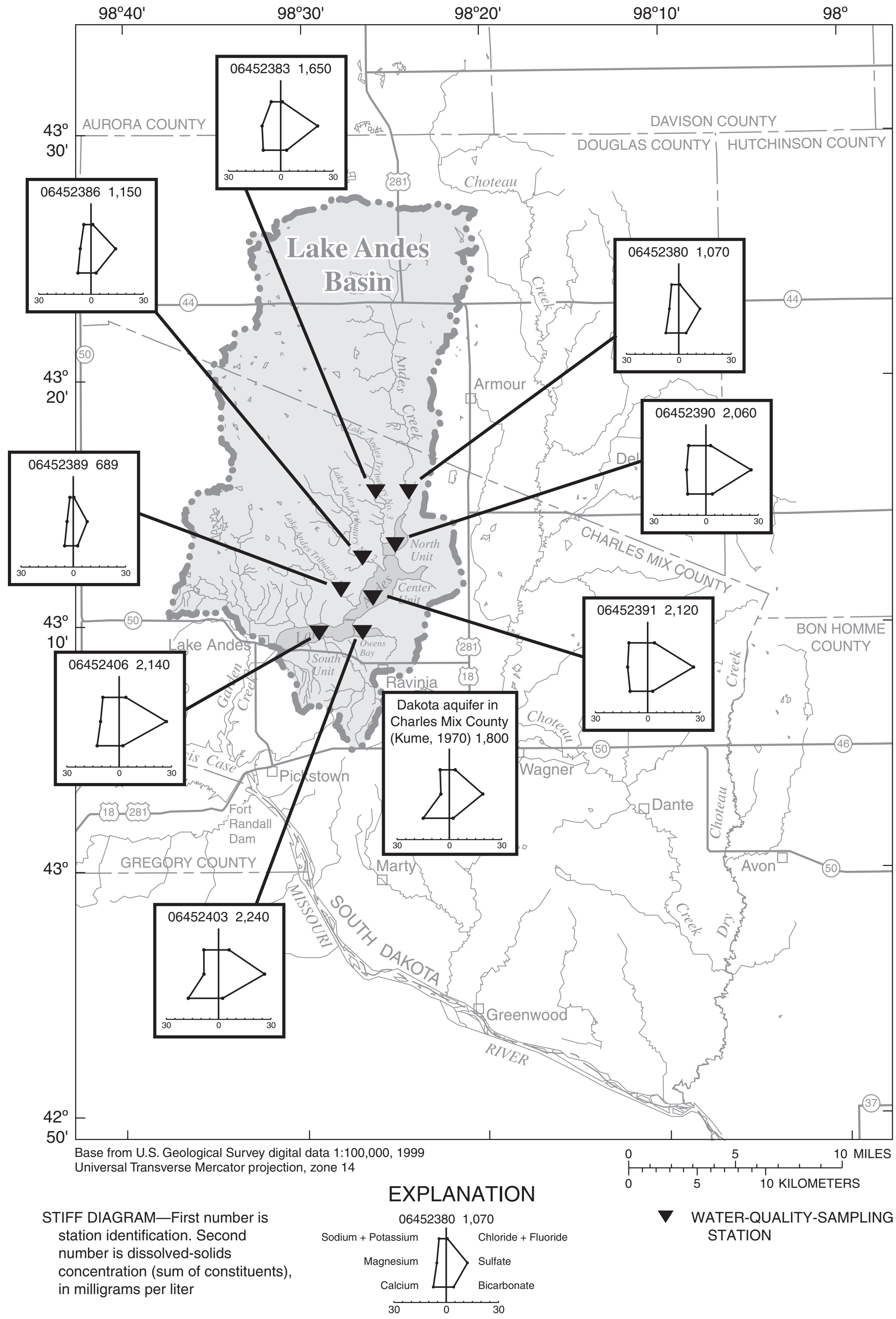


Figure 13. Stiff diagrams showing average proportions of major ions for selected sites in the Lake Andes Basin for periods of record listed in table 5.

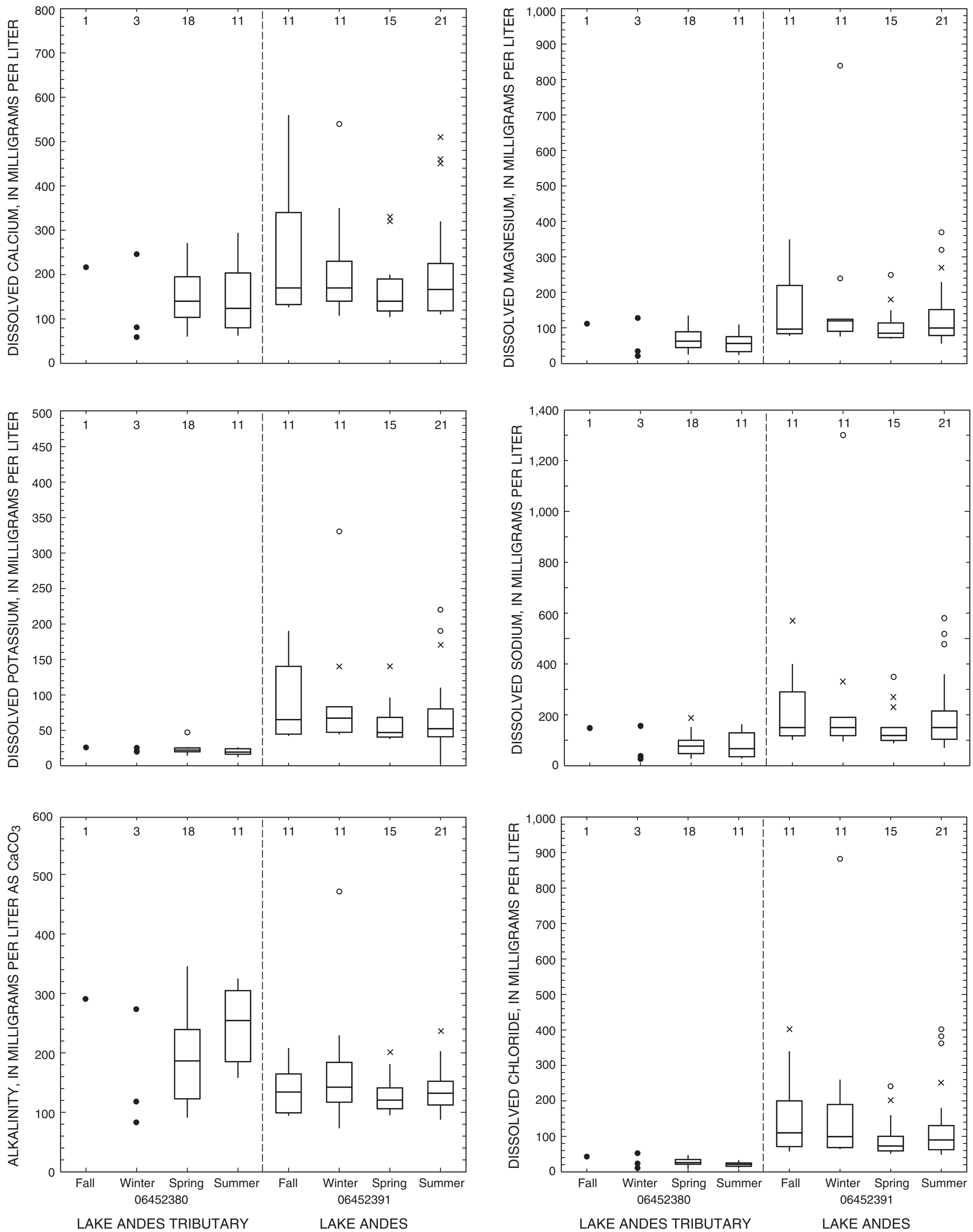


Figure 14. Boxplots showing seasonal distribution of major-ion constituents for selected representative tributary and lake stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

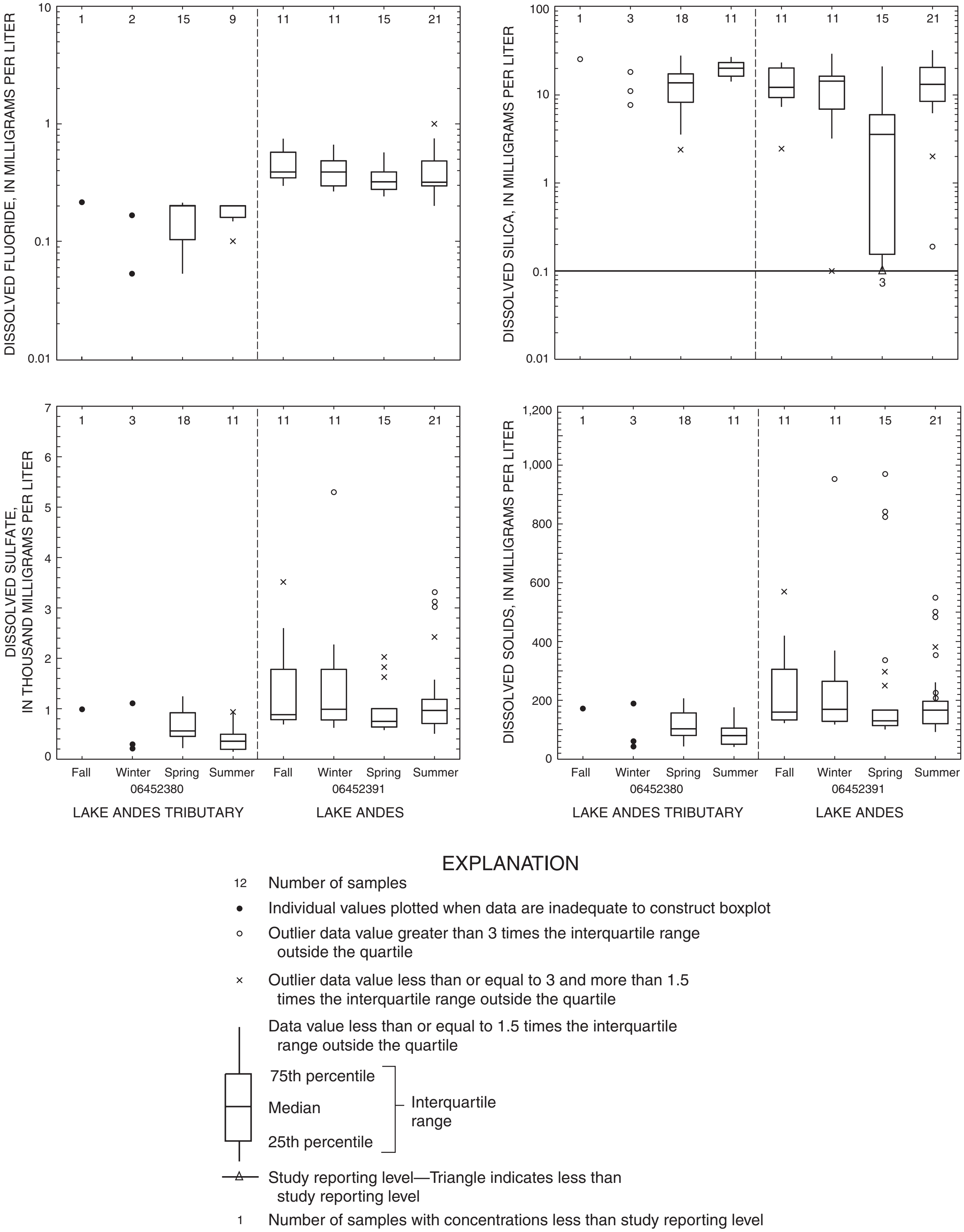


Figure 14. Boxplots showing seasonal distribution of major-ion constituents for selected representative tributary and lake stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).—Continued

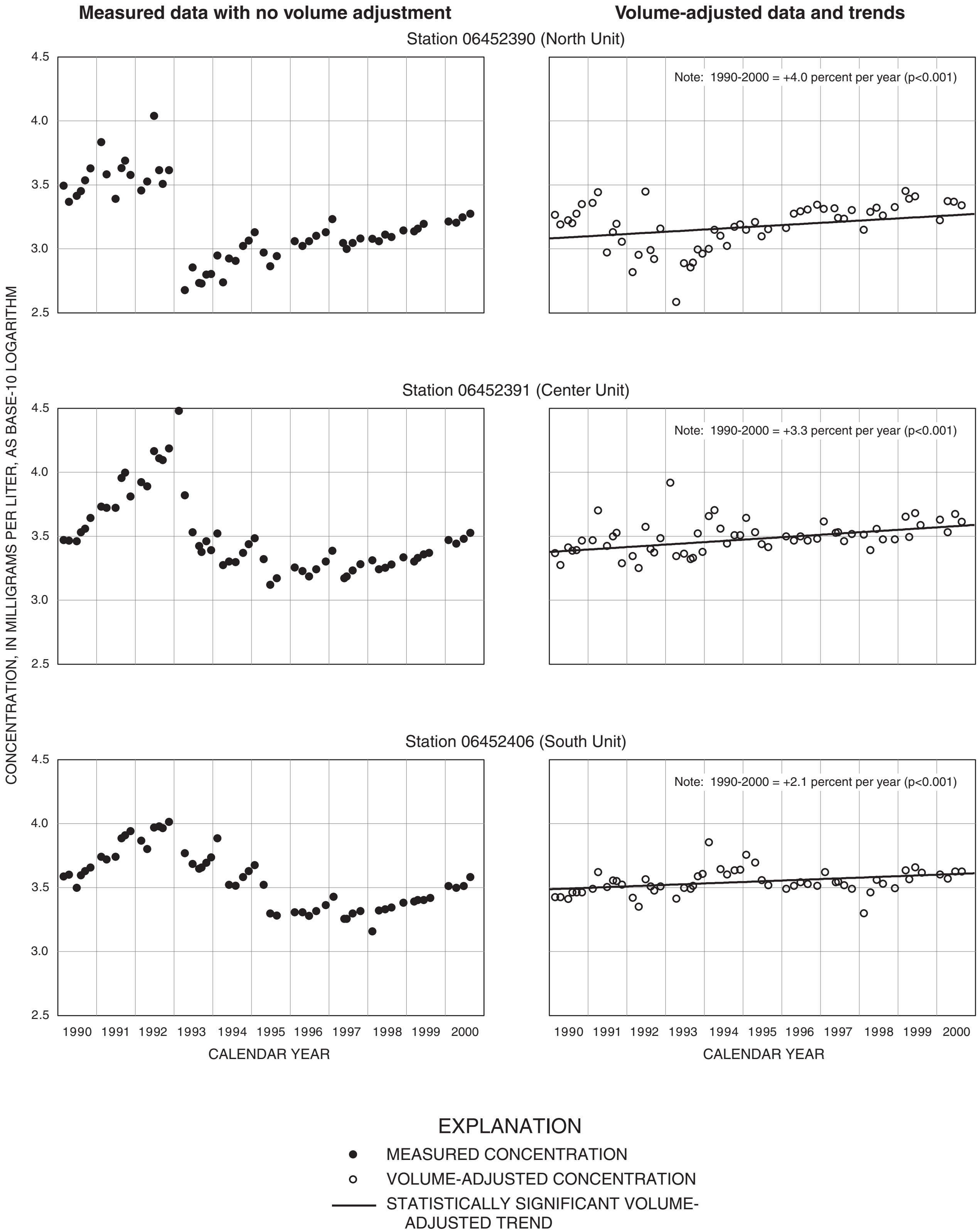


Figure 15. Concentrations of dissolved solids (sum of constituents) and volume-adjusted trends for selected Lake Andes stations (location of stations shown in figure 1).

Trends in dissolved-solids concentrations for the individual units of Lake Andes were modeled by fitting a monotonic linear trend to the period 1990-2000. This approach was used for all of the lake stations in order to maintain consistency in the trend analyses between the lake stations. Examination of the pattern of volume-adjusted concentrations for station 06452390 (Lake Andes North Unit) indicates that data for the period 1990-92 differ somewhat from the data for the period 1993-2000. This pattern might be due to ineffectiveness of the trend model to adequately adjust for volume-related variability in the data, or there might actually be a decreasing trend in volume-adjusted dissolved-solids concentrations for the period 1990-92.

All of the Lake Andes units showed statistically significant ($p<0.001$) increasing volume-adjusted trends in dissolved-solids concentrations from 1990-2000. The North Unit has a trend of +4.0 percent per year; the Center Unit has a trend of +3.3 percent per year; and the South Unit has a trend of +2.1 percent per year. The decrease in strength of the trends moving downstream through Lake Andes may be due to several factors. Most tributary inflow to Lake Andes enters the North Unit, which also has the smallest volume of the three units. Thus, the North Unit probably is most responsive to water-quality changes in the tributary basins. Also, the North Unit probably has a greater proportion of its volume in contact with bottom sediment, which can result in greater response to sediment-water column interactions. Both the Center and South Units receive most of their inflow from the adjacent upstream units, and they have relatively large volumes. Thus water-quality trends are somewhat damped in these units.

Volume-adjusted dissolved-solids concentrations in Lake Andes probably were increasing during the period 1990-2000. Possible explanations for the observed trends are unknown, but might be related to effects of long-term changes in land use and agricultural operations. Given the violation of minimum-data recommendations for the trend analysis, the trend results should not be interpreted as confident determinations of the presence or absence of significant trends.

Nitrogen and Phosphorus Nutrients

Statistical distributions of selected nitrogen and phosphorus nutrient constituents for Lake Andes tributary and lake stations are shown in figure 16. Seasonal distributions of selected nutrient constituents for a single representative tributary station (06452380) and a single representative lake station (06452391) are presented in figure 17.

Whole-water nitrogen (the sum of whole-water ammonia plus organic nitrogen and dissolved nitrite plus nitrate nitrogen) concentrations generally are similar between the different tributary stations, although concentrations for station 06452380 are slightly lower than the other stations. Median whole-water nitrogen concentrations range from about 1.6 mg/L to about 3.8 mg/L (table 10, fig. 16). The whole-water nitrogen concentrations in the tributary stations are relatively large, but similar to other streams draining agricultural lands in the upper Midwest (Tornes and others, 1997). Much of the nitrogen in the tributaries is in organic form, especially for station 06452380. Organic nitrogen accounts for an average of about 90 percent of whole-water nitrogen for station 06452380, compared to an average of about 50 to 60 percent of whole-water nitrogen for stations 06452383 and 06452386. Differences in the forms of nitrogen between the tributaries may reflect differences in nutrient sources and land use upstream from the sampling stations.

Because of the sparsity of data in the individual seasonal periods, it is difficult to discern clear seasonal patterns in nitrogen and phosphorus nutrients for station 06452380 (Andes Creek), which represents the Lake Andes tributaries. It appears that for some nutrient constituents, including dissolved ammonia, dissolved nitrite, dissolved nitrite plus nitrate, dissolved phosphorus, and whole-water phosphorus, the summer concentrations tended to be larger than the spring concentrations. For whole-water ammonia plus organic nitrogen and whole-water nitrogen, the spring and summer concentrations tended to be similar.

Daily loads of nitrogen and phosphorus transported at the tributary stations for the days that samples were collected were calculated using equation 2. Simple linear regressions were then performed on log transformations of streamflow and load to develop equations to estimate load based on streamflow (table 12). Due to the small number of samples for stations 06452383, 06452386, and 06452389, load and streamflow data for those stations were combined in the regression analyses. Thus, for these three stations, a single regression equation that fit the combined data was developed for nitrogen load based on streamflow, and a single regression equation that fit the combined data was developed for phosphorus load based on streamflow.

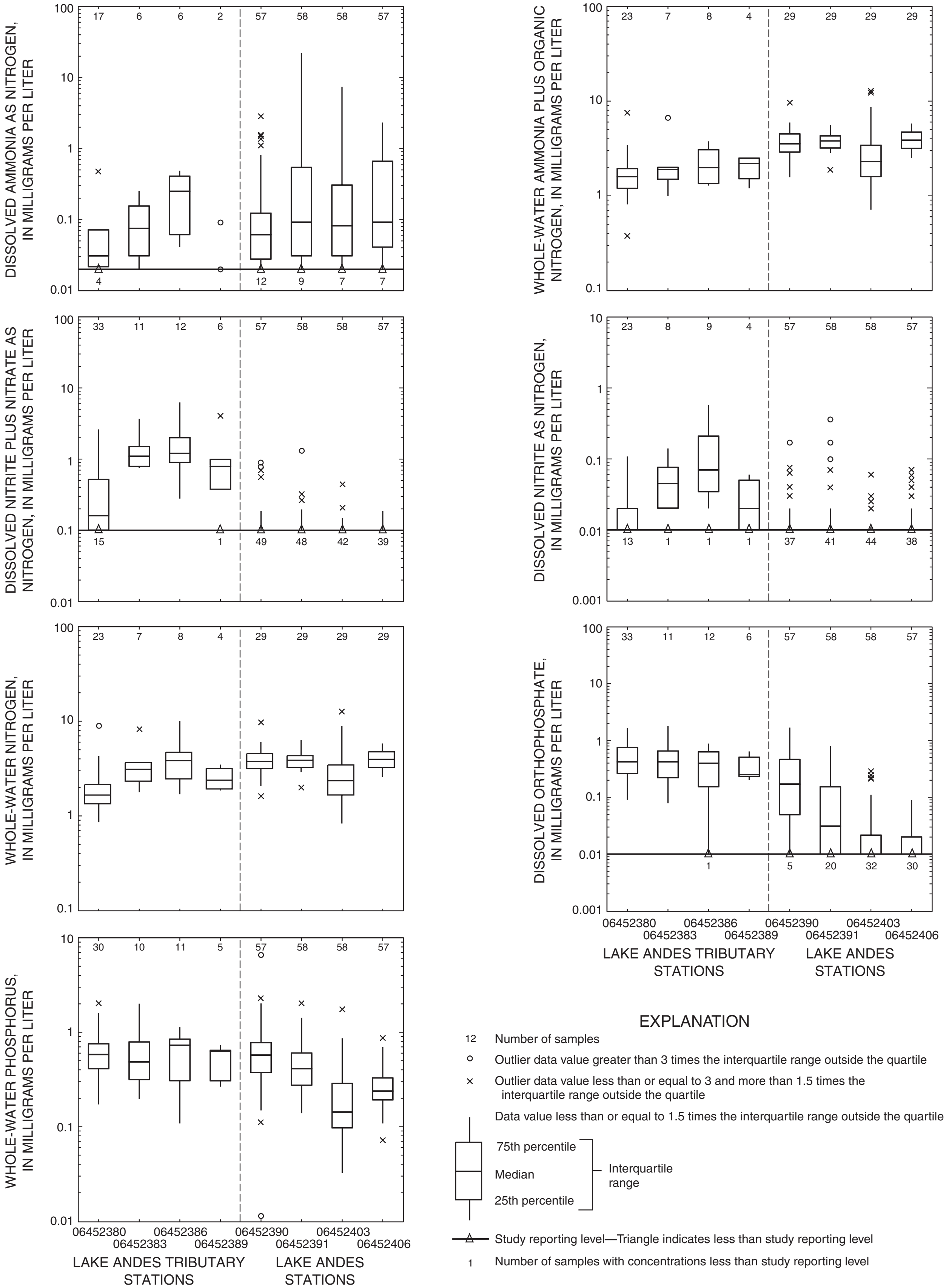


Figure 16. Boxplots of selected nitrogen and phosphorus constituents for selected stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

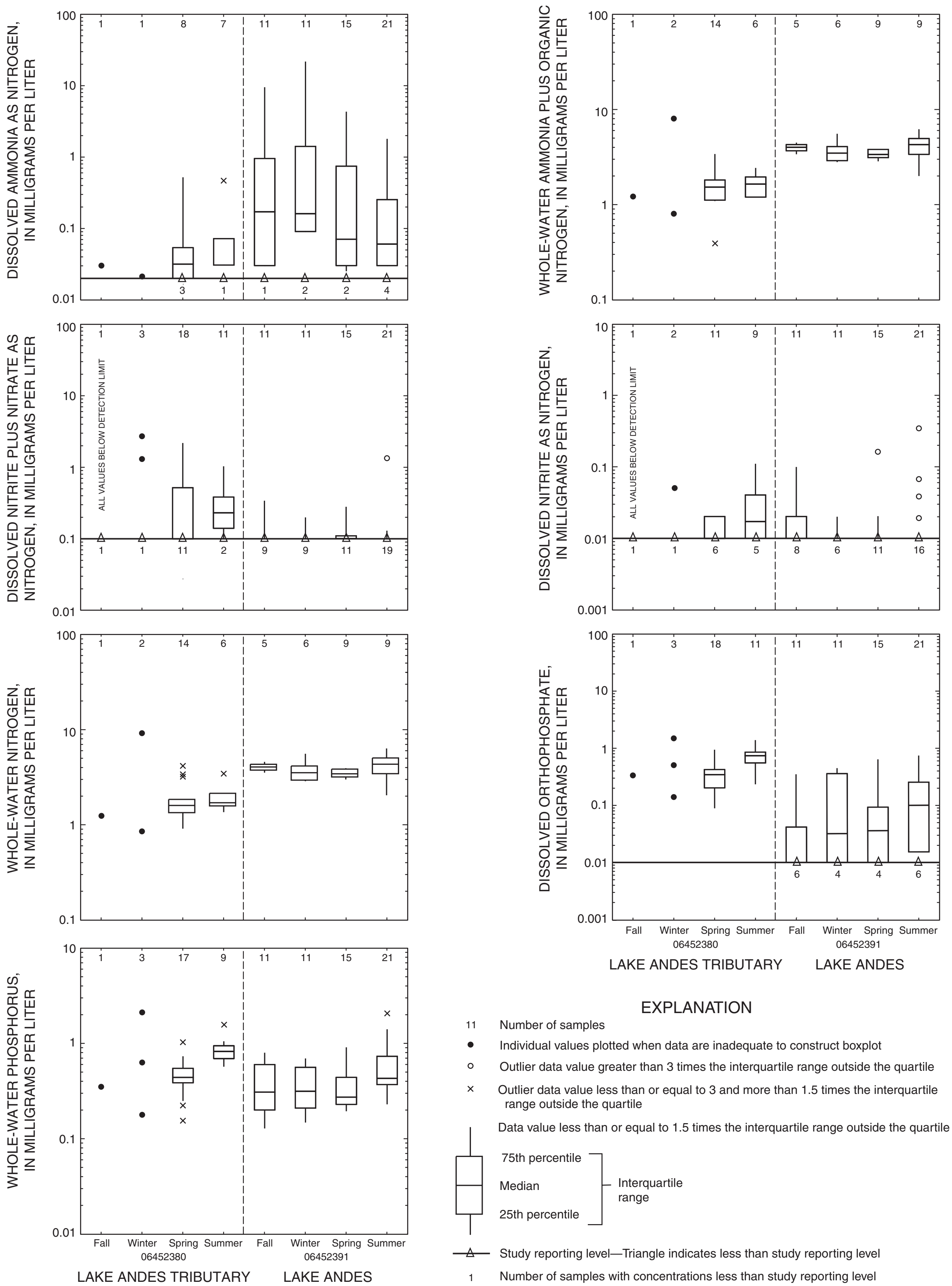


Figure 17. Boxplots showing seasonal distributions of selected nitrogen and phosphorus nutrient constituents for selected representative tributary and lake stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

Table 12. Results of regression analyses for estimating daily nutrient loads based on streamflow for Lake Andes tributary stations, 1983-2000

[Location of stations shown in figure 1. L_N, nitrogen load, in pounds per day; L_P, phosphorus load, in pounds per day; Q, streamflow, in cubic feet per second, and $\tilde{C}$, retransformation bias-correction factor]

Station identification	Nitrogen				Phosphorus			
	Number of samples	R^2	Equation	Retransformation bias-correction factor ($\tilde{C}$)	Number of samples	R^2	Equation	Retransformation bias-correction factor ($\tilde{C}$)
06452380	23	0.88	$L_N = 10.75 \times Q^{0.953} \times \tilde{C}$	1.197	30	0.86	$L_P = 3.03 \times Q^{0.985} \times \tilde{C}$	1.179
06452383, 06452386, and 06452389 combined	18	0.92	$L_N = 16.91 \times Q^{1.041} \times \tilde{C}$	1.138	25	0.83	$L_P = 2.51 \times Q^{1.055} \times \tilde{C}$	1.239

Table 13. Statistical summaries of estimated daily loads of nitrogen and phosphorus for Lake Andes tributary stations, 1983-2000

[Location of stations shown in figure 1]

	Nitrogen load, in pounds per day				Phosphorus load, in pounds per day			
	06452380	06452383	06452386	06452389	06452380	06452383	06452386	06452389
Mean	37.3	4.70	13.4	2.80	11.4	0.77	2.22	0.46
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25th percentile	0.28	0.00	0.00	0.00	0.07	0.00	0.00	0.00
50th percentile	0.77	0.36	0.26	0.00	0.20	0.06	0.04	0.00
75th percentile	11.3	1.01	1.63	0.45	3.12	0.16	0.25	0.07
Maximum	834	829	1,000	489	266	141	171	82.4

The results of the regression analyses indicate that the regression coefficients (that is, the slopes of the regression lines) are very close to 1, indicating that the load/streamflow relations for the various stations are almost entirely a function of streamflow. Thus, differences in loads between the stations primarily reflect differences in streamflow. This pattern is especially true for the Lake Andes tributaries.

Daily loads of nitrogen and phosphorus for 1983-2000 were estimated using the regression equations in conjunction with streamflow estimates summarized in table 1. Statistical summaries of loads of nutrients transported at the tributary stations are presented in table 13. Errors associated with the nutrient load estimates are difficult to accurately quantify and may be substantial; however, the statistical summaries of the estimates probably provide reasonably accurate representations of the relative contribution of nutrients by the tributaries to Lake Andes. Andes Creek (station 06452380) probably contributes the largest load of nitrogen to Lake Andes, with tributary 2 (06452386), tributary 3 (06452383), and tributary 1 (06452389) contributing lesser loads, respectively.

Whole-water nitrogen concentrations in Lake Andes are similar between the different stations (fig. 16), although Owens Bay, which primarily is fed by an artesian well completed in the Dakota aquifer and is typically isolated from Lake Andes, generally has lower concentrations. Median whole-water nitrogen concentrations for the Lake Andes stations range from about 2.4 to 4.0 mg/L (table 11) and are similar to concentrations reported for hypereutrophic northern temperate lakes (Barica, 1974; Sando and Lent, 1995). Organic nitrogen accounts for an average of about 90 percent of whole-water nitrogen for all of the lake stations. Occurrence of nitrogen constituents in Lake Andes probably is governed by cycling of nitrogen between the lake sediments and algal populations in the water column. The largest concentrations of ammonia, a reduced inorganic form of nitrogen, occur during the fall and winter (fig. 17). During these periods, microbial breakdown of organic material in the sediments releases ammonia to the water column, but algal populations are small and do not take up the available nutrients. Whole-water nitrogen concentrations (consisting mostly of organic nitrogen) are largest during the summer (fig. 17) when algal populations generally are largest. Inorganic forms of nitrogen, such as ammonia and nitrate, are at very small concentrations during the summer (fig. 17) because most of the available inorganic nitrogen is taken up for algal growth. Very small concentrations of inorganic forms of nitrogen (that is, ammonia, nitrite, and nitrate) occur during algal growth periods in the spring and summer, which might indicate that nitrogen plays a substantial role in limiting algal growth in Lake Andes.

The masses of nitrogen and phosphorus in Lake Andes (fig. 18) for the days that samples were collected were calculated using equation 3. Generally, the mass of nitrogen in Lake Andes fluctuates between about 150 to 230 tons (fig. 18). The mass of nitrogen in Lake Andes does not show a strong relation with lake volume; in other words, increases and decreases in mass of nitrogen do not correspond consistently with increases and decreases in lake volume. The relatively weak relation between nitrogen mass and lake volume (Pearson correlation coefficient = 0.12) might indicate that internal lake processes, such as the cycling of nitrogen between the lake sediments and algal populations, play a substantial role in governing the occurrence of nitrogen in the water column. On a seasonal basis, nitrogen mass in Lake Andes typically is highest during the late summer. Late summer maxima for nitrogen mass probably result from actively growing algal populations incorporating available nitrogen and maintaining the nitrogen within the water column. Also, large populations of nitrogen-fixing blue-green algae may occur during the summer and increase the nitrogen mass.

Whole-water phosphorus concentrations are similar between the different tributary stations, with median concentrations ranging from about 0.5 mg/L to about 0.7 mg/L (table 10, fig. 16). The whole-water phosphorus concentrations in the tributary stations are large, but similar to other streams draining agricultural lands in the upper Midwest (Tornes and others, 1997). Much of the phosphorus in the tributaries is in dissolved inorganic form, that is, dissolved orthophosphate. Dissolved orthophosphate accounts for an average of about 70 to 80 percent of whole-water phosphorus for the tributary stations. Calculated daily loads of phosphorus for the tributary stations (table 13) indicate that Andes Creek (station 06452380) probably contributes the largest load of phosphorus to Lake Andes, with tributary 3 (station 06452383), tributary 2 (station 06452386) and tributary 1 (station 06452389) contributing lesser loads, respectively. Whole-water nitrogen to whole-water phosphorus ratios for tributary stations are relatively small (table 10), with medians that range from 3.7 to 7.5. Low whole-water nitrogen to whole-water phosphorus ratios (that is, ratios that are less than 10; Smith, 1982) favor nitrogen limitation with respect to algal growth.

Whole-water phosphorus concentrations for lake stations are large, with median concentrations that range from about 0.2 to 0.5 mg/L. Whole-water phosphorus concentrations generally decrease downstream through Lake Andes (fig. 16). Most of the phosphorus for the lake stations is in organic form; organic phosphorus accounts for an average of about 60 to 90 percent of whole-water phosphorus for lake stations. Thus, phosphorus enters Lake Andes largely in inorganic form, that is, as dissolved orthophosphate, but as it moves through the lake system, the inorganic phosphorus is either converted to organic form, or adsorbs to particulate matter and sediments from the water column. This pattern also is evident in changes in whole-water nitrogen to whole-water phosphorus ratios in Lake Andes. Whole-water nitrogen to whole-water phosphorus ratios increase moving downstream through Lake Andes. In the most upstream part of the lake (North Unit; station 06452390), whole-water nitrogen to whole-water phosphorus ratios are low (median of 8.34), similar to ratios in the tributary waters, and within ranges that favor nitrogen limitation of algal growth (Smith, 1982). In the Center Unit of Lake Andes (station

06452391), whole-water nitrogen to whole-water phosphorus ratios are intermediate (median of 13.1), and within ranges where nitrogen and phosphorus might jointly interact in limiting algal growth (Smith, 1982). In the downstream part of Lake Andes (South Unit; station 06452406), the median whole-water nitrogen to whole-water phosphorus ratio increases to 21.9, which is within the range where phosphorus plays a larger role in limiting algal growth. Whole-water phosphorus concentrations for Owens Bay, which primarily is fed by an artesian well completed in the Dakota aquifer and typically is isolated from Lake Andes, generally are lower than concentrations for the main units of Lake Andes (fig. 16). Whole-water nitrogen to whole-water phosphorus ratios for Owens Bay are intermediate (median 14.1) and within ranges where nitrogen and phosphorus might jointly interact in limiting algal growth (Smith, 1982).

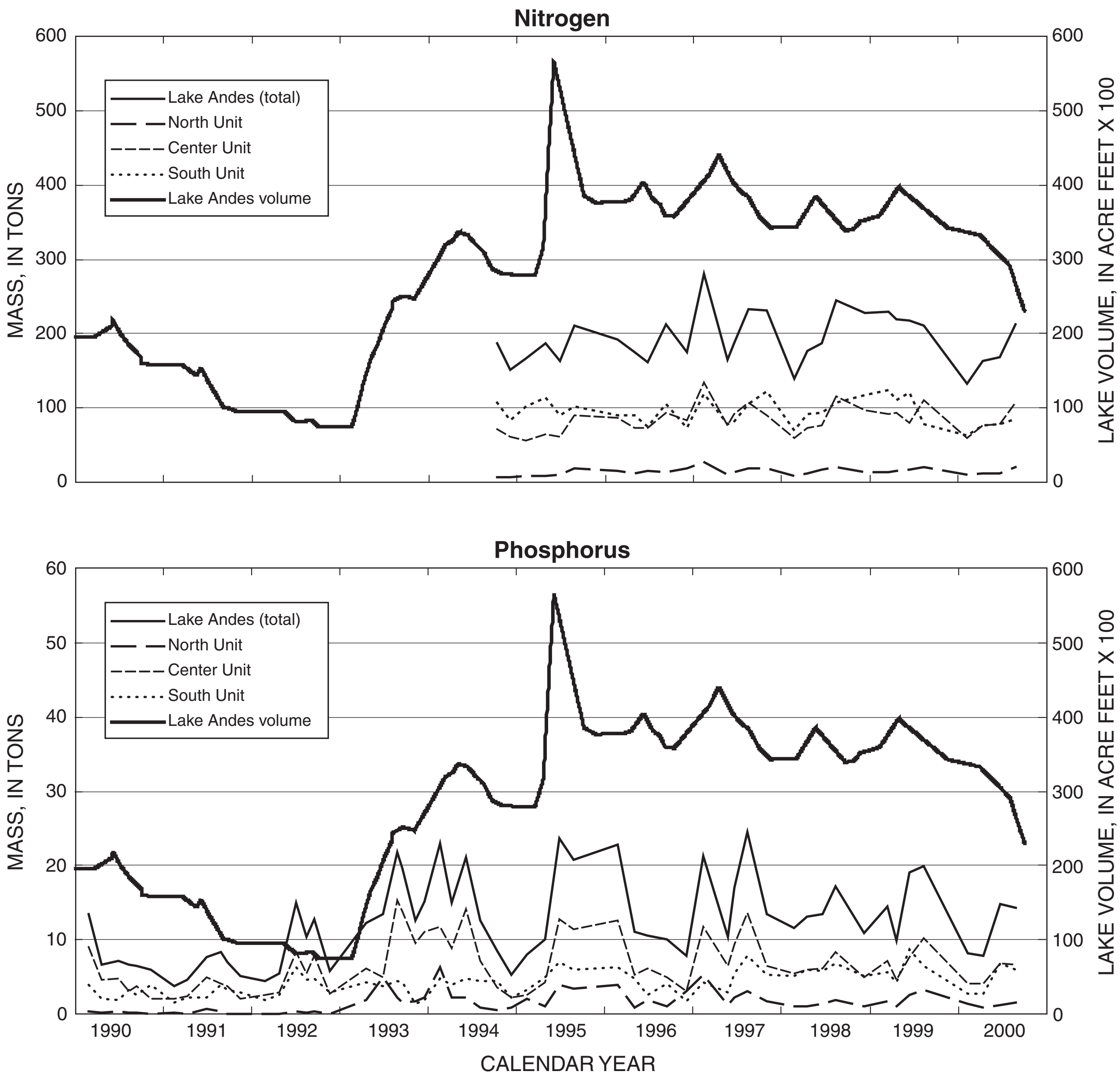


Figure 18. Masses of nitrogen and phosphorus in Lake Andes.

In the Center Unit of Lake Andes (station 06452391), dissolved orthophosphate and whole-water phosphorus concentrations (consisting mostly of organic phosphorus) are largest during the summer (fig. 17). The occurrence of summer maxima and the presence of fairly substantial concentrations of dissolved orthophosphate when algal populations generally are largest indicate that nitrogen probably exerts the greatest influence in limiting algal growth in the upstream parts of Lake Andes.

Generally, the mass of phosphorus in Lake Andes fluctuates between about 6 to 20 tons (fig. 18). Mass of phosphorus in Lake Andes shows a fairly strong relation with lake volume (Pearson correlation coefficient = 0.65), probably indicating that occurrence of phosphorus in the lake is strongly influenced by tributary loading. On a seasonal basis, phosphorus mass in Lake Andes typically is highest during the spring when lake levels rise as a result of tributary inflows.

Whole-water phosphorus concentrations and volume-adjusted trends for selected stations in the Lake Andes Basin are presented in figure 19. Trends in whole-water phosphorus for the individual units of Lake Andes were modeled by fitting a monotonic linear trend to the period 1990-2000. This approach was used for all of the lake stations in order to maintain consistency in the trend analyses between the lake stations. All of the Lake Andes units showed statistically significant ($p<0.001$) increasing volume-adjusted trends in dissolved-solids concentrations from 1990-2000. The North Unit has a trend of +8.6 percent per year; the Center Unit has a trend of +5.7 percent per year; and the South Unit has a trend of +11.2 percent per year. Volume-adjusted whole-water phosphorus concentrations in Lake Andes probably were increasing during the period 1990-2000. Possible explanations for the observed trends are unknown, but might be related to effects of long-term changes in land use and agricultural operations. Given the violation of minimum-data recommendations for the trend analysis, the trend results should not be interpreted as confident determinations of the presence or absence of significant trends.

Trace Elements

Statistical distributions of arsenic and selenium for Lake Andes tributary and lake stations are shown in figure 20. Seasonal distributions of arsenic and selenium for a single representative tributary station (06452380) and a single representative lake station (06452391) are presented in figure 21.

Arsenic concentrations generally are similar between the tributary stations, with median concentrations ranging from 3 to 5 µg/L (micrograms per liter). Selenium concentrations are substantially lower for station 06452380 (median concentration of 3 µg/L) than for stations 06452383 and 06452386 (median concentrations of 34 and 18 µg/L, respectively). The selenium concentrations for 06452383 and 06452386 are relatively large and frequently exceed aquatic-life criteria (both acute and chronic; table 9). Factors affecting differences in selenium concentrations between the tributary stations are unknown, but probably relate to differences in geology and/or land use in the drainage basins upstream from the stations. On a seasonal basis, arsenic concentrations for station 06452380 (Andes Creek) were larger in summer, and selenium concentrations were smaller in summer (fig. 21).

Arsenic concentrations for the lake stations are relatively large and generally are similar between the Lake Andes North, Center, and South Units, but Owens Bay concentrations (station 06452403) tend to be substantially lower (fig. 20), probably due to lower arsenic concentrations in the Dakota aquifer, which is the primary source of water for Owens Bay. Arsenic concentrations in the Lake Andes North, Center, and South Units tend to be larger than in the tributary waters. Geochemical processing of arsenic in Lake Andes may result in release of arsenic adsorbed to particulate material. Lake Andes arsenic concentrations tend to be largest during the summer (fig. 21), which may be related to variability in pH. Arsenic concentrations are correlated with pH values for the lake stations, and pH values tend to be larger during the summer when actively growing algal populations consume dissolved carbon dioxide. However, arsenic geochemistry can be complex and may be affected by many factors.

Selenium concentrations for the lake stations tend to be relatively small, and substantially lower than for the tributary stations. Selenium concentrations for station 06452390, which is the most upstream lake station and the most influenced by tributary inflow, are slightly larger than the more downstream stations. Apparently, geochemical processes result in removal of selenium from the water column in Lake Andes.

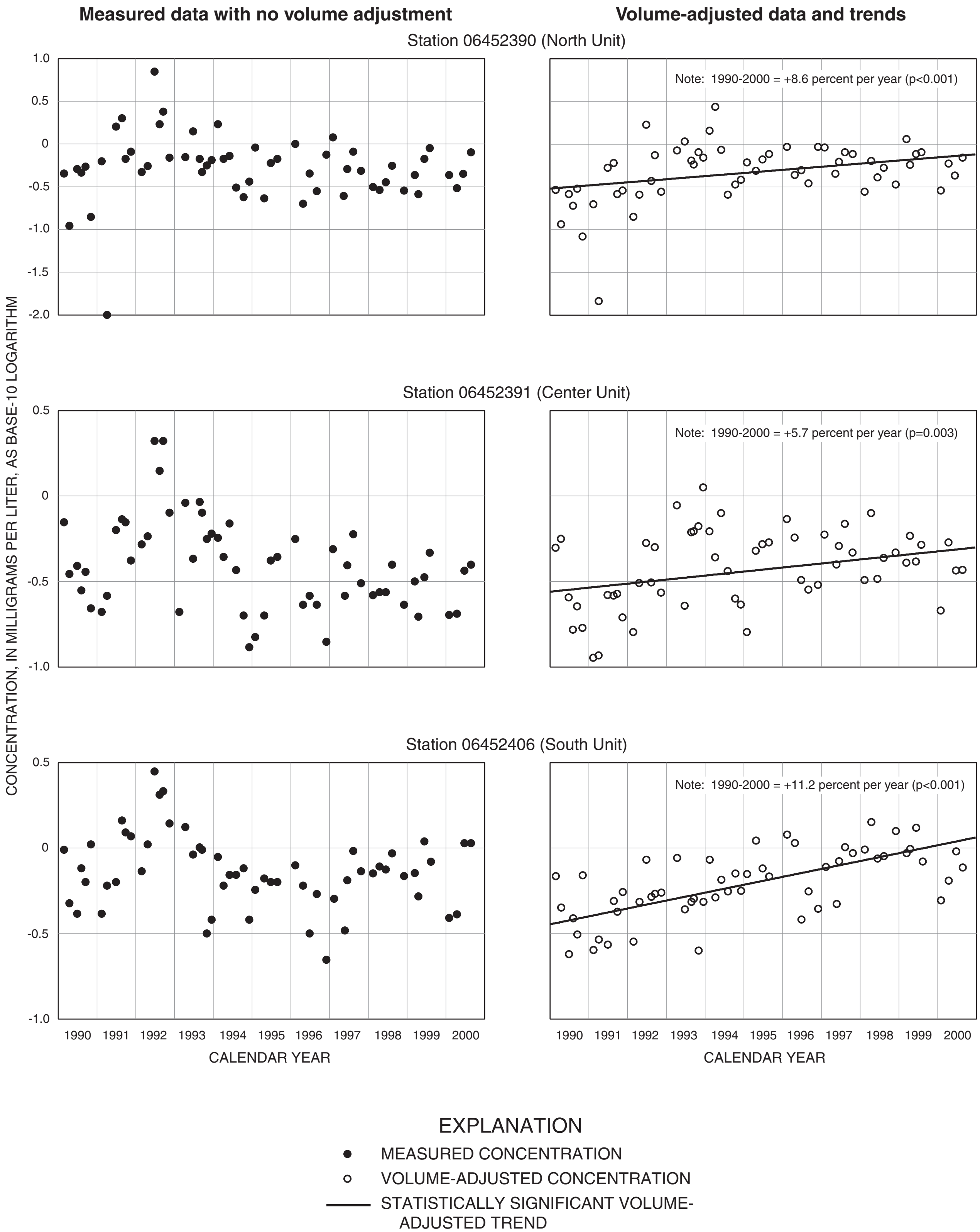


Figure 19. Concentrations of whole-water phosphorus and volume-adjusted trends for selected Lake Andes stations (location of stations shown in figure 1).

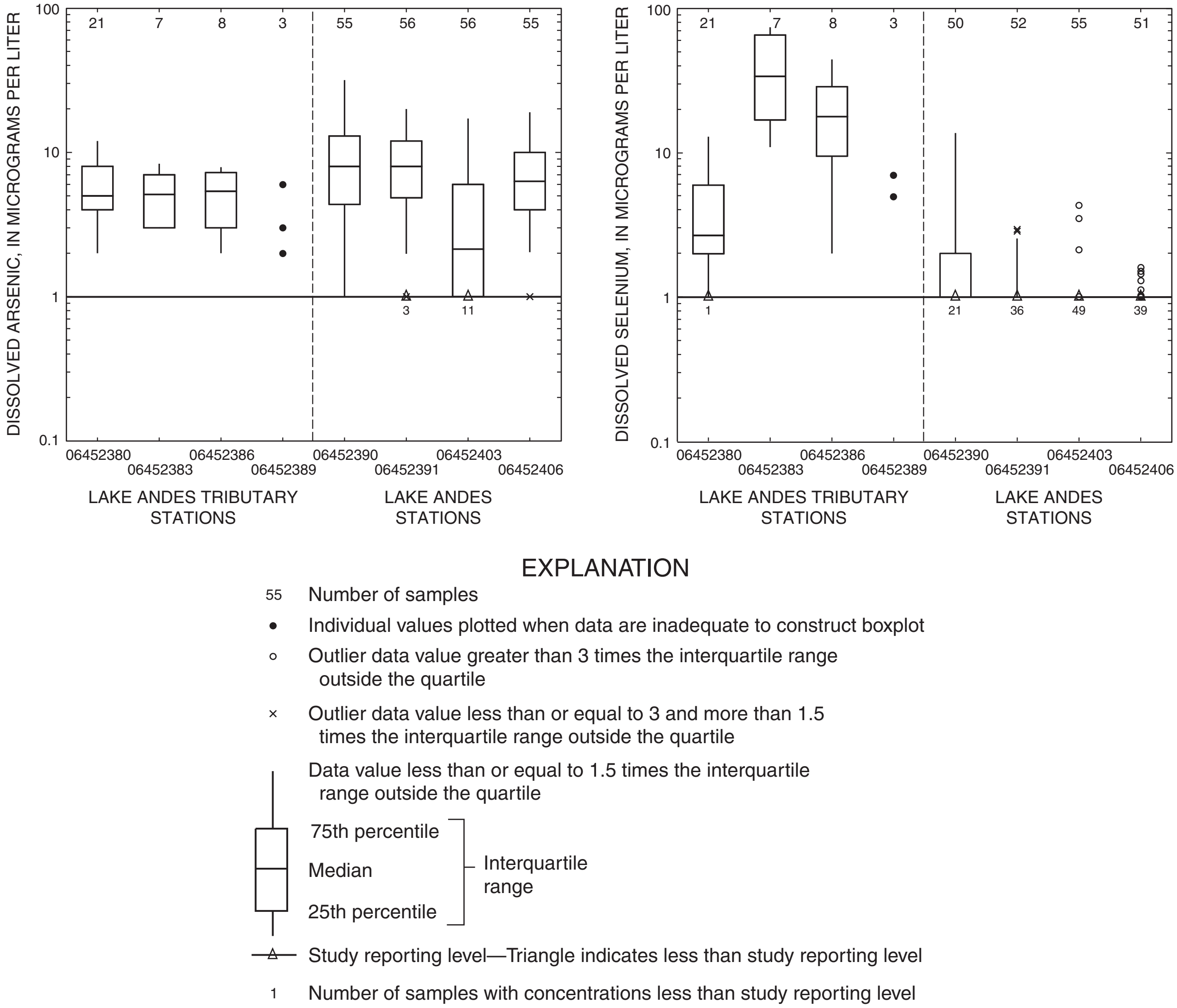


Figure 20. Boxplots of arsenic and selenium concentrations for selected stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

Trends in volume-adjusted dissolved arsenic concentrations (fig. 22) for the individual units of Lake Andes were modeled by fitting a monotonic linear trend to the period 1990-2000. This approach was used for all of the lake stations in order to maintain consistency in the trend analyses between the lake stations. The North and South Units have statistically significant trends in volume-adjusted arsenic concentrations of +4.2 and +7.9 percent per year, respectively. Examination of the volume-adjusted concentrations for the South Unit (station 06452406) indicates that the volume-adjusted concentrations do not increase consistently over the period 1990-2000. During 1995-96, volume-adjusted concentrations decrease. This pattern might be due to ineffectiveness of the trend model to adequately adjust for volume-related variability in the data, or volume-adjusted arsenic concentrations in the South Unit might cycle between periods of increase and periods of decrease. Overall, volume adjusted arsenic concentrations in the North and South Units of Lake Andes probably were generally increasing during the period 1990-2000. Geochemical processes that

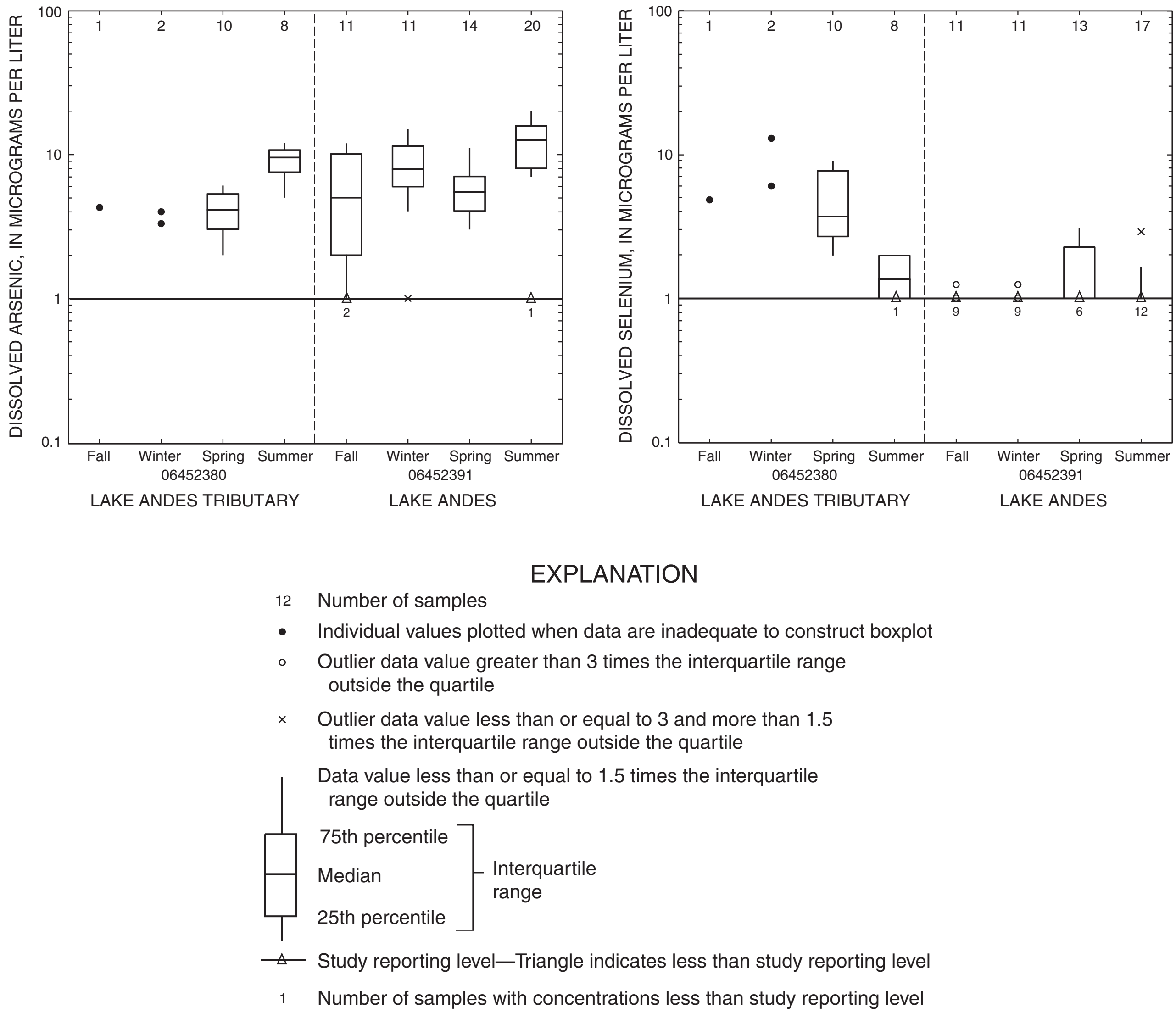


Figure 21. Boxplots showing seasonal distributions of arsenic and selenium concentrations for selected representative tributary and lake stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

govern arsenic concentrations can be complex, and given the available data, it is difficult to confidently determine factors that might contribute to increases in arsenic concentrations. Given the violation of minimum-data recommendations for the trend analysis, the trend results should not be interpreted as confident determinations of the presence or absence of significant trends.

Trend analyses were not performed on the selenium data because of the large proportion (between 42 to 75 percent) of the selenium concentrations that were less than the study reporting level, substantially violating the time series model recommendation of no more than 10 percent. However, examination of the raw (that is, not adjusted for lake volume) selenium concentrations in relation to time (fig. 23) indicates that a greater frequency of large selenium concentrations occurs later in the study period. It is possible that selenium concentrations in Lake Andes were increasing during the study period, but the increases cannot be accurately quantified.

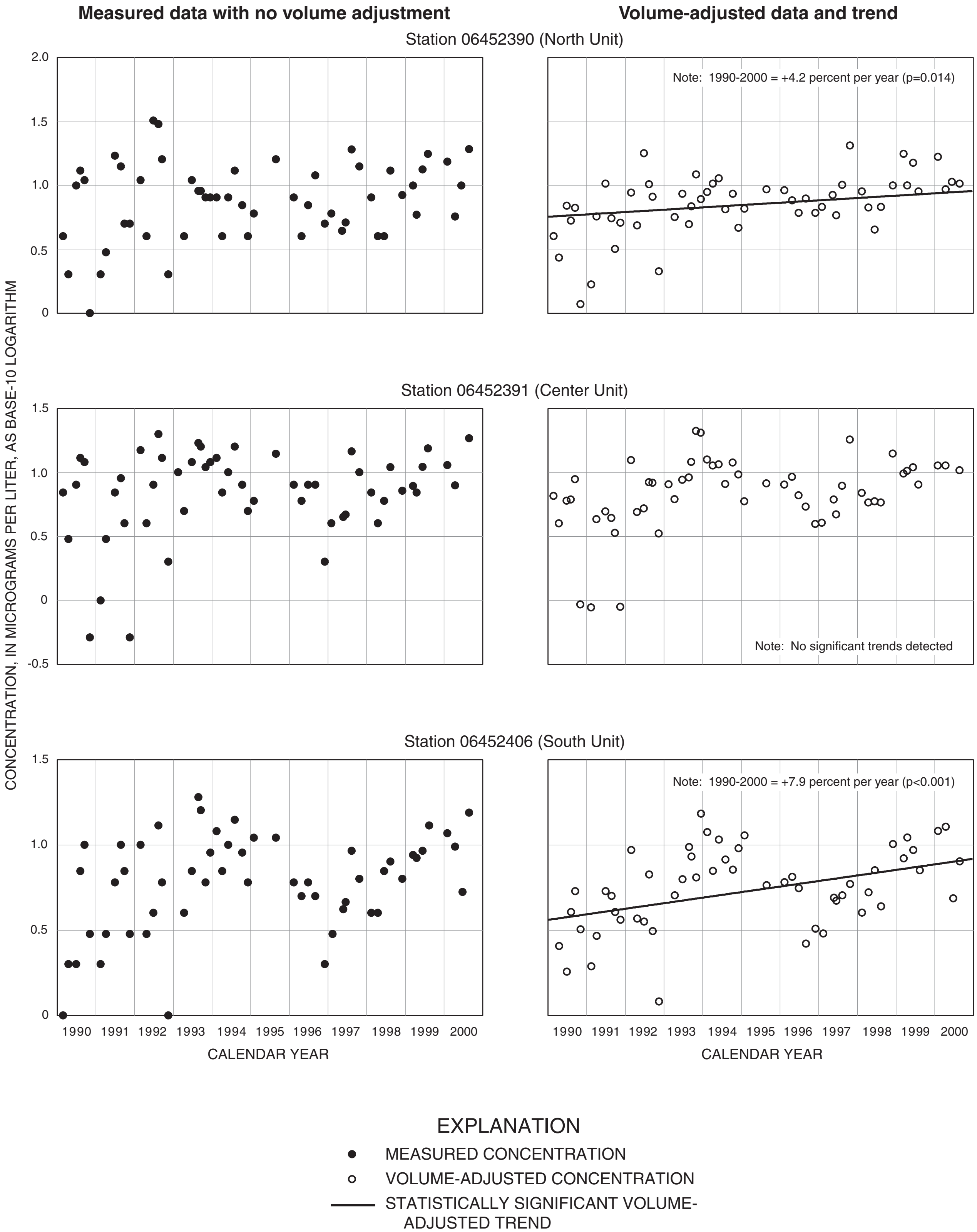


Figure 22. Concentrations of arsenic and volume-adjusted trends for selected Lake Andes stations (location of stations shown in figure 1).

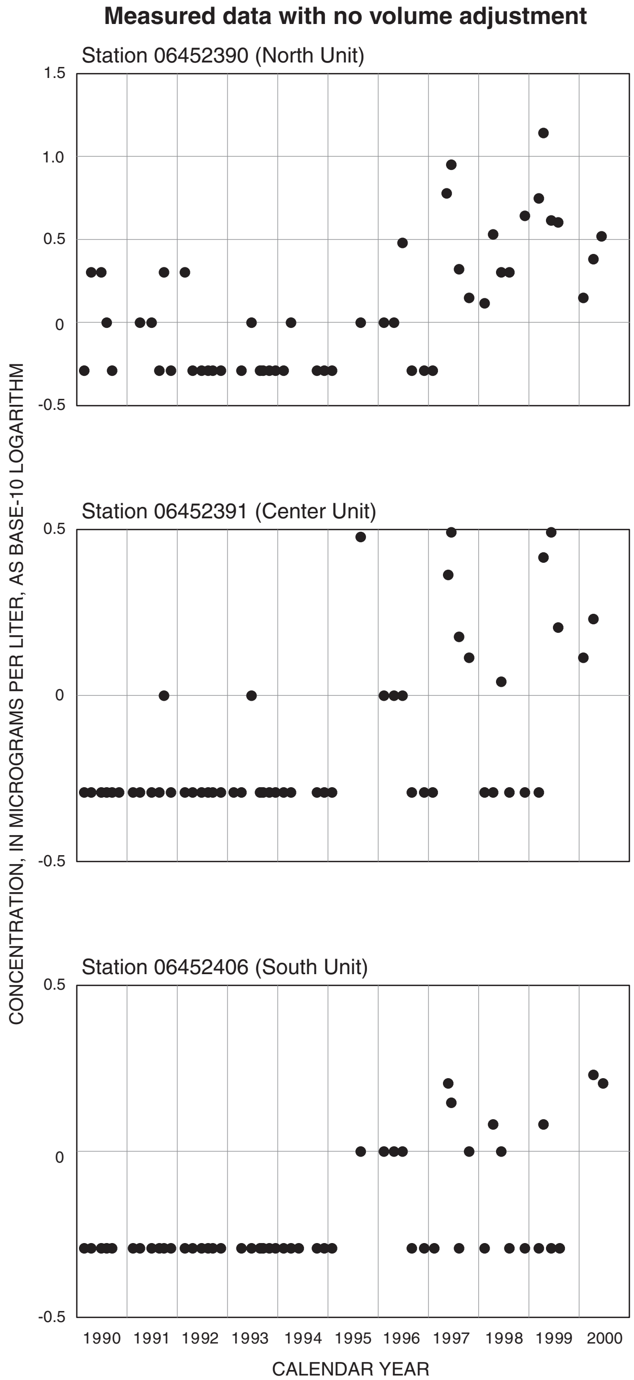


Figure 23. Measured concentrations of selenium for selected Lake Andes stations (location of stations shown in figure 1).

Pesticides

Generally, analyses for pesticides were performed for four lake sampling stations (06452390, 06452391, 06452403, and 06452406). Samples for pesticide analysis were collected twice per year, once in the spring and once in the summer. Numerous pesticides were analyzed for (table 7), but few of the pesticides were detected at concentrations greater than the laboratory reporting levels. Analytical results are reported only for the pesticides that were detected at least one time for at least one of the sampling stations. Statistical summaries of detected pesticides are presented in table 14. The pesticides 2,4-D and atrazine were the most commonly detected pesticides for all of the stations (table 14). Statistical distributions of 2,4-D and atrazine for the four Lake Andes stations are shown in figure 24. Median concentrations for 2,4-D for the North, Center, and South Units of Lake Andes stations range from 0.07 to 0.11 μg/L; the median concentration for Owens Bay is 0.04 μg/L. Median concentrations for atrazine for the North, Center, and South Units of Lake Andes stations range from 0.2 to 0.4 μg/L; the median concentration for Owens Bay is less than 0.1 μg/L. Concentrations of both 2,4-D and atrazine are largest for station 06452390 (the most upstream station that is most influenced by tributary inflow). Concentrations of pesticides in Owens Bay are smaller than in Lake Andes.

Suspended and Bottom Sediment

Statistical distributions of suspended-sediment concentrations for selected Lake Andes tributary stations are shown in figure 25. Median suspended-sediment concentrations for Lake Andes tributary stations range from 22 to 56 mg/L (table 10, fig. 25). The more upstream tributaries (stations 06452380 and 06452383) have smaller medians (22 and 29 mg/L, respectively) than the more downstream tributaries (stations 06452386 and 06452389), which have medians of 56 and 49 mg/L, respectively. Most of the suspended sediment transported in the Lake Andes tributaries consists of particles less than 63 μm in diameter, as evidenced by median percent fines values greater than 95 percent for all of the tributary stations (table 10).

Table 14. Statistical summaries of analytical results for selected pesticide constituents for selected Lake Andes stations, 1990-2000

[Location of stations shown in figure 1. All constituents in micrograms per liter. <, less than]

Station identification number	Constituent	2,4-D	2,4-DP	Alachlor	Ametryne	Atrazine	De-ethyl atrazine	De-isopropyl atrazine	Bromacil	Cyanazine	Metolachlor	Metribuzin	Simazine
06452390 (North Unit)	Number of samples	20	19	20	21	22	18	19	20	22	22	22	21
	Number of detections[1]	18	1	1	3	19	9	3	0	2	7	0	7
	Percent detections[1]	90.0	5.3	5.0	14.3	86.4	50.0	15.8	0.0	9.1	31.8	0.0	33.3
	Mean	0.17	0.02	<0.1	<0.1	0.6	<0.2	<0.2	<0.2	<0.2	0.3	<0.1	<0.1
	Median	0.11	<0.01	<0.1	<0.1	0.4	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Minimum	<0.01	<0.01	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Maximum	0.63	0.2	0.3	0.1	2	0.5	0.2	<0.2	0.5	1.2	<0.1	0.2
06452391 (Center Unit)	Number of samples	20	19	19	20	21	18	18	19	21	21	21	21
	Number of detections[1]	18	1	0	2	17	3	1	0	3	4	1	4
	Percent detections[1]	90.0	5.3	0.0	10.0	81.0	16.7	5.6	0.0	14.3	19.0	4.8	19.0
	Mean	0.08	0.01	<0.1	<0.1	0.4	<0.2	<0.2	<0.2	<0.2	0.2	<0.1	<0.1
	Median	0.07	<0.01	<0.1	<0.1	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Minimum	<0.01	<0.01	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Maximum	0.33	0.13	<0.1	0.1	1.1	0.4	0.2	<0.2	0.6	1.5	0.2	0.2
06452403 (Owens Bay)	Number of samples	18	18	19	21	21	18	18	19	21	21	21	21
	Number of detections[1]	11	0	0	0	9	1	0	1	3	0	0	2
	Percent detections[1]	61.1	0.0	0.0	0.0	42.9	5.6	0.0	5.3	14.3	0.0	0.0	9.5
	Mean	0.06	<0.01	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Median	0.04	<0.01	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Minimum	<0.01	<0.01	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Maximum	0.19	<0.01	<0.1	<0.1	0.4	0.2	<0.2	0.2	0.4	<0.2	<0.1	0.2
06452406 (South Unit)	Number of samples	18	18	19	21	21	18	18	19	21	21	21	21
	Number of detections[1]	16	0	1	1	17	2	2	0	2	5	0	2
	Percent detections[1]	88.9	0.0	5.3	4.8	81.0	11.1	11.1	0.0	9.5	23.8	0.0	9.5
	Mean	0.09	<0.01	<0.1	<0.1	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Median	0.08	<0.01	<0.1	<0.1	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Minimum	<0.01	<0.01	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1
	Maximum	0.25	<0.01	0.1	0.1	0.6	0.3	0.2	<0.2	0.5	0.5	<0.1	0.2

[1]"Number of detections" refers to number of samples that had concentrations larger than the study reporting level.

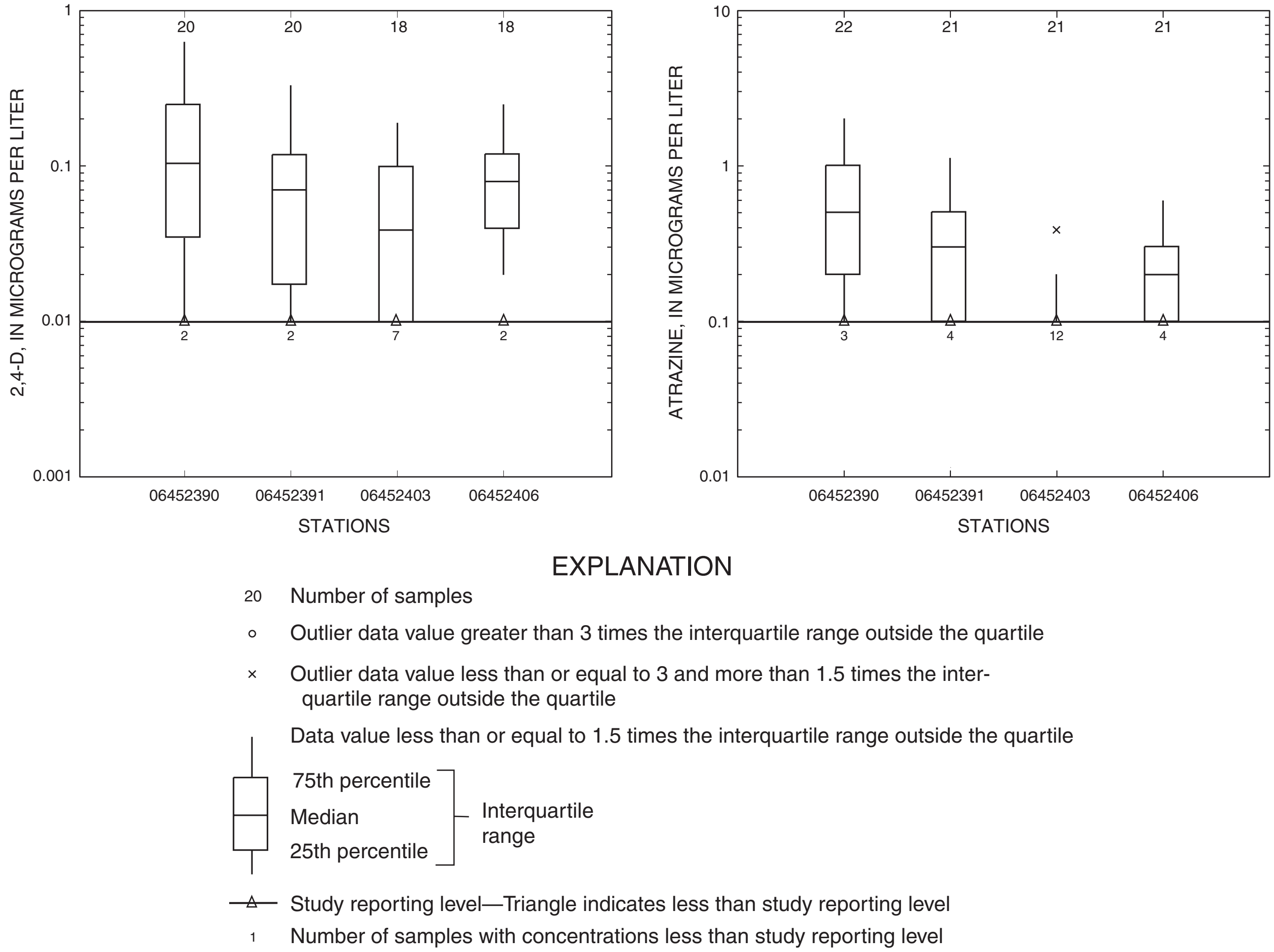


Figure 24. Boxplots of 2,4-D and atrazine concentrations for selected stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

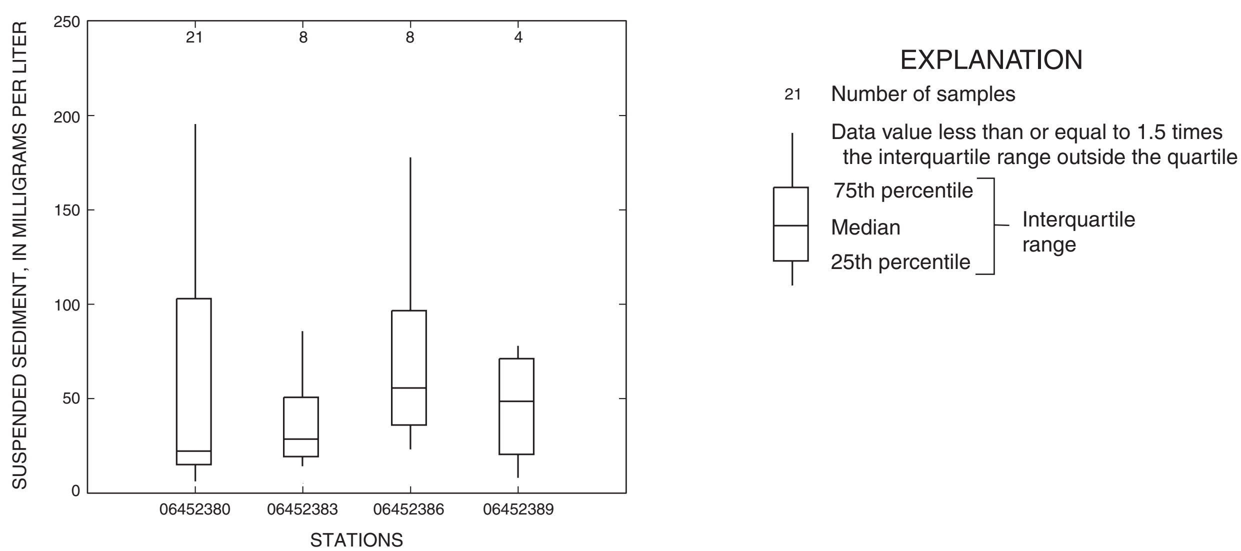


Figure 25. Boxplots of suspended-sediment concentrations for selected tributary stations in the Lake Andes Basin for periods of record listed in table 5 (location of stations shown in figure 1).

Selected sediment-quality guidelines are presented in table 15 for comparison with sediment-quality results. Statistical summaries of constituent concentrations in bottom-sediment samples for tributary and lake stations in the Lake Andes Basin are presented in tables 16 and 17, respectively. Although a relatively small number of samples for the tributary stations makes comparison difficult, concentrations of most constituents generally had similar ranges and medians for the tributary stations. However, station 06452380 generally had lower concentrations of several metals, including chromium, copper, and nickel than the other tributary stations. Also, station 06452383 had substantially higher selenium concentrations and lower strontium concentrations than the other tributary stations. All of the tributary stations had median arsenic and nickel concentrations that exceed U.S. Environmental Protection Agency (USEPA) threshold effects guidelines (tables 15 and 16). The maximum nickel concentrations for stations 06452386 and 06452389 exceed USEPA probable effects guidelines. Two of the stations (06452383 and 06452389) had median chromium concentrations that are very near or exceed USEPA threshold effects guidelines. Three of the stations (06452383, 06452386, and 06452389) had median copper concentrations that exceed USEPA threshold effects guidelines. Selenium concentrations at all of the stations are very near or greater than the upper limit of the baseline range for western soils. All of the stations also had median selenium concentrations that exceed the National Irrigation Water Quality Program (NIWQP) level of concern, and all of the selenium concentrations for station 06452383 exceed the NIWQP toxicity threshold.

Table 15. Selected sediment-quality guidelines and indices

[All values in micrograms per gram. --, not applicable]

Property or constituent	U.S. Environmental Protection Agency sediment-quality guidelines (U.S. Environmental Protection Agency, 1998)		NOAA National Status and Trends Program Sediment Quality Guidelines (Long and others, 1995)		National Irrigation Water Quality Program (U.S. Department of the Interior, 1998)		Western U.S. soils (modified from Shacklette and Boerngen, 1984)	
	Threshold effects level	Probable effects level	Effects range low[1]	Effects range median[2]	Level of concern	Toxicity threshold	Geometric mean	Baseline range[3]
Arsenic	7.24	41.6	8.2	70	8.2	70	5.5	1.2-22
Cadmium	0.676	4.21	1.2	9.6	--	--	--	--
Chromium	52.3	160	81	370	--	--	41	8.5-200
Copper	18.7	108	34	270	34	270	21	4.9-90
Lead	30.2	112	47	220	--	--	17	5.2-55
Molybdenum	--	--	--	--	--	--	0.85	0.18-4.0
Nickel	15.9	42.8	21	52	--	--	--	--
Selenium	--	--	--	--	1	4	0.23	0.039-1.4
Silver	0.733	1.77	1	3.7	--	--	--	--
Vanadium	--	--	--	--	--	--	70	18-270
Zinc	124	271	150	410	150	410	55	17-180

[1]Defined as the concentration at which occasional adverse biological effects may result.
[2]Defined as the concentration at which frequent adverse biological effects may result.
[3]Defined as the range in which 95 percent of sample concentrations are expected to occur.

Table 16. Statistical summaries of constituent concentrations in bottom-sediment samples for Lake Andes tributary stations, 1993-2000

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; --, data insufficient to determine; <, less than]

Property or constituent	06452380 (Andes Creek)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	8	8	55	47	26	110
Magnesium (mg/g)	8	8	13	10	7	34
Potassium (mg/g)	8	8	13	15	4	17
Sodium (mg/g)	8	8	11	11	8	14
Phosphorus (mg/g)	8	8	1	1	1	2
Aluminum	8	8	45,375	47,000	34,000	53,000
Arsenic	7	7	11	11	5.4	17
Barium	8	8	743	715	620	890
Beryllium	8	6	<1	1	<1	1
Bismuth	8	0	<10	<10	<10	<10
Cadmium	8	0	<2	<2	<2	<2
Cerium	8	8	42	48	17	57
Chromium	8	8	35	36	21	44
Cobalt	8	8	9	10	7	11
Copper	8	8	12	11	3	18
Europium	8	0	<2	<2	<2	<2
Gallium	8	5	7	6	<4	14
Gold	8	0	<8	<8	<8	<8
Holmium	8	0	<4	<4	<4	<4
Iron	8	8	27,125	26,500	21,000	40,000
Lanthanum	8	8	25	27	11	34
Lead	8	8	12	12	7	17
Lithium	8	8	17	18	10	22
Manganese	8	8	5,763	4,050	2,900	14,000
Molybdenum	8	1	<2	<2	<2	3
Neodymium	8	8	21	20	14	35
Nickel	8	8	28	28	18	38
Niobium	8	5	4	4	<4	7
Scandium	8	8	6	6	4	7
Selenium	7	7	1.2	1.3	0.7	1.7
Silver	8	0	<2	<2	<2	<2
Strontium	8	8	254	250	220	300
Tantalum	8	0	<40	<40	<40	<40
Thorium	8	6	7	7	<4	10
Tin	8	0	<5	<5	<5	<5
Titanium	8	8	1,663	1,550	800	2,400
Uranium	8	0	<100	<100	<100	<100
Vanadium	8	8	68	73	35	91
Ytterbium	8	8	2	2	1	2
Yttrium	8	8	16	17	10	21
Zinc	8	8	74	67	33	150

Table 16. Statistical summaries of constituent concentrations in bottom-sediment samples for Lake Andes tributary stations, 1993-2000—Continued

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; --, data insufficient to determine; <, less than]

Property or constituent	06452383 (Lake Andes tributary no. 3)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	3	3	32	25	22	49
Magnesium (mg/g)	3	3	10	10	9	11
Potassium (mg/g)	3	3	17	17	16	18
Sodium (mg/g)	3	3	7	7	6	8
Phosphorus (mg/g)	3	3	1	1	1	2
Aluminum	3	3	54,000	53,000	51,000	58,000
Arsenic	3	3	11	11	10	12
Barium	3	3	650	650	630	670
Beryllium	3	3	1	1	1	1
Bismuth	3	0	<10	<10	<10	<10
Cadmium	3	0	<2	<2	<2	<2
Cerium	3	3	48	49	44	50
Chromium	3	3	53	52	48	59
Cobalt	3	3	11	12	7	13
Copper	3	3	24	22	20	29
Europium	3	0	<2	<2	<2	<2
Gallium	3	3	13	12	11	15
Gold	3	0	<8	<8	<8	<8
Holmium	3	0	<4	<4	<4	<4
Iron	3	3	27,667	27,000	25,000	31,000
Lanthanum	3	3	30	29	28	33
Lead	3	3	18	18	16	20
Lithium	3	3	25	24	23	28
Manganese	3	3	2,267	1,900	1,700	3,200
Molybdenum	3	0	<2	<2	<2	<2
Neodymium	3	3	25	26	23	26
Nickel	3	3	38	38	36	39
Niobium	3	3	8	9	7	9
Scandium	3	3	8	8	7	9
Selenium	2	2	8.9	8.9	8.8	8.9
Silver	3	0	<2	<2	<2	<2
Strontium	3	3	193	180	160	240
Tantalum	3	0	<40	<40	<40	<40
Thorium	3	3	8	8	8	9
Tin	3	0	<5	<5	<5	<5
Titanium	3	3	2,233	2,200	2,100	2,400
Uranium	3	0	<100	<100	<100	<100
Vanadium	3	3	117	110	110	130
Ytterbium	3	3	2	2	2	2
Yttrium	3	3	20	19	19	21
Zinc	3	3	110	100	99	130

Table 16. Statistical summaries of constituent concentrations in bottom-sediment samples for Lake Andes tributary stations, 1993-2000—Continued

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; --, data insufficient to determine; <, less than]

Property or constituent	06452386 (Lake Andes tributary no. 2)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	3	3	40	33	29	57
Magnesium (mg/g)	3	3	10	10	9	11
Potassium (mg/g)	3	3	16	16	14	17
Sodium (mg/g)	3	3	9	9	9	10
Phosphorus (mg/g)	3	3	1	1	1	2
Aluminum	3	3	49,667	51,000	44,000	54,000
Arsenic	3	3	12	13	8.6	13
Barium	3	3	753	750	680	830
Beryllium	3	3	1	1	1	1
Bismuth	3	0	<10	<10	<10	<10
Cadmium	3	1	<2	<2	<2	2
Cerium	3	3	51	54	41	57
Chromium	3	3	45	48	39	49
Cobalt	3	3	12	13	9	14
Copper	3	3	19	20	17	21
Europium	3	0	<2	<2	<2	<2
Gallium	3	3	13	10	4	25
Gold	3	0	<8	<8	<8	<8
Holmium	3	0	<4	<4	<4	<4
Iron	3	3	27,000	26,000	24,000	31,000
Lanthanum	3	3	32	33	26	36
Lead	3	3	13	13	12	13
Lithium	3	3	21	21	19	22
Manganese	3	3	5,267	3,800	1,000	11,000
Molybdenum	3	1	<2	<2	<2	2
Neodymium	3	3	26	26	23	28
Nickel	3	3	41	39	39	44
Niobium	3	3	7	5	5	10
Scandium	3	3	7	7	6	7
Selenium	2	2	1.8	1.8	1.6	1.9
Silver	3	0	<2	<2	<2	<2
Strontium	3	3	243	230	220	280
Tantalum	3	0	<40	<40	<40	<40
Thorium	3	3	7	8	6	8
Tin	3	0	<5	<5	<5	<5
Titanium	3	3	2,033	2,200	1,600	2,300
Uranium	3	0	<100	<100	<100	<100
Vanadium	3	3	117	120	100	130
Ytterbium	3	3	2	2	2	2
Yttrium	3	3	20	20	19	20
Zinc	3	3	89	89	81	96

Table 16. Statistical summaries of constituent concentrations in bottom-sediment samples for Lake Andes tributary stations, 1993-2000—Continued

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; --, data insufficient to determine; <, less than]

Property or constituent	06452389 (Lake Andes tributary no. 1)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	3	3	43	42	41	45
Magnesium (mg/g)	3	3	10	11	9	11
Potassium (mg/g)	3	3	17	17	16	18
Sodium (mg/g)	3	3	6	5	5	9
Phosphorus (mg/g)	3	3	1	2	1	2
Aluminum	3	3	55,000	56,000	51,000	58,000
Arsenic	3	3	12	11	10	14
Barium	3	3	663	590	560	840
Beryllium	3	3	1	1	1	1
Bismuth	3	0	<10	<10	<10	<10
Cadmium	3	0	<2	<2	<2	<2
Cerium	3	3	56	55	52	62
Chromium	3	3	52	57	43	57
Cobalt	3	3	13	13	12	15
Copper	3	3	28	31	20	34
Europium	3	0	<2	<2	<2	<2
Gallium	3	2	--	9	<4	9
Gold	3	0	<8	<8	<8	<8
Holmium	3	0	<4	<4	<4	<4
Iron	3	3	29,667	31,000	26,000	32,000
Lanthanum	3	3	36	37	33	37
Lead	3	3	25	25	15	36
Lithium	3	3	28	29	23	31
Manganese	3	3	2,300	1,900	1,800	3,200
Molybdenum	3	2	--	2	<2	3
Neodymium	3	3	33	32	28	38
Nickel	3	3	43	43	40	46
Niobium	3	3	8	9	6	10
Scandium	3	3	8	8	7	9
Selenium	3	3	2.6	3.2	0.8	3.7
Silver	3	0	<2	<2	<2	<2
Strontium	3	3	267	270	230	300
Tantalum	3	0	<40	<40	<40	<40
Thorium	3	3	8	8	7	10
Tin	3	0	<5	<5	<5	<5
Titanium	3	3	2,367	2,500	2,100	2,500
Uranium	3	0	<100	<100	<100	<100
Vanadium	3	3	130	130	120	140
Ytterbium	3	3	2	2	2	2
Yttrium	3	3	22	21	20	24
Zinc	3	3	109	120	77	130

[1]"Number of detections" refers to number of samples that had concentrations larger than the study reporting level.

[2]When calculating mean values for constituents with censored data (that is, having some concentrations reported as less than the study reporting level), a value of one-half the study reporting level was assigned to the samples reported as less thans.

Table 17. Statistical summaries of constituent concentrations in bottom-sediment samples for Lake Andes stations, 1992-2000

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; <, less than]

Property or constituent	06452390 (North Unit)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	22	22	46	44	39	65
Magnesium (mg/g)	22	22	11	11	10	14
Potassium (mg/g)	22	22	17	17	12	19
Sodium (mg/g)	22	22	7	6	5	15
Phosphorus (mg/g)	22	22	1	1	1	2
Aluminum	22	22	53,182	55,000	38,000	59,000
Arsenic	21	21	11	11	7.3	18
Barium	22	22	570	595	220	840
Beryllium	22	21	1	1	<1	2
Bismuth	22	0	<10	<10	<10	<10
Cadmium	22	0	<2	<2	<2	<2
Cerium	22	22	48	49	29	57
Chromium	22	22	51	54	23	61
Cobalt	22	22	11	12	5	14
Copper	22	22	30	31	6	50
Europium	22	0	<2	<2	<2	<2
Gallium	22	21	12	12	<4	15
Gold	22	0	<8	<8	<8	<8
Holmium	22	0	<4	<4	<4	<4
Iron	22	22	28,955	30,000	16,000	33,000
Lanthanum	22	22	29	29	17	34
Lead	22	22	21	21	8	36
Lithium	22	22	27	28	11	33
Manganese	22	22	2,345	1,800	1,200	13,000
Molybdenum	22	8	2	2	<2	3
Neodymium	22	22	25	25	11	38
Nickel	22	22	38	41	16	44
Niobium	22	19	9	8	<4	14
Scandium	22	22	8	8	4	9
Selenium	21	21	3.0	3.2	0.5	4.7
Silver	22	0	<2	<2	<2	<2
Strontium	22	22	295	290	260	380
Tantalum	22	0	<40	<40	<40	<40
Thorium	22	20	8	8	<4	10
Tin	22	0	<5	<5	<5	<5
Titanium	22	22	2,114	2,200	700	2,600
Uranium	22	0	<100	<100	<100	<100
Vanadium	22	22	118	130	32	140
Ytterbium	22	22	2	2	1	2
Yttrium	22	22	19	20	11	24
Zinc	22	22	115	125	40	140

Table 17. Statistical summaries of constituent concentrations in bottom-sediment samples for Lake Andes stations, 1992-2000—Continued

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; <, less than]

Property or constituent	06452391 (Center Unit)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	22	22	64	64	49	78
Magnesium (mg/g)	22	22	11	11	10	14
Potassium (mg/g)	22	22	16	17	12	19
Sodium (mg/g)	22	22	7	6	5	13
Phosphorus (mg/g)	22	22	1	2	1	2
Aluminum	22	22	48,045	48,500	39,000	53,000
Arsenic	19	19	12	11	7.8	20
Barium	22	22	590	555	180	1,200
Beryllium	22	22	1	1	1	1
Bismuth	22	0	<10	<10	<10	<10
Cadmium	22	1	<2	<2	<2	2
Cerium	22	22	44	44	28	55
Chromium	22	22	46	48	29	56
Cobalt	22	22	12	12	8	15
Copper	22	22	28	29	8	42
Europium	22	0	<2	<2	<2	<2
Gallium	22	19	10	11	<4	17
Gold	22	0	<8	<8	<8	<8
Holmium	22	0	<4	<4	<4	<4
Iron	22	22	26,773	27,000	23,000	29,000
Lanthanum	22	22	26	27	17	31
Lead	22	22	19	20	10	27
Lithium	22	22	26	28	11	30
Manganese	22	22	3,173	2,500	1,600	10,000
Molybdenum	22	18	3	3	<2	8
Neodymium	22	22	23	23	14	37
Nickel	22	22	42	44	30	53
Niobium	22	18	8	8	<4	12
Scandium	22	22	7	7	4	8
Selenium	21	21	2.3	2.1	0.8	3.6
Silver	22	0	<2	<2	<2	<2
Strontium	22	22	451	480	280	560
Tantalum	22	0	<40	<40	<40	<40
Thorium	22	20	7	7	<4	11
Tin	22	0	<5	<5	<5	<5
Titanium	22	22	1,841	1,950	800	2,200
Uranium	22	0	<100	<100	<100	<100
Vanadium	22	22	118	125	45	130
Ytterbium	22	22	2	2	1	2
Yttrium	22	22	17	17	14	20
Zinc	22	22	117	120	69	160

Table 17. Statistical summaries of constituent concentrations in bottom-sediment samples for Lake Andes stations, 1992-2000—Continued

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; <, less than]

Property or constituent	06452403 (Owens Bay)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	22	22	55	55	21	100
Magnesium (mg/g)	22	22	9	8	5	26
Potassium (mg/g)	22	22	14	14	12	16
Sodium (mg/g)	22	22	8	7	1	14
Phosphorus (mg/g)	22	22	2	2	1	3
Aluminum	22	22	43,773	44,500	37,000	52,000
Arsenic	18	18	10	9	2.1	44
Barium	22	22	758	575	460	2,700
Beryllium	22	10	<1	<1	<1	2
Bismuth	22	0	<10	<10	<10	<10
Cadmium	22	1	<2	<2	<2	2
Cerium	22	22	40	40	22	61
Chromium	22	22	35	37	18	52
Cobalt	22	22	9	9	3	15
Copper	22	22	18	17	6	34
Europium	22	0	<2	<2	<2	<2
Gallium	22	22	10	9	4	26
Gold	22	0	<8	<8	<8	<8
Holmium	22	0	<4	<4	<4	<4
Iron	22	22	20,286	18,000	8,300	34,000
Lanthanum	22	22	23	24	12	35
Lead	22	22	14	14	7	25
Lithium	22	22	20	19	9	29
Manganese	22	22	2,064	1,450	430	12,000
Molybdenum	22	5	<2	<2	<2	8
Neodymium	22	22	20	20	9	45
Nickel	22	22	26	24	9	38
Niobium	22	17	6	6	<4	10
Scandium	22	22	6	6	3	8
Selenium	21	21	1.2	0.9	0.2	2.8
Silver	22	0	<2	<2	<2	<2
Strontium	22	22	521	500	260	810
Tantalum	22	0	<40	<40	<40	<40
Thorium	22	18	6	5	<4	9
Tin	22	0	<5	<5	<5	<5
Titanium	22	22	1,991	1,650	700	10,000
Uranium	22	0	<100	<100	<100	<100
Vanadium	22	22	73	70	22	120
Ytterbium	22	21	2	2	<1	2
Yttrium	22	22	15	15	8	23
Zinc	22	22	65	58	11	130

Table 17. Statistical summaries of constituent concentrations in bottom-sediment samples for Lake Andes stations, 1992-2000—Continued

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; <, less than]

Property or constituent	06452406 (South Unit)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	22	22	65	67	35	78
Magnesium (mg/g)	22	22	11	11	7	12
Potassium (mg/g)	22	22	17	17	13	18
Sodium (mg/g)	22	22	6	5	5	15
Phosphorus (mg/g)	22	22	1	1	1	2
Aluminum	22	22	51,409	52,000	39,000	58,000
Arsenic	20	20	11	11	5.4	20
Barium	22	22	525	560	200	660
Beryllium	22	21	1	1	<1	2
Bismuth	22	0	<10	<10	<10	<10
Cadmium	22	1	<2	<2	<2	<2
Cerium	22	22	47	48	22	75
Chromium	22	22	50	53	18	69
Cobalt	22	22	11	12	4	14
Copper	22	22	26	27	3	37
Europium	22	0	<2	<2	<2	<2
Gallium	22	20	11	11	<4	18
Gold	22	0	<8	<8	<8	<8
Holmium	22	0	<4	<4	<4	<4
Iron	22	22	27,091	28,000	10,000	31,000
Lanthanum	22	22	29	30	12	44
Lead	22	22	18	19	8	23
Lithium	22	22	30	32	9	36
Manganese	22	22	2,441	2,350	1,900	3,600
Molybdenum	22	15	3	2	<2	6
Neodymium	22	22	25	25	7	42
Nickel	22	22	39	41	11	47
Niobium	22	19	8	8	<4	13
Scandium	22	22	8	8	3	9
Selenium	21	20	1.8	1.9	<.1	3.0
Silver	22	0	<2	<2	<2	<2
Strontium	22	22	541	565	230	670
Tantalum	22	0	<40	<40	<40	<40
Thorium	22	19	8	8	<4	13
Tin	22	0	<5	<5	<5	<5
Titanium	22	22	2,055	2,100	600	3,700
Uranium	22	0	<100	<100	<100	<100
Vanadium	22	22	119	125	24	150
Ytterbium	22	21	2	2	<1	2
Yttrium	22	22	18	19	9	23
Zinc	22	22	114	120	35	140

[1]"Number of detections" refers to number of samples that had concentrations larger than the study reporting level.

[2]When calculating mean values for constituents with censored data (that is, having some concentrations reported as less than the study reporting level), a value of one-half the study reporting level was assigned to the samples reported as less thans.

For Lake Andes stations, medians and ranges for most constituents in bottom-sediment samples generally were similar between the different stations. However, selenium concentrations tended to be higher for station 06452390 (North Unit) compared to the other stations, and generally decreased downstream through Lake Andes. Strontium concentrations tended to be lower for station 06452390 (North Unit) and generally increased downstream through Lake Andes. Concentrations of several metals, including chromium, copper, nickel, and selenium are smaller for Owens Bay (station 06452403) than for the Lake Andes stations, whereas concentrations of barium were larger for Owens Bay. All of the Lake Andes stations had median arsenic and nickel concentrations that exceed USEPA threshold effects guidelines (tables 15 and 17). The median nickel concentrations for station 06452391 and the maximum nickel concentrations for stations 06452390 and 06452406 also exceed the USEPA probable effects guidelines. The median chromium concentrations for stations 06452390 and 06452406 exceed USEPA threshold effects guidelines. Selenium concentrations for the lake stations generally are greater than the baseline range for western soils. All of the stations also had median selenium concentrations that equal or exceed the NIWQP level of concern, and the maximum concentration for station 06452390 exceeds the NIWQP toxicity threshold.

Concentrations of ^{137}Cs, selenium (normalized for total carbon), and total carbon for two vertical sediment cores collected in the South Unit of Lake Andes in October 2000 are shown in figure 26. Results of the vertical sediment cores indicate that selenium loading to Lake Andes steadily increased during the period 1952 through 2000. Results of the vertical sediment cores also may provide information on changes in rates of sediment and selenium deposition in Lake Andes; however, accurate determination of these rates requires detailed analysis of core-shortening processes, which is beyond the scope of this report. Core shortening is a phenomenon associated with the use of a gravity corer and has been estimated to shorten the core by as much as 50 percent (Emery and Hulsemann, 1964; Christensen, 1999). No matter what the effects of core shortening might be, it can be reasonably concluded that there has been at least about 1 ft of sediment deposited at the core sampling station during the period 1952-2000.

Choteau Creek Basin and Missouri River near the Mouth of Choteau Creek

In the Choteau Creek Basin, water-quality data were collected at three stations. Water-quality data also were collected for two Missouri River stations near the mouth of Choteau Creek. Statistical summaries of water-quality data for Choteau Creek and the Missouri River in the vicinity of Choteau Creek are shown in tables 18 and 19, respectively.

Field-Measured Properties and Constituents

Statistical distributions of field-measured properties and constituents for stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek are shown in figure 27. Seasonal distributions of field-measured properties and constituents for a single representative Choteau Creek station (06453300) and a single representative Missouri River station (06453305) are presented in figure 28.

Median dissolved-oxygen concentrations for Choteau Creek and Missouri River stations (tables 18 and 19, fig. 27) range from 7.5 to 10.8 mg/L and 10.5 to 10.9 mg/L, respectively. Dissolved-oxygen concentrations generally exceed the South Dakota surface-water-quality minimum criterion of 5.0 µg/L for warmwater permanent fish-life propagation (fig. 27, table 9). Dissolved-oxygen concentrations increase downstream on Choteau Creek (fig. 27), and are very similar between the two Missouri River stations. Concentrations generally are largest during the fall and winter and smallest during the summer (fig. 28), probably due mostly to temperature effects on oxygen solubility.

Water samples from the various locations in the Choteau Creek Basin have similar median pH values, ranging from 7.9 to 8.1. Median pH values for the Missouri River stations range from 8.2 to 8.3. All pH values are within the acceptable range for warmwater permanent fish-life propagation (tables 9, 18, and 19). Highest pH values for Choteau Creek occur during the spring, whereas very little seasonal variability in pH is shown for the Missouri River stations (fig. 28).

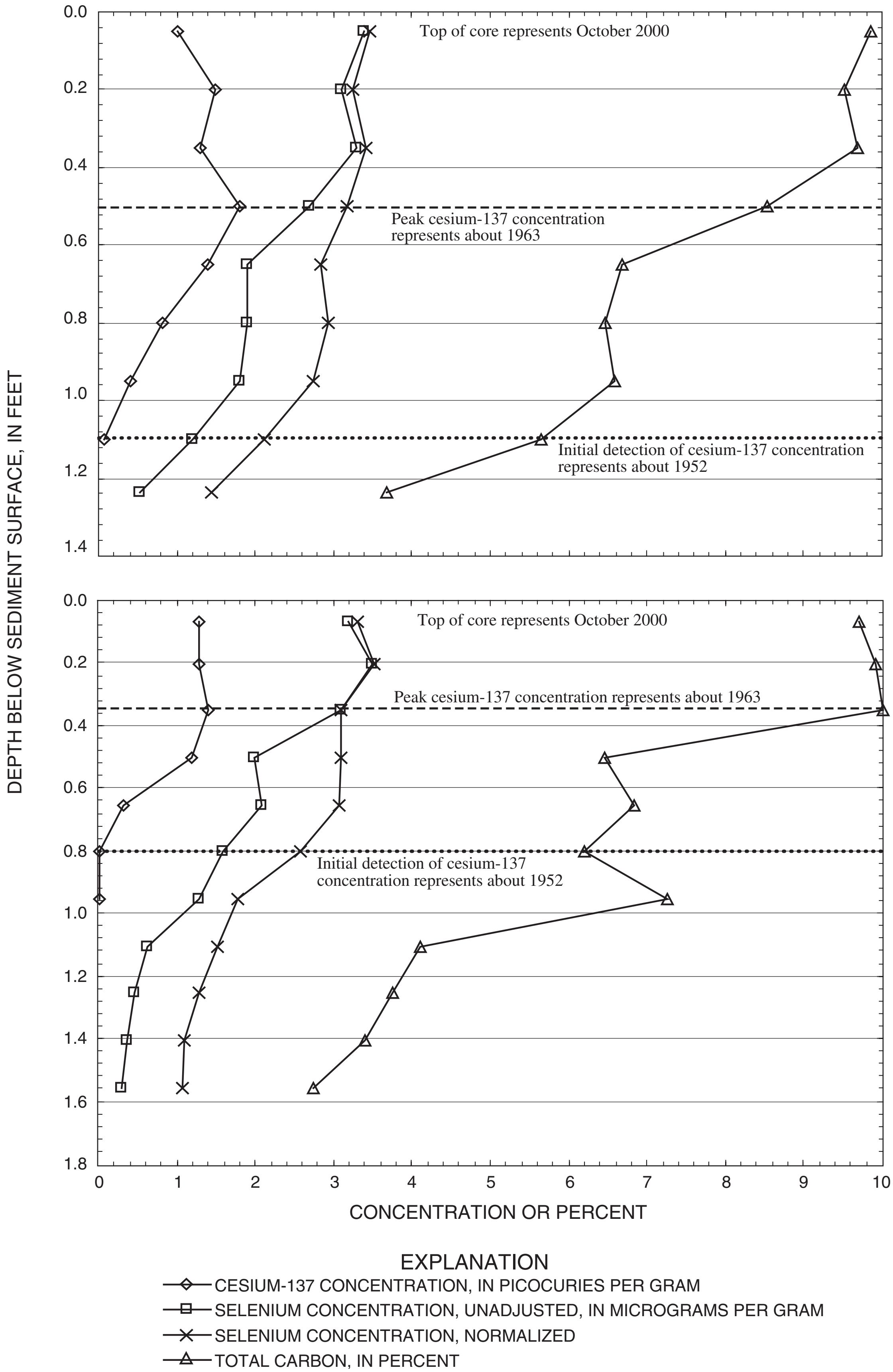


Figure 26. Concentrations of cesium-137, selenium (normalized for organic carbon concentration), and organic carbon in vertical sediment core samples collected at Lake Andes near Owens Bay (430941098273400), October 2000.

Table 18. Statistical summaries of water-quality results for Choteau Creek stations

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; --, data insufficient to determine; <, less than]

Property or constituent	06453200 (Choteau Creek near Wagner)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Streamflow at time of sampling (ft^3/s)	61	NA	81	17.0	<0.1	1,270
Oxygen, dissolved	41	NA	7.3	7.5	0.4	15.7
Oxygen, dissolved (percent saturation)	40	NA	71	71	3	143
pH (standard units)	64	NA	8.0	8.0	6.9	8.9
Specific conductance (µS/cm)	63	NA	1,820	1,600	730	4,900
Water temperature (°C)	64	NA	14.4	14.3	0.0	32.5
Calcium, dissolved	65	65	179	150	77	500
Magnesium, dissolved	65	65	89	77	28	240
Potassium, dissolved	65	65	21	20	3	47
Sodium, dissolved	65	65	122	100	36	470
Alkalinity, dissolved	65	65	262	254	78	494
Chloride, dissolved	65	65	49	35	12	350
Fluoride, dissolved	55	54	0.2	0.2	<0.1	0.7
Silica, dissolved	65	65	15	15	0.6	44
Sulfate, dissolved	65	65	770	690	260	2,400
Solids, dissolved, residue on evaporation at 180°C	42	42	1,630	1,440	610	4,490
Solids, dissolved, sum of constituents (calculated)	65	NA	1,400	1,180	548	4,290
Ammonia, as nitrogen, dissolved	31	23	0.12	0.05	<0.02	1.8
Ammonia plus organic nitrogen, whole-water	42	42	2.0	1.7	0.8	7.5
Nitrite plus nitrate, as nitrogen, dissolved	65	15	0.23	<0.1	<0.1	2.8
Nitrite, as nitrogen, dissolved	42	11	0.02	<0.01	<0.01	0.20
Nitrogen, whole-water (calculated)	42	NA	2.2	2.0	0.88	8.5
Phosphorus, dissolved	34	34	0.53	0.31	0.03	1.7
Orthophosphate, as phosphorus, dissolved	65	64	0.44	0.34	<0.01	1.6
Phosphorus, whole-water	57	57	0.62	0.51	0.02	1.9
Total nitrogen/total phosphorus ratio (percent; calculated)	42	NA	4.8	3.6	1.2	19.9
Arsenic, dissolved (µg/L)	38	38	5	4	1	12
Selenium, dissolved (µg/L)	38	26	3	1	<1	10
Suspended sediment	29	29	77	27	4	482
Percent fines	25	25	80	90	24	100

Table 18. Statistical summaries of water-quality results for Choteau Creek stations—Continued

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; --, data insufficient to determine; <, less than]

Property or constituent	06453252 (Choteau Creek near Dante)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Streamflow at time of sampling (ft^3/s)	114	NA	55	2.8	<0.1	1,280
Oxygen, dissolved	73	NA	9.8	9.6	0.4	25.1
Oxygen, dissolved (percent saturation)	72	NA	95	92	3	190
pH (standard units)	114	NA	7.9	7.9	7.0	8.6
Specific conductance (µS/cm)	113	NA	2,230	2,280	800	5,270
Water temperature (°C)	115	NA	13.4	13.5	0.0	30.0
Calcium, dissolved	115	115	245	240	78	750
Magnesium, dissolved	115	115	110	110	33	320
Potassium, dissolved	115	115	20	20	2	39
Sodium, dissolved	115	115	130	120	26	363
Alkalinity, dissolved	115	115	261	253	78	576
Chloride, dissolved	112	112	54	44	13	300
Fluoride, dissolved	90	90	0.3	0.3	0.1	0.7
Silica, dissolved	115	115	14	14	0.8	36
Sulfate, dissolved	115	115	1,040	1,080	250	3,000
Solids, dissolved, residue on evaporation at 180°C	75	75	2,000	1,980	601	4,940
Solids, dissolved, sum of constituents (calculated)	112	NA	1,760	1,780	555	4,820
Ammonia, as nitrogen, dissolved	51	41	0.14	0.04	<0.02	1.5
Ammonia plus organic nitrogen, whole-water	63	63	2.1	1.8	0.2	8.0
Nitrite plus nitrate, as nitrogen, dissolved	115	44	0.24	<0.1	<0.1	1.6
Nitrite, as nitrogen, dissolved	76	28	0.02	<0.01	<0.01	0.20
Nitrogen, whole-water (calculated)	63	NA	2.3	2.0	0.82	9.1
Phosphorus, dissolved	64	63	0.23	0.10	<0.01	0.93
Orthophosphate, as phosphorus, dissolved	113	103	0.20	0.07	<0.01	1.2
Phosphorus, whole-water	95	95	0.42	0.34	0.03	2.0
Total nitrogen/total phosphorus ratio (percent; calculated)	62	NA	6.8	5.7	1.8	38.8
Arsenic, dissolved (µg/L)	61	60	5	4	<1	14
Selenium, dissolved (µg/L)	62	60	8	6	<1	62
Suspended sediment	50	50	119	95	2	410
Percent fines	47	47	83	91	22	100

Table 18. Statistical summaries of water-quality results for Choteau Creek stations—Continued

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; --, data insufficient to determine; <, less than]

Property or constituent	06453300 (Choteau Creek below Avon)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Streamflow at time of sampling (ft^3/s)	58	NA	46	6.7	<0.1	718
Oxygen, dissolved	56	NA	11.0	10.8	4.9	18.8
Oxygen, dissolved (percent saturation)	55	NA	110	108	59	167
pH (standard units)	57	NA	8.0	8.1	7.2	8.5
Specific conductance (µS/cm)	58	NA	1,830	1,800	922	2,650
Water temperature (°C)	57	NA	14.4	13.0	0.0	32.5
Calcium, dissolved	58	58	214	210	88	300
Magnesium, dissolved	58	58	79	74	37	159
Potassium, dissolved	58	58	16	16	6	22
Sodium, dissolved	58	58	91	85	41	160
Alkalinity, dissolved	58	58	238	244	138	414
Chloride, dissolved	58	58	33	27	14	200
Fluoride, dissolved	58	58	0.3	0.3	0.1	0.4
Silica, dissolved	58	58	17	17	6	24
Sulfate, dissolved	58	58	798	774	310	1,350
Solids, dissolved, residue on evaporation at 180°C	58	58	1,480	1,440	678	2,320
Solids, dissolved, sum of constituents (calculated)	58	NA	1,390	1,350	634	2,180
Ammonia, as nitrogen, dissolved	58	42	0.05	0.02	<0.02	0.50
Ammonia plus organic nitrogen, whole-water	29	29	0.9	0.9	0.2	1.9
Nitrite plus nitrate, as nitrogen, dissolved	58	8	0.10	<0.1	<0.1	0.95
Nitrite, as nitrogen, dissolved	58	9	<0.01	<0.01	<0.01	0.06
Nitrogen, whole-water (calculated)	29	NA	1.0	0.99	0.27	2.0
Phosphorus, dissolved	0	NA	--	--	--	--
Orthophosphate, as phosphorus, dissolved	58	26	0.07	<0.01	<0.01	0.64
Phosphorus, whole-water	57	56	0.16	0.08	<0.01	0.93
Total nitrogen/total phosphorus ratio (percent; calculated)	28	NA	9.9	9.3	2.1	43.7
Arsenic, dissolved (µg/L)	54	51	3	2	<1	12
Selenium, dissolved (µg/L)	53	49	5	4	<1	16
Suspended sediment	53	53	133	106	28	658
Percent fines	46	46	75	86	20	100

[1]"Number of detections" refers to number of samples that had concentrations larger than the study reporting level.

[2]When calculating mean values for constituents with censored data (that is, having some concentrations reported as less than the study reporting level), a value of one-half the study reporting level was assigned to the samples reported as less thans.

Table 19. Statistical summaries of water-quality results for Missouri River stations near the mouth of Choteau Creek

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; --, data insufficient to determine; <, less than]

Property or constituent	06453120 (Missouri River above Choteau Creek)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Streamflow at time of sampling (ft^3/s)	0	NA	--	--	--	--
Oxygen, dissolved	57	NA	10.7	10.9	6.7	15.6
Oxygen, dissolved (percent saturation)	57	NA	99	99	38	117
pH (standard units)	58	NA	8.2	8.3	7.0	8.6
Specific conductance (µS/cm)	58	NA	786	781	648	909
Water temperature (°C)	57	NA	11.9	11.1	0.2	24.5
Calcium, dissolved	58	58	59	59	53	73
Magnesium, dissolved	58	58	23	23	20	25
Potassium, dissolved	58	58	5	5	4	7
Sodium, dissolved	58	58	73	72	64	85
Alkalinity, dissolved	58	58	162	164	147	175
Chloride, dissolved	58	58	12	12	9	17
Fluoride, dissolved	58	58	0.5	0.5	0.4	0.9
Silica, dissolved	58	58	6	5	4	8
Sulfate, dissolved	58	58	229	230	200	294
Solids, dissolved, residue on evaporation at 180°C	58	58	514	511	394	623
Solids, dissolved, sum of constituents (calculated)	58	NA	503	502	454	588
Ammonia, as nitrogen, dissolved	57	42	0.02	0.02	<0.02	0.09
Ammonia plus organic nitrogen, whole-water	28	27	0.3	0.3	<0.2	0.5
Nitrite plus nitrate, as nitrogen, dissolved	57	20	<0.1	<0.1	<0.1	0.36
Nitrite, as nitrogen, dissolved	57	7	0.02	<0.01	<0.01	0.02
Nitrogen, whole-water (calculated)	28	NA	0.42	0.42	0.18	0.75
Phosphorus, dissolved	0	NA	--	--	--	--
Orthophosphate, as phosphorus, dissolved	56	12	<0.01	<0.01	<0.01	0.02
Phosphorus, whole-water	51	37	0.02	0.01	<0.01	0.15
Total nitrogen/total phosphorus ratio (percent; calculated)	16	NA	22.8	18.8	2.9	49.0
Arsenic, dissolved (µg/L)	56	56	2	2	1	4
Selenium, dissolved (µg/L)	53	48	2	2	<1	3
Suspended sediment	0	NA	--	--	--	--
Percent fines	0	NA	--	--	--	--

Table 19. Statistical summaries of water-quality results for Missouri River stations near the mouth of Choteau Creek—Continued

[Location of stations shown in figure 1; periods of record listed in table 5. All values in milligrams per liter, except as indicated. ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; NA, not applicable; --, data insufficient to determine; <, less than]

Property or constituent	06453305 (Missouri River below Choteau Creek)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Streamflow at time of sampling (ft^3/s)	0	NA	--	--	--	--
Oxygen, dissolved	56	NA	10.6	10.5	6.4	15.7
Oxygen, dissolved (percent saturation)	56	NA	100	98	82	126
pH (standard units)	57	NA	8.1	8.2	7.3	8.7
Specific conductance (µS/cm)	57	NA	792	791	651	923
Water temperature (°C)	56	NA	12.3	12.3	0.5	25.0
Calcium, dissolved	57	57	60	60	51	71
Magnesium, dissolved	57	57	23	23	20	27
Potassium, dissolved	57	57	5	5	5	7
Sodium, dissolved	57	57	73	72	63	83
Alkalinity, dissolved	57	57	163	164	147	181
Chloride, dissolved	57	57	12	12	9	17
Fluoride, dissolved	57	57	0.5	0.5	0.2	0.8
Silica, dissolved	57	57	6	5	4	8
Sulfate, dissolved	57	57	233	230	200	296
Solids, dissolved, residue on evaporation at 180°C	57	57	521	519	454	628
Solids, dissolved, sum of constituents (calculated)	57	NA	508	501	454	592
Ammonia, as nitrogen, dissolved	56	38	0.02	0.02	<0.02	0.09
Ammonia plus organic nitrogen, whole-water	28	28	0.3	0.3	0.2	0.4
Nitrite plus nitrate, as nitrogen, dissolved	56	20	<0.1	<0.1	<0.1	0.35
Nitrite, as nitrogen, dissolved	56	6	<0.01	<0.01	<0.01	0.02
Nitrogen, whole-water (calculated)	28	NA	0.44	0.41	0.25	0.69
Phosphorus, dissolved	0	NA	--	--	--	--
Orthophosphate, as phosphorus, dissolved	56	14	<0.01	<0.01	<0.01	0.07
Phosphorus, whole-water	51	40	0.03	0.02	<0.01	0.42
Total nitrogen/total phosphorus ratio (percent; calculated)	15	NA	18.9	16.7	6.0	40.0
Arsenic, dissolved (µg/L)	56	54	2	2	<1	4
Selenium, dissolved (µg/L)	54	49	2	2	<1	4
Suspended sediment	0	NA	--	--	--	--
Percent fines	0	NA	--	--	--	--

[1]"Number of detections" refers to number of samples that had concentrations larger than the study reporting level.

[2]When calculating mean values for constituents with censored data (that is, having some concentrations reported as less than the study reporting level), a value of one-half the study reporting level was assigned to the samples reported as less thans.

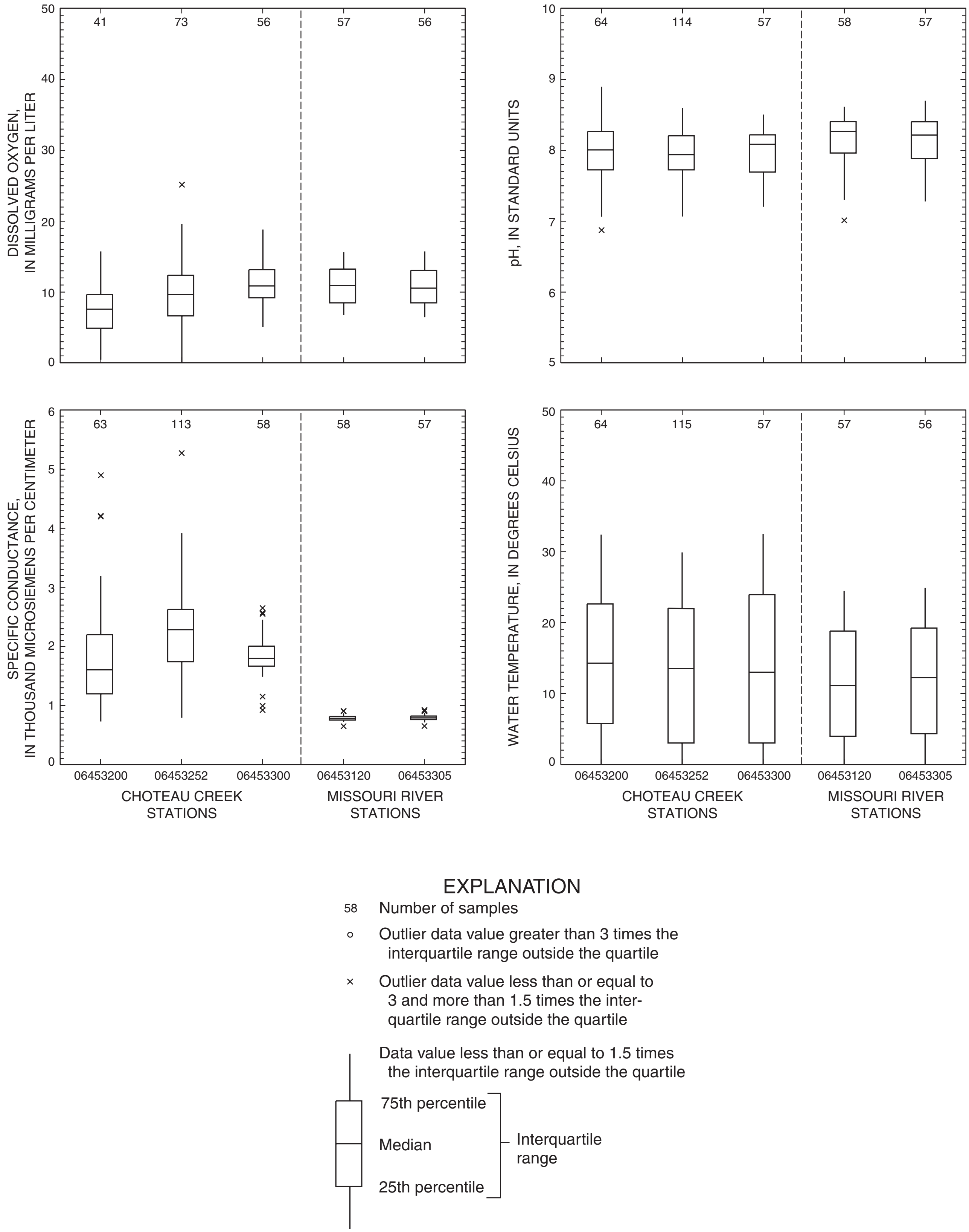


Figure 27. Boxplots of field-measured properties and constituents for selected stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (location of stations shown in figure 1).

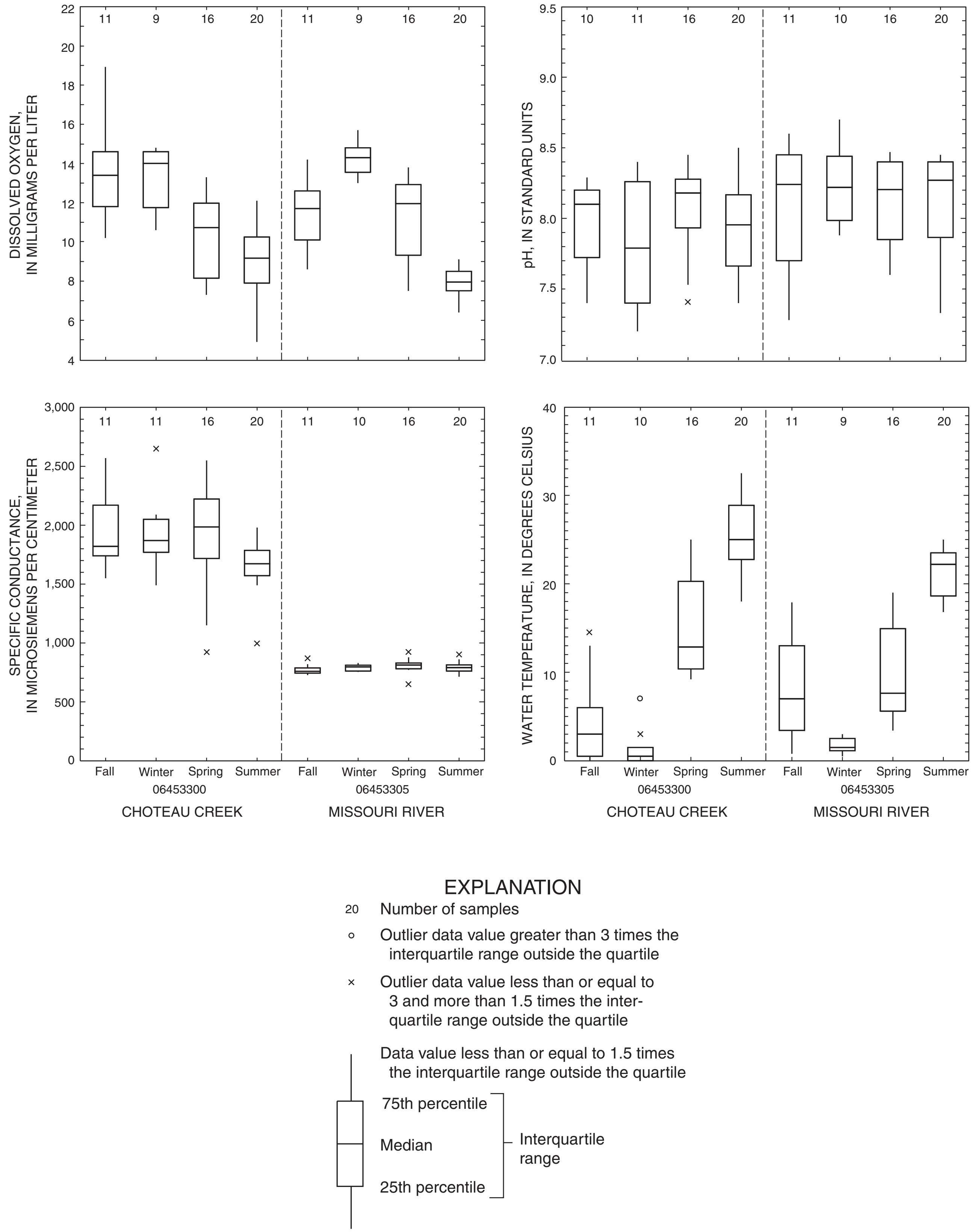


Figure 28. Boxplots showing seasonal distributions of selected field-measured properties and constituents for selected representative stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (location of stations shown in figure 1).

Median specific-conductance values for Choteau Creek stations range from 1,600 to 2,280 µS/cm, and station 06453252 generally has larger specific-conductance values than the other two stations. Differences in specific conductance between stations on Choteau Creek may be due to effects of local tributary and/or ground-water inflow, and might also be influenced by differences in the sample collection periods for the different stations (table 5). Median specific-conductance values for the Missouri River stations range from 781 to 791 µS/cm. Highest specific-conductance values for Choteau Creek occur during the spring, whereas very little seasonal variability in specific conductance is shown for the Missouri River stations (fig. 28). Specific-conductance values for Choteau Creek and Missouri River stations are nearly always below criteria for irrigation and fish and wildlife propagation, recreation, and livestock watering (tables 9, 18, and 19).

Median water temperatures for Choteau Creek stations are very similar, ranging from 13.0 to 14.3°C. Median temperatures for the two Missouri River stations range from 11.1 to 12.3°C. Seasonal variability in water temperature for Choteau Creek and the Missouri River is typical of northern temperate water bodies, with lowest temperatures during the winter and highest temperatures during the summer (fig. 28). Water temperatures for Choteau Creek stations generally are below the warmwater permanent fish-life propagation criterion, but station 06453300 does exceed this criterion during the summer in about 25 percent of the samples collected (fig. 28). All water temperature measurements for Missouri River stations are below the warmwater permanent fish-life propagation criterion.

Major Ions

Statistical distributions of major ions for stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek are shown in figure 29. Stiff diagrams showing average proportions of major ions for Choteau Creek and Missouri River stations are shown in figure 30. Seasonal distributions of major-ion constituents for a single representative Choteau Creek station (06453300) and a single representative Missouri River station (06453305) are presented in figure 31.

Generally, concentrations of major ions in water samples from Choteau Creek stations tend to be similar (figs. 29 and 30). However, concentrations of most major ions tend to be larger for station 06453252 than the other two Choteau Creek stations. Differences in major-ion concentrations between stations on Choteau Creek may be due to effects of local tributary and/or ground-water inflow, and also might be influenced by differences in the sample collection periods for the different stations (table 5). For all of the Choteau Creek stations, calcium is dominant among the cations, and sulfate is dominant among the anions (fig. 30). Median dissolved-solids concentrations (sum of constituents) range from 1,180 to 1,780 mg/L. Dissolved-solids concentrations for station 06453300 do not exceed relevant criteria (tables 9 and 18). Dissolved-solids concentrations for stations 06453200 and 06453252 infrequently exceed the fish and wildlife propagation, recreation, and livestock watering 30-day mean criterion and only rarely exceed the maximum daily criterion (tables 9 and 18). On a seasonal basis, median values for dissolved-solids concentration for Choteau Creek were largest in spring and smallest in summer (fig. 31). Distributions of some major ions, including calcium, magnesium, alkalinity, and sulfate, generally were lower in summer than the other seasons.

Major-ion concentrations for the Missouri River stations generally are smaller than the Choteau Creek stations and show very little variability due to the effects of reservoir regulation (figs. 29 and 30; table 19). Differences in major-ion concentrations between stations 06453120 and 06453305 are negligible, indicating that Choteau Creek inflows have very little effect on major-ion concentrations in the Missouri River. For the two Missouri River stations, calcium, magnesium, and sodium are approximately codominant among the cations, and bicarbonate and sulfate are about codominant among the anions (fig. 30). Median dissolved-solids concentrations for the Missouri River stations range from 501 to 502 mg/L, and never exceed relevant water-quality standards (tables 9 and 19). Dissolved-solids and major-ion concentrations for the Missouri River stations show little seasonal variability (fig. 31; table 19) due to the effects of reservoir regulation.

Trends in flow-adjusted dissolved-solids concentrations for Choteau Creek stations (fig. 32) were modeled by fitting a monotonic linear trend to the period 1983-2000 for Choteau Creek near Wagner (station 06453200) and Choteau Creek near Dante (station 06453252), and to the period 1990-2000 for Choteau Creek below Avon (station 06453300). The shorter trend analysis period for Choteau Creek below Avon (station 06453300) was due to lack of data prior to 1990.

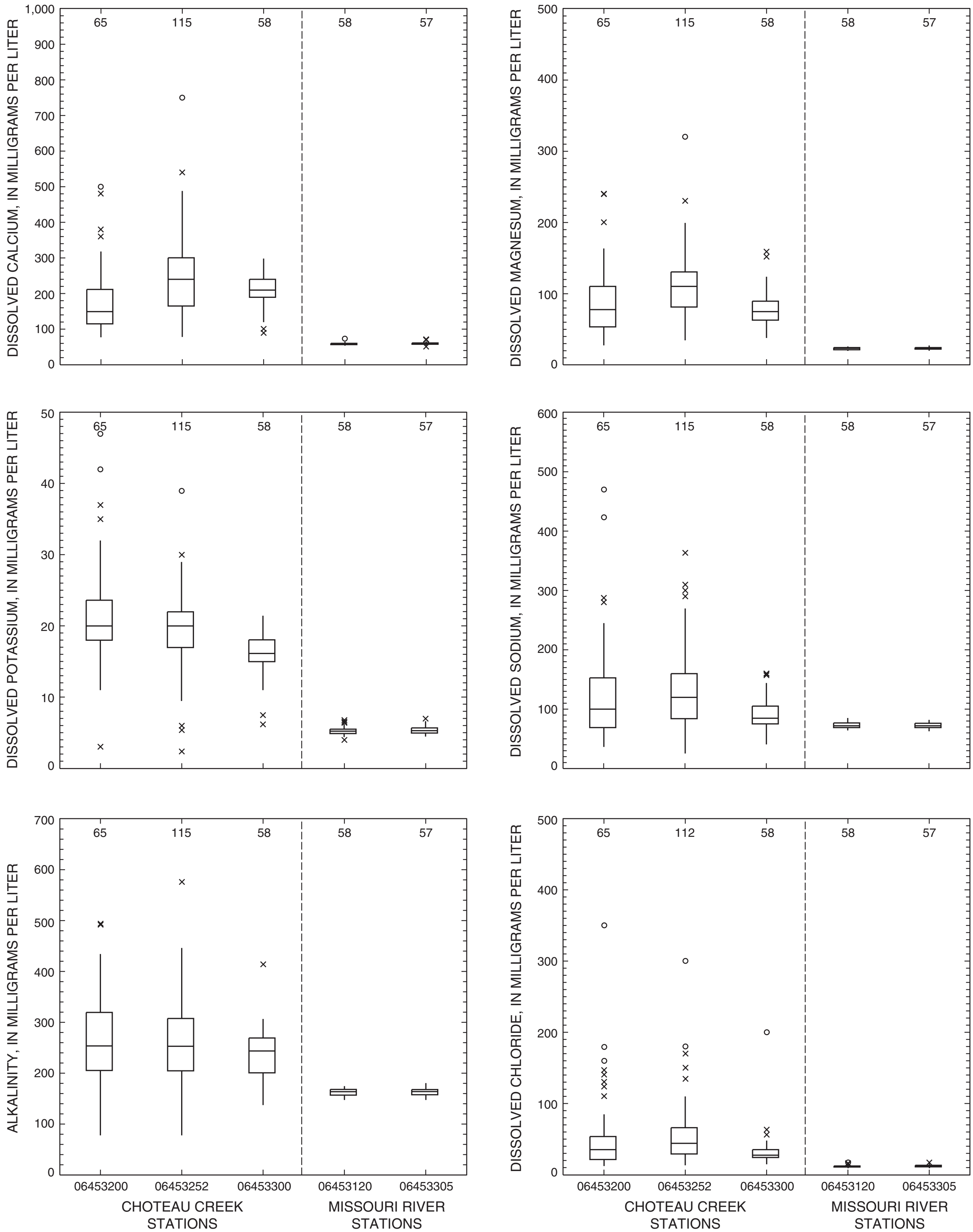


Figure 29. Boxplots of major-ion constituents for selected stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (location of stations shown in figure 1).

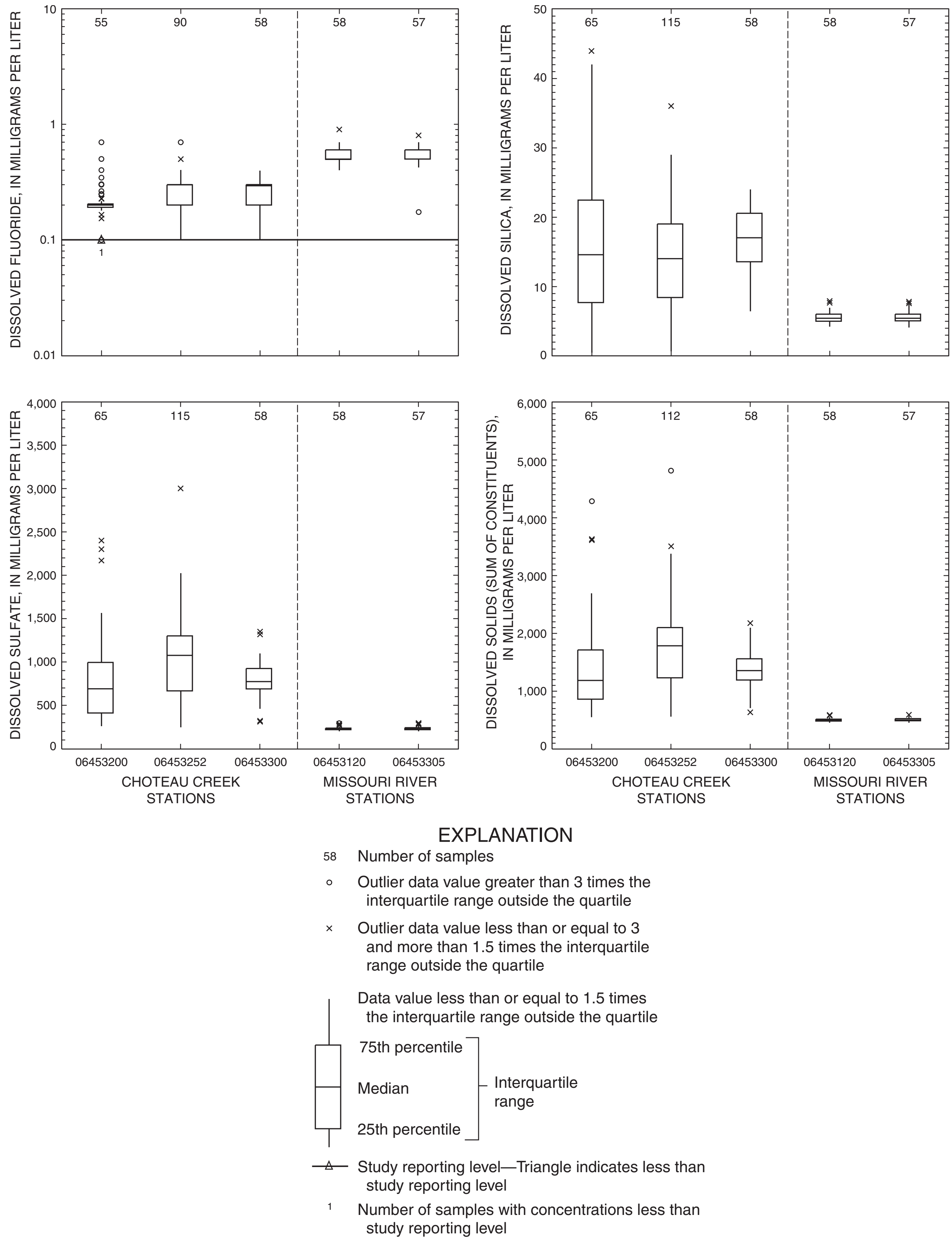


Figure 29. Boxplots of major-ion constituents for selected stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (location of stations shown in figure 1).—Continued

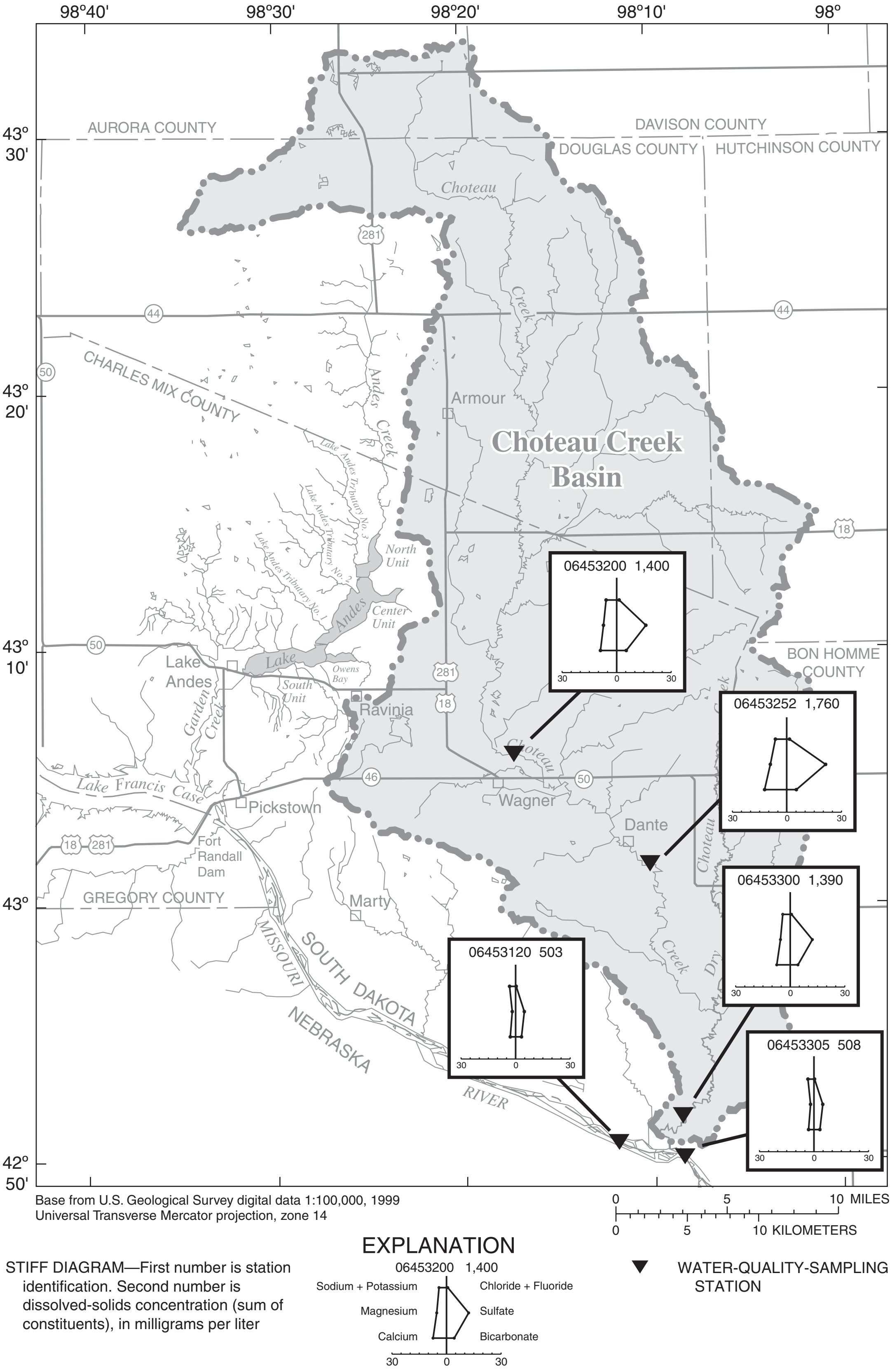


Figure 30. Stiff diagrams showing average proportions of major ions for selected sites in the Choteau Creek Basin and on the Missouri River near the mouth of the Choteau Creek for periods of record listed in table 5.

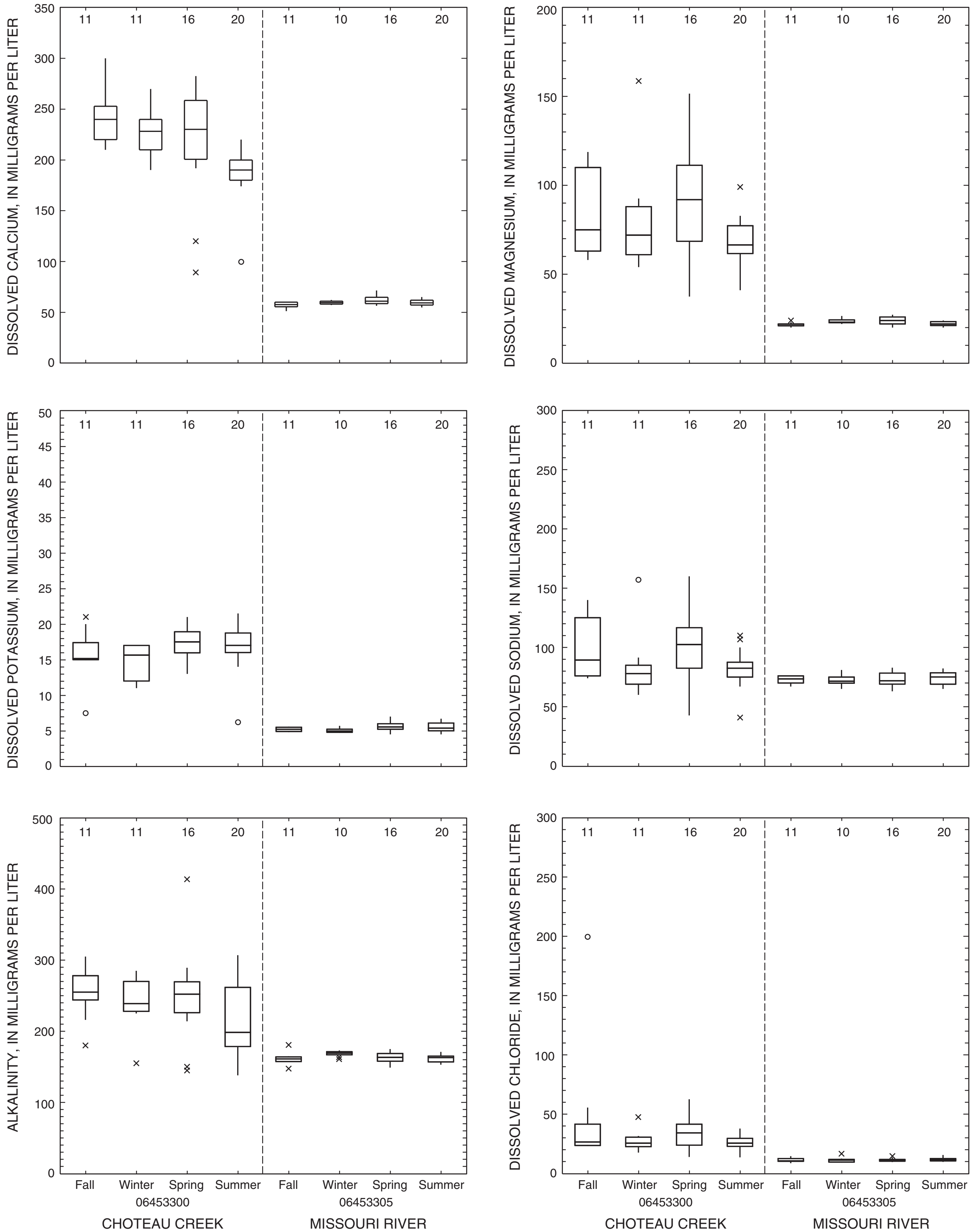
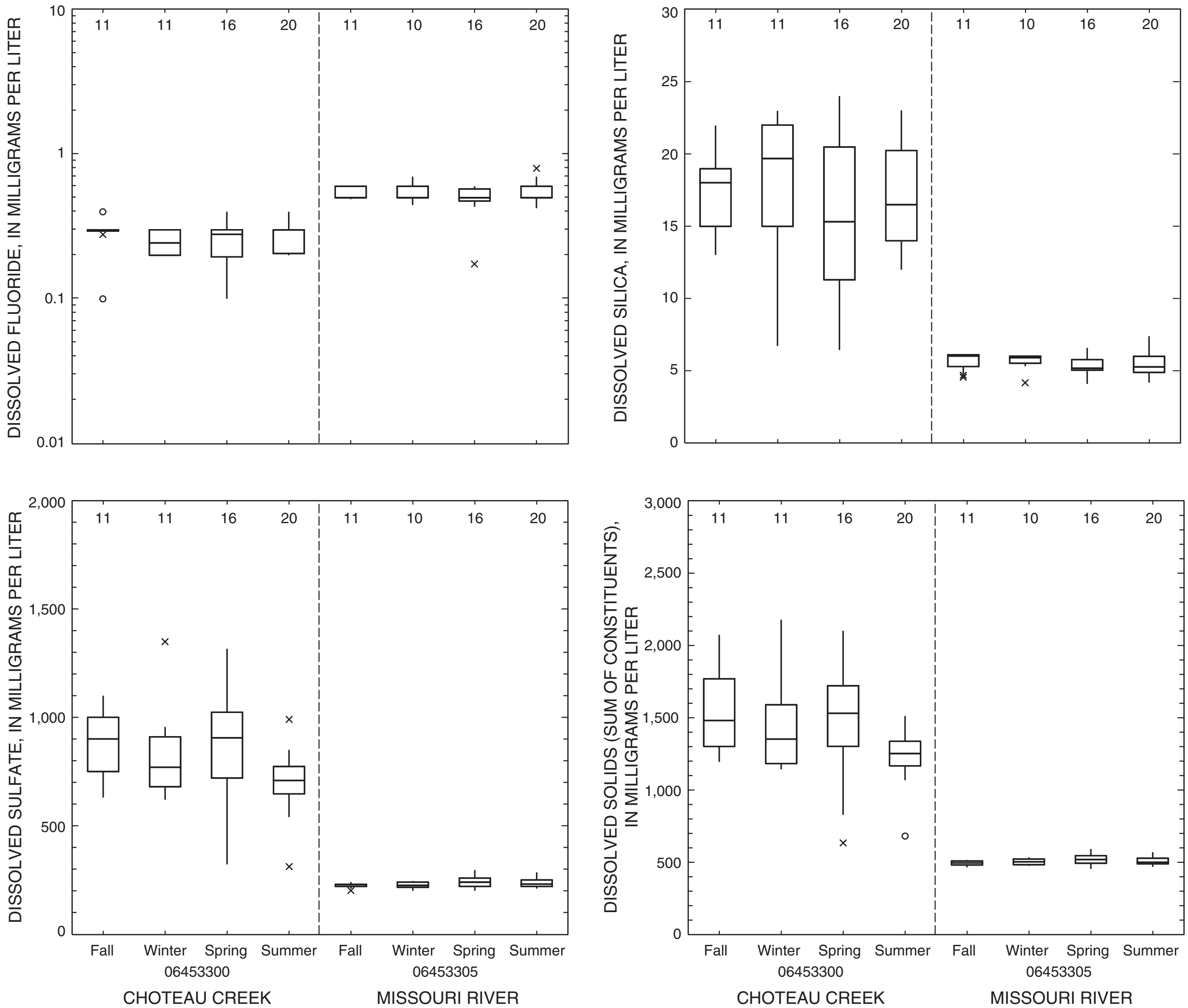


Figure 31. Boxplots showing seasonal distribution of major-ion constituents for selected representative stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (location of stations shown in figure 1).



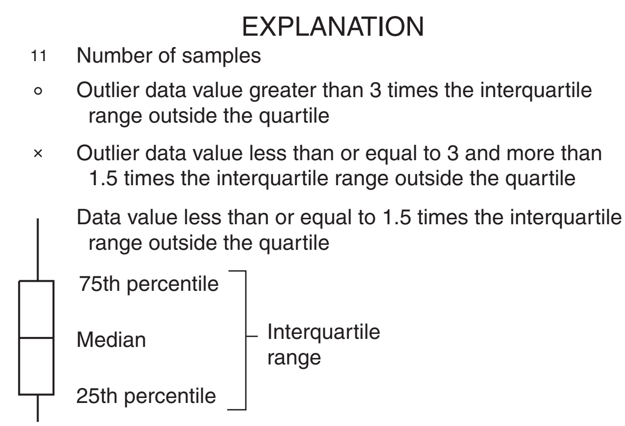


Figure 31. Boxplots showing seasonal distribution of major-ion constituents for selected representative stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (location of stations shown in figure 1).—Continued

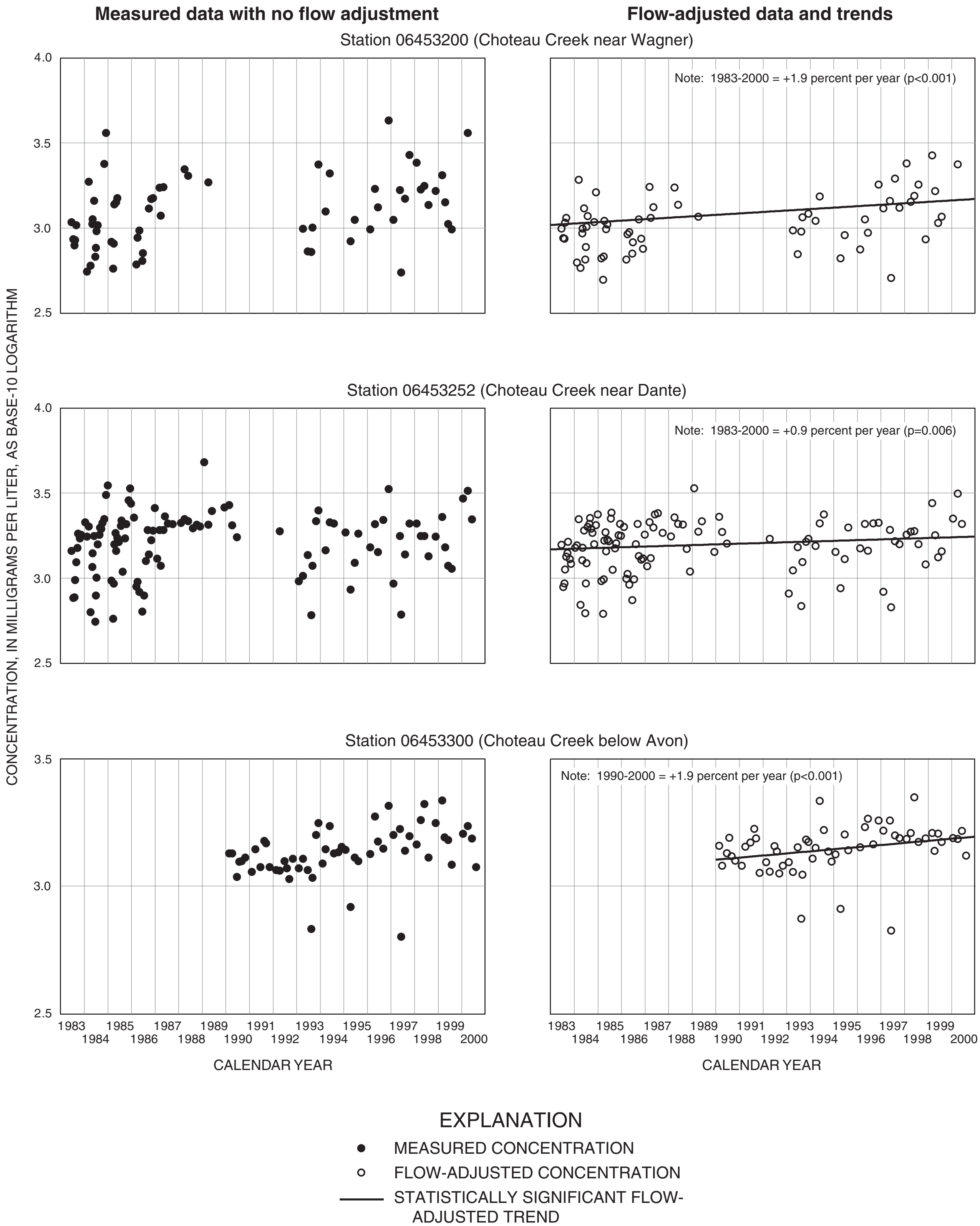


Figure 32. Concentrations of dissolved solids (sum of constituents) and flow-adjusted trends for selected stations in the Choteau Creek Basin (location of stations shown in figure 1).

All three Choteau Creek stations generally have similar statistically significant increases in flow-adjusted dissolved-solids concentrations. Choteau Creek near Wagner (station 06453200) and Choteau Creek near Dante (station 06453252) show increases of 1.9 and 0.9 percent per year for the period 1983-2000, respectively, and Choteau Creek below Avon shows an increase of 1.9 percent per year for the period 1990-2000. Flow-adjusted dissolved-solids concentrations in Choteau Creek probably were increasing during the period 1983-2000. Possible explanations for the observed trends are unknown, but might be related to effects of long-term changes in land use and agricultural operations. Given the violation of minimum-data recommendations for the trend analysis for Choteau Creek near Wagner (station 06453200) and Choteau Creek below Avon (station 06453300), the trend results for those stations should not be interpreted as confident determination of the presence or absence of significant trends.

Nutrients

Statistical distributions of nitrogen and phosphorus constituents for Choteau Creek and Missouri River stations are shown in figure 33. Seasonal distributions of nutrient constituents for a single representative Choteau Creek station (06453300) and a single representative Missouri River station (06453305) are presented in figure 34.

For Choteau Creek stations, whole-water nitrogen concentrations (table 18, fig. 33) are similar between stations 06453200 and 06453252 (medians of 1.95 and 2.04 mg/L, respectively), but whole-water nitrogen concentrations for station 06453300 are substantially smaller (median of 0.99 mg/L). In general, whole-water nitrogen concentrations for all of the Choteau Creek stations are relatively large, but similar to other streams draining agricultural lands in the upper Midwest (Tornes and others, 1997). Most of the nitrogen in Choteau Creek is in organic form, which generally accounts for an average of between about 85 to 90 percent of whole-water nitrogen.

Median whole-water nitrogen concentrations for the Missouri River stations range from 0.41 to 0.42 mg/L (table 19), which are relatively small. An average of about 65 percent of whole-water nitrogen occurs in organic form for the Missouri River stations.

Daily loads of whole-water nitrogen and phosphorus transported at the Choteau Creek stations for the days that samples were collected were calculated using equation 2. Simple linear regressions were then performed on log transformations of streamflow and load, to develop equations to estimate load based on streamflow (table 20). Daily loads of nitrogen and phosphorus for water years 1983-2000 were estimated using the regression equations in conjunction with streamflow estimates summarized in table 1. Statistical summaries of loads of nutrients transported at the tributary stations are presented in table 21. Errors associated with the nutrient load estimates are difficult to accurately quantify and may be substantial; however, the statistical summaries of the estimates probably provide reasonably accurate representations of the relative differences in transport of nutrients for the different stations on Choteau Creek. Nitrogen loads increase substantially downstream on Choteau Creek, probably due mostly to increases in streamflow.

Median whole-water phosphorus concentrations decrease downstream on Choteau Creek, from 0.51 mg/L for Choteau Creek near Wagner (station 06453200) to 0.34 mg/L for Choteau Creek near Dante (station 06453252) to 0.08 mg/L for Choteau Creek below Avon (station 06453300) (fig. 33, table 18). The whole-water phosphorus concentrations are large, especially for the two upstream stations, but similar to other streams draining agricultural lands in the upper Midwest (Tornes and others, 1997). For Choteau Creek near Wagner (station 06453200), the most upstream station, an average of about 65 percent of whole-water phosphorus occurs in dissolved inorganic form, that is, as dissolved orthophosphate. Dissolved orthophosphate accounts for an average of about 50 percent of whole-water phosphorus for Choteau Creek near Dante (station 06453252), and about 35 percent of whole-water phosphorus for Choteau Creek below Avon (station 06453300). Differences in forms of phosphorus probably indicate that there are different sources of phosphorus and/or processing of phosphorus in the creek channel downstream through the basin. Although phosphorus concentrations decrease downstream in the Choteau Creek Basin, calculated daily loads of phosphorus (table 21) increase downstream due to substantial increase in streamflow between the stations.

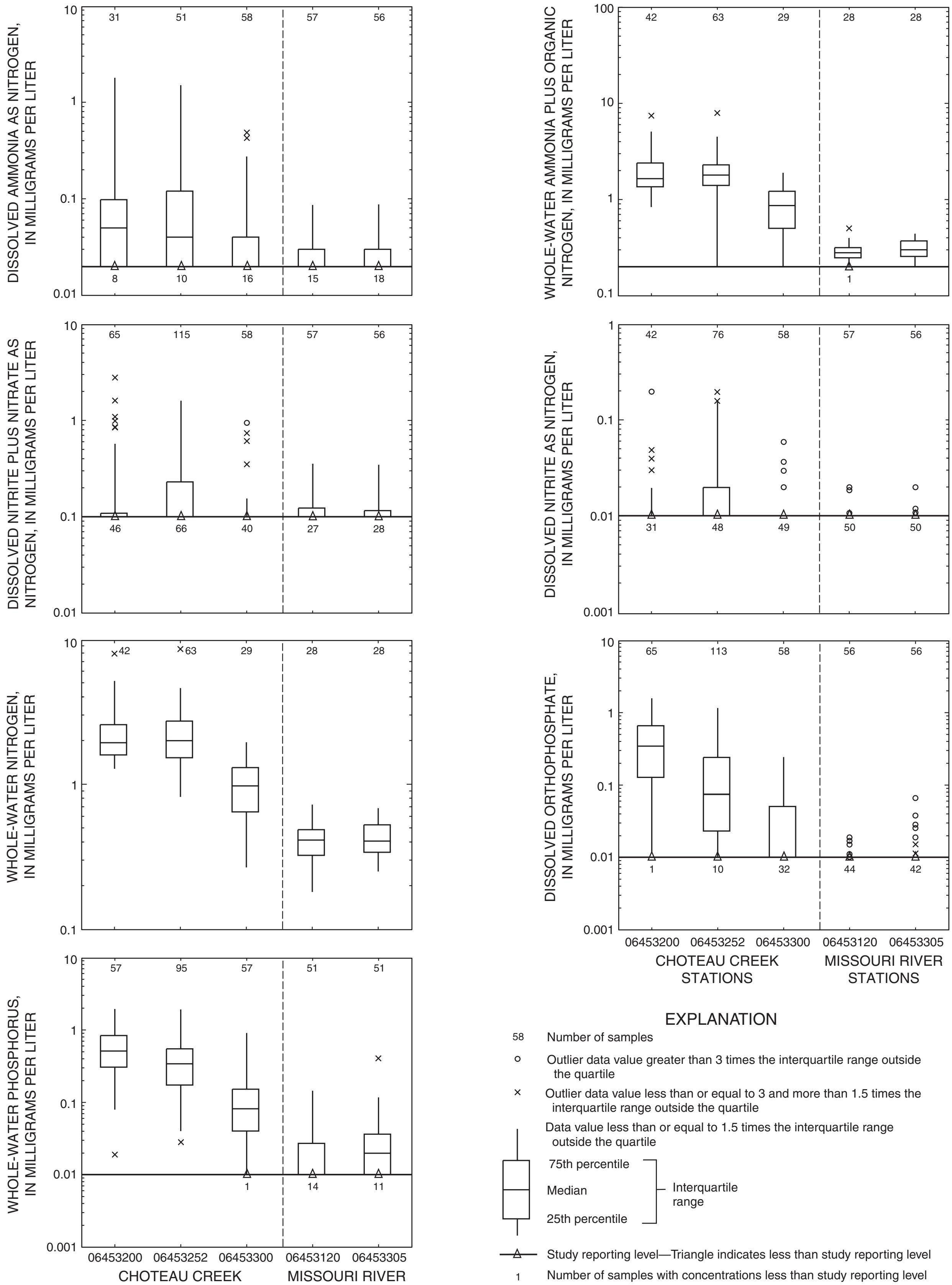


Figure 33. Boxplots of selected nitrogen and phosphorus constituents for selected stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (location of stations shown in figure 1).

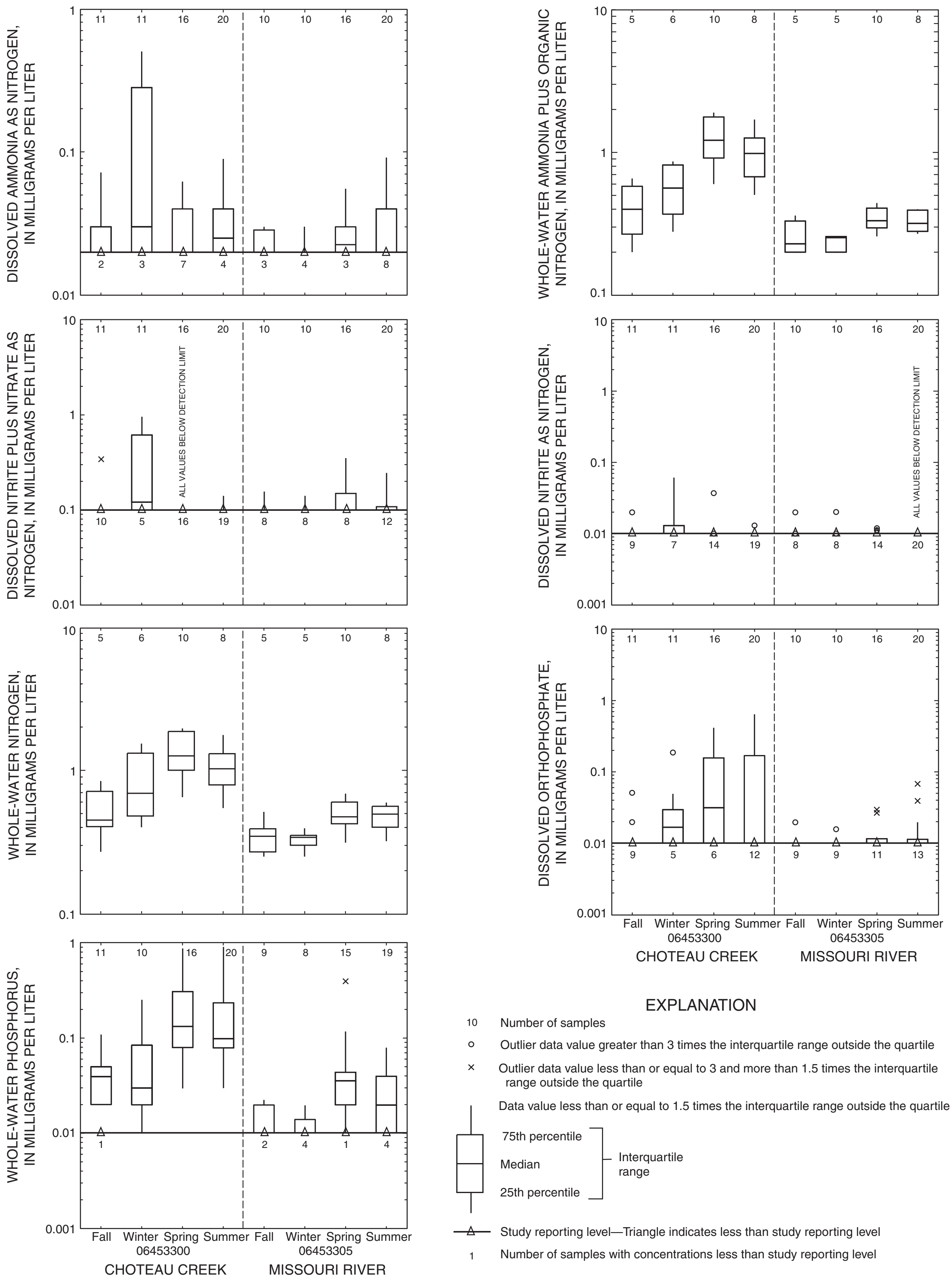


Figure 34. Boxplots showing seasonal distributions of nitrogen and phosphorus constituents for selected representative stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (location of stations shown in figure 1).

Table 20. Results of regression analyses for estimating daily nutrient loads based on streamflow for Choteau Creek stations, 1983-2000

[Location of stations shown in figure 1. L_N, nitrogen load, in pounds per day; L_P, phosphorus load, in pounds per day; Q, streamflow, in cubic feet per second, and $\tilde{C}$, retransformation bias-correction factor]

Station identification	Nitrogen				Phosphorus			
	Number of samples	R^2	Equation	Retransformation bias-correction factor ($\tilde{C}$)	Number of samples	R^2	Equation	Retransformation bias-correction factor ($\tilde{C}$)
06453200	42	0.96	$L_N = 12.25 \times Q^{0.939} \times \tilde{C}$	1.129	57	0.87	$L_P = 2.49 \times Q^{0.999} \times \tilde{C}$	1.354
06453252	62	0.98	$L_N = 11.69 \times Q^{0.967} \times \tilde{C}$	1.082	95	0.96	$L_P = 1.54 \times Q^{1.114} \times \tilde{C}$	1.272
06453300	29	0.97	$L_N = 2.16 \times Q^{1.261} \times \tilde{C}$	1.062	58	0.92	$L_P = 0.19 \times Q^{1.416} \times \tilde{C}$	1.301

Table 21. Statistical summaries of estimated daily loads of nitrogen and phosphorus for Choteau Creek stations, 1983-2000

[Location of stations shown in figure 1]

	Nitrogen load, in pounds per day			Phosphorus load, in pounds per day		
	06453200	06453252	06453300	06453200	06453252	06453300
Mean	264	407	748	88.1	143	228
Minimum	0.00	0.00	0.24	0.00	0.00	0.02
25th percentile	0.00	1.00	12.7	0.00	0.11	1.73
50th percentile	1.10	6.63	31.3	0.23	0.93	4.74
75th percentile	65.6	112	134	17.7	24.2	24.2
Maximum	9,260	15,400	113,000	3,420	7,000	46,500

On a seasonal basis for Choteau Creek, median values for both whole-water nitrogen and whole-water phosphorus were largest in spring and summer, and smallest in fall and winter (fig. 34). Concentrations of dissolved inorganic nitrogen forms (ammonia, nitrite, and nitrite plus nitrate) were larger in winter than in the other seasons. The median concentration for dissolved orthophosphate was largest in spring.

Median whole-water phosphorus concentrations for the Missouri River near the mouth of Choteau Creek range from 0.01 to 0.02 mg/L (table 19), which are relatively small. Dissolved inorganic phosphorus (orthophosphate) concentrations are nearly always less than the laboratory reporting level of 0.01 mg/L.

On a seasonal basis for the Missouri River stations, median values for both whole-water nitrogen and whole-water phosphorus were largest in spring and summer, and smallest in fall and winter (fig. 34). Concentrations of dissolved ammonia also generally were larger in spring and summer than in winter and fall.

Trends in flow-adjusted whole-water phosphorus concentrations for Choteau Creek stations (fig. 35) were modeled by fitting a monotonic linear trend to the period 1983-2000 for Choteau Creek near Wagner (station 06453200) and Choteau Creek near Dante (station 06453252), and to the period 1990-2000 for Choteau Creek below Avon (station 06453300). The shorter trend analysis period for Choteau Creek below Avon (station 06453300) was due to lack of data prior to 1990.

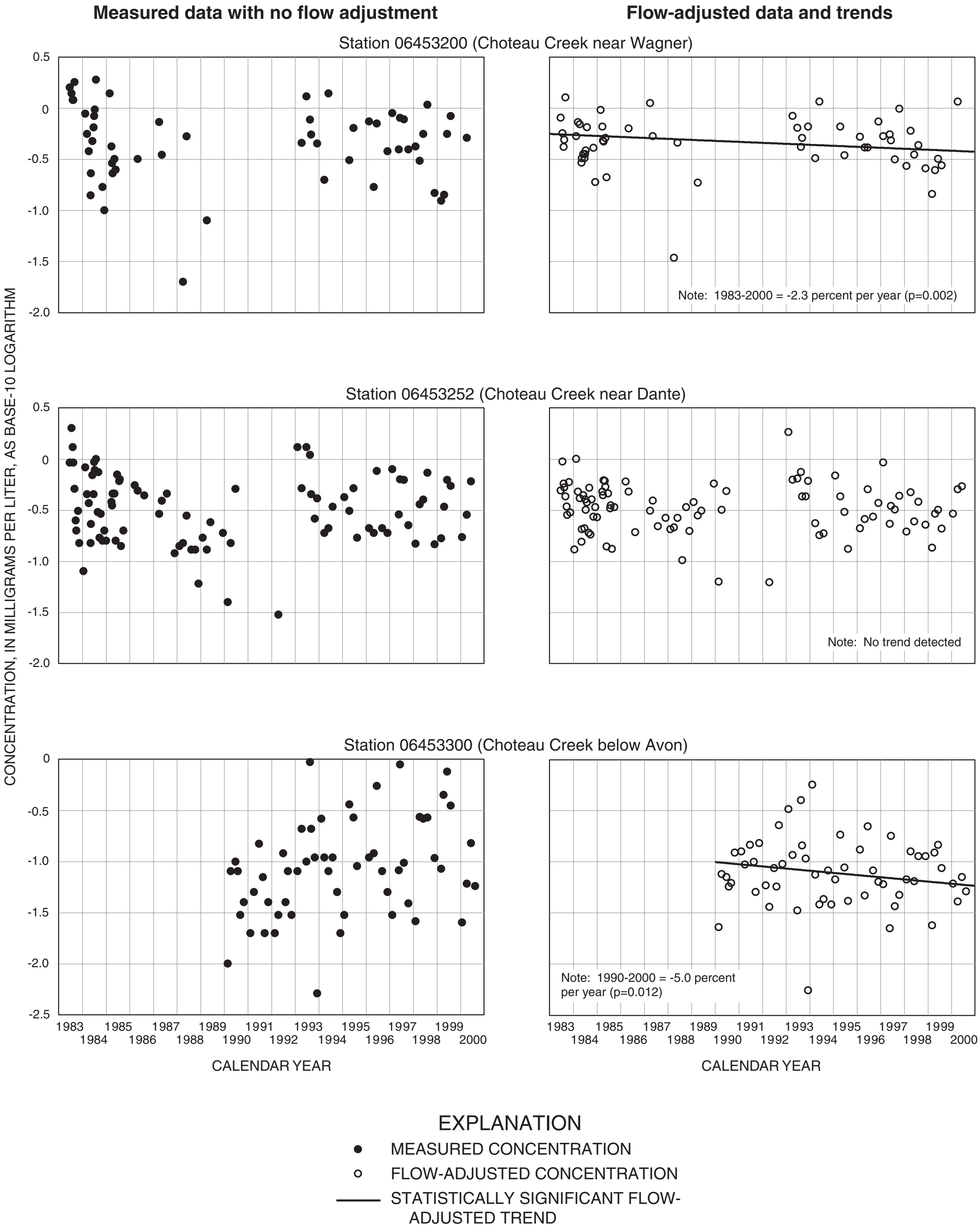


Figure 35. Concentrations of whole-water phosphorus and flow-adjusted trends for selected stations in the Choteau Creek Basin (location of stations shown in figure 1).

Choteau Creek near Wagner (station 06453200) and Choteau Creek below Avon (station 06453300) have statistically significant decreases in flow-adjusted whole-water phosphorus concentration of -2.3 and -5.0 percent per year. Choteau Creek near Dante (station 06453252) showed no trend in flow-adjusted whole-water phosphorus concentration. Although there was some variability in trend results for different Choteau Creek stations, flow-adjusted whole-water phosphorus concentrations for some reaches of Choteau Creek probably were decreasing during the period 1983-2000. Possible explanations for the observed trends are unknown, but might be related to effects of long-term changes in land use and agricultural operations. Given the violation of minimum-data recommendations for the trend analysis for Choteau Creek near Wagner (station 06453200) and Choteau Creek below Avon (station 06453300), the trend results for those stations should not be interpreted as confident determination of the presence or absence of significant trends.

Trace Elements

Statistical distributions of arsenic and selenium for stations on Choteau Creek and the Missouri River near the mouth of Choteau Creek are shown in figure 36. Seasonal distributions of arsenic and selenium for a single representative Choteau Creek station (06453300) and a single representative Missouri River station (06453305) are presented in figure 37.

For Choteau Creek stations, arsenic concentrations (table 18, fig. 36) are similar between stations 06453200 and 06453252 (both stations have medians of 4 µg/L), but arsenic concentrations for station 06453300 are smaller (median of 2 µg/L). The arsenic concentrations are relatively small and do not exceed water-quality standards or criteria. Selenium concentrations are lower for station 06453200 (the most upstream station; median concentration of 1 µg/L) than for stations 06453252 and 06453300 (median concentrations of 6 and 4 µg/L, respectively). The selenium concentrations for 06453252 and 06453300 are relatively large; the medians exceed the aquatic-life chronic criterion, and the largest concentrations for these stations exceed or approach the acute criterion (tables 9 and 18). Factors affecting differences in selenium concentrations between the tributary stations are unknown, but may relate to differences in geology and/or land use in the basins upstream from the stations. On a seasonal basis for Choteau Creek, median concentrations of arsenic were largest in spring and summer, and smallest in fall and winter (fig. 37; table 18). Median concentrations of selenium were largest in winter and spring, and smallest in summer and fall.

For Missouri River stations, arsenic and selenium concentrations are relatively small, with median concentrations of 2 µg/L for both constituents for both stations (table 19). Neither arsenic nor selenium concentrations for either station exceed relevant water-quality criteria. On a seasonal basis for the Missouri River, distributions of arsenic concentrations showed substantial overlap for all seasons (fig. 37). Median concentrations of selenium were larger in spring than in the other seasons.

Trends in flow-adjusted dissolved arsenic and selenium concentrations (fig. 38) were modeled by fitting a monotonic linear trend to the period 1983-2000 for Choteau Creek near Dante (station 06453252), and to the period 1990-2000 for Choteau Creek below Avon (station 06453300). The shorter trend analysis period for Choteau Creek below Avon (station 06453300) was due to lack of data prior to 1990. Trend analyses were not performed for arsenic and selenium for Choteau Creek near Wagner due to insufficient data.

Choteau Creek near Dante (station 06453252) and Choteau Creek below Avon (station 06453300) have statistically significant increases in flow-adjusted arsenic concentration of +1.6 and +3.0 percent per year. Choteau Creek below Avon (station 06453300) has a statistically significant increase in flow-adjusted selenium concentration of +6.4 percent per year. Possible explanations for the observed trends are unknown, but might be related to effects of long-term changes in land use and agricultural operations. Given the violation of minimum-data recommendations for the trend analyses, the trend results should not be interpreted as confident determination of the presence or absence of significant trends.

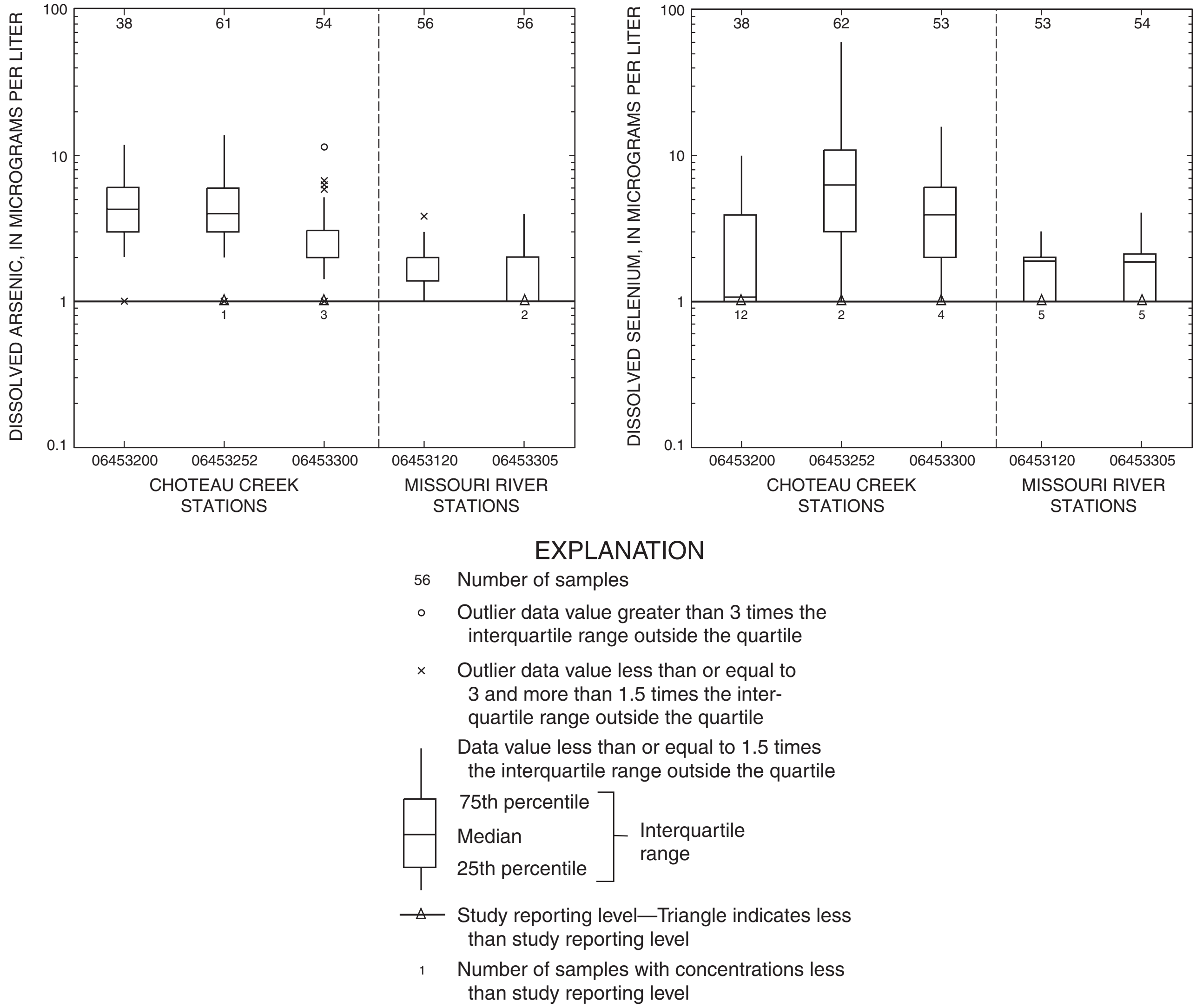


Figure 36. Boxplots of arsenic and selenium concentrations for selected stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (locations of stations shown in figure 1).

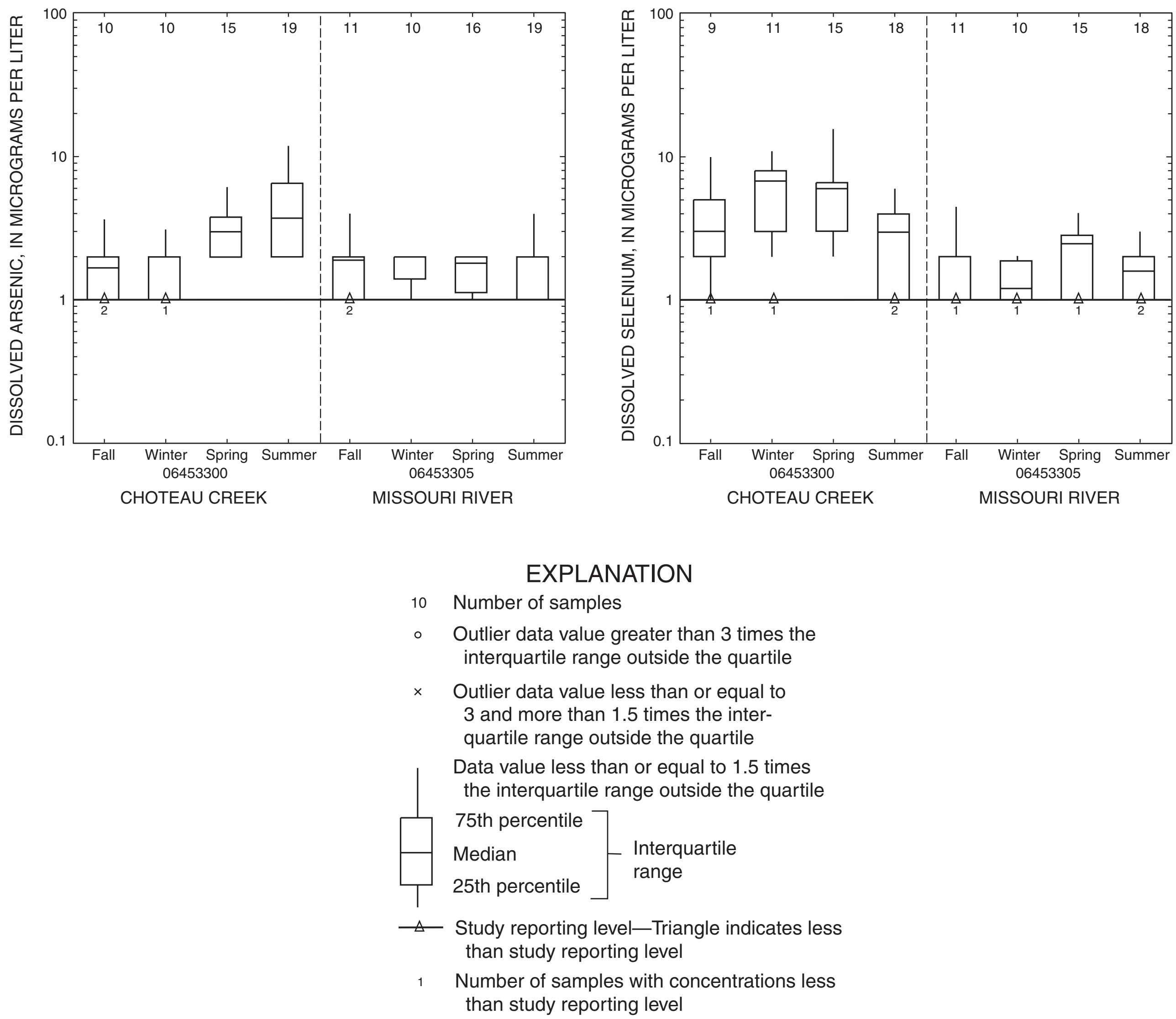


Figure 37. Boxplots showing seasonal distributions of arsenic and selenium concentrations for selected representative stations in the Choteau Creek Basin and on the Missouri River near the mouth of Choteau Creek for periods of record listed in table 5 (location of stations shown in figure 1).

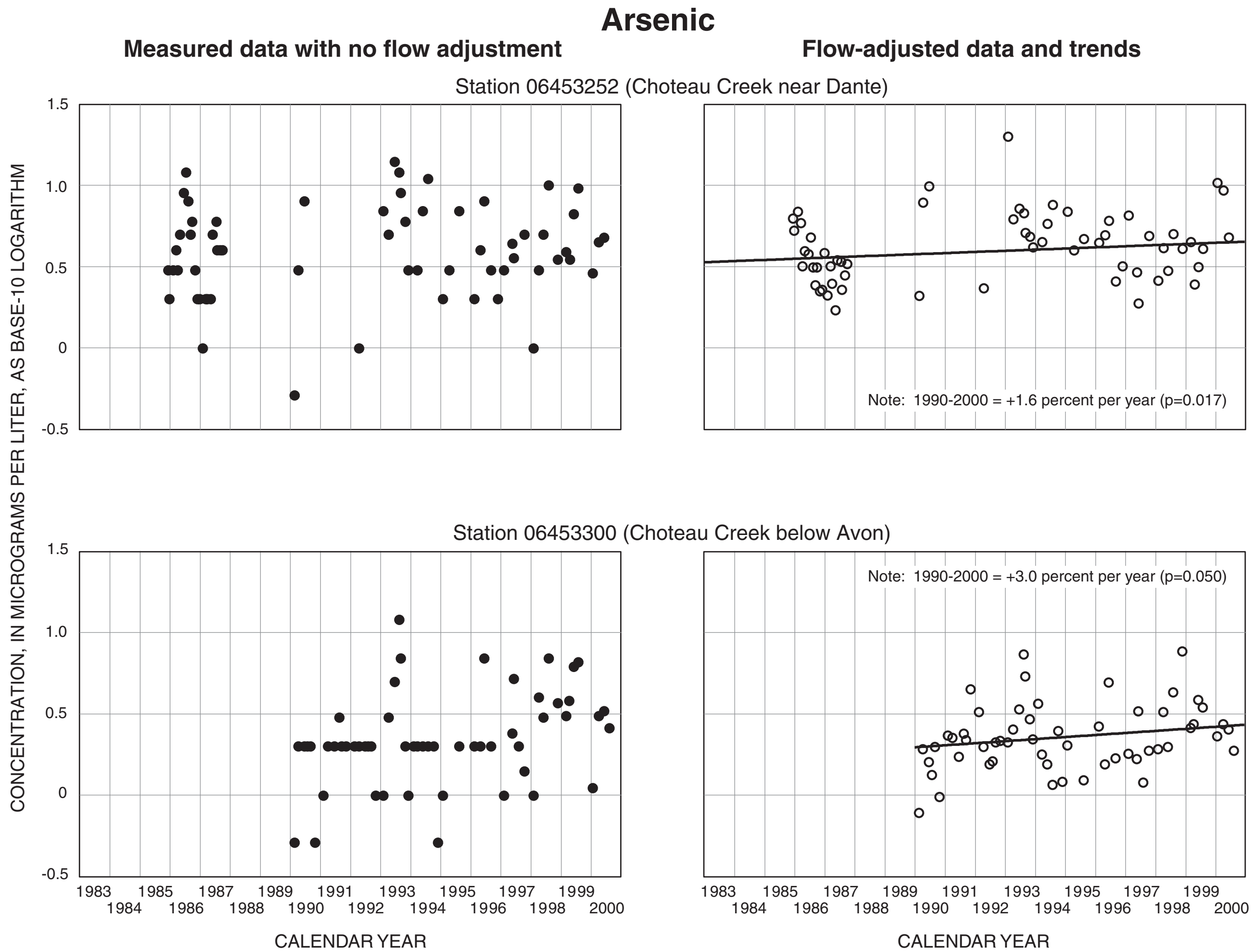


Figure 38. Concentrations of arsenic and selenium and flow-adjusted trends for selected stations in the Choteau Creek Basin (location of stations shown in figure 1).

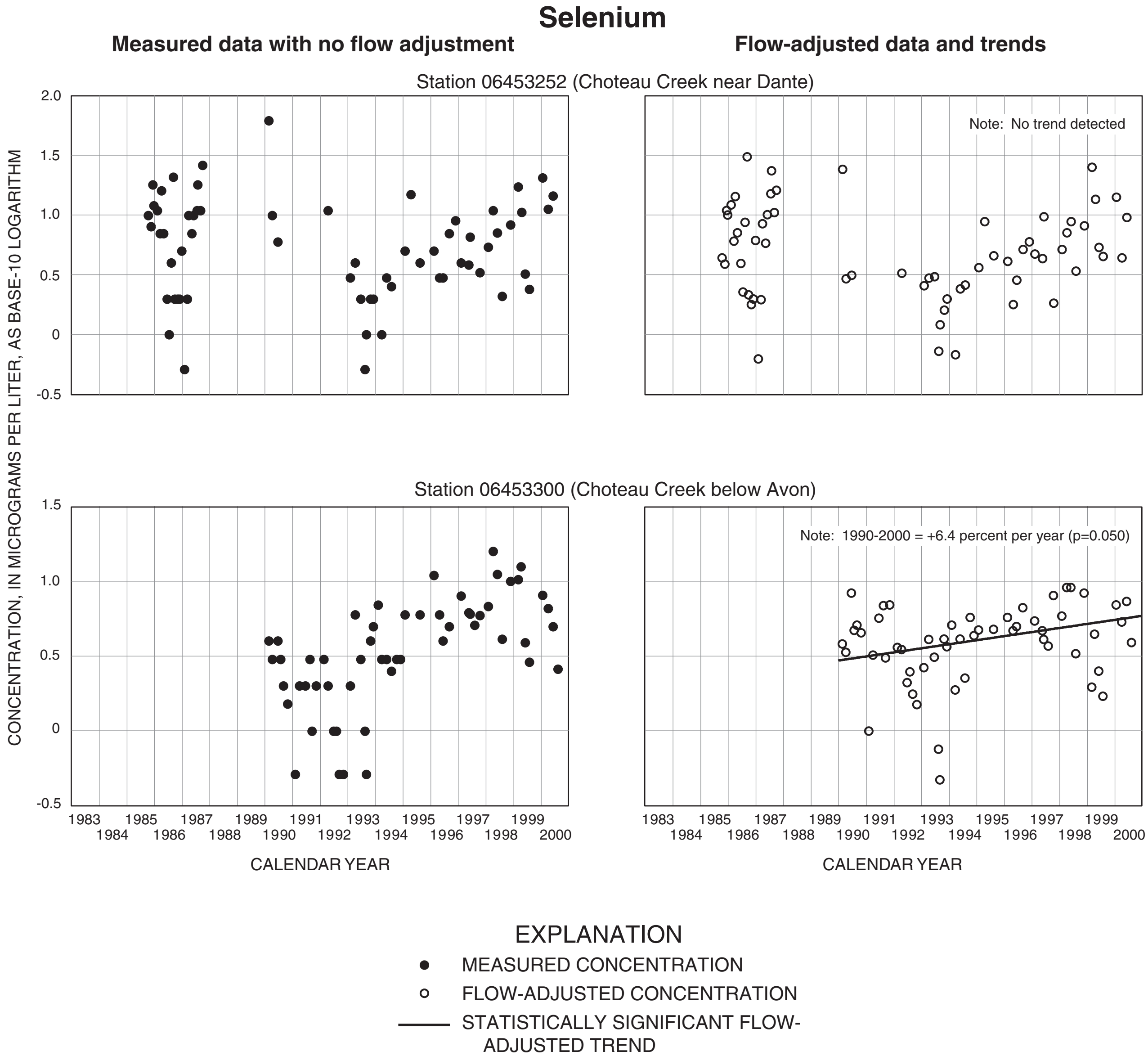


Figure 38. Concentrations of arsenic and selenium and flow-adjusted trends for selected stations in the Choteau Creek Basin (location of stations shown in figure 1).—Continued

Suspended and Bottom Sediment

Statistical distributions of suspended-sediment concentrations for Choteau Creek stations are shown in figure 39. Median suspended-sediment concentrations for Choteau Creek stations range from 27 to 106 mg/L (table 18, fig. 39), with the more downstream stations (stations 06453252 and 06453300) having larger medians (95 and 106 mg/L, respectively), and similar distributions (fig. 39). Most of the suspended sediment transported in the Lake Andes consists of particles less than 63 μm in diameter, as evidenced by median percent fines values greater than 85 percent for all of the Choteau Creek stations (table 18).

Trends in flow-adjusted suspended-sediment concentrations (fig. 40) were modeled by fitting a monotonic linear trend to the period 1983-2000 for Choteau Creek near Dante (station 06453252), and to the period 1990-2000 for Choteau Creek below Avon (station 06453300). The shorter trend-analysis period for Choteau Creek below Avon (station 06453300) was due to lack of data prior to 1990. Trend analyses were not performed for suspended sediment for Choteau Creek near Wagner (station 06453200) due to insufficient data.

No significant trend was detected for Choteau Creek near Dante (station 06453252). Choteau Creek below Avon (station 06453300) has a statistically significant decrease in flow-adjusted suspended-sediment concentration of -5.0 percent per year. Possible explanations for the observed trend are unknown, but might be related to effects of long-term changes in land use and agricultural operations. Given the violation of minimum-data recommendations for the trend analyses, the trend results should not be interpreted as confident determination of the presence or absence of significant trends.

Statistical summaries of constituent concentrations in bottom-sediment samples for Choteau Creek and Missouri River stations are shown in tables 22 and 23, respectively. Concentrations of most constituents generally had similar ranges and medians for the Choteau Creek stations. However, concentrations of several metals, including aluminum, chromium, copper, iron, lead, titanium, and zinc show consistent downstream decreases in median concentrations. Concentrations of manganese and strontium show consistent downstream increases in concentrations. Station 06453252 has a higher median arsenic concentration than the other two stations. All of the Choteau Creek stations had median arsenic and nickel concentrations that exceed USEPA threshold effects guidelines (tables 15 and 22). The largest nickel concentrations for all of the Choteau Creek stations exceed USEPA probable effects guidelines. The median copper concentration for station 06453200 exceeds the USEPA threshold effects guidelines. Selenium concentrations at all of the stations generally are greater than the baseline range for western soils. All of the stations also had

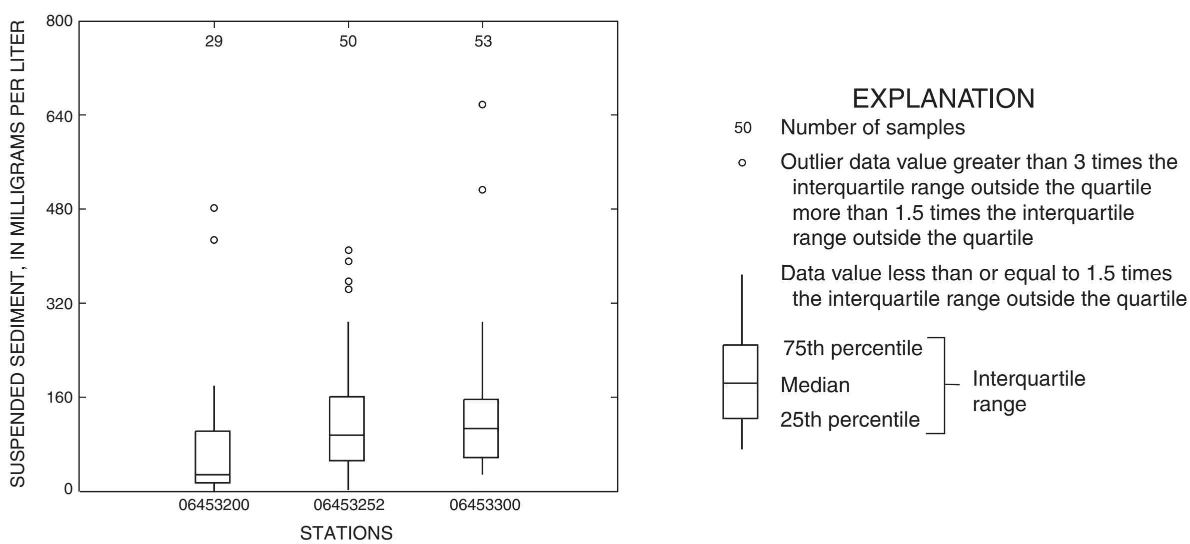


Figure 39. Boxplot of suspended-sediment concentrations for selected stations in the Choteau Creek Basin for periods of record listed in table 5 (location of stations shown in figure 1).

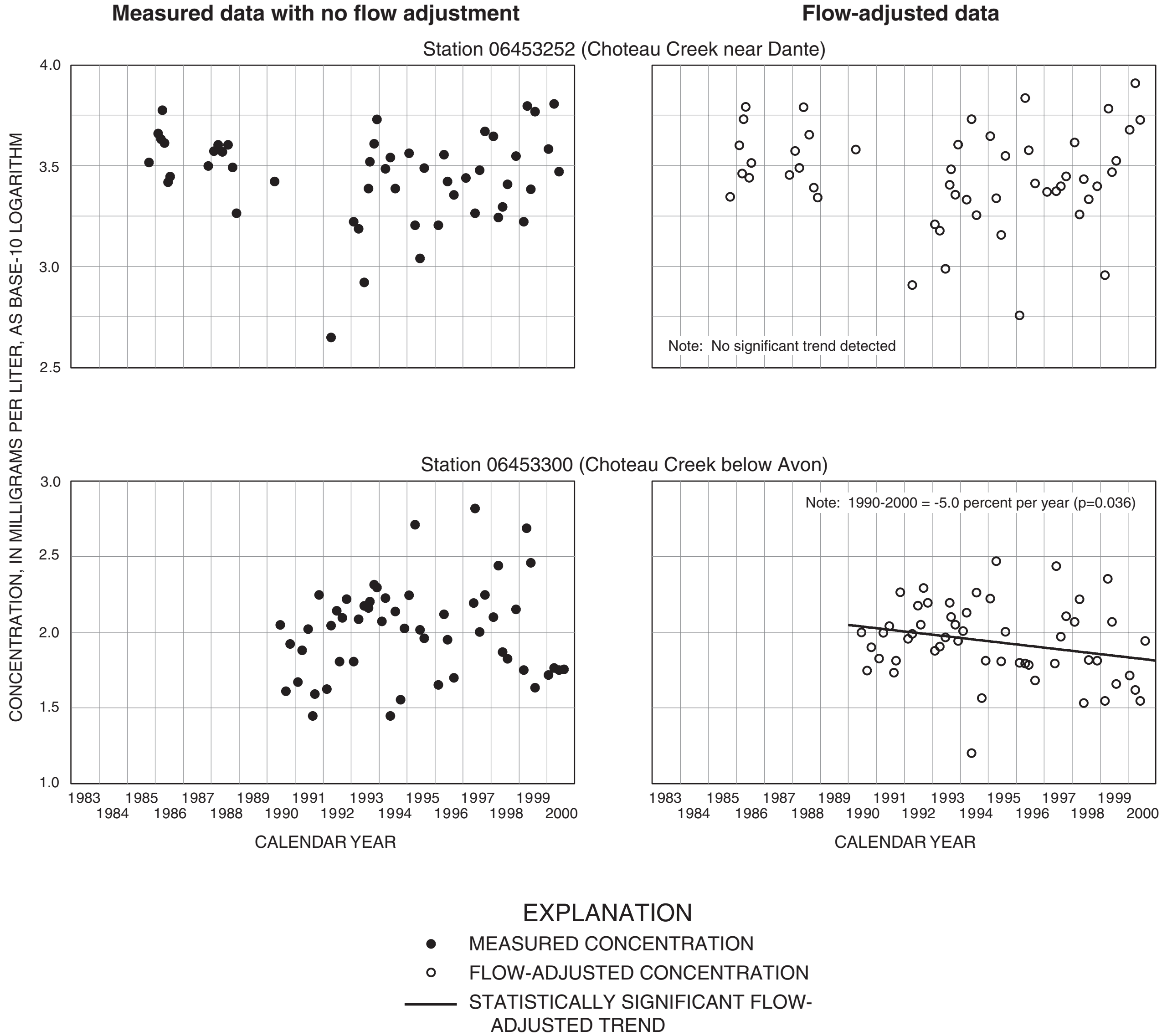


Figure 40. Concentrations of suspended sediment and flow-adjusted data for selected stations in the Choteau Creek Basin for periods of record listed in table 5 (location of stations shown in figure 1).

median selenium concentrations that exceed the NIWQP level of concern, and the largest concentrations for stations 06453200 and 06453252 exceed the NIWQP toxicity threshold.

For the Missouri River stations, median concentrations of most constituents were larger for station 06453305, which is downstream from Choteau Creek, than for station 06453120, which is upstream from Choteau Creek. Several metals, including chromium, copper, titanium, and zinc have the largest increases in median concentration between the two stations. The median selenium concentration for the downstream station was about two times larger than the upstream station. Both of the Missouri River stations had median arsenic and nickel concentrations that exceed USEPA threshold effects guidelines (tables 15 and 23). The largest nickel concentration for station 06453305 also exceeds the USEPA probable effects guidelines. The median copper concentration for station 06453305 exceeds USEPA threshold effects guidelines. The median selenium concentration for station 06453305 exceeds the NIWQP level of concern, and the maximum concentration for station 06453305 exceeds the NIWQP toxicity threshold.

Table 22. Statistical summaries of constituent concentrations in bottom-sediment samples for Choteau Creek stations, 1992-2000

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; <, less than]

Property or constituent	06453200 (Choteau Creek near Wagner)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	13	13	47	48	24	91
Magnesium (mg/g)	13	13	12	11	9	14
Potassium (mg/g)	13	13	16	16	13	18
Sodium (mg/g)	13	13	8	9	5	12
Phosphorus (mg/g)	13	13	1	1	1	1
Aluminum	13	13	53,100	53,000	40,000	61,000
Arsenic	13	13	12	11	7.4	17
Barium	13	13	729	690	600	900
Beryllium	13	12	1	1	<1	2
Bismuth	13	0	<10	<10	<10	<10
Cadmium	13	1	<2	<2	<2	3
Cerium	13	13	48	50	30	58
Chromium	13	13	50	48	24	74
Cobalt	13	13	12	11	8	15
Copper	13	13	22	23	8	33
Europium	13	0	<2	<2	<2	<2
Gallium	13	10	10	10	<4	16
Gold	13	0	<8	<8	<8	<8
Holmium	13	0	<4	<4	<4	<4
Iron	13	13	29,500	30,000	17,000	36,000
Lanthanum	13	13	29	30	18	36
Lead	13	13	18	18	9	25
Lithium	13	13	26	25	12	38
Manganese	13	13	2,440	2,300	1,100	4,100
Molybdenum	13	4	<2	<2	<2	7
Neodymium	13	13	25	27	14	38
Nickel	13	13	36	35	26	47
Niobium	13	11	8	8	<4	15
Scandium	13	13	8	7	4	10
Selenium	12	12	2.1	1.7	1.0	6.1
Silver	13	0	<2	<2	<2	<2
Strontium	13	13	240	240	190	310
Tantalum	13	0	<40	<40	<40	<40
Thorium	13	12	7	7	<4	9
Tin	13	0	<5	<5	<5	<5
Titanium	13	13	2,080	2,100	1,100	2,900
Uranium	13	0	<100	<100	<100	<100
Vanadium	13	13	122	130	59	180
Ytterbium	13	13	2	2	1	3
Yttrium	13	13	18	19	11	21
Zinc	13	13	102	99	47	140

Table 22. Statistical summaries of constituent concentrations in bottom-sediment samples for Choteau Creek stations, 1992-2000—Continued

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; <, less than]

Property or constituent	06453252 (Choteau Creek near Dante)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	17	17	59	58	44	78
Magnesium (mg/g)	17	17	11	11	7	16
Potassium (mg/g)	17	17	14	14	11	17
Sodium (mg/g)	17	17	11	11	5	15
Phosphorus (mg/g)	17	17	1	1	1	2
Aluminum	17	17	45,400	44,000	39,000	60,000
Arsenic	15	15	16	16	8.5	21
Barium	17	17	856	690	530	3,600
Beryllium	17	12	<1	1	<1	1
Bismuth	17	1	<10	<10	<10	10
Cadmium	17	2	<2	<2	<2	2
Cerium	17	17	39	40	20	55
Chromium	17	17	35	36	19	59
Cobalt	17	17	11	10	7	14
Copper	17	17	13	13	3	26
Europium	17	0	<2	<2	<2	<2
Gallium	17	11	10	10	<4	19
Gold	17	0	<8	<8	<8	<8
Holmium	17	0	<4	<4	<4	<4
Iron	17	17	23,200	23,000	12,000	36,000
Lanthanum	17	17	23	25	13	31
Lead	17	17	18	13	9	47
Lithium	17	17	17	15	9	33
Manganese	17	17	3,700	3,000	2,100	8,000
Molybdenum	17	8	2	<2	<2	10
Neodymium	17	17	20	21	11	30
Nickel	17	17	32	34	15	47
Niobium	17	10	6	5	<4	10
Scandium	17	17	5	5	3	10
Selenium	16	16	1.8	1.3	0.5	8.2
Silver	17	0	<2	<2	<2	<2
Strontium	17	17	276	280	240	330
Tantalum	17	0	<40	<40	<40	<40
Thorium	17	12	6	6	<4	12
Tin	17	0	<5	<5	<5	<5
Titanium	17	17	1,420	1,400	700	2,300
Uranium	17	0	<100	<100	<100	<100
Vanadium	17	17	86	85	42	180
Ytterbium	17	16	1	2	<1	2
Yttrium	17	17	15	15	9	21
Zinc	17	17	68	68	17	130

Table 22. Statistical summaries of constituent concentrations in bottom-sediment samples for Choteau Creek stations, 1992-2000—Continued

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; <, less than]

Property or constituent	6453300 (Choteau Creek below Avon)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	21	21	61	52	38	110
Magnesium (mg/g)	21	21	10	9	7	24
Potassium (mg/g)	21	21	15	14	13	18
Sodium (mg/g)	21	21	12	13	9	14
Phosphorus (mg/g)	21	21	1	1	1	2
Aluminum	21	21	41,300	40,000	34,000	54,000
Arsenic	19	19	13	11	7.1	21
Barium	21	21	1,330	1,100	680	4,000
Beryllium	21	7	<1	<1	<1	1
Bismuth	21	2	<10	<10	<10	20
Cadmium	21	1	<2	<2	<2	2
Cerium	21	21	36	35	21	60
Chromium	21	21	26	24	14	50
Cobalt	21	21	10	10	4	17
Copper	21	21	11	9	3	24
Europium	21	0	<2	<2	<2	<2
Gallium	21	17	11	10	<4	30
Gold	21	0	<8	<8	<8	<8
Holmium	21	0	<4	<4	<4	<4
Iron	21	21	22,000	22,000	14,000	31,000
Lanthanum	21	21	22	22	13	33
Lead	21	21	11	11	5	17
Lithium	21	21	12	11	7	24
Manganese	21	21	6,150	4,800	2,800	15,000
Molybdenum	21	10	3	2	<2	7
Neodymium	21	21	16	16	9	26
Nickel	21	21	29	27	15	53
Niobium	21	9	4	4	<4	7
Scandium	21	21	4	4	2	8
Selenium	20	20	1.8	1.9	0.7	3.0
Silver	21	0	<2	<2	<2	<2
Strontium	21	21	297	290	210	410
Tantalum	21	0	<40	<40	<40	<40
Thorium	21	13	5	5	<4	12
Tin	21	0	<5	<5	<5	<5
Titanium	21	21	1,150	1,100	500	2,500
Uranium	21	0	<100	<100	<100	<100
Vanadium	21	21	66	65	28	120
Ytterbium	21	18	1	1	<1	2
Yttrium	21	21	15	14	9	22
Zinc	21	21	61	59	38	100

[1]"Number of detections" refers to number of samples that had concentrations larger than the study reporting level.

[2]When calculating mean values for constituents with censored data (that is, having some concentrations reported as less than the study reporting level), a value of one-half the study reporting level was assigned to the samples reported as less thans.

Table 23. Statistical summaries of constituent concentrations in bottom-sediment samples for Missouri River stations, 1992-2000

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; <, less than]

Property or constituent	06453120 (Missouri River above Choteau Creek)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	22	22	20	16	11	65
Magnesium (mg/g)	22	22	5	4	2	22
Potassium (mg/g)	22	22	16	16	12	19
Sodium (mg/g)	22	22	10	10	8	12
Phosphorus (mg/g)	22	22	1	1	0	1
Aluminum	22	22	38,000	36,500	28,000	65,000
Arsenic	20	20	13	13	6.4	20
Barium	22	22	933	875	700	13,00
Beryllium	22	5	<1	<1	<1	2
Bismuth	22	0	<10	<10	<10	<10
Cadmium	22	0	<2	<2	<2	<2
Cerium	22	22	39	37	23	65
Chromium	22	22	24	19	8	61
Cobalt	22	22	9	8	3	13
Copper	22	22	7	6	2	23
Europium	22	0	<2	<2	<2	<2
Gallium	22	20	8	7	<4	15
Gold	22	0	<8	<8	<8	<8
Holmium	22	0	<4	<4	<4	<4
Iron	22	22	19,400	18,000	14,000	28,000
Lanthanum	22	22	23	22	14	39
Lead	22	22	14	14	7	28
Lithium	22	22	11	9	5	31
Manganese	22	22	1,370	790	360	5,100
Molybdenum	22	1	<2	<2	<2	2
Neodymium	22	22	18	16	10	31
Nickel	22	22	23	22	15	36
Niobium	22	11	4	<4	<4	14
Scandium	22	19	4	3	<2	9
Selenium	21	21	0.9	0.7	0.2	3.1
Silver	22	0	<2	<2	<2	<2
Strontium	22	22	212	215	140	340
Tantalum	22	0	<40	<40	<40	<40
Thorium	22	13	5	4	<4	11
Tin	22	0	<5	<5	<5	<5
Titanium	22	22	1,970	950	400	18,000
Uranium	22	0	<100	<100	<100	<100
Vanadium	22	22	44	35	20	120
Ytterbium	22	20	1	1	<1	2
Yttrium	22	22	13	12	9	21
Zinc	22	22	47	42	28	91

Table 23. Statistical summaries of constituent concentrations in bottom-sediment samples for Missouri River stations, 1992-2000—Continued

[Location of stations shown in figure 1. All values in micrograms per gram, except as indicated. mg/g, milligrams per gram; <, less than]

Property or constituent	06453305 (Missouri River below Choteau Creek)					
	Number of samples	Number of detections[1]	Mean[2]	Median	Minimum	Maximum
Calcium (mg/g)	22	22	33	26	12	110
Magnesium (mg/g)	22	22	8	8	2	11
Potassium (mg/g)	22	22	16	17	9	19
Sodium (mg/g)	22	22	9	10	3	13
Phosphorus (mg/g)	22	22	1	1	0	1
Aluminum	22	22	45,500	44,500	24,000	63,000
Arsenic	21	21	16	13	8.7	31
Barium	22	22	902	810	310	2,000
Beryllium	22	15	1	1	<1	5
Bismuth	22	0	<10	<10	<10	<10
Cadmium	22	4	<2	<2	<2	5
Cerium	22	22	51	52	23	110
Chromium	22	22	41	41	12	87
Cobalt	22	22	12	12	7	27
Copper	22	21	20	19	<1	50
Europium	22	0	<2	<2	<2	<2
Gallium	22	21	11	9	<4	28
Gold	22	0	<8	<8	<8	<8
Holmium	22	0	<4	<4	<4	<4
Iron	22	22	23,200	22,000	14,000	34,000
Lanthanum	22	22	30	29	13	67
Lead	22	22	15	15	6	24
Lithium	22	22	19	18	7	36
Manganese	22	22	2,270	1,150	420	10,000
Molybdenum	22	7	4	<2	<2	32
Neodymium	22	22	24	24	9	45
Nickel	22	22	41	31	18	100
Niobium	22	16	8	8	<4	14
Scandium	22	21	5	5	<5	9
Selenium	21	21	2.0	1.2	0.2	6.7
Silver	22	0	<2	<2	<2	<2
Strontium	22	22	283	255	160	730
Tantalum	22	0	<40	<40	<40	<40
Thorium	22	19	7	7	<4	12
Tin	22	0	<5	<5	<5	<5
Titanium	22	22	1,890	1,800	500	5,500
Uranium	22	0	<100	<100	<100	<100
Vanadium	22	22	105	87	26	330
Ytterbium	22	20	2	2	<1	3
Yttrium	22	22	17	18	9	24
Zinc	22	22	79	75	32	170

[1]"Number of detections" refers to number of samples that had concentrations larger than the study reporting level.

[2]When calculating mean values for constituents with censored data (that is, having some concentrations reported as less than the study reporting level), a value of one-half the study reporting level was assigned to the samples reported as less thans.

SUMMARY AND CONCLUSIONS

The Bureau of Reclamation has proposed construction of the Lake Andes/Wagner Irrigation Demonstration Project to investigate environmental effects of irrigation of glacial till soils substantially derived from marine shales and containing high levels of the trace element selenium. During 1983-2000, the U.S. Geological Survey has been collecting hydrologic, water-quality, and sediment data in the Lake Andes and Choteau Creek Basins, and on the Missouri River upstream and downstream from Choteau Creek, to provide baseline information in support of the proposed demonstration project. This report summarizes and describes these data sets.

Lake Andes has a drainage area of about 230 mi^2 (square miles). Tributaries to Lake Andes are ephemeral and characterized by frequent periods of no flow. Water-level fluctuations in Lake Andes can be large, and the lake has been completely dry on several occasions. Lake Andes is divided into three units: North, Center, and South.

Choteau Creek has a drainage area of 619 mi^2. In the upstream part of the basin, Choteau Creek is essentially ephemeral, and flows will frequently be zero or near zero. Downstream from Wagner, Choteau Creek receives ground-water discharge providing perennial flow during most years. Choteau Creek enters the Missouri River about 28 river miles downstream from Fort Randall Dam. Choteau Creek contribution to the Missouri River relative to release from Fort Randall Dam generally is small.

Dissolved-oxygen concentrations for Lake Andes and its tributaries typically range from about 8 to 11 mg/L (milligrams per liter). Water samples from various locations in the Lake Andes Basin have pH values that typically range from about 7.8 to 8.4. Typical specific-conductance values for Lake Andes tributaries range from about 800 to 1,800 µS/cm (microsiemens per centimeter at 25 degrees Celsius). Specific-conductance values for Lake Andes tend to be higher than the tributaries, with typical ranges from 1,800 to 2,600 µS/cm. Specific-conductance values tend to increase downstream in the lake. Water temperatures at various locations in the Lake Andes Basin are similar, and are typical of shallow northern temperate water bodies.

For Lake Andes tributaries, calcium, magnesium, and sodium are approximately codominant among the cations, and sulfate is the dominant anion. Dissolved-solids concentrations typically range from about 1,000 mg/L to about 1,700 mg/L. Major-ion concentrations for Lake Andes tend to be higher than the tributaries, probably due to evaporative concentration and/or flux of solutes from lake-bottom sediments. Proportions of major ions are similar for different locations in Lake Andes (with the exception of Owens Bay), with calcium, magnesium, and sodium being approximately codominant among cations, and sulfate being the dominant anion. Owens Bay is characterized by a calcium sulfate water type. Dissolved-solids concentrations for Lake Andes typically range from about 1,400 to 2,000 mg/L. All of the Lake Andes stations showed statistically significant ($p<0.001$) increasing volume-adjusted trends in dissolved-solids concentrations from 1990-2000.

Whole-water nitrogen and phosphorus concentrations are similar among the Lake Andes tributaries. Median whole-water nitrogen concentrations range from about 1.6 to 2.4 mg/L, and median whole-water phosphorus concentrations range from about 0.5 to 0.7 mg/L. Organic nitrogen accounts for an average of about 90 percent of whole-water nitrogen for Andes Creek (the largest tributary to Lake Andes), but accounts for an average of about 50 to 60 percent of whole-water nitrogen for the other tributaries. Much of the phosphorus in the tributaries is in dissolved inorganic form (dissolved orthophosphate), which accounts for an average of about 70 to 80 percent of whole-water phosphorus in the tributaries. Andes Creek contributes the largest loads of nitrogen and phosphorus to Lake Andes.

Whole-water nitrogen concentrations in Lake Andes are similar among the different units and are relatively large, with medians that range from about 2.4 to 4.0 mg/L. Organic nitrogen accounts for an average of about 90 percent of whole-water nitrogen in all of the units of Lake Andes. The mass of nitrogen in Lake Andes generally fluctuates between about 150 to 230 tons. Median whole-water phosphorus concentrations for the different Lake Andes units range from 0.2 to 0.5 mg/L, and decrease downstream through Lake Andes. The average organic phosphorus proportion of whole-water phosphorus ranges from 60 to 90 percent for the different units of Lake Andes. The mass of phosphorus in Lake Andes generally fluctuates between about 6 to 20 tons.

Arsenic concentrations generally are similar among the Lake Andes tributary stations, with median concentrations ranging from 3 to 5 µg/L (micrograms per liter). Median selenium concentrations are substantially lower for Andes Creek (3 µg/L) than for the other tributary stations (34, 18, and 7 μg/L). Median arsenic concentrations in Lake Andes generally are similar among the different lake stations (about 7 μg/L), but the median for Owens Bay (2 μg/L) is substantially lower. Selenium concentrations for the lake stations tend to be relatively small (medians ranging from less than 1 to 2 μg/L), and substantially lower than tributary stations. For the period 1990-2000, arsenic concentrations in the North and South Units of Lake Andes show increasing trends.

The pesticides 2,4-D and atrazine were the most commonly detected pesticides in Lake Andes. Median concentrations for 2,4-D for Lake Andes range from 0.07 to 0.11 μg/L; the median concentration for Owens Bay is 0.04 μg/L. Median concentrations for atrazine for Lake Andes range from 0.2 to 0.4 μg/L; the median concentration for Owens Bay is less than 0.1 μg/L. Concentrations of both 2,4-D and atrazine are largest for the most upstream part of Lake Andes that is most influenced by tributary inflow.

Median suspended-sediment concentrations for Lake Andes tributaries range from 22 to 56 mg/L. Most of the suspended sediment transported in the Lake Andes tributaries consists of particles less than 63 μm (micrometers) in diameter.

Concentrations of most constituents in bottom sediments generally had similar ranges and medians for the Lake Andes tributaries. However, Andes Creek generally had lower concentrations of several metals. For Lake Andes, medians and ranges for most constituents generally were similar among the different units. However, selenium concentrations tended to be higher in the upstream part of the lake, and generally decreased downstream in Lake Andes. Concentrations of several metals are smaller for Owens Bay than for the Lake Andes units. Results of vertical sediment cores collected from a single site in the South Unit of Lake Andes in October 2000 indicate that selenium loading to Lake Andes increased during the period 1952 through 2000.

Median dissolved-oxygen concentrations for Choteau Creek and Missouri River stations typically range from about 7.5 to 11 mg/L and 10.5 to 11 mg/L, respectively. Water samples for Choteau Creek stations have similar median pH values, ranging from 7.9 to 8.1. Median pH values for the Missouri River stations range from 8.2 to 8.3. Median specific-conductance values for Choteau Creek stations range from 1,600 to 2,280 μS/cm, and specific-conductance values for Choteau Creek near Dante (the middle of the three stations on Choteau Creek) are larger than both upstream and downstream stations. Median specific-conductance values for the Missouri River stations range from 781 to 791 μS/cm. Median water temperatures for Choteau Creek stations are very similar, ranging from 13.0 to 14.3°C (degrees Celsius). Median temperatures for the two Missouri River stations range from 11.1 to 12.3°C.

For all of the Choteau Creek stations, calcium is dominant among the cations, and sulfate is dominant among the anions. Median dissolved-solids concentrations range from 1,180 to 1,780 mg/L. Analyses of flow-adjusted trends indicate generally similar statistically significant increases in dissolved-solids concentrations for all of the Choteau Creek stations. For the two Missouri River stations, calcium, magnesium, and sodium are approximately codominant among the cations, and bicarbonate and sulfate are about codominant among the anions. Differences in major-ion concentrations between the two Missouri River stations are negligible, indicating that Choteau Creek inflows generally have very little effect on major-ion concentrations in the Missouri River. Median dissolved-solids concentrations for the Missouri River stations range from 501 to 502 mg/L.

Whole-water nitrogen concentrations for the upstream and middle stations on Choteau Creek are similar (medians of 1.9 and 2.0 mg/L), but whole-water nitrogen concentrations for the downstream station are substantially smaller (median of 1.0 mg/L). Most of the nitrogen in Choteau Creek is in organic form, which generally accounts for an average of between about 85 to 90 percent of whole-water nitrogen. Nitrogen loads in Choteau Creek increase substantially downstream, probably due mostly to increases in streamflow. Median whole-water nitrogen concentrations for the Missouri River stations range from 0.41 to 0.42 mg/L, which are relatively small. An average of about 65 percent of whole-water nitrogen occurs in organic form for the Missouri River stations.

Median whole-water phosphorus concentrations decrease downstream on Choteau Creek, from 0.51 mg/L at the most upstream station to 0.08 mg/L at the most downstream station. The whole-water phosphorus concentrations in Choteau Creek are large, especially for the upstream and middle stations. At the most upstream station, an average of about 65 percent of phosphorus occurs in dissolved inorganic form (dissolved orthophosphate). At the most downstream station, an average of about 35 percent of phosphorus occurs in dissolved inorganic form. Although phosphorus concentrations decrease downstream in the Choteau Creek Basin, daily loads of phosphorus increase downstream due to substantial increase in streamflow. Trends in flow-adjusted whole-water phosphorus concentrations for the Choteau Creek stations varied. Median whole-water phosphorus concentrations for the Missouri River near the mouth of Choteau Creek range from 0.01 to 0.02 mg/L, which are relatively small. Dissolved inorganic phosphorus is nearly always below the study reporting level of 0.01 mg/L.

For Choteau Creek stations, arsenic concentrations are similar among the upstream and middle stations (both stations have medians of 4 µg/L), but arsenic concentrations for the downstream station (median of 2 µg/L) are lower. Selenium concentrations are lower for the most upstream station (median concentration of 1 µg/L) than for the middle and downstream stations (median concentrations of 6 and 4 µg/L). Trends in flow-adjusted arsenic and selenium concentrations for Choteau Creek stations varied. For Missouri River stations, arsenic and selenium concentrations are relatively small, with median concentrations of 2 µg/L for both constituents for both stations.

Median suspended-sediment concentrations for Choteau Creek stations range from 27 to 106 mg/L. Most of the suspended sediment transported in the Choteau Creek consists of particles less than 63 µm in diameter. Trends in flow-adjusted suspended-sediment concentrations for Choteau Creek stations varied.

Concentrations of most constituents in bottom sediments generally had similar ranges and medians for the Choteau Creek stations. However, concentrations of several metals show consistent downstream decreases in median concentrations. For the Missouri River stations, median concentrations of most constituents in bottom sediments were larger for the station downstream from Choteau Creek. Several metals, including chromium, copper, titanium, and zinc have the largest increases in median concentration between the two stations. The median selenium concentration for the downstream station was about two times larger than the upstream station.

One of the objectives of the Lake Andes/Choteau Creek water-quality monitoring program was to describe the water- and bottom-sediment quality of the Lake Andes and Choteau Creek Basins in a manner that would help in evaluating water-quality changes that might occur in the basins if the proposed Bureau of Reclamation Irrigation Demonstration Project is constructed. The analyses that were conducted for this report show that water-quality conditions in the basins change over seasonal and annual time periods. Results of the trend analyses also indicate that long-term changes in water quality might be occurring in the basins. It is emphasized again that the results of the trend analyses should be used with caution due to the violations of minimum data requirements. Perhaps the strongest conclusion that might be drawn from the trend analyses is that establishing accurate estimates of "baseline" conditions for water-quality properties and constituents in the basins is difficult. Water-quality effects that might occur as a result of specific land-use changes must be considered in relation to more long-term and general variability that occurs.

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SUPPLEMENTAL INFORMATION

Table 24. Analytical results for quality-control laboratory equipment blank samples

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, no data; M, constituent determined to be present but at an unquantified concentration less than the reporting level]

Date	Calcium, dissolved (mg/L as Ca) (00915)	Magnesium, dissolved (mg/L as Mg) (00925)	Sodium, dissolved (mg/L as Na) (00930)	Silica, dissolved (mg/L as SiO_2) (00955)	Nitrogen ammonia, dissolved (mg/L as N) (00608)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) (00631)	Nitrogen, nitrite, dissolved (mg/L as N) (00613)
02-10-94	0.03	M	M	<0.1	<0.002	<0.005	0.001
12-05-94	.01	M	<.1	M	--	--	--
09-15-95	.06	0.03	.1	M	<.002	<.005	.001
06-20-96	.01	M	M	M	.004	<.005	.001
09-20-96	.03	M	M	<.1	<.002	<.005	<.001
06-13-97	<.01	<.01	<.1	.2	<.002	.007	.001
07-23-98	<.01	<.01	<.1	.1	.048	.017	.001
03-11-99	<.01	<.01	<.1	<.1	.002	<.005	<.001
04-05-00	.03	M	.1	.1	<.002	<.005	<.001

Date	Phosphorus, orthophos-phate, dissolved (mg/L as P) (00671)	Aluminum, dissolved (µg/L as Al) (01106)	Antimony, dissolved (µg/L as Sb) (01095)	Barium, dissolved (µg/L as Ba) (01005)	Beryllium, dissolved (µg/L as Be) (01010)	Boron, dissolved (µg/L as B) (01020)	Cadmium, dissolved (µg/L as Cd) (01025)
02-10-94	<0.001	3	<1	M	<1	<20	<0.3
12-05-94	--	1	<1	<1	<1	<2	<.3
09-15-95	<.001	2	<1	<1	<1	3	<.3
06-20-96	<.001	1	<1	<1	<1	<2	<.3
09-20-96	<.001	3	<1	M	<1	4	<.3
06-13-97	.001	1	<1	<1	<1	13	<.3
07-23-98	.015	1	<1	<1	<1	20	<.3
03-11-99	.002	<1	<1	<1	<1	2	<.3
04-05-00	.004	<1	<1	<1	<1	<2	<.3

Table 24. Analytical results for quality-control laboratory equipment blank samples–Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, no data; M, constituent determined to be present but at an unquantified concentration less than the reporting level]

Date	Chromium, dissolved (µg/L as Cr) (01030)	Cobalt, dissolved (µg/L as Co) (01035)	Copper, dissolved (µg/L as Cu) (01040)	Iron, dissolved (µg/L as Fe) (01046)	Lead, dissolved (µg/L as Pb) (01049)	Manganese, dissolved (µg/L as Mn) (01056)	Molybdenum, dissolved (µg/L as Mo) (01060)
02-10-94	0.3	<1	M	M	<1	<1	<1
12-05-94	<.2	<1	<1	<1	<1	<1	<1
09-15-95	.3	<1	<1	<1	<1	M	<1
06-20-96	<.2	<1	<1	<1	<1	<1	<1
09-20-96	.3	<1	<1	<1	<1	3	<1
06-13-97	<.2	<1	<1	<1	<1	<1	<1
07-23-98	<.2	<1	<1	<1	<1	<1	<1
03-11-99	<.2	<1	<1	<1	<1	<1	<1
04-05-00	<.2	<1	<1	<1	<1	<1	<1

Date	Nickel, dissolved (µg/L as Ni) (01065)	Silver, dissolved (µg/L as Ag) (01075)	Strontium, dissolved (µg/L as Sr) (01080)	Thallium, dissolved (µg/L as Tl) (01057)	Zinc, dissolved (µg/L as Zn) (01090)	Uranium, natural, water, dissolved, (µg/L) (22703)
02-10-94	<1	<1	<0.1	<0.1	1	<1
12-05-94	<1	<1	<.1	<.1	<1	<1
09-15-95	<1	<1	.2	<.1	1	<1
06-20-96	<1	<1	<.1	<.1	1	<1
09-20-96	1	<1	.2	<.1	1	<1
06-13-97	<1	<1	<.1	<.1	<1	<1
07-23-98	<1	<1	<.1	<.1	1	<1
03-11-99	<1	<1	<.1	<.1	<1	<1
04-05-00	<1	<1	<.1	<.1	10	<1

Table 25. Analytical results for quality-control field equipment blank samples collected at Lake Andes above Ravinia (station 06452390)

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; °C, degrees Celsius; µg/L, micrograms per liter, <, less than; --, no data; E, estimated; M, constituent determined to be present but at an unquantified concentration less than the reporting level]

Major-ion constituents						
Date	Specific conductance (µS/cm) (90095)	Calcium, dissolved (mg/L as Ca) (00915)	Magnesium, dissolved (mg/L as Mg) (00925)	Potassium dissolved (mg/L as K) (00935)	Sodium, dissolved (mg/L as Na) (00930)	Alkalinity, titration to pH 4.5, laboratory (mg/L as $CaCO_3$) (90410)
10-12-94	3	<0.02	<0.01	0.3	<0.2	2
04-26-95	2	.03	<.01	<.1	<.2	<1
08-23-95	3	<.02	<.01	<.1	<.2	2
02-20-96	2	<.02	<.01	<.1	<.2	1
09-10-96	4	<.02	<.01	<.1	<.2	1
02-10-97	3	<.02	<.01	<.1	<.2	2
08-12-97	2	.03	.01	<.1	<.2	2
02-18-98	2	<.02	<.01	<.1	<.1	1
08-11-98	2	<.02	<.01	<.1	<.1	2
03-15-99	3	E.01	M	<.1	M	1
08-09-99	4	<.02	M	<.1	<.1	2
02-07-00	E2	E.01	<.01	<.2	<.1	2
08-22-00	5	<.02	<.01	<.2	<.1	2

Date	Chloride, dissolved (mg/L as Cl) (00940)	Fluoride, dissolved (mg/L as F) (00950)	Silica, dissolved (mg/L as SiO_2) (00955)	Sulfate, dissolved (mg/L as SO_4) (00945)	Solids, residue on evaporation at 180°C, dissolved (mg/L) (70300)
10-12-94	<0.1	<0.1	<0.1	<0.1	<1
04-26-95	<.1	<.1	.2	<.1	18
08-23-95	<.1	<.1	<.1	0.1	<1
02-20-96	<.1	<.1	<.1	<.1	24
09-10-96	<.1	<.1	<.1	<.1	<1
02-10-97	<.1	<.1	.1	<.1	<1
08-12-97	<.1	<.1	.3	<.1	2
02-18-98	<.1	<.1	<.1	<.1	20
08-11-98	<.1	<.1	<.1	<.1	<10
03-15-99	<.1	<.1	.2	<.1	<10
08-09-99	<.1	<.1	.6	<.1	<10
02-07-00	<.3	<.1	.5	<.3	<10
08-22-00	<.3	<.1	<.1	<.3	<10

Table 25. Analytical results for quality-control field equipment blank samples collected at Lake Andes above Ravinia (station 06452390)–Continued

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; °C, degrees Celsius; µg/L, micrograms per liter, <, less than; --, no data; E, estimated; M, constituent determined to be present but at an unquantified concentration less than the reporting level]

Nitrogen and phosphorus constituents						
Date	Nitrogen ammonia, dissolved (mg/L as N) (00608)	Nitrogen ammonia plus organic, whole-water (mg/L as N) (00625)	Nitrogen nitrite plus nitrate, dissolved (mg/L as N) (00631)	Nitrogen, nitrite, dissolved (mg/L as N) (00613)	Phosphorus orthophosphate, dissolved (mg/L as P) (00671)	Phosphorus, whole-water (mg/L as P) (00665)
10-12-94	0.02	<0.20	<0.050	<0.010	<0.010	0.01
04-26-95	<.015	<.20	<.050	<.010	<.010	<.010
08-23-95	<.015	<.20	<.050	<.010	<.010	.03
02-20-96	<.015	<.20	<.050	<.010	<.010	<.010
09-10-96	<.015	<.20	.06	<.010	<.010	<.010
02-10-97	<.015	<.20	<.050	<.010	<.010	<.010
08-12-97	<.015	<.20	<.050	<.010	<.010	<.010
02-18-98	<.020	<.10	.081	<.010	.019	<.010
08-11-98	.081	<.10	<.050	<.010	.016	<.010
03-15-99	<.020	<.10	<.050	<.010	<.010	<.050
08-09-99	<.020	<.10	<.050	<.010	<.010	<.050
02-07-00	<.020	<.10	<.050	<.010	<.010	<.050
08-22-00	<.020	<.10	<.050	<.010	<.010	<.050

Selected trace-element constituents				
Date	Arsenic, dissolved (µg/L as As) (01000)	Cadmium, dissolved (µg/L as Cd) (01025)	Lead, dissolved (µg/L as Pb) (01049)	Selenium, dissolved (µg/L as Se) (01145)
10-12-94	<1.0	<1.0	<1	<1.0
04-26-95	--	--	--	--
08-23-95	<1.0	<1.0	<1	<1.0
02-20-96	<1.0	<1.0	<1	<1.0
09-10-96	<1.0	<1.0	<1	<1.0
02-10-97	<1.0	--	--	<1.0
08-12-97	<1.0	--	--	<1.0
02-18-98	<1.0	--	--	<1.0
08-11-98	<1.0	--	--	<1.0
03-15-99	<1.0	--	--	<1.0
08-09-99	<1.0	--	--	<1.0
02-07-00	<2.0	--	--	<2.4
08-22-00	<2.0	--	--	<2.4