Water Quality of the Viburnum Trend Subdistrict, Exploration Area, and Strother Creek, Southeastern Missouri, 1964–2006

By Michael J. Kleeschulte

Chapter 6 of

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Edited by Michael J. Kleeschulte

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Abstract

The lead ore deposits of the Viburnum Trend Subdistrict (Viburnum Trend), southeastern Missouri are a part of the largest known lead reserve within the United States. Mining in the Viburnum Trend began in 1960 and has continued uninterrupted since; presently (2008), six mines are active. Total ore production from individual mines ranges from 20 to more than 50 million tons, and ore contains as much as 8 percent lead and 3 percent zinc.

Water-quality data collected from streams and springs draining lead and zinc mining areas along the Viburnum Trend Subdistrict and non-mining areas to the south in the Current River and Eleven Point River Basins from April through June 2002 were compared to quantify changes in water quality spatially and with distance downstream from active mining. Data from 37 historical water-quality samples collected from 1964 to 2005 downstream from the Buick Mine in Strother Creek also were analyzed to document water-quality changes in this stream with time.

Three groups were used for comparison: non-mining sites which are sites upstream from mining activity or mine tailings or sites where no mining activity is present in the basin; near-mining sites where there is mining activity or mine tailings ponds within 7.5 miles upstream from the site; and distal-mining sites where mining activity is conducted more than 7.5 miles upstream from the site.

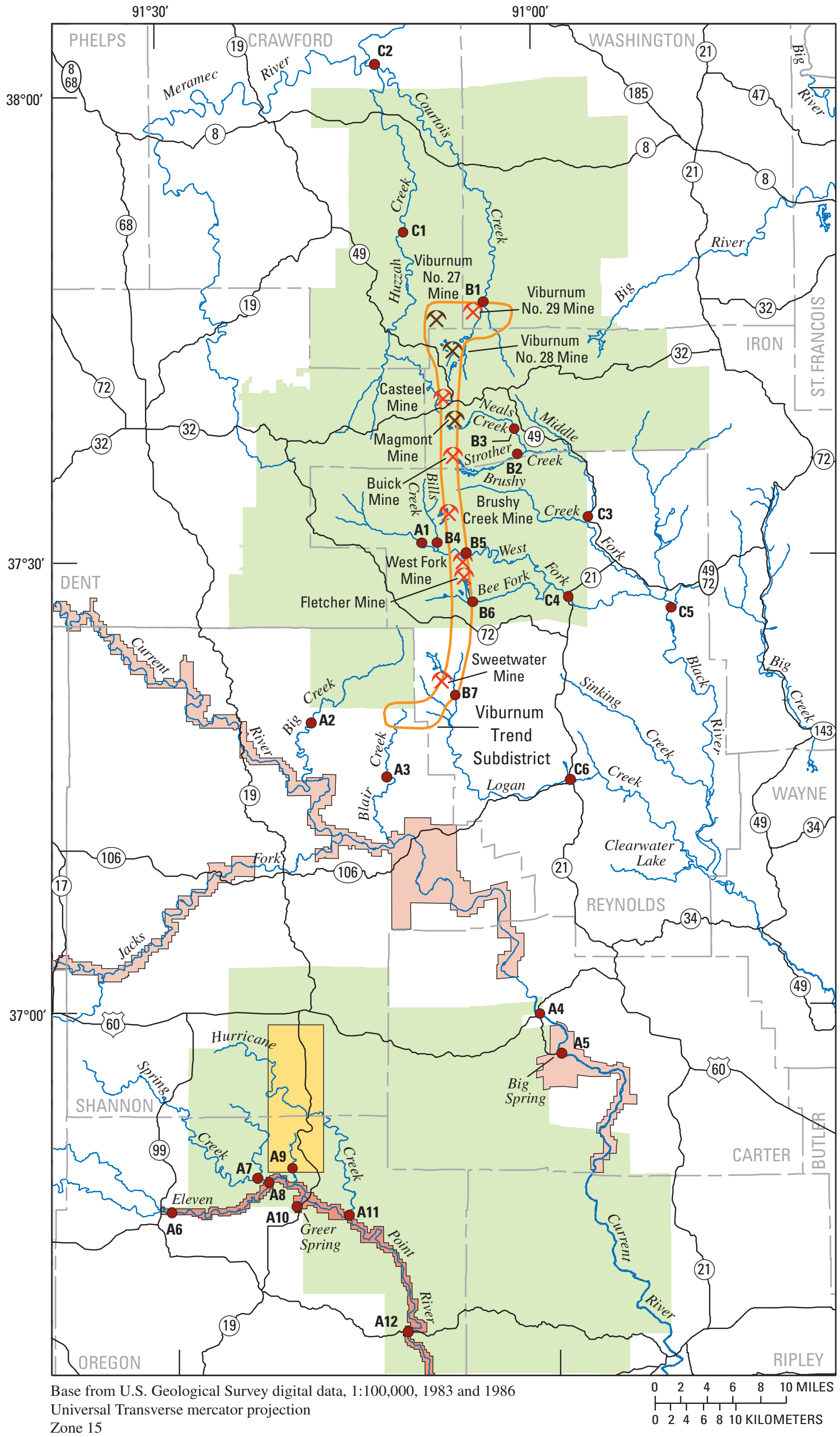
Samples collected from non-mining sites had little variability in general chemical composition, but samples from near-mining and distal-mining sites had differing sodium, chloride, and sulfate concentrations. Most surface- and spring-water samples collected during this study were calcium-magnesium-bicarbonate water type, except for Strother Creek near Goodland, which was calcium-magnesium-sulfate type. When compared to non-mining sites, most near-mining and distal-mining sites had elevated sulfate and chloride concentrations. Sodium, chloride, and sulfate concentrations peaked at near-mining sites, then decreased downstream at distal-mining sites; however, concentrations at distal-mining sites did not decrease to the lower concentrations detected at non-mining sites.

Trace-element concentrations also were different at the three site groups. The copper, nickel, lead, zinc, lithium, and strontium concentrations also peaked at near-mining sites, but decreased downstream at distal-mining sites to concentrations statistically similar to those observed at non-mining sites. Cadmium concentrations were similar at near-mining and distal-mining sites, but were significantly smaller at non-mining sites. Cobalt concentrations peaked at near-mining sites, and then decreased at the distal-mining sites; however, even though the concentrations significantly decreased downstream from mining activity, they did not achieve the lesser concentrations measured at the non-mining sites.

Historical water-quality data from 1964 through 2005 from two near-mining sites on Strother Creek downstream from the Buick Mine indicated surface-water quality changes with time. The data were separated into four periods and statistically analyzed. Sodium, chloride, sulfate, and potassium concentrations significantly increased after 1967 (pre-mining period is considered 1964–67) in Strother Creek Basin, and remained elevated through the most recent sampling period (1995 through 2005). Sulfate concentrations continued to significantly increase during each successive period sampled. Calcium and magnesium concentrations also increased with time. The concentrations of copper, manganese, and zinc were similar during the pre-mining and most recent periods.

Introduction

The lead ore deposits of the Viburnum Trend Subdistrict (Viburnum Trend), southeastern Missouri, are a part of the largest known lead reserve within the United States (U.S. Geological Survey, 2008a). Mining in the Viburnum Trend began in 1960 and has continued uninterrupted since. As many as 10 mines have operated in the Viburnum Trend, and presently (2008), six mines are active (fig. 1). Total ore production from individual mines ranges from 20 to more than 50 million tons, and ore contains as much as 8 percent



Base from U.S. Geological Survey digital data, 1:100,000, 1983 and 1986
Universal Transverse mercator projection
Zone 15

EXPLANATION

🟩 **Mark Twain National Forest**

🟧 **Ozark National Scenic Riverways**

🟥 **Eleven Point National Wild and Scenic River**

🟨 **Exploration area**

A9 ● **Water-quality sampling site and identifier** (table 1)

⚒ **Mine**—Red color indicates active mine (2008)

Note: West Fork Mine is currently (2008) considered part of Fletcher Mine.

Figure 1. Study area and water-quality sampling sites.

lead and 3 percent zinc (C.M. Seeger, Missouri Department of Natural Resources, Division of Geology and Land Survey, written commun., 2008). Ore mined underground is brought to the surface and milled at several of the mines. Tailings (waste rock) from the milling process are pumped as slurry to large surface impoundments that fill headwater stream valleys. After ore mineral concentrates have been prepared for shipment, they are transported by truck directly to a smelter, or in the case of copper and zinc, by truck to a rail system for shipment to a smelter.

As ore reserves are being depleted in the Viburnum Trend, exploration for new deposits is expanding farther south in part of the Mark Twain National Forest (fig. 1). Two federally designated streams occur in this region, the Ozark National Scenic Riverways, administered by the National Park Service and the Eleven Point National Wild and Scenic River managed by the U.S. Department of Agriculture, Forest Service. This area of mature karst terrain contains the two largest springs in Missouri—Big Spring and Greer Spring (Vineyard and Feder, 1982).

The potential expansion of mining activities into these federally designated areas has prompted a series of long-term environmental studies that are characterizing the effects of lead and zinc mining in southeastern Missouri.

Study Area Description

The study area includes streams that drain the Viburnum Trend, and streams draining non-mining areas to the south (fig. 1). The area lies within a large region of well-developed karst terrain that is characterized by the presence of caves, springs, sinkholes, and gaining and losing streams. The topography is characterized by deep, narrow valleys and narrow, steep-sided ridges that resulted from deep dissection of the carbonate bedrock by surface and karst drainage. More than 300 feet (ft) of relief is common between the ridge top and the adjacent valley.

Purpose and Scope

Water samples were collected by the U.S. Geological Survey (USGS) from streams and springs in the Huzzah Creek and Black River Basins that drain the Viburnum Trend and from the non-mining Current River and Eleven Point River Basins to the south. Twenty-five samples were collected during high-base flow from April through June 2002 to quantify water-quality changes spatially and with distance downstream from active mining. Data from 37 historical water-quality samples collected from 1964 to 2005 downstream from the Buick Mine in Strother Creek also were analyzed to document water-quality changes in this stream with time.

Methodology

The Huzzah Creek and Black River Basin sampling sites (fig. 1) were selected based on their proximity to active mining sites and tailings ponds. Sampling sites that were upstream from known mining activity or in stream basins where no known mining activity has occurred were used as baseline water-quality sites. In the Current River and Eleven Point River Basins, stream and spring sites were selected that have an increased probability of being affected if future mining activities would occur in the exploration area. This determination was based on proximity of the site to the exploration area and results of dye-tracing tests performed in the Mark Twain National Forest that delineated spring recharge areas (data on file at the USGS, Rolla, Missouri, and the Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla, Missouri). Base flow occurs during periods of minimum streamflow and minimum daily fluctuations when discharge is sustained by diffuse ground water and spring inflow, not by surface runoff. Base flow rates change seasonally and generally are higher during spring or early summer than during the late summer and fall. This sample collection effort was suspended at one point because intense rainfall caused runoff to occur and the base-flow conditions, required for sampling, to cease.

Springs are excellent water-quality monitoring sites because they are points at which ground-water flow converges and typically are representative of the water in the entire recharge area for the spring. Spring recharge areas can contain ground-water flow from less than one to hundreds of square miles, and typically, the size of the recharge area is reflected by the volume of the spring discharge.

Sample sites were classified into proximity-to-mining groups based on the location of the site to the nearest mining activities or tailings ponds. The classification contains three groups: non-mining sites, which are sampling sites upstream from mining activity or tailings ponds, or sites where no mining activity is present in the basin; near-mining sites, where mining activity or tailings ponds occur within 7.5 miles (mi) upstream from sampling site; and distal-mining sites, where mining activity occurs upstream from the sampling sites at distances greater than 7.5 mi.

Because water in Strother Creek had a large sulfate concentration and elevated calcium, magnesium, potassium, sodium, and chloride concentrations as compared to water from non-mining sites, and water-quality data that preceded mining in the basin were available, a time-trend analysis was performed. These historical data were collected for different studies with different objectives; consequently, different suites of constituents were analyzed and reported. Concentrations for major anions and cations were available for most samples, but some trace-element data also are available. Some nutrient data also are available for Strother Creek and are on file at the USGS office in Rolla, Missouri.

Sample Collection

The 1995 and later samples were collected from cross sections in the stream or spring branch where water was moving with sufficient velocity to allow mixing of the water. These samples were collected using the equal-width increment (EWI) method (Wilde and others, 1999). This method consists of dividing the stream into 10 to 15 sampling verticals of equal width. At each sampling vertical, a water sample was collected using a hand-held, depth integrating sampler (DH-81) constructed of polypropylene and nylon with a Teflon container. The sampler was raised and lowered using the same transit rate at each vertical, and the amount of water collected in the sample bottle was a function of velocity and depth of water at the vertical. The water sample from each vertical was composited into a polyethylene churn splitter using the techniques described by Wilde and others (1999). Water samples collected before 1976 used methods and procedures that were established and acceptable at the time. The historical methods and procedures that were used to collect the water samples are described in publications of the National Water Quality Laboratory (NWQL) (USGS, 2008b).

The aliquot to be analyzed was dispensed from the composite water sample in the churn splitter. The chemical constituents to be analyzed in the “dissolved” phase were filtered onsite through a 0.45-micrometer (µm) cellulose-nitrate membrane filter supported between Lucite plates, using a peristaltic pump as the pressure source. After onsite filtration of the water and rinsing of the sample bottle, the samples were placed into polyethylene bottles. Cation and trace-element samples were preserved with ultrapure nitric acid to a pH less than 2; samples for dissolved anions were not acidified.

Stream or spring discharge, specific conductance, pH, and water temperature were measured onsite, and alkalinity was determined at all sampling locations (Wilde and Radtke, 1998). At sites where no USGS gaging station was present, discharge measurements were made with a current meter using the general methods described by Rantz and others (1982). At sites near gaging stations, stage readings were converted to discharge using the stage-discharge relation developed for the site (Rantz and others, 1982). Specific conductance values were measured using a portable conductivity meter with temperature compensation designed to express readings in microsiemens per centimeter at 25 ºC (µS/cm). The pH was measured with a portable pH meter. Water temperature was measured with a thermistor to the nearest 0.1 ºC. The acid neutralizing capacity (ANC) was determined by incremental titration past the bicarbonate-carbonic acid inflection point using 0.1600 normal (N) sulfuric acid.

All water-quality samples collected from 1995 and later were analyzed by the USGS NWQL in Lakewood, Colorado. Samples collected before 1976 were analyzed using standard procedures that were acceptable at the time. Samples were analyzed for inorganic constituents according to methods described by Taggart (2002). When chemical constituents were detected at concentrations that were less than concentrations deemed reliable for reporting as numerical values, they were considered to be less than the reporting level. In the water-quality tables at the back of this chapter, these data are indicated by a less than (<) symbol in front of the reporting level value. Suspended-sediment samples were collected using the EWI method from about 10 verticals across the stream with a depth-integrating sampler. All suspended sediment concentrations were determined in the USGS sediment laboratory in Rolla, Missouri, using the evaporation method (Guy, 1969). The historical Strother Creek data were analyzed according to acceptable procedures available at the time of collection. There were no duplicate or split samples for comparison or quality control purposes collected with the 2002 sample set or the historical Strother Creek sample set.

Data Analysis

The water-sample composition described in this chapter can be diagrammatically represented in terms of major dissolved ionic constituents. The relation among these major constituents can be displayed by grouping ions with similar chemical properties on trilinear diagrams. Units on trilinear diagrams generally are expressed as percentages of the total milliequivalents per liter for each ion in a sample, and the assumption is made that the sum of these percentages is equal to 100.

Trilinear diagrams approximate the general composition of the water by showing proportions of the water-quality constituents relative to three cationic and anionic groups. On trilinear diagrams, there are three separate areas where each sample is plotted. The central diamond is used to show the overall chemical character of the water. The position of each point in the diamond indicates the composition of the sample in terms of the cation-anion groups that correspond to the four vertices of the diamond. The triangle in the lower left is used to display the relations of the three groups of cations in the sample and the triangle in the lower right is used to display the relations of the three groups of anions (Hem, 1985).

Stiff diagrams are another method used to display the major chemical composition of water samples. This method uses a distinctive pattern or polygon to represent general water composition. The diagram uses three parallel horizontal axes extending on each side of a vertical axis that represents zero. The milliequivalent concentration of cations is plotted to the left of zero and anions are plotted to the right of zero. All ions are plotted on the diagram using the same scale, and on all diagrams each ion is plotted in the same order (Hem, 1985).

Boxplots provide a visual summary of the 25th, 50th, and 75th percentiles and any extreme values in the distribution. The boxplot consists of the median value (50th percentile) plotted as a horizontal line, and a box is drawn from the 25th percentile to the 75th percentile. The box length is the interquartile range (IQR) and represents one-half of the data values. The IQR is insensitive to the presence of extreme values in the distribution. If the median value does not divide the box into two equal parts, it indicates asymmetry in the data distribution. Adjacent values are located outside the box and within 1.5 times the IQR. They are shown as whiskers connected to and drawn vertically outward from the 25th and 75th percentile lines. The individual data points represented by adjacent values are not plotted along the whisker lines. The length of the whisker connected to the 75th percentile represents the value of the largest adjacent point; the length of the whisker connected to the 25th percentile represents the smallest adjacent value. Values more extreme in either direction than the adjacent values are plotted individually. The values equal to 1.5 to 3.0 times the IQR are called "far-out values" and are represented by an asterisk (D.R. Helsel, U.S. Geological Suurvey, written commun., 1989). Values greater than "far-out values" are represented by a circle.

Statistical analyses can be used to examine the distribution of values for an individual variable or for comparing two or more groups of data. The computer software SYSTAT (SYSTAT Software Inc., 2002) was used for statistical hypothesis tests, summary statistics, and the boxplot preparation. A level of significance (α-value) less than 0.05 caused rejection of the null hypothesis that states the water-quality concentrations for compared groups were similar. The "attained significance level" (p-value) is a probability value determined from the data (Helsel and Hirsch, 1995) and measures the "believability" of the null hypothesis. The larger the p-value, the more likely is the observed test statistic when the null hypothesis is true and the weaker the evidence to reject the null hypothesis.

The summary statistics, including the minimum, maximum, range, mean, standard deviation, the 25th, median, 75th percentiles, and IQR were calculated for the water samples collected as a result of this study. When a constituent concentration was less than the reporting level, the reporting level value was substituted for the "less than" value during the summary statistics calculation. A "less than" symbol (<) was inserted before the appropriate calculated value listed in the summary statistics table.

Water Quality of the Viburnum Trend and Exploration Area

The concentrations of major anions and cations and trace elements from samples collected from the Viburnum Trend, exploration area, and Strother Creek were compared graphically and statistically. Trilinear diagrams, stiff diagrams, and boxplots can be used to show differences in chemical composition, whereas statistical analyses indicate if those differences are significant. The samples collected in 2002 were analyzed to determine if concentrations changed with distance downstream from mining activity. The historical data from Strother Creek were analyzed to determine if concentrations changed with time.

Major Ions

The general chemical composition of most water samples collected during this study was a calcium-magnesium bicarbonate type (table 1, at the back of this chapter). Non-mining sites had little variability (fig. 2) and generally plotted within a "tight" cluster represented by the blue areas on the trilinear diagram. These data plotted approximately at the left vertex of the central diamond field that represents the 100 percent calcium plus magnesium and carbonate plus bicarbonate water type. The data extended over a larger area in the lower left triangle, but are centered on approximately an equal distribution of calcium and magnesium. The anion distribution is near the vertex of 100 percent bicarbonate plus carbonate distribution.

Water-quality data from the near-mining sites and the distal-mining sites had much more variability in general chemical composition than the non-mining sites. Much of the variability was caused by differing percentages of sodium, chloride, and sulfate that were much larger in samples from near-mining sites than in samples from non-mining or distal-mining sites (table 1). Concentrations of these three constituents in samples from distal-mining sites generally were intermediate to concentrations present in non-mining and near-mining sites.

Applications for trilinear diagrams include assessing water-analysis groups to determine if a specific water can be a mixture of other waters for which analyses are available. The analysis of a water sample that is a result of a mixture of two different water types (Y and Z) will plot on the straight line YZ on the central diamond field of the trilinear diagram if the ions do not react chemically as a result of mixing (Hem, 1985).

Water samples from individual basins along the Viburnum Trend can be analyzed to indicate obvious mixing scenarios. The three northern-most sampling sites (B1, C1, and C2) are on Courtois Creek and Huzzah Creek (fig. 1). The headwaters of Courtois Creek upstream from the Courtois site (B1) drain tailings piles from Viburnum No. 28 and No. 29 Mines, and the headwaters of Huzzah Creek upstream from the Davisville site (C1) drain waters from the Casteel Mine. The Huzzah Creek near Scotia (site C2) is downstream and receives flow from sites B1 and C1. The central diamond on figure 2 indicates that the waters from these three sites have different relative proportions of major ions than non-mining samples and do not plot in a straight line. Instead, C2, the most downstream site on Huzzah Creek (near Scotia sample), plots within a triangle formed by the two upstream samples and the shaded area representing non-mining samples in the central diamond and the lower left cation triangle. The analysis indicates that the water at the Scotia site C2 is not a simple mixing of the two tributaries, but also contains a third component. Because the sample from site C2 plots off-line defined by the other two samples and plots closer to the area represented by the non-mining sites (baseline for indigenous waters), the third component appears to be inflow of indigenous waters upstream from site C2.

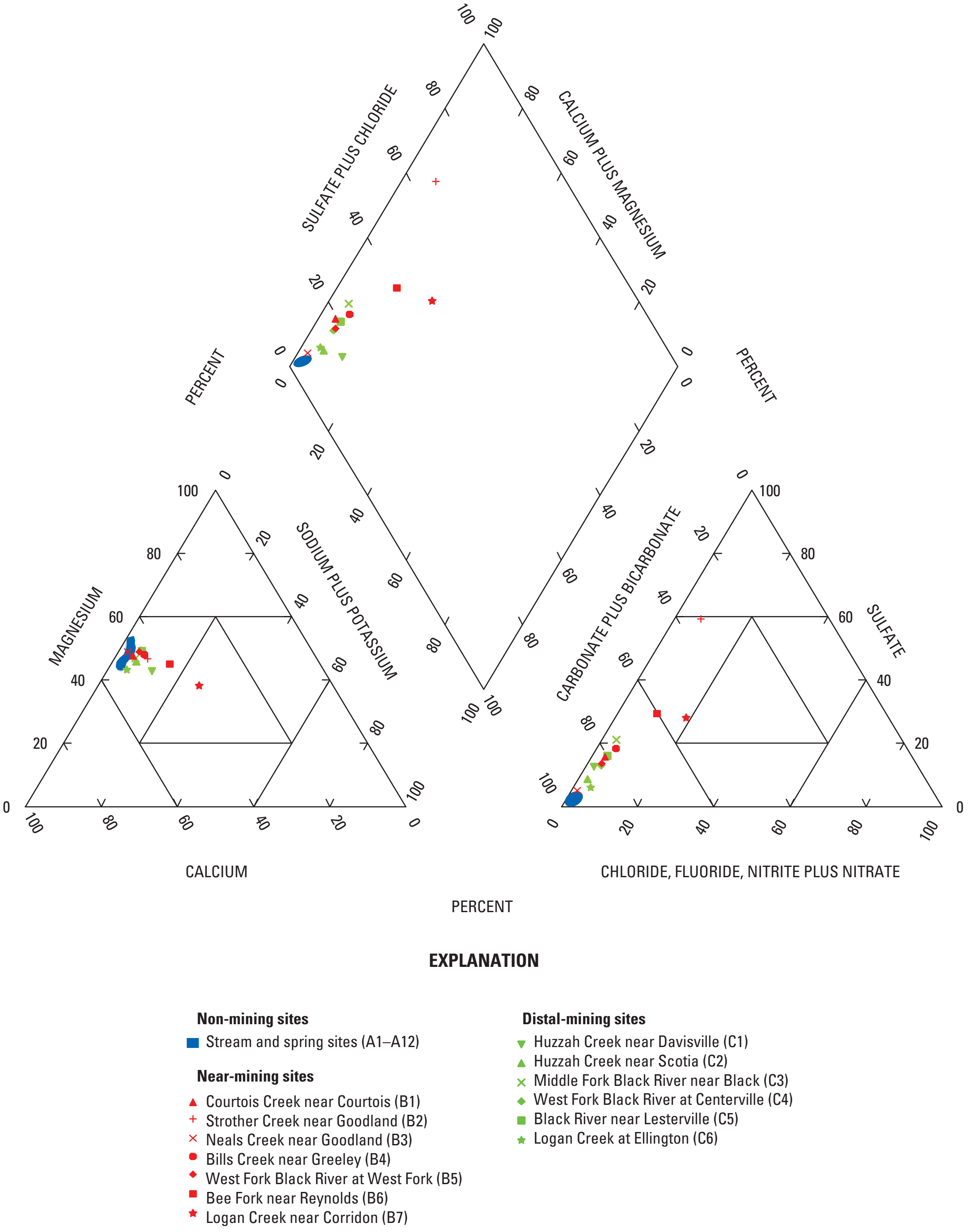


Figure 2. General water-quality samples from proximity-to-mining groups, April through June 2002.

The northern-most sampling sites in the Black River Basin include three sites (B2, B3, and C3) in the Middle Fork Black River (Middle Fork) Basin. Strother Creek near Goodland (site B2) drains the Buick Mine tailings pile (fig. 1), Neals Creek near Goodland (site B3) drains the inactive Magmont Mine tailings pile that has been reclaimed, and Middle Fork near Black (site C3) is downstream from the other two sites. The samples from Neals Creek site B3 plot in or near all the shaded areas on figure 2 that are considered typical for indigenous waters (baseline non-mining sites), and appears to be on a mixing line that uses the sample from Strother Creek site B2 as one end point and the non-mining sites as the other. Strother Creek site B2 had a large sulfate concentration (table 1), but a closer inspection indicates the site also had elevated concentrations of calcium, magnesium, potassium, sodium, and chloride as compared to the samples from Neals Creek site B3 or the non-mining sites. The Middle Fork site C3 is downstream from sites B2 and B3 and the sample plots along a mixing line between these two upstream sites.

Five sites were sampled in the West Fork Black River Basin. The most upstream site is West Fork Black River near Greeley (site A1), which plotted in the shaded area that is considered baseline for indigenous waters. Downstream, other West Fork Black River sites included Bills Creek near Greeley (site B4, downstream from the Brushy Creek Mine tailings pile), West Fork Black River at West Fork (site B5, downstream from the West Fork Mine), Bee Fork near Reynolds (site B6, downstream from the Fletcher Mine tailings pile), and the most downstream site West Fork Black River at Centerville (site C4). Samples from the three near-mining sites and the distal-mining site had greatly elevated sulfate concentrations [16 to 40 mg/L (milligrams per liter)] and elevated sodium concentrations (2.99 to 9.28 mg/L) when compared to the range of sulfate concentrations (2.2 to 4.1 mg/L) and sodium concentrations (0.70 to 1.45 mg/L) from non-mining sites (table 1). Chloride concentrations were slightly elevated (6.8 mg/L) in the sample from Bills Creek site B4. Samples from the two West Fork Black River sites, West Fork Black River at West Fork (site B5) and West Fork Black River at Centerville (site C4), plot at about the same location on figure 2. These samples appear to be the result of simple mixing of waters that have Bills Creek site B4 and indigenous waters (baseline non-mining sites) as possible end members even though Bee Fork contributes flow between the two sites. The sample from Bee Fork site B6 had the largest concentrations of sodium (9.28 mg/L), chloride (10 mg/L), and sulfate (40 mg/L) of the five West Fork Black River Basin samples.

The Black River at Lesterville (site C5) site is the most downstream sampling site in the mainstem of the Black River Basin and included waters from Middle Fork near Black (site C3) and West Fork Black River at Centerville (site C4), along with other tributaries that flowed into the river upstream from the sampling site. The general water composition of the Lesterville sample (site C5) indicates an elevated sulfate concentration (15 mg/L) and slightly elevated sodium (2.34 mg/L) and chloride (2.6 mg/L) concentrations as compared to concentrations from samples collected at non-mining sites (table 1). The Lesterville sample (site C5) appears to be the result of the mixing of waters from the downstream-most samples collected from the West Fork Black River Basin (site C4) and the Middle Fork Basin (site C3) and plots on the mixing line defined with these two sites being the end members (fig. 2).

Two sites were sampled in Logan Creek, one was downstream from the Sweetwater Mine tailings pond near Corridon (site B7) and the other was in a lower reach of the basin at Ellington (site C6). Downstream from Corridon site B7, the entire flow in Logan Creek is lost through the streambed and the creek remains dry for several miles until flow begins again a few miles upstream from the Ellington site C6. The Corridon site B7 has the largest concentrations of sodium (17.2 mg/L) and chloride (19 mg/L) of all the sampled sites, and elevated sulfate (39 mg/L) concentrations (table 1), whereas the water sampled at Ellington site C6 had slightly elevated sulfate (5.4 mg/L) and nitrate (2.3 mg/L) concentrations. The Ellington site C6 sample plots on the mixing line with the Corridon site B7 and the shaded area representing the non-mining sites being the end members (fig. 2).

Stiff diagrams also were used to graphically represent the general chemical composition of the individual water samples from the near- and distal-mining sites and one representative sample from the non-mining sites. Unlike the trilinear diagram that plots percentages of major cations and anions, stiff diagrams give an indication of the concentration of plotted constituents by plotting the milliequivalents of each constituent. The sites on figure 3 are shown in downstream order for each basin, and all diagrams use the same unit length on the horizontal axis. An increase in the overall width of the diagram indicates a greater concentration of the various constituents plotted.

All non-mining sites have similar general water chemistry; therefore, their stiff diagrams have a similar appearance and all sites were represented by the single analysis from West Fork Black River near Greeley (site A1; fig. 3). The cation side of the stiff diagram (left side of the vertical axis) for this sample shows the sodium plus potassium concentration was negligible. The magnesium and calcium concentrations were about equal, which is represented by the nearly vertical line connecting these two horizontal axes. On the anion side (right side of the vertical axis), the chloride plus fluoride and sulfate concentrations also were negligible and the bicarbonate plus carbonate concentration was dominant.

Stiff diagrams for most of near- and distal-mining water samples had a shape similar to the non-mining samples, with slight variations to the basic pattern and width. On the cation side of the vertical axis, the most consistent variation was the noticeable increase on the sodium plus potassium horizontal axis at several sites. On the anion side of the vertical axis, the bicarbonate plus carbonate horizontal axis remained the dominant component for nearly all samples. With the exception of the Strother Creek near Goodland (site B2) sample, which was a calcium-magnesium-sulfate water, the general chemical composition of most water samples collected during this study

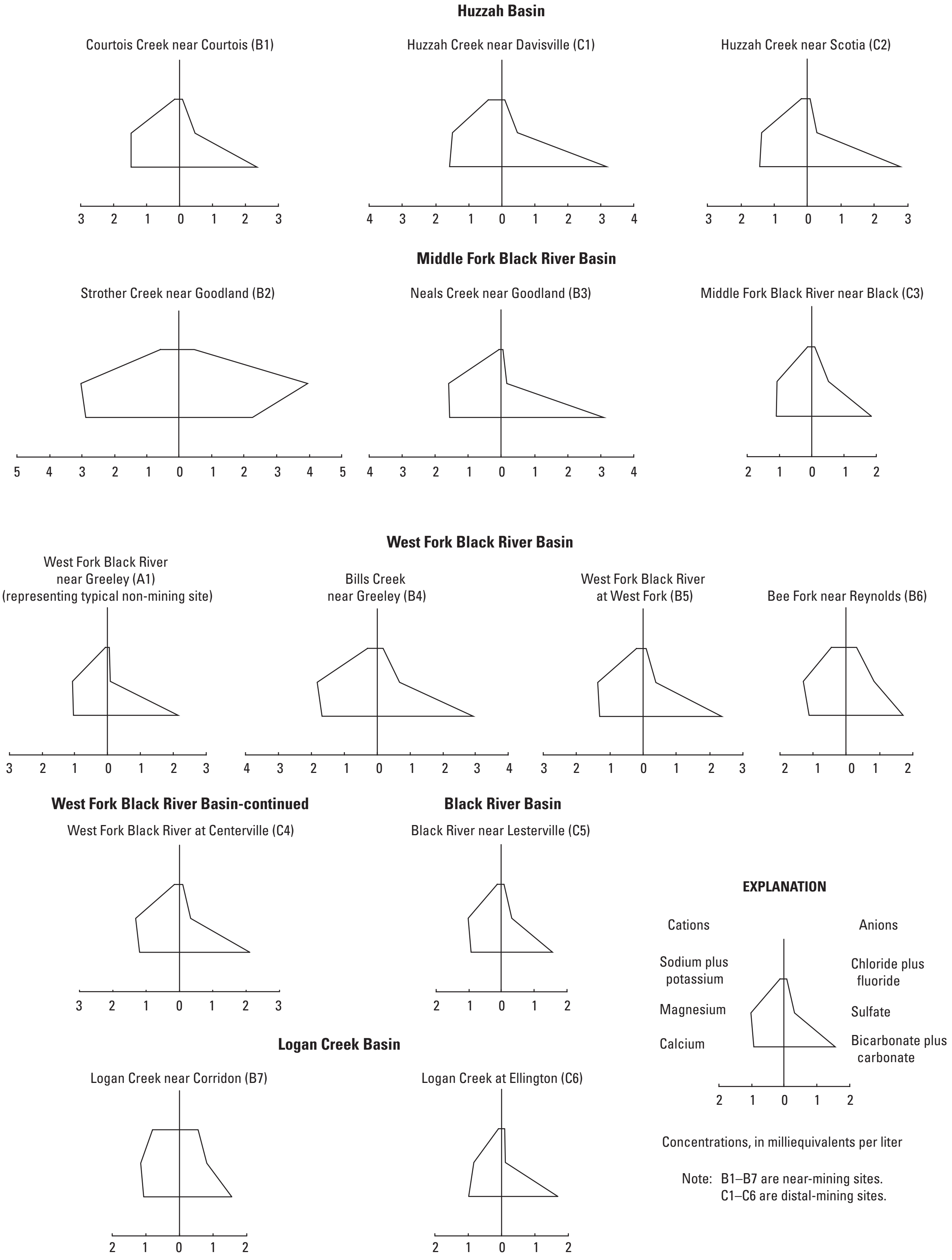


Figure 3. General water quality from near- and distal-mining sites and the West Fork Black River near Greeley (non-mining site), April through May 2002.

was a calcium-magnesium-bicarbonate water. However, sulfate and chloride concentrations were elevated in several samples from near- and distal-mining sites compared to concentrations that were typically detected at non-mining sites (table 1; figs. 2, 3).

The general chemical composition of the water samples in the three groups was statistically compared using the nonparametric Kruskal-Wallis statistical test (Helsel and Hirsch, 1995; SYSTAT Software Inc., 2002). Significant differences (p-values less than 0.05) were detected for sodium, chloride, and sulfate concentrations between the three groups. A Tukey's multiple comparison test (SYSTAT Software Inc., 2002) was applied to the ranked concentration data of these three constituents to identify which specific proximity-to-mining groups were statistically different. This analysis indicated that the sodium, chloride, and sulfate concentrations were statistically similar in near- and distal-mining sites, but these concentrations in non-mining sites were significantly smaller than the other two groups. These differences can be seen graphically in the boxplots on figure 4, which show that sodium, chloride, and sulfate concentrations increased from non-mining sites, peaked at near-mining sites, and then decreased downstream at distal-mining sites. Whereas concentrations decreased between near- and distal-mining sites, this decline did not reach the smaller concentrations detected in samples from non-mining sites.

Trace-Element Concentrations

Arsenic, cadmium, cobalt, copper, lead, nickel, and zinc are the primary elements associated with the sulfide minerals of Mississippi Valley Type (MVT) ores and, therefore, are referred to as MVT-related metals in this chapter. The concentrations of these metals and of barium, chromium, lithium, manganese, rubidium, and strontium were analyzed by proximity-to-mining group (table 2, at the back of this chapter; fig. 4). Because all but one arsenic concentration was less than the reporting level (table 1), this element was omitted from further analysis. The same statistical approach used to analyze the general chemical composition was used for these trace elements. Using the Kruskal-Wallis statistical test, all the MVT-related metals (except arsenic), lithium, and strontium had p-values less than 0.05, which indicated that a significant difference existed in concentrations between the three groups. Applying the Tukey's multiple comparison test (SYSTAT Software Inc., 2002) to the ranked concentration data of these eight elements indicated that the distribution of the MVT-related metals copper, nickel, lead, and zinc, and the trace elements lithium and strontium in non-mining sites and distal-mining sites were statistically similar (p-value greater than 0.05). However, the elevated concentrations of these elements in near-mining sites were significantly larger (p-value less than 0.05) than the other two groups. The concentrations for these trace elements peaked at near-mining sites (fig. 4), but decreased downstream at distal-mining sites to concentrations similar to those observed at the non-mining sites. Cadmium concentrations were similar at the near- and distal-mining sites, but were significantly smaller at non-mining sites. This indicates that cadmium concentrations peaked at near-mining sites (fig. 4), remained persistent in the stream and did not significantly decrease downstream at the distal-mining sites. Cobalt concentrations were significantly different for all three site types. Cobalt concentrations peaked at near-mining sites (fig. 4) and then decreased at the distal-mining sites. Even though the concentrations significantly decreased downstream, they did not achieve the lower concentrations detected at the non-mining sites.

Strother Creek Water Quality

Historical water-quality data collected by the USGS from 1964 through 2005 are available from two Strother Creek sampling sites downstream from the Buick Mine. Water-quality data were collected from 1964 through 1975 at varying intervals ranging from once a year to four times a year at Strother Creek near Oates (ST1), which is about 1 mi upstream from the Strother Creek near Goodland (site B2) sampling site discussed previously (B2; figs. 1, 5). Little Creek flows into Strother Creek between these two sampling sites. No water-quality analyses were available for Little Creek; however, a specific conductance value of 409 µS/cm was recorded during a seepage run on Strother Creek in August 2006 (chapter 2 of this report). Specific conductance measurements ranged from 708 to 1,155 µS/cm in the mainstem of Strother Creek downstream from mining activities. In several streams draining non-mining areas, specific conductance values from about 400 to 450 µS/cm were measured during the same seepage run. Based on these values, Little Creek is assumed to discharge water unaffected by mining and, therefore, water samples from the two Strother Creek sites are assumed to be comparable for this analysis. After 1975, the next water sample collected was in 1995 near Oates (site ST1). The two water-quality samples collected in 2002 and 2005 from the Goodland site (site B2) were added to the larger sample set from the Oates site.

Both Strother Creek sampling sites are upstream from the junction with Neals Creek and both receive water from the Buick Mine, which began production in 1969 (chapter 1 of this report) and currently (2008) is producing ore. Mine development and site preparation were occurring at the Buick Mine before ore production began. A tailings dam was constructed in 1966 and a railroad line to the mine was completed in 1967 as the mine was being developed (chapter 1 of this report).

The water-quality data from the two Strother Creek sampling sites were separated into four periods based on sampling date and statistically analyzed to determine if certain constituent concentrations had changed with time. The time frame for the pre-mining samples (period T1) was determined to be 1964 through 1967. This pre-mining period was not extended to the beginning of ore production in 1969. The effects of pre-ore

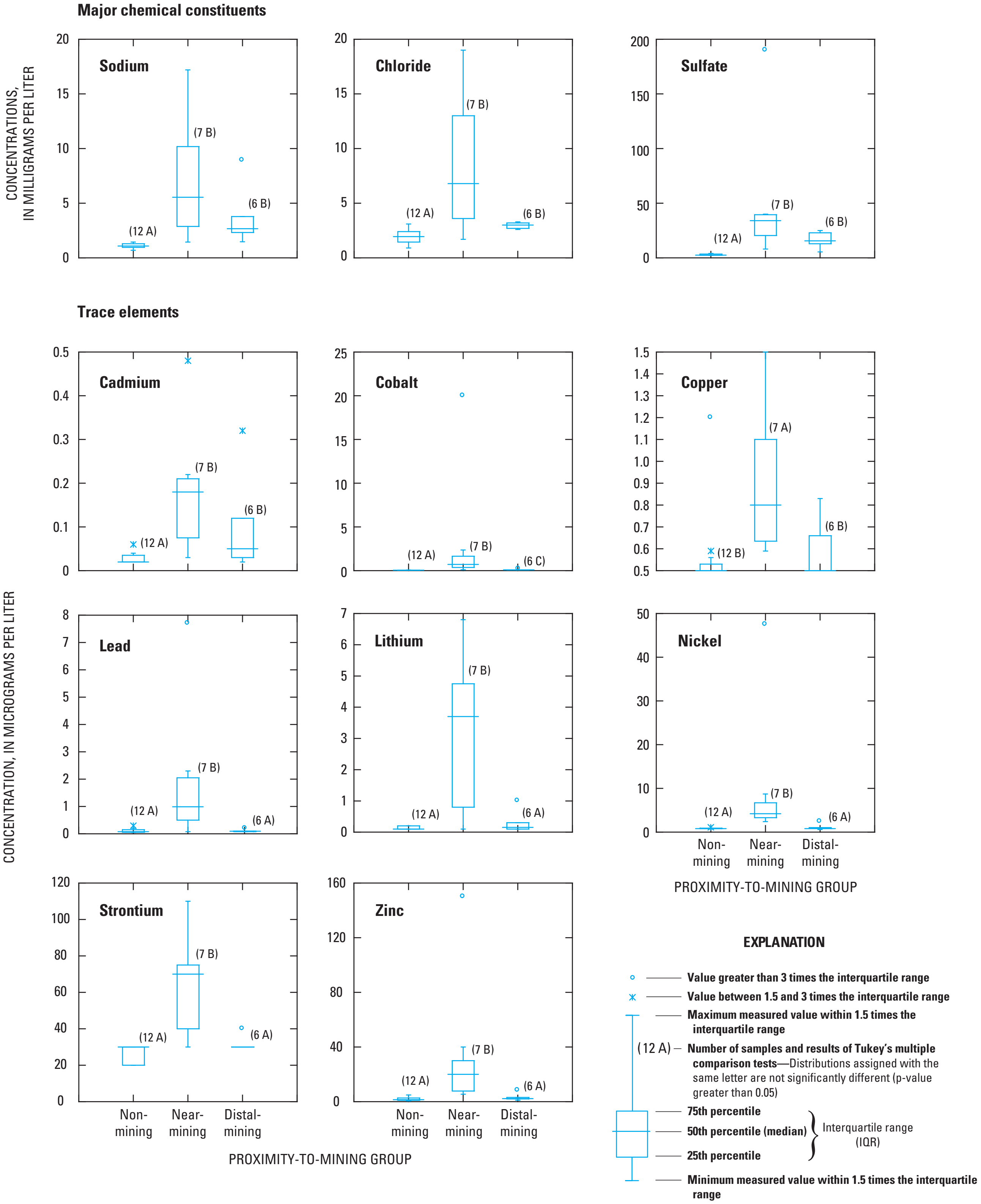
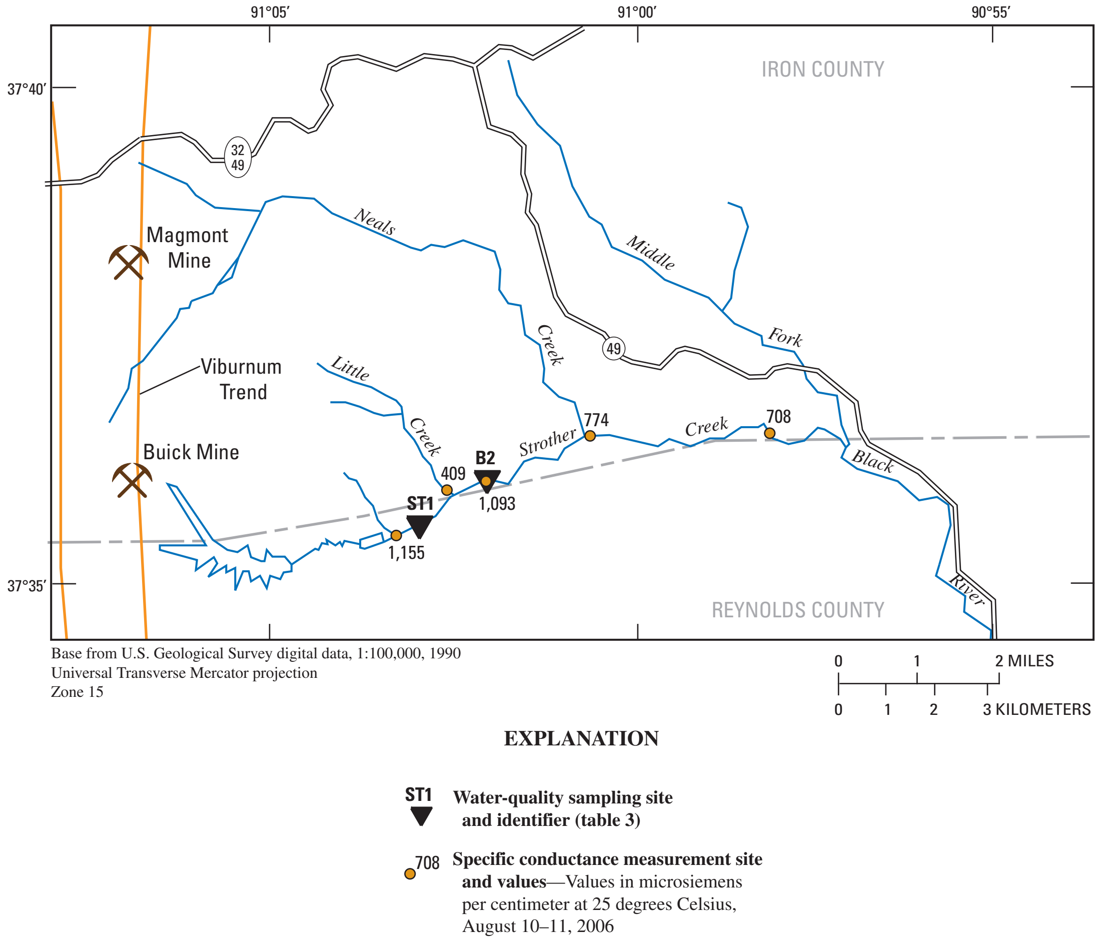


Figure 4. General water-quality and trace-element concentrations for the proximity-to-mining groups, April through June 2002.



Base from U.S. Geological Survey digital data, 1:100,000, 1990
Universal Transverse Mercator projection
Zone 15

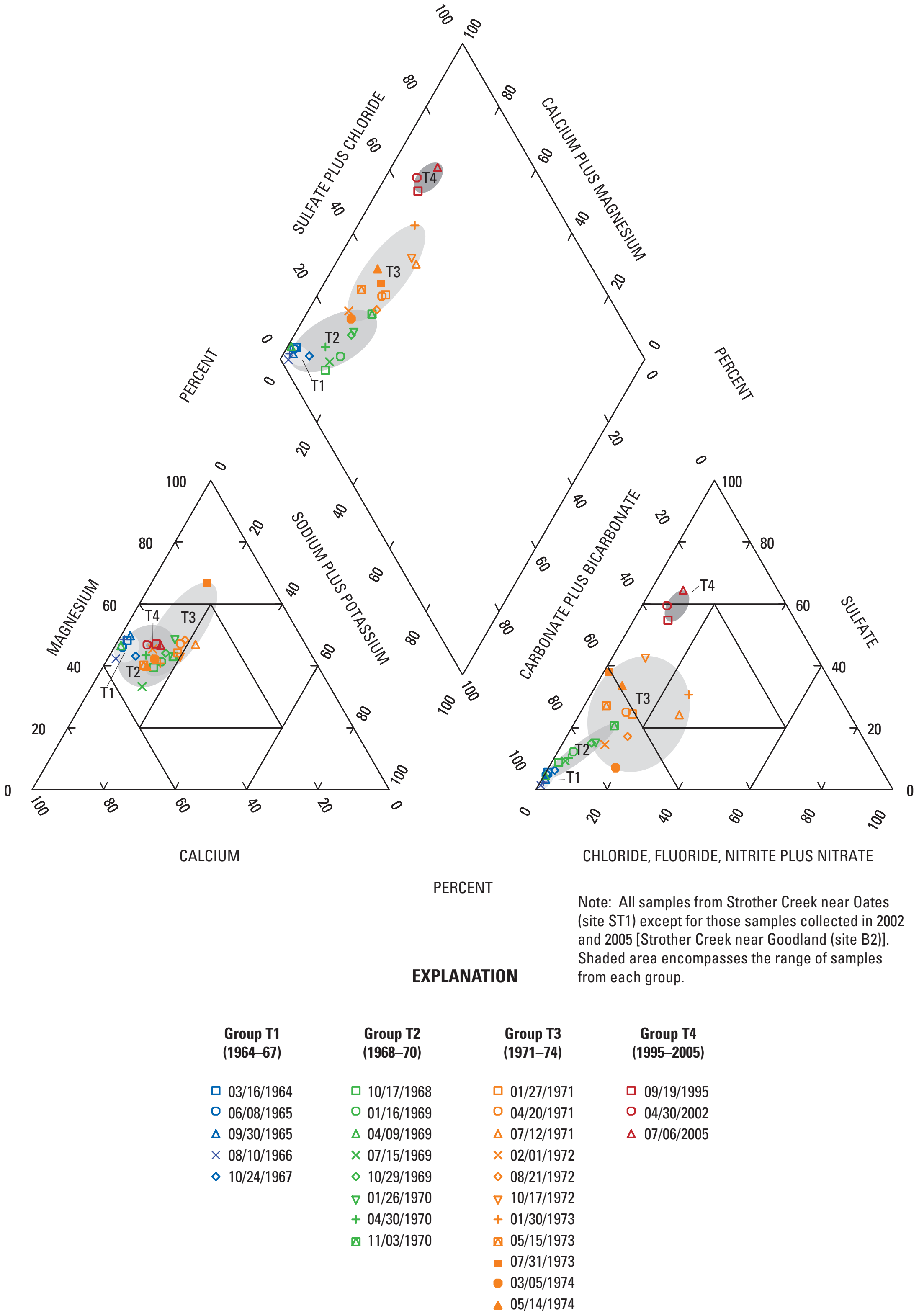
Figure 5. Water-quality sampling sites in Strother Creek and specific conductance values, August 10–11, 2006.

removal construction activities at the mine on the water quality of Strother Creek are uncertain. However, because the water-quality sample collected in 1967 plotted differently than the previous samples, this infers water-quality changes apparently were occurring in Strother Creek before ore removal (fig. 6). A much larger data set existed for samples collected from 1968 to 1975. These data arbitrarily were divided into the smaller periods T2 (1968 through 1970) and T3 (1971 through 1975). Period T4 (1995 through 2005) represents the most recent data collected after the more frequent sampling ended in 1975. Two of the 1974 and all of the 1975 samples were not plotted because no calcium or magnesium analyses were performed.

Water quality in Strother Creek (fig. 6; table 3, at the back of this chapter) changed during 1964 to 2005 as indicated by the sodium, chloride, and sulfate concentrations that increased steadily with time. The non-parametric Kruskal-Wallis statistical test (Helsel and Hirsch, 1995; SYSTAT Software Inc., 2002) was performed on the grouped concentration data from Strother Creek to determine if there was an equality of distribution among the four groups. The results indicated that there was a statistical difference in the distribution of the major cations and anions and the trace elements. The MVT-related metals, arsenic, cadmium, and lead, had incomplete data sets and could not be statistically analyzed by groups.

The Tukey's method for multiple comparisons (SYSTAT Software Inc., 2002) was applied to the ranked concentration data of those constituents that have a statistical difference in distribution (p-values less than 0.05). Results need to be used with caution because of the small number of samples available for the statistical test from some groups. Concentrations of the major cations and anions (sodium, chloride, sulfate, calcium, magnesium, and potassium) during the most recent period (T4; 1995 through 2005) were significantly larger than the pre-mining period (T1; 1964 through 1967) (fig. 7). The sodium, chloride, sulfate, and potassium concentrations significantly increased after 1967 and remained elevated through the most recent sampling period (T4; 1995 through 2005). Sulfate concentrations continued to significantly increase during each successive period. Calcium and magnesium concentrations also have significantly increased with time (fig. 7).

Trace-element concentration data for copper, cobalt, manganese, nickel, and zinc were sufficient to perform a statistical analysis with time. Because many period T1 and T2 concentrations were reported as "not detected" the reporting level value at the time the analysis was performed was



Note: All samples from Strother Creek near Oates (site ST1) except for those samples collected in 2002 and 2005 [Strother Creek near Goodland (site B2)]. Shaded area encompasses the range of samples from each group.

Figure 6. General surface-water quality of Strother Creek, 1964–2005.

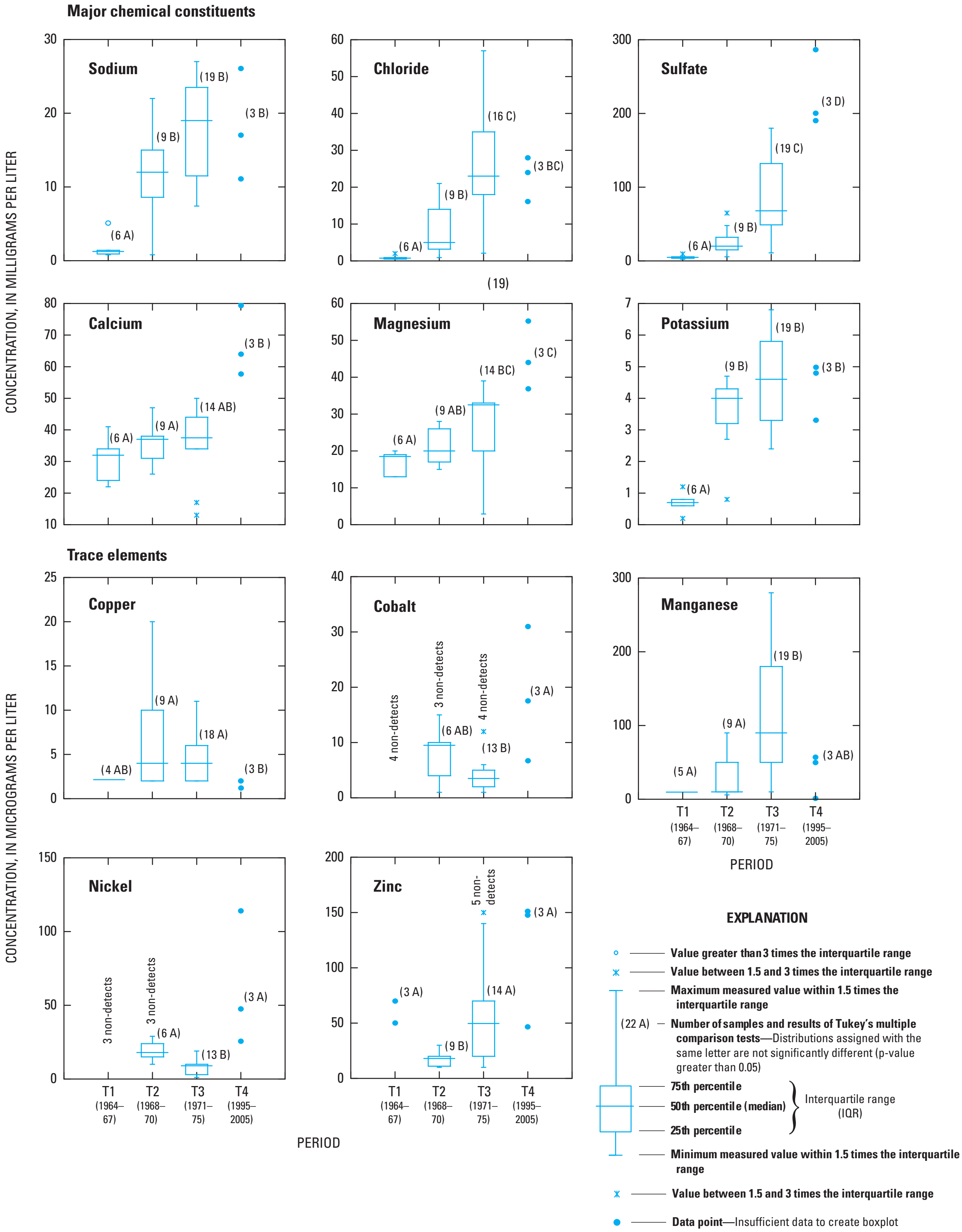


Figure 7. Major chemical constituents and trace-element concentrations for Strother Creek near Oates and Goodland, 1964–2005.

substituted for each specific constituent concentration. If the reporting level for an analysis could not be determined or was many times greater than later analysis, no concentration was substituted. Consequently, no concentrations were substituted for the reported non-detected concentrations of cobalt and nickel during period T1, and no values were substituted for the five non-detected concentrations for zinc in period T3.

The trace-element concentrations (copper, manganese, and zinc) for periods T1 and T4 were statistically similar during both of these time periods. However, manganese concentrations indicated a significant increase during period T3, and zinc concentrations significantly decreased during period T2 when compared to the concentrations from period T1. Copper concentrations during periods T2 and T3 (1968 through 1975) increased compared to the pre-mining period, but the increase was not statistically significant.

No pre-mining cobalt and nickel concentration data were available to document conditions during the pre-mining period T1; however, a comparison of data for these two constituent concentrations can be made between the early mining period (T2) and the most current (T4) samples. Cobalt concentrations did not change significantly from period T2 to T4, but nickel concentrations decreased significantly during period T3, only to increase again during period T4.

Summary

The lead ore deposits of the Viburnum Trend Subdistrict (Viburnum Trend), in southeastern Missouri are a part of the largest known lead reserve within the United States. Mining in the Viburnum Trend began in 1960 and has continued uninterrupted since. As many as 10 mines have operated in the Viburnum Trend, and presently (2008), six mines are active. Total ore production from individual mines ranges from 20 to more than 50 million tons.

Water-quality data collected from April through June 2002 from streams and springs draining lead and zinc mining areas along the Viburnum Trend and non-mining areas to the south in the Current River and Eleven Point River Basins were compared to quantify water-quality changes spatially and with distance downstream from active mining. Data from 37 historical water-quality samples collected from 1964 to 2005 downstream from the Buick Mine in Strother Creek also were analyzed to document water-quality changes in this stream with time.

Three groups, based on the location of the sampling site to the nearest mining activities or tailings ponds, were used to compare the general chemical composition and trace-element concentrations in surface- and spring-water samples collected from April through June 2002. The three groups include: non-mining sites, sites upstream from mining activity or mine tailings, or sites where no mining activity is present in the basin; near-mining sites, mining activity or mine tailings ponds within 7.5 miles upstream from the sampling site; and distal-mining sites, mining activity distally upstream from sampling site at distances greater than 7.5 miles.

Samples collected from the non-mining sites were calcium-magnesium bicarbonate type, which had little variability and plotted within a “tight” cluster in all three fields of the trilinear diagram. Water-quality data from the near-mining and distal-mining sites had more variability, which generally was caused by differing percentages of sodium, chloride, and sulfate. The upstream-most sites on Courtois Creek and Huzzah Creek drain mining areas, and each have different relative proportions of major ions than non-mining sites. The Huzzah Creek near Scotia site receives water from these two upstream sites and appears to be a mixture of the two upstream sites and ground-water inflow of indigenous water.

Water-sample analysis for the downstream-most Middle Fork Black River site appears to be the product of simple mixing of the waters sampled from the upstream Strother Creek and Neals Creek sites. The Neals Creek site is downstream from the Magmont Mine tailings pile that has been reclaimed; the water-quality analysis plots on the trilinear diagram near the area considered typical for indigenous waters. The Strother Creek site is downstream from the Buick Mine and had a large sulfate concentration and elevated calcium, magnesium, potassium, sodium, and chloride concentrations as compared to samples from Neals Creek and non-mining sites.

Five sites in the West Fork Black River Basin were sampled—one of which is a non-mining site that plotted on the trilinear diagram in the area considered baseline for indigenous waters. The other four sites had greatly elevated sulfate concentrations [16 to 40 mg/L (milligrams per liter)] and elevated sodium concentrations (2.99 to 9.28 mg/L) when compared to the range of sulfate concentrations (2.2 to 4.1 mg/L) and sodium concentrations (0.7 to 1.45 mg/L) from non-mining sites. The Bee Fork sample had the largest concentrations of sodium (9.28 mg/L), chloride (10 mg/L), and sulfate (40 mg/L) of the five West Fork Black River Basin samples.

The downstream-most site in the Black River Basin at Lesterville had elevated sulfate (15 mg/L) concentrations and slightly elevated sodium (2.34 mg/L) and chloride (2.6 mg/L) concentrations as compared to samples from non-mining sites. The upstream-most sampling site in Logan Creek, which drains the Sweetwater Mine tailings pond, had the largest concentrations of sodium (17. 2 mg/L) and chloride (19 mg/L) of all the sampled sites, and elevated sulfate (39 mg/L) concentrations compared to non-mining sites. Further downstream at the Ellington site, the water sample had slightly elevated sulfate (5.4 mg/L) and nitrate (2.3 mg/L) concentrations and plots on the mixing line with the upstream Logan Creek site and non-mining sites.

The general chemical composition of most water samples collected during this study is a calcium-magnesium-bicarbonate water type, except for Strother Creek, which is a calcium-magnesium-sulfate type. When compared to non-mining samples, most near-mining and distal-mining sites had elevated sulfate and chloride concentrations.

Sodium, chloride, and sulfate concentrations peak at near-mining sites, then decrease at distal-mining sites, but do not reach the lower concentrations detected at non-mining sites. The copper, nickel, lead, zinc, lithium, and strontium concentrations in non-mining sites and distal-mining sites were similar, but were significantly larger at near-mining sites when compared to the other two groups. These trace-element concentrations peaked at near-mining sites, but decreased downstream at distal-mining sites to concentrations similar to those detected at non-mining sites. Cadmium concentrations were similar at near-mining and distal-mining sites, but were significantly smaller at non-mining sites. Cobalt concentrations peaked at near-mining sites and then decreased at the distal-mining sites. However, even though the concentrations significantly decreased downstream from mining activity, they did not achieve the lesser concentrations detected at the non-mining sites.

Historical water-quality data collected from 1964 through 2005 for two near-mining sites on Strother Creek downstream from the Buick Mine indicated surface-water quality changes with time. The data were separated into four periods and statistically analyzed; period T1 represents pre-mining data (1964 through 1967), period T2 includes 1968 through 1970 data, period T3 includes 1971 through 1975 data, and period T4 includes 1995 through 2005 data.

Sodium, chloride, sulfate, and potassium concentrations significantly increased after 1967 in Strother Creek Basin and remained elevated through the most recent sampled period (1995 through 2005). Sulfate concentrations continued to significantly increase during each successive period. Calcium and magnesium concentrations also have increased with time. The copper, manganese, and zinc concentrations were similar during the pre-mining and most recent periods. However, manganese concentrations significantly increased during 1971 through 1975, and zinc concentrations decreased during 1968 through 1970 as compared to the pre-mining period.

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Tables

Table 1. Water-quality data for the Viburnum Trend and exploration area, April–June 2002.

[mm/dd/yyyy, month, day, year; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; NA, not applicable; ANC, acid neutralizing capacity; <, less than; µg/L, micrograms per liter]

Site number (fig. 1)	Distance to mining (miles)	Site	Date (mm/dd/yyyy)	Time	Discharge (ft³/s)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Calcium (mg/L)
				Non-mining sites					
A1	NA	West Fork Black River near Greeley	05/06/2002	1300	61	8.2	220	18.8	21.0
A2	NA	Big Creek at Mauser Mill	05/29/2002	1100	37	7.9	247	17.5	28.3
A3	NA	Blair Creek	05/29/2002	1300	16	7.9	226	17.5	24.9
A4	NA	Current River at Van Buren	06/11/2002	1030	1,910	7.7	279	20.0	26.2
A5	NA	Big Spring near Van Buren	06/11/2002	0900	697	7.0	271	13.8	26.2
A6	NA	Eleven Point River at Thomasville	06/10/2002	1200	93	7.8	294	17.7	29.7
A7	NA	Spring Creek Tributary	06/12/2002	1500	17	7.5	305	15.7	29.3
A8	NA	Spring Creek	06/25/2002	1400	74	8.2	305	19.2	32.2
A9	NA	McCormack Spring	06/12/2002	1715	4.6	7.5	379	13.7	36.6
A10	NA	Greer Spring	06/10/2002	1700	580	7.4	260	13.8	26.2
A11	NA	Hurricane Creek	06/12/2002	1130	44	7.8	305	18.1	29.2
A12	NA	Eleven Point River at Bardley	06/10/2002	1500	1,200	8.2	288	17.6	28.7
				Near-mining sites					
B1	4.0	Courtois Creek near Courtois	04/29/2002	1300	90	8.3	294	16.4	29.5
B2	6.4	Strother Creek near Goodland	04/30/2002	1100	31	8.1	641	17.2	57.6
B3	7.5	Neals Creek near Goodland	04/30/2002	0830	19	8.1	299	13.3	31.5
B4	3.7	Bills Creek near Greeley	05/06/2002	1430	19	8.2	370	18.5	33.3
B5	.9	West Fork Black River at West Fork	05/06/2002	1600	107	8.2	282	19.0	25.6
B6	.6	Bee Fork near Reynolds	05/06/2002	1800	22	7.7	155	19.9	22.6
B7	4.3	Logan Creek near Corridon	05/29/2002	1530	16	7.7	313	19.6	21.3
				Distal-mining sites					
C1	33.6	Huzzah Creek near Davisville	04/29/2002	1545	207	8.6	326	18.5	31.4
C2	51.9	Huzzah Creek near Scotia	04/29/2002	1845	821	8.5	286	17.8	28.9
C3	25.2	Middle Fork Black River near Black	04/30/2002	1400	268	8.1	238	16.1	22.0
C4	17.5	West Fork Black River at Centerville	05/07/2002	1000	176	8.2	265	17.6	24.0
C5	34.5	Black River near Lesterville	05/07/2002	1100	642	8.0	210	16.9	18.6
C6	35.1	Logan Creek at Ellington	05/29/2002	1800	41	7.6	200	18.7	19.8

Table 1. Water-quality data for the Viburnum Trend and exploration area, April-June 2002.—Continued

[mm/dd/yyyy, month, day, year; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; NA, not applicable; ANC, acid neutralizing capacity; <, less than; µg/L, micrograms per liter]

Site number (fig. 1)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	ANC (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)
Non-mining sites											
A1	13.0	0.8	1.17	109	132	<1	1.3	<0.08	3.6	4.1	<0.08
A2	14.3	1.0	1.04	130	158	<1	1.5	<.08	3.4	3.9	.5
A3	12.7	1.3	.87	105	128	<1	1.6	<.08	3.6	3.7	<.08
A4	17.2	.9	1.45	135	165	<1	2.5	<.08	2.7	3.4	1.2
A5	17.0	.9	1.27	131	160	<1	2.2	<.08	3.5	2.3	2.5
A6	17.9	1.2	1.11	148	181	<1	2.3	<.08	3.2	2.4	2.5
A7	19.9	.5	.70	151	185	<1	.9	<.08	3.4	2.5	<.08
A8	17.0	1.1	1.05	149	182	<1	2.3	<.08	3.8	2.5	2.6
A9	25.3	.5	.96	191	233	<1	1.4	<.08	3.7	2.2	<.08
A10	16.3	1.4	1.44	124	151	<1	3.1	<.08	3.9	2.4	4.3
A11	19.6	.8	.97	144	176	<1	1.7	<.08	3.3	2.8	.9
A12	17.5	1.2	1.31	136	166	<1	2.7	<.08	3.2	2.4	2.3
Near-mining sites											
B1	17.8	0.8	2.62	118	144	<1	3.5	0.08	4.0	22	<0.08
B2	36.7	3.3	11.1	112	137	<1	16	.2	2.8	190	2.5
B3	19.2	.7	1.44	154	188	<1	1.7	<.08	3.5	8.1	<.08
B4	21.7	1.2	5.55	147	180	<1	6.8	.1	3.9	34	2.1
B5	16.4	1.0	3.13	120	146	<1	3.7	.09	3.6	19	.4
B6	15.6	1.4	9.28	85	104	<1	10	.2	3.2	40	1.2
B7	14.0	2.0	17.2	78	95	<1	19	.3	2.8	39	.5
Distal-mining sites											
C1	18.0	1.0	8.92	159	191	<1	2.9	0.08	3.6	23	0.2
C2	16.8	.9	3.78	140	170	<1	2.7	<.08	3.8	13	.2
C3	13.1	1.0	2.32	92	113	<1	3.2	<.08	3.7	25	.5
C4	16.0	.9	2.99	106	129	<1	3.3	.09	3.4	16	.4
C5	12.4	1.0	2.34	78	95	<1	2.6	<.08	3.9	15	.3
C6	10.1	1.2	1.47	84	103	<1	3.1	<.08	3.3	5.4	2.3

Table 1. Water-quality data for the Viburnum Trend and exploration area, April-June 2002.—Continued

[mm/dd/yyyy, month, day, year; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; NA, not applicable; ANC, acid neutralizing capacity; <, less than; µg/L, micrograms per liter]

Site number (fig. 1)	Phosphorus (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Bismuth (µg/L)	Cadmium (µg/L)	Cesium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)
Non-mining sites												
A1	<0.01	2	<0.1	<1.0	27.4	<0.05	<0.005	0.06	<0.01	2.2	0.08	1.2
A2	<.01	3	<.1	<1.0	31.9	<.05	<.005	.02	<.01	1.7	.06	.56
A3	<.01	8	<.1	<1.0	26.1	<.05	<.005	.04	.03	1.1	.06	.59
A4	<.01	1	<.1	<1.0	32.8	<.05	<.005	<.02	<.01	1.1	.06	<.5
A5	<.01	5	<.1	<1.0	29.3	<.05	<.005	.03	.02	1.4	.04	<.5
A6	<.01	1	<.1	<1.0	33.1	<.05	<.005	<.02	<.01	2.2	.07	<.5
A7	<.01	.3	<.1	<1.0	19.1	<.05	<.005	<.02	<.01	1.1	.04	<.5
A8	.01	5	<.3	<1.0	30.9	<.05	<.2	.04	<.02	<1	.05	<.5
A9	<.01	6	<.1	<1.0	24.3	<.05	<.005	.02	<.01	1.4	.06	<.5
A10	<.01	5	<.1	<1.0	32.5	<.05	<.005	<.02	.02	2.0	.04	<.5
A11	<.01	.7	<.1	<1.0	27.2	<.05	<.005	<.02	<.01	<1	.06	<.5
A12	<.01	1	<.1	<1.0	31.0	<.05	<.005	<.02	<.01	2.2	.06	<.5
Near-mining sites												
B1	<0.01	2	0.1	<1.0	31.7	<0.05	<0.005	0.48	<0.01	1.7	0.23	1.5
B2	<.01	2	1	2	30.8	<.05	<.005	.22	.06	2.0	20	1.2
B3	<.01	1	.1	<1.0	31.4	<.05	<.005	.20	<.01	2.3	.10	.66
B4	<.01	2	.3	<1.0	30.7	<.05	<.005	.18	<.01	2.8	2.4	1.0
B5	<.01	3	.1	<1.0	29.2	<.05	<.005	.03	<.01	2.5	.93	.61
B6	<.01	3	.3	<1.0	35.5	<.05	<.005	.05	.02	2.0	.50	.59
B7	<.01	3	.1	<1.0	50.3	<.05	<.005	.10	<.01	1.1	.71	.80
Distal-mining sites												
C1	<0.01	2	0.8	<1.0	35.2	<0.05	<0.005	0.32	<0.01	3.0	0.08	0.83
C2	<.01	3	.2	<1.0	87.7	<.05	<.005	.12	.02	2.6	.09	.66
C3	<.01	2	.2	<1.0	28.4	<.05	<.005	.07	<.01	1.6	.21	<.5
C4	<.01	1	.1	<1.0	29.6	<.05	<.005	.03	<.01	1.1	.09	<.5
C5	<.01	5	<.1	<1.0	31.6	<.05	<.005	<.02	.02	<1	.08	<.5
C6	<.01	2	<.1	<1.0	39.0	<.05	<.005	.03	<.01	1.2	.07	<.5

Table 1. Water-quality data for the Viburnum Trend and exploration area, April-June 2002.—Continued

[mm/dd/yyyy, month, day, year; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; NA, not applicable; ANC, acid neutralizing capacity; <, less than; µg/L, micrograms per liter]

Site number (fig. 1)	Gallium (µg/L)	Germanium (µg/L)	Iron (µg/L)	Lanthanum (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Niobium (µg/L)	Rubidium (µg/L)	Scandium (µg/L)
Non-mining sites												
A1	<0.02	<0.02	<50	<0.01	0.2	<0.1	2.9	<0.2	0.7	0.04	0.66	0.7
A2	<.02	<.02	<50	.02	.1	<.1	6.0	<.2	.8	.04	.92	1.2
A3	<.02	<.02	<50	.03	.3	.2	3.9	<.2	.8	.03	.77	1.1
A4	<.02	<.02	<50	.01	.05	<.1	4.5	<.2	.8	<.02	.87	.8
A5	<.02	<.02	<50	.05	.07	.1	0.4	.23	.9	<.02	1	.9
A6	<.02	<.02	<50	.02	.05	.2	10	.32	.8	.04	.95	.9
A7	<.02	<.02	<50	.02	.07	<.1	1.1	.29	.8	<.02	.56	1
A8	<.05	<.05	<50	.02	.2	.2	3.5	<2	.9	<.20	1	1
A9	<.02	<.02	<50	.10	.1	<.1	1.3	<.2	1.1	<.02	.68	1
A10	<.02	<.02	<50	.06	.05	.1	.2	.32	.8	.02	1	1
A11	<.02	<.02	<50	.01	.09	<.1	7.4	.20	.9	<.02	.84	.9
A12	<.02	<.02	<50	.02	.06	.2	6.0	.31	.9	<.02	1	.9
Near-mining sites												
B1	<0.02	<0.02	<50	0.01	0.4	0.3	2.6	0.43	3.6	0.06	0.80	1
B2	<.02	.04	<50	.01	2.3	3.7	50	6	47.5	.06	5	.6
B3	<.02	<.02	<50	.01	.08	<.1	1.9	.34	2.4	.05	.62	.8
B4	<.02	.03	<50	.01	7.7	4.4	4.3	1	8.7	.03	1	.8
B5	<.02	<.02	<50	<.01	1.0	1.3	30	.64	4.2	.04	.99	.7
B6	<.02	<.02	<50	.01	1.8	5.1	6.7	2	4.7	.04	2	.7
B7	<.02	<.02	<50	<.01	.6	6.8	260	2	3.0	.03	3	.8
Distal-mining sites												
C1	<0.02	<0.02	<50	0.02	0.1	<0.1	3.5	0.40	1.0	0.06	0.86	0.8
C2	<.02	<.02	<50	.02	.09	<.1	8.0	.29	1.0	.04	.71	.8
C3	<.02	<.02	<50	.01	.08	.2	1.9	.91	2.4	.05	.98	.9
C4	<.02	<.02	<50	<.01	.2	1	1.6	.55	1.0	.02	.89	.7
C5	<.02	<.02	<50	.02	.08	.3	3.3	.38	.8	.02	.86	.7
C6	<.02	<.02	<50	.01	.1	<.1	7.5	.24	.6	.02	.91	.8

Table 1. Water-quality data for the Viburnum Trend and exploration area, April-June 2002.—Continued

[mm/dd/yyyy, month, day, year; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; NA, not applicable; ANC, acid neutralizing capacity; <, less than; µg/L, micrograms per liter]

Site number (fig. 1)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Thorium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Yttrium (µg/L)	Zinc (µg/L)	Zirconium (µg/L)	Uranium (µg/L)	Suspended sediment (mg/L)
Non-mining sites												
A1	<1	<3	20	<0.1	0.005	<0.1	1.0	0.02	2.6	<0.05	0.1	14
A2	<1	<3	30	<.1	<.005	<.1	.8	.03	2.0	<.05	.1	13
A3	<1	<3	20	<.1	<.005	<.1	.5	.04	4.9	<.05	.1	16
A4	<1	<3	30	<.1	<.005	<.1	.7	.04	0.8	<.05	.2	17
A5	<1	<3	20	<.1	<.005	.3	.7	.09	2.8	<.05	.2	31
A6	<1	<3	30	<.1	.005	<.1	1.0	.03	1.0	<.05	.2	13
A7	<1	<3	20	<.1	<.005	<.1	.6	.02	.6	<.05	.1	18
A8	<1	<3	30	<.1	<.200	<.5	<.5	.04	3.7	<.2	.2	18
A9	<1	<3	30	<.1	<.005	<.1	.6	.11	2.0	<.05	.2	22
A10	<1	<3	30	<.1	<.005	<.1	.8	.08	1.0	<.05	.2	15
A11	<1	<3	20	<.1	<.005	<.1	.5	.03	1.0	<.05	.1	23
A12	<1	<3	30	<.1	<.005	<.1	1.0	.04	.9	<.05	.2	18
Near-mining sites												
B1	<1	<3	40	<.1	.020	<.1	.7	.03	20	<.05	.1	27
B2	<1	<3	110	<.1	.020	2.0	.7	.03	150	<.05	.2	59
B3	<1	<3	30	<.1	.007	<.1	1.0	.02	5.4	<.05	.1	23
B4	<1	<3	70	<.1	.009	.2	1.1	.03	40	<.05	.1	18
B5	<1	<3	40	<.1	.007	<.1	1.1	.02	10	<.05	.1	14
B6	<1	<3	70	<.1	.008	.3	.8	.02	5.5	<.05	.2	19
B7	<1	<3	80	<.1	<.005	.4	.4	.02	20	<.05	.1	19
Distal-mining sites												
C1	<1	<3	30	<.1	.009	.1	1.4	.03	2.4	<.05	.2	21
C2	<1	<3	30	<.1	.006	<.1	1.1	.04	2.0	<.05	.1	19
C3	<1	<3	30	<.1	.008	.2	.8	.02	8.3	<.05	.1	14
C4	<1	<3	40	<.1	.006	<.1	.7	.02	2.0	<.05	.1	14
C5	<1	<3	30	<.1	<.005	<.1	.6	.04	1.0	<.05	.1	12
C6	<1	<3	30	<.1	<.005	<.1	.5	.02	3.1	<.05	.1	9

Table 2. Water-quality summary statistics for major anions and cations and trace elements, April–June 2002.

[mg/L, milligrams per liter; proximity-to-mining category—A, non-mining sites; B, near-mining sites, mining activities within 7.5 miles upstream; C, distal-mining sites, mining acitivity greater than 7.5 miles upstream; Q25, 25th percentile; Q50, 50th percentile; Q75, 75th percentile; interquartile range, difference between Q75 and Q25; µg/L, micrograms per liter; <, less than; --, not computed]

	Sodium (mg/L)				Chloride (mg/L)				Sulfate (mg/L)			
	All sites	Proximity-to-mining group			All sites	Proximity-to-mining group			All sites	Proximity-to-mining group		
		A	B	C		A	B	C		A	B	C
Number of cases	25	12	7	6	25	12	7	6	25	12	7	6
Minimum	.70	.70	1.44	1.47	.9	.9	1.7	2.6	2.2	2.2	8.1	5.4
Maximum	17.2	1.45	17.2	8.92	19.0	3.1	19.0	3.3	190	4.1	190	25.0
Range	16.5	.75	15.8	7.45	18.1	2.2	17.3	.7	188	1.9	182	19.6
Mean	3.42	1.11	7.19	3.64	4.1	2.0	8.7	3.0	19.4	2.9	50.3	16.2
Standard deviation	4.05	.23	5.67	2.70	4.5	.7	6.7	.3	37.6	.7	62.7	7.1
Q25	1.11	.97	2.88	2.32	1.7	1.5	3.6	2.8	2.5	2.4	20.5	13.5
Q50 median	1.45	1.08	5.55	2.66	2.7	2.0	6.8	3.0	5.4	2.5	34.0	15.5
Q75	3.13	1.28	10.2	3.58	3.3	2.4	13.0	3.2	22.0	3.5	39.5	21.2
Interquartile range	2.02	.31	7.32	1.26	1.6	.9	9.4	.4	19.5	1.1	19.0	7.7
	Barium (µg/L)				Cadmium (µg/L)				Chromium (µg/L)			
	All sites	Proximity-to-mining group			All sites	Proximity-to-mining group			All sites	Proximity-to-mining group		
		A	B	C		A	B	C		A	B	C
Number of cases	25	12	7	6	25	12	7	6	25	12	7	6
Minimum	19.1	19.1	29.2	28.4	<.02	<.02	0.03	<.02	<1.0	< 1.0	1.1	<1.0
Maximum	87.7	33.1	50.3	87.7	.48	.06	.48	.32	3.0	2.2	2.8	3.0
Range	68.6	14.0	21.1	59.3	--	--	.45	--	--	--	1.7	--
Mean	33.5	28.8	34.2	41.9	<.09	<.03	.18	<.10	<1.7	<1.5	2.1	<1.8
Standard deviation	12.6	4.2	7.3	22.8	<.11	<.01	.15	<.11	<.6	<.5	.6	<.8
Q25	29.2	26.9	30.8	30.1	<.02	<.02	.08	.03	1.1	1.1	1.8	1.1
Q50 median	31.0	30.1	31.4	33.4	.03	<.02	.18	.05	1.7	1.4	2.0	1.4
Q75	32.8	32.1	33.6	38.1	.10	.03	.21	.11	2.2	2.0	2.4	2.4
Interquartile range	3.6	5.1	2.8	8.0	--	--	.13	.08	1.1	0.9	.6	1.3
	Cobalt (µg/L)				Copper (µg/L)				Lead (µg/L)			
	All sites	Proximity-to-mining group			All sites	Proximity-to-mining group			All sites	Proximity-to-mining group		
		A	B	C		A	B	C		A	B	C
Number of cases	25	12	7	6	25	12	7	6	25	12	7	6
Minimum	.04	.04	.10	.07	<.5	< .5	.59	<.5	.05	.05	.08	.08
Maximum	20.0	.08	20.0	.21	1.5	1.2	1.5	.83	7.7	.30	7.70	.20
Range	20.0	.04	19.9	.14	--	--	.91	--	7.7	.25	7.62	.12
Mean	1.05	.06	3.55	.10	<.7	<.6	.91	<.58	.63	.11	1.98	.11
Standard deviation	3.98	.01	7.29	.05	<.3	<.2	.34	<.14	1.6	.08	2.64	.05
Q25	.06	.05	.36	.08	<.5	<.5	.64	< .5	.08	.06	.50	.08
Q50 median	.08	.06	.71	.08	<.5	<.5	.80	< .5	.10	.08	.99	.10
Q75	.21	.06	1.65	.09	.66	.50	1.1	.62	.30	.12	2.05	.10
Interquartile range	.15	.01	1.29	.01	--	--	.46	--	.22	.06	1.55	.02

Table 2. Water-quality summary statistics for major anions and cations and trace elements, April–June 2002.—Continued

[mg/L, milligrams per liter; proximity-to-mining category—A, non-mining site; B, near-mining sites, mining activities within 7.5 miles upstream; C, distal-mining sites, mining acitivity greater than 7.5 miles upstream; Q25, 25th percentile; Q50, 50th percentile; Q75, 75th percentile; interquartile range, difference between Q75 and Q25; µg/L, micrograms per liter; <, less than; --, not computed]

	Lithium (µg/L)				Manganese (µg/L)				Nickel (µg/L)			
	All sites	Proximity-to-mining group			All sites	Proximity-to-mining group			All sites	Proximity-to-mining group		
		A	B	C		A	B	C		A	B	C
Number of cases	25	12	7	6	25	12	7	6	25	12	7	6
Minimum	<.1	<.1	<.1	<.1	.2	.2	1.9	1.6	.6	.7	2.4	.6
Maximum	6.8	.2	6.8	1.0	260	10	260	8.0	47.5	1.1	47.5	2.4
Range	--	--	--	--	260	9.8	258	6.4	46.9	.4	45.1	1.8
Mean	<1.0	<.1	<3.1	<.3	17	3.9	51	4.3	3.6	.8	10.6	1.1
Standard deviation	<1.9	<.05	<2.6	<.4	52	3.0	94	2.8	9.3	.1	16.4	.6
Q25	<.1	<.1	.8	<.1	1.9	1.2	3.4	2.2	.8	.8	3.3	.8
Q50 median	.2	.1	3.7	.2	3.9	3.7	6.7	3.4	.9	.8	4.2	1.0
Q75	.3	.2	4.8	.3	7.4	6.0	40	6.5	2.4	.9	6.7	1.0
Interquartile range	--	--	4.0	--	5.5	4.8	36.6	4.3	1.6	.1	3.4	.2
	Rubidium (µg/L)				Strontium (µg/L)				Zinc (µg/L)			
	All sites	Proximity-to-mining group			All sites	Proximity-to-mining group			All sites	Proximity-to-mining group		
		A	B	C		A	B	C		A	B	C
Number of cases	25	12	7	6	25	12	7	6	25	12	7	6
Minimum	.56	.56	.62	.71	20	20	30	30	.6	.6	5.4	1.0
Maximum	5.00	1.00	5.00	.98	110	30	110	40	150	4.9	150	8.3
Range	4.44	.44	4.38	.27	90	10	80	10	149.4	4.3	144.6	7.3
Mean	1.15	.85	1.92	.87	38	26	63	32	11.7	1.9	35.8	3.1
Standard deviation	.94	.15	1.60	.09	22	5	28	4	30.1	1.3	51.7	2.6
Q25	.80	.75	.90	.86	30	20	40	30	1.0	1.0	7.8	2.0
Q50 median	.91	.90	1.00	.88	30	30	70	30	2.6	1.5	20.0	2.2
Q75	1.00	1.00	2.50	.90	40	30	75	30	5.5	2.7	30.0	2.9
Interquartile range	.20	.25	1.6	.04	10	10	35	0	4.5	1.7	22.2	.9

Table 3. Surface-water quality data for Strother Creek near Oates and Goodland, 1964–2005.

[All constituents dissolved unless otherwise indicated as total; mm/dd/yyyy, month, day, year; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; ANC, acid neutralizing capacity; $CaCO_3$, calcium carbonate; --, no data; N, nitrogen; µg/L, micrograms per liter; <, less than; ND, not detected]

Group	Date (mm/dd/yyyy)	Discharge (ft³/s)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	ANC total (mg/L as $CaCO_3$)
					Strother Creek near Oates (ST1)					
T1	03/16/1964	--	8.2	207	--	22	13	0.6	0.9	--
(1964–1967)	06/08/1965	--	8.0	220	--	24	13	.6	.8	--
	09/30/1965	3.1	7.9	225	--	30	19	.8	1.4	--
	01/26/1966	1.5	8.1	250	--	34	20	.2	1.1	154
	08/10/1966	1.5	8.1	300	--	41	19	.8	1.4	170
	10/24/1967	2.0	7.9	286	15	34	18	1.2	5.1	143
T2	10/17/1968	12	8.0	300	20	31	16	3.9	8.6	158
(1968–1970)	01/16/1969	13	8.0	260	6	26	15	3.2	9.1	106
	04/09/1969	13	8.2	270	15	37	20	.8	.8	146
	07/15/1969	11	8.4	360	27	47	18	4.0	12	198
	10/29/1969	9.1	7.8	405	12	38	25	4.3	14	170
	01/26/1970	15	8.0	412	7	34	28	4.1	15	170
	04/30/1970	3.9	8.0	304	18	30	17	2.7	6.1	140
	08/20/1970	10	9.2	486	27	37	26	4.7	22	--
	11/03/1970	14	8.4	500	12	39	26	4.4	18	166
T3	01/27/1971	10	8.6	550	1	46	33	5.6	23	162
(1971–1975)	04/20/1971	12	8.4	540	17	39	32	5.0	20	166
	07/12/1971	10	8.3	570	28	36	33	6.5	26	138
	11/08/1971	12	7.6	650	10	48	33	6.0	26	158
	02/01/1972	1.3	7.3	420	3	38	24	2.8	9.5	174
	06/06/1972	10	7.4	550	24	42	33	5.1	21	168
	08/21/1972	9.9	7.8	600	32	44	39	6.0	25	168
	10/17/1972	14	8.1	650	14	50	35	6.6	27	158
	01/30/1973	14	8.0	425	6	37	21	3.9	13	118
	05/15/1973	16	8.2	375	18	34	17	2.7	7.4	126

Table 3. Surface-water quality data for Strother Creek near Oates and Goodland, 1964–2005.—Continued

[All constituents dissolved unless otherwise indicated as total; mm/dd/yyyy, month, day, year; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; ANC, acid neutralizing capacity; $CaCO_3$, calcium carbonate; --, no data; N, nitrogen; µg/L, micrograms per liter; <, less than; ND, not detected]

Group	Date (mm/dd/yyyy)	Discharge (ft^3/s)	pH (standard units)	Specific conductance (µS/cm)	Temperature (°C)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	ANC total (mg/L as $CaCO_3$)
Strother Creek near Oates (ST1)—Continued										
T3 (1971–1975)	07/31/1973	8.7	7.5	460	26	17	39	3.8	15	126
	11/27/1973	107	7.6	340	12	13	2.9	2.7	8.3	80
	03/05/1974	22	7.9	360	14	35	20	2.9	10	124
	05/14/1974	23	8.3	370	18	34	17	2.4	8.6	126
	08/13/1974	7.1	8.3	625	27	--	--	6.8	24	106
	10/30/1974	12	8.3	700	18	--	--	5.2	23	136
	01/07/1975	14	7.8	600	4	--	--	3.8	19	150
	04/22/1975	14.2	8.3	500	15	--	--	3.7	14	130
	07/29/1975	13	8.0	560	27	--	--	4.6	18	162
T4 (1995–2005)	09/19/1995	9.9	8.1	729	19.7	64	44	4.8	17	142
Strother Creek near Goodland (B2)										
	04/30/2002	30.6	8.1	641	17.2	58	37	3.3	11	111
	07/06/2005	8.5	7.9	864	25.9	80	55	5.0	26	[a]123

Table 3. Surface-water quality data for Strother Creek near Oates and Goodland, 1964–2005.—Continued

[All constituents dissolved unless otherwise indicated as total; mm/dd/yyyy, month, day, year; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; ANC, acid neutralizing capacity; $CaCO_3$, calcium carbonate; --, no data; N, nitrogen; µg/L, micrograms per liter; <, less than; ND, not detected]

Group	Date (mm/dd/yyyy)	Bicarbonate, total (mg/L)	Carbonate, total (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)
Strother Creek near Oates (ST1)											
T1 (1964–1967)	03/16/1964	122	<1	0.5	ND	6.5	5.6	0.2	--	--	ND
	06/08/1965	138	<1	.5	ND	8.6	5.4	.1	30	--	--
	09/30/1965	165	<1	.9	0.1	8.4	4.4	.1	30	--	--
	01/26/1966	188	<1	.9	.1	6.2	3.6	ND	--	--	--
	08/10/1966	207	<1	.6	.2	9.7	2.2	--	[b].06	--	--
	10/24/1967	174	<1	2.0	.2	7.4	9.4	ND	40	10	--
T2 (1968–1970)	10/17/1968	193	<1	2.4	.2	8.0	14	.1	90	ND	ND
	01/16/1969	129	<1	3.2	.4	10.0	15	.4	1,600	ND	ND
	04/09/1969	178	<1	.9	ND	6.6	5.6	.1	ND	200	ND
	07/15/1969	233	4	5.0	.6	8.8	20	--	ND	ND	ND
	10/29/1969	207	<1	12	.3	9.0	32	--	ND	63	3
	01/26/1970	207	<1	14	.4	6.2	32	--	300	ND	ND
	04/30/1970	171	<1	4.7	ND	7.3	16	.3	ND	ND	ND
	08/20/1970	--	--	21	.5	6.7	65	.3	ND	140	ND
	11/03/1970	197	2	20	.1	7.0	48	.3	15,000	--	ND
T3 (1971–1975)	01/27/1971	193	2	25	1.4	6.0	62	.4	ND	--	ND
	04/20/1971	200	1	24	.1	.6	64	1.2	ND	--	ND
	07/12/1971	163	2	57	.1	.8	66	.9	ND	--	ND
	11/08/1971	193	<1	--	--	7.2	13	[c]1.7	ND	--	ND
	02/01/1972	212	<1	20	< .1	--	33	[c].7	ND	--	ND
	06/06/1972	205	<1	--	--	8.6	75	[c].5	ND	--	ND
	08/21/1972	205	<1	30	.6	6.0	42	[c]<.1	ND	--	ND
	10/17/1972	193	<1	22	< .1	4.2	134	[c]<.1	< 100	--	ND
	01/30/1973	144	<1	55	.1	6.9	83	[c].5	< 100	--	ND
	05/15/1973	154	<1	7.5	.5	8.0	49	[c].1	< 100	--	ND

Table 3. Surface-water quality data for Strother Creek near Oates and Goodland, 1964–2005.—Continued

[All constituents dissolved unless otherwise indicated as total; mm/dd/yyyy, month, day, year; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; ANC, acid neutralizing capacity; $CaCO_3$, calcium carbonate; --, no data; N, nitrogen; µg/L, micrograms per liter; <, less than; ND, not detected]

Group	Date (mm/dd/yyyy)	Bicarbonate, total (mg/L)	Carbonate, total (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)
Strother Creek near Oates (ST1)—Continued											
T3 (1971–1975)	07/31/1973	154	<1	2.1	0.1	5.0	76	[c]<0.1	10	--	ND
	11/27/1973	98	<1	--	.1	--	49	[c].3	< 100	--	ND
	03/05/1974	151	<1	22	.3	--	11	[c].6	< 100	--	ND
	05/14/1974	154	<1	11	.2	--	68	[c].5	< 100	--	< 2
	08/13/1974	--	--	40	--	--	130	[c]1.3	--	--	ND
	10/30/1974	--	--	50	--	--	180	[c]1.9	--	--	ND
	01/07/1975	--	--	28	--	--	135	[c]1.6	--	--	< 2
	04/22/1975	--	--	17	--	--	140	[c].8	--	--	ND
	07/29/1975	--	--	19	--	--	140	[c]<.1	--	--	< 2
T4 (1995–2005)	09/19/1995	165	<1	24	.2	6.2	200	.73	31	--	< 1
Strother Creek near Goodland (B2)											
	04/30/2002	137	<1	16	0.2	2.8	190	2.5	31	--	0.2
	07/06/2005	150	<1	28	.2	6.7	287	--	46	82	.1

Table 3. Surface-water quality data for Strother Creek near Oates and Goodland, 1964–2005.—Continued

[All constituents dissolved unless otherwise indicated as total; mm/dd/yyyy, month, day, year; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; ANC, acid neutralizing capacity; $CaCO_3$, calcium carbonate; --, no data; N, nitrogen; µg/L, micrograms per liter; <, less than; ND, not detected]

Group	Date (mm/dd/yyyy)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manganese (µg/L)	Nickel (µg/L)	Silver (µg/L)	Strontium (µg/L)	Zinc (µg/L)
Strother Creek near Oates (ST1)												
T1	03/16/1964	ND	ND	[b]0.01	--	20	--	ND	--	--	--	50
(1964–1967)	06/08/1965	ND	ND	ND	--	ND	--	ND	ND	--	--	70
	09/30/1965	ND	ND	ND	--	ND	--	ND	ND	--	--	70
	01/26/1966	--	--	--	--	--	--	ND	--	--	--	--
	08/10/1966	--	--	--	--	--	ND	ND	--	--	[b]0.03	--
	10/24/1967	ND	ND	ND	--	ND	ND	--	ND	--	20	--
T2	10/17/1968	ND	ND	ND	--	ND	20	10	ND	--	140	10
(1968–1970)	01/16/1969	ND	10	ND	--	ND	ND	10	ND	--	60	10
	04/09/1969	ND	ND	ND	--	10	ND	ND	20	--	20	30
	07/15/1969	ND	10	20	--	ND	ND	20	10	--	220	20
	10/29/1969	5	4	4	6	ND	ND	50	29	8	210	13
	01/26/1970	5	1	10	33	25	13	54	16	ND	200	21
	04/30/1970	5	15	10	22	6	ND	6	15	ND	200	11
	08/20/1970	7	ND	10	17	ND	6	10	ND	ND	--	18
	11/03/1970	14	9	4	40	60	--	90	24	20	--	20
T3	01/27/1971	6	12	4	100	32	--	70	ND	ND	--	40
(1971–1975)	04/20/1971	1	ND	2	ND	23	--	25	14	ND	--	10
	07/12/1971	4	2	5	20	20	--	60	2	ND	--	30
	11/08/1971	1	ND	11	ND	4	--	30	1	ND	--	20
	02/01/1972	1	1	4	ND	8	--	ND	6	2	--	ND
	06/06/1972	ND	ND	--	ND	4	--	140	19	ND	--	70
	08/21/1972	ND	3	2	10	2	--	40	1	ND	--	ND
	10/17/1972	ND	ND	3	< 10	ND	--	40	10	ND	--	60
	01/30/1973	< 20	4	8	< 10	ND	--	210	3	ND	--	140
	05/15/1973	< 20	5	4	< 10	ND	--	180	12	ND	--	70

Table 3. Surface-water quality data for Strother Creek near Oates and Goodland, 1964–2005.—Continued

[All constituents dissolved unless otherwise indicated as total; mm/dd/yyyy, month, day, year; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; ANC, acid neutralizing capacity; $CaCO_3$, calcium carbonate; --, no data; N, nitrogen; µg/L, micrograms per liter; <, less than; ND, not detected]

Group	Date (mm/dd/yyyy)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manganese (µg/L)	Nickel (µg/L)	Silver (µg/L)	Strontium (µg/L)	Zinc (µg/L)
Strother Creek near Oates (ST1)—Continued												
T3 (1971–1975)	07/31/1973	ND	< 2	5	18.75	< 2	--	90	9	ND	--	20
	11/27/1973	ND	6	6	40	65	--	210	10	ND	--	90
	03/05/1974	ND	5	11	30	12	--	280	10	ND	--	60
	05/14/1974	ND	< 2	3	50	4	--	120	6	ND	--	< 20
	08/13/1974	--	--	2	--	5	--	80	--	--	--	ND
	10/30/1974	--	--	< 2	--	2	--	140	--	--	--	40
	01/07/1975	--	--	7	--	4	--	200	--	--	--	150
	04/22/1975	--	--	4	--	4	--	180	--	--	--	ND
	07/29/1975	--	--	< 2	--	10	--	60	--	--	--	ND
T4 (1995–2005)	09/19/1995	2	31	2	19	3	--	57	114	< 1	--	148
Strother Creek near Goodland (B2)												
	04/30/2002	2	18	1	< 50	2	4	50	48	< 3	106	151
	07/06/2005	<.8	7	2	< 6	1	6	1.4	26	< .2	160	46

[a] Dissolved concentration.

[b] Suspicious value may have been entered in data base as milligrams per liter.

[c] Total concentration.