Questa Baseline and Pre-Mining Ground-Water Quality Investigation. 20. Water Chemistry of the Red River and Selected Seeps, Tributaries, and Precipitation, Taos County, New Mexico, 2000-2004

Scientific Investigations Report 2006-5028

Prepared in cooperation with the New Mexico Environment Department

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

Front cover: Photographs of the Red River from the USGS stream-gaging station at the Questa Ranger Station looking upstream in August 2002 (left side) and September 18, 2002 (right side).

science for a changing world

Questa Baseline and Pre-Mining Ground-Water Quality Investigation. 20. Water Chemistry of the Red River and Selected Seeps, Tributaries, and Precipitation, Taos County, New Mexico, 2000-2004

By Philip L. Verplanck, R. Blaine McCleskey, and D. Kirk Nordstrom

Scientific Investigations Report 2006-5028

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

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

U.S. Geological Survey, Reston, Virginia 2006

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Verplanck, P.L., McCleskey, R.B., and Nordstrom, D.K., 2006, Questa baseline and pre-mining ground-water quality investigation. 20. Water chemistry of the Red River and selected seeps, tributaries, and precipitation, Taos County, New Mexico: U.S. Geological Survey Scientific Investigations Report 2006-5028, 139 p.

Contents

FIGURES

TABLES

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
micrometer (µm)	0.00003937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square centimeter (cm^2)	0.1550	square inch (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
square kilometer (km^2)	247.1	acre
	Volume	
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
liter per second (L/s)	15.85	gallon per minute (gal/min)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound, avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32
Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)
Horizontal coordinate information is referenced to North American Datum of 1927 (NAD 27)
Altitude, as used in this report, refers to distance above the vertical datum.
Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).
Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations used in this report

---	not analyzed, measured, or calculated
<	less than
°C	degrees Celsius
C.I.	charge imbalance
DOC	dissolved organic carbon
FA	filtered-acidified
FU	filtered-unacidified
FIAS	flow injection analysis system
ft^3/s	cubic feet per second
GFAAS	graphite furnace atomic absorption spectrometry
GMWL	global meteoric water line
GPS	global positioning system
HCl	hydrochloric acid
HDPE	high-density polyethylene
HGAAS	hydride-generation atomic-absorption spectrometry
HNO_3	nitric acid
IC	ion chromatography
ICP-MS	inductively coupled plasma-mass spectrometry
ICP-OES	inductively coupled plasma-optical emission spectrometry
ID	identification
ISE	ion-selective electrode
km	kilometers
km^2	square kilometers
m	meters
mm	millimeter
meq/L	milliequivalents per liter
mM	millimoles per liter
mg/L	milligrams per liter
MPV	most probable value
N	normality
nm	nanometer
NTU	nephelometric turbidity units
μg/L	micrograms per liter
μm	micrometer
μS/cm	microsiemens per centimeter
UV	ultraviolet
PE	polyethylene
RA	raw-acidified
REE	rare earth element
RMMWL	Rocky Mountain meteoric water line
RSD	relative standard deviation
RU	raw-unacidified
s	standard deviation
SC	specific conductance
SI	saturation index
SRWS	standard reference water sample
St. Cr.	Straight Creek
TOC	total organic carbon
UFA	ultrafiltered-acidified
v/v	volume per volume
USGS	U.S. Geological Survey

Questa Baseline and Pre-Mining Ground-Water Quality Investigation. 20. Water Chemistry of the Red River and Selected Seeps, Tributaries, and Precipitation, Taos County, New Mexico, 2000-2004

By Philip L. Verplanck, R. Blaine McCleskey, and D. Kirk Nordstrom

ABSTRACT

As part of a multi-year project to infer the pre-mining ground-water quality at Molycorp's Questa mine site, surface-water samples of the Red River, some of its tributaries, seeps, and snow samples were collected for analysis of inorganic solutes and of water and sulfate stable isotopes in selected samples. The primary aim of this study was to document diel, storm event, and seasonal variations in water chemistry for the Red River and similar variations in water chemistry for Straight Creek, a natural analog site similar in topography, hydrology, and geology to the mine site for inferring pre-mining water-quality conditions.

Red River water samples collected between 2000 and 2004 show that the largest variations in water chemistry occur during late summer rainstorms, often monsoonal in nature. Within hours, discharge of the Red River increased from 8 to 102 cubic feet per second and pH decreased from 7.80 to 4.83. The highest concentrations of metals (iron, aluminum, zinc, manganese) and sulfate also occur during such events. Low-pH and high-solute concentrations during rainstorm runoff are derived primarily from alteration "scar" areas of naturally high mineralization combined with steep topography that exposes continually altered rock because erosion is too rapid for vegetative growth.

The year 2002 was one of the driest on record, and Red River discharge reflected the low seasonal snow pack. No snowmelt peak appeared in the hydrograph record, and a late summer storm produced the highest flow for the year. Snowmelt was closer to normal during 2003 and demonstrated the dilution effect of snowmelt on water chemistry. Two diel sampling events were conducted for the Red River, one during low flow and the other during high flow, at two locations, at the Red River gaging station and just upstream from Molycorp's mill site. No discernible diel trends were observed except for dissolved zinc and manganese at the upstream site during low flow.

Straight Creek drainage water was sampled periodically from 2001 to 2004 at the down stream end of surface drainage near the point at which it disappeared into the debris fan. This water has a minimal range in pH (2.7 to 3.2) but a substantial concentration range in many solutes; for example, sulfate concentrations varied from 525 to 2,660 mg/L. Many elements covary with sulfate suggesting that dilution is the primary control of the range in solute concentrations. A transect of water samples higher in the scar area were collected in October of 2003. They had a lower range in pH (2.44 to 3.05) and higher solute concentrations than those collected periodically from lower in the catchment. Water isotopes for the upper transect samples indicated slight evaporation, and in part, may account for the higher solute concentrations. Drainage waters also were collected from Hottentot, Junebug, Hansen, Little Hansen, and Goat Hill Gulch drainages. Most constituents from other scar drainage waters showed ranges of concentration similar to those of the Straight Creek waters. An exception was water collected from Goat Hill Gulch,

which has some of the highest concentrations of any surface-water sample collected but also contained waste-rock leachates.

INTRODUCTION

The Red River Valley, Taos County, New Mexico, is the site of a multidisciplinary U.S. Geological Survey (USGS) investigation to determine current and estimate pre-mining ground-water quality. One of the objectives was to characterize the chemistry of surface waters and identify processes that control surface-water chemistry. Depending on location, surface waters can flow to ground water or receive flow from ground water and, by understanding variations in surface-water chemistry, insight into ground-water chemistry and flow paths can be gained.

Surface-water chemistry of mountain streams can vary according to seasonal and diel (24-hour) cycles as well as during storm events. In the southern Rocky Mountains, seasonal variations are primarily driven by snowmelt in the late spring and monsoonal-related thunderstorms in the late-summer (Ingersoll, 2000). The late-summer flow of monsoonal moisture drives late-day thunderstorms and can lead to periods of heavy rain that last up to a few days. These storm events not only increase stream discharge, but also dissolve soluble salts, wash fine material from hill slopes into streams, and force higher concentration pore waters into drainages. Daily fluctuations in solar radiation affect not only photosynthesis and photo-sensitive elements such as dissolved iron, but also lead to temperature fluctuations which can affect solubility and sorption processes. Recent diel studies of mountain streams have shown that in some settings substantial variations occur in iron, cadmium, manganese, nickel, and zinc (McKnight and Bencala, 1988; Nimick and others, 2003, 2005).

The USGS, in cooperation with the New Mexico Environment Department, studied the water chemistry of the Red River and selected seeps, tributaries, and snow to characterize and improve understanding of surface-water chemistry.

Purpose and Scope

The purpose of this report is to present water-chemistry data from surface-water investigations conducted between 2000 and 2004 and to describe processes that likely control surface-water chemistry in the Red River study area. Water-chemistry data for the Red River Valley include analytical results for samples collected at the USGS streamflow-gaging station near Questa (number 08265000; 2000-2003), samples from a storm-event study, samples from a diel study, and snow samples. Other surface-water-chemistry data reported include analytical results for scar-tributary samples (September 2001 and May 2004) and Straight Creek samples (October 2000 to October 2003). Data presented in this report include field measurements of pH, specific conductance, dissolved oxygen, Eh, and temperature, and laboratory determinations of the concentrations of major inorganic and selected trace-element constituents. For a subset of these samples, a more comprehensive suite of trace elements (determined by inductively-coupled plasma-mass spectrometry) and oxygen, hydrogen, and sulfur stable isotopic compositions are reported. In addition, determinations of trace element concentrations by inductively-coupled plasma-mass spectrometry for selected Red River mainstem and inflow (tributaries and seeps) samples collected during the tracer-synoptic study in August 2001 and March 2002 are reported. Field measurements and concentrations of major inorganic and selected trace element constituents for these samples were previously published (McCleskey and others, 2003b). Quality assurance/quality control results for these analyses also have been published (McCleskey and others, 2004). Ground-water chemistry for well SC1B, published in Naus and others (2005), is used for mass-balance calculations. SC1B is a bedrock well located in the upper part of the Straight Creek debris fan. Ground-water levels in SC1A, an alluvial well located in the upper part of the Straight Creek debris fan, are also discussed.

Physical Description of the Study Area

The Red River drains 490 square kilometers of the Taos Range, southern Sangre de Cristo Mountains and empties into the Rio Grande north of Taos, New Mexico (fig. 1). This region is part of the Southern Rocky Mountains physiographic province. The main area of study within the Red River basin extends from the town of Red River to the USGS streamflow-gaging station near Questa (USGS streamflow-gaging station number 08265000) and encompasses approximately 170 square kilometers of the drainage basin and approximately 20 kilometers of river reach. The Molycorp, Inc., Questa Molybdenum mine site lies north of the Red River in the western part of the study area and occupies approximately 15 square kilometers.

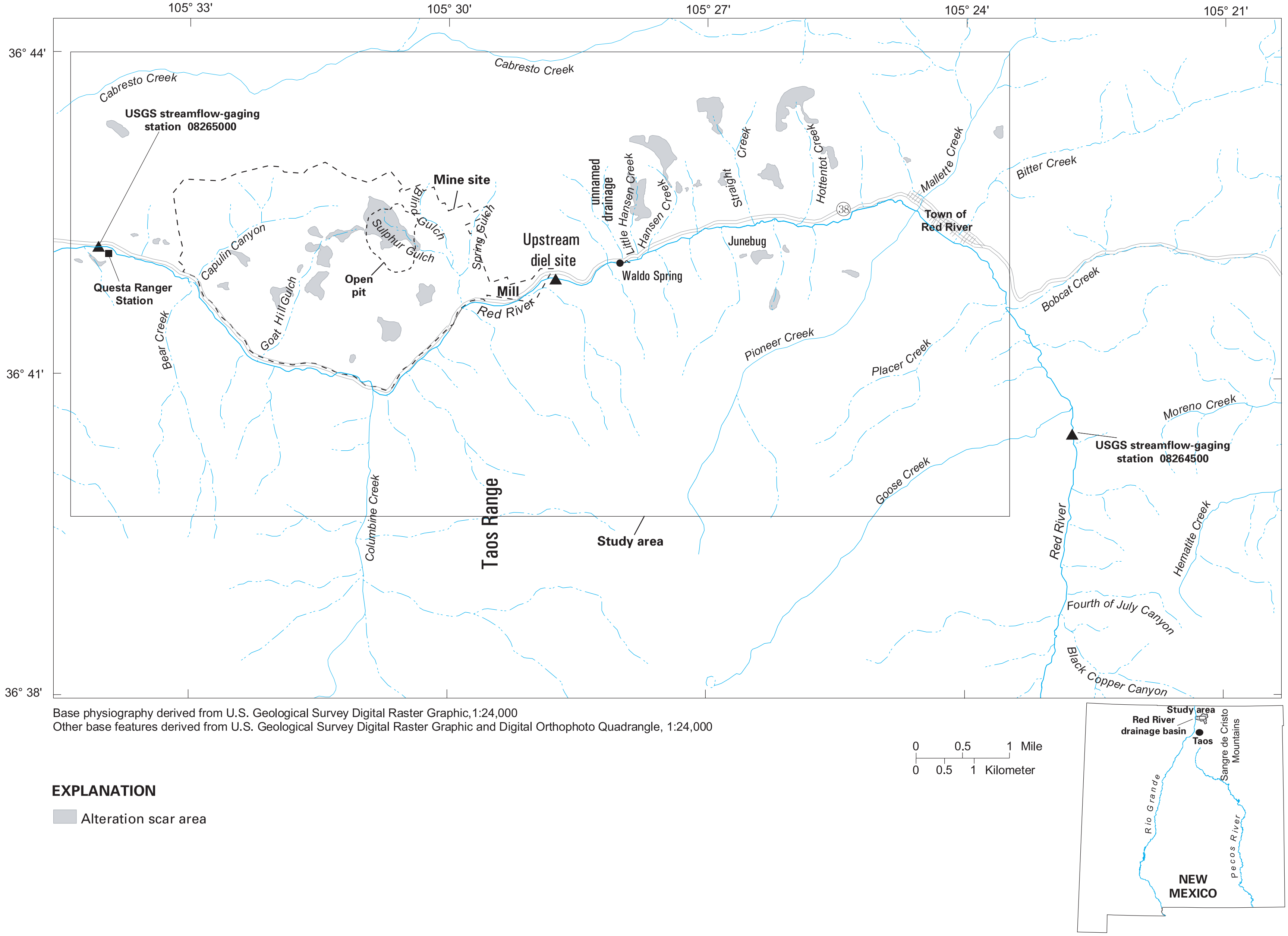
Geology

In the study area, the Red River follows the southern edge of the Questa caldera, and is the southern extent of the Oligocene Latir volcanic field (Lipman and Reed, 1979; Meyer and Leonardson, 1990). The topography is steep, rising rapidly from the basin floor at an altitude of about 2,270 meters near the Questa Ranger Station to ridge crests with altitudes exceeding 3,200 meters. The geology of the basin consists of Proterozoic crystalline basement, primarily gneisses and intermediate-composition plutonic rocks that have been intruded by and are overlain by intermediate to felsic volcanic units associated with the Latir volcanic field. Subsequent to formation of the Questa caldera at about 25.7 million years ago within the Red River Valley, these units were intruded by high-silica granitic stocks at 24.1 to 24.6 million years ago (Czamanski and others, 1990). These stocks are believed to be the source of the hydrothermal fluids that formed the Questa molybdenum deposit and caused the extensive hydrothermal alteration observed in parts of the study area (Leonardson and others, 1983; Czamanski and others, 1990; and Meyer, 1991). Hydrothermal activity associated with the Questa caldera is believed to have caused regional propylitization, altering mafic mineral phases to chlorite, epidote, and calcite. These propylitized rocks and other slightly younger lithologies were more extensively altered during the hydrothermal activity associated with the granitic stocks. Hydrothermally altered areas are characterized by pyrite mineralization, and quartz-sericite-pyrite and pyrite-kaolinite assemblages (Meyer and Leonardson, 1990; Ludington and others, 2004). Surface weathering (supergene alteration) has, in part, transformed these mineral assemblages to iron oxides, gypsum, and clay minerals (Meyer and Leonardson, 1990; Ludington and others, 2004). These areas, referred to as alteration "scar areas," contain incompetent bedrock and sparse vegetation and consequently have high erosion rates (fig. 1). A more detailed discussion of the geology, alteration, and weathering processes is presented in Ludington and others (2004).

Climate and Vegetation

In this region, surface water is fed by snowmelt, rainfall, and ground water. At higher elevations in the Southern Rocky Mountains most of the precipitation falls in the winter and spring forming the seasonal snowpack (Ingersoll, 2000), such that snowmelt is the greatest source of water to streams in the region. Between 1915 and 2002, the annual average temperature was 4°C at the Red River climate station (297323), the precipitation and snowfall were 52 centimeters and 370 centimeters, respectively, and the daily temperature generally fluctuated by 18°C throughout the year (Western Regional Climate Center, 2003).

Vegetation type is controlled primarily by climate, soil composition, and topography. Within the study area, climate can vary over short distances because of differences in topography and distance from the Rio Grande Valley. The bedrock geology and intensity of hydrothermal alteration is a primary control of soil composition. Topographic controls of vegetation include slope, aspect, and altitude. In general, lower and south-facing slopes are drier and warmer, and upper and north-facing slopes are cooler and more moist. Hillslopes tend to support conifers, including ponderosa pine (*Pinus ponderosa*), limber pine (*Pinus flexius*),



Base physiography derived from U.S. Geological Survey Digital Raster Graphic,1:24,000
Other base features derived from U.S. Geological Survey Digital Raster Graphic and Digital Orthophoto Quadrangle, 1:24,000

Figure 1. Location of the mine site, drainages sampled, and study area within the Red River basin.

and douglas fir (*Pseudotsuga taxifolia*). Along the Red River, willows (*Salix spp.*), cottonwoods (*Populus spp.*), grasses, and forbs are present.

Hydrology

The Red River originates near Wheeler Peak in the Taos Range and flows north and west for approximately 40 km to the confluence with the Rio Grande. Within the watershed the longest record of stream flow is from USGS streamflow-gaging station 08265000 near Questa, which has a nearly continuous record from October 1, 1924, to the present. Above the town of Red River, a second USGS streamflow-gaging station, USGS 08265000, recorded stream discharge from May 1, 1963, to December 31, 1973. The hydrograph for 08265000 (figs. 2A and B) has a typical Rocky Mountain watershed shape with annual peaks resulting from snowmelt runoff, intermittent peaks associated with summer storm events, and low-flow conditions from late summer until the beginning of spring snowmelt.

Acknowledgments

The authors appreciate the input from the project advisory committee whose members represent Amigos Bravos, Molycorp, Inc. and its consultants, and the New Mexico Environment Department. Cooperation from the U.S. Forest Service aided the field sampling. Molycorp Inc., provided assistance and granted us access to their property. Comprehensive reviews by James W. Ball and David A. Nimick improved this report. The authors acknowledge Tyler B. Coplen's laboratory, Reston, Virginia, for providing water isotopes, and Robert O. Rye's laboratory, Denver, Colorado, for providing sulfate stable isotopes.

METHODS

Sampling Sites

The Red River was sampled at the USGS streamflow-gaging station 08265000 near the U.S. Forest Service Questa Ranger Station (fig. 1; table 1). Twenty-one samples were collected under a range of hydrologic conditions including low flow, rising limb, peak flow, and storm (fig. 3). In addition, the Red River was sampled upstream from the mine (fig 1, table 1) during the high- and low-flow diel studies. Straight Creek surface water was collected during each sampling trip. The location of the sampling site varied because of changes in flow and access. The Straight Creek surface-water dataset includes data for nine samples collected at a site approximately 200 m upstream from the debris fan, three samples farther downstream (02WA102, 02WA112, and 03WA111), and two samples collected during the September 2002 storm event (02WA154 and 02WA158; fig. 4; table 1). During the September 2001 low-flow tributary sampling trip, samples of the most upstream Straight Creek water (01WA155, Straight Creek-high) and the most downstream water (01WA154, Straight Creek-low) were collected. On October 23, 2003, five Straight Creek samples were collected to evaluate downstream variation in water chemistry. This sampling event is referred to as the Straight Creek transect and includes, from upstream to downstream, samples 03WA168, 03WA169, 03WA170, 03WA171, and 03WA172 (fig. 4; table 1). During September 2001, a suite of low-flow tributary samples were collected. Sampling sites included Goat Hill Gulch (01WA159), Waldo Spring (01WA163), an unnamed drainage west of Little Hansen (01WA162), Little Hansen (01WA153), the most upstream water in Hansen Creek (01WA152, Hansen-high), the most downstream stream water in Hansen Creek (01WA151, Hansen-low), Junebug-east (01WA161), Junebug-west (01WA162), the most upstream water in Hottentot Creek (01WA157, Hottentot-high), and the most downstream stream water in Hottentot Creek (01WA156, Hottentot-low). In May 2003 two samples of water (03WA102 and 03WA103) draining the Capulin Canyon scar area were collected (fig. 1; table 1). To

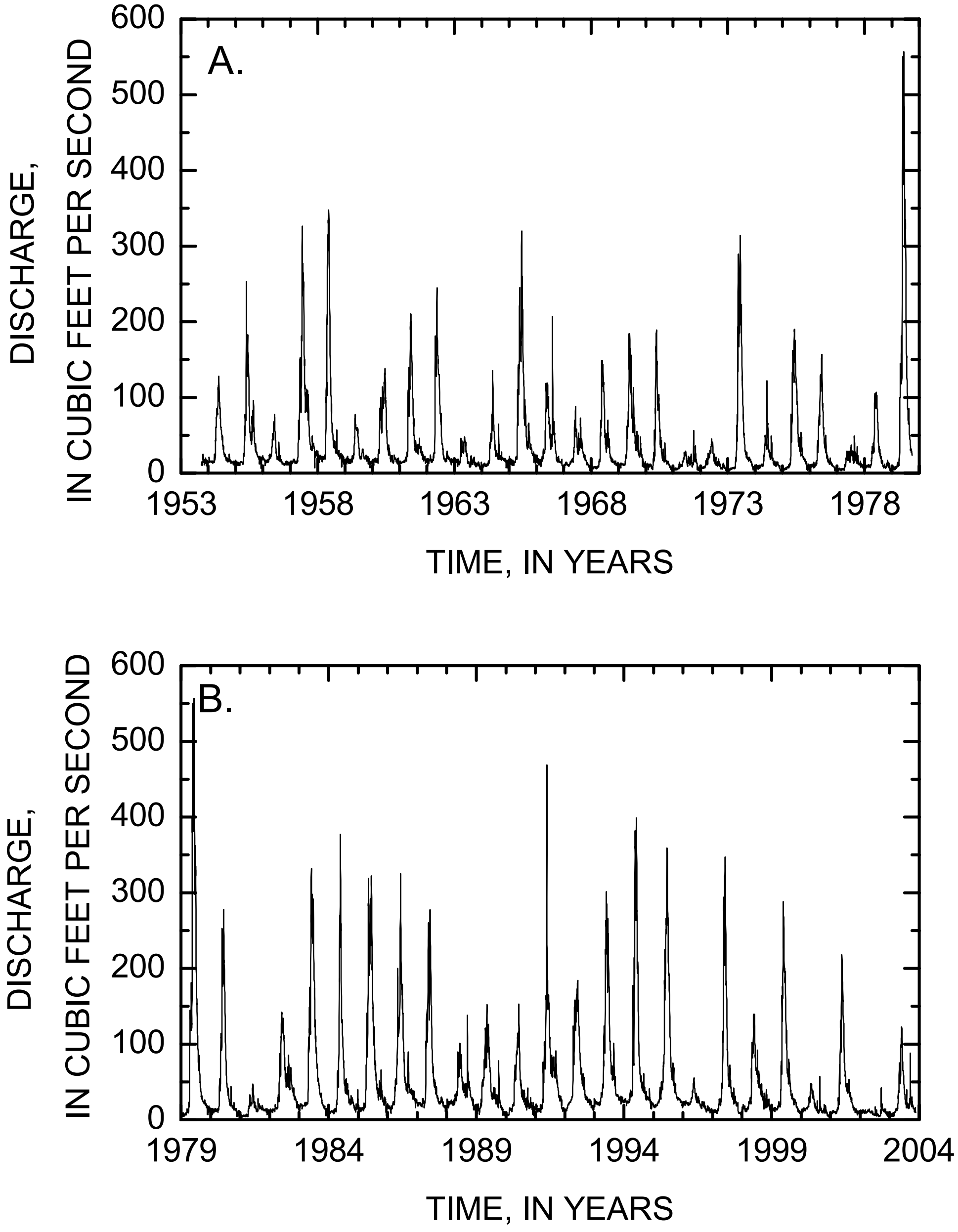


Figure 2. Daily mean discharge of the Red River measured at USGS streamflow-gaging station 08265000 at the Questa Ranger Station for years (A) 1953 through 1979 and (B) 1979 through 2003.

determine the isotopic composition of the seasonal snowpack, five snow samples were collected (table 1). In addition, a rain (03WA113) and a snow (03WA112) sample were collected at Straight Creek during a precipitation event in April 2003 (table 1).

Table 1. Locations of sampling sites

[GPS, global positioning system; N, north; W, west; S, south; St. Cr., Straight Creek]

Sample Location	Latitude (N)	Longitude (W)	Sample code number
Red River at USGS Gage	36°42'11"	105°34'03"	several
Red River below Mill	36°41'41"	105°29'38"	03WA104
Red River above Mill	36°41'50"	105°29'59"	03WA164
Red River 5847	36°42'19"	105°27'18"	03WA105
Capulin Canyon Scar	36°42'07"	105°32'29"	04WA102
Capulin Canyon Scar	36°42'19"	105°32'26"	04WA103
Goat Hill Gulch	36°41'57"	105°31'41"	01WA159
Waldo Spring	34°42'04"	105°28'03"	01WA163
Unnamed drainage west of Little Hansen	34°42'19"	105°28'06"	01WA162
Little Hansen	36°42'27"	105°27'53"	01WA153
Hansen (high)	36°42'58"	105°27'31"	01WA152
Hansen (low)	36°42'318"	105°27'20"	01WA151
Straight Creek	36°43'16"	105°26'51"	00WA197
Straight Creek (high)	36°43'27"	105°26'58"	01WA155
Straight Creek (low)	36°43'08"	105°26'43"	01WA154
Straight Creek	36°42'58"	105°26'40"	02WA102
Straight Creek	36°42'59"	105°26'40"	02WA112
Straight Creek	36°43'14"	105°26'48"	02WA121
Straight Creek	36°43'14"	105°26'50"	02WA124
Straight Creek	36°42'58"	105°26'40"	02WA154
Straight Creek	36°43'00"	105°26'41"	02WA158
Straight Creek "at pipe"	36°43'16"	105°26'51"	see figure 4
Straight Creek	No GPS; should be close to other St. Cr. Sites		03WA101
Straight Creek	36°43'11"	105°26'45"	03WA111
Straight Creek	36°43'14"	105°26'50"	03WA165
Straight Creek transect	36°43'14"	105°26'59"	03WA168
Straight Creek transect	36°43'24"	105°26'57"	03WA169
Straight Creek transect	36°43'21"	105°26'54"	03WA170
Straight Creek transect	36°43'18"	105°26'53"	03WA171
Straight Creek transect	36°43'14"	105°26'50"	03WA172
Junebug (east)	36°42'12"	105°26'26"	01WA161
Junebug (west)	36°42'11"	105°26'28"	01WA160
Hottentot (high)	36°43'33"	105°25'59"	01WA157
Hottentot (low)	36°43'13"	105°25'49"	01WA156
Bitter Creek	36°41'18"	105°24' 9"	02WA156
Straight Creek snow	36°42'47"	105°26' 38"	03WA112
Straight Creek rain	36°42'26"	105°26' 46"	03WA113
Snow - Hansen Creek basin	36°42'44"	105°27'25"	02WA111
Snow - N. side, N. facing	36°44'6"	105°27'14"	02WA107
Snow - S. side, Bretts steakhouse	36°42'25"	105°25'20"	02WA109
Snow - S. side, Elephant Rock	36°42'20"	105°26'54"	02WA108
Snow - Straight Creek basin	36°43'13"	105°26'49"	02WA110

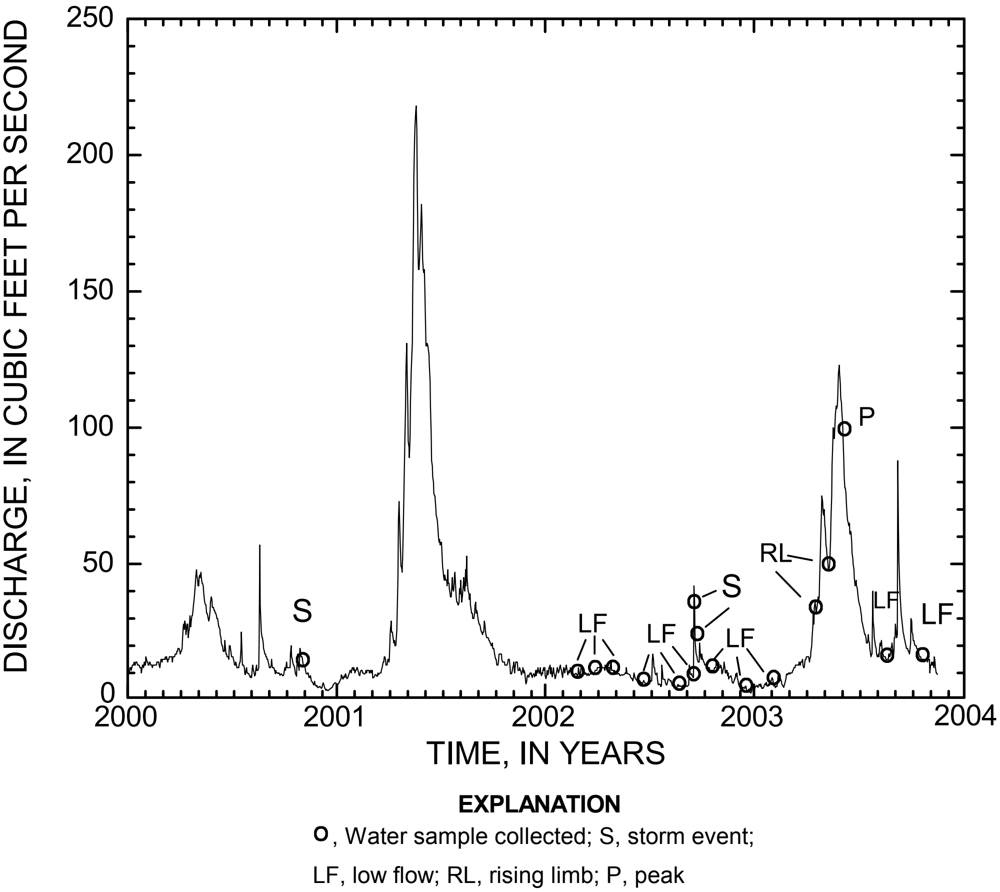
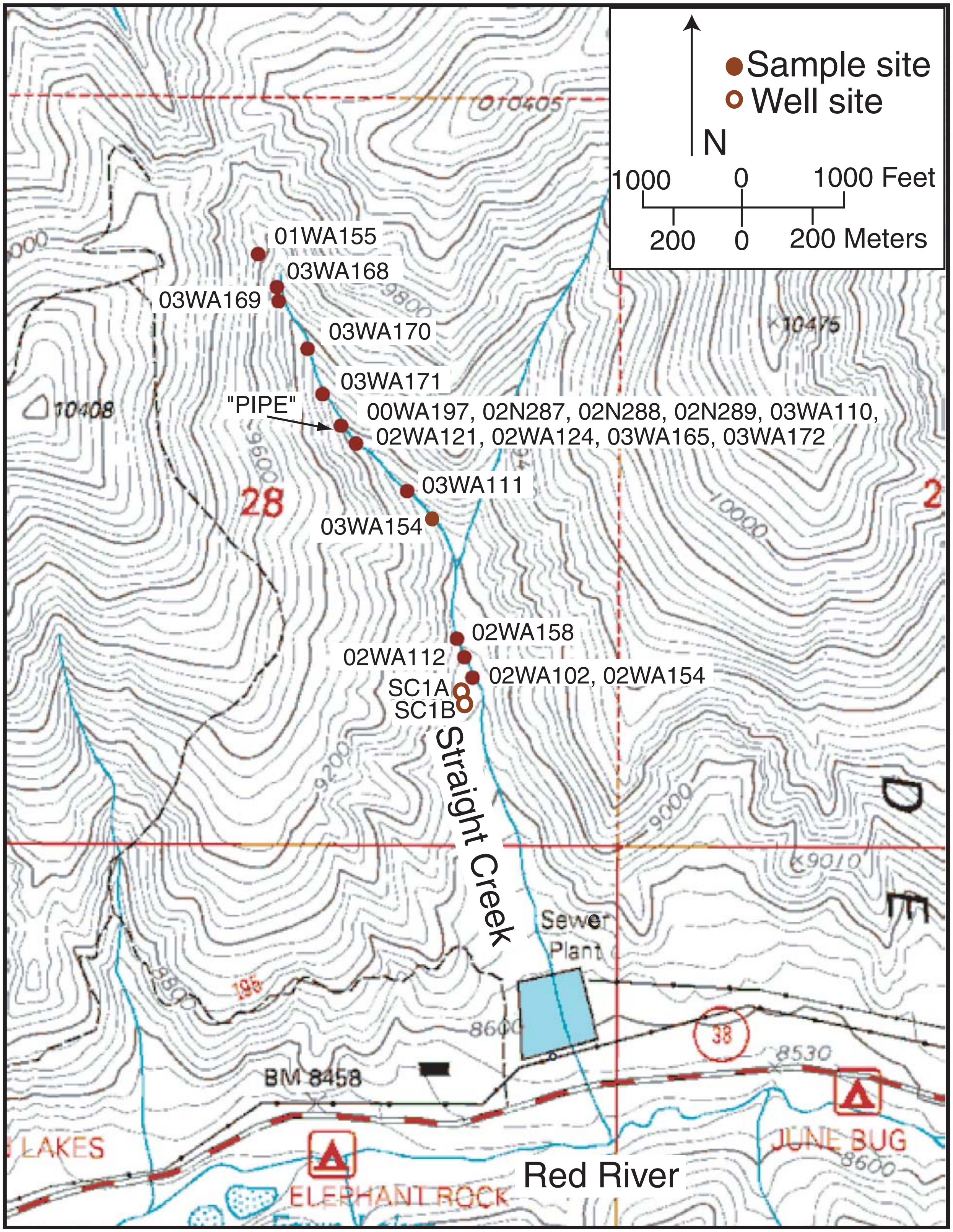


Figure 3. Daily mean discharge of the Red River measured at USGS streamflow-gaging station 08265000 at the Questa Ranger Station from years 2000 through 2003, with hydrologic condition.

Water-Chemistry Sampling

Depending on the discharge and stream depth, surface-water samples were collected as grab samples or using equal-width and depth-integrated sampling methods using a model DH-81 depth-integrating water-sampling device (Ward and Harr, 1990). Samples were filtered on site through a 142-mm diameter all-plastic filter holder (Kennedy and others, 1976) containing a 0.1-µm-pore-size mixed-cellulose-ester filter membrane, through a disposable capsule filter having a nominal pore size of 0.45 µm, or through a syringe filter having a pore size of either 0.2 or 0.45 µm. In this report constituent concentrations measured in filtered subsamples are called “dissolved”, and constituent concentrations in unfiltered subsamples (RA) are called “total recoverable”.

Snowpack sampling occurred in March 2002 when the snow depth was at a maximum but prior to melting. North-facing slopes were sampled to avoid areas that might have been in direct sunlight. Snow pits were dug to the ground surface, and depth-integrated snow samples were collected from the entire face. Samples were stored in prerinsed, plastic bags and placed in a cooler. Upon returning to the laboratory, samples were melted and sample splits were taken for various chemical analyses, following the same procedures as surface-water samples.



Base from U.S. Geological Survey Red River Quadrangle, 1:24,000 (1995)

Figure 4. Topographic map of Straight Creek study area showing locations of sampling sites.

Several sample splits were collected for determination of concentrations of inorganic constituents, redox species, and dissolved organic carbon (DOC). Container preparation and stabilization of filtered samples are summarized in table 2. Samples for the determination of concentrations of cations and trace metals (As, Al, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Gd, Hf, Ho, K, La, Li, Lu, Mg, Mn, Mo, Na, Nd, Ni, Pb, Pr, Rb, Re, Sb, Se, SiO_2, Sm, Sr, Ta, Tb, Te, Th, Tl, Tm, U, V, W, Y, Yb, Zr, and Zn), major anions (Br, Cl, F, NO_3, and SO_4), alkalinity, and DOC were filtered and then stabilizing reagents were added when necessary. Sample bottles were prerinsed with filtered water prior to sample collection. Samples for the determination of DOC concentrations were filtered through the same filter used to collect the inorganic constituents. At least 1 L of sample was passed through the filter assembly before a DOC sample was collected. Samples were collected for sulfur isotopes ($\delta^{34}S$ and $\delta^{18}O$) and water isotopes ($\delta^{2}H$ and $\delta^{18}O$) during selected samplings. In this report delta notation (δ) is used to describe the isotopic concentration of water and sulfur isotopes. In delta notation, the ratio of the heavy and light isotope is compared to that of a reference standard (Clark and Fritz, 1999).

Laboratory Methods

Water-quality samples were stored on ice in coolers and either shipped overnight delivery or hand delivered to the USGS laboratories in Boulder, Colorado. Prior to analysis, samples were refrigerated. Analytical techniques, detection limits, equipment used, pertinent references, and comments are described briefly in table 3. Oxygen and hydrogen isotopic determinations of water samples were performed at the USGS Stable Isotope Laboratory in Reston, Virginia. Sulfur and oxygen isotopic determinations of dissolved sulfate were performed by the USGS Crustal Imaging Team Laboratory in Denver, Colorado. Analyses of all other samples were performed by the USGS Branch of Regional Research Laboratory in Boulder, Colorado.

Estimates of detection limits are assumed equal to 3 times the standard deviation of several dozen measurements of the constituent in a blank solution treated as a sample. Typical analytical precision, expressed as percent relative standard deviation, is based on several analytical runs and calculated using analytical data for standard reference water samples. Precision for any single analytical run is better than that for multiple analytical runs, but using multiple analytical runs to calculate precision provides a more realistic estimate of error when comparing results for samples analyzed at different times. The typical relative standard deviations, or precision estimates, are for analyte concentrations greater than 10 times the detection limit and less than the high standard. When an analyte concentration was greater than that of the high standard, the sample was diluted, introducing an additional source of error. Techniques, general conditions, and variants of standard procedures are discussed in the following sections.

All reagents were of purity at least equal to the reagent-grade standards of the American Chemical Society. Double-distilled or deionized water and re-distilled or trace-metal-grade acids were used in all preparations. Samples were diluted as necessary to bring analyte concentrations within the optimal range of the method. Each sample was analyzed in at least duplicate for each dilution for all constituents. Reagent blanks were analyzed to evaluate contamination from reagents used to prepare standards and dilutions.

Quality Assurance and Quality Control

Several techniques were used to assure the quality of the analytical data (McCleskey and others, 2004). These techniques included use of field blanks, standard reference water samples (SRWS's), charge imbalance (C.I.), spike recoveries, determination by alternative methods, and determination by different laboratories. Quality assurance and quality control checks for DOC included analyses of laboratory reagent blanks and synthetic samples made from potassium biphthalate, sodium bicarbonate, and sodium benzoate. Quality assurance and quality control results for samples in this report can be found in McCleskey and others (2004), which presents all the analyses of field and trip blanks and displays plots of the duplicate samples.

Table 2. Container preparation and stabilization methods for samples

[HCl, hydrochloric acid; HNO_3, nitric acid; $K_2Cr_2O_7$, potassium dichromate; mL, milliliters; N, normal; v/v, volume per volume; w/v, weight per volume; %, percent]

Sample type(s)	Storage container and preparation	Stabilization treatment in addition to refrigeration
Cations and trace metals (Al, As, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Gd, Hf, Ho, K, La, Li, Lu, Mg, Mn, Mo, Na, Nd, Ni, Pb, Pr, Rb, Re, Sb, Se, SiO_2, Sm, Sr, Ta, Tb, Te, Th, Tl, Tm, U, V, W, Y, Yb, Zn, and Zr)	Polyethylene bottles, soaked in 5% HCl and rinsed 3 times with distilled water	1% (v/v) concentrated redistilled or Ultrex 7.7 N HNO_3 added
Mercury (Hg)	Borosilicate glass bottles, soaked with 5 % HNO_3 and rinsed 3 times with deionized water	5 mL of concentrated redistilled HNO_3 (added in the field) + 0.04 % w/v $K_2Cr_2O_7$ per 125 mL of sample (added in the laboratory)
Iron and arsenic redox species (Fe(T), Fe(II), As(T), and As(III))	Opaque polyethylene bottles, soaked in 5% HCl and rinsed 3 times with distilled water	1% (v/v) redistilled 6 N or Omni 1:1 trace-metal grade HCl added
Alkalinity and major anions (Br, Cl, F, HCO_3, NO_3, and SO_4)	Polyethylene bottles filled with distilled water and allowed to stand for 24 hours, then rinsed 3 times with distilled water	None
Dissolved organic carbon (DOC)	Baked glass bottle	None
Sulfur isotopes	Polyethylene bottles filled with distilled water and allowed to stand for 24 hours, then rinsed 3 times with distilled water	None
Water isotopes	Glass bottle	None

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references

[CVAFS, cold-vapor atomic fluorescence spectrometry; GFAAS, graphite furnace atomic absorption spectrometry; HGAAS, hydride generation atomic absorption spectrometry; IC, ion chromatography; ICP-MS, inductively-coupled plasma-mass spectrometry; ICP-OES, inductively coupled plasma-optical emission spectrometry; ISE, ion-selective electrode; mg/L, milligrams per liter; mM, millimolar; MS, mass spectrometry; µg/L, micrograms per liter; ng/L, nanograms per liter; nm, nanometer; °C, degrees centigrade; RSD, relative standard deviation; TOC, total organic carbon; ---, not measured or calculated; %, percent]

Constituent	Analytical Technique	Detection limit[1] / Typical precision[2]	Equipment Used	Reference(s) and comments
Calcium (Ca)	ICP-OES	0.4 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 315.887 nm, view: radial
Magnesium (Mg)	ICP-OES	0.04 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 280.270 nm, view: axial
Sodium (Na)	ICP-OES	0.05 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 589.592 nm, view: radial
Potassium (K)	ICP-OES	0.02 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 766.490 nm, view: axial
Sulfate (SO_4)	IC	0.3 mg/L / 3%	Dionex model 2010i ion chromatograph with AG4A guard and AS4A separator columns and Anion Self-Regenerating Suppressor-II	1.8 mM $NaHCO_3$ + 1.7 mM Na_2CO_3 eluent (Brinton and others, 1995)
Alkalinity (as HCO_3)	Titration	1.0 mg/L / 2%	Orion Research model 960/940 autotitrator, potentiometric detection, end-point determined by the first derivative technique	(Barringer and Johnsson, 1989)
Fluoride (F)	ISE	0.05 mg/L / 4%	Orion Research model 96-09 combination F- electrode	Sample mixed 1:1 with total ionic strength adjustment buffer (Barnard and Nordstrom, 1980)
Chloride (Cl)	IC	0.09 mg/L / 4%	Dionex model 2010i ion chromatograph with AG4A guard and AS4A separator columns and an Anion Self-Regenerating Suppressor-II	1.8 mM $NaHCO_3$ + 1.7 mM Na_2CO_3 eluent (Brinton and others, 1995)
Silica (SiO_2)	ICP-OES	0.06 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 251.611 nm, view: axial

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references – Continued

Constituent	Analytical Technique	Detection limit[1] / Typical precision[2]	Equipment Used	Reference(s) and comments
Aluminum (Al)	ICP-OES	0.07 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 308.215 nm, view: axial
	GFAAS[3]	0.001 mg/L / 7%	Perkin-Elmer model 4110ZL	Analytical wavelength: 309.3 nm, modifier: 15 µg $Mg(NO_3)_2$, atomization temperature: 2300°C
Total iron (Fe(T))	ICP-OES	0.007 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 238.204. nm, view: axial
	Colorimetry	0.001 mg/L / 3%	Hewlett-Packard model 8452A diode array spectrometer with 1 and 5 cm cells	FerroZine method (Stookey, 1970; To and others, 1999)
Ferrous iron (Fe(II))	Colorimetry	0.002 mg/L / 3%	Hewlett-Packard model 8452A diode array spectrometer with 1 and 5 cm cells	(Stookey, 1970; To and others, 1999)
Boron (B)	ICP-OES	0.010 mg/L / 7%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 249.678 nm, view: axial
	ICP-MS[4]	0.002 mg/L / 5%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 11 (Garbarino and Taylor, 1995; Taylor and Garbarino, 1991)
Lithium (Li)	ICP-OES	0.001 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 670.784 nm, view: axial
Strontium (Sr)	ICP-OES	0.0003 mg/L / 4%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 421.552 nm, view: axial
Barium (Ba)	ICP-OES	0.0008 mg/L / 4%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 455.403 nm, view: axial
Manganese (Mn)	ICP-OES	0.002 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 257.610 nm, view: axial
Zinc (Zn)	ICP-OES	0.005 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 206.200 nm, view: radial

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references – Continued

Constituent	Analytical Technique	Detection limit[1] / Typical precision[2]	Equipment Used	Reference(s) and comments
Lead (Pb)	ICP-OES	0.008 mg/L / 6%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 220.353 nm, view: axial
	GFAAS[3]	0.0003 mg/L / 7%	Perkin-Elmer model 4110ZL	Analytical wavelength: 283.3 nm, view: axial; modifier: 50 µg PO_4 + 3 µg $Mg(NO_3)_2$, atomization temperature: 1600°C
	ICP-MS[4]	0.00001 mg/L / 2%	Perkin-Elmer SCIEX ELAN 6000	A weighted average of the 206, 207 and 208 isotopes was used (Garbarino and Taylor, 1995; Taylor and Garbarino, 1991)
Nickel (Ni)	ICP-OES	0.002 mg/L / 3%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 231.604. nm, view: axial
	GFAAS[3]	0.0005 mg/L / 5%	Perkin-Elmer model 4110ZL	Analytical wavelength: 231.604 nm, view: axial, atomization temperature: 2300°C
Copper (Cu)	ICP-OES	0.002 mg/L / 7%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 324.754. nm, view: axial
	GFAAS[3]	0.0005 mg/L / 6%	Perkin-Elmer model 4110ZL	Analytical wavelength: 324.8 nm, modifier: 5 µg Pd + 3 µg $Mg(NO_3)_2$, atomization temperature: 2000°C
Cadmium (Cd)	ICP-OES	0.002 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 214.428. nm, view: axial
	GFAAS[3]	0.0002 mg/L / 7%	Perkin-Elmer model 4110ZL	Analytical wavelength: 228.8 nm, modifier: 50 µg PO_4 + 3 µg $Mg(NO_3)_2$, atomization temperature: 1500°C
Chromium (Cr)	ICP-OES	0.002 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 206.149. nm, view: axial
	GFAAS[3]	0.0005 mg/L / 6%	Perkin-Elmer model 4110ZL	Analytical wavelength: 357.9 nm, modifier: 15 µg $Mg(NO_3)_2$, atomization temperature: 2300°C

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references – Continued

Constituent	**Analytical Technique**	**Detection limit[1] / Typical precision[2]**	**Equipment Used**	**Reference(s) and comments**
Cobalt (Co)	ICP-OES	0.007 mg/L / 5%	Leeman Labs Direct Reading Echelle or	Analytical wavelength: 228.616. nm, view: axial
	GFAAS[3]	0.0008 mg/L / 7%	Perkin-Elmer model 4110ZL	Analytical wavelength: 242.5 nm, modifier: 15 µg $Mg(NO_3)_2$, atomization temperature: 2400°C
Beryllium (Be)	ICP-OES	0.001 mg/L / 4%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 313.042 nm, view: axial
Molybdenum (Mo)	ICP-OES	0.007 mg/L / 7%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 277.540 nm, view: axial
	ICP-MS[4]	0.0005 mg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 95 (Garbarino and Taylor, 1995)
Vanadium (V)	ICP-OES	0.002 mg/L / 5%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 292.401 nm, view: axial
	ICP-MS[4]	0.0003 mg/L / 2%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 51 (Garbarino and Taylor, 1995)
Arsenic (As)	ICP-OES	0.04 mg/L / 7%	Leeman Labs Direct Reading Echelle	Analytical wavelength: 188.977. nm, view: axial
	HGAAS	0.0001mg/L / 3%	Perkin-Elmer AAnalyst 300 atomic absorption spectrometer with a FIAS-100 flow injection analysis system, quartz cell, and furnace	Pre-reduction of As(V) using KI + ascorbic acid + HCl (McCleskey and others, 2003a)
Selenium (Se)	ICP-OES	0.04 mg/L / ---	Leeman Labs Direct Reading Echelle	Analytical wavelength: 196.026. nm, view: axial
	GFAAS[3]	0.001 mg/L / 7%	Perkin-Elmer model 4110ZL	Analytical wavelength: 196.0 nm, modifier: 5 µg Pd + 3 µg $Mg(NO_3)_2$, atomization temperature: 1300°C
	ICP-MS[4]	0.0002 mg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 77 (Garbarino and Taylor, 1995)

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references – Continued

Constituent	Analytical Technique	Detection limit[1] / Typical precision[2]	Equipment Used	Reference(s) and comments
Mercury (Hg)	CVAFS	0.4 ng/L / 4%	PS Analytical, model Galahad, direct cold-vapor atomic fluorescence spectrometry	Taylor and others (1997), Roth and others (2001)
Bismuth (Bi)	ICP-MS[4]	0.001 µg/L / ---	Perkin-Elmer SCIEX ELAN 6000	Isotope: 209
Cerium (Ce)	ICP-MS[4]	0.0004 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 140 (Verplanck and others, 2001)
Cesium (Cs)	ICP-MS[4]	0.002 µg/L / ---	Perkin-Elmer SCIEX ELAN 6000	Isotope: 133
Dysprosium (Dy)	ICP-MS[4]	0.0004 µg/L / 7%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 163 (Verplanck and others, 2001)
Erbium (Er)	ICP-MS[4]	0.0004 µg/L / 6%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 167 (Verplanck and others, 2001)
Europium (Eu)	ICP-MS[4]	0.001 µg/L / 5%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 151, problems with Ba interference (Verplanck and others, 2001)
Gadolinium (Gd)	ICP-MS[4]	0.0006 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 158 (Verplanck and others, 2001)
Hafnium (Hf)	ICP-MS[4]	0.0005 µg/L / ---	Perkin-Elmer SCIEX ELAN 6000	Isotope: 178
Holmium (Ho)	ICP-MS[4]	0.0002 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 165 (Verplanck and others, 2001)
Lanthanum (La)	ICP-MS[4]	0.0004 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 139 (Verplanck and others, 2001)
Lutetium (Lu)	ICP-MS[4]	0.0002 µg/L / 5%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 175 (Verplanck and others, 2001)
Neodymium (Nd)	ICP-MS[4]	0.0008 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 146 (Verplanck and others, 2001)
Praseodymium (Pr)	ICP-MS[4]	0.0002 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 141 (Verplanck and others, 2001)
Rubidium (Rb)	ICP-MS[4]	0.001 µg/L / ---	Perkin-Elmer SCIEX ELAN 6000	Isotope: 85

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references – Continued

Constituent	Analytical Technique	Detection limit[1] / Typical precision[2]	Equipment Used	Reference(s) and comments
Rhenium (Re)	ICP-MS[4]	0.0007 µg/L / ---	Perkin-Elmer SCIEX ELAN 6000	Isotope: 187
Antimony (Sb)	ICP-MS[4]	0.004 µg/L / 2%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 121 (Garbarino and Taylor, 1995; Taylor and Garbarino, 1991)
Samarium (Sm)	ICP-MS[4]	0.0008 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 147 (Verplanck and others, 2001)
Tantalum (Ta)	ICP-MS[4]	0.002 µg/L / ---	Perkin-Elmer SCIEX ELAN 6000	Isotope: 181
Terbium (Tb)	ICP-MS[4]	0.0002 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 159 (Verplanck and others, 2001)
Tellurium (Te)	ICP-MS[4]	0.008 µg/L / ---	Perkin-Elmer SCIEX ELAN 6000	Isotope: 126
Thorium (Th)	ICP-MS[4]	0.001 µg/L / ---	Perkin-Elmer SCIEX ELAN 6000	Isotope: 232
Thallium (Tl)	ICP-MS[4]	0.004 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 205 (Garbarino and Taylor, 1995; Taylor and Garbarino, 1991)
Thulium (Tm)	ICP-MS[4]	0.0002 µg/L / 4%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 169 (Verplanck and others, 2001)
Uranium (U)	ICP-MS[4]	0.0005 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 238 (Garbarino and Taylor, 1995; Taylor and Garbarino, 1991)
Tungsten (W)	ICP-MS[4]	0.006 µg/L / 6%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 182
Yttrium (Y)	ICP-MS[4]	0.0003 µg/L / 3%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 89
Ytterbium (Yb)	ICP-MS[4]	0.0005 µg/L / 4%	Perkin-Elmer SCIEX ELAN 6000	Isotope: 174 (Verplanck and others, 2001)
Zirconium (Zr)	ICP-MS[4]	0.001 µg/L / ---	Perkin-Elmer SCIEX ELAN 6000	Isotope: 90
Dissolved organic carbon (DOC)	TOC	0.1 mg/L	Oceanography International Model 700 TOC Analyzer	Wet oxidation method (Aiken, 1992)

Table 3. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references – Continued

Constituent	Analytical Technique	Detection limit[1] / Typical precision [2]	Equipment Used	Reference(s) and comments
Hydrogen sulfide (H_2S)	Colorimetry	0.002 mg/L	Hach model DR-2000 UV-Vis absorption spectrometer and Hach method # 8131 reagents	Method based on APHA (1985)
$^{18}O/^{16}O$ ($\delta^{18}O$)	MS	0.1 per mil[2]	DuPont model 21-491 mass spectrometer	Standardization against Vienna Standard Mean Ocean Water (VSMOW) ($\delta^{18}O$ = 0 per mil) and Standard Light Antartic Precipitation (SLAP) ($\delta^{18}O$ = -55.5 per mil) (Epstein and Mayeda, 1953)
$^{2}H/^{1}H$ ($\delta^{2}H$)	MS	0.1 per mil[2]	V.G. Micromass model 602 mass spectrometer	Standardization against VSMOW (δ2H = 0 per mil) and SLAP (δ2H = -428 per mil) (Coplen and others, 1991)
$^{34}S/^{32}S$ ($\delta^{34}S$) of sulfate	MS	0.1 per mil[2]	Carlo Erba NC2500 elemental analyzer coupled to either a Micromass Optima or a Finnigan Delta Plus XL mass spectrometer	Analyses were done by combustion using continuous flow methods described by Giesemann and others (1994). Sulfate ion removed from the samples using barium sulfate precipitation method
$^{18}O/^{16}O$ ($\delta^{18}O$) of sulfate	MS	0.1 per mil[2]	Micromass Optima mass spectrometer	Sulfate ion removed from the samples using barium sulfate precipitation method

---

[1] Some samples were diluted for ICP-MS analysis; reported detection limits must be multiplied by the dilution factor for these samples (for example, the detection limit for a sample diluted to 1:10 is ten times the undiluted detection limit reported in this table.

[2] Percent relative standard deviations, or precision, are for analyte concentrations greater than 10 times the detection limit and less than the high standard. Percent relative standard deviations are based on several analytical runs. The precision likely would be better for any single analytical run.

[3] GFAAS was used when the concentration of the constituent was below or near the ICP-OES detection limit

[4] ICP-MS was used for a selected subset of samples

WATER CHEMISTRY

Red River Water Chemistry, 2000-2003

To evaluate seasonal fluctuations in chemistry, 20 water-chemistry samples were routinely collected from February 2002 through October 2003 at the USGS streamflow-gaging station 08265000 near the U.S. Forest Service Questa Ranger Station (tables 1, 4, and 5). One additional sample was collected in October 2000. This dataset complements the compilation and interpretation of historical surface-water quality by Maest and others (2004).

As described by Maest and others (2004), one factor controlling the chemistry of the Red River at the Questa Ranger Station gage is variation of stream discharge. The hydrograph for the gaging station for the period 2000 to 2004 is shown in figure 3 with sample collection times shown by open circles. In 2002, conditions were anomalous because of extreme drought, highlighted by the absence of a spring snowmelt peak (fig. 3). Monthly mean discharges for May through August 2002 were the lowest on record (U.S. Geological Survey, 2004), which started in October 1924. Although these were the lowest monthly mean flows recorded during spring runoff, 3 other years (1971, 1977, and 1981) had flows during spring runoff that were substantially lower than the mean recorded flows. The highest discharge for 2002 occurred during a storm event in September. The hydrograph for 2003 is more typical in shape although the monthly mean discharges for April to July were less than the 75-year mean for those months. Overall, the water quality samples cover the major hydrologic conditions in 2002-2003 including low flow, a summer-storm event, and peak flow during spring runoff.

As a result of the drought year of 2002, most of the samples (11 samples) represent low-flow conditions, based on the criteria outlined in Maest and others (2004). These low-flow samples were circumneutral with a mean pH value of 7.4 and ranged from 6.41 to 7.92 (fig. 5). The overall range in pH was from 4.83, measured during a storm event, to 8.07, measured during peak flow.

Specific conductance varied from 195 to 607 microsiemens per centimeter (fig. 6). The lowest measured specific conductance occurred during the snowmelt peak in 2003, and the highest measured specific conductance occurred during a September storm event in 2002. Concentrations of many dissolved constituents in the low-flow samples, including aluminum, calcium, manganese, nickel, silica, and sulfate, plot between concentrations of snowmelt peak (lower) and storm event (higher) samples (table 4; figs. 7-9). The monthly sampling for 2003 overlapped with the spring snowmelt runoff peak, with two samples on the rising limb (4/16/03 and 5/11/03) and one sample near the peak (6/5/03). These three samples had the lowest concentration of many dissolved constituents (Ca, Mg, Mn, SO_4, and Sr) for all the Questa Ranger Station gage samples collected from 2000 to 2003, and in most cases, the concentrations in the peak discharge sample (6/5/03) were the lowest of the sample set. Similar results were observed in the historical dataset compiled by Maest and others (2004).

The alkalinities of the rising limb and snowmelt peak samples were slightly greater (50.6 to 57.9 mg/L) than the mean low-flow concentration (46.6 mg/L; fig. 10). Simple dilution of Red River water by melting snow cannot account for these higher values. Water with some alkalinity needs to enter the Red River. Because the Red River above the town of Red River has alkalinity greater than that of the lower portion of the Red River, the upstream portion of the Red River is a likely source of the alkalinity. Water draining the south side of the Red River Valley may be another source.

As reported by Vail Engineering Inc. (2000), the Red River specific conductance correlates with sulfate concentration. Results from the 2000-2004 Questa Ranger Station gage samples (fig. 11) are consistent with this observation. Sulfate and specific conductance are strongly correlated because sulfate is the dominant anion, contributing nearly half of the specific conductance of the water. The slope of the linear fit is similar to that of the historical dataset compiled by Maest and others (2004), but the correlation coefficient R^2 value (0.91) is substantially greater than that for the historical dataset (0.62). The greater correlation in this dataset is likely because all the samples were analyzed at the same laboratory with better quality control and quality assurance over a relatively short time period and the historical data set may include a wider range of hydrologic conditions.

Table 4. Surface-water analyses

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location **Sample code number** **Collection Date**	**Red River at USGS Gage** **00QV01** **10/31/2000**	**Red River at USGS Gage** **00QV01** **10/31/2000**	**Red River at USGS Gage** **02WA101** **2/24/2002**	**Red River at USGS Gage** **02WA101** **2/24/2002**	**Red River at USGS Gage** **02WA113** **3/20/2002**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.1	---	0.1	---	0.1
pH	7.52	7.52	7.04	7.04	7.54
SC (µS/cm)	360	360	405	405	419
Temperature (°C)	---	---	5.3	5.3	2.5
D.O., mg/L	---	---	---	---	---
Eh (v)	---	---	---	---	0.400
<u>Constituent, mg/L</u>					
Ca	51.6	53.4	52.8	53.6	59.3
Mg	11.4	11.2	12.3	12.6	11.8
Na	6.22	6.31	7.09	6.96	7.17
K	0.54	1.09	1.25	1.24	1.22
SO_4	130	---	151	---	158
Alkalinity as HCO_3^-	54.2	---	40.3	---	41.8
F	0.837	---	1.01	---	0.978
Cl	3.53	---	4.16	---	5.28
Br	<0.1	---	<0.1	---	<0.1
SiO_2	10.7	12.6	12.6	13.5	14.0
Al	<0.08	2.06	1.07	2.83	<0.08
Fe(T)	<0.007	0.404	0.181	0.426	0.134
Fe(II)	---	---	0.079	---	0.099
B	0.003	<0.01	0.007	0.007	0.015
Li	<0.001	0.010	<0.001	<0.001	<0.001
Sr	0.301	0.307	0.302	0.313	0.350
Ba	0.033	0.037	0.032	0.033	0.034
Mn	0.381	0.394	0.494	0.490	0.722
Zn	0.074	0.143	0.140	0.175	0.206
Pb	<0.008	<0.008	<0.008	<0.008	<0.008
Ni	0.015	0.016	0.022	0.023	0.032
Cu	<0.003	0.018	0.013	0.032	0.005
Cd	<0.001	<0.001	<0.001	<0.001	0.002
Cr	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.002	<0.002	0.006	0.007	0.009
Be	<0.001	<0.001	<0.001	0.001	<0.001
Mo	---	---	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.0001	<0.05	<0.0001	<0.05	<0.0001
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
δ^2H (‰)	---	---	-96.11	---	---
$\delta^{18}O$ (‰)	---	---	-13.54	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
$\delta^{34}S$ (‰)	---	---	---	---	---
Sum cations (meq/L)	3.51	---	3.67	---	3.91
Sum anions (meq/L)	3.43	---	3.56	---	3.77
Charge imbalance (percent)	2.3	---	3.0	---	3.7

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**
Sample code number	**02WA113**	**02WA120**	**02WA120**	**02WA123**	**02WA123**
Collection Date	**3/20/2002**	**4/24/2002**	**4/24/2002**	**6/17/2002**	**6/17/2002**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.1	---	0.1	---
pH	7.54	7.85	7.85	7.85	7.85
SC (µS/cm)	419	391	391	451	451
Temperature (°C)	2.5	6.4	6.4	18.8	18.8
D.O., mg/L	---	---	---	---	---
Eh (v)	0.400	0.310	0.310	---	---
<u>Constituent, mg/L</u>					
Ca	58.9	52.2	52.9	62.5	62.0
Mg	11.5	11.7	11.9	14.9	14.7
Na	7.20	5.30	5.34	7.88	7.79
K	1.25	8.52	8.45	1.35	1.39
SO_4	---	144	---	187	---
Alkalinity as HCO_3^-	---	53.8	---	41.3	---
F	---	1.25	---	1.15	---
Cl	---	4.60	---	4.46	---
Br	---	<0.1	---	<0.1	---
SiO_2	16.4	10.1	11.2	10.3	11.9
Al	3.28	<0.08	1.93	0.193	2.15
Fe(T)	0.585	0.059	0.279	<0.001	0.294
Fe(II)	---	0.037	---	<0.001	---
B	0.013	0.011	0.012	<0.01	<0.01
Li	<0.001	<0.001	<0.001	0.007	0.007
Sr	0.356	0.281	0.282	0.364	0.357
Ba	0.038	0.031	0.034	0.035	0.036
Mn	0.753	0.395	0.392	0.402	0.395
Zn	0.257	0.081	0.116	0.084	0.157
Pb	<0.008	<0.008	<0.008	<0.008	<0.008
Ni	0.034	0.020	0.019	0.024	0.026
Cu	0.037	<0.003	0.017	0.005	0.025
Cd	0.002	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002
Co	0.009	<0.002	<0.002	0.005	0.005
Be	0.001	<0.001	0.001	<0.001	0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.0001	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
$\delta^{2}H$ (‰)	---	-97.21	---	---	---
$\delta^{18}O$ (‰)	---	-13.45	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
$\delta^{34}S$ (‰)	---	---	---	---	---
Sum cations (meq/L)	---	3.67	---	4.15	---
Sum anions (meq/L)	---	3.71	---	4.15	---
Charge imbalance (percent)	---	-0.9	---	-0.2	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**
Sample code number	**02N075**	**02N075**	**02WA153**	**02WA153**	**02WA155**
Collection Date	**8/20/2002**	**8/20/2002**	**9/17/2002**	**9/17/2002**	**9/18/2002**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.45	---	0.1	---	0.1
pH	7.19	7.19	7.80	7.80	4.83
SC (µS/cm)	484	484	408	408	607
Temperature (°C)	17.5	17.5	12.8	12.8	8.8
D.O., mg/L	---	---	---	---	---
Eh (v)	0.425	0.425	---	---	---
Constituent, mg/L					
Ca	62.4	60.4	56.1	56.7	95.5
Mg	14.4	14.2	12.8	11.3	11.8
Na	8.95	8.25	6.12	6.16	5.04
K	1.60	1.59	1.29	1.28	2.47
SO_4	193	---	162	---	314
Alkalinity as HCO_3^-	29.9	---	49.4	---	<1
F	0.994	---	1.10	---	0.371
Cl	5.48	---	4.35	---	4.55
Br	<0.1	---	<0.1	---	<0.1
SiO_2	11.5	13.1	11.0	12.7	10.5
Al	0.135	2.90	0.189	2.51	2.88
Fe(T)	0.006	1.30	0.011	0.813	0.596
Fe(II)	0.003	---	0.004	---	0.420
B	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.007	0.007	0.007	0.007	0.012
Sr	0.356	0.351	0.316	0.304	0.354
Ba	0.020	0.033	0.025	0.036	0.043
Mn	0.591	0.581	0.471	0.486	1.97
Zn	0.048	0.134	0.056	0.125	0.607
Pb	<0.0003	0.009	<0.008	<0.008	<0.008
Ni	0.017	0.023	0.015	0.018	0.072
Cu	0.006	0.044	0.006	0.026	0.037
Cd	0.0007	0.0010	<0.001	<0.001	0.003
Cr	<0.0005	0.0014	<0.002	<0.002	<0.002
Co	<0.0007	0.009	0.005	0.007	0.034
Be	<0.001	0.001	<0.001	0.001	0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.0001	0.0004	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
$\delta^{2}H$ (‰)	---	---	---	---	---
$\delta^{18}O$ (‰)	---	---	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	-5.2	---	-4.8
$\delta^{34}S$ (‰)	---	---	-2.5	---	-3.5
Sum cations (meq/L)	4.16	---	3.72	---	5.36
Sum anions (meq/L)	4.11	---	3.90	---	5.57
Charge imbalance (percent)	1.2	---	-4.9	---	-3.9

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**
Sample code number	**02WA155**	**02WA157**	**02WA157**	**02N077**	**02N077**
Collection Date	**9/18/2002**	**9/19/2002**	**9/19/2002**	**10/15/2002**	**10/15/2002**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.1	---	0.45	---
pH	4.83	7.21	7.21	7.12	7.12
SC (µS/cm)	607	375	375	440	440
Temperature (°C)	8.8	7.3	7.3	---	---
D.O., mg/L	---	---	---	---	---
Eh (v)	---	---	---	---	---
Constituent, mg/L					
Ca	97.0	53.0	52.0	53.9	54.0
Mg	13.6	10.3	9.83	12.4	16.0
Na	5.08	5.40	5.40	6.20	7.10
K	4.30	2.47	2.01	1.18	1.20
SO_4	---	161	---	160	---
Alkalinity as HCO_3^-	---	22.2	---	53.2	---
F	---	0.688	---	0.864	---
Cl	---	4.31	---	1.78	---
Br	---	<0.1	---	<0.1	---
SiO_2	29.4	26.2	13.5	11.4	14.0
Al	19.2	4.01	5.24	0.076	2.40
Fe(T)	61.6	3.65	8.77	0.008	0.720
Fe(II)	---	0.353	---	---	---
B	0.014	<0.01	<0.01	<0.01	<0.01
Li	0.020	0.005	0.006	0.006	0.006
Sr	0.425	0.261	0.278	0.283	0.310
Ba	0.194	0.096	0.155	0.030	0.036
Mn	3.01	0.732	0.873	0.428	0.490
Zn	0.696	0.152	0.193	0.078	0.150
Pb	0.066	<0.008	0.014	<0.008	0.001
Ni	0.116	0.029	0.035	0.025	0.024
Cu	0.250	0.029	0.055	0.003	0.041
Cd	0.006	0.001	0.002	0.0006	0.0009
Cr	0.031	0.004	0.005	<0.0005	0.0005
Co	0.059	0.012	0.016	0.003	0.009
Be	0.004	<0.001	0.001	<0.001	0.001
Mo	0.010	<0.007	<0.007	<0.007	<0.007
V	0.034	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.05	<0.05	<0.0001	<0.0001
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
δ^2H (‰)	---	---	---	---	---
$\delta^{18}O$ (‰)	---	---	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	-5.4	---	---	---
$\delta^{34}S$ (‰)	---	-3.0	---	---	---
Sum cations (meq/L)	---	3.51	---	3.66	---
Sum anions (meq/L)	---	3.45	---	3.91	---
Charge imbalance (percent)	---	1.6	---	-6.8	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Red River at USGS Gage_R**	**Red River at USGS Gage_R**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**
Sample code number	**02N079**	**02N079**	**02N078**	**02N078**	**03WA102**
Collection Date	**10/15/2002**	**10/15/2002**	**12/14/2002**	**12/14/2002**	**2/3/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.45	---	0.45	---	0.1
pH	7.12	7.12	6.74	6.74	7.12
SC (µS/cm)	440	440	480	480	514
Temperature (°C)	---	---	0.0	0.0	2.4
D.O., mg/L	---	---	---	---	---
Eh (v)	---	---	---	---	0.465
Constituent, mg/L					
Ca	53.5	53.2	77.9	76.7	62.8
Mg	12.0	12.5	17.9	17.9	15.7
Na	5.95	6.26	8.35	8.21	8.25
K	1.15	1.26	1.34	1.30	1.57
SO_4	200	---	256	---	198
Alkalinity as HCO_3^-	---	---	19.3	---	33.4
F	0.808	---	1.08	---	1.13
Cl	3.91	---	5.19	---	5.10
Br	<0.1	---	<0.1	---	<0.1
SiO_2	10.9	12.0	12.4	13.8	11.5
Al	0.110	2.28	0.155	4.56	<0.08
Fe(T)	0.040	0.476	0.303	0.494	0.076
Fe(II)	0.012	---	0.292	---	0.072
B	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.006	0.007	0.008	0.008	0.008
Sr	0.280	0.284	0.420	0.416	0.364
Ba	0.029	0.034	0.029	0.031	0.029
Mn	0.429	0.436	1.01	0.999	0.557
Zn	0.105	0.161	0.350	0.366	0.218
Pb	0.0003	0.001	<0.008	<0.008	<0.008
Ni	0.023	0.020	0.042	0.043	0.036
Cu	0.005	0.041	0.010	0.044	<0.003
Cd	0.0007	0.0009	0.001	0.001	0.001
Cr	<0.0005	<0.0005	<0.0005	0.0013	<0.002
Co	0.008	0.005	0.013	0.013	0.008
Be	<0.001	0.001	<0.001	0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	0.5	---	0.9
$\delta^{2}H$ (‰)	---	---	---	---	---
$\delta^{18}O$ (‰)	---	---	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
$\delta^{34}S$ (‰)	---	---	---	---	---
Sum cations (meq/L)	3.53	---	5.10	---	4.34
Sum anions (meq/L)	3.87	---	5.11	---	4.35
Charge imbalance (percent)	-9.1	---	-0.03	---	-0.2

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**
Sample code number	**03WA102**	**03WA103**	**03WA103**	**03WA106**	**03WA106**
Collection Date	**2/3/2003**	**4/14/2003**	**4/14/2003**	**4/15/2003**	**4/15/2003**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.1	---	0.1	---
pH	7.12	7.70	7.70	7.70	7.70
SC (µS/cm)	514	320	320	284	284
Temperature (°C)	2.4	10.2	10.2	9.6	9.6
D.O., mg/L	---	---	---	---	---
Eh (v)	0.465	0.294	0.294	0.275	0.275
<u>Constituent, mg/L</u>					
Ca	60.8	42.6	43.3	38.6	39.1
Mg	16.9	9.47	9.54	8.68	8.90
Na	8.55	5.92	5.79	5.61	5.57
K	1.62	1.04	1.14	1.12	1.16
SO_4	---	97.1	---	83.4	---
Alkalinity as HCO_3^-	---	47.3	---	52.3	---
F	---	0.821	---	0.740	---
Cl	---	4.70	---	4.20	---
Br	---	<0.1	---	<0.1	---
SiO_2	14.8	11.8	14.0	10.6	13.2
Al	2.99	0.207	2.05	0.127	2.06
Fe(T)	0.399	0.001	1.20	0.005	1.26
Fe(II)	---	<0.001	---	<0.001	---
B	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.008	0.004	0.004	0.004	0.004
Sr	0.391	0.252	0.262	0.230	0.228
Ba	0.031	0.028	0.049	0.026	0.050
Mn	0.549	0.226	0.317	0.203	0.283
Zn	0.257	0.044	0.140	0.048	0.117
Pb	<0.008	<0.008	<0.008	<0.008	<0.008
Ni	0.036	0.014	0.019	0.013	0.016
Cu	0.026	0.005	0.027	0.005	0.026
Cd	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002
Co	0.010	0.002	0.004	0.004	0.005
Be	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.05	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	2.1	---	3.5	---
$\delta^{2}H$ (‰)	---	-100.68	---	-99.68	---
$\delta^{18}O$ (‰)	---	-13.83	---	-13.78	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
$\delta^{34}S$ (‰)	---	---	---	---	---
Sum cations (meq/L)	---	2.97	---	2.73	---
Sum anions (meq/L)	---	2.73	---	2.56	---
Charge imbalance (percent)	---	8.2	---	6.7	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^oC, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location **Sample code number** **Collection Date**	**Red River at USGS Gage** **03WA108** **4/16/2003**	**Red River at USGS Gage** **03WA108** **4/16/2003**	**Red River at USGS Gage** **03WA114** **5/11/2003**	**Red River at USGS Gage** **03WA114** **5/11/2003**	**Red River at USGS Gage** **03N074** **6/5/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.1	---	0.1	---	0.45
pH	7.43	7.43	7.75	7.75	8.07
SC (µS/cm)	328	328	281	281	195
Temperature (°C)	4.4	4.4	13.5	13.5	---
D.O., mg/L	---	---	---	---	7.35
Eh (v)	0.292	0.292	0.366	0.366	---
Constituent, mg/L					
Ca	41.2	44.6	39.1	39.4	29.2
Mg	10.5	10.9	8.92	9.14	4.02
Na	6.24	6.16	6.01	6.06	2.46
K	1.07	1.11	1.07	1.46	0.68
SO_4	101	---	81.9	---	44.8
Alkalinity as HCO_3^-	50.6	---	56.6	---	57.9
F	0.824	---	0.725	---	0.591
Cl	4.60	---	3.22	---	1.98
Br	<0.1	---	<0.1	---	<0.1
SiO_2	11.5	13.5	13.0	17.5	8.61
Al	0.180	1.62	0.346	2.17	0.134
Fe(T)	0.004	0.661	0.006	2.37	0.008
Fe(II)	0.002	---	0.002	---	0.006
B	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.004	0.005	0.004	0.005	<0.001
Sr	0.266	0.273	0.227	0.233	0.156
Ba	0.030	0.042	0.033	0.091	0.028
Mn	0.249	0.300	0.185	0.240	0.096
Zn	0.087	0.138	0.060	0.118	0.013
Pb	<0.008	<0.008	<0.008	<0.008	<0.0003
Ni	0.016	0.025	0.014	0.018	0.009
Cu	0.004	0.032	0.006	0.019	0.003
Cd	<0.001	<0.001	<0.001	<0.001	0.0003
Cr	<0.002	<0.002	<0.002	<0.002	<0.0005
Co	0.004	0.004	<0.002	0.003	0.001
Be	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.05	<0.05	<0.05	<0.0001
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	1.9	---	2.1	---	1.7
δ^2H (‰)	-100.58	---	-99.18	---	-98.93
$\delta^{18}O$ (‰)	-13.77	---	-14.04	---	-13.89
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	-5.5
$\delta^{34}S$ (‰)	---	---	---	---	-1.9
Sum cations (meq/L)	3.01	---	2.78	---	1.85
Sum anions (meq/L)	2.87	---	2.56	---	1.88
Charge imbalance (percent)	4.7	---	8.5	---	-1.7

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage_R**	**Red River at USGS Gage_R**
Sample code number	**03N074**	**03N102**	**03N102**	**03N113**	**03N113**
Collection Date	**6/5/2003**	**8/21/2003**	**8/21/2003**	**8/21/2003**	**8/21/2003**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.45	---	0.45	---
pH	8.07	6.41	6.41	6.41	6.41
SC (µS/cm)	195	357	357	357	357
Temperature (°C)	---	14.5	14.5	14.5	14.5
D.O., mg/L	7.35	7.14	7.14	7.14	7.14
Eh (v)	---	0.408	0.408	0.408	0.408
Constituent, mg/L					
Ca	29.2	48.6	49.1	43.9	44.4
Mg	3.84	10.3	10.4	9.44	9.78
Na	2.46	6.80	6.66	6.03	5.93
K	0.740	1.17	1.18	1.10	1.27
SO_4	---	116	---	116	---
Alkalinity as HCO_3^-	---	62.7	---	63.1	---
F	---	0.797	---	0.876	---
Cl	---	3.24	---	3.28	---
Br	---	<0.1	---	<0.1	---
SiO_2	9.70	11.2	12.5	10.5	11.7
Al	0.751	<0.08	1.11	<0.08	1.42
Fe(T)	0.769	0.006	0.381	0.004	0.416
Fe(II)	---	<0.001	---	<0.001	---
B	<0.01	<0.01	<0.01	<0.01	<0.01
Li	<0.001	0.007	0.007	0.005	0.006
Sr	0.158	0.289	0.292	0.257	0.258
Ba	0.055	0.029	0.037	0.032	0.038
Mn	0.143	0.134	0.174	0.139	0.246
Zn	0.052	<0.005	<0.005	<0.005	0.094
Pb	0.0074	<0.0003	<0.0003	<0.0003	0.0011
Ni	0.017	0.023	0.025	0.025	0.027
Cu	0.011	0.005	0.015	0.005	0.015
Cd	<0.0001	0.0006	0.0007	0.0003	0.0007
Cr	0.004	<0.0005	0.0011	<0.0005	0.0012
Co	0.001	0.002	0.002	0.003	0.002
Be	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.0001	<0.05	<0.0001	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	1.4	---	1.3	---
$\delta^{2}H$ (‰)	---	-93.31	---	---	---
$\delta^{18}O$ (‰)	---	-13.38	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
$\delta^{34}S$ (‰)	---	---	---	---	---
Sum cations (meq/L)	---	3.30	---	2.98	---
Sum anions (meq/L)	---	3.26	---	3.30	---
Charge imbalance (percent)	---	1.0	---	-10.1	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location **Sample code number** **Collection Date**	**Red River at USGS Gage** **03WA163** **10/21/2003**	**Red River at USGS Gage** **03WA163** **10/21/2003**	**Red River at USGS Gage** **03WA166** **10/22/2003**	**Red River at USGS Gage** **03WA166** **10/22/2003**	**Red River below Mill** **03WA104** **4/14/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.1	---	0.1	---	0.1
pH	7.92	7.92	7.82	7.82	8.09
SC (µS/cm)	370	370	373	373	256
Temperature (°C)	9.0	9.0	8.6	8.6	9.1
D.O., mg/L	---	---	---	---	---
Eh (v)	0.444	0.444	0.459	0.459	0.328
Constituent, mg/L					
Ca	46.6	52.0	51.2	49.9	34.9
Mg	13.5	13.3	12.1	12.4	7.60
Na	6.04	6.13	6.52	6.20	5.44
K	1.23	1.27	1.48	1.31	1.00
SO_4	115	---	130	---	58.8
Alkalinity as HCO_3^-	58.7	---	60.8	---	64.2
F	1.01	---	0.523	---	0.46
Cl	3.83	---	3.44	---	4.90
Br	<0.1	---	<0.1	---	<0.1
SiO_2	14.5	16.3	13.4	16.2	12.7
Al	0.221	1.77	0.241	1.55	0.129
Fe(T)	0.011	0.326	0.014	0.277	0.003
Fe(II)	0.007	---	0.009	---	<0.001
B	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.006	0.006	0.007	0.006	0.004
Sr	0.346	0.355	0.347	0.357	0.217
Ba	0.038	0.041	0.045	0.040	0.028
Mn	0.316	0.342	0.389	0.302	0.105
Zn	0.134	0.173	0.115	0.142	0.011
Pb	<0.008	<0.008	<0.008	<0.008	<0.008
Ni	0.022	0.024	0.020	0.023	0.004
Cu	0.005	0.021	0.008	0.022	0.004
Cd	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	0.003	0.004	0.004	<0.002	<0.002
Co	0.003	0.006	0.006	0.004	<0.002
Be	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.05	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	1.2	---	0.8	---	2.9
δ^{2}H (‰)	---	---	---	---	---
δ^{18}O (‰)	---	---	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
δ^{34}S (‰)	---	---	---	---	---
Sum cations (meq/L)	3.45	---	3.55	---	2.50
Sum anions (meq/L)	3.21	---	3.48	---	2.30
Charge imbalance (percent)	7.2	---	2.1	---	8.3

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Red River below Mill**	**Red River below Mill**	**Red River below Mill**	**Red River above Mill**	**Red River above Mill**
Sample code number	**03WA104**	**03WA107**	**03WA107**	**03WA164**	**03WA164**
Collection Date	**4/14/2003**	**4/15/2003**	**4/15/2003**	**10/21/2003**	**10/21/2003**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.1	---	0.1	---
pH	8.09	7.72	7.72	8.12	8.12
SC (µS/cm)	256	242	242	290	290
Temperature (°C)	9.1	6.8	6.8	8.9	8.9
D.O., mg/L	---	---	---	---	---
Eh (v)	0.328	0.251	0.251	0.442	0.442
Constituent, mg/L					
Ca	34.7	32.1	31.6	37.2	41.6
Mg	7.65	7.11	7.08	10.3	10.4
Na	5.48	5.66	5.60	4.46	4.71
K	1.12	1.00	1.05	1.14	1.19
SO$_4$	---	55.0	---	75.8	---
Alkalinity as HCO$_3^-$	---	58.3	---	75.2	---
F	---	0.464	---	0.561	---
Cl	---	4.70	---	2.73	---
Br	---	<0.1	---	<0.1	---
SiO$_2$	15.1	12.0	13.5	15.6	16.6
Al	1.64	0.275	1.35	0.203	0.727
Fe(T)	3.01	0.048	1.73	0.004	0.216
Fe(II)	---	0.003	---	0.003	---
B	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.004	0.004	0.004	0.006	0.005
Sr	0.227	0.204	0.194	0.278	0.279
Ba	0.127	0.027	0.062	0.038	0.036
Mn	0.275	0.100	0.200	0.158	0.193
Zn	0.082	0.010	0.058	0.017	0.049
Pb	<0.008	<0.008	<0.008	<0.008	<0.008
Ni	0.013	0.004	0.009	0.008	0.010
Cu	0.027	0.004	0.025	0.004	0.010
Cd	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	0.003	<0.002	<0.002	0.003	0.005
Co	0.004	<0.002	0.004	0.004	0.004
Be	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.05	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	2.3	---	1.2	---
δ^{2}H (‰)	---	-101.46	---	---	---
δ^{18}O (‰)	---	-13.92	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
δ^{34}S (‰)	---	---	---	---	---
Sum cations (meq/L)	---	2.35	---	2.75	---
Sum anions (meq/L)	---	2.14	---	2.73	---
Charge imbalance (percent)	---	9.4	---	0.9	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location **Sample code number** **Collection Date**	**Red River above Mill** **03WA167** **10/22/2003**	**Red River above Mill** **03WA167** **10/22/2003**	**Red River 5847** **03WA105** **4/15/2003**	**Red River 5847** **03WA105** **4/15/2003**	**Capulin Scar** **04WA102** **5/6/2004**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.1	---	0.1	---	0.22
pH	8.00	8.00	8.14	8.14	3.24
SC (µS/cm)	292	292	223	223	---
Temperature (°C)	9.6	9.6	7.1	7.1	10.0
D.O., mg/L	---	---	---	---	---
Eh (v)	0.492	0.492	0.310	0.310	---
Constituent, mg/L					
Ca	43.2	45.0	31.4	29.6	46.2
Mg	9.22	10.8	7.16	6.78	36.2
Na	5.64	5.48	5.17	5.29	5.66
K	1.27	1.17	1.02	1.01	2.13
SO_4	80.4	---	41.6	---	668
Alkalinity as HCO_3^-	75.2	---	66.3	---	---
F	0.973	---	0.410	---	5.84
Cl	3.03	---	4.40	---	1.68
Br	<0.1	---	<0.1	---	<0.1
SiO_2	14.6	16.7	12.9	12.9	55.7
Al	0.198	0.717	0.385	0.537	56.6
Fe(T)	0.001	0.190	0.017	0.617	1.75
Fe(II)	0.001	---	<0.001	---	---
B	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.006	0.006	0.003	0.003	0.087
Sr	0.272	0.282	0.200	0.193	0.045
Ba	0.044	0.042	0.040	0.043	<0.0008
Mn	0.184	0.180	0.091	0.100	6.04
Zn	0.027	0.052	0.033	0.037	1.50
Pb	<0.008	<0.008	<0.008	<0.008	<0.008
Ni	0.008	0.009	0.005	0.006	0.234
Cu	0.005	0.012	0.021	0.032	1.79
Cd	<0.001	<0.001	<0.001	<0.001	0.003
Cr	0.003	<0.002	<0.002	<0.002	0.005
Co	<0.002	0.004	<0.002	<0.002	0.138
Be	<0.001	<0.001	<0.001	<0.001	0.010
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.05	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	1.0	---	---	---	---
$\delta^{2}H$ (‰)	---	---	-103.88	---	---
$\delta^{18}O$ (‰)	---	---	-14.22	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
$\delta^{34}S$ (‰)	---	---	---	---	---
Sum cations (meq/L)	3.00	---	2.32	---	8.59
Sum anions (meq/L)	2.83	---	2.00	---	9.78
Charge imbalance (percent)	5.7	---	14.7	---	-12.9

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location **Sample code number** **Collection Date**	**Capulin Scar** **04WA103** **5/6/2004**	**Goat Hill** **01WA159** **9/14/2001**	**Goat Hill** **01WA159** **9/14/2001**	**Waldo Spring** **01WA163** **9/15/2001**	**Waldo Spring** **01WA163** **9/15/2001**
Treatment	FA/FU	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	0.22	0.1	---	0.1	---
pH	2.98	2.77	2.77	5.61	5.61
SC (µS/cm)	1,409	10,480	10,480	908	908
Temperature (°C)	10.7	10.5	10.5	9.6	9.6
D.O., mg/L	---	---	---	---	---
Eh (v)	---	0.716	0.716	---	---
Constituent, mg/L					
Ca	19.8	410	410	130	130
Mg	27.3	900	920	36.0	36.0
Na	2.68	20.0	20.0	15.5	15.0
K	1.03	0.92	1.00	1.70	1.70
SO_4	746	13,500	---	480	---
Alkalinity as HCO_3^-	---	---	---	7.50	---
F	4.95	28	---	1.0	---
Cl	5.81	3.0	---	8.0	---
Br	<0.1	<0.1	---	<0.1	---
SiO_2	50.1	100	99.0	23.0	22.0
Al	69.1	1,300	1,300	2.90	3.60
Fe(T)	21.4	541	540	0.103	0.100
Fe(II)	---	19.0	---	0.084	---
B	<0.01	0.016	0.017	0.005	0.006
Li	0.073	1.20	1.20	0.010	0.010
Sr	0.013	1.20	1.10	1.20	1.20
Ba	<0.0008	<0.0008	0.002	0.011	0.011
Mn	3.15	503	530	0.990	0.890
Zn	0.865	110	120	0.330	0.290
Pb	<0.008	0.063	0.058	<0.008	<0.008
Ni	0.263	8.60	8.40	0.063	0.057
Cu	2.34	10.0	9.80	0.007	0.019
Cd	0.003	0.500	0.520	0.001	0.002
Cr	0.034	0.480	0.490	<0.002	<0.002
Co	0.145	3.50	4.20	0.018	0.015
Be	0.003	0.350	0.350	0.001	0.001
Mo	<0.007	0.210	0.210	<0.007	<0.007
V	<0.005	0.010	0.010	<0.005	<0.005
As(T)	<0.05	0.035	0.340	<0.0001	<0.05
As(III)	---	<0.001	---	<0.001	---
Se	<0.05	0.14	0.16	<0.05	<0.05
DOC	---	---	---	---	---
$\delta^{2}H$ (‰)	---	-85.98	---	-96.80	---
$\delta^{18}O$ (‰)	---	-11.83	---	-13.44	---
$\delta^{18}O_{Sulfate}$ (‰)	---	-8.8	---	-5.8	---
$\delta^{34}S$ (‰)	---	-8.7	---	-4.0	---
Sum cations (meq/L)	8.49	136	---	8.50	---
Sum anions (meq/L)	8.95	122	---	8.35	---
Charge imbalance (percent)	-5.2	10.2	---	1.9	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location **Sample code number** **Collection Date**	**Unnamed drainage** **01WA162** **9/15/2001**	**Unnamed drainage** **01WA162** **9/15/2001**	**Little Hansen** **01WA153** **9/11/2001**	**Little Hansen** **01WA153** **9/11/2001**	**Hansen (high)** **01WA152** **9/11/2001**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.1	---	0.1	---	0.1
pH	7.71	7.71	2.66	2.66	3.38
SC (µS/cm)	1,080	1,080	4,630	4,630	2,140
Temperature (°C)	9.5	9.5	16.7	16.7	12.1
D.O., mg/L	---	---	---	---	---
Eh (v)	---	---	0.766	0.766	0.705
Constituent, mg/L					
Ca	176	180	470	490	290
Mg	39.1	40.0	270	290	50.0
Na	22.6	22.2	23.5	24.0	11.0
K	2.38	2.35	0.190	0.290	6.70
SO_4	412	---	3,700	---	1,600
Alkalinity as HCO_3^-	213	---	---	---	---
F	2.0	---	8.0	---	2.0
Cl	4.0	---	6.0	---	2.0
Br	<0.1	---	<0.1	---	<0.1
SiO_2	19.1	18.4	81.0	79.0	49.0
Al	<0.08	<0.08	170	180	100
Fe(T)	0.010	0.055	126	140	24.3
Fe(II)	0.010	---	0.381	---	5.98
B	0.007	0.007	0.010	0.010	0.007
Li	0.024	0.024	0.320	0.320	0.075
Sr	2.03	1.99	3.10	3.50	1.30
Ba	0.019	0.021	0.002	0.003	0.005
Mn	<0.001	0.018	25.4	26.3	7.70
Zn	<0.005	<0.005	4.16	4.32	2.90
Pb	<0.008	<0.008	<0.008	<0.008	<0.008
Ni	<0.002	<0.002	1.50	1.50	0.370
Cu	<0.003	<0.003	0.550	0.560	0.087
Cd	<0.001	<0.001	0.021	0.022	0.006
Cr	<0.002	<0.002	0.047	0.046	0.004
Co	<0.002	<0.002	0.520	0.830	0.150
Be	<0.001	<0.001	0.033	0.033	0.015
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	0.0002	<0.05	0.0020	<0.05	<0.0001
As(III)	---	---	<0.001	---	<0.001
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
$\delta^{2}H$ (‰)	-100.69	---	-81.32	---	-93.97
$\delta^{18}O$ (‰)	-13.70	---	-10.69	---	-12.70
$\delta^{18}O_{Sulfate}$ (‰)	-5.8	---	-7.4	---	-6.5
$\delta^{34}S$ (‰)	-3.8	---	-5.1	---	-8.6
Sum cations (meq/L)	11.0	---	43.1	---	19.9
Sum anions (meq/L)	10.2	---	42.7	---	20.8
Charge imbalance (percent)	7.6	---	0.8	---	-4.5

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Hansen (high)**	**Hansen (low)**	**Hansen (low)**	**Straight Creek**	**Straight Creek**
Sample code number	**01WA152**	**01WA151**	**01WA151**	**00WA197**	**00WA197**
Collection Date	**9/11/2001**	**9/11/2001**	**9/11/2001**	**10/29/2000**	**10/29/2000**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.1	---	0.1	---
pH	3.38	4.04	4.04	2.73	2.73
SC (µS/cm)	2,140	2,710	2,710	2,970	2,970
Temperature (°C)	12.1	6.5	6.5	2.6	2.6
D.O., mg/L	---	---	---	---	---
Eh (v)	0.705	0.527	0.527	---	---
Constituent, mg/L					
Ca	290	530	530	237	234
Mg	50.0	72.0	72.0	77.5	79.5
Na	11.0	13.0	13.0	1.93	2.30
K	6.70	6.80	7.00	0.655	1.05
SO_4	---	2,100	---	2,030	---
Alkalinity as HCO_3^-	---	---	---	---	---
F	---	3.0	---	8.88	---
Cl	---	2.0	---	4.80	---
Br	---	<0.1	---	<0.1	---
SiO_2	48.0	48.0	46.0	34.0	37.0
Al	110	76.0	81.0	101	104
Fe(T)	25.0	0.279	0.280	219	220
Fe(II)	---	0.038	---	5.92	---
B	0.007	0.007	0.007	<0.01	0.005
Li	0.073	0.077	0.073	0.161	0.165
Sr	1.40	2.60	2.50	0.203	0.207
Ba	0.007	0.007	0.007	0.002	0.010
Mn	7.70	14.2	14.4	19.8	21.1
Zn	2.90	2.86	2.92	8.02	8.39
Pb	<0.008	<0.008	<0.008	0.017	0.023
Ni	0.380	0.550	0.550	0.732	0.756
Cu	0.087	0.190	0.190	2.59	2.59
Cd	0.006	0.008	0.009	0.042	0.041
Cr	0.005	0.002	0.002	0.071	0.071
Co	0.200	0.210	0.330	0.328	0.349
Be	0.015	0.015	0.015	0.027	0.027
Mo	<0.007	<0.007	<0.007	---	---
V	<0.005	<0.005	<0.005	<0.005	0.009
As(T)	<0.05	<0.0001	<0.05	0.016	<0.05
As(III)	---	<0.001	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
δ^2H (‰)	---	-88.74	---	---	---
$\delta^{18}O$ (‰)	---	-11.87	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	-8.0	---	---	---
$\delta^{34}S$ (‰)	---	-6.9	---	---	---
Sum cations (meq/L)	---	26.9	---	26.3	---
Sum anions (meq/L)	---	28.5	---	24.0	---
Charge imbalance (percent)	---	-5.5	---	8.8	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Straight Creek (high)**	**Straight Creek (high)**	**Straight Creek (low)**	**Straight Creek (low)**	**Straight Creek**
Sample code number	**01WA155**	**01WA155**	**01WA154**	**01WA154**	**02WA102**
Collection Date	**9/12/2001**	**9/12/2001**	**9/12/2001**	**9/12/2001**	**2/24/2002**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.1	---	0.1	---	0.1
pH	2.66	2.66	2.82	2.82	3.17
SC (µS/cm)	3,290	3,290	3,440	3,440	1,600
Temperature (°C)	14.4	14.4	7.8	7.8	0.6
D.O., mg/L	---	---	---	---	---
Eh (v)	0.753	0.753	0.745	0.745	0.711
Constituent, mg/L					
Ca	262	264	478	481	212
Mg	91.8	90.7	109	118	29.6
Na	4.32	4.23	9.68	9.77	2.07
K	0.572	0.632	0.449	0.457	0.715
SO_4	2,630	---	2,530	---	825
Alkalinity as HCO_3^-	---	---	---	---	---
F	4.0	---	8.0	---	3.97
Cl	3.0	---	4.0	---	<0.2
Br	<0.1	---	<0.1	---	<0.1
SiO_2	109	103	89.3	90.2	12.7
Al	139	145	107	110	27.7
Fe(T)	246	256	53.4	53.7	8.97
Fe(II)	8.17	---	0.244	---	3.53
B	0.008	0.008	0.006	0.006	<0.01
Li	0.206	0.214	0.194	0.196	0.051
Sr	0.340	0.318	0.454	0.504	0.158
Ba	0.0006	0.0009	0.002	0.002	0.0008
Mn	31.9	31.8	23.6	24.1	6.56
Zn	12.8	12.9	7.82	7.95	2.27
Pb	0.037	0.035	<0.008	<0.008	<0.008
Ni	0.784	0.764	0.753	0.778	0.209
Cu	1.72	1.68	1.75	1.81	0.597
Cd	0.041	0.042	0.037	0.038	0.011
Cr	0.045	0.043	0.041	0.042	0.012
Co	0.329	0.435	0.283	0.450	0.100
Be	0.044	0.043	0.027	0.027	0.008
Mo	0.020	0.017	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	0.0050	<0.05	0.0004	<0.05	<0.0001
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
$\delta^{2}H$ (‰)	-81.47	---	-86.56	---	-133.9
$\delta^{18}O$ (‰)	-10.92	---	-11.90	---	-17.0
$\delta^{18}O_{Sulfate}$ (‰)	-8.7	---	-7.1	---	---
$\delta^{34}S$ (‰)	-6.8	---	-4.2	---	---
Sum cations (meq/L)	29.2	---	31.3	---	13.1
Sum anions (meq/L)	29.5	---	32.6	---	12.6
Charge imbalance (percent)	-1.1	---	-4.1	---	3.9

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Straight Creek**	**Straight Creek**	**Straight Creek**	**Straight Creek**	**Straight Creek**
Sample code number	**02WA102**	**02WA112**	**02WA112**	**02WA121**	**02WA121**
Collection Date	**2/24/2002**	**3/20/2002**	**3/20/2002**	**4/24/2002**	**4/24/2002**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.1	---	0.1	---
pH	3.17	3.25	3.25	2.98	2.98
SC (µS/cm)	1,600	1,200	1,200	2,920	2,920
Temperature (°C)	0.6	3.0	3.0	10.9	10.9
D.O., mg/L	---	---	---	---	---
Eh (v)	0.711	0.674	0.674	0.782	0.782
<u>Constituent, mg/L</u>					
Ca	210	131	142	337	337
Mg	27.8	17.9	19.8	106	103
Na	2.22	1.25	1.44	7.93	8.25
K	0.812	0.402	0.406	2.50	2.84
SO_4	---	525	---	1,950	---
Alkalinity as HCO_3^-	---	---	---	---	---
F	---	0.664	---	1.06	---
Cl	---	2.22	---	7.49	---
Br	---	<0.1	---	<0.1	---
SiO_2	14.3	7.92	8.98	76.2	75.5
Al	27.6	14.9	15.5	83.1	83.9
Fe(T)	9.37	6.01	9.00	44.7	42.1
Fe(II)	---	1.65	---	0.256	---
B	<0.01	<0.01	<0.01	0.011	0.013
Li	0.055	0.028	0.032	0.145	0.157
Sr	0.170	0.107	0.134	0.612	0.611
Ba	0.003	0.003	0.0008	<0.0008	0.002
Mn	6.34	4.17	4.49	20.0	19.0
Zn	2.21	1.49	1.64	7.30	6.99
Pb	<0.008	<0.008	<0.008	<0.008	<0.008
Ni	0.235	0.213	0.258	0.706	0.690
Cu	0.598	0.386	0.391	1.55	1.54
Cd	0.012	0.013	0.016	0.038	0.038
Cr	0.015	0.014	0.017	0.038	0.035
Co	0.117	0.098	0.117	0.301	0.294
Be	0.008	0.007	0.009	0.024	0.025
Mo	<0.007	<0.007	0.019	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.0001	<0.05	0.0002	<0.0001
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
$\delta^{2}H$ (‰)	---	---	---	-97.3	---
$\delta^{18}O$ (‰)	---	---	---	-13.1	---
$\delta^{18}O_{Sulfate}$ (‰)	---	-6.3	---	-6.7	---
$\delta^{34}S$ (‰)	---	-3.3	---	-4.5	---
Sum cations (meq/L)	---	8.33	---	24.8	---
Sum anions (meq/L)	---	8.43	---	25.3	---
Charge imbalance (percent)	---	-1.1	---	-2.1	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Straight Creek**	**Straight Creek**	**Straight Creek**	**Straight Creek**	**Straight Creek**
Sample code number	**02WA124**	**02WA124**	**02WA154**	**02WA154**	**02WA158**
Collection Date	**6/19/2002**	**6/19/2002**	**9/18/2002**	**9/18/2002**	**9/20/2002**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.1	---	0.1	---	0.1
pH	2.97	2.97	3.01	3.01	2.79
SC (µS/cm)	2,910	2,910	2,240	2,240	3,280
Temperature (°C)	11.6	11.6	6.0	6.0	10.7
D.O., mg/L	---	---	---	---	---
Eh (v)	---	---	---	---	---
Constituent, mg/L					
Ca	350	358	325	306	423
Mg	117	119	39.7	39.4	81.4
Na	8.99	10.0	1.62	1.90	3.74
K	0.381	0.423	1.83	3.50	1.09
SO_4	2,050	---	1,530	---	2,480
Alkalinity as HCO_3^-	---	---	---	---	---
F	7.86	---	0.945	---	1.25
Cl	5.44	---	2.06	---	2.60
Br	<0.1	---	<0.1	---	<0.1
SiO_2	83.6	80.0	21.1	33.0	71.3
Al	96.0	91.8	54.4	60.9	104
Fe(T)	30.7	32.2	48.8	117	135
Fe(II)	0.487	---	1.24	---	0.535
B	<0.01	<0.01	<0.01	0.012	0.014
Li	0.193	0.206	0.080	0.094	0.169
Sr	0.657	0.643	0.194	0.227	0.363
Ba	<0.0008	0.0006	0.013	0.046	0.003
Mn	21.5	20.7	9.64	9.51	20.8
Zn	7.42	7.46	3.76	3.63	8.15
Pb	<0.008	<0.008	0.010	0.051	0.012
Ni	0.798	0.796	0.396	0.398	0.771
Cu	1.67	1.66	1.44	1.42	2.72
Cd	0.039	0.037	0.020	0.021	0.038
Cr	0.041	0.039	0.039	0.070	0.064
Co	0.341	0.349	0.158	0.165	0.356
Be	0.024	0.022	0.014	0.014	0.027
Mo	0.012	<0.007	<0.007	0.019	0.026
V	<0.005	<0.005	<0.005	0.035	<0.005
As(T)	<0.05	<0.05	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
δ^2H (‰)	---	---	---	---	---
$\delta^{18}O$ (‰)	---	---	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	-6.2	---	-7.1
$\delta^{34}S$ (‰)	---	---	-3.2	---	-3.7
Sum cations (meq/L)	26.2	---	19.2	---	29.1
Sum anions (meq/L)	26.8	---	20.9	---	30.1
Charge imbalance (percent)	-2.0	---	-8.5	---	-3.6

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location **Sample code number** **Collection Date**	**Straight Creek** **02WA158** **9/20/2002**	**Straight Creek "at pipe"** **02N287** **10/15/2002**	**Straight Creek "at pipe"** **02N287** **10/15/2002**	**Straight Creek "at pipe"** **02N288** **12/11/2002**	**Straight Creek "at pipe"** **02N288** **12/11/2002**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.45	---	0.45	---
pH	2.79	3.00	3.00	3.07	3.07
SC (µS/cm)	3,280	3,150	3,150	3,380	3,380
Temperature (°C)	10.7	7.5	7.5	1.0	1.0
D.O., mg/L	---	---	---	---	---
Eh (v)	---	---	---	---	---
Constituent, mg/L					
Ca	422	399	443	384	377
Mg	78.1	118	133	127	127
Na	4.55	9.20	9.90	9.78	9.06
K	1.50	1.19	1.14	0.661	0.685
SO_4	---	2,440	---	2,230	---
Alkalinity as HCO_3^-	---	---	---	---	---
F	---	10.7	---	9.50	---
Cl	---	3.10	---	2.98	---
Br	---	<0.1	---	<0.1	---
SiO_2	75.6	86.0	91.6	75.7	75.7
Al	119	103	105	105	104
Fe(T)	144	64.3	73.4	65.8	76.8
Fe(II)	---	0.217	---	<0.001	---
B	0.013	0.012	<0.01	0.012	0.012
Li	0.192	0.217	0.208	0.222	0.206
Sr	0.344	0.685	0.762	0.706	0.700
Ba	0.015	0.002	0.002	<0.0008	0.004
Mn	21.5	23.5	26.2	24.0	24.2
Zn	7.73	8.50	9.62	9.39	9.34
Pb	0.015	0.022	0.038	<0.008	0.130
Ni	0.731	0.787	0.912	0.844	0.830
Cu	2.50	1.92	1.92	1.96	1.93
Cd	0.040	0.043	0.044	0.044	0.049
Cr	0.068	0.043	0.044	0.041	0.051
Co	0.325	0.355	0.324	0.378	0.368
Be	0.029	0.030	0.030	0.029	0.030
Mo	0.027	0.020	<0.007	0.016	0.020
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	0.0015	0.0029	0.0010	0.0035
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	0.002	<0.05
DOC	---	---	---	1.2	---
$\delta^{2}H$ (‰)	---	---	---	-95.2	---
$\delta^{18}O$ (‰)	---	---	---	-13.1	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
$\delta^{34}S$ (‰)	---	---	---	---	---
Sum cations (meq/L)	---	28.6	---	30.1	---
Sum anions (meq/L)	---	32.2	---	29.2	---
Charge imbalance (percent)	---	-11.7	---	2.9	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Straight Creek _R "at pipe"**	**Straight Creek _R "at pipe"**	**Straight Creek**	**Straight Creek**	**Straight Creek "at pipe"**
Sample code number	**02N289**	**02N289**	**03WA101**	**03WA101**	**03WA110**
Collection Date	**12/11/2002**	**12/11/2002**	**2/3/2003**	**2/3/2003**	**4/16/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.45	---	0.1	---	0.1
pH	3.07	3.07	3.00	3.00	2.89
SC (µS/cm)	3,170	3,170	3,090	3,090	2,220
Temperature (°C)	13.0	13.0	0.0	0.0	7.9
D.O., mg/L	4.83	4.83	---	---	---
Eh (v)	---	---	0.780	0.780	0.771
Constituent, mg/L					
Ca	376	381	372	373	244
Mg	123	127	113	106	74.5
Na	10.3	10.3	8.31	8.20	3.57
K	0.693	0.732	0.474	0.791	0.788
SO_4	2,210	---	2,020	---	1,580
Alkalinity as HCO_3^-	---	---	---	---	---
F	9.90	---	11.3	---	2.60
Cl	3.05	---	3.00	---	1.80
Br	<0.1	---	<0.1	---	<0.1
SiO_2	75.5	74.7	66.1	69.1	51.6
Al	98.8	104	92.2	84.3	89.9
Fe(T)	65.5	72.0	50.0	53.1	96.2
Fe(II)	<0.001	---	0.029	---	0.504
B	0.012	0.011	<0.01	<0.01	<0.01
Li	0.228	0.236	0.162	0.174	0.136
Sr	0.703	0.696	0.693	0.685	0.372
Ba	<0.0008	0.002	<0.0008	0.012	0.002
Mn	23.7	24.5	22.3	23.4	17.8
Zn	9.21	9.19	8.09	8.57	6.81
Pb	0.005	0.023	<0.008	0.024	0.018
Ni	0.829	0.820	0.736	0.810	0.625
Cu	1.94	1.92	2.01	1.92	1.98
Cd	0.047	0.046	0.040	0.049	0.032
Cr	0.046	0.045	0.037	0.039	0.039
Co	0.374	0.361	0.338	0.358	0.244
Be	0.031	0.030	0.025	0.026	0.024
Mo	0.023	0.017	0.017	0.012	0.020
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	0.0007	0.0010	0.0003	<0.05	0.0010
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	1.4	---	1.4	---	1.7
$\delta^{2}H$ (‰)	---	---	---	---	-99.40
$\delta^{18}O$ (‰)	---	---	---	---	-13.59
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
$\delta^{34}S$ (‰)	---	---	---	---	---
Sum cations (meq/L)	28.0	---	28.3	---	22.6
Sum anions (meq/L)	28.1	---	27.1	---	19.2
Charge imbalance (percent)	-0.5	---	4.2	---	16

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Straight Creek "at pipe"**	**Straight Creek**	**Straight Creek**	**Straight Creek "at pipe"**	**Straight Creek "at pipe"**
Sample code number	**03WA110**	**03WA111**	**03WA111**	**03WA115**	**03WA115**
Collection Date	**4/16/2003**	**4/16/2003**	**4/16/2003**	**5/11/2003**	**5/11/2003**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.22	---	0.1	---
pH	2.89	2.88	2.88	2.86	2.86
SC (µS/cm)	2,220	2,410	2,410	3,080	3,080
Temperature (°C)	7.9	9.8	9.8	6.3	6.3
D.O., mg/L	---	---	---	---	---
Eh (v)	0.771	0.780	0.780	0.791	0.791
Constituent, mg/L					
Ca	246	227	233	347	341
Mg	74.5	63.7	64.6	115	117
Na	3.27	4.57	4.06	8.03	9.25
K	0.970	0.318	0.315	1.05	1.09
SO_4	---	1,510	---	1,940	---
Alkalinity as HCO_3^-	---	---	---	---	---
F	---	2.50	---	10.8	---
Cl	---	2.10	---	11.5	---
Br	---	<0.1	---	<0.1	---
SiO_2	53.8	53.0	55.2	72.6	70.3
Al	87.3	70.1	68.2	90.7	91.4
Fe(T)	112	67.9	68.2	81.1	82.1
Fe(II)	---	0.855	---	0.204	---
B	<0.01	0.011	<0.01	0.010	0.015
Li	0.136	0.133	0.113	0.201	0.220
Sr	0.367	0.344	0.367	0.548	0.557
Ba	0.010	0.0009	0.002	0.003	0.002
Mn	18.2	15.1	15.0	18.9	19.2
Zn	6.61	5.50	5.36	7.98	8.21
Pb	0.024	<0.008	<0.008	0.017	0.011
Ni	0.611	0.529	0.551	0.718	0.711
Cu	1.84	1.40	1.60	1.69	1.69
Cd	0.032	0.027	0.027	0.039	0.042
Cr	0.040	0.032	0.030	0.036	0.043
Co	0.253	0.213	0.209	0.303	0.327
Be	0.024	0.021	0.020	0.026	0.028
Mo	0.020	0.009	0.008	0.012	0.017
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	0.0004	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	1.4	---
δ^2H (‰)	---	---	---	---	---
$\delta^{18}O$ (‰)	---	---	---	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
$\delta^{34}S$ (‰)	---	---	---	---	---
Sum cations (meq/L)	---	19.1	---	28.4	---
Sum anions (meq/L)	---	19.7	---	24.8	---
Charge imbalance (percent)	---	-3.5	---	13.3	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Straight Creek "at pipe"**	**Straight Creek "at pipe"**	**Straight Creek "at pipe"**	**Straight Creek "at pipe"**	**Straight Creek**
Sample code number	**03N072**	**03N072**	**03N122**	**03N122**	**03WA165**
Collection Date	**6/4/2003**	**6/4/2003**	**8/22/2003**	**8/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.45	---	0.45	---	0.1
pH	2.85	2.85	2.93	2.93	2.85
SC (µS/cm)	3,170	3,170	3,640	3,640	3,230
Temperature (°C)	13.0	13.0	11.5	11.5	10.8
D.O., mg/L	4.83	4.83	6.34	6.34	---
Eh (v)	---	---	0.824	0.824	0.819
<u>Constituent, mg/L</u>					
Ca	361	359	401	415	310
Mg	120	120	130	139	112
Na	8.12	8.10	8.30	8.40	8.92
K	0.961	1.04	0.718	0.819	0.587
SO_4	2,040	---	2,660	---	2,240
Alkalinity as HCO_3^-	---	---	---	---	---
F	11.9	---	14.0	---	7.56
Cl	5.10	---	1.87	---	1.60
Br	0.13	---	<0.1	---	<0.1
SiO_2	83.3	80.8	88.0	90.7	91.7
Al	90.6	90.8	119	118	101
Fe(T)	69.0	68.2	88.1	89.7	77.9
Fe(II)	0.470	---	0.480	---	0.279
B	0.012	0.013	<0.01	<0.01	0.017
Li	0.205	0.199	0.270	0.270	0.227
Sr	0.612	0.622	0.611	0.608	0.613
Ba	0.002	0.002	<0.0008	0.003	0.002
Mn	20.7	20.9	26.3	28.1	20.9
Zn	7.84	7.75	10.5	10.4	7.04
Pb	0.0074	0.0083	0.009	0.015	<0.008
Ni	0.800	0.805	1.05	1.04	0.668
Cu	1.82	1.84	2.63	2.60	1.99
Cd	0.048	0.046	0.061	0.055	0.042
Cr	0.046	0.039	0.065	0.065	0.044
Co	0.354	0.362	0.419	0.436	0.311
Be	0.029	0.028	0.032	0.034	0.028
Mo	0.017	0.014	<0.007	<0.007	0.012
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	0.0005	<0.05	0.0008	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	1.8	---	2.1	---	1.4
δ^{2}H (‰)	---	---	---	---	-91.78
δ^{18}O (‰)	---	---	---	---	-12.26
$\delta^{18}O_{Sulfate}$ (‰)	---	---	---	---	---
δ^{34}S (‰)	---	---	---	---	---
Sum cations (meq/L)	28.0	---	30.3	---	25.8
Sum anions (meq/L)	25.8	---	33.9	---	28.9
Charge imbalance (percent)	8.3	---	-11.3	---	-11.3

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Straight Creek**	**Straight Creek Transect**	**Straight Creek Transect**	**Straight Creek Transect**	**Straight Creek Transect**
Sample code number	**03WA165**	**03WA168**	**03WA168**	**03WA169**	**03WA169**
Collection Date	**10/22/2003**	**10/23/2003**	**10/23/2003**	**10/23/2003**	**10/23/2003**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.22	---	0.22	---
pH	2.85	2.44	2.44	2.63	2.63
SC (µS/cm)	3,230	3,620	3,620	3,880	3,880
Temperature (°C)	10.8	13.7	13.7	10.3	10.3
D.O., mg/L	---	---	---	---	---
Eh (v)	0.819	0.741	0.741	0.781	0.781
Constituent, mg/L					
Ca	340	306	303	343	370
Mg	126	105	116	110	122
Na	8.01	3.12	3.17	2.94	2.20
K	0.526	0.126	0.129	0.075	0.089
SO_4	---	2,860	---	2,980	---
Alkalinity as HCO_3^-	---	---	---	---	---
F	---	9.61	---	10.7	---
Cl	---	0.759	---	0.688	---
Br	---	<0.1	---	<0.1	---
SiO_2	93.4	110	107	110	112
Al	104	96.5	179	93.7	171
Fe(T)	86.1	298	389	269	278
Fe(II)	---	6.87	---	1.98	---
B	0.011	0.025	0.028	0.031	0.030
Li	0.205	0.246	0.253	0.246	0.190
Sr	0.613	0.331	0.343	0.266	0.390
Ba	0.002	0.0009	0.004	0.0010	0.005
Mn	20.8	36.9	39.9	38.1	41.5
Zn	6.81	14.7	14.4	14.6	14.3
Pb	0.014	0.057	0.056	0.023	0.024
Ni	0.716	0.908	0.920	0.947	0.967
Cu	1.89	2.42	2.39	2.64	2.92
Cd	0.044	0.047	0.049	0.044	0.036
Cr	0.046	0.069	0.066	0.068	0.050
Co	0.362	0.400	0.366	0.388	0.382
Be	0.033	0.054	0.057	0.050	0.037
Mo	0.019	0.045	0.042	0.045	0.047
V	<0.005	<0.005	0.006	<0.005	<0.005
As(T)	<0.05	<0.05	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
$\delta^{2}H$ (‰)	---	-83.50	---	-80.47	---
$\delta^{18}O$ (‰)	---	-10.94	---	-10.73	---
$\delta^{18}O_{Sulfate}$ (‰)	---	-7.3	---	-7.2	---
$\delta^{34}S$ (‰)	---	-6.6	---	-5.8	---
Sum cations (meq/L)	---	32.0	---	30.9	---
Sum anions (meq/L)	---	33.0	---	36.2	---
Charge imbalance (percent)	---	-2.9	---	-15.8	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; μS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Straight Creek Transect**	**Straight Creek Transect**	**Straight Creek Transect**	**Straight Creek Transect**	**Straight Creek Transect**
Sample code number	**03WA170**	**03WA170**	**03WA171**	**03WA171**	**03WA172**
Collection Date	**10/23/2003**	**10/23/2003**	**10/23/2003**	**10/23/2003**	**10/23/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU
Filtration pore size, µm	0.22	---	0.22	---	0.22
pH	2.66	2.66	3.05	3.05	2.90
SC (µS/cm)	3,860	3,860	3,810	3,810	3,220
Temperature (°C)	7.4	7.4	13.3	13.3	10.9
D.O., mg/L	---	---	---	---	---
Eh (v)	0.747	0.747	0.790	0.790	0.831
Constituent, mg/L					
Ca	425	438	434	466	374
Mg	131	140	160	176	125
Na	4.13	4.54	7.94	6.98	8.45
K	0.076	0.096	0.037	0.041	0.027
SO_4	2,950	---	2,990	---	2,310
Alkalinity as HCO_3^-	---	---	---	---	---
F	12.0	---	12.8	---	11.7
Cl	0.905	---	1.65	---	1.69
Br	<0.1	---	<0.1	---	<0.1
SiO_2	93.4	102	82.6	98.0	78.8
Al	131	138	125	129	110
Fe(T)	192	240	130	149	76.7
Fe(II)	6.27	---	1.13	---	0.026
B	0.030	0.030	0.029	0.030	0.020
Li	0.229	0.254	0.269	0.242	0.209
Sr	0.569	0.590	0.684	0.729	0.580
Ba	0.0010	0.015	0.002	0.014	0.002
Mn	34.9	36.9	30.9	32.9	23.9
Zn	12.7	12.3	10.4	10.8	7.54
Pb	0.021	0.030	0.033	0.046	0.011
Ni	1.02	0.917	0.965	0.917	0.708
Cu	2.68	2.53	2.65	2.53	1.65
Cd	0.048	0.046	0.053	0.055	0.038
Cr	0.060	0.058	0.055	0.056	0.047
Co	0.419	0.437	0.420	0.419	0.322
Be	0.037	0.041	0.036	0.032	0.027
Mo	0.029	0.038	0.023	0.022	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.05	<0.05	<0.05	<0.05
As(III)	---	---	---	---	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
δ^2H (‰)	-82.75	---	-85.84	---	-91.6
δ^{18}O (‰)	-10.96	---	-11.61	---	-12.32
$\delta^{18}O_{Sulfate}$ (‰)	-7.1	---	-7.2	---	-7.4
δ^{34}S (‰)	-4.7	---	-3.9	---	-4.2
Sum cations (meq/L)	35.8	---	33.2	---	29.3
Sum anions (meq/L)	35.3	---	37.0	---	29.1
Charge imbalance (percent)	1.6	---	-11.0	---	0.8

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location	**Straight Creek Transect**	**Junebug (east)**	**Junebug (east)**	**Junebug (west)**	**Junebug (west)**
Sample code number	**03WA172**	**01WA161**	**01WA161**	**01WA160**	**01WA160**
Collection Date	**10/23/2003**	**9/14/2001**	**9/14/2001**	**9/14/2001**	**9/14/2001**
Treatment	RA	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	---	0.1	---	0.1	---
pH	2.90	3.07	3.07	4.40	4.40
SC (µS/cm)	3,220	3,660	3,660	3,020	3,020
Temperature (°C)	10.9	15.2	15.2	15.6	15.6
D.O., mg/L	---	---	---	---	---
Eh (v)	0.831	0.743	0.743	0.647	0.647
Constituent, mg/L					
Ca	416	510	520	530	540
Mg	138	210	220	200	210
Na	7.99	12.0	12.0	14.0	14.0
K	0.037	1.30	1.30	3.40	3.80
SO_4	---	2,900	---	2,200	---
Alkalinity as HCO_3^-	---	---	---	---	---
F	---	7.0	---	4.0	---
Cl	---	3.0	---	3.0	---
Br	---	<0.1	---	<0.1	---
SiO_2	86.7	38.0	37.0	18.0	18.0
Al	116	84.0	83.0	14.0	20.0
Fe(T)	88.4	50.1	50.0	0.698	7.20
Fe(II)	---	1.96	---	0.291	---
B	0.010	0.004	0.004	0.003	0.004
Li	0.186	0.390	0.380	0.240	0.240
Sr	0.629	5.40	5.70	8.30	8.70
Ba	0.005	0.002	0.002	0.004	0.006
Mn	26.4	20.4	20.1	6.80	6.80
Zn	8.48	6.63	6.75	2.20	2.30
Pb	0.010	<0.008	<0.008	<0.008	<0.008
Ni	0.759	1.20	1.30	0.450	0.470
Cu	1.91	3.50	3.50	2.40	2.50
Cd	0.042	0.051	0.052	0.016	0.016
Cr	0.042	0.009	0.009	0.0010	0.003
Co	0.342	0.550	0.800	0.150	0.230
Be	0.027	0.034	0.033	0.005	0.006
Mo	0.021	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005
As(T)	<0.05	<0.0001	<0.05	<0.0001	<0.05
As(III)	---	<0.001	---	<0.001	---
Se	<0.05	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---	---
$\delta^{2}H$ (‰)	---	-70.51	---	-76.30	---
$\delta^{18}O$ (‰)	---	-9.54	---	-10.06	---
$\delta^{18}O_{Sulfate}$ (‰)	---	-5.1	---	-6.1	---
$\delta^{34}S$ (‰)	---	-3.4	---	-4.1	---
Sum cations (meq/L)	---	34.2	---	29.7	---
Sum anions (meq/L)	---	37.0	---	29.9	---
Charge imbalance (percent)	---	-7.6	---	-0.8	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location **Sample code number** **Collection Date**	**Hottentot (high)** **01WA157** **9/13/2001**	**Hottentot (high)** **01WA157** **9/13/2001**	**Hottentot (low)** **01WA156** **9/13/2001**	**Hottentot (low)** **01WA156** **9/13/2001**
Treatment	FA/FU	RA	FA/FU	RA
Filtration pore size, µm	0.1	---	0.1	---
pH	2.60	2.60	2.73	2.73
SC (µS/cm)	3,040	3,040	2,190	2,190
Temperature (°C)	10.6	10.6	9.7	9.7
D.O., mg/L	---	---	---	---
Eh (v)	0.784	0.784	0.824	0.824
<u>Constituent, mg/L</u>				
Ca	90.0	91.0	46.0	45.0
Mg	68.0	67.0	41.0	41.0
Na	3.30	3.30	3.10	3.10
K	0.660	0.700	0.150	0.200
SO_4	2,400	---	1,200	---
Alkalinity as HCO_3^-	---	---	---	---
F	3.0	---	3.0	---
Cl	3.0	---	2.0	---
Br	<0.1	---	<0.1	---
SiO_2	100	99.0	90.0	87.0
Al	140	140	80.0	83.0
Fe(T)	399	400	151	151
Fe(II)	4.12	---	0.251	---
B	0.006	0.007	0.005	0.006
Li	0.095	0.093	0.074	0.074
Sr	0.093	0.087	0.081	0.079
Ba	0.0006	0.002	0.003	0.004
Mn	16.1	16.4	5.80	5.80
Zn	6.44	6.41	3.70	3.70
Pb	0.018	0.017	<0.008	<0.008
Ni	0.800	0.790	0.400	0.390
Cu	2.30	2.40	0.540	0.530
Cd	0.058	0.059	0.019	0.019
Cr	0.090	0.089	0.032	0.031
Co	0.360	0.430	0.170	0.190
Be	0.023	0.023	0.011	0.011
Mo	0.044	0.050	<0.007	<0.007
V	0.014	0.014	<0.005	<0.005
As(T)	0.047	0.110	0.0040	<0.05
As(III)	<0.001	---	<0.001	---
Se	<0.05	<0.05	<0.05	<0.05
DOC	---	---	---	---
$\delta^{2}H$ (‰)	-85.14	---	-90.36	---
$\delta^{18}O$ (‰)	-12.00	---	-12.62	---
$\delta^{18}O_{Sulfate}$ (‰)	-7.6	---	-7.6	---
$\delta^{34}S$ (‰)	-4.6	---	-3.9	---
Sum cations (meq/L)	26.0	---	14.4	---
Sum anions (meq/L)	24.3	---	13.9	---
Charge imbalance (percent)	6.8	---	3.3	---

Table 4. Surface-water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; R, replicate; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; (T), total dissolved in FA and total recoveralbe in RA; v, volts; <, less than; ---, not analyzed; ‰, per mil]

Sample Location **Sample code number** **Collection Date**	**Bitter Creek** **02WA156** **9/19/2002**	**Bitter Creek** **02WA156** **9/19/2002**
Treatment	FA/FU	RA
Filtration pore size, µm	0.1	---
pH	6.59	6.59
SC (µS/cm)	343	343
Temperature (°C)	6.6	6.6
D.O., mg/L	---	---
Eh (v)	---	---
Constituent, mg/L		
Ca	30.0	28.0
Mg	12.0	10.0
Na	8.50	8.70
K	9.90	8.40
SO_4	150	---
Alkalinity as HCO_3^-	5.0	---
F	0.506	---
Cl	6.18	---
Br	<0.1	---
SiO_2	7.00	6.70
Al	0.660	1.10
Fe(T)	0.568	1.00
Fe(II)	0.134	---
B	<0.01	0.011
Li	0.009	0.010
Sr	0.160	0.150
Ba	0.025	0.026
Mn	0.310	0.320
Zn	0.130	0.130
Pb	<0.008	<0.008
Ni	0.023	0.024
Cu	0.093	0.120
Cd	0.001	0.001
Cr	<0.002	0.003
Co	0.011	0.012
Be	<0.001	<0.001
Mo	<0.007	<0.007
V	<0.005	<0.005
As(T)	<0.05	<0.05
As(III)	---	---
Se	<0.05	<0.05
DOC	---	---
$\delta^{2}H$ (‰)	---	---
$\delta^{18}O$ (‰)	---	---
$\delta^{18}O_{Sulfate}$ (‰)	---	---
$\delta^{34}S$ (‰)	---	---
Sum cations (meq/L)	2.90	---
Sum anions (meq/L)	3.11	---
Charge imbalance (percent)	-7.1	---

Table 5. ICP-MS analyses of surface water

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**	**Red River at USGS Gage**
Sample code number	**RRC-19780**	**RRL-19780**	**RRL-19780**	**RRC-19780**	**RRL-19780**
Collection Date	**3/30/2002**	**8/17/2001**	**8/17/2001**	**3/30/2002**	**8/17/2001**
Treatment	UFA	UFA	FA	RA	RA
Constituent, µg/L					
Al	169	145	215	---	---
As	0.08	0.39	0.21	0.17	0.68
B	7.0	8.3	8.5	6.7	8.3
Ba	35	31	30	39	74
Be	0.040	0.057	0.072	0.54	0.44
Bi	< 0.005	< 0.002	< 0.005	0.011	0.078
Cd	0.61	0.72	0.66	0.69	0.79
Ce	0.25	0.28	0.36	7.1	8.9
Co	5.2	3.4	3.3	5.3	4.1
Cr	0.20	0.18	< 0.2	0.26	1.4
Cs	< 0.02	< 0.01	< 0.02	< 0.01	0.20
Cu	3.4	5.2	3.9	26	19
Dy	0.012	0.018	0.026	0.98	0.81
Er	0.0060	0.0091	0.012	0.37	0.32
Eu	0.0038	0.0053	0.0073	0.27	0.27
Gd	0.021	0.030	0.041	1.5	1.3
Hf	---	---	---	---	---
Ho	0.0024	0.0036	0.0048	0.16	0.13
La	0.14	0.16	0.19	2.6	3.9
Li	7.4	9.2	9.1	6.5	5.0
Lu	0.0006	0.0009	0.0012	0.030	0.026
Mn	476	426	437	453	459
Mo	3.4	2.8	2.8	3.2	3.6
Nd	0.15	0.19	0.25	6.3	6.2
Ni	20	19	18	20	21
Pb	0.06	0.098	0.10	1.0	8.3
Pr	0.034	0.045	0.058	1.3	1.4
Rb	1.4	1.1	1.1	1.5	3.4
Re	0.76	0.66	0.63	0.72	0.67
Sb	0.067	0.11	0.043	0.030	0.079
Se	< 0.4	< 0.2	< 0.4	< 0.2	< 0.2
Sm	0.025	0.030	0.041	1.5	1.4
Ta	---	---	---	---	---
Tb	0.0026	0.0040	0.0052	0.20	0.17
Te	< 0.01	< 0.005	< 0.01	0.020	0.14
Th	0.0069	0.0048	0.0048	0.044	0.36
Tl	0.006	0.005	< 0.006	0.006	0.033
Tm	0.0008	0.0010	0.0015	0.043	0.037
U	0.94	0.89	0.90	1.5	1.2
V	< 0.3	< 0.1	< 0.3	0.3	1.7
W	< 0.004	0.004	0.005	0.006	0.012
Y	0.12	0.16	0.21	4.7	3.9
Yb	0.0038	0.0060	0.0071	0.24	0.20
Zn	60	---	80	---	---
Zr	0.019	0.020	0.014	0.013	0.056

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Red River below Bear Creek inflow**	**Red River below Bear Creek inflow**	**Pooled seep below engineered Capulin Gulch**	**Seep No. 13 with Ulothrix stringers**	**Discharge from French Drain**
Sample code number	**RRL-18000**	**RRL-18000**	**RR-17670**	**RR-17595**	**RR-17574**
Collection Date	**8/17/2001**	**8/17/2001**	**8/17/2001**	**8/17/2001**	**8/17/2001**
Treatment	UFA	RA	FA	FA	FA
Constituent, µg/L					
Al	193	---	---	---	---
As	0.11	0.57	1.4	1.3	0.84
B	8.9	8.2	< 5	11	10
Ba	30	71	6.8	6.9	20
Be	0.048	0.38	17	15	6.7
Bi	< 0.002	0.066	< 0.02	< 0.02	0.026
Cd	0.62	0.75	16	15	6.0
Ce	0.16	6.6	130	97	49
Co	3.1	3.7	200	170	87
Cr	0.15	1.2	4.4	2.6	< 2
Cs	< 0.01	0.15	0.20	0.17	0.10
Cu	4.1	17	---	---	---
Dy	0.012	0.65	28	23	10
Er	0.0062	0.25	11	9.1	4.1
Eu	0.0045	0.24	7.9	6.4	2.8
Gd	0.020	1.0	41	33	15
Hf	---	---	0.17	0.14	0.080
Ho	0.0024	0.11	4.6	3.8	1.7
La	0.075	2.9	27	17	8.4
Li	5.0	4.6	83	62	25
Lu	0.0006	0.020	0.94	0.78	0.37
Mn	394	398	---	---	---
Mo	2.8	3.4	< 0.5	< 0.5	1.4
Nd	0.11	4.9	170	130	57
Ni	18	19	---	---	---
Pb	0.064	6.8	0.83	1.0	0.73
Pr	0.024	1.1	31	24	10
Rb	1.0	3.0	19	15	4.0
Re	0.65	0.63	0.90	0.87	0.84
Sb	0.073	0.074	< 0.04	< 0.04	0.18
Se	< 0.2	< 0.2	7.7	5.9	2.2
Sm	0.018	1.1	40	33	14
Ta	---	---	< 0.006	< 0.006	< 0.006
Tb	0.0023	0.13	5.6	4.6	2.0
Te	< 0.005	0.10	0.05	< 0.05	< 0.05
Th	0.0038	0.30	0.22	0.25	0.11
Tl	0.004	0.026	0.19	0.13	0.04
Tm	0.0008	0.030	1.3	1.1	0.48
U	0.88	1.1	17	14	6.3
V	< 0.1	1.5	< 0.9	< 0.9	< 0.9
W	0.004	0.012	< 0.02	0.02	< 0.02
Y	0.12	3.2	130	110	45
Yb	0.0042	0.16	7.3	6.1	2.9
Zn	77	---	---	---	---
Zr	0.016	0.039	0.11	0.17	0.16

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Red River under power lines above Bear Creek**	**Red River under power lines above Bear Creek**	**Red River at campground below Goat Hill Gulch**	**Red River below Goat Hill Gulch**	**Red River below Goat Hill Gulch**
Sample code number	**RRL-17012**	**RRL-17012**	**RRL-16400**	**RRL-16100**	**RRL-16100**
Collection Date	**8/17/2001**	**8/17/2001**	**8/17/2001**	**8/17/2001**	**8/17/2001**
Treatment	UFA	RA	UFA	UFA	RA
Constituent, µg/L					
Al	201	---	194	209	---
As	0.12	1.6	0.11	0.14	1.0
B	8.4	9.5	8.2	9.9	8.6
Ba	31	145	30	33	103
Be	0.038	0.50	0.030	0.062	0.37
Bi	< 0.002	0.15	< 0.002	< 0.002	0.11
Cd	0.56	0.83	0.50	0.60	0.70
Ce	0.17	13	0.14	0.23	8.8
Co	2.2	3.7	2.0	2.1	3.1
Cr	0.20	3.1	0.13	0.20	2.1
Cs	< 0.01	0.72	< 0.01	< 0.01	0.32
Cu	3.2	17	3.1	6.2	15
Dy	0.013	0.73	0.011	0.021	0.60
Er	0.0069	0.28	0.0067	0.010	0.24
Eu	0.0039	0.30	0.0035	0.0081	0.25
Gd	0.018	1.2	0.016	0.031	1.0
Hf	---	---	---	---	---
Ho	0.0028	0.12	0.0024	0.0041	0.100
La	0.087	6.4	0.076	0.14	4.1
Li	4.3	5.5	4.3	4.8	4.8
Lu	0.0006	0.024	0.0005	0.0010	0.020
Mn	335	423	316	305	352
Mo	2.6	5.0	2.4	2.4	3.6
Nd	0.12	7.3	0.10	0.19	5.3
Ni	16	22	14	16	19
Pb	0.078	18	0.056	0.23	13
Pr	0.027	1.8	0.023	0.042	1.3
Rb	1.0	7.8	0.96	1.1	4.4
Re	0.78	0.83	0.67	0.68	0.65
Sb	0.055	0.12	0.057	0.070	0.098
Se	< 0.2	< 0.4	< 0.2	< 0.2	< 0.2
Sm	0.020	1.5	0.018	0.034	1.1
Ta	---	---	---	---	---
Tb	0.0023	0.15	0.0021	0.0043	0.13
Te	< 0.005	0.29	< 0.005	0.006	0.21
Th	0.0035	0.82	0.0045	0.0049	0.53
Tl	0.010	0.072	0.005	0.005	0.041
Tm	0.0010	0.034	0.0007	0.0011	0.027
U	0.92	1.2	0.89	0.91	1.0
V	0.2	4.0	0.2	0.2	2.4
W	0.004	0.013	0.004	0.005	0.011
Y	0.12	3.6	0.099	0.17	3.1
Yb	0.0042	0.18	0.0038	0.0065	0.15
Zn	45	---	37	67	---
Zr	0.013	0.054	0.013	0.015	0.041

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Red River above Goat Hill Gulch**	**Red River above Goat Hill Gulch**	**Goat Hill Gulch**	**Pond with old metal relic**	**Red River below spring no. 39**
Sample code number	**RRL-15765**	**RRL-15765**	**01WA159**	**RR-15687**	**RRL-15600**
Collection Date	**8/17/2001**	**8/17/2001**	**9/14/2001**	**8/17/2001**	**8/17/2001**
Treatment	UFA	RA	FA	FA	UFA
Constituent, µg/L					
Al	180	---	---	590	154
As	0.13	1.2	110	< 0.2	0.16
B	8.7	9.0	< 20	10	9.3
Ba	31	130	4.0	23	32
Be	0.044	0.43	330	0.19	0.059
Bi	< 0.002	0.13	0.15	0.018	< 0.002
Cd	0.52	0.72	---	3.4	0.57
Ce	0.16	11	12000	0.36	0.23
Co	2.0	3.2	---	1.8	2.1
Cr	0.11	2.8	490	< 2	0.13
Cs	< 0.01	0.56	< 0.2	0.06	< 0.01
Cu	2.4	16	---	8.5	3.7
Dy	0.013	0.65	1200	0.088	0.021
Er	0.0066	0.24	390	0.036	0.0099
Eu	0.0046	0.26	250	0.024	0.0082
Gd	0.019	1.1	1800	0.15	0.033
Hf	---	---	8.3	< 0.004	---
Ho	0.0027	0.11	180	0.014	0.0039
La	0.095	5.4	3500	0.44	0.14
Li	4.1	5.0	1000	5.0	38
Lu	0.0006	0.022	26	< 0.002	0.0009
Mn	298	371	---	170	301
Mo	2.3	4.7	19	2.7	2.4
Nd	0.13	6.3	8400	0.58	0.19
Ni	14	19	---	37	15
Pb	0.036	14	2.0	0.20	0.050
Pr	0.028	1.6	1800	0.13	0.042
Rb	1.00	6.9	5.1	2.7	1.0
Re	0.66	0.68	0.59	6.7	0.66
Sb	0.046	0.11	< 0.2	< 0.04	0.070
Se	< 0.2	< 0.4	240	1.6	< 0.2
Sm	0.020	1.2	1900	0.091	0.033
Ta	---	---	< 0.02	< 0.006	---
Tb	0.0024	0.13	250	0.016	0.0042
Te	< 0.005	0.24	4.6	< 0.05	< 0.005
Th	0.0040	0.68	130	0.03	0.0035
Tl	0.005	0.063	< 0.1	0.04	0.004
Tm	0.0007	0.029	42	0.003	0.0011
U	0.86	1.1	210	0.87	0.88
V	0.1	3.6	22	< 0.9	0.1
W	0.005	0.012	< 0.09	< 0.02	0.005
Y	0.11	3.2	5200	0.88	0.17
Yb	0.0045	0.16	220	0.016	0.0063
Zn	39	---	---	---	63
Zr	0.013	0.043	3.7	0.083	0.012

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Red River**	**Red River**	**Spring No. 39**	**Draining gravel bar and spring**	**Shaft Spring**
Sample code number	**RRC-15547**	**RRC-15547**	**RR-15408**	**RR-14973**	**RR-14570**
Collection Date	**3/30/2002**	**3/30/2002**	**8/17/2001**	**8/17/2001**	**8/17/2001**
Treatment	UFA	RA	FA	FA	FA
Constituent, µg/L					
Al	131	679	---	---	---
As	0.09	0.12	0.42	0.17	0.16
B	7.6	6.1	15	13	11
Ba	36	38	12	34	34
Be	0.050	0.18	5.9	2.0	2.2
Bi	< 0.002	0.008	0.025	0.024	0.024
Cd	0.36	0.39	7.1	3.4	9.5
Ce	0.22	1.8	20	0.30	1.6
Co	2.2	2.3	59	0.35	0.15
Cr	0.10	0.22	< 2	< 2	< 2
Cs	< 0.01	< 0.01	0.10	0.07	0.12
Cu	3.0	8.2	---	11	23
Dy	0.033	0.32	19	0.37	1.5
Er	0.015	0.13	8.4	0.15	0.62
Eu	0.0100	0.11	3.8	0.12	0.52
Gd	0.049	0.48	21	0.71	2.7
Hf	---	---	0.13	0.007	0.014
Ho	0.0060	0.055	3.4	0.067	0.27
La	0.11	0.75	7.1	2.1	6.1
Li	5.1	4.9	55	9.7	6.2
Lu	0.0013	0.011	0.54	0.013	0.043
Mn	154	160	---	23	400
Mo	2.6	2.6	2.1	6.6	< 0.5
Nd	0.22	1.9	39	3.3	12
Ni	14	14	---	---	---
Pb	0.12	0.70	0.64	0.17	0.74
Pr	0.045	0.38	6.2	0.68	2.6
Rb	1.0	1.2	5.6	2.2	3.5
Re	0.73	0.69	8.2	6.1	6.8
Sb	0.056	0.029	< 0.04	< 0.04	0.05
Se	< 0.2	< 0.2	4.9	0.6	0.6
Sm	0.047	0.44	11	0.53	2.1
Ta	---	---	< 0.006	< 0.006	< 0.006
Tb	0.0059	0.064	3.5	0.076	0.33
Te	< 0.005	0.014	< 0.05	< 0.05	< 0.05
Th	0.0060	0.025	0.03	0.10	0.19
Tl	< 0.003	0.005	0.04	0.04	< 0.03
Tm	0.0019	0.015	0.82	0.016	0.061
U	1.1	1.1	1.2	0.61	0.63
V	0.1	0.2	< 0.9	< 0.9	< 0.9
W	0.003	0.003	< 0.02	< 0.02	< 0.02
Y	0.26	1.9	140	3.5	12
Yb	0.0095	0.081	4.0	0.082	0.31
Zn	55	82	---	---	---
Zr	0.016	0.014	0.14	0.33	0.50

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Red River above highway bridge below Mn seeps**	**Red River above highway bridge below Mn seeps**	**Spring from manganocrete**	**Seep from manganocrete**	**Cabin Springs**
Sample code number	**RRL-14142**	**RRL-14142**	**RR-13751**	**RR-13750**	**RR-13675**
Collection Date	**8/17/2001**	**8/17/2001**	**8/17/2001**	**8/17/2001**	**8/17/2001**
Treatment	UFA	RA	FA	FA	FA
Constituent, µg/L					
Al	220	---	---	---	---
As	0.13	0.49	1.6	1.4	1.6
B	9.7	9.1	8.6	12	7.5
Ba	32	64	15	14	23
Be	0.025	0.21	9.8	8.9	9.4
Bi	< 0.002	0.057	0.016	0.023	0.017
Cd	0.37	0.48	31	25	29
Ce	0.17	6.1	260	200	250
Co	2.1	2.6	180	120	160
Cr	0.12	1.1	< 2	< 2	< 2
Cs	< 0.01	0.06	0.20	0.13	0.13
Cu	3.8	12	---	---	---
Dy	0.014	0.53	32	25	30
Er	0.0072	0.20	13	10.0	12
Eu	0.0058	0.20	11	9.1	11
Gd	0.021	0.83	48	38	45
Hf	---	---	0.21	0.16	0.19
Ho	0.0026	0.087	5.3	4.2	5.1
La	0.098	2.7	100	79	98
Li	4.1	4.1	32	26	31
Lu	0.0006	0.017	0.99	0.80	0.96
Mn	327	349	---	---	---
Mo	2.0	2.4	0.5	1.0	0.6
Nd	0.13	4.1	210	170	200
Ni	7.1	9.1	---	---	---
Pb	0.068	5.0	0.59	0.56	0.85
Pr	0.028	0.95	47	37	44
Rb	1.0	2.5	6.4	4.7	6.2
Re	0.28	0.26	16	13	15
Sb	0.057	0.063	< 0.04	0.06	< 0.04
Se	< 0.2	< 0.2	8.3	6.5	8.0
Sm	0.022	0.91	45	38	44
Ta	---	---	< 0.006	< 0.006	< 0.006
Tb	0.0026	0.11	6.5	5.2	6.2
Te	< 0.005	0.079	< 0.05	< 0.05	< 0.05
Th	0.0048	0.21	0.10	0.10	0.08
Tl	0.018	0.018	0.03	0.05	0.03
Tm	0.0008	0.024	1.4	1.1	1.3
U	0.79	0.88	15	8.1	14
V	0.1	1.2	< 0.9	< 0.9	< 0.9
W	0.006	0.008	< 0.02	< 0.02	< 0.02
Y	0.11	2.6	160	130	150
Yb	0.0041	0.14	7.7	6.2	7.4
Zn	21	79	---	---	---
Zr	0.011	0.036	0.22	0.20	0.27

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Red River below Columbine Creek**	**Red River below Columbine Creek**	**Red River below Columbine Creek**	**Seep at bedrock manganocrete contact**	**Red River near mill water tank**
Sample code number	**RRL-13300**	**RRL-13300**	**RRL-13300**	**RR-12287**	**RRM-10200**
Collection Date	**8/17/2001**	**8/17/2001**	**8/17/2001**	**8/20/2001**	**8/20/2001**
Treatment	UFA	FA	RA	FA	UFA
Constituent, µg/L					
Al	195	177	---	---	172
As	0.13	0.11	0.50	0.34	0.13
B	10	9.3	8.9	< 5	10
Ba	32	31	65	22	34
Be	0.012	0.017	0.10	0.93	0.015
Bi	< 0.005	< 0.002	0.061	< 0.02	< 0.002
Cd	0.11	0.091	0.17	6.3	0.14
Ce	0.058	0.09	3.8	25	0.052
Co	0.60	0.53	1.1	16	1.4
Cr	< 0.2	0.11	1.0	< 2	< 0.1
Cs	< 0.02	< 0.01	0.08	0.08	< 0.01
Cu	4.0	2.7	7.7	12	2.9
Dy	0.0057	0.010	0.24	2.8	0.0057
Er	0.0039	0.0050	0.092	1.2	0.0032
Eu	0.0034	0.0022	0.097	0.86	0.0025
Gd	0.0090	0.015	0.39	4.5	0.0076
Hf	---	---	---	0.019	---
Ho	0.0012	0.0020	0.038	0.50	0.0012
La	0.031	0.048	1.8	21	0.025
Li	4.2	3.7	3.8	5.8	4.6
Lu	0.0006	0.0006	0.0091	0.076	0.0004
Mn	106	98	128	---	135
Mo	2.1	1.9	2.5	1.9	1.3
Nd	0.050	0.081	2.2	21	0.044
Ni	3.2	2.4	4.2	---	5.1
Pb	0.09	0.042	6.0	0.12	0.024
Pr	0.011	0.018	0.54	5.3	0.0091
Rb	1.0	1.00	2.5	3.5	0.97
Re	0.11	0.10	0.11	9.0	0.025
Sb	0.063	0.031	0.068	< 0.04	0.062
Se	< 0.4	< 0.2	< 0.2	1.3	< 0.2
Sm	0.0074	0.016	0.46	3.5	0.0078
Ta	---	---	---	< 0.006	---
Tb	0.0010	0.0022	0.048	0.59	0.0011
Te	< 0.01	0.005	0.090	< 0.05	< 0.005
Th	0.0038	0.0031	0.23	0.05	0.0018
Tl	0.006	0.006	0.018	< 0.03	< 0.003
Tm	0.0004	0.0007	0.012	0.12	0.0004
U	0.73	0.72	0.76	0.72	0.51
V	< 0.3	< 0.1	1.2	< 0.9	< 0.1
W	0.006	0.005	0.010	< 0.02	0.005
Y	0.047	0.073	1.1	21	0.044
Yb	0.0029	0.0043	0.065	0.58	0.0026
Zn	7.0	2.6	41	---	7.7
Zr	0.011	0.014	0.033	0.18	0.012

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; μg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Red River at bend near highway**	**Red River at bend near highway**	**Red River at bend near highway**	**Red River at bend near highway**	**Waldo Spring**
Sample code number	**RRF-7800**	**RRM-7800**	**RRF-7800**	**RRM-7800**	**01WA163**
Collection Date	**3/31/2002**	**8/20/2001**	**3/31/2002**	**8/20/2001**	**9/15/2001**
Treatment	UFA	UFA	RA	RA	FA
Constituent, μg/L					
Al	132	173	884	676	---
As	0.09	0.13	0.14	0.25	0.33
B	27	11	19	9.3	7.4
Ba	32	35	37	47	10
Be	0.030	0.019	0.20	0.12	1.1
Bi	< 0.002	< 0.002	0.008	0.025	0.027
Cd	0.31	0.18	0.36	0.23	1.2
Ce	0.18	0.081	3.1	2.3	20
Co	3.0	1.7	3.3	1.9	16
Cr	0.20	< 0.1	0.24	0.38	< 2
Cs	< 0.01	< 0.01	< 0.01	< 0.01	0.08
Cu	3.7	3.8	12	9.5	13
Dy	0.011	0.0066	0.40	0.24	2.4
Er	0.0054	0.0039	0.16	0.10	0.90
Eu	0.0040	0.0034	0.15	0.094	0.98
Gd	0.016	0.011	0.62	0.37	4.1
Hf	---	---	---	---	0.024
Ho	0.0023	0.0015	0.069	0.043	0.40
La	0.076	0.038	1.1	0.94	7.8
Li	7.3	4.8	5.6	4.4	10
Lu	0.0005	0.0005	0.015	0.0093	0.067
Mn	213	145	222	157	---
Mo	1.2	1.3	1.3	1.3	< 0.5
Nd	0.12	0.063	2.7	1.7	20
Ni	11	6.1	12	7.0	66
Pb	0.028	0.036	0.68	1.9	0.19
Pr	0.026	0.014	0.57	0.37	4.1
Rb	1.0	1.0	1.2	1.5	1.9
Re	0.033	0.028	0.033	0.025	0.079
Sb	0.030	0.056	0.032	0.045	< 0.04
Se	< 0.2	< 0.2	< 0.2	< 0.2	0.7
Sm	0.018	0.011	0.65	0.40	4.2
Ta	---	---	---	---	< 0.006
Tb	0.0019	0.0012	0.080	0.048	0.51
Te	< 0.005	< 0.005	0.009	0.035	< 0.05
Th	0.0032	0.0028	0.021	0.050	0.02
Tl	0.005	0.008	0.004	0.006	< 0.03
Tm	0.0007	0.0005	0.020	0.013	0.10
U	0.47	0.51	0.59	0.55	0.48
V	< 0.1	0.2	0.2	0.5	< 0.9
W	0.003	0.003	0.004	0.005	0.02
Y	0.091	0.059	2.0	1.3	12
Yb	0.0040	0.0030	0.11	0.070	0.52
Zn	40	17	76	51	---
Zr	0.013	0.018	0.016	0.024	0.14

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Small drainage with iron stain**	**Unnamed drainage west of Little Hansen**	**Pool above culvert on Little Hansen debris fan**	**Little Hansen**	**Hansen (high)**
Sample code number	**RR-7352**	**01WA162**	**RR-6971**	**01WA153**	**01WA152**
Collection Date	**8/20/2001**	**9/15/2001**	**8/18/2001**	**9/11/2001**	**9/11/2001**
Treatment	FA	FA	FA	FA	FA
Constituent, µg/L					
Al	510	240	---	---	---
As	1.0	0.19	3.7	7.1	2.9
B	< 5	11	< 8	< 8	5.7
Ba	22	20	7.2	2.9	6.5
Be	0.12	< 0.08	19	34	15
Bi	0.020	0.020	< 0.05	< 0.05	0.038
Cd	< 0.04	< 0.04	9.2	19	4.5
Ce	5.4	0.060	370	740	340
Co	27	0.08	360	680	150
Cr	< 2	< 2	60	52	4.3
Cs	0.11	0.07	0.27	0.14	0.26
Cu	6.0	5.5	---	---	---
Dy	0.39	0.007	34	67	27
Er	0.16	< 0.009	13	25	7.5
Eu	0.17	< 0.002	18	33	7.1
Gd	0.71	< 0.006	54	100	60
Hf	0.006	< 0.004	0.28	0.53	0.20
Ho	0.073	< 0.002	5.6	11	3.6
La	2.4	0.030	130	290	97
Li	7.4	23	100	250	64
Lu	0.010	< 0.002	0.98	2.1	0.56
Mn	---	6.5	---	---	---
Mo	1.1	1.2	< 1	3	< 0.6
Nd	3.6	0.031	270	500	310
Ni	33	1.1	---	---	---
Pb	0.15	0.10	0.42	0.66	3.0
Pr	0.79	0.008	58	110	63
Rb	3.1	0.62	3.2	1.3	9.3
Re	0.023	0.011	0.030	0.048	0.011
Sb	0.10	0.06	< 0.06	< 0.06	< 0.03
Se	< 0.5	< 0.5	12	19	7.8
Sm	0.67	< 0.01	61	110	78
Ta	< 0.006	< 0.006	< 0.009	< 0.009	< 0.005
Tb	0.083	0.001	7.1	14	7.0
Te	0.16	< 0.05	3.4	0.70	0.16
Th	0.07	0.04	14	14	0.78
Tl	0.03	< 0.03	< 0.05	< 0.05	0.07
Tm	0.018	< 0.002	1.5	3.0	0.81
U	0.13	0.91	18	23	4.2
V	< 0.9	< 0.9	1	1	< 0.6
W	< 0.02	< 0.02	< 0.04	< 0.04	< 0.02
Y	2.5	0.035	150	300	91
Yb	0.089	< 0.006	8.3	17	4.4
Zn	48	19	---	---	---
Zr	0.088	0.099	0.59	1.1	0.27

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Hansen (low)**	**Red River near Fawn Lakes campground**	**Red River near Fawn Lakes campground**	**Red River along reach of rapid flow**	**Red River below Straight Creek debris flow**
Sample code number	**01WA151**	**RRM-6000**	**RRM-6000**	**RRU-4800**	**RRH-4500**
Collection Date	**9/11/2001**	**8/20/2001**	**8/20/2001**	**8/24/2001**	**4/1/2002**
Treatment	FA	UFA	RA	UFA	UFA
Constituent, µg/L					
Al	---	167	433	118	116
As	2.8	0.20	0.26	0.18	0.11
B	7.5	11	11	7.0	6.7
Ba	8.4	38	48	43	44
Be	16	0.017	0.054	0.010	0.009
Bi	< 0.03	0.006	0.030	< 0.002	< 0.002
Cd	8.7	0.13	0.17	0.16	0.17
Ce	350	0.17	1.1	0.019	0.019
Co	210	0.71	0.92	1.00	1.0
Cr	< 3	0.12	0.36	0.13	< 0.1
Cs	0.12	< 0.01	< 0.01	< 0.01	< 0.01
Cu	---	7.9	9.7	3.3	3.7
Dy	33	0.022	0.14	0.0049	0.0048
Er	9.7	0.012	0.066	0.0034	0.0037
Eu	10	0.0063	0.040	0.0018	0.0016
Gd	72	0.026	0.16	0.0047	0.0046
Hf	0.24	---	---	---	---
Ho	4.7	0.0046	0.024	0.0011	0.0010
La	120	0.083	0.54	0.011	0.012
Li	64	4.4	4.2	4.7	4.7
Lu	0.81	0.0014	0.0070	0.0003	0.0004
Mn	---	93	102	117	118
Mo	1.1	1.3	1.4	1.2	1.3
Nd	310	0.11	0.71	0.019	0.020
Ni	---	3.4	4.1	4.3	4.5
Pb	0.94	0.46	2.1	0.037	0.037
Pr	62	0.025	0.16	0.0035	0.0042
Rb	4.6	1.2	1.5	0.93	0.94
Re	0.014	0.021	0.023	0.026	0.025
Sb	0.04	0.063	0.047	0.058	0.060
Se	8.7	< 0.2	< 0.2	< 0.2	< 0.2
Sm	78	0.025	0.17	0.0037	0.0041
Ta	< 0.005	---	---	---	---
Tb	8.0	0.0040	0.024	0.0007	0.0008
Te	0.22	< 0.005	0.021	< 0.005	< 0.005
Th	0.13	0.0097	0.048	0.0030	0.0028
Tl	0.07	0.004	0.007	< 0.003	< 0.003
Tm	1.1	0.0014	0.0091	0.0006	0.0004
U	5.4	0.60	0.62	0.63	0.64
V	< 0.6	0.4	0.6	0.2	0.2
W	0.02	0.004	0.005	0.004	0.003
Y	130	0.15	0.80	0.053	0.053
Yb	6.3	0.0099	0.049	0.0027	0.0034
Zn	---	8.4	30	7.8	11
Zr	0.42	0.018	0.027	0.011	0.0082

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Straight Creek**	**Straight Creek**	**Straight Creek**	**Straight Creek (high)**	**Straight Creek (low)**
Sample code number	**00WA197**	**02WA112**	**02WA121**	**01WA155**	**01WA154**
Collection Date	**10/29/2000**	**3/20/2002**	**4/24/2002**	**9/12/2001**	**9/12/2001**
Treatment	FA	FA	FA	FA	FA
Constituent, µg/L					
Al		---	---	---	---
As	15	0.51	3.9	14	5.4
B	<23	< 5	4.7	< 8	< 8
Ba	9.8	0.57	1.7	1.6	2.9
Be	19	5.2	23	43	27
Bi	0.085	0.020	< 0.03	< 0.05	< 0.05
Cd	30	7.2	36	36	39
Ce	48	94	720	1400	810
Co	277	72	300	320	330
Cr	61	7.4	26	38	41
Cs	---	0.11	0.11	0.25	0.27
Cu	638	---	---	---	---
Dy	34	6.5	44	66	49
Er	11	2.3	15	20	17
Eu	17	2.6	17	19	21
Gd	70	11	77	150	92
Hf	---	0.044	0.32	0.56	0.37
Ho	5.2	0.98	6.6	9.4	7.6
La	17	33	270	510	300
Li	101	27	150	200	170
Lu	0.90	0.18	1.1	1.6	1.3
Mn	---	---	---	---	---
Mo	13	0.6	1.5	9	6
Nd	401	64	460	850	530
Ni	612	---	---	---	---
Pb	12	0.27	1.5	27	1.7
Pr	87	14	110	200	120
Rb	4.8	1.2	1.2	2.3	1.6
Re	1.2	0.27	1.4	1.5	1.4
Sb	0.10	0.05	< 0.03	0.12	0.09
Se	8.6	2.0	11	19	15
Sm	86	13	94	180	110
Ta	---	< 0.006	< 0.005	< 0.009	< 0.009
Tb	7.9	1.4	9.7	16	11
Te	6.1	0.16	0.72	1.7	0.85
Th	33	1.1	9.9	26	14
Tl	0.058	0.04	0.04	0.07	< 0.05
Tm	1.3	0.25	1.7	2.2	1.9
U	25	3.8	17	31	22
V	5.4	< 0.9	< 0.6	2	< 1
W	---	< 0.02	< 0.02	< 0.04	< 0.04
Y	132	26	170	250	210
Yb	7.5	1.4	9.2	12	10
Zn	---	---	---	---	---
Zr	0.24	0.11	0.38	0.50	0.44

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Junebug (east)**	**Junebug (west)**	**Hottentot Creek (high)**	**Hottentot Creek (low)**	**Red River above Hottentot Creek**
Sample code number	**01WA161**	**01WA160**	**01WA157**	**01WA156**	**RRU-3052**
Collection Date	**9/14/2002**	**9/14/2001**	**9/13/2001**	**9/13/2001**	**8/24/2001**
Treatment	FA	FA	FA	FA	UFA
Constituent, µg/L					
Al	---	---	---	---	88
As	5.8	1.4	51	5.8	0.14
B	< 8	< 8	< 8	< 5	6.5
Ba	2.4	4.7	1.6	4.3	45
Be	34	5.7	22	9.8	0.023
Bi	< 0.05	< 0.05	< 0.05	0.024	< 0.002
Cd	54	18	47	12	0.27
Ce	1200	310	370	150	0.18
Co	530	170	330	170	1.3
Cr	7.7	< 6	87	31	< 0.1
Cs	0.15	0.27	0.29	0.22	< 0.01
Cu	---	---	---	---	4.4
Dy	66	16	42	17	0.0099
Er	26	6.4	14	6.2	0.0071
Eu	35	8.8	12	5.1	0.0027
Gd	100	27	72	28	0.013
Hf	0.50	0.13	0.32	0.11	---
Ho	11	2.7	6.3	2.7	0.0025
La	580	160	150	61	0.031
Li	300	190	88	71	4.6
Lu	2.2	0.56	1.1	0.52	0.0009
Mn	---	---	---	---	132
Mo	< 1	< 1	28	2.2	1.2
Nd	690	170	310	120	0.048
Ni	---	---	---	---	6.8
Pb	2.5	3.7	0.69	0.80	0.10
Pr	170	43	67	27	0.011
Rb	2.5	4.7	3.0	2.2	0.88
Re	5.7	6.0	0.45	0.21	0.023
Sb	< 0.06	< 0.06	0.20	0.06	0.052
Se	17	6	16	7.2	< 0.2
Sm	120	31	75	29	0.010
Ta	< 0.009	< 0.009	< 0.009	< 0.006	---
Tb	13	3.5	9.4	3.7	0.0020
Te	0.13	0.07	3.4	0.67	< 0.005
Th	10	0.43	42	12	0.0035
Tl	< 0.05	< 0.05	0.08	0.03	0.005
Tm	3.2	0.75	1.6	0.69	0.0009
U	39	14	27	7.6	0.61
V	< 1	< 1	11	2.5	0.2
W	< 0.04	< 0.04	< 0.04	< 0.02	0.005
Y	310	75	160	73	0.11
Yb	18	4.2	8.9	3.9	0.0061
Zn	---	---	---	---	43
Zr	1.0	0.54	0.39	0.17	0.019

Table 5. ICP-MS analyses of surface water -- Continued

[FA, filtered acidified; µg/L, micrograms per liter; RA, raw acidified; UFA, ultra-filtered-acidified; <, less than; ---, not analyzed]

Sample Location	**Red River above Hottentot Creek**	**Red River above town of Red River**	**Red River above town of Red River**	**Red River above town of Red River**
Sample code number	**RRU-3052**	**RRU-0**	**RRU-0**	**RRU-0**
Collection Date	**8/24/2001**	**8/24/2001**	**8/24/2001**	**8/24/2001**
Treatment	RA	UFA	FA	RA
Constituent, µg/L				
Al	441	14	17	106
As	0.15	0.15	0.15	0.14
B	5.8	5.7	6.9	5.3
Ba	48	41	41	45
Be	0.076	< 0.002	0.003	< 0.002
Bi	0.004	< 0.002	< 0.002	< 0.002
Cd	0.29	0.010	0.019	0.008
Ce	0.91	0.021	0.010	0.13
Co	1.4	0.019	0.021	0.036
Cr	0.35	0.11	< 0.1	0.15
Cs	< 0.01	< 0.01	< 0.01	< 0.01
Cu	12	0.69	1.0	0.61
Dy	0.17	0.0027	0.0019	0.0090
Er	0.088	0.0024	0.0020	0.0043
Eu	0.048	0.0008	0.0017	0.0032
Gd	0.19	0.0035	0.0023	0.013
Hf	---	---	---	---
Ho	0.033	0.0007	0.0004	0.0017
La	0.44	0.015	0.0071	0.075
Li	4.2	1.8	2.1	1.8
Lu	0.0096	0.0003	0.0002	0.0006
Mn	137	2.0	1.9	4.5
Mo	1.2	1.0	1.1	0.95
Nd	0.73	0.017	0.0090	0.071
Ni	5.9	0.44	0.51	0.33
Pb	0.61	0.051	0.039	0.16
Pr	0.15	0.0040	0.0019	0.018
Rb	1.2	0.43	0.45	0.56
Re	0.023	0.0039	0.0049	0.0046
Sb	0.030	0.029	0.060	0.053
Se	< 0.2	< 0.2	< 0.2	< 0.2
Sm	0.18	0.0038	0.0019	0.015
Ta	---	---	---	---
Tb	0.029	0.0005	0.0003	0.0016
Te	0.005	< 0.005	< 0.005	< 0.005
Th	0.023	0.0009	0.0017	0.0029
Tl	0.003	0.008	0.024	< 0.003
Tm	0.012	0.0003	0.0002	0.0007
U	0.62	0.73	0.74	0.73
V	0.6	0.3	0.3	0.4
W	0.004	0.002	0.004	0.006
Y	1.1	0.026	0.020	0.055
Yb	0.067	0.0020	0.0012	0.0040
Zn	48	2.1	3.1	19
Zr	0.015	0.0076	0.012	0.010

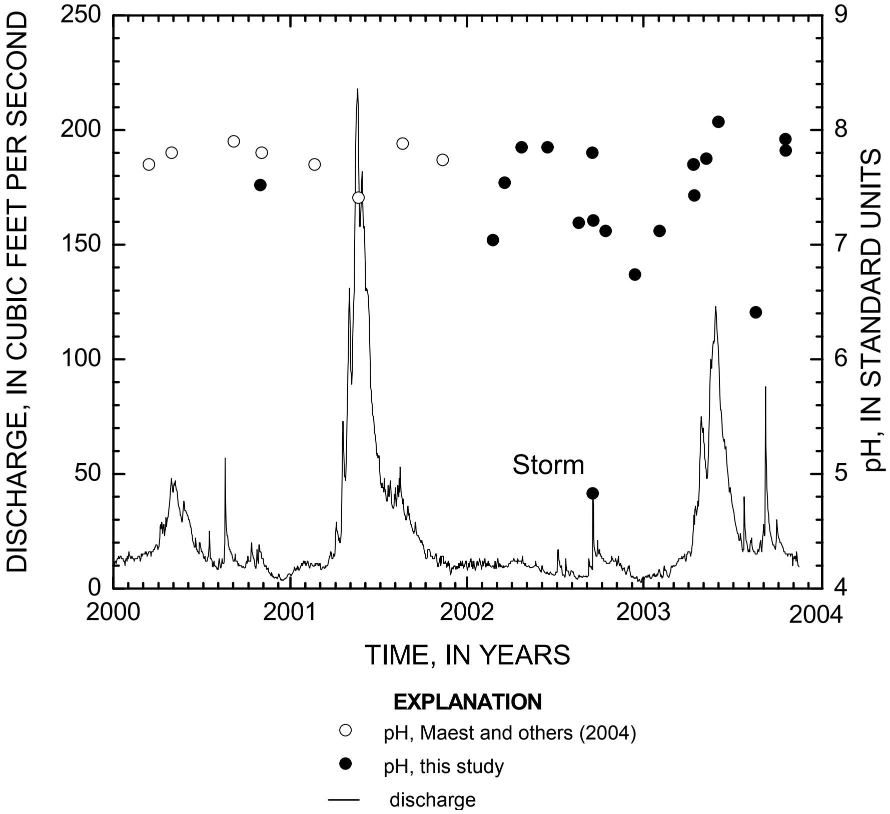


Figure 5. pH and daily mean discharge of the Red River measured at USGS streamflow-gaging station 08265000 at the Questa Ranger Station from 2000 through 2003.

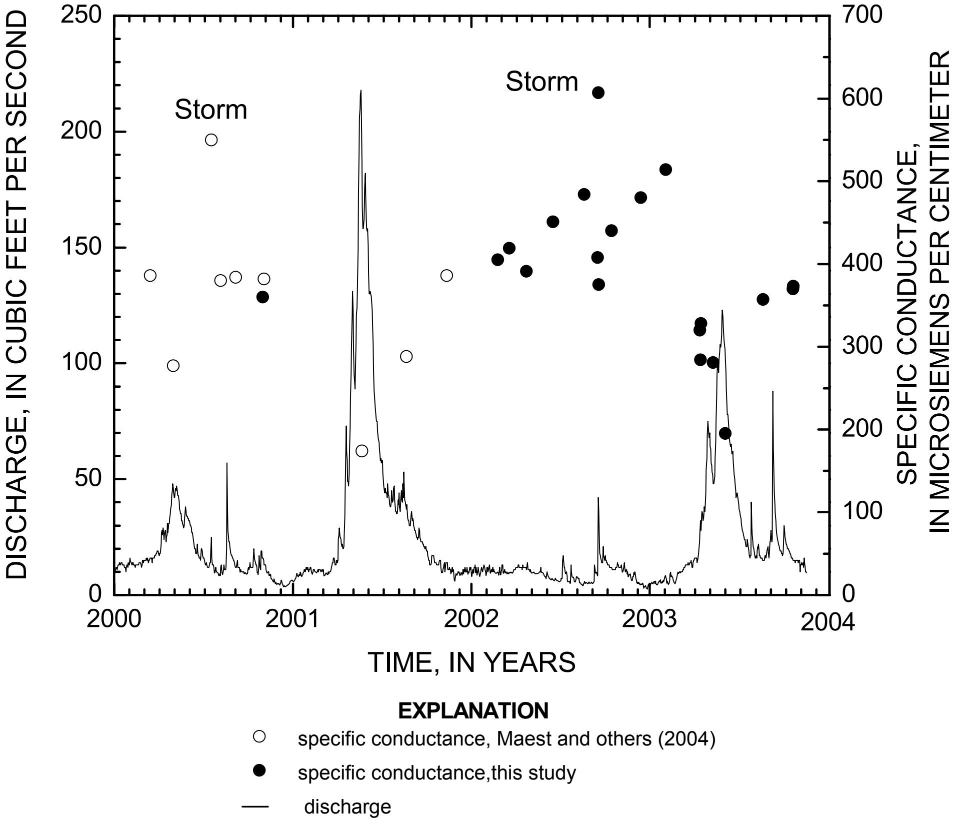


Figure 6. Specific conductance and daily mean discharge of the Red River measured at the USGS streamflow-gaging station 08265000 at the Questa Ranger Station from 2000 through 2003.

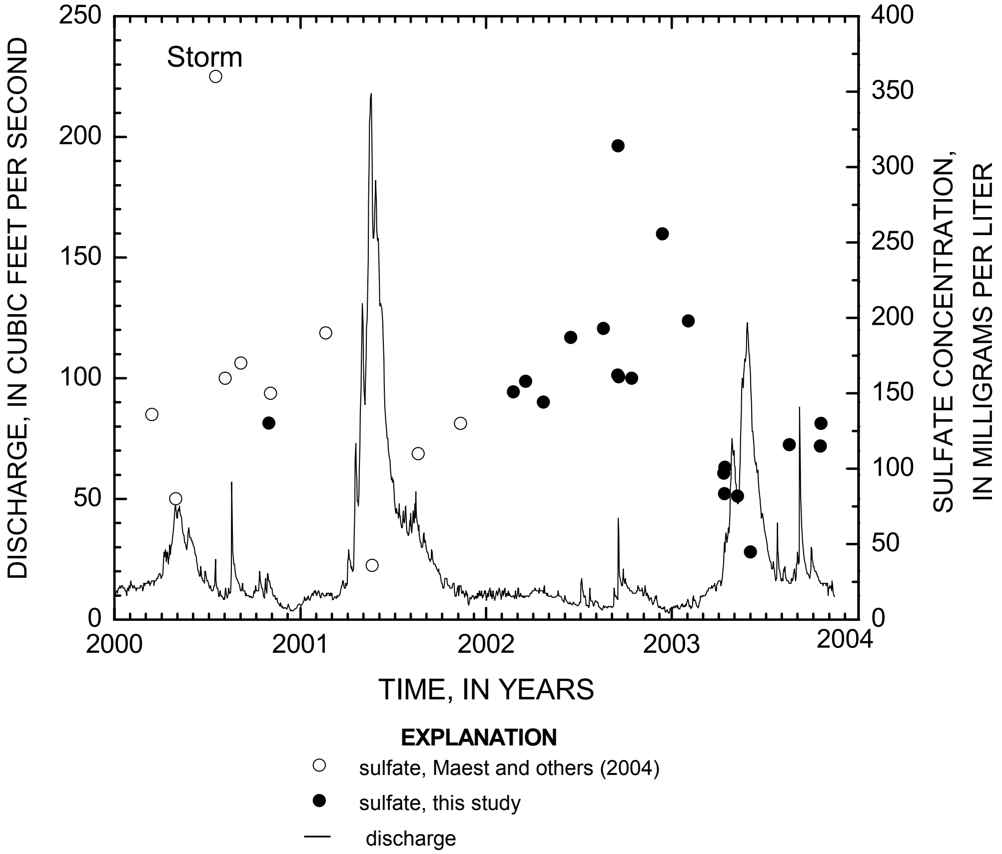


Figure 7. Sulfate concentration and daily mean discharge of the Red River measured at USGS streamflow-gaging station 08265000 at the Questa Ranger Station from 2000 through 2003.

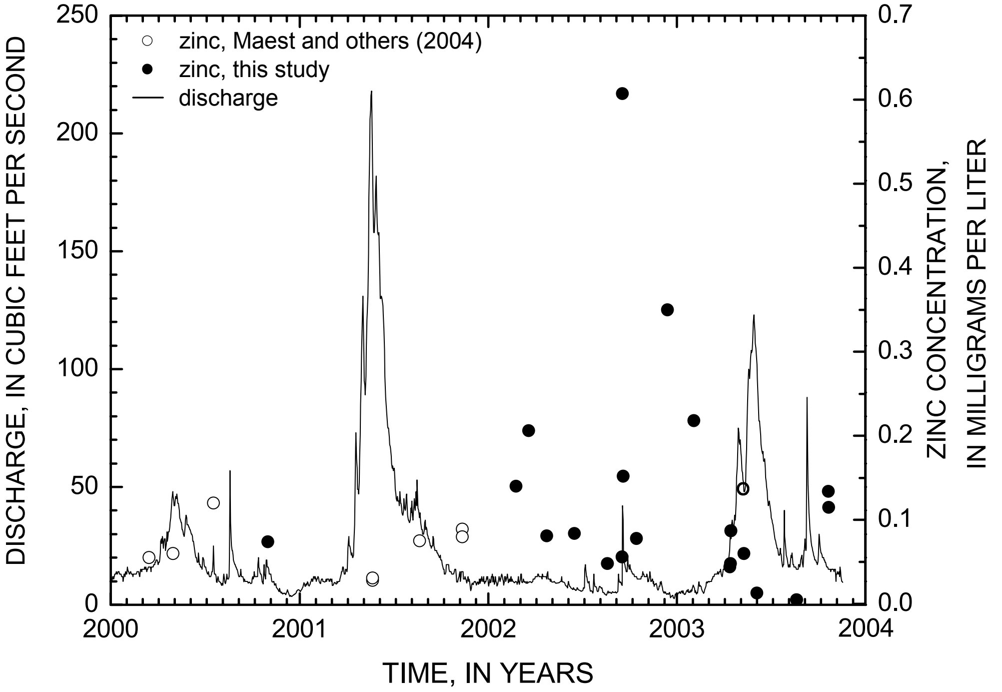


Figure 8. Zinc concentration and daily mean discharge of the Red River measured at the USGS streamflow-gaging station 08265000 from 2000 through 2003. Concentrations determined to be less than detection limit are plotted as zero.

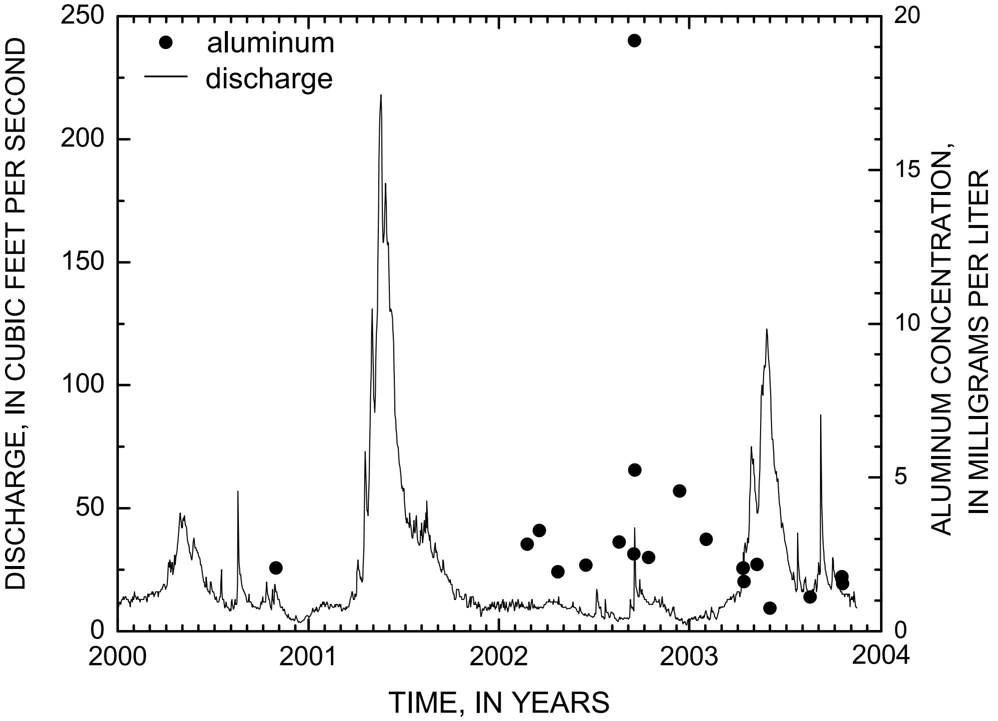


Figure 9. Aluminum concentration and daily mean discharge of the Red River measured at USGS streamflow-gaging station 08265000 at the Questa Ranger Station from 2000 through 2003.

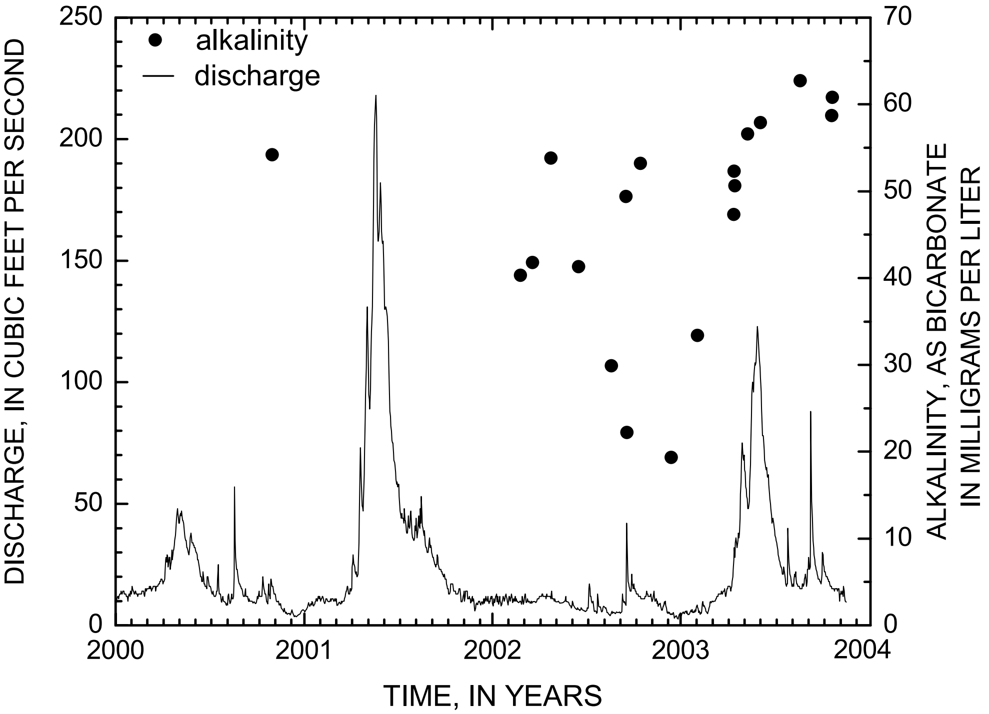


Figure 10. Alkalinity and daily mean discharge of the Red River measured at the USGS streamflow-gaging station 08265000 at Questa Ranger Station from 2000 through 2003.

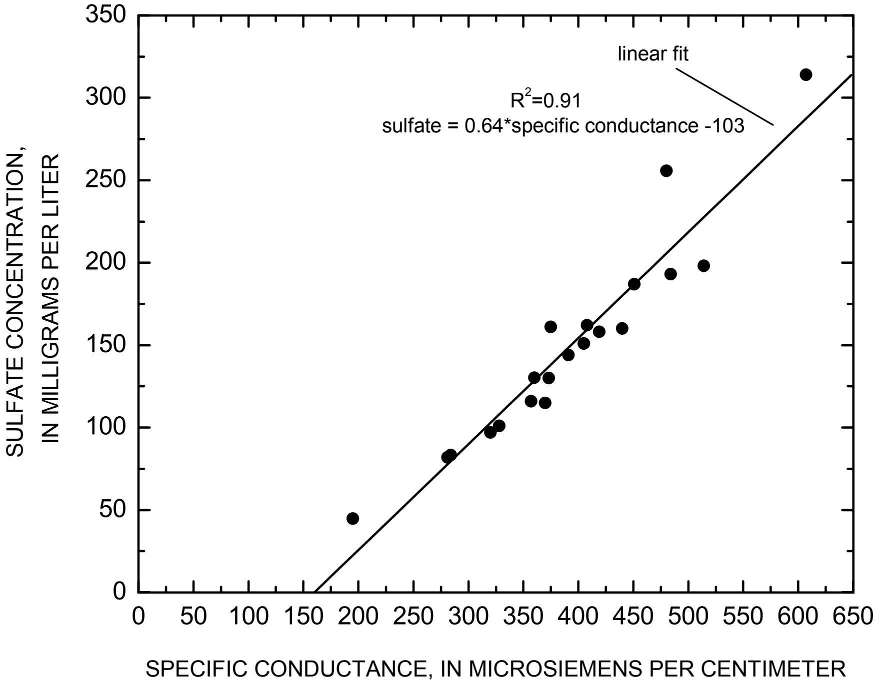


Figure 11. Specific conductance in relation to sulfate concentration in the Red River at USGS streamflow-gaging station 08265000 at the Questa Ranger Station.

One of the predominant cations in the Red River alluvial aquifer is calcium (LoVetere and others, 2004), and calcium concentrations tend to covary with sulfate concentrations (fig. 12). Naus and others (2005) documented that in Straight Creek ground waters gypsum was the main source of dissolved calcium. By plotting the molar concentrations of calcium and sulfate, insight into sulfate sources for surface water can be gained. The Ca:SO_4 1:1 line in figure 12 represents the stoichiometric dissolution of gypsum. The field above the line requires addition of calcium from a mineral phase with little or no sulfate such as calcite, calcic plagioclase, hornblende or epidote, and the field below the line requires an additional sulfate source without calcium such as pyrite or other sulfide minerals. While most samples plot near the 1:1 line, some points plot well to the right. The point farthest to the right of the line was collected during the September 2002 storm event, and this sample has the lowest pH value (4.83). During the storm event, surface water was entering the Red River from upstream altered areas, likely supplying the additional source of sulfate. The point farthest to the left of the line was collected during the peak spring discharge in June 2003, and this point suggests that at this time of year calcium is added to the Red River from relatively nonmineralized parts of the watershed, either upstream from the study area or from the south side of the Red River

Zinc is an element of interest because of its potential toxicity to aquatic life and has previously been discussed in Maest and others (2004). Figure 13 displays the Zn concentrations in both the dissolved and total recoverable samples. The proportion of total recoverable zinc that is dissolved varies from approximately 35 to 95 percent. Two factors likely control the partitioning of zinc between the aqueous and solid phases, pH and the amount of suspended sediment. The pH of the Red River is in the range where zinc begins to sorb onto colloidal phases (pH of 6.5 to 7.5, Dzombak and Morel, 1990; Ball and others, 2005).

Red River Questa Ranger Station Gage Site Water Chemistry, 1965-2003

After compiling historical surface-water data for 1965-2001, Maest and others (2004) examined seasonal and temporal variations of Red River water chemistry. Their study focused on sulfate and zinc concentrations because many

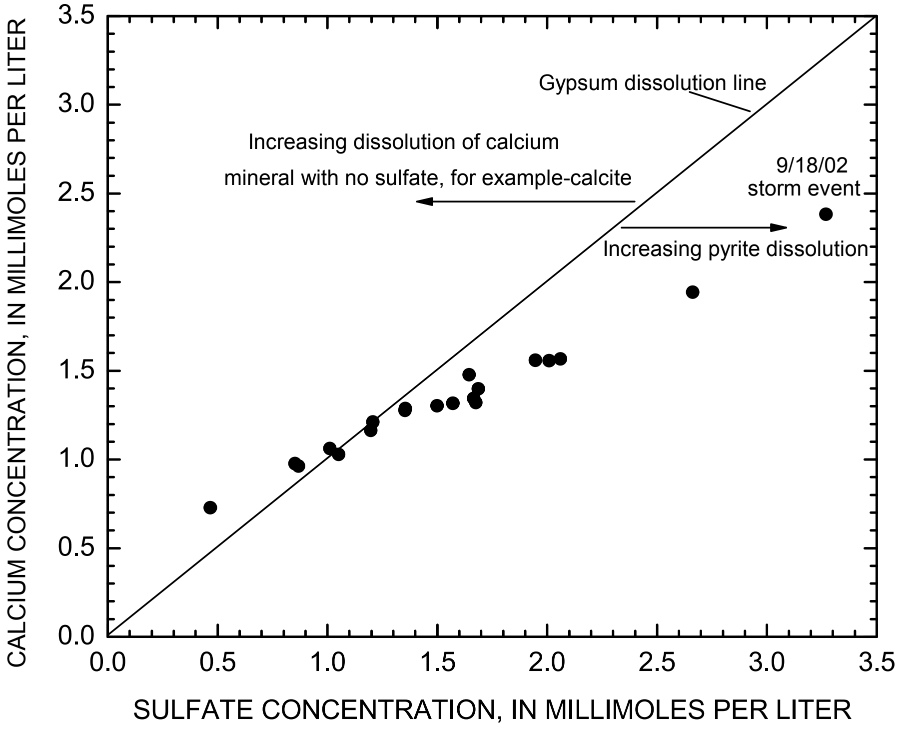


Figure 12. Calcium concentration in relation to sulfate concentration in the Red River at the USGS streamflow-gaging station 08265000 at the Questa Ranger Station, with gypsum congruent dissolution line.

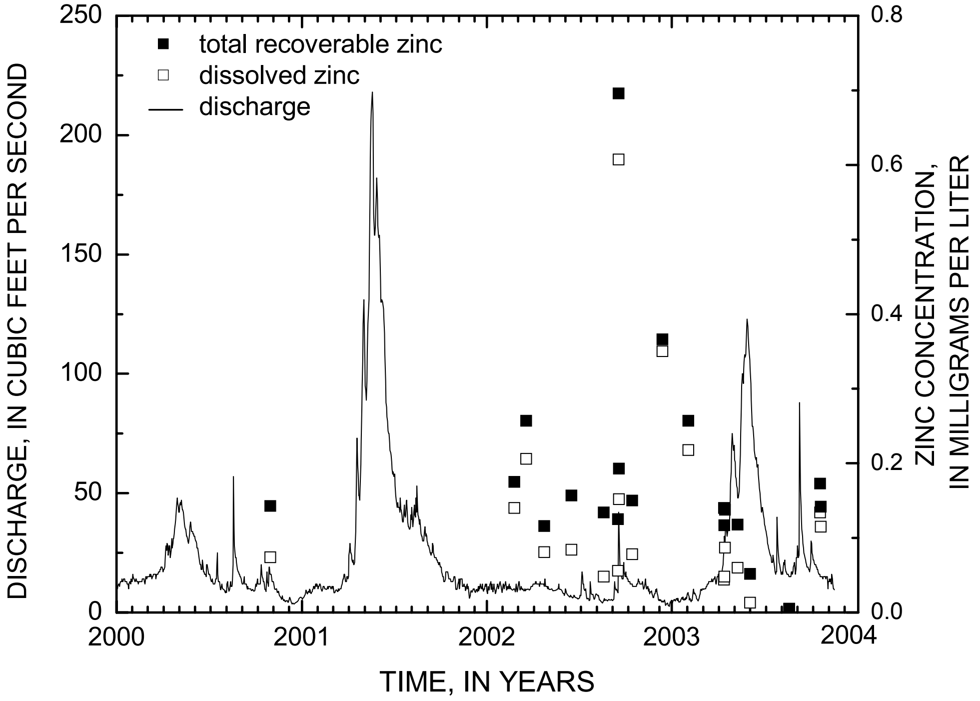


Figure 13. Zinc concentration and daily mean discharge of the Red River measured at USGS streamflow-gaging station 08265000 at the Questa Ranger Station from 2000 through 2003.

samples were analyzed for these constituents which tend to behave relatively conservatively. For samples collected at the Questa Ranger Station gage site, the mean sulfate concentration for the low-flow samples from 2000-2003 was 152 mg/L. This value is greater than the mean value of 120 mg/L for all the low-flow samples collected during 1965-2001 (Maest and others, 2004), but similar to the mean value of 153 mg/L for low-flow samples collected between 1992 and 2001 (fig. 14). Since publication of the historical compilation by Maest and others (2004), additional analyses of Red River samples have been located. Robertson GeoConsultants Inc. (2001b) include figures with daily sulfate concentrations at the Questa Ranger Station gage and at the Molycorp mill site for the period August 1975 through December 1976 and weekly sulfate concentrations at these sites from August 1975 through May 1984 and from March 1985 through December 1985.

Comparing the hydrograph and the detailed sulfate determinations at the Questa Ranger Station provides further insight into the relation between flow and concentration (fig. 15). The period of time between August 1975 and January 1981 was chosen because it includes the daily sulfate data and the hydrograph contains a range in snowmelt conditions from relatively low flow (1977) to high flow (1979). With the exception of storm events, sulfate concentration is inversely correlated with discharge. As the discharge rises in the spring, the sulfate concentrations decrease, and as the discharge decreases in the summer, fall and winter, the sulfate concentration increases. Similar to 2002, 1977 was a drought year with the maximum daily mean discharge of 49 ft^3/s, and the minimum sulfate concentration (30 mg/L) during spring snowmelt period substantially higher than the minimum sulfate concentrations during the snowmelt peaks of the preceding and following years (5 mg/L and 14 mg/L, respectively).

Figure 15 also displays another important aspect of Red River water quality. In simplistic terms, the Red River can be conceived as carbonate-buffered water with above-neutral pH as it enters the town of Red River. From that point downstream it receives a number of acidic ground-water inflows that acidify the water and increase the concentrations of solutes such as sulfate and manganese. Extended dry periods, or droughts, would result in decreased flows of carbonate-buffered water, but the acidic ground-water inflow would remain the same because it has a 10- to 30-year residence time (Naus and others, 2005). Hence, continued increases in sulfate concentrations would be expected during dry periods. This trend can be seen in figure 15, especially after the 1976 snowmelt period. From the end of snowmelt in 1976 to the end of the year, a continual increase in sulfate concentration is observed. Furthermore, it should be noted that the variation in sulfate concentration is much greater at low flow than during snowmelt or during the approach to low flow. This variability may be caused by storm events or upgradient surface and ground-water management, and it complicates the interpretation of water chemistry trends.

Figure 16 displays the sulfate concentration in the Red River at the Questa Ranger Station from 1965 through 2003 with the hydrologic flow regime assigned for each sample. This figure is similar to figure 6 in Maest and others (2004), but includes additional historical samples from Robertson GeoConsultants Inc. (2001b) as well as data from this report. The mean sulfate concentration for 556 low-flow samples collected at the Questa Ranger Station from 1975 through 1985 is 77 mg/L with a standard deviation of 35 mg/L, and the mean concentration of 38 low-flow samples collected at the Questa Ranger Station from 1992 through 2004 is 150 mg/L with a standard deviation of 37 mg/L. Maest and others (2004) noted that the low-flow samples display a trend in sulfate concentration with time, an overall increase in concentration from 1965 through 2001, with a possible decrease after 1993. Vail Engineering, Inc. (2000) and URS (2001) suggested that the increase in sulfate concentrations over time resulted from changes in the amount of ground-water extracted for Molycorp mill operations, but Maest and others (2004) found no correspondence between the steady increase in sulfate and the timing of mill extractions. Addressing this issue is beyond the scope of this study.

Data from previous drought years were evaluated to determine if the drought of 2002 would explain the increase in sulfate. Three years in the recent past (1971, 1977, and 1981) had hydrographs similar to the 2002 hydrograph, displaying only a minimal spring runoff peak (figs. 2A and B). No sulfate data are available

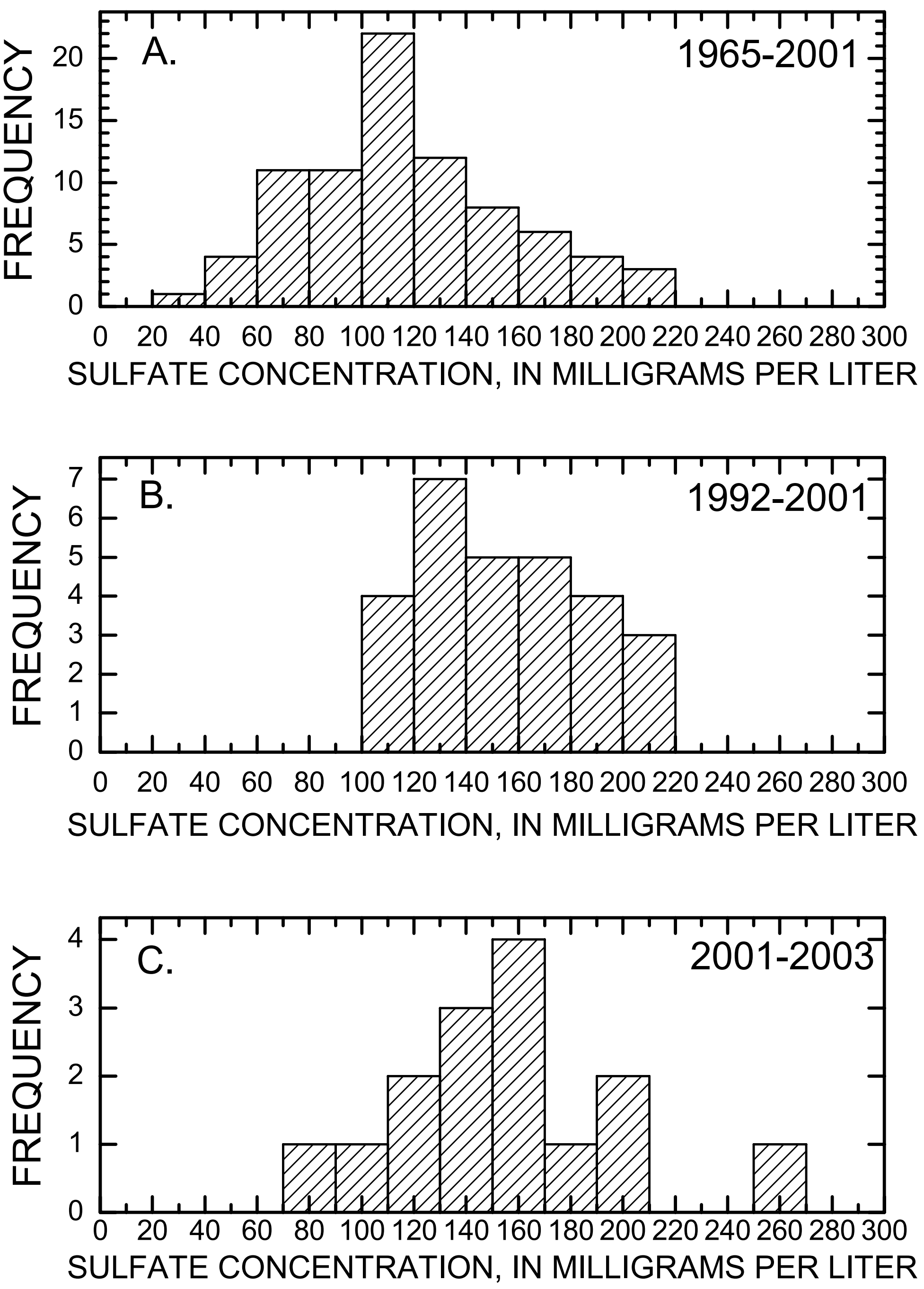


Figure 14. Histograms of sulfate concentration of low-flow samples through time with (A) 1965-2001, (B) 1992-2001, and (C) 2001-2003. Duplicate samples are not plotted.

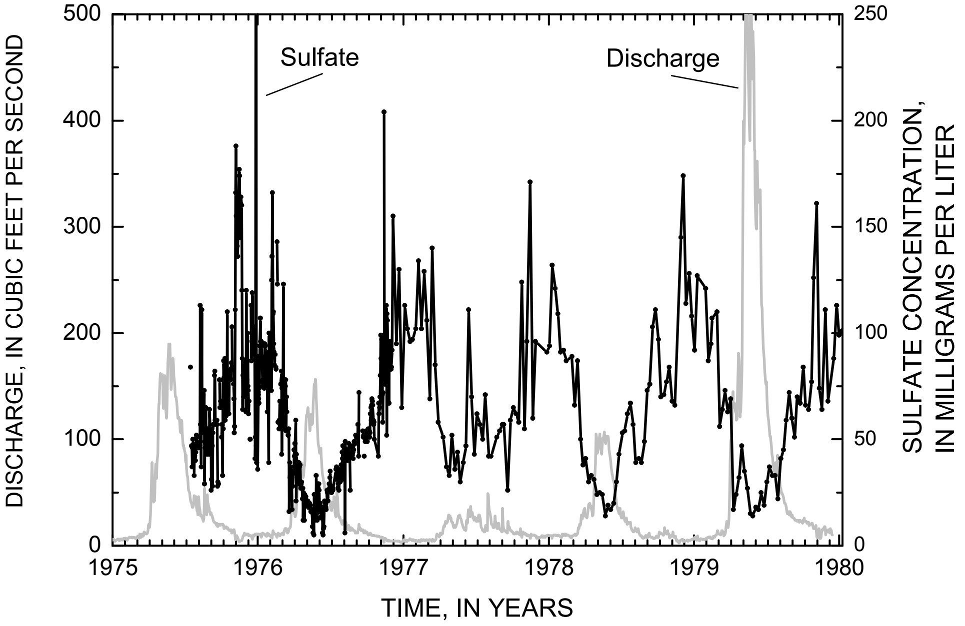


Figure 15. Sulfate concentration and daily mean discharge of the Red River measured at USGS streamflow-gaging station 08265000 at the Questa Ranger Station from 1975 through 1979. Sulfate concentrations from Robertson GeoConsultants (2001b).

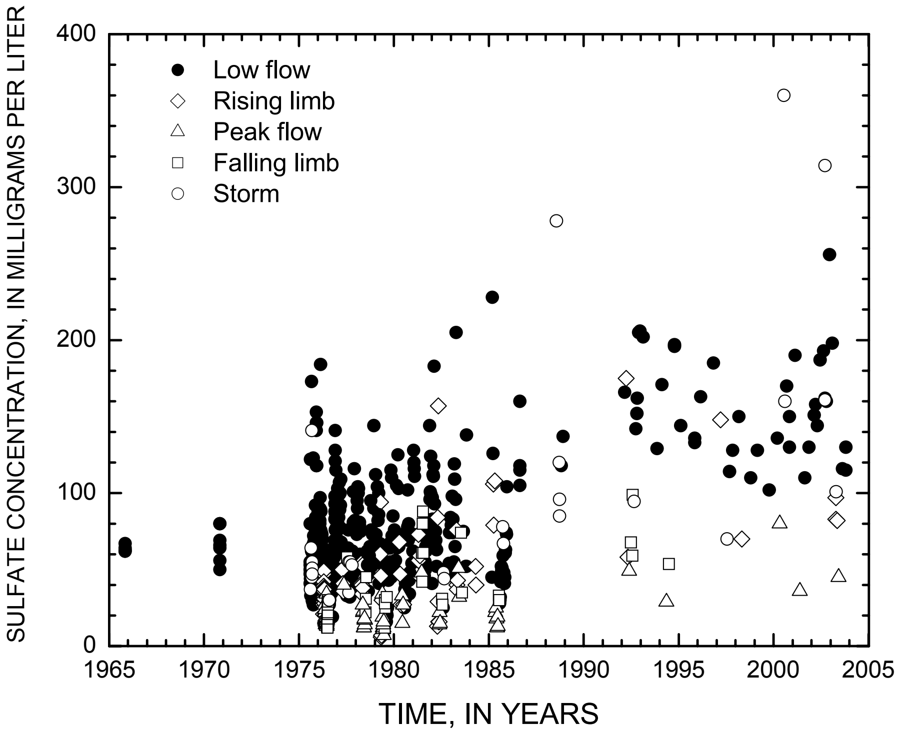


Figure 16. Sulfate concentration of the Red River measured at USGS streamflow-gaging station 08265000 at the Questa Ranger Station from 1965 through 2003, with hydrologic discrimination. Historical data from Robertson GeoConsultants (2001b) and Maest and others (2004).

for 1971, but weekly sulfate data for 1977, the most similar hydrograph to 2002, were reported by Robertson GeoConsultants Inc. (2001b). The 54 low-flow sulfate analyses reported for January 1977 through March 1978 had a mean value of 81 mg/L and a standard deviation of 33 mg/L, substantially less than the mean sulfate concentration of 179 mg/L with a 35 mg/L standard deviation for the nine low-flow samples collected from January 2002 through March 2003. Thus, the recent increase in sulfate concentration is not simply due to the 2002 drought year because the data from 1977 did not show a substantial increase in sulfate concentration. Extended drought periods may play a role in Red River water quality, because the highest low-flow sulfate concentrations occurred at the end of the 2002 drought period (fig. 3; 256 mg/L in December 2002 and 198 mg/L in February 2003). A possible reason for the increase in sulfate during extended drought periods is that during these periods, the relative contribution of ground water to the flow of the Red River likely increases.

Additional historical water quality from Robertson GeoConsultants Inc. (2001b) also increases the number of paired sulfate values collected upstream and downstream from the Molycorp mine site. Figure 17 displays low-flow dissolved sulfate concentrations for the Red River through time for paired samples collected at the Questa Ranger Station gage and upstream from the mine site. This figure includes low-flow samples from Maest and others (2004), who combined results from five stations upstream from the mine site, and samples from Robertson GeoConsultants Inc. (2001b) collected at Questa Ranger Station gage and at the Red River adjacent to the Molycorp mill site. Although the mean sulfate concentration increases from 66 to 80 mg/L between these sites, the respective standard deviations of 28 and 39 mg/L preclude the conclusion that this increase is statistically significant. This data set can be separated into two time periods, 1975 to 1985 and 1992 to 2001. For the earlier time period, the mean sulfate concentration upstream from the mine site is 66 mg/L with a standard deviation of 28 mg/L and at the Questa Ranger Station gage is 77 mg/L with a standard deviation of 37 mg/L. For the second time period, the mean sulfate concentration upstream from the mine site is 95 mg/L with a standard deviation of 14 mg/L and at the Questa Ranger Station gage is 150 mg/L with a standard deviation of 30 mg/L. In the recent time period, the increase in sulfate concentration along the mine reach is statistically significant.

This conclusion is in agreement with a study by Allen and others (1999) who in 1997 and 1998 collected monthly water samples from six sites along the Red River including upstream from the town of Red River, at the confluence of Hottentot, upstream from the mine property, and downstream from the Questa Ranger Station gage. Allen and others (1999) concluded that sulfate and zinc loading not only increased in the reach between the town of Red River and the mine property because of drainage from the alteration scars, but also increased in the reach downstream from the mine waste-rock piles. Similarly, results from the USGS August 2001 tracer study documented a substantial increase in sulfate concentration and load from immediately upstream from the mine site to the Questa Ranger Station gage (McCleskey and others, 2003b; Kimball and others, in press).

Dissolved zinc concentrations (43 analyses) were not determined as frequently as sulfate concentrations, but the data span from 1978 to 2001 (Maest and others, 2004; fig. 18). The dissolved zinc concentrations in the 11 low-flow samples have a mean value of 0.11 mg/L and range from 0.005 to 0.35 mg/L (fig. 8). These values are similar to the mean and range for all the low-flow samples (mean of 0.11 mg/L; range of <0.003 to 0.34 mg/L) in the historical dataset. Unfortunately, with this limited zinc dataset it is not possible to make statistically rigorous conclusions as to the effect of drought on the Red River water quality.

The overall trends in chemistry related to seasonal variations observed in the limited 2000-2003 dataset are consistent with the observations of Maest and others (2004; figs. 15 and 16). For example, the lowest sulfate concentration (44.8 mg/L) occurred during peak flow from snowmelt in June 2003, and the highest sulfate concentration (314 mg/L) occurred during the September 2002 storm event.

Red River Storm Events, 2001-2003

Although the Red River exhibits low-flow conditions for much of the year, dynamic changes from spring runoff or summer storm events have a major effect on the water

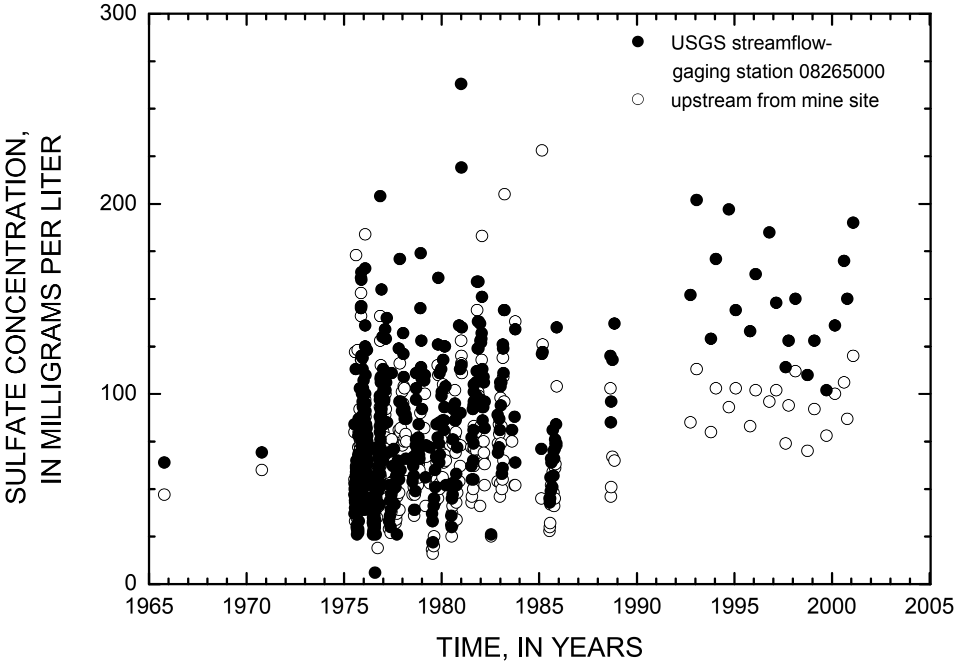


Figure 17. Sulfate concentration in the Red River upstream and downstream from the mine site during low-flow conditions. Historical data from Robertson GeoConsultants (2001b) and Maest and others (2004).

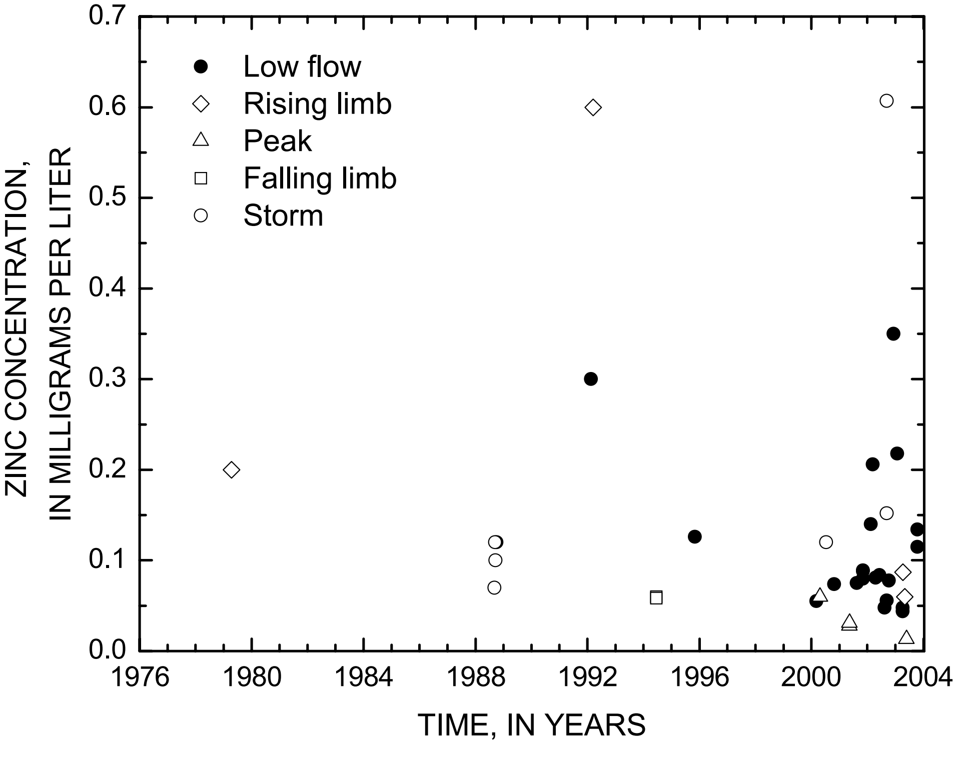


Figure 18. Zinc concentration of the Red River measured at the USGS streamflow-gaging 08265000 station at the Questa Ranger Station from 1976 through 2003, with hydrologic discrimination. Historical data from Maest and others (2004).

chemistry. During September 2002, a storm event which produced the peak discharge for the year (fig. 3) was sampled. Three water samples were collected at the Questa Ranger Station gage, the first sample on September 17, 6 hours before a rainstorm began, the second sample on September 18, shortly after the peak discharge and about 14 hours after the rainstorm began, and the third sample on September 19, during the falling limb of the hydrograph. Instantaneous discharge at the USGS Questa Ranger Station gage increased from 8 to 102 ft^3/s (fig. 19). During the storm, acid runoff from hydrothermally altered scars entered the Red River and caused it to become acidic and highly turbid (fig. 5 and cover photographs). From the first to the second sample, pH decreased from 7.80 to 4.83, alkalinity decreased from 49.4 to <1 mg/L, SO_4 increased from 162 to 314 mg/L, dissolved Fe increased from to 0.011 to 0.596 mg/L, dissolved Al increased from 0.189 to 2.88 mg/L, and dissolved Zn increased from 0.056 to 0.607 mg/L. The total recoverable concentrations of Fe and Al increased from the first to the second sample by nearly 2 and 1 orders of magnitude, respectively; the second sample contained predominantly particulate Fe (99 percent) and Al (85 percent). When the third sample was collected, the total recoverable concentrations of Fe and Al had decreased by about 7- and 4-fold from the second sample, and a much higher proportion of the Fe (42 percent) and Al (77 percent) was dissolved. The proportion of total dissolved Fe that was Fe(III), calculated by difference, decreased from 64 percent to 29 percent from the first to the second sample and increased to 90 percent when the third sample was collected.

To determine the source of the turbidity, the material trapped on the filter membranes was collected, dried, and analyzed by X-ray diffraction. The analytical methods are similar to

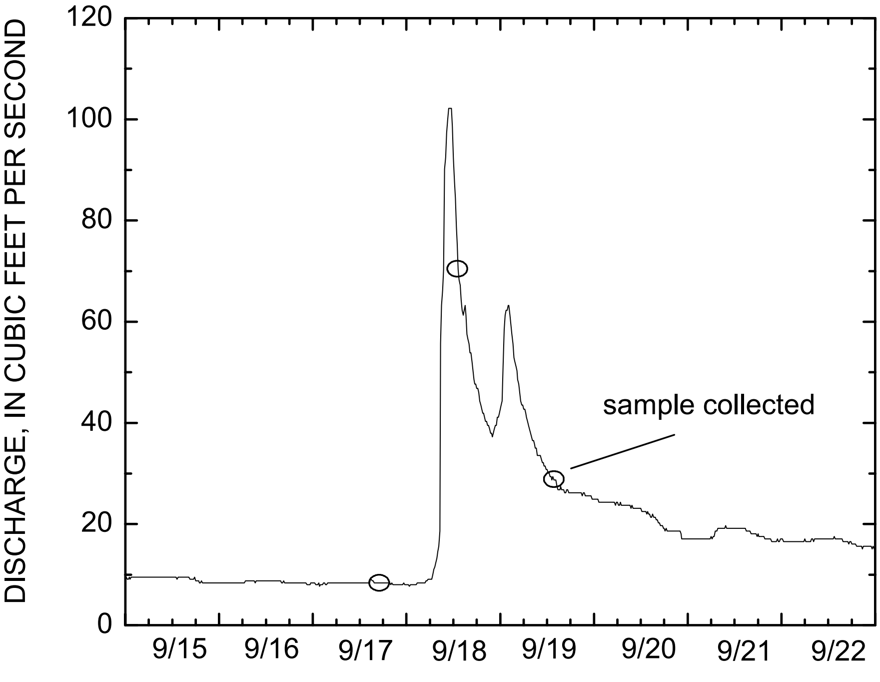


Figure 19. Instantaneous discharge of the Red River measured at USGS streamflow-gaging station 08265000 at the Questa Ranger Station from September 15 - 22, 2002.

those described in Ludington and others (2004). The material trapped on the filter from the Questa Ranger Station gage sample collected prior to the storm was pale yellow, relatively small in volume, and consisted of amorphous material, quartz, kaolinite, and mica. The trapped material from the two Questa Ranger Station gage samples collected during the storm was pale yellow and consisted of smectite, mica, kaolinite, quartz, chlorite, amorphous material, and jarosite. A water sample was collected from Straight Creek, an upstream tributary to the Red River that drains an alteration scar, during the storm (sample 02WA154 on September 18), and the material trapped on the filter was analyzed. This material was pale yellow and consisted of smectite, mica, kaolinite, quartz, chlorite, amorphous material, and jarosite, similar to the particulate material at the Questa Ranger Station gage. This mineralogy suggests that much of the turbidity in the lower Red River during the storm event is derived from runoff from the scar areas.

Two previous water-quality surveys of the Red River were performed during late summer thunderstorm events (Smolka and Tague, 1987, 1989). Both storm events were localized in individual subbasins and did not cover the entire watershed. The first thunderstorm event occurred on August 18, 1986, and the pH of the Red River, sampled at the Elephant Rock campground located between Straight and Hansen Creeks, decreased from 8.1 to 3.8 (Smolka and Tague, 1987). At this site, turbidity increased from 1.6 to greater than 500 NTU (turbidity units) resulting in large increases in total recoverable aluminum, arsenic barium, chromium, iron, lead, copper, manganese, and zinc concentrations. Dissolved sulfate concentration increased from 40 to 208 mg/L. The event lasted approximately one hour. No change in pH was observed at the USGS Questa Ranger Station stream gage. Furthermore, no change in the daily mean discharge, recorded at the USGS Questa Ranger Station gage, was observed. The second rainstorm event occurred on September 13, 1988, in the Bitter Creek basin. The pH value of Bitter Creek decreased from 7.6 to 5.7, and the pH of the Red River downstream from the confluence decreased from 7.7 to 6.4 (Smolka and Tague, 1989). At this Red River site, turbidity increased from 2 to 145 NTU. In another study, Garn (USGS, 2003) documented a pH drop from 7.4 to 3.8 for the Red River at the Questa Ranger Station gage for a storm event on September 7, 1986.

Red River Diel Variations, 2003

Diel samples were collected from the Red River during high-flow (May 2003) and low-flow (October 2003) conditions at two sites: the USGS gaging station near the Questa Ranger Station and another site just upstream from the mill at a pull-out where a dirt road crosses the river and above the influence of any mining activities at the Molycorp mine site (upsteam diel site on figure 1). Substantial diel cycles, 2-fold increases, in dissolved Cd, Mn, Ni, and Zn concentrations have been observed for neutral and alkaline streams draining historical mining areas in Montana and Idaho (Nimick and others, 2003).

During the high-flow diel study, samples were collected about every 2 hours beginning at approximately 12:00 noon on May 13 and ending at 12:00 noon on May 14 from the Red River at the Questa Ranger Station gage and at the site just upstream from the mill. Stream temperature, pH, and specific conductance were measured at the time of sample collection. A 500-mL grab sample was collected and processed within 30 minutes. The samples were syringe filtered through a 0.22-µm membrane. No anion samples were collected for this time period. The instantaneous streamflow, measured at the USGS gaging station, during the high-flow diel study ranged from 49 to 55 ft^3/s and increased throughout the sampling period. Results from the high-flow diel study are presented in table 6.

During the low-flow diel study, samples were collected every 1.5 hours beginning at approximately 17:30 on October 20 and ending at 17:30 on October 22 from the Red River at the Questa Ranger Station gage and at the site just upstream from the mill. At both sites, stream temperature, dissolved oxygen, pH, and specific conductance were measured every 20 minutes using a Hydrolab multiparameter instrument that was placed in the center of the river. The Hydrolab data are reported in table 7. Water samples were pumped from the stream using an automated sampler and stored in the dark and chilled until processed. Samples were filtered using a 0.1-µm filter membrane. During the low-flow diel study, streamflow was 15 ft^3/s and

Table 6. High-flow diel water analyses

[FA, filtered acidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed]

Sample Location and number Collection Date Collection Time	**Red River at USGS Gage 1 5/13/2003 12:00**	**Red River at USGS Gage 2 5/13/2003 14:00**	**Red River at USGS Gage 2 5/13/2003 14:00**	**Red River at USGS Gage 3 5/13/2003 16:00**	**Red River at USGS Gage 3 5/13/2003 16:00**	**Red River at USGS Gage 4 5/13/2003 18:15**
Treatment	FA	FA	RA	FA	RA	FA
pH	7.55	7.51	7.51	7.90	7.90	7.95
SC (µS/cm)	276	275	275	275	275	273
Temperature (°C)	8.3	8.2	8.2	8.5	8.5	8.4
Constituent, mg/L						
Ca	35.7	35.9	35.3	36.1	36.0	35.7
Mg	7.69	7.65	7.79	7.78	7.95	7.65
Na	4.77	4.75	4.77	4.85	4.77	4.73
K	0.841	0.835	0.918	0.840	0.942	0.871
SiO_2	11.1	11.1	12.2	11.3	12.9	11.1
Al	0.185	0.196	1.09	0.199	1.27	0.187
Fe(T)	0.002	0.003	0.462	0.003	0.756	0.003
Fe(II)	0.001	0.001	---	0.001	---	0.000
B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.003	0.003	0.004	0.003	0.004	0.003
Sr	0.216	0.214	0.217	0.217	0.217	0.216
Ba	0.031	0.031	0.039	0.031	0.047	0.032
Mn	0.154	0.153	0.171	0.154	0.185	0.147
Zn	0.044	0.045	0.086	0.041	0.097	0.039
Ni	0.007	0.007	0.013	0.007	0.014	0.005
Cu	0.004	<0.003	0.012	<0.003	0.014	<0.003
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 6. High-flow diel water analyses -- Continued

[FA, filtered acidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed]

Sample Location and number **Collection Date** **Collection Time**	**Red River at USGS Gage 4** **5/13/2003** **18:15**	**Red River at USGS Gage 5** **5/13/2003** **20:00**	**Red River at USGS Gage 5** **5/13/2003** **20:00**	**Red River at USGS Gage 6** **5/13/2003** **22:00**	**Red River at USGS Gage 6** **5/13/2003** **22:00**	**Red River at USGS Gage 7** **5/14/2003** **0:00**
Treatment	RA	FA	RA	FA	RA	FA
pH	7.95	7.82	7.82	7.96	7.96	7.92
SC (µS/cm)	273	273	273	273	273	272
Temperature (°C)	8.4	8.2	8.2	7.7	7.7	7.2
Constituent, mg/L						
Ca	35.2	35.6	34.7	35.2	34.7	35.3
Mg	7.74	7.65	7.61	7.57	7.75	7.46
Na	4.76	4.80	4.66	4.79	4.74	4.79
K	0.924	0.859	0.949	0.828	0.991	0.866
SiO_2	12.4	11.4	12.8	11.0	13.6	11.2
Al	1.04	0.191	1.32	0.182	1.67	0.151
Fe(T)	0.449	0.003	1.04	0.006	1.87	0.009
Fe(II)	---	0.001	---	0.002	---	0.003
B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.004	0.003	0.004	0.003	0.004	0.003
Sr	0.215	0.218	0.212	0.211	0.218	0.213
Ba	0.038	0.031	0.048	0.031	0.085	0.031
Mn	0.163	0.147	0.192	0.144	0.211	0.146
Zn	0.083	0.043	0.101	0.048	0.123	0.050
Ni	0.013	0.006	0.013	0.006	0.016	0.006
Cu	0.012	<0.003	0.015	<0.003	0.019	<0.003
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 6. High-flow diel water analyses -- Continued

[FA, filtered acidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed]

Sample Location and number Collection Date Collection Time	**Red River at USGS Gage 7 5/14/2003 0:00**	**Red River at USGS Gage 8 5/14/2003 2:00**	**Red River at USGS Gage 9 5/14/2003 4:00**	**Red River at USGS Gage 9 5/14/2003 4:00**	**Red River at USGS Gage 10 5/14/2003 6:05**	**Red River at USGS Gage 10 5/14/2003 6:05**
Treatment	RA	FA	FA	RA	FA	RA
pH	7.92	7.9	7.87	7.87	7.99	7.99
SC (µS/cm)	272	271	270	270	270	270
Temperature (°C)	7.2	6.8	6.2	6.2	5.3	5.3
Constituent, mg/L						
Ca	34.6	35.5	35.3	36.1	34.6	34.9
Mg	7.56	7.35	7.47	8.20	7.35	7.59
Na	4.72	4.84	4.67	4.94	4.69	4.69
K	0.955	0.840	0.832	1.15	0.818	0.913
SiO_2	12.7	11.2	11.2	15.3	10.9	12.3
Al	1.14	0.167	0.153	2.04	0.203	1.08
Fe(T)	0.746	0.031	0.007	2.79	0.009	0.523
Fe(II)	---	0.006	0.007	---	0.009	---
B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.004	0.003	0.003	0.004	0.003	0.004
Sr	0.208	0.214	0.211	0.228	0.208	0.212
Ba	0.042	0.031	0.031	0.125	0.031	0.040
Mn	0.176	0.149	0.147	0.240	0.144	0.166
Zn	0.100	0.047	0.051	0.150	0.051	0.089
Ni	0.013	0.007	0.007	0.019	0.006	0.013
Cu	0.013	<0.003	<0.003	0.022	<0.003	0.012
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 6. High-flow diel water analyses -- Continued

[FA, filtered acidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed]

Sample Location and number Collection Date Collection Time	**Red River at USGS Gage 11 5/14/2003 8:15**	**Red River at USGS Gage 11 5/14/2003 8:15**	**Red River at USGS Gage 12 5/14/2003 9:55**	**Red River at USGS Gage 12 5/14/2003 9:55**	**Red River at USGS Gage 13 5/14/2003 12:00**	**Red River at USGS Gage 13 5/14/2003 12:00**
Treatment	FA	RA	FA	RA	FA	RA
pH	7.88	7.88	7.88	7.88	7.94	7.94
SC (µS/cm)	270	270	268	268	266	266
Temperature (°C)	5.0	5.0	6.5	6.5	9.4	9.4
Constituent, mg/L						
Ca	35.2	36.1	34.6	35.2	34.5	34.7
Mg	7.54	8.54	7.43	7.94	7.24	7.60
Na	4.64	4.94	4.73	4.81	4.63	4.55
K	0.820	1.40	0.868	1.07	0.835	1.09
SiO_2	11.4	18.5	11.0	14.3	11.0	14.5
Al	0.211	4.78	0.224	1.73	0.246	1.91
Fe(T)	0.004	3.69	0.002	1.92	0.003	2.33
Fe(II)	0.001	---	0.000	---	0.000	---
B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.003	0.003	0.003	0.004	0.003	0.004
Sr	0.213	0.221	0.210	0.215	0.207	0.216
Ba	0.031	0.082	0.031	0.078	0.031	0.090
Mn	0.145	0.232	0.140	0.222	0.142	0.232
Zn	0.048	0.139	0.045	0.126	0.038	0.136
Ni	0.006	0.022	0.006	0.016	0.006	0.017
Cu	<0.003	0.084	<0.003	0.019	<0.003	0.024
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Be	<0.001	0.001	<0.001	<0.001	<0.001	<0.001

Table 6. High-flow diel water analyses -- Continued

[FA, filtered acidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed]

Sample Location and number Collection Date Collection Time	**Red River Above Mill 1 5/13/2003 12:15**	**Red River Above Mill 2 5/13/2003 14:10**	**Red River Above Mill 2 5/13/2003 14:10**	**Red River Above Mill 3 5/13/2003 16:10**	**Red River Above Mill 3 5/13/2003 16:10**	**Red River Above Mill 4 5/13/2003 18:25**
Treatment	FA	FA	RA	FA	RA	FA
pH	7.78	7.81	7.81	7.99	7.99	8.04
SC (µS/cm)	222	224	224	225	225	223
Temperature (°C)	8.3	8.4	8.4	8.3	8.3	7.7
Constituent, mg/L						
Ca	28.9	29.2	28.6	29.4	28.8	28.9
Mg	6.00	6.14	6.21	6.23	6.17	6.17
Na	4.42	4.27	4.24	4.44	4.33	4.43
K	0.781	0.757	0.822	0.773	0.826	0.805
SiO_2	11.6	11.6	12.0	11.7	11.8	11.7
Al	0.224	0.224	0.484	0.227	0.441	0.218
Fe(T)	0.007	0.010	0.285	0.029	0.217	0.010
Fe(II)	0.002	0.003	---	0.008	---	0.002
B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.003	0.003	0.003	0.003	0.003	0.003
Sr	0.181	0.178	0.179	0.182	0.179	0.182
Ba	0.033	0.032	0.036	0.032	0.034	0.032
Mn	0.071	0.071	0.086	0.073	0.084	0.074
Zn	0.008	0.007	0.025	0.010	0.025	0.008
Ni	<0.002	<0.002	0.005	<0.002	0.005	<0.002
Cu	<0.003	<0.003	0.008	<0.003	0.008	<0.003
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 6. High-flow diel water analyses -- Continued

[FA, filtered acidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed]

Sample Location and number Collection Date Collection Time	**Red River Above Mill 4 5/13/2003 18:25**	**Red River Above Mill 5 5/13/2003 20:12**	**Red River Above Mill 5 5/13/2003 20:12**	**Red River Above Mill 6 5/13/2003 22:10**	**Red River Above Mill 6 5/13/2003 22:10**	**Red River Above Mill 7 5/14/2003 0:11:00**
Treatment	RA	FA	RA	FA	RA	FA
pH	8.04	7.94	7.94	8.01	8.01	7.63
SC (µS/cm)	223	224	224	224	224	224
Temperature (°C)	7.7	7.2	7.2	6.9	6.9	6.5
Constituent, mg/L						
Ca	28.7	28.9	28.3	29.3	28.4	29.4
Mg	6.34	6.10	6.09	6.23	6.28	6.25
Na	4.39	4.47	4.24	4.54	4.38	4.59
K	0.898	0.783	0.837	0.813	0.872	0.803
SiO_2	13.1	11.5	12.0	11.6	12.9	11.5
Al	0.801	0.195	0.518	0.195	0.702	0.176
Fe(T)	1.08	0.029	0.386	0.013	0.795	0.022
Fe(II)	---	0.009	---	0.004	---	0.008
B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.004	0.003	0.003	0.003	0.004	0.003
Sr	0.177	0.179	0.176	0.183	0.181	0.183
Ba	0.053	0.032	0.037	0.033	0.051	0.033
Mn	0.117	0.074	0.093	0.075	0.110	0.074
Zn	0.041	0.008	0.028	0.012	0.041	0.013
Ni	0.006	<0.002	0.005	<0.002	0.006	<0.002
Cu	0.014	<0.003	0.008	<0.003	0.011	<0.003
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 6. High-flow diel water analyses -- Continued

[FA, filtered acidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed]

Sample Location and number Collection Date Collection Time	**Red River Above Mill 7 5/14/2003 0:11:00**	**Red River Above Mill 8 5/14/2003 2:10**	**Red River Above Mill 8 5/14/2003 2:10**	**Red River Above Mill 9 5/14/2003 4:15**	**Red River Above Mill 9 5/14/2003 4:15**	**Red River Above Mill 10 5/14/2003 6:20**
Treatment	RA	FA	RA	FA	RA	FA
pH	7.63	7.93	7.93	7.96	7.96	7.93
SC (µS/cm)	224	223	223	223	223	222
Temperature (°C)	6.5	5.9	5.9	5.2	5.2	4.5
Constituent, mg/L						
Ca	28.8	28.9	29.9	28.9	30.4	28.8
Mg	6.12	6.14	6.35	6.06	6.54	6.05
Na	4.36	4.22	4.55	4.22	4.60	4.14
K	0.822	0.766	0.942	0.758	1.02	0.740
SiO_2	12.2	11.4	13.1	11.3	13.6	11.2
Al	0.472	0.189	0.668	0.181	0.804	0.146
Fe(T)	0.256	0.517	0.810	0.015	1.11	0.021
Fe(II)	---	0.023	---	0.005	---	0.006
B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.003	0.003	0.004	0.003	0.004	0.003
Sr	0.180	0.178	0.192	0.181	0.195	0.178
Ba	0.036	0.032	0.052	0.033	0.052	0.032
Mn	0.089	0.074	0.114	0.074	0.125	0.072
Zn	0.028	0.012	0.049	0.012	0.045	0.012
Ni	0.005	<0.002	0.008	<0.002	0.008	<0.002
Cu	0.009	<0.003	0.013	<0.003	0.014	<0.003
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 6. High-flow diel water analyses -- Continued

[FA, filtered acidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed]

Sample Location and number Collection Date Collection Time	**Red River Above Mill 10 5/14/2003 6:20**	**Red River Above Mill 11 5/14/2003 8:25**	**Red River Above Mill 11 5/14/2003 8:25**	**Red River Above Mill 12 5/14/2003 10:05**	**Red River Above Mill 12 5/14/2003 10:05**	**Red River Above Mill 13 5/14/2003 12:10**
Treatment	RA	FA	RA	FA	RA	FA
pH	7.93	7.98	7.98	8.02	8.02	8.1
SC (µS/cm)	222	220	220	220	220	220
Temperature (°C)	4.5	4.5	4.5	6.2	6.2	9.5
Constituent, mg/L						
Ca	29.6	28.4	29.5	28.8	29.7	29.5
Mg	6.27	6.01	6.35	6.04	6.34	6.34
Na	4.37	4.24	4.43	4.24	4.44	4.49
K	0.894	0.758	1.59	0.821	7.26	0.945
SiO_2	12.8	11.6	13.5	11.3	13.3	13.8
Al	0.559	0.172	0.802	0.175	0.807	0.873
Fe(T)	0.435	0.009	1.04	0.041	1.14	0.006
Fe(II)	---	0.002	---	0.040	---	0.003
B	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Li	0.003	0.003	0.004	0.003	0.004	0.005
Sr	0.189	0.174	0.185	0.178	0.189	0.184
Ba	0.040	0.032	0.055	0.032	0.057	0.045
Mn	0.101	0.081	0.121	0.078	0.130	0.090
Zn	0.032	0.018	0.047	0.017	0.089	0.025
Ni	0.008	0.005	0.021	0.005	0.011	0.008
Cu	0.010	0.007	0.016	0.006	0.019	0.075
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 6. High-flow diel water analyses -- Continued

[FA, filtered acidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed]

Sample Location and number	**Red River Above Mill 13**
Collection Date	**5/14/2003**
Collection Time	**12:10**
Treatment	RA
pH	8.1
SC (µS/cm)	220
Temperature (°C)	9.5
Constituent, mg/L	
Ca	29.6
Mg	6.35
Na	4.36
K	1.40
SiO_2	13.3
Al	0.836
Fe(T)	1.13
Fe(II)	---
B	<0.01
Li	0.004
Sr	0.187
Ba	0.054
Mn	0.123
Zn	0.043
Ni	0.007
Cu	0.015
Cd	<0.001
Co	<0.007
Be	<0.001

Table 7. Low-flow diel study field measurements

[°C, degrees Celsius; DO, dissolved oxygen; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; SC, specific conductance; %, percent]

Sample Site	Date	Time	pH	Temperature (°C)	DO (% saturation)	DO (mg/L)	SC (µS/cm)
Red River at Gage	10/20/2003	16:00	7.71	8.52	114	9.84	359
Red River at Gage	10/20/2003	16:20	7.74	8.37	114	9.84	359
Red River at Gage	10/20/2003	16:40	7.76	8.21	114	9.87	359
Red River at Gage	10/20/2003	17:00	7.78	8.13	113	9.80	359
Red River at Gage	10/20/2003	17:20	7.79	8.08	112	9.72	359
Red River at Gage	10/20/2003	17:40	7.80	8.06	112	9.74	359
Red River at Gage	10/20/2003	18:00	7.82	8.02	112	9.76	360
Red River at Gage	10/20/2003	18:20	7.81	7.99	111	9.68	360
Red River at Gage	10/20/2003	18:40	7.82	7.95	111	9.68	360
Red River at Gage	10/20/2003	19:00	7.82	7.90	112	9.75	360
Red River at Gage	10/20/2003	19:20	7.83	7.85	111	9.71	360
Red River at Gage	10/20/2003	19:40	7.83	7.78	112	9.77	361
Red River at Gage	10/20/2003	20:00	7.84	7.71	111	9.73	361
Red River at Gage	10/20/2003	20:20	7.83	7.63	111	9.74	361
Red River at Gage	10/20/2003	20:40	7.83	7.55	112	9.90	362
Red River at Gage	10/20/2003	21:00	7.83	7.45	112	9.89	363
Red River at Gage	10/20/2003	21:20	7.83	7.35	112	9.94	362
Red River at Gage	10/20/2003	21:40	7.83	7.26	112	9.93	363
Red River at Gage	10/20/2003	22:00	7.83	7.16	112	9.96	362
Red River at Gage	10/20/2003	22:20	7.83	7.07	112	9.96	363
Red River at Gage	10/20/2003	22:40	7.83	6.97	113	10.11	363
Red River at Gage	10/20/2003	23:00	7.82	6.88	112	10.05	363
Red River at Gage	10/20/2003	23:20	7.82	6.78	112	10.08	363
Red River at Gage	10/20/2003	23:40	7.82	6.68	114	10.22	363
Red River at Gage	10/21/2003	0:00	7.82	6.57	113	10.18	364
Red River at Gage	10/21/2003	0:20	7.82	6.48	113	10.20	364
Red River at Gage	10/21/2003	0:40	7.82	6.37	113	10.20	363
Red River at Gage	10/21/2003	1:00	7.82	6.26	112	10.22	363
Red River at Gage	10/21/2003	1:20	7.82	6.16	113	10.27	364
Red River at Gage	10/21/2003	1:40	7.82	6.06	114	10.41	364
Red River at Gage	10/21/2003	2:00	7.82	5.97	113	10.35	364
Red River at Gage	10/21/2003	2:20	7.82	5.88	113	10.35	364
Red River at Gage	10/21/2003	2:40	7.82	5.80	114	10.49	364
Red River at Gage	10/21/2003	3:00	7.82	5.71	114	10.51	364
Red River at Gage	10/21/2003	3:20	7.82	5.63	114	10.53	364
Red River at Gage	10/21/2003	3:40	7.82	5.55	113	10.48	363
Red River at Gage	10/21/2003	4:00	7.82	5.46	113	10.51	364
Red River at Gage	10/21/2003	4:20	7.81	5.37	114	10.64	364
Red River at Gage	10/21/2003	4:40	7.81	5.27	115	10.70	363
Red River at Gage	10/21/2003	5:00	7.84	5.19	114	10.65	363
Red River at Gage	10/21/2003	5:20	7.87	5.11	114	10.68	363
Red River at Gage	10/21/2003	5:40	7.78	5.02	115	10.79	364
Red River at Gage	10/21/2003	6:00	7.88	4.94	114	10.71	364
Red River at Gage	10/21/2003	6:20	7.71	4.86	114	10.77	363
Red River at Gage	10/21/2003	6:40	7.88	4.78	115	10.86	363
Red River at Gage	10/21/2003	7:00	7.74	4.72	116	10.93	362
Red River at Gage	10/21/2003	7:20	7.86	4.64	115	10.87	362
Red River at Gage	10/21/2003	7:40	7.82	4.56	115	10.94	362
Red River at Gage	10/21/2003	8:00	7.79	4.50	116	10.99	362
Red River at Gage	10/21/2003	8:20	7.81	4.46	116	11.03	362
Red River at Gage	10/21/2003	8:40	7.78	4.46	115	10.96	362
Red River at Gage	10/21/2003	9:00	7.87	4.52	116	11.07	362
Red River at Gage	10/21/2003	9:20	7.80	4.64	116	10.97	362
Red River at Gage	10/21/2003	9:40	7.84	4.78	115	10.83	362
Red River at Gage	10/21/2003	10:00	7.85	4.99	115	10.82	363
Red River at Gage	10/21/2003	10:20	7.81	5.31	115	10.75	364
Red River at Gage	10/21/2003	10:40	7.81	5.69	115	10.58	364
Red River at Gage	10/21/2003	11:00	7.82	6.07	113	10.35	365
Red River at Gage	10/21/2003	11:20	7.82	6.48	114	10.29	365
Red River at Gage	10/21/2003	11:40	7.83	6.91	112	10.01	365

Table 7. Low-flow diel study field measurements -- Continued

[°C, degrees Celsius; DO, dissolved oxygen; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; SC, specific conductance; %, percent]

Sample Site	Date	Time	pH	Temperature (°C)	DO (% saturation)	DO (mg/L)	SC (µS/cm)
Red River at Gage	10/21/2003	12:00	7.83	7.34	113	9.97	365
Red River at Gage	10/21/2003	12:20	7.83	7.75	112	9.78	366
Red River at Gage	10/21/2003	12:40	7.83	8.14	111	9.61	366
Red River at Gage	10/21/2003	13:00	7.84	8.48	111	9.56	366
Red River at Gage	10/21/2003	13:20	7.84	8.74	110	9.41	366
Red River at Gage	10/21/2003	13:40	7.83	8.91	111	9.44	366
Red River at Gage	10/21/2003	14:00	7.84	9.02	110	9.32	367
Red River at Gage	10/21/2003	14:20	7.84	9.05	110	9.36	367
Red River at Gage	10/21/2003	14:40	7.84	8.98	111	9.45	366
Red River at Gage	10/21/2003	15:00	7.85	8.90	111	9.46	366
Red River at Gage	10/21/2003	15:20	7.84	8.75	110	9.44	366
Red River at Gage	10/21/2003	15:40	7.84	8.57	111	9.50	365
Red River at Gage	10/21/2003	16:00	7.83	8.41	110	9.50	366
Red River at Gage	10/21/2003	16:20	7.83	8.24	110	9.55	366
Red River at Gage	10/21/2003	16:40	7.82	8.10	111	9.64	366
Red River at Gage	10/21/2003	17:00	7.81	8.06	111	9.67	366
Red River at Gage	10/21/2003	17:20	7.81	8.04	110	9.59	366
Red River at Gage	10/21/2003	17:40	7.81	8.02	110	9.58	367
Red River at Gage	10/21/2003	18:00	7.81	8.00	111	9.67	367
Red River at Gage	10/21/2003	18:20	7.81	7.99	111	9.65	367
Red River at Gage	10/21/2003	18:40	7.81	7.96	111	9.63	368
Red River at Gage	10/21/2003	19:00	7.81	7.94	111	9.64	368
Red River at Gage	10/21/2003	19:20	7.82	7.91	111	9.68	369
Red River at Gage	10/21/2003	19:40	7.82	7.86	111	9.69	369
Red River at Gage	10/21/2003	20:00	7.82	7.81	111	9.71	369
Red River at Gage	10/21/2003	20:20	7.82	7.74	110	9.68	369
Red River at Gage	10/21/2003	20:40	7.82	7.65	110	9.66	369
Red River at Gage	10/21/2003	21:00	7.82	7.55	111	9.78	369
Red River at Gage	10/21/2003	21:20	7.82	7.44	111	9.83	370
Red River at Gage	10/21/2003	21:40	7.81	7.34	110	9.74	370
Red River at Gage	10/21/2003	22:00	7.81	7.24	110	9.80	371
Red River at Gage	10/21/2003	22:20	7.81	7.14	111	9.90	370
Red River at Gage	10/21/2003	22:40	7.81	7.06	111	9.93	371
Red River at Gage	10/21/2003	23:00	7.81	6.98	112	9.98	370
Red River at Gage	10/21/2003	23:20	7.81	6.89	111	9.95	370
Red River at Gage	10/21/2003	23:40	7.81	6.79	111	9.96	371
Red River at Gage	10/22/2003	0:00	7.81	6.69	111	9.95	371
Red River at Gage	10/22/2003	0:20	7.81	6.60	112	10.11	371
Red River at Gage	10/22/2003	0:40	7.81	6.51	111	10.07	371
Red River at Gage	10/22/2003	1:00	7.80	6.43	111	10.05	371
Red River at Gage	10/22/2003	1:20	7.81	6.35	111	10.07	371
Red River at Gage	10/22/2003	1:40	7.81	6.26	111	10.13	371
Red River at Gage	10/22/2003	2:00	7.80	6.19	112	10.16	371
Red River at Gage	10/22/2003	2:20	7.81	6.12	112	10.24	371
Red River at Gage	10/22/2003	2:40	7.80	6.06	111	10.15	372
Red River at Gage	10/22/2003	3:00	7.80	5.98	112	10.23	372
Red River at Gage	10/22/2003	3:20	7.80	5.93	111	10.21	372
Red River at Gage	10/22/2003	3:40	7.80	5.86	112	10.26	372
Red River at Gage	10/22/2003	4:00	7.80	5.79	111	10.25	372
Red River at Gage	10/22/2003	4:20	7.80	5.72	113	10.42	372
Red River at Gage	10/22/2003	4:40	7.80	5.66	112	10.33	372
Red River at Gage	10/22/2003	5:00	7.80	5.58	113	10.42	372
Red River at Gage	10/22/2003	5:20	7.79	5.51	113	10.50	372
Red River at Gage	10/22/2003	5:40	7.81	5.45	112	10.40	372
Red River at Gage	10/22/2003	6:00	7.83	5.37	112	10.45	371
Red River at Gage	10/22/2003	6:20	7.86	5.30	113	10.51	372
Red River at Gage	10/22/2003	6:40	7.72	5.22	114	10.61	371
Red River at Gage	10/22/2003	7:00	7.79	5.15	113	10.60	371
Red River at Gage	10/22/2003	7:20	7.90	5.08	114	10.72	371
Red River at Gage	10/22/2003	7:40	7.80	5.02	115	10.75	371

Table 7. Low-flow diel study field measurements -- Continued

[°C, degrees Celsius; DO, dissolved oxygen; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; SC, specific conductance; %, percent]

Sample Site	Date	Time	pH	Temperature (°C)	DO (% saturation)	DO (mg/L)	SC (µS/cm)
Red River at Gage	10/22/2003	8:00	7.90	4.97	114	10.75	370
Red River at Gage	10/22/2003	8:20	7.89	4.94	113	10.66	370
Red River at Gage	10/22/2003	8:40	7.70	4.95	114	10.70	370
Red River at Gage	10/22/2003	9:00	7.85	4.98	115	10.80	370
Red River at Gage	10/22/2003	9:20	7.75	5.07	114	10.69	370
Red River at Gage	10/22/2003	9:40	7.80	5.21	114	10.67	370
Red River at Gage	10/22/2003	10:00	7.80	5.40	115	10.64	370
Red River at Gage	10/22/2003	10:20	7.80	5.71	114	10.47	370
Red River at Gage	10/22/2003	10:40	7.80	6.09	113	10.30	370
Red River at Gage	10/22/2003	11:00	7.81	6.46	113	10.23	370
Red River at Gage	10/22/2003	11:20	7.81	6.86	113	10.09	370
Red River at Gage	10/22/2003	11:40	7.82	7.29	112	9.92	370
Red River at Gage	10/22/2003	12:00	7.82	7.73	110	9.67	370
Red River at Gage	10/22/2003	12:20	7.82	8.15	111	9.60	370
Red River at Gage	10/22/2003	12:40	7.83	8.55	110	9.43	370
Red River at Gage	10/22/2003	13:00	7.83	8.88	110	9.36	370
Red River at Gage	10/22/2003	13:20	7.83	9.14	109	9.26	370
Red River at Gage	10/22/2003	13:40	7.83	9.31	108	9.14	370
Red River at Gage	10/22/2003	14:00	7.83	9.43	109	9.17	370
Red River at Gage	10/22/2003	14:20	7.83	9.45	109	9.18	370
Red River at Gage	10/22/2003	14:40	7.83	9.38	109	9.19	370
Red River at Gage	10/22/2003	15:00	7.83	9.29	108	9.11	370
Red River at Gage	10/22/2003	15:20	7.82	9.13	108	9.15	370
Red River at Gage	10/22/2003	15:40	7.82	8.94	108	9.20	370
Red River at Gage	10/22/2003	16:00	7.81	8.76	108	9.25	370
Red River at Gage	10/22/2003	16:20	7.81	8.59	109	9.39	370
Red River at Gage	10/22/2003	16:40	7.81	8.44	108	9.33	370
Red River at Gage	10/22/2003	17:00	7.81	8.38	109	9.37	370
Red River at Gage	10/22/2003	17:20	7.81	8.33	109	9.41	370
Red River at Gage	10/22/2003	17:40	7.81	8.31	109	9.38	370
Red River at Gage	10/22/2003	18:00	7.81	8.29	108	9.36	371
Red River above Mill	10/20/2003	16:40	8.25	9.16	110	9.35	239
Red River above Mill	10/20/2003	17:00	8.27	9.17	110	9.30	239
Red River above Mill	10/20/2003	17:20	8.25	9.14	109	9.26	239
Red River above Mill	10/20/2003	17:40	8.23	9.08	109	9.26	240
Red River above Mill	10/20/2003	18:00	8.21	9.00	109	9.30	240
Red River above Mill	10/20/2003	18:20	8.20	8.91	108	9.23	239
Red River above Mill	10/20/2003	18:40	8.18	8.80	107	9.28	240
Red River above Mill	10/20/2003	19:00	8.17	8.69	109	9.32	240
Red River above Mill	10/20/2003	19:20	8.16	8.58	109	9.39	241
Red River above Mill	10/20/2003	19:40	8.16	8.44	109	9.41	240
Red River above Mill	10/20/2003	20:00	8.16	8.30	110	9.49	241
Red River above Mill	10/20/2003	20:20	8.16	8.17	110	9.55	241
Red River above Mill	10/20/2003	20:40	8.16	8.03	110	9.62	241
Red River above Mill	10/20/2003	21:00	8.16	7.91	108	9.65	240
Red River above Mill	10/20/2003	21:20	8.16	7.79	111	9.68	240
Red River above Mill	10/20/2003	21:40	8.16	7.69	111	9.70	241
Red River above Mill	10/20/2003	22:00	8.16	7.58	111	9.73	241
Red River above Mill	10/20/2003	22:20	8.16	7.47	111	9.80	241
Red River above Mill	10/20/2003	22:40	8.16	7.33	111	9.87	241
Red River above Mill	10/20/2003	23:00	8.16	7.22	112	9.91	241
Red River above Mill	10/20/2003	23:20	8.15	7.09	112	9.96	241
Red River above Mill	10/20/2003	23:40	8.16	6.98	111	9.95	240
Red River above Mill	10/21/2003	0:00	8.15	6.82	113	10.11	241
Red River above Mill	10/21/2003	0:20	8.15	6.69	113	10.16	241
Red River above Mill	10/21/2003	0:40	8.15	6.54	113	10.21	240
Red River above Mill	10/21/2003	1:00	8.15	6.41	113	10.28	240
Red River above Mill	10/21/2003	1:20	8.15	6.27	114	10.35	241
Red River above Mill	10/21/2003	1:40	8.15	6.14	114	10.42	241
Red River above Mill	10/21/2003	2:00	8.15	6.02	115	10.52	241

Table 7. Low-flow diel study field measurements -- Continued

[°C, degrees Celsius; DO, dissolved oxygen; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; SC, specific conductance; %, percent]

Sample Site	Date	Time	pH	Temperature (°C)	DO (% saturation)	DO (mg/L)	SC (µS/cm)
Red River above Mill	10/21/2003	2:20	8.15	5.89	115	10.56	241
Red River above Mill	10/21/2003	2:40	8.15	5.78	112	10.62	241
Red River above Mill	10/21/2003	3:00	8.15	5.67	116	10.67	241
Red River above Mill	10/21/2003	3:20	8.14	5.54	116	10.75	240
Red River above Mill	10/21/2003	3:40	8.15	5.43	116	10.80	240
Red River above Mill	10/21/2003	4:00	8.15	5.32	116	10.84	240
Red River above Mill	10/21/2003	4:20	8.15	5.20	116	10.89	240
Red River above Mill	10/21/2003	4:40	8.15	5.09	117	10.95	240
Red River above Mill	10/21/2003	5:00	8.15	4.97	116	10.89	238
Red River above Mill	10/21/2003	5:20	8.15	4.88	117	11.07	239
Red River above Mill	10/21/2003	5:40	8.15	4.76	118	11.15	239
Red River above Mill	10/21/2003	6:00	8.15	4.68	118	11.19	239
Red River above Mill	10/21/2003	6:20	8.15	4.58	118	11.25	239
Red River above Mill	10/21/2003	6:40	8.15	4.49	116	11.32	239
Red River above Mill	10/21/2003	7:00	8.15	4.40	119	11.37	239
Red River above Mill	10/21/2003	7:20	8.15	4.32	119	11.42	239
Red River above Mill	10/21/2003	7:40	8.16	4.24	120	11.50	239
Red River above Mill	10/21/2003	8:00	8.17	4.18	121	11.58	239
Red River above Mill	10/21/2003	8:20	8.18	4.13	121	11.65	239
Red River above Mill	10/21/2003	8:40	8.18	4.08	121	11.69	239
Red River above Mill	10/21/2003	9:00	8.19	4.06	122	11.72	239
Red River above Mill	10/21/2003	9:20	8.20	4.08	122	11.73	238
Red River above Mill	10/21/2003	9:40	8.21	4.19	122	11.75	238
Red River above Mill	10/21/2003	10:00	8.23	4.31	123	11.72	238
Red River above Mill	10/21/2003	10:20	8.23	4.45	122	11.65	238
Red River above Mill	10/21/2003	10:40	8.24	4.64	122	11.56	238
Red River above Mill	10/21/2003	11:00	8.25	4.91	122	11.45	239
Red River above Mill	10/21/2003	11:20	8.25	5.20	121	11.27	238
Red River above Mill	10/21/2003	11:40	8.26	5.57	120	11.11	238
Red River above Mill	10/21/2003	12:00	8.27	5.94	119	10.94	239
Red River above Mill	10/21/2003	12:20	8.28	6.35	118	10.75	239
Red River above Mill	10/21/2003	12:40	8.28	6.76	118	10.56	239
Red River above Mill	10/21/2003	13:00	8.29	7.14	117	10.41	240
Red River above Mill	10/21/2003	13:20	8.30	7.51	116	10.23	239
Red River above Mill	10/21/2003	13:40	8.30	7.86	115	10.06	239
Red River above Mill	10/21/2003	14:00	8.31	8.23	114	9.92	239
Red River above Mill	10/21/2003	14:20	8.31	8.56	114	9.78	239
Red River above Mill	10/21/2003	14:40	8.32	8.83	114	9.71	239
Red River above Mill	10/21/2003	15:00	8.32	9.04	113	9.60	239
Red River above Mill	10/21/2003	15:20	8.32	9.18	112	9.52	240
Red River above Mill	10/21/2003	15:40	8.32	9.29	112	9.46	242
Red River above Mill	10/21/2003	16:00	8.31	9.34	111	9.40	240
Red River above Mill	10/21/2003	16:20	8.30	9.32	111	9.36	240
Red River above Mill	10/21/2003	16:40	8.28	9.30	110	9.31	240
Red River above Mill	10/21/2003	17:00	8.26	9.29	110	9.28	240
Red River above Mill	10/21/2003	17:20	8.24	9.25	109	9.24	241
Red River above Mill	10/21/2003	17:40	8.22	9.19	109	9.22	241
Red River above Mill	10/21/2003	18:00	8.20	9.08	109	9.26	241
Red River above Mill	10/21/2003	18:20	8.18	8.96	107	9.27	241
Red River above Mill	10/21/2003	18:40	8.16	8.86	109	9.27	241
Red River above Mill	10/21/2003	19:00	8.15	8.75	109	9.32	241
Red River above Mill	10/21/2003	19:20	8.15	8.65	109	9.35	242
Red River above Mill	10/21/2003	19:40	8.15	8.52	109	9.37	242
Red River above Mill	10/21/2003	20:00	8.15	8.40	109	9.41	242
Red River above Mill	10/21/2003	20:20	8.15	8.26	109	9.47	242
Red River above Mill	10/21/2003	20:40	8.15	8.14	110	9.52	243
Red River above Mill	10/21/2003	21:00	8.15	8.03	110	9.56	242
Red River above Mill	10/21/2003	21:20	8.15	7.93	110	9.62	243
Red River above Mill	10/21/2003	21:40	8.15	7.82	110	9.65	243
Red River above Mill	10/21/2003	22:00	8.15	7.72	111	9.70	243

Table 7. Low-flow diel study field measurements -- Continued

[°C, degrees Celsius; DO, dissolved oxygen; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; SC, specific conductance; %, percent]

Sample Site	Date	Time	pH	Temperature (°C)	DO (% saturation)	DO (mg/L)	SC (µS/cm)
Red River above Mill	10/21/2003	22:20	8.15	7.61	111	9.77	243
Red River above Mill	10/21/2003	22:40	8.15	7.51	111	9.80	243
Red River above Mill	10/21/2003	23:00	8.15	7.38	111	9.86	243
Red River above Mill	10/21/2003	23:20	8.14	7.23	112	9.92	243
Red River above Mill	10/21/2003	23:40	8.14	7.09	112	10.00	243
Red River above Mill	10/22/2003	0:00	8.14	6.94	112	10.04	243
Red River above Mill	10/22/2003	0:20	8.14	6.81	112	10.09	243
Red River above Mill	10/22/2003	0:40	8.14	6.70	112	10.10	243
Red River above Mill	10/22/2003	1:00	8.14	6.57	112	10.11	242
Red River above Mill	10/22/2003	1:20	8.14	6.45	113	10.20	242
Red River above Mill	10/22/2003	1:40	8.14	6.34	113	10.29	242
Red River above Mill	10/22/2003	2:00	8.14	6.24	114	10.33	242
Red River above Mill	10/22/2003	2:20	8.14	6.14	114	10.39	242
Red River above Mill	10/22/2003	2:40	8.14	6.03	114	10.45	242
Red River above Mill	10/22/2003	3:00	8.14	5.94	114	10.48	242
Red River above Mill	10/22/2003	3:20	8.14	5.85	114	10.49	241
Red River above Mill	10/22/2003	3:40	8.14	5.76	115	10.57	241
Red River above Mill	10/22/2003	4:00	8.14	5.67	115	10.63	241
Red River above Mill	10/22/2003	4:20	8.14	5.56	115	10.69	241
Red River above Mill	10/22/2003	4:40	8.14	5.49	115	10.69	241
Red River above Mill	10/22/2003	5:00	8.14	5.40	117	10.83	241
Red River above Mill	10/22/2003	5:20	8.14	5.32	117	10.87	241
Red River above Mill	10/22/2003	5:40	8.14	5.24	117	10.91	241
Red River above Mill	10/22/2003	6:00	8.14	5.15	117	10.96	241
Red River above Mill	10/22/2003	6:20	8.14	5.06	117	11.01	241
Red River above Mill	10/22/2003	6:40	8.14	4.98	117	11.04	241
Red River above Mill	10/22/2003	7:00	8.14	4.91	118	11.11	241
Red River above Mill	10/22/2003	7:20	8.14	4.82	118	11.15	241
Red River above Mill	10/22/2003	7:40	8.15	4.76	119	11.20	240
Red River above Mill	10/22/2003	8:00	8.16	4.70	119	11.27	240
Red River above Mill	10/22/2003	8:20	8.17	4.65	119	11.32	240
Red River above Mill	10/22/2003	8:40	8.18	4.60	120	11.38	240
Red River above Mill	10/22/2003	9:00	8.18	4.57	120	11.40	240
Red River above Mill	10/22/2003	9:20	8.19	4.57	121	11.46	240
Red River above Mill	10/22/2003	9:40	8.21	4.67	121	11.47	240
Red River above Mill	10/22/2003	10:00	8.22	4.77	121	11.42	240
Red River above Mill	10/22/2003	10:20	8.23	4.90	121	11.37	240
Red River above Mill	10/22/2003	10:40	8.24	5.08	121	11.31	240
Red River above Mill	10/22/2003	11:00	8.25	5.34	120	11.19	240
Red River above Mill	10/22/2003	11:20	8.25	5.63	119	11.03	240
Red River above Mill	10/22/2003	11:40	8.26	6.01	119	10.87	240
Red River above Mill	10/22/2003	12:00	8.27	6.37	118	10.71	240
Red River above Mill	10/22/2003	12:20	8.28	6.78	117	10.49	240
Red River above Mill	10/22/2003	12:40	8.29	7.19	116	10.31	240
Red River above Mill	10/22/2003	13:00	8.30	7.56	116	10.18	240
Red River above Mill	10/22/2003	13:20	8.31	7.92	115	10.02	240
Red River above Mill	10/22/2003	13:40	8.31	8.26	114	9.86	240
Red River above Mill	10/22/2003	14:00	8.32	8.61	113	9.71	241
Red River above Mill	10/22/2003	14:20	8.33	8.93	113	9.59	240
Red River above Mill	10/22/2003	14:40	8.33	9.20	112	9.48	241
Red River above Mill	10/22/2003	15:00	8.33	9.38	111	9.38	241
Red River above Mill	10/22/2003	15:20	8.33	9.52	111	9.31	241
Red River above Mill	10/22/2003	15:40	8.33	9.60	110	9.25	240
Red River above Mill	10/22/2003	16:00	8.32	9.64	110	9.19	240
Red River above Mill	10/22/2003	16:20	8.31	9.61	109	9.15	240
Red River above Mill	10/22/2003	16:40	8.28	9.57	109	9.10	241
Red River above Mill	10/22/2003	17:00	8.26	9.56	108	9.07	241
Red River above Mill	10/22/2003	17:20	8.24	9.53	108	9.04	242

Table 8. Low-flow diel water analyses

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; ^{o}C, degrees Celsius; µS/cm, microsiemens per centimeter; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River at USGS Gage 1**	**Red River at USGS Gage 1**	**Red River at USGS Gage 2**	**Red River at USGS Gage 2**	**Red River at USGS Gage 3**	**Red River at USGS Gage 3**
Collection Date	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**
Collection Time	**0:00**	**17:30**	**19:00**	**19:00**	**20:30**	**20:30**
Filtration Date	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.73	7.73	7.80	7.80	7.78	7.78
SC (µS/cm)	365	365	365	365	367	367
Constituent, mg/L						
Ca	52.7	---	48.2	---	48.1	---
Mg	11.7	---	11.1	---	11.2	---
Na	5.72	---	5.25	---	5.26	---
K	1.20	---	0.99	---	1.09	---
Li	0.005	---	0.005	---	0.005	---
SO_4	125	---	125	---	127	---
Alkalinity as HCO_3^-	60.1	---	61.6	---	62.4	---
F	0.87	---	0.89	---	0.86	---
Cl	4.15	---	3.42	---	3.22	---
NO_3	0.28	---	0.27	---	0.27	---
Sr	0.296	0.327	0.259	0.328	0.273	0.304
Ba	0.037	0.042	0.032	0.043	0.034	0.040
SiO_2	12.4	15.3	12.4	17.1	12.6	14.7
Al	0.060	1.69	0.105	1.93	0.122	1.72
Fe	<0.007	0.253	<0.007	0.321	<0.007	0.284
Mn	0.290	0.323	0.258	0.362	0.285	0.316
Cu	<0.003	0.017	<0.003	0.019	<0.003	0.018
Zn	0.087	0.173	0.100	0.167	0.089	0.140
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	0.002	0.004	<0.002	0.003	<0.002	<0.002
Co	<0.005	<0.005	<0.005	0.005	<0.005	<0.005
Ni	0.018	0.023	0.018	0.023	0.016	0.024
Pb	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	0.001	<0.001	0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.56	---	3.27	---	3.27	---
Sum anions (meq/L)	3.41	---	3.45	---	3.48	---
Charge imbalance (percent)	4.3	---	-5.3	---	-6.0	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microssiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location **Collection Date** **Collection Time** **Filtration Date**	**Red River at USGS Gage 4** **10/20/2003** **22:00** **10/21/2003**	**Red River at USGS Gage 4** **10/20/2003** **22:00** **10/21/2003**	**Red River at USGS Gage 5** **10/20/2003** **23:30** **10/21/2003**	**Red River at USGS Gage 5** **10/20/2003** **23:30** **10/21/2003**	**Red River at USGS Gage 6** **10/21/2003** **1:00** **10/21/2003**	**Red River at USGS Gage 6** **10/21/2003** **1:00** **10/21/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.78	7.78	7.78	7.78	7.77	7.77
SC (µS/cm)	367	367	367	367	370	370
Constituent, mg/L						
Ca	55.3	---	50.1	---	51.3	---
Mg	12.5	---	11.6	---	10.1	---
Na	5.81	---	5.38	---	4.65	---
K	1.18	---	1.02	---	0.92	---
Li	0.006	---	0.005	---	0.004	---
SO_4	127	---	128	---	128	---
Alkalinity as HCO_3^-	62.6	---	62.6	---	62.6	---
F	0.90	---	0.88	---	0.98	---
Cl	3.16	---	3.11	---	3.13	---
NO_3	0.27	---	0.29	---	0.33	---
Sr	0.303	0.294	0.265	0.305	0.275	0.312
Ba	0.037	0.037	0.033	0.038	0.033	0.041
SiO_2	11.9	12.9	11.0	14.0	9.64	14.2
Al	0.090	1.17	0.055	1.49	0.058	1.75
Fe	<0.007	0.155	<0.007	0.241	<0.007	0.293
Mn	0.327	0.277	0.260	0.296	0.236	0.323
Cu	<0.003	0.010	<0.003	0.012	<0.003	0.014
Zn	0.092	0.118	0.099	0.143	0.089	0.158
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	0.002	<0.002	0.002	<0.002	0.004
Co	<0.005	<0.005	<0.005	<0.005	<0.005	0.007
Ni	0.018	0.020	0.016	0.021	0.017	0.022
Pb	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.74	---	3.40	---	3.31	---
Sum anions (meq/L)	3.45	---	3.49	---	3.51	---
Charge imbalance (percent)	8.1	---	-2.7	---	-5.9	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River at USGS Gage 7**	**Red River at USGS Gage 7**	**Red River at USGS Gage 8**	**Red River at USGS Gage 8**	**Red River at USGS Gage 9**	**Red River at USGS Gage 9**
Collection Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Collection Time	**2:30**	**2:30**	**4:00**	**4:00**	**5:30**	**5:30**
Filtration Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.74	7.74	7.76	7.76	7.80	7.80
SC (µS/cm)	372	372	369	369	369	369
Constituent, mg/L						
Ca	50.3	---	51.6	---	53.6	---
Mg	11.6	---	13.1	---	13.5	---
Na	5.29	---	6.19	---	6.27	---
K	1.17	---	1.24	---	1.23	---
Li	0.005	---	0.006	---	0.006	---
SO_4	125	---	128	---	129	---
Alkalinity as HCO_3^-	62.5	---	62.6	---	62.5	---
F	1.10	---	1.02	---	0.99	---
Cl	3.16	---	3.22	---	3.31	---
NO_3	0.35	---	0.36	---	0.35	---
Sr	0.302	0.300	0.316	0.276	0.318	0.296
Ba	0.037	0.038	0.040	0.035	0.039	0.039
SiO_2	10.3	14.3	13.7	12.9	13.5	14.3
Al	0.072	1.69	0.096	1.25	0.078	1.63
Fe	<0.007	0.288	<0.007	0.183	<0.007	0.292
Mn	0.248	0.327	0.328	0.296	0.345	0.319
Cu	<0.003	0.015	<0.003	0.011	<0.003	0.015
Zn	0.089	0.151	0.110	0.164	0.117	0.156
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	0.002	<0.002	0.003	<0.002	0.003
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.017	0.023	0.022	0.020	0.020	0.021
Pb	<0.009	<0.009	0.010	<0.009	<0.009	<0.009
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.41	---	3.63	---	3.76	---
Sum anions (meq/L)	3.45	---	3.49	---	3.49	---
Charge imbalance (percent)	-1.1	---	3.9	---	7.3	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location **Collection Date** **Collection Time** **Filtration Date**	**Red River at USGS Gage 10** **10/21/2003** **7:00** **10/21/2003**	**Red River at USGS Gage 10** **10/21/2003** **7:00** **10/21/2003**	**Red River at USGS Gage 11** **10/21/2003** **8:30** **10/21/2003**	**Red River at USGS Gage 11** **10/21/2003** **8:30** **10/21/2003**	**Red River at USGS Gage 12** **10/21/2003** **10:00** **10/21/2003**	**Red River at USGS Gage 12** **10/21/2003** **10:00** **10/21/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.80	7.80	7.67	7.67	7.66	7.66
SC (µS/cm)	368	368	374	374	368	368
Constituent, mg/L						
Ca	54.8	---	51.2	---	51.9	---
Mg	13.3	---	13.8	---	12.0	---
Na	6.29	---	6.03	---	5.55	---
K	1.21	---	1.18	---	1.20	---
Li	0.006	---	0.006	---	0.005	---
SO_4	128	---	131	---	130	---
Alkalinity as HCO_3^-	62.3	---	62.3	---	61.6	---
F	1.02	---	1.02	---	1.17	---
Cl	3.17	---	3.17	---	3.20	---
NO_3	0.34	---	0.34	---	0.35	---
Sr	0.314	0.273	0.300	0.258	0.301	0.278
Ba	0.038	0.035	0.038	0.033	0.037	0.035
SiO_2	13.9	13.0	13.6	10.9	13.2	12.6
Al	0.063	1.44	0.067	1.20	0.054	1.55
Fe	<0.007	0.319	<0.007	0.179	<0.007	0.233
Mn	0.314	0.298	0.340	0.252	0.329	0.316
Cu	<0.003	0.016	<0.003	0.013	<0.003	0.015
Zn	0.117	0.172	0.126	0.125	0.101	0.147
Cd	<0.001	0.001	<0.001	<0.001	<0.001	0.002
Cr	<0.002	<0.002	0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.023	0.022	0.023	0.020	0.019	0.022
Pb	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.80	---	3.65	---	3.52	---
Sum anions (meq/L)	3.47	---	3.53	---	3.52	---
Charge imbalance (percent)	8.9	---	3.3	---	0.2	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River at USGS Gage 13**	**Red River at USGS Gage 13**	**Red River at USGS Gage 14**	**Red River at USGS Gage 14**	**Red River at USGS Gage 15**	**Red River at USGS Gage 15**
Collection Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Collection Time	**11:30**	**11:30**	**13:00**	**13:00**	**14:30**	**14:30**
Filtration Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.66	7.66	7.73	7.73	7.85	7.85
SC (µS/cm)	369	369	368	368	367	367
Constituent, mg/L						
Ca	50.8	---	53.4	---	52.5	---
Mg	11.0	---	12.1	---	13.3	---
Na	5.24	---	5.69	---	5.87	---
K	1.09	---	1.22	---	1.11	---
Li	0.005	---	0.006	---	0.005	---
SO_4	129	---	130	---	130	---
Alkalinity as HCO_3^-	61.2	---	61.1	---	61.2	---
F	1.09	---	1.06	---	1.04	---
Cl	3.45	---	3.14	---	3.14	---
NO_3	0.32	---	0.30	---	0.30	---
Sr	0.283	0.256	0.311	0.260	0.297	0.257
Ba	0.034	0.030	0.038	0.033	0.036	0.032
SiO_2	11.0	11.5	13.9	11.5	13.5	11.3
Al	0.052	1.38	0.117	1.41	0.093	1.41
Fe	<0.007	0.225	<0.007	0.217	<0.007	0.217
Mn	0.286	0.271	0.352	0.276	0.340	0.262
Cu	<0.003	0.015	<0.003	0.017	<0.003	0.015
Zn	0.090	0.139	0.085	0.125	0.104	0.123
Cd	<0.001	<0.001	<0.001	0.001	<0.001	0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.017	0.022	0.023	0.022	0.023	0.020
Pb	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.38	---	3.61	---	3.67	---
Sum anions (meq/L)	3.52	---	3.49	---	3.49	---
Charge imbalance (percent)	-3.9	---	3.1	---	4.8	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River at USGS Gage 16**	**Red River at USGS Gage 16**	**Red River at USGS Gage 17**	**Red River at USGS Gage 17**	**Red River at USGS Gage 18**	**Red River at USGS Gage 18**
Collection Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Collection Time	**16:00**	**16:00**	**17:30**	**17:30**	**19:00**	**19:00**
Filtration Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.84	7.84	7.82	7.82	7.62	7.62
SC (µS/cm)	368	368	368	368	370	370
Constituent, mg/L						
Ca	56.6	---	54.0	---	55.2	---
Mg	12.7	---	12.4	---	12.2	---
Na	5.83	---	5.39	---	5.92	---
K	1.19	---	1.05	---	1.22	---
Li	0.006	---	0.005	---	0.006	---
SO_4	131	---	131	---	131	---
Alkalinity as HCO_3^-	61.5	---	61.2	---	60.8	---
F	1.03	---	1.03	---	1.04	---
Cl	3.13	---	3.14	---	3.15	---
NO_3	0.28	---	0.28	---	0.28	---
Sr	0.311	0.261	0.272	0.244	0.315	0.261
Ba	0.039	0.033	0.033	0.031	0.039	0.032
SiO_2	13.2	11.2	12.6	10.5	11.7	10.4
Al	0.129	1.18	0.103	1.06	0.068	1.04
Fe	<0.007	0.167	<0.007	0.150	<0.007	0.274
Mn	0.324	0.269	0.314	0.255	0.307	0.257
Cu	<0.003	0.012	<0.003	0.011	<0.003	0.011
Zn	0.110	0.112	0.100	0.107	0.109	0.116
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	0.003
Co	<0.005	<0.005	<0.005	<0.005	0.005	<0.005
Ni	0.018	0.021	0.017	0.018	0.018	0.022
Pb	0.010	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.80	---	3.63	---	3.71	---
Sum anions (meq/L)	3.52	---	3.52	---	3.51	---
Charge imbalance (percent)	7.9	---	3.0	---	5.4	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River at USGS Gage 19**	**Red River at USGS Gage 19**	**Red River at USGS Gage 20**	**Red River at USGS Gage 20**	**Red River at USGS Gage 21**	**Red River at USGS Gage 21**
Collection Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Collection Time	**20:30**	**20:30**	**22:00**	**22:00**	**23:30**	**23:30**
Filtration Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.61	7.61	7.65	7.65	7.60	7.60
SC (µS/cm)	372	372	374	374	374	374
Constituent, mg/L						
Ca	58.3	---	55.3	---	50.1	---
Mg	13.1	---	12.6	---	10.7	---
Na	5.84	---	5.53	---	5.53	---
K	1.13	---	1.13	---	1.12	---
Li	0.006	---	0.006	---	0.005	---
SO_4	132	---	132	---	132	---
Alkalinity as HCO_3^-	52.7	---	60.5	---	61.0	---
F	1.12	---	1.06	---	1.04	---
Cl	9.85	---	3.29	---	3.19	---
NO_3	0.47	---	0.30	---	0.30	---
Sr	0.310	0.234	0.291	0.277	0.300	0.290
Ba	0.038	0.030	0.035	0.034	0.036	0.035
SiO_2	11.9	10.5	12.0	12.2	10.8	12.7
Al	0.081	1.23	0.060	1.32	<0.05	1.33
Fe	<0.007	0.207	<0.007	0.193	<0.007	0.196
Mn	0.311	0.254	0.334	0.298	0.256	0.310
Cu	<0.003	0.012	<0.003	0.016	<0.003	0.016
Zn	0.107	0.128	0.114	0.116	0.086	0.141
Cd	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	0.006	<0.005	0.005	<0.005
Ni	0.019	0.020	0.017	0.019	0.019	0.022
Pb	0.011	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.92	---	3.72	---	3.33	---
Sum anions (meq/L)	3.58	---	3.52	---	3.56	---
Charge imbalance (percent)	9.1	---	5.5	---	-6.7	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyze; meq/L, milliequivalents per liter]

Location	**Red River at USGS Gage 22**	**Red River at USGS Gage 22**	**Red River at USGS Gage 23**	**Red River at USGS Gage 23**	**Red River at USGS Gage 24**	**Red River at USGS Gage 24**
Collection Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Collection Time	**1:00**	**1:00**	**2:30**	**2:30**	**4:00**	**4:00**
Filtration Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.61	7.61	7.63	7.63	7.58	7.58
SC (µS/cm)	375	375	374	374	376	376
Constituent, mg/L						
Ca	54.9	---	56.6	---	53.1	---
Mg	12.7	---	13.3	---	11.6	---
Na	5.47	---	5.80	---	5.84	---
K	1.14	---	1.22	---	1.23	---
Li	0.006	---	0.006	---	0.006	---
SO_4	132	---	133	---	133	---
Alkalinity as HCO_3^-	60.6	---	60.7	---	60.8	---
F	1.02	---	1.06	---	1.05	---
Cl	3.76	---	3.21	---	3.34	---
NO_3	0.35	---	0.38	---	0.41	---
Sr	0.292	0.266	0.313	0.281	0.296	0.295
Ba	0.036	0.033	0.039	0.035	0.037	0.037
SiO_2	12.3	11.9	12.8	12.3	11.7	14.0
Al	0.057	1.36	0.071	1.43	0.109	1.55
Fe	<0.007	0.206	<0.007	0.213	<0.007	0.230
Mn	0.319	0.305	0.333	0.316	0.320	0.346
Cu	<0.003	0.016	<0.003	0.015	0.005	0.017
Zn	0.108	0.201	0.108	0.137	0.096	0.154
Cd	<0.001	0.002	<0.001	<0.001	<0.001	0.001
Cr	<0.002	<0.002	<0.002	<0.002	0.003	0.004
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.020	0.023	0.024	0.023	0.023	0.025
Pb	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.71	---	3.85	---	3.56	---
Sum anions (meq/L)	3.55	---	3.53	---	3.56	---
Charge imbalance (percent)	4.3	---	8.7	---	0.0	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River at USGS Gage 25**	**Red River at USGS Gage 25**	**Red River at USGS Gage 26**	**Red River at USGS Gage 26**	**Red River at USGS Gage 27**	**Red River at USGS Gage 27**
Collection Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Collection Time	**5:30**	**5:30**	**7:00**	**7:00**	**8:30**	**8:30**
Filtration Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.56	7.56	7.48	7.48	7.72	7.72
SC (µS/cm)	376	376	376	376	375	375
Constituent, mg/L						
Ca	53.8	---	48.2	---	56.8	---
Mg	11.6	---	10.8	---	12.1	---
Na	5.66	---	5.46	---	6.01	---
K	1.13	---	1.17	---	1.24	---
Li	0.006	---	0.006	---	0.007	---
SO_4	133	---	133	---	132	---
Alkalinity as HCO_3^-	48.2	---	60.4	---	60.5	---
F	1.02	---	1.05	---	1.18	---
Cl	9.99	---	3.28	---	3.29	---
NO_3	0.64	---	0.41	---	0.41	---
Sr	0.288	0.290	0.270	0.281	0.311	0.304
Ba	0.034	0.036	0.033	0.035	0.037	0.038
SiO_2	11.7	13.5	11.1	12.3	12.9	13.5
Al	0.102	1.68	0.079	1.60	0.104	1.39
Fe	<0.007	0.276	<0.007	0.241	<0.007	0.310
Mn	0.311	0.350	0.292	0.312	0.358	0.333
Cu	0.003	0.017	<0.003	0.017	0.004	0.017
Zn	0.093	0.153	0.090	0.144	0.077	0.132
Cd	<0.001	0.002	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	0.003	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.022	0.023	0.023	0.023	0.023	0.026
Pb	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.58	---	3.25	---	3.77	---
Sum anions (meq/L)	3.55	---	3.58	---	3.54	---
Charge imbalance (percent)	0.8	---	-9.6	---	6.6	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microssiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River at USGS Gage 28**	**Red River at USGS Gage 28**	**Red River at USGS Gage 29**	**Red River at USGS Gage 29**	**Red River at USGS Gage 30**	**Red River at USGS Gage 30**
Collection Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Collection Time	**10:00**	**10:00**	**11:30**	**11:30**	**13:00**	**13:00**
Filtration Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.73	7.73	7.72	7.72	7.73	7.73
SC (µS/cm)	375	375	373	373	372	372
Constituent, mg/L						
Ca	54.1	---	54.5	---	50.4	---
Mg	12.9	---	13.1	---	11.0	---
Na	6.29	---	6.15	---	5.61	---
K	1.31	---	1.23	---	1.16	---
Li	0.007	---	0.006	---	0.007	---
SO_4	132	---	132	---	132	---
Alkalinity as HCO_3^-	60.5	---	60.3	---	60.1	---
F	1.06	---	1.07	---	1.11	---
Cl	3.21	---	3.20	---	3.24	---
NO_3	0.38	---	0.36	---	0.35	---
Sr	0.340	0.276	0.317	0.269	0.312	0.280
Ba	0.040	0.034	0.037	0.034	0.036	0.035
SiO_2	14.3	12.5	13.6	12.5	11.1	11.9
Al	0.140	1.28	0.125	1.44	0.119	1.34
Fe	0.206	0.201	<0.007	0.209	<0.007	0.175
Mn	0.373	0.323	0.360	0.321	0.290	0.305
Cu	0.007	0.014	<0.003	0.015	<0.003	0.014
Zn	0.085	0.140	0.084	0.129	0.071	0.116
Cd	0.001	0.001	<0.001	<0.001	<0.001	0.001
Cr	0.003	0.003	<0.002	<0.002	<0.002	0.003
Co	<0.005	<0.005	0.006	<0.005	<0.005	<0.005
Ni	0.021	0.023	0.023	0.023	0.025	0.022
Pb	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	0.001	<0.001	0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.73	---	3.76	---	3.37	---
Sum anions (meq/L)	3.53	---	3.52	---	3.54	---
Charge imbalance (percent)	5.4	---	6.4	---	-4.9	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location **Collection Date** **Collection Time** **Filtration Date**	**Red River at USGS Gage 31** **10/22/2003** **14:30** **10/22/2003**	**Red River at USGS Gage 31** **10/22/2003** **14:30** **10/22/2003**	**Red River at USGS Gage 32** **10/22/2003** **16:00** **10/22/2003**	**Red River at USGS Gage 32** **10/22/2003** **16:00** **10/22/2003**	**Red River at USGS Gage 33** **10/22/2003** **17:30** **10/22/2003**	**Red River at USGS Gage 33** **10/22/2003** **17:30** **10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.78	7.78	7.76	7.76	7.76	7.76
SC (µS/cm)	372	372	372	372	373	373
Constituent, mg/L						
Ca	57.8	---	49.6	---	49.1	---
Mg	12.4	---	10.8	---	10.7	---
Na	5.60	---	5.36	---	5.04	---
K	1.06	---	1.13	---	1.02	---
Li	0.005	---	0.007	---	0.006	---
SO_4	132	---	132	---	133	---
Alkalinity as HCO_3^-	60.5	---	60.5	---	60.4	---
F	1.05	---	1.16	---	1.08	---
Cl	3.18	---	3.57	---	3.25	---
NO_3	0.32	---	0.30	---	0.31	---
Sr	0.268	0.290	0.291	0.322	0.274	0.284
Ba	0.031	0.035	0.034	0.040	0.032	0.035
SiO_2	11.1	13.0	11.1	15.1	11.1	13.8
Al	0.134	1.32	0.121	1.83	0.107	1.43
Fe	<0.007	0.188	<0.007	0.284	<0.007	0.214
Mn	0.290	0.318	0.286	0.360	0.291	0.308
Cu	<0.003	0.012	<0.003	0.021	0.003	0.015
Zn	0.080	0.123	0.063	0.142	0.077	0.148
Cd	<0.001	0.001	<0.001	0.002	<0.001	<0.001
Cr	0.004	0.002	0.003	0.003	0.003	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.018	0.020	0.019	0.025	0.021	0.024
Pb	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.82	---	3.31	---	3.27	---
Sum anions (meq/L)	3.50	---	3.56	---	3.57	---
Charge imbalance (percent)	8.6	---	-7.3	---	-8.8	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River Above Mill 1**	**Red River Above Mill 1**	**Red River Above Mill 2**	**Red River Above Mill 2**	**Red River Above Mill 3**	**Red River Above Mill 3**
Collection Date	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**
Collection Time	**16:45**	**16:45**	**18:15**	**18:15**	**19:45**	**19:45**
Filtration Date	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.99	7.99	7.97	7.97	7.99	7.99
SC (µS/cm)	290	290	290	290	290	290
Constituent, mg/L						
Ca	38.8	---	39.8	---	40.3	---
Mg	8.9	---	8.9	---	9.0	---
Na	4.55	---	4.68	---	4.76	---
K	1.00	---	1.04	---	1.03	---
Li	0.005	---	0.005	---	0.005	---
SO_4	77.2	---	79.1	---	79.3	---
Alkalinity as HCO_3^-	72.6	---	75.9	---	76.2	---
F	0.496	---	0.468	---	0.455	---
Cl	3.43	---	2.70	---	2.69	---
NO_3	0.3	---	1.1	---	1.3	---
Sr	0.226	0.246	0.231	0.254	0.231	0.248
Ba	0.035	0.039	0.036	0.041	0.036	0.040
SiO_2	12.7	13.1	12.6	13.6	12.6	15.1
Al	0.112	0.697	0.078	0.740	0.080	0.785
Fe	0.010	0.152	<0.007	0.184	0.011	0.183
Mn	0.151	0.155	0.153	0.174	0.158	0.193
Cu	<0.003	0.009	<0.003	0.011	<0.003	0.013
Zn	0.017	0.050	0.021	0.053	0.028	0.062
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.008	0.011	0.007	0.009	0.011	0.009
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	2.72	---	2.77	---	2.80	---
Sum anions (meq/L)	2.74	---	2.82	---	2.83	---
Charge imbalance (percent)	-0.6	---	-1.7	---	-0.8	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River Above Mill 4**	**Red River Above Mill 4**	**Red River Above Mill 5**	**Red River Above Mill 5**	**Red River Above Mill 6**	**Red River Above Mill 6**
Collection Date	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/20/2003**	**10/21/2003**	**10/21/2003**
Collection Time	**21:15**	**21:15**	**22:45**	**22:45**	**0:15**	**0:15**
Filtration Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.94	7.94	7.93	7.93	7.95	7.95
SC (µS/cm)	291	291	292	292	292	292
Constituent, mg/L						
Ca	40.7	---	41.2	---	41.9	---
Mg	9.0	---	9.0	---	9.0	---
Na	4.85	---	4.81	---	4.93	---
K	1.04	---	1.04	---	1.11	---
Li	0.005	---	0.005	---	0.005	---
SO_4	78.7	---	79.7	---	79.0	---
Alkalinity as HCO_3^-	75.6	---	75.9	---	76.0	---
F	0.373	---	0.373	---	0.507	---
Cl	2.89	---	2.72	---	2.83	---
NO_3	1.4	---	1.4	---	1.3	---
Sr	0.240	0.281	0.235	0.273	0.242	0.266
Ba	0.038	0.046	0.037	0.044	0.037	0.043
SiO_2	12.7	15.2	12.6	15.3	13.1	13.8
Al	0.053	0.854	0.101	0.849	0.077	0.824
Fe	0.007	0.221	<0.007	0.219	<0.007	0.239
Mn	0.163	0.202	0.163	0.205	0.168	0.208
Cu	<0.003	0.013	<0.003	0.013	<0.003	0.010
Zn	0.030	0.056	0.025	0.091	0.035	0.067
Cd	0.002	<0.001	0.0013	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.011	0.014	0.011	0.016	0.014	0.010
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	2.83	---	2.85	---	2.90	---
Sum anions (meq/L)	2.81	---	2.83	---	2.82	---
Charge imbalance (percent)	0.8	---	0.8	---	2.7	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River Above Mill 7**	**Red River Above Mill 7**	**Red River Above Mill 8**	**Red River Above Mill 8**	**Red River Above Mill 9**	**Red River Above Mill 9**
Collection Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Collection Time	**1:45**	**1:45**	**3:15**	**3:15**	**4:45**	**4:45**
Filtration Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.92	7.92	7.93	7.93	8.00	8.00
SC (µS/cm)	292	292	291	291	290	290
Constituent, mg/L						
Ca	42.7	---	43.0	---	42.4	47.6
Mg	9.3	---	9.3	---	9.3	10.5
Na	5.14	---	5.19	---	5.14	5.97
K	1.09	---	1.08	---	1.10	1.67
Li	0.005	---	0.006	---	0.006	0.006
SO_4	80.1	---	80.1	---	79.6	---
Alkalinity as HCO_3^-	75.9	---	75.9	---	75.6	---
F	0.455	---	0.524	---	0.532	---
Cl	2.74	---	2.71	---	3.04	---
NO_3	1.3	---	1.3	---	1.2	---
Sr	0.250	0.255	0.253	0.263	0.243	0.274
Ba	0.039	0.042	0.038	0.043	0.037	0.045
SiO_2	13.4	15.6	13.2	15.9	13.3	15.3
Al	0.077	0.799	0.064	0.803	<0.05	0.889
Fe	<0.007	0.394	<0.007	0.240	<0.007	0.291
Mn	0.175	0.200	0.177	0.211	0.174	0.216
Cu	<0.003	0.013	<0.003	0.013	<0.003	0.013
Zn	0.031	0.085	0.035	0.085	0.037	0.133
Cd	0.0015	<0.001	0.002	<0.001	0.0014	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	0.002	0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.011	0.012	0.010	0.012	0.009	0.014
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	2.96	---	2.97	---	2.95	---
Sum anions (meq/L)	2.83	---	2.83	---	2.83	---
Charge imbalance (percent)	4.5	---	4.9	---	4.2	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyze

Location **Collection Date** **Collection Time** **Filtration Date**	**Red River Above Mill 10** **10/21/2003** **6:15** **10/21/2003**	**Red River Above Mill 10** **10/21/2003** **6:15** **10/21/2003**	**Red River Above Mill 11** **10/21/2003** **7:45** **10/21/2003**	**Red River Above Mill 11** **10/21/2003** **7:45** **10/21/2003**	**Red River Above Mill 12** **10/21/2003** **9:15** **10/21/2003**	**Red River Above Mill 12** **10/21/2003** **9:15** **10/21/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.96	7.96	7.90	7.90	7.91	7.91
SC (µS/cm)	291	291	290	290	291	291
Constituent, mg/L						
Ca	42.3	---	42.7	---	41.4	---
Mg	9.3	---	9.3	---	9.7	---
Na	5.06	---	4.91	---	5.04	---
K	1.12	---	1.08	---	1.06	---
Li	0.005	---	0.006	---	0.005	---
SO_4	79.9	---	79.6	---	79.6	---
Alkalinity as HCO_3^-	75.6	---	75.8	---	75.9	---
F	0.465	---	0.350	---	0.478	---
Cl	2.71	---	2.66	---	2.84	---
NO_3		---	1.1	---	1.1	---
Sr	0.243	0.285	0.248	0.242	0.250	0.243
Ba	0.037	0.046	0.037	0.039	0.037	0.038
SiO_2	13.8	15.8	13.0	13.6	13.9	13.6
Al	0.062	0.879	<0.05	0.756	<0.05	0.761
Fe	0.008	0.260	<0.007	0.276	<0.007	0.193
Mn	0.181	0.217	0.182	0.189	0.183	0.184
Cu	<0.003	0.015	<0.003	0.010	<0.003	0.010
Zn	0.038	0.082	0.037	0.061	0.035	0.052
Cd	0.002	<0.001	0.002	<0.001	0.002	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.014	0.012	0.015	0.012	0.011	0.010
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	2.94	---	2.95	---	2.93	---
Sum anions (meq/L)	2.80	---	2.81	---	2.82	---
Charge imbalance (percent)	4.8	---	4.7	---	3.6	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River Above Mill 13**	**Red River Above Mill 13**	**Red River Above Mill 14**	**Red River Above Mill 14**	**Red River Above Mill 15**	**Red River Above Mill 15**
Collection Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Collection Time	**10:55**	**10:55**	**12:25**	**12:25**	**13:55**	**13:55**
Filtration Date	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**	**10/21/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.94	7.94	7.98	7.98	8.03	8.03
SC (µS/cm)	290	290	291	291	290	290
Constituent, mg/L						
Ca	43.1	---	43.7	---	43.5	---
Mg	9.9	---	9.8	---	10.2	---
Na	5.01	---	5.07	---	5.04	---
K	1.13	---	1.14	---	1.16	---
Li	0.005	---	0.006	---	0.005	---
SO_4	80.2	---	77.6	---	79.6	---
Alkalinity as HCO_3^-	75.2	---	69.4	---	74.5	---
F	0.458	---	0.491	---	0.391	---
Cl	2.62	---	2.85	---	2.71	---
NO_3	1.1	---	1.0	---	1.0	---
Sr	0.269	0.241	0.245	0.256	0.255	0.256
Ba	0.041	0.038	0.037	0.039	0.038	0.040
SiO_2	14.1	13.3	13.1	13.9	13.9	15.1
Al	0.116	0.710	0.113	0.670	0.136	0.832
Fe	<0.007	0.182	<0.007	0.144	<0.007	0.305
Mn	0.182	0.177	0.165	0.177	0.171	0.185
Cu	<0.003	0.011	<0.003	0.011	<0.003	0.011
Zn	0.026	0.067	0.025	0.059	0.018	0.676
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	0.006	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.010	0.010	0.007	0.011	0.010	0.010
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	2.93	---	3.05	---	3.06	---
Sum anions (meq/L)	2.82	---	2.69	---	2.78	---
Charge imbalance (percent)	4.0	---	12.4	---	9.6	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^oC, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location **Collection Date** **Collection Time** **Filtration Date**	**Red River Above Mill 16** **10/21/2003** **15:25** **10/21/2003**	**Red River Above Mill 16** **10/21/2003** **15:25** **10/21/2003**	**Red River Above Mill 17** **10/21/2003** **16:55** **10/21/2003**	**Red River Above Mill 17** **10/21/2003** **16:55** **10/21/2003**	**Red River Above Mill 18** **10/21/2003** **18:25** **10/21/2003**	**Red River Above Mill 18** **10/21/2003** **18:25** **10/21/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	8.06	8.06	8.02	8.02	8.02	8.02
SC (µS/cm)	291	291	290	290	292	292
Constituent, mg/L						
Ca	44.0	---	41.1	---	41.6	---
Mg	10.4	---	10.1	---	10.5	---
Na	5.51	---	5.22	---	5.11	---
K	1.26	---	1.16	---	1.14	---
Li	0.006	---	0.006	---	0.005	---
SO_4	79.6	---	80.2	---	80.3	---
Alkalinity as HCO_3^-	74.7	---	74.7	---	76.2	---
F	0.385	---	0.351	---	0.355	---
Cl	2.57	---	2.76	---	2.58	---
NO_3	1.0	---	0.9	---	1.2	---
Sr	0.275	0.249	0.258	0.242	0.256	0.247
Ba	0.041	0.038	0.039	0.037	0.040	0.038
SiO_2	14.5	14.5	14.4	13.7	14.9	13.8
Al	0.176	0.744	0.157	0.680	0.161	0.713
Fe	<0.007	0.164	<0.007	0.160	<0.007	0.169
Mn	0.171	0.177	0.175	0.165	0.174	0.173
Cu	<0.003	0.011	<0.003	0.008	<0.003	0.010
Zn	0.022	0.050	0.023	0.072	0.030	0.634
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.010	0.011	0.009	0.011	0.012	0.011
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.13	---	2.95	---	3.00	---
Sum anions (meq/L)	2.78	---	2.80	---	2.82	---
Charge imbalance (percent)	11.8	---	5.2	---	6.0	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location **Collection Date** **Collection Time** **Filtration Date**	**Red River Above Mill 19** **10/21/2003** **19:55** **10/22/2003**	**Red River Above Mill 19** **10/21/2003** **19:55** **10/22/2003**	**Red River Above Mill 20** **10/21/2003** **21:25** **10/22/2003**	**Red River Above Mill 20** **10/21/2003** **21:25** **10/22/2003**	**Red River Above Mill 21** **10/21/2003** **22:55** **10/22/2003**	**Red River Above Mill 21** **10/21/2003** **22:55** **10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.90	7.90	7.84	7.84	7.94	7.94
SC (µS/cm)	293	293	294	294	294	294
Constituent, mg/L						
Ca	42.5	---	41.7	---	42.2	---
Mg	10.1	---	10.2	---	10.5	---
Na	5.19	---	5.33	---	5.54	---
K	1.22	---	1.18	---	1.19	---
Li	0.006	---	0.006	---	0.006	---
SO_4	80.8	---	80.3	---	80.8	---
Alkalinity as HCO_3^-	75.9	---	75.6	---	75.7	---
F	0.461	---	0.351	---	0.471	---
Cl	2.78	---	2.75	---	2.79	---
NO_3	1.7	---	1.8	---	1.9	---
Sr	0.265	0.238	0.261	0.241	0.268	0.255
Ba	0.041	0.039	0.041	0.040	0.042	0.040
SiO_2	14.1	13.1	14.2	13.4	15.4	13.6
Al	0.104	0.701	0.084	0.700	0.144	0.719
Fe	<0.007	0.187	<0.007	0.182	<0.007	0.303
Mn	0.182	0.172	0.184	0.180	0.195	0.177
Cu	<0.003	0.010	<0.003	0.011	<0.003	0.011
Zn	0.034	0.052	0.040	0.050	0.039	0.056
Cd	<0.001	<0.001	<0.001	<0.001	0.0015	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	0.003	<0.002
Co	<0.005	<0.005	<0.005	<0.005	0.011	<0.005
Ni	0.012	0.009	0.012	0.010	0.013	0.010
Pb	<0.008	<0.008	<0.008	<0.008	<0.009	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	3.01	---	2.99	---	3.05	---
Sum anions (meq/L)	2.85	---	2.83	---	2.85	---
Charge imbalance (percent)	5.6	---	5.5	---	6.8	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River Above Mill 22**	**Red River Above Mill 22**	**Red River Above Mill 23**	**Red River Above Mill 23**	**Red River Above Mill 24**	**Red River Above Mill 24**
Collection Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Collection Time	**0:25**	**0:25**	**1:55**	**1:55**	**3:25**	**3:25**
Filtration Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.86	7.86	7.86	7.86	7.86	7.86
SC (µS/cm)	295	295	294	294	294	294
Constituent, mg/L						
Ca	41.0	---	43.5	---	40.4	---
Mg	10.4	---	10.8	---	9.2	---
Na	5.52	---	5.58	---	5.01	---
K	1.21	---	1.14	---	1.18	---
Li	0.006	---	0.006	---	0.007	---
SO_4	81.1	---	81.1	---	81.5	---
Alkalinity as HCO_3^-	75.5	---	75.4	---	75.5	---
F	0.460	---	0.432	---	0.372	---
Cl	2.82	---	2.73	---	2.80	---
NO_3	1.9	---	1.6	---	1.5	---
Sr	0.271	0.245	0.265	0.227	0.248	0.245
Ba	0.043	0.041	0.041	0.036	0.038	0.039
SiO_2	14.6	13.7	15.0	12.9	13.2	13.7
Al	0.107	0.711	0.083	0.628	0.163	0.677
Fe	<0.007	1.245	<0.007	0.127	0.017	0.169
Mn	0.192	0.179	0.200	0.169	0.185	0.182
Cu	<0.003	0.009	<0.003	0.007	0.004	0.009
Zn	0.040	0.059	0.038	0.060	0.036	0.056
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	0.003	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.010	0.011	0.012	0.010	0.010	0.011
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	2.98	---	3.13	---	2.84	---
Sum anions (meq/L)	2.86	---	2.84	---	2.86	---
Charge imbalance (percent)	4.3	---	9.9	---	-0.8	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River Above Mill 25**	**Red River Above Mill 25**	**Red River Above Mill 26**	**Red River Above Mill 26**	**Red River Above Mill 27**	**Red River Above Mill 27**
Collection Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Collection Time	**4:55**	**4:55**	**6:25**	**6:25**	**7:55**	**7:55**
Filtration Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.87	7.87	7.84	7.84	7.84	7.84
SC (µS/cm)	293	293	293	293	293	293
Constituent, mg/L						
Ca	38.8	---	39.9	---	40.6	---
Mg	8.8	---	8.9	---	8.9	---
Na	4.86	---	4.89	---	4.88	---
K	1.05	---	1.11	---	1.10	---
Li	0.006	---	0.006	---	0.005	---
SO_4	80.3	---	81.1	---	80.7	---
Alkalinity as HCO_3^-	75.2	---	75.3	---	75.8	---
F	0.411	---	0.418	---	0.456	---
Cl	2.84	---	2.69	---	2.80	---
NO_3	1.2	---	1.3	---	1.2	---
Sr	0.239	0.233	0.241	0.216	0.250	0.227
Ba	0.037	0.039	0.037	0.034	0.037	0.035
SiO_2	13.1	14.1	13.1	12.8	13.3	13.2
Al	0.118	0.921	0.131	0.613	0.138	0.658
Fe	<0.007	2.374	<0.007	0.169	<0.007	0.167
Mn	0.174	0.177	0.179	0.169	0.180	0.175
Cu	0.004	0.009	0.005	0.008	0.006	0.008
Zn	0.034	1.502	0.032	0.052	0.033	0.050
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.012	0.012	0.011	0.011	0.012	0.010
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	2.72	---	2.78	---	2.82	---
Sum anions (meq/L)	2.83	---	2.85	---	2.85	---
Charge imbalance (percent)	-4.0	---	-2.3	---	-1.1	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River Above Mill 28**	**Red River Above Mill 28**	**Red River Above Mill 29**	**Red River Above Mill 29**	**Red River Above Mill 30**	**Red River Above Mill 30**
Collection Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Collection Time	**9:25**	**9:25**	**10:55**	**10:55**	**12:25**	**12:25**
Filtration Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	7.94	7.94	7.96	7.96	7.97	7.97
SC (µS/cm)	292	292	292	292	291	291
Constituent, mg/L						
Ca	41.0	---	42.1	---	40.6	---
Mg	9.0	---	8.9	---	8.9	---
Na	5.04	---	4.87	---	4.85	---
K	1.16	---	1.01	---	1.08	---
Li	0.006	---	0.005	---	0.005	---
SO_4	80.6	---	80.7	---	81.1	---
Alkalinity as HCO_3^-	75.8	---	75.7	---	75.1	---
F	0.431	---	0.354	---	0.500	---
Cl	2.68	---	2.66	---	2.70	---
NO_3	1.2	---	1.1	---	1.1	---
Sr	0.251	0.226	0.251	0.226	0.248	0.235
Ba	0.038	0.083	0.037	0.034	0.037	0.036
SiO_2	12.9	14.9	12.3	12.1	13.1	13.1
Al	0.117	1.83	0.117	0.595	0.170	0.636
Fe	<0.007	0.532	<0.007	0.118	<0.007	0.120
Mn	0.171	0.175	0.157	0.167	0.166	0.164
Cu	0.004	0.010	0.005	0.008	0.005	0.008
Zn	0.032	0.075	0.029	0.046	0.024	0.044
Cd	0.0010	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.012	0.011	0.013	0.009	0.010	0.007
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	2.85	---	2.88	---	2.81	---
Sum anions (meq/L)	2.84	---	2.83	---	2.84	---
Charge imbalance (percent)	0.4	---	1.8	---	-1.0	---

Table 8. Low-flow diel water analyses -- Continued

[FA, filtered acidified; FU, filtered unacidified; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; ^{o}C, degrees Celsius; RA, raw acidified; SC, specific conductance; <, less than; ---, not analyzed; meq/L, milliequivalents per liter]

Location	**Red River Above Mill 31**	**Red River Above Mill 31**	**Red River Above Mill 32**	**Red River Above Mill 32**	**Red River Above Mill 33**	**Red River Above Mill 33**
Collection Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Collection Time	**13:55**	**13:55**	**15:25**	**15:25**	**16:55**	**16:55**
Filtration Date	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**	**10/22/2003**
Treatment	FA/FU	RA	FA/FU	RA	FA/FU	RA
pH (lab)	8.00	8.00	8.02	8.02	8.03	8.03
SC (µS/cm)	292	292	291	291	292	292
Constituent, mg/L						
Ca	42.8	---	43.8	---	41.8	---
Mg	9.2	---	9.4	---	9.5	---
Na	5.10	---	5.08	---	5.02	---
K	1.16	---	1.18	---	1.19	---
Li	0.005	---	0.007	---	0.006	---
SO_4	81.2	---	81.1	---	81.0	---
Alkalinity as HCO_3^-	75.3	---	75.0	---	75.8	---
F	0.458	---	0.507	---	0.453	---
Cl	2.64	---	2.60	---	2.59	---
NO_3	0.9	---	0.7	---	0.8	---
Sr	0.258	0.210	0.257	0.212	0.253	0.212
Ba	0.038	0.031	0.038	0.032	0.039	0.032
SiO_2	13.1	11.8	12.8	11.7	14.0	10.9
Al	0.190	0.596	0.193	0.561	0.226	0.579
Fe	<0.007	0.123	0.008	0.110	<0.007	0.105
Mn	0.163	0.143	0.150	0.138	0.163	0.135
Cu	0.008	0.008	0.005	0.006	<0.003	0.008
Zn	0.021	0.048	0.023	0.031	0.022	0.036
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ni	0.012	0.008	0.011	0.009	0.012	0.010
Pb	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sum cations (meq/L)	2.96	---	3.01	---	2.93	---
Sum anions (meq/L)	2.83	---	2.82	---	2.83	---
Charge imbalance (percent)	4.2	---	6.6	---	3.3	---

changed very little during the study. Results from the low-flow diel study are presented in table 8.

At both sites during high flow and at the Questa Ranger Station gage during low flow, concentrations of chemical constituents do not appear to have varied on a diel cycle. Upstream from the Questa mine mill during low-flow (October 2003), the pH increased during the day from 8.15 to 8.34 due to photosynthetic consumption of CO_2 (fig. 20). Dissolved oxygen concentrations increased during the night as the temperature decreased (fig. 21), owing to oxygen aqueous solubility increasing as temperature decreases. Only dissolved zinc and manganese concentrations had definite diel patterns, decreasing to a minimum at about noon and increasing to a maximum before sunrise (fig. 22). Trace metal diel cycles have been observed in several Rocky Mountain streams and possible causes are (1) upstream metal loading, (2) streamflow variations, (3) biological activity, (4) precipitation/dissolution reactions, and (5) adsorption/desorption reactions (Fuller and Davis, 1989; Brick and Moore, 1996; Nimick and others, 2003, 2005). Photosynthesis-induced pH changes were determined to be the major cause of the Zn diel cycle in Prickly Pear Creek, Mont. (pH 8.0-8.4) during low-flow conditions in July 2001 (Jones and others, 2004).

Summary of Red River Water Quality

The 21 water-chemistry samples collected at the USGS streamflow-gaging station near the Questa Ranger Station occurred during a range of flow conditions including a drought year and a major storm event. Overall, the water at this site is circumneutral, calcium-sulfate-bicarbonate type. Hydrologic flow regime is a primary control of Red River water quality, with storm events creating the most dramatic changes in water quality. During the September 2002 storm event the discharge at the USGS Questa Ranger Station gage increased from 8 to 102 ft^3/s, and acid runoff from hydrothermally altered scars entered the Red River causing it to become acidic and highly turbid (figs. 5 and cover photograph). During the first day of the storm, the pH decreased from 7.80 to 4.83, alkalinity decreased from about 50 to <1 mg/L, SO_4 increased from 162 to 314 mg/L, dissolved Fe increased from to 0.011 to 0.596 mg/L, dissolved Al increased from 0.189 to 2.88 mg/L, and dissolved Zn increased from 0.056 to 0.607 mg/L. Previous studies by Smolka and Tague (1987; 1989) during smaller, more localized events documented a decrease in the pH of the Red River near the Elephant Rock campground from 8.1 to 3.8 because of runoff from upstream scar areas, and Garn (USGS, 2003) also documented a pH drop from 7.4 to 3.8 for the Red River at the Questa Ranger Station gage for a storm event on September 7, 1986.

Historical water quality of the Red River was assessed by Maest and others (2004) but was further evaluated in this report because of more recent measurements and the discovery of additional sulfate data. The overall conclusion by Maest and others (2004) that the sulfate concentration at the Questa Ranger Station gage has increased over time is supported by this study. No significant increase in dissolved sulfate concentration in the Red River from upstream from the Molycrop mill to the gage was observed from 1975 to 1985 but an increase in dissolved sulfate did occur in this reach between 1992 and 2004. Determining the driving force of these increases is beyond the scope of this study. Possible driving forces include surface-water and ground-water extractions for Molycorp mill use and ground-water flow from the Molycorp mine site.

Straight Creek Water Chemistry, 2001-2003

The Straight Creek subbasin was chosen as an analog site for evaluating pre-mining baseline conditions because of its geologic, topographic, and geomorphologic characteristics (Naus and others, 2005). A set of eight alluvial and three bedrock wells was installed in the debris fan at the base of the subbasin and sampled monthly or quarterly from March 2002 to June 2004. During most of the year, water emerges from the bedrock or colluvium near the drainage divide and flows over bedrock or ferricrete to the debris fan. After entering the main channel in the upper portion of the debris fan, discharge decreases until the surface flow completely seeps into the bed. Infiltration of Straight Creek surface water appears to be the primary source of water to the uppermost alluvial well (SC1A; Naus and others, 2005). During some high-flow conditions, for example during the September 2002 storm event, water continues to flow in the main channel of the Straight Creek debris fan to

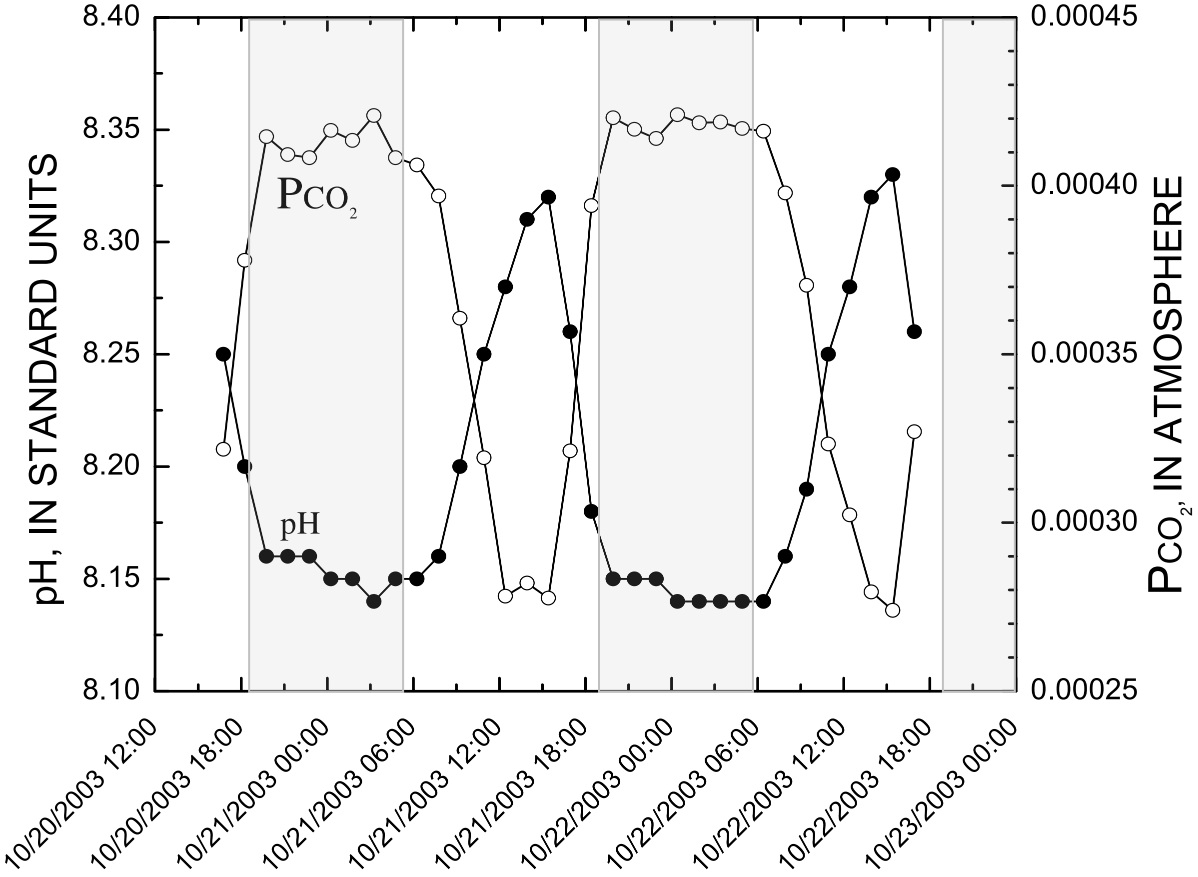


Figure 20. pH and calculated P_{CO_2} diel trends for low-flow conditions in the Red River at upstream mill site.

the Red River. To determine the chemistry of water entering the top of the debris fan, surface-water samples were collected during each well-sampling event.

The range in pH for Straight Creek surface-water samples was 2.44 to 3.25, and the range for just the lower Straight Creek samples was 2.73 to 3.25 (table 4). Considering the differences in hydrologic conditions among the samples including baseflow, snowmelt, and storm events, this range is narrow. Robertson GeoConsultants Inc. (2001a) report a similar range in pH, 2.6-3.0 for surface waters in Straight Creek collected above the debris fan during 2000. Water from upper Straight Creek near the drainage divide had the lowest pH value (2.44) and along the downstream transect sampling of October 2003, the pH increased to a value of 2.90. This trend is similar to the upper and lower Straight Creek sampling in September 2001, when the pH value increased from 2.66 to 2.82.

During most Straight Creek sampling trips discharge at the pipe was measured using a calibrated bucket and stop watch or using a portable flume. Discharge varied from 3.7 to 91 gallons per minute (fig. 23A). Peak discharges occurred in September 2002 during a storm event and April 2003 during a rain and snow event. Although there was a 10-fold increase in discharge during the storm, little change in pH occurred (fig. 23A). Determining the relation between flow and solute concentration is difficult with this limited dataset and the uncertainty in the flow-measurement technique. The February and March 2002 samples had the lowest dissolved zinc and sulfate concentrations because these samples were collected during the middle of the day when the ice and snow that covered the channel were melting and diluting the stream water. Relatively low sulfate and zinc concentrations also were measured during a spring rain and snow event and on the first morning of the September 2002 storm event.

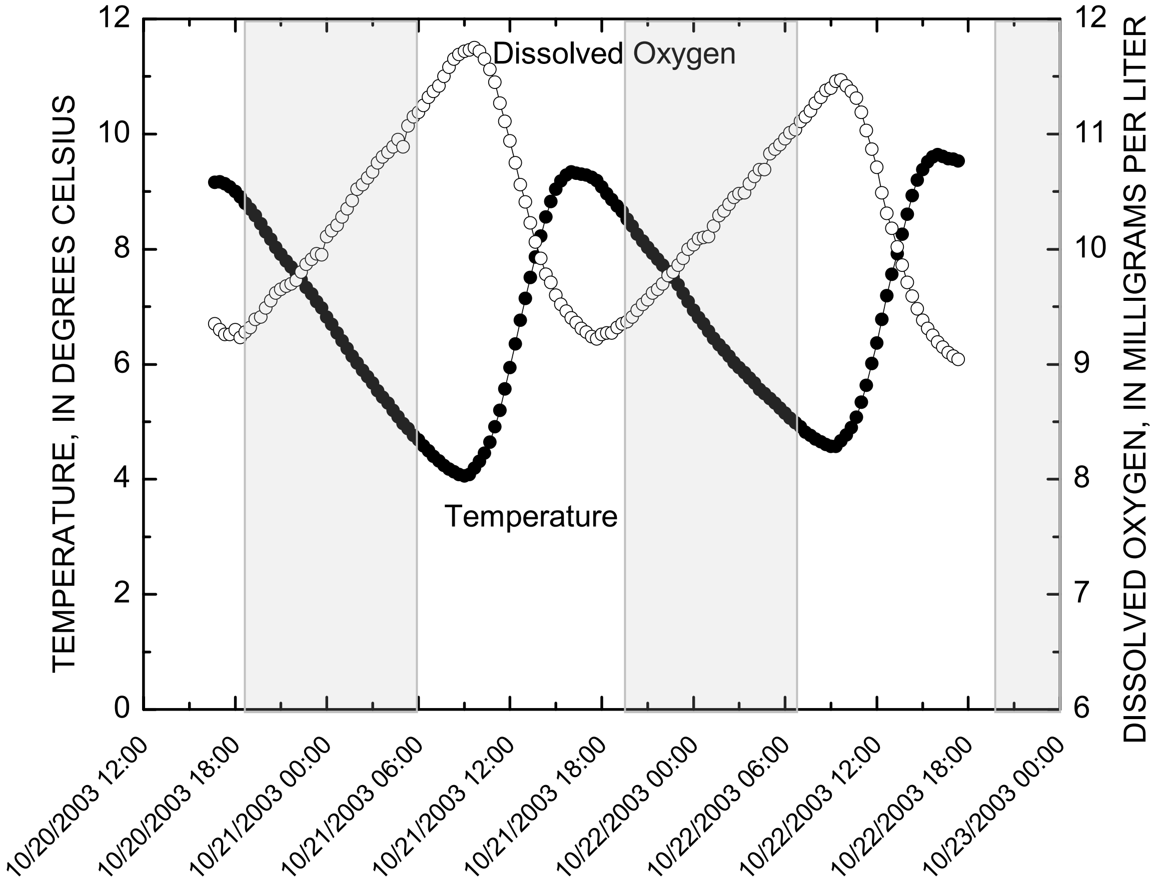


Figure 21. Diel trends in temperature and dissolved oxygen concentrations for low-flow conditions in the Red River at upstream mill site.

(figs. 23B and C). Robertson GeoConsultants Inc. (2001a) reported high-frequency sampling of a storm event that occurred on July 16, 2000. In contrast to our results, the highest sulfate concentration (7,100 mg/L) occurred in a sample collected with an estimated flow of 30 gallons per minute, approximately an hour and 20 minutes after the peak flow of 270 gallons per minute.

Static water level in well SC1A, the uppermost alluvial well in the debris fan, was measured monthly from April 2002 to May 2004. Peak flow of Straight Creek appears to produce a rise in the static water level in well SC1A (figs. 24A and B).

Similar to the Red River samples, a strong correlation exists between specific conductance and sulfate concentrations (fig. 25). The two samples with the lowest specific conductance and sulfate concentrations were collected in February and March 2002 when the creek was partially covered with ice. The relatively dilute water likely had a substantial fraction of melted ice. The three samples with intermediate specific conductance (about 2,250 µS/cm) and sulfate concentrations (about 1,500 mg/L) were collected during precipitation events in September 2002 and April 2003. The highest sulfate concentrations (about 2,950 mg/L) were from samples along the October 2003 downstream transect, and a substantial decrease in sulfate concentration (from 2,990 to 2,310 mg/L) occurred between the fourth and fifth transect site (03WA171 and 03WA172), suggesting that more dilute waters were entering Straight Creek.

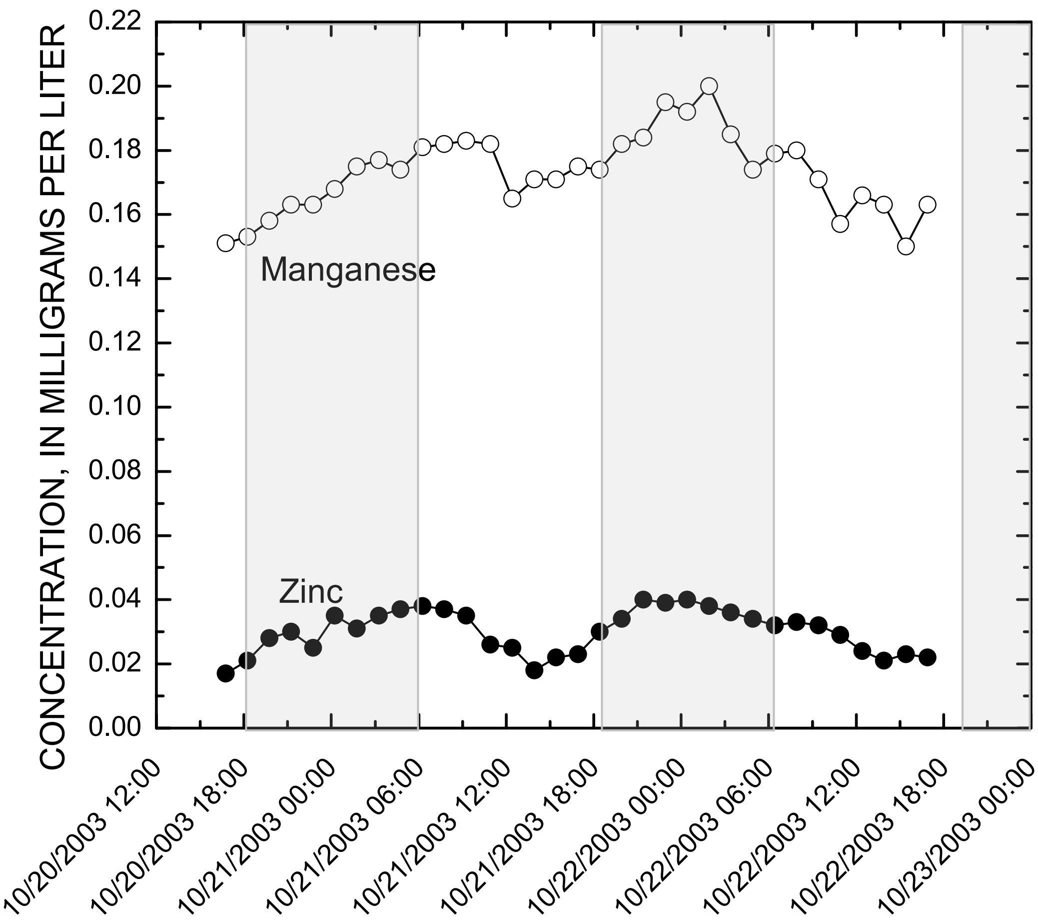


Figure 22. Diel trends in dissolved zinc and dissolved manganese concentrations for low-flow conditions in the Red River at upstream mill site.

Sulfate concentration in waters draining mineralized areas typically is controlled by dissolution of sulfide and sulfate minerals. In the Straight Creek subbasin, pyrite is the primary sulfide mineral and gypsum is the primary sulfate mineral Plumlee and others (in press). To evaluate the importance of gypsum dissolution as a control of sulfate in the Straight Creek waters, the plot of molar concentrations of calcium and sulfate is useful (fig. 26A). All the samples from Straight Creek plot well to the right of the 1:1 Ca:SO_4 line, consistent with pyrite being the dominant control of sulfate in these waters. The two points that lie nearest to the line are the February and March 2003 samples when the creek was partially covered by ice. All these samples are at least slightly undersaturated with respect to gypsum (fig. 26B).

Concentrations of many dissolved trace metals in the Straight Creek surface-water dataset display a positive correlation with sulfate concentration (figs. 27A-C). The lower-concentration samples were collected during precipitation events or during periods of ice melting (February and March 2003) when Straight Creek water was diluted.

The concentration of dissolved iron is poorly correlated with sulfate concentration (fig. 28A). Unlike sulfate which tends to behave conservatively in acidic systems, iron can change redox state and will precipitate in oxygenated waters. In contrast to the ground water in the Straight Creek basin (Naus and

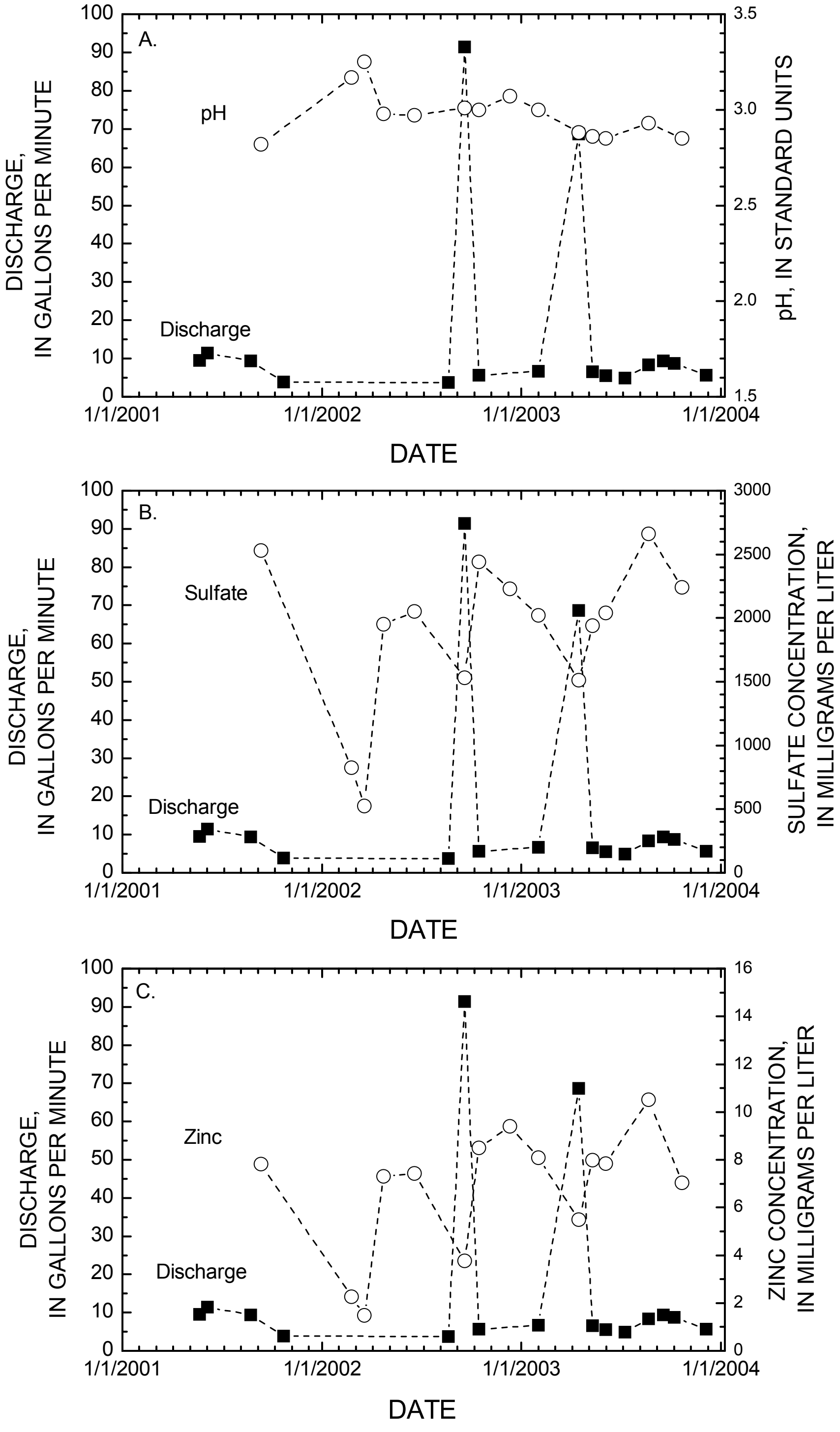


Figure 23. Discharge of Straight Creek from 2001 through 2003 with (A) pH, (B) sulfate concentration, and (C) dissolved zinc concentration.

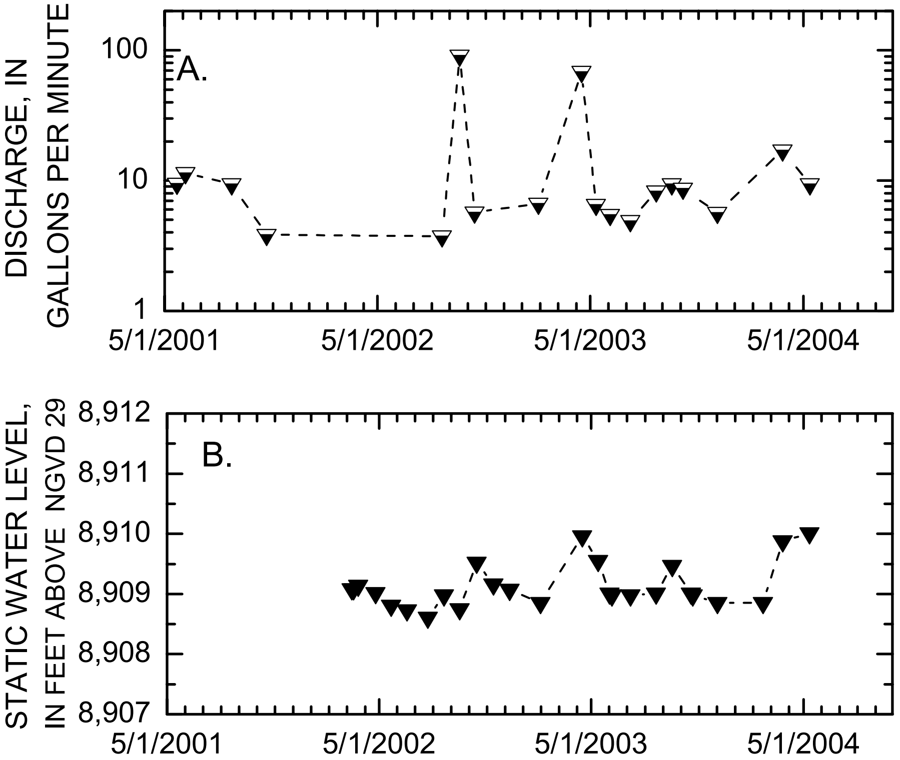


Figure 24. (A) Discharge variation in Straight Creek and (B) static water level for Straight Creek debris fan, alluvial well SC1A.

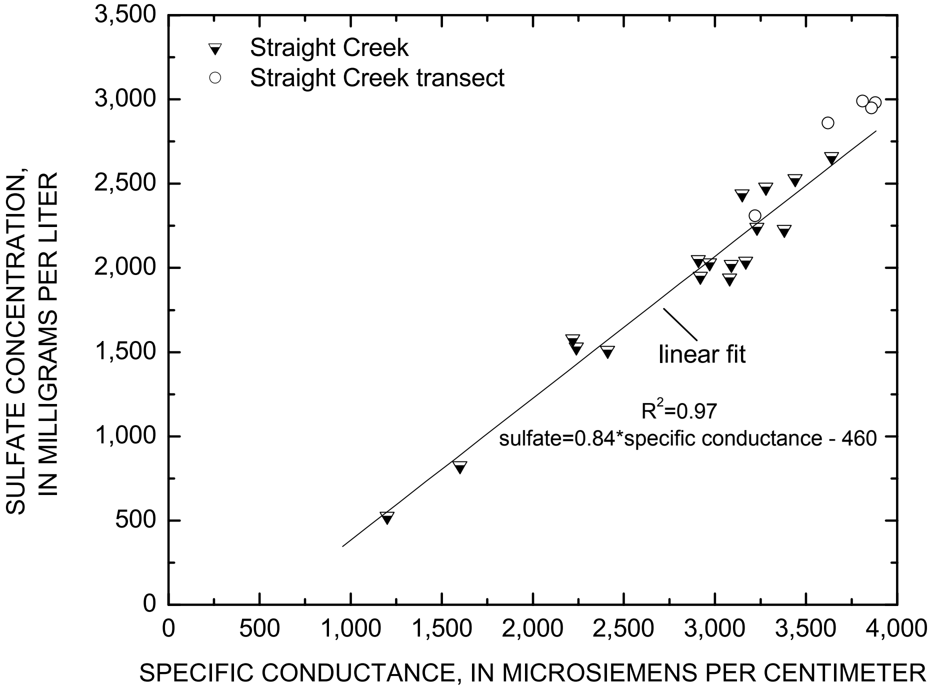


Figure 25. Specific conductance in relation to sulfate concentration in Straight Creek.

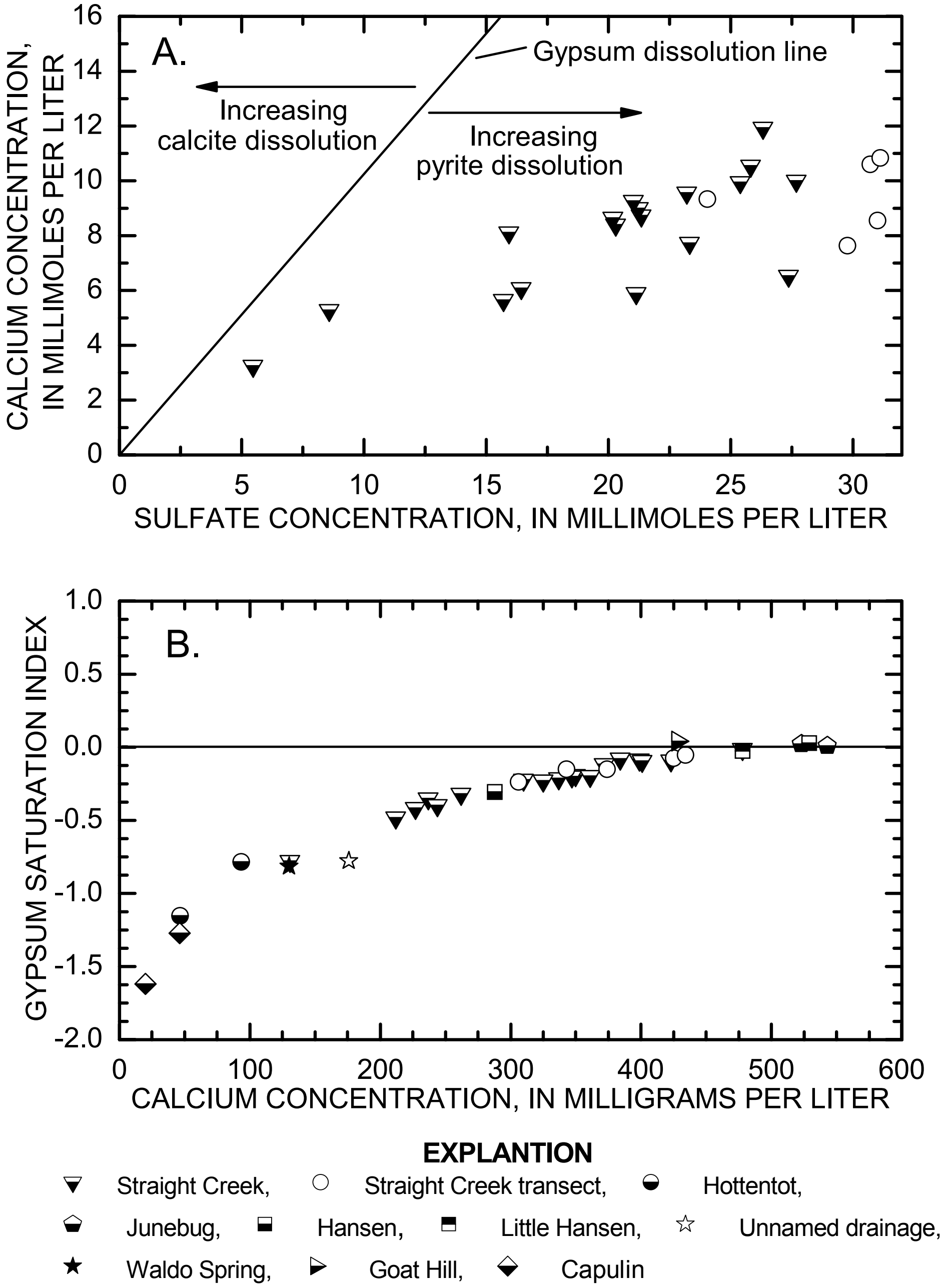


Figure 26. (A) Calcium concentration in relation to sulfate concentration in Straight Creek with gypsum congruent dissolution line and (B) gypsum saturation indices in relation to calcium concentration.

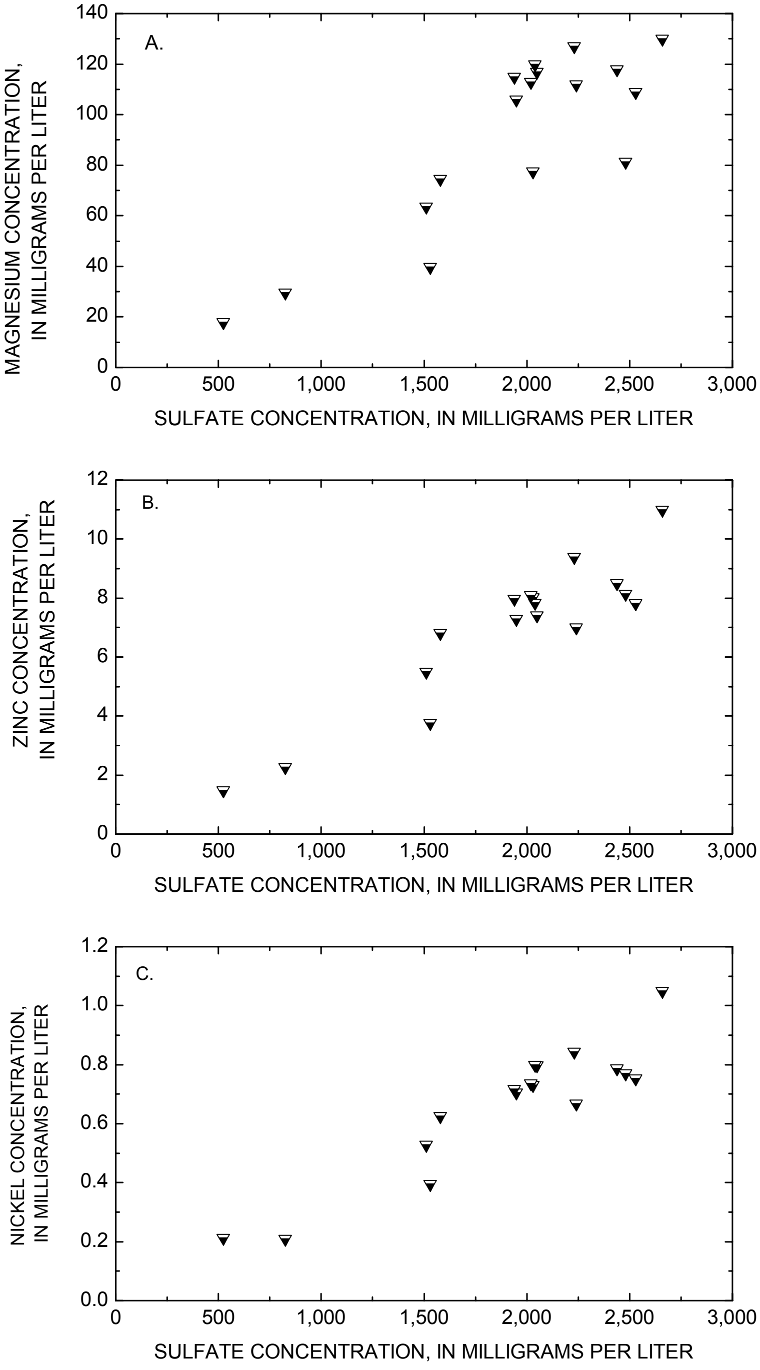


Figure 27. (A) Dissolved magnesium, (B) zinc, and (C) nickel concentration in relation to sulfate concentration in Straight Creek.

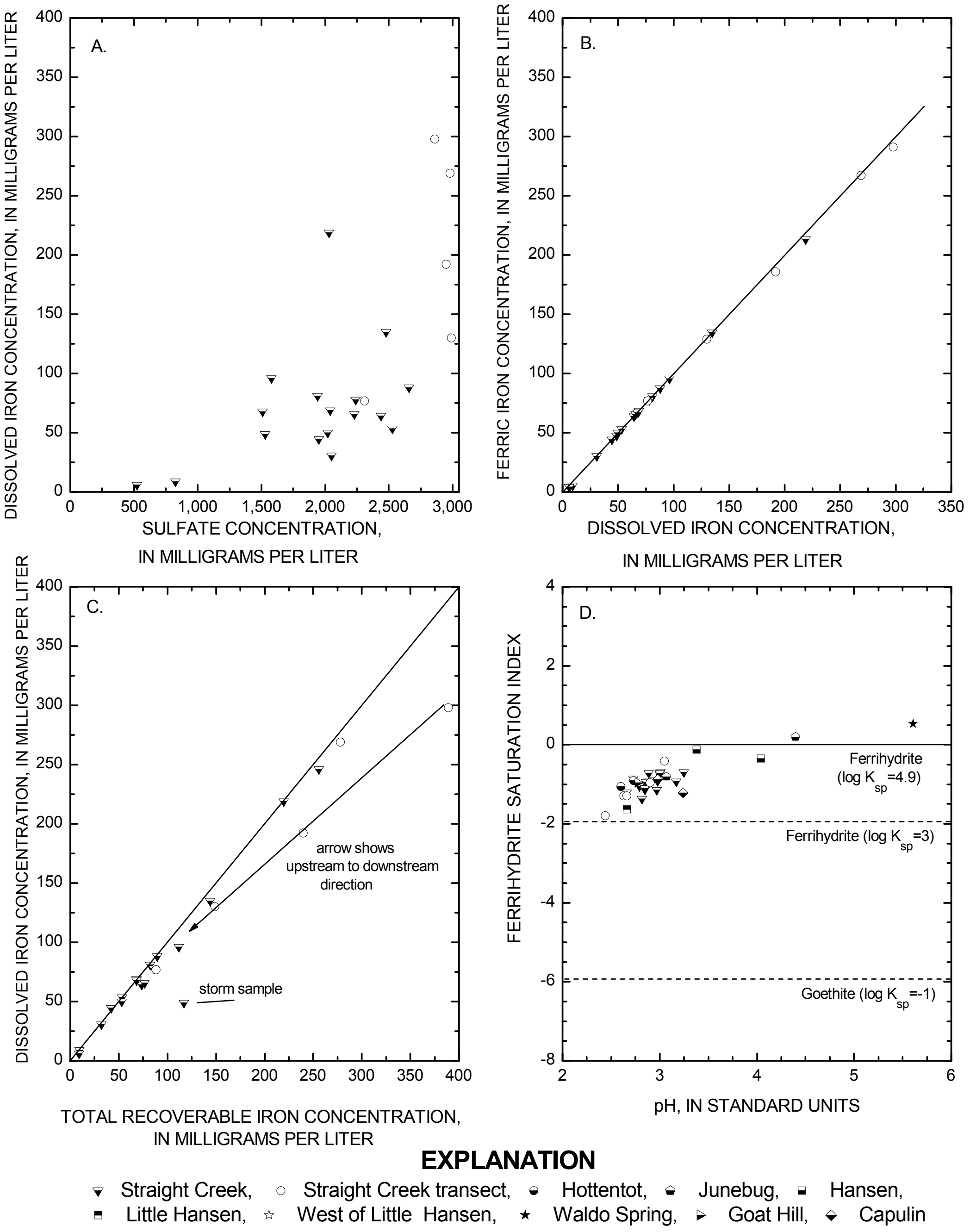


Figure 28. (A) Dissolved iron concentration in relation to sulfate concentration, (B) dissolved ferric iron concentration in relation to dissolved iron concentration, (C) dissolved iron concentration in relation to total recoverable iron concentration, and (D) ferrihydrite saturation indices in relation to pH.

others, 2005), almost all the dissolved iron in Straight Creek surface water exists as ferric iron (fig. 28B), indicating rapid, probably microbially catalyzed, oxidation of ferrous iron derived from ground-water discharge to the stream. The highest concentration of dissolved iron occurred in the uppermost Straight Creek October 2003, transect sample (03WA168), and the dissolved iron concentration decreased with distance in the downstream direction. When dissolved iron concentrations are compared with total recoverable iron concentrations, two of the upstream transect samples and one of the storm-event samples lie substantially below the 1:1 correlation line (fig. 28C), consistent with a fraction of the iron in the water column being particulate. This trend suggests that the downstream decrease in dissolved iron concentration is at least in part the result of precipitation of iron. The total-recoverable iron concentration also decreased, which indicates possible removal of iron precipitates from the water column. Iron precipitation is consistent with the presence of ferricrete within some reaches of the stream channel. Dilution by water with less dissolved iron may account for some of the downstream decrease in dissolved iron.

For the October 2003, downstream transect samples, the dissolved iron concentration decreased with increasing pH. The relation is consistent with the increase in iron saturation with increasing pH. Mineral phases that might control iron concentrations include siderite or ferrihydrite. Siderite is undersaturated in these acid waters because the carbonate concentrations are too low. Ferrihydrite saturation appears to be a primary control on dissolved iron concentration (fig. 28D).

If oxidation of ferrous iron to ferric iron and subsequent precipitation as ferrihydrite were the only process affecting the chemistry of the Straight Creek as it flows downstream, the pH would not increase because the formation of iron oxyhydroxides produces H^+ thus lowering the pH. The downstream increase in pH suggests that additional water enters Straight Creek and this water has slightly higher pH than the upper samples (pH 2.44-2.66). Because the overall range in pH for the Straight Creek samples collected under different hydrologic conditions was relatively narrow, the water entering Straight Creek below the upper section likely has a pH of less than 4.

Because many of the trends in this dataset reflect lower concentrations caused by dilution, it is difficult to separate elements into suites that are derived from similar sources. Elements that behave differently under the same hydrologic conditions would appear to have different sources. Some elements that are chemically similar, cobalt and nickel for example, covary (fig. 29) and therefore likely have the same source. Nickel concentrations also covary with magnesium concentrations suggesting a similar source mineral (fig. 30). Zinc and manganese concentrations covary, again suggesting a similar source mineral or lithology (fig. 31). Copper and zinc concentrations are less well-correlated (fig. 32), but in aqueous solutions their behavior is pH dependent. Thus, it is difficult to determine whether they have similar sources. From the first to the fourth sample along the downstream profile, the zinc concentration decreases from 14.7 to 10.8 mg/L whereas the copper concentration remains relatively constant (2.42 to 2.64 mg/L), suggesting that zinc has a different source than copper.

High-silica magmas were the parental material for molybdenum mineralization at Questa and were enriched in a suite of trace elements including fluorine, beryllium, and lithium as well as tin, tungsten, and uranium (Elston, 1994). Fluoride, beryllium, and lithium concentrations also are elevated in the acid waters of Straight Creek. With the exception of the most upstream transect samples (03WA168 and 03WA169), beryllium and lithium concentrations covary (fig. 33A), but fluoride is less well correlated (fig. 33B).

Rare Earth Elements

A subset of samples was analyzed by ICP-MS to evaluate whether additional trace-element data (table 5) could help unravel the chemical evolution of these waters. Rare earth elements (REEs) are a suite of 14 metals from atomic number 57 (La) to 71 (Lu) that have similar chemical and physical properties. The REEs are frequently used as geochemical tracers because of their coherent chemical behavior. Concentrations of REEs usually are normalized to a reference standard, such as chondrite or North American Shale Composite. We have chosen to normalize these waters to chondrite

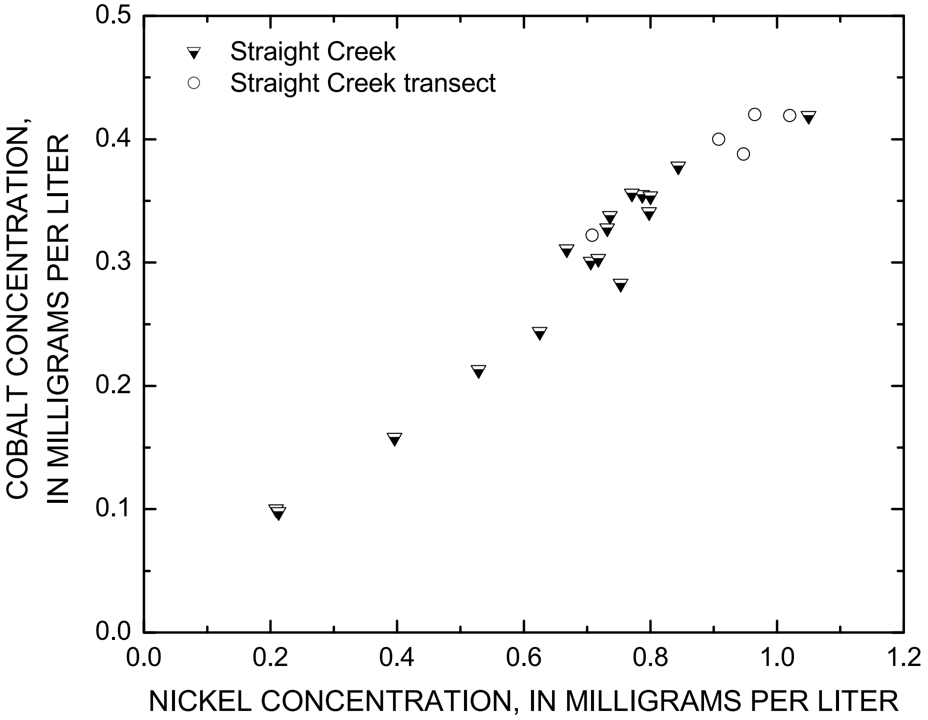


Figure 29. Cobalt concentration in relation to nickel concentration in Straight Creek.

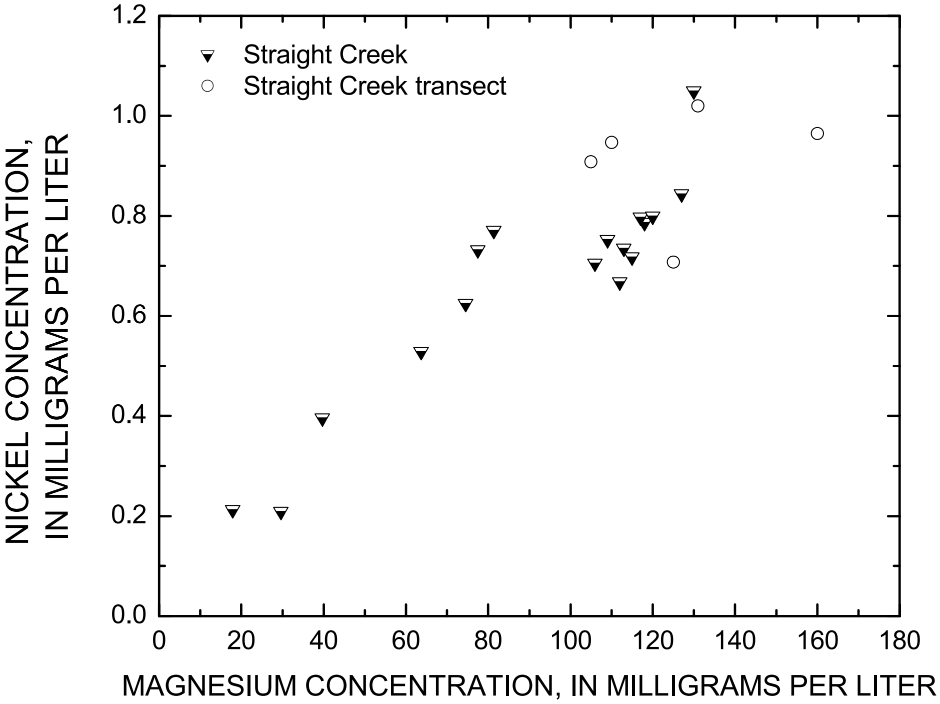


Figure 30. Nickel concentration in relation to magnesium concentration in Straight Creek.

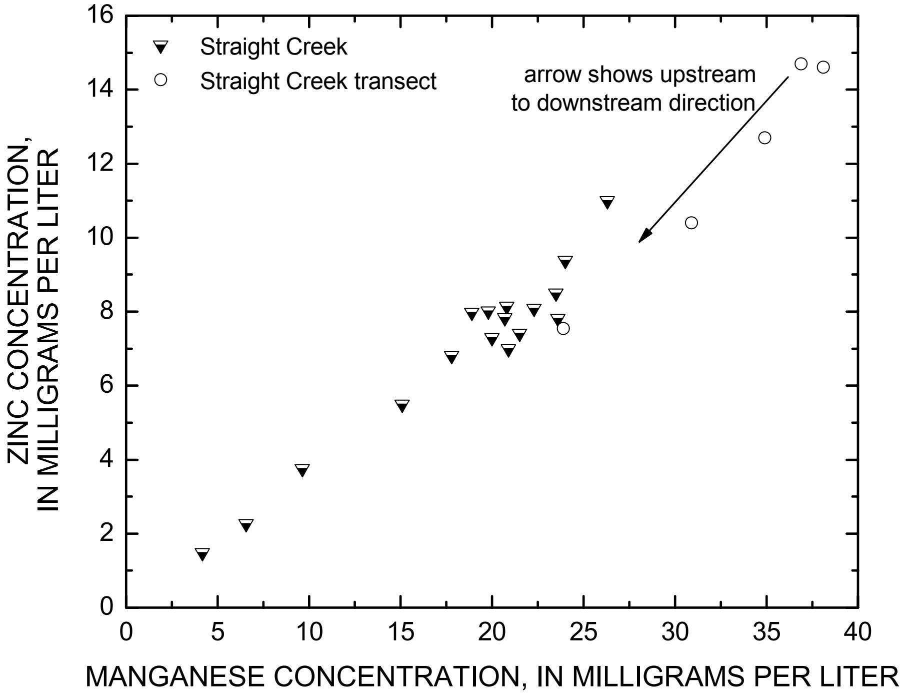


Figure 31. Zinc concentration in relation to manganese concentration in Straight Creek.

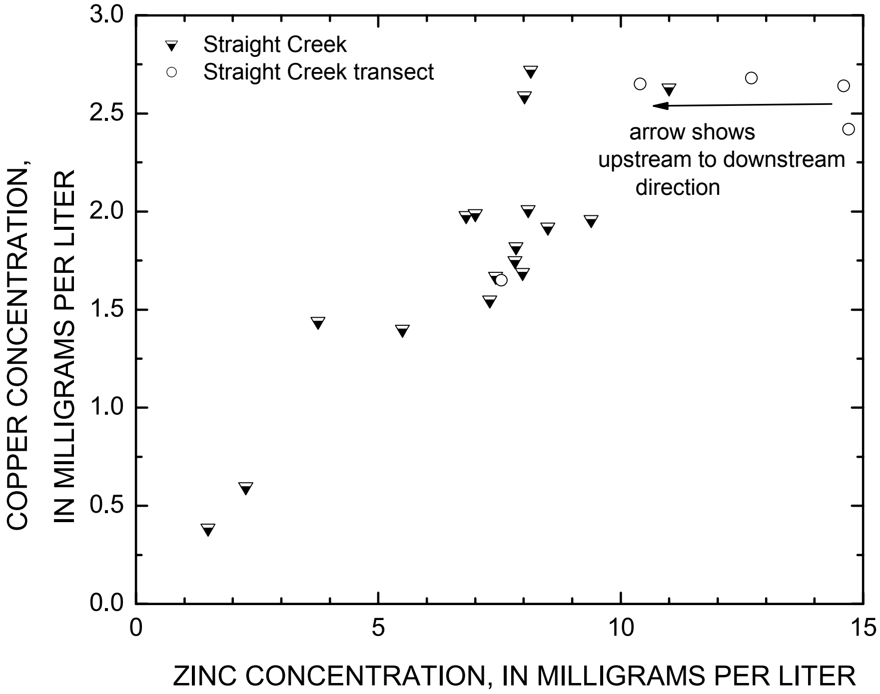


Figure 32. Copper concentration in relation to zinc concentration in Straight Creek.

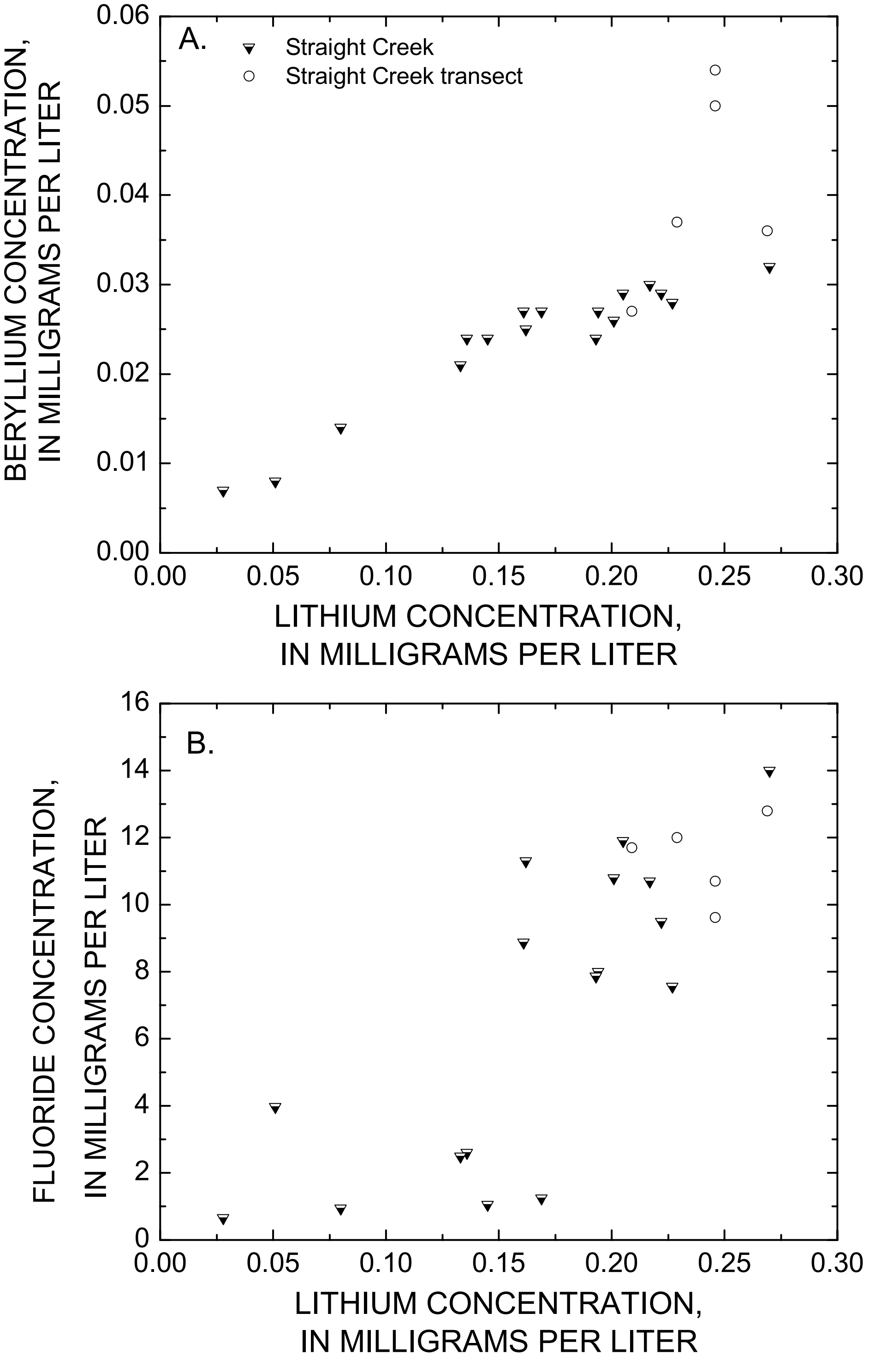


Figure 33. (A) Beryllium concentration in relation to lithium concentration in Straight Creek and (B) fluoride concentration in relation to lithium concentration in Straight Creek.

values from Anders and Ebihara (1982) because we are particularly interested in europium variations in our samples.

Although the REE concentrations varied by nearly an order of magnitude, the four samples collected from the Straight Creek sampling site (00WA197, 01WA154, 02WA112, and 02WA121) above the alluvial fan display similar REE patterns (fig. 34) with a relatively flat light REE (La to Nd) portion, a moderate negative Eu anomaly, and a moderate slope for the heavy REEs (Dy to Lu). This pattern is similar to the REE patterns for the sample from SC1A (fig. 34). The Straight Creek sample with the substantially lower REE concentrations was collected in March 2002 while snow that had fallen the previous day was melting. The sample collected from the upper portion of Straight Creek (Straight Creek high; 01WA155) has a substantially larger Eu anomaly (fig. 34). This water drains the Amalia Tuff which also displays a large negative Eu anomaly (Johnson and Lipman, 1988; Lipman, 1988). In contrast, the precaldera andesites that are lithologically below the Amalia Tuff do not contain a Eu anomaly. The smaller Eu anomaly of the lower Straight Creek waters could originate by mixing of water that drains the andesite, and does not contain a Eu anomaly, with water from upper Straight Creek.

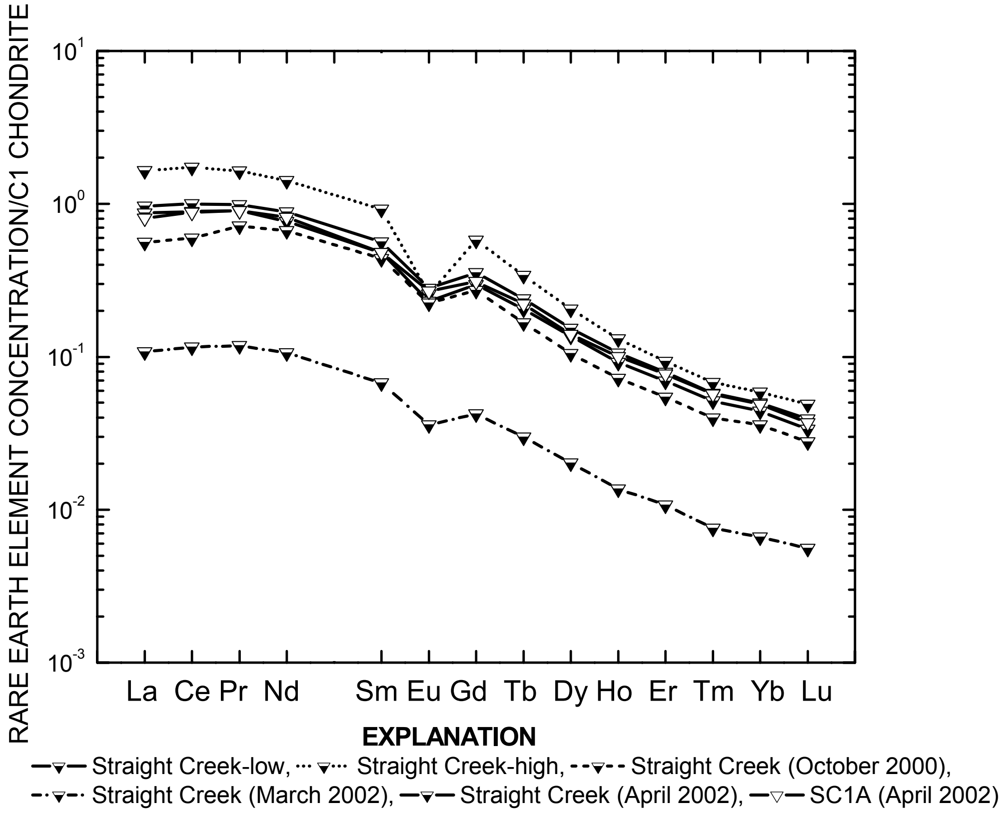


Figure 34. Rare earth elements in selected Straight Creek waters. Concentrations normalized to C1 chondrite values from Anders and Ebihara (1982).

Stable Isotopes

The oxygen and hydrogen isotopic compositions of selected samples are plotted along with the global meteoric water line, the Rocky Mountain meteoric water line, snow samples from the Red River watershed, and snow and rain samples collected in April 2003 (Naus and others, 2005; fig. 35A). The isotopic composition of most of the Straight Creek waters lies in the central part of the graph; one sample lies within the field defined by the composite snow samples. This sample (02WA102; collected February 2002) is one of the most dilute Straight Creek samples and appears to have a substantial fraction of seasonal snowmelt. Figure 35B is a closer look at the Straight Creek and transect samples. These samples define a slight evaporation trend. The slope of the best linear fit (dotted line in figure 35B) for δD and $\delta^{18}O$ is 6.3 for these nine points so that there is about a one per mil oxygen isotope shift for the heaviest stable isotope values. The slope of the δD- $\delta^{18}O$ evaporative line is affected by humidity, temperature, and wind speed. This decreased slope could be caused by evaporation at around 90 percent humidity (Clark and Fritz, 1999), but the average annual humidity in this region is much lower. Most of the alteration scars occur at higher elevations, 3,000 to 3,500 m, and snowpack is a primary source of moisture. Along the north side of the Red River Valley there also is considerable exposure to solar radiation that should contribute to evaporative enrichment of the snowpack. Evaporative enrichment of snow with δD- $\delta^{18}O$ slopes close to 6 is entirely reasonable and has been measured under experimentally controlled conditions (Moser and Stichler, 1975). Furthermore, in the upper sites, 03WA168-03WA170, flow is slow and the water depth is quite shallow, optimal conditions for evaporation.

The oxygen and sulfur isotopic compositions of sulfate in selected Straight Creek samples collected at the site upstream of the debris fan display little variation (fig. 36). This isotopic composition is similar to that of well SC1A (Naus and others, 2005). The oxygen isotopic compositions of sulfate in the set of Straight Creek downstream transect samples displayed little variation (-7.1 to -7.4), but the sulfur isotopic compositions increased downstream from -6.6 to -4.2.

Mineralogical Controls on Water Chemistry

To evaluate possible weathering reactions that control the solute chemistry of Straight Creek, inverse geochemical models based on measured water chemistry and mineralogical data were constructed. These mass-balance calculations were done using the geochemical modeling program NETPATH (Plummer and others, 1994). The first set of calculations were undertaken to constrain the weathering reactions needed to convert rain water to Straight Creek surface water. In these simulations, hypothetical meteoric water was reacted with known minerals in the catchment to determine whether the measured water chemistry was consistent with weathering of the local bedrock. The chemistry of meteoric water was estimated using annual, volume-weighted mean concentrations from the National Atmospheric Deposition Program's monitoring station at Capulin Volcano National Monument, and the Straight Creek most probable values from D. K. Nordstrom (U.S. Geological Survey, written commun., October 2005) were used as the final water. Elements included in this exercise were aluminum, calcium, copper, fluoride, iron, magnesium, potassium, silica, sodium, sulfur, and zinc. Mineralogical data were taken from Loucks and others (1977), Martineau and others (1977), Briggs and others (2003), Ludington and others (2004), and Plumlee and others (in press).

The modeling results are presented in table 9. Two models were found that satisfy the chemical and mineralogical data. Both models call for the dissolution of gypsum, pyrite, kaolinite, albite, fluorite, sphalerite, illite, and chalcopyrite and the precipitation of silica and goethite. One model uses chlorite for the source of magnesium, and the other calls for dolomite. Goethite was used as the iron precipitate, but other iron oxyhydroxide minerals, such as jarosite and schwertmannite, are likely to be iron sinks as well.

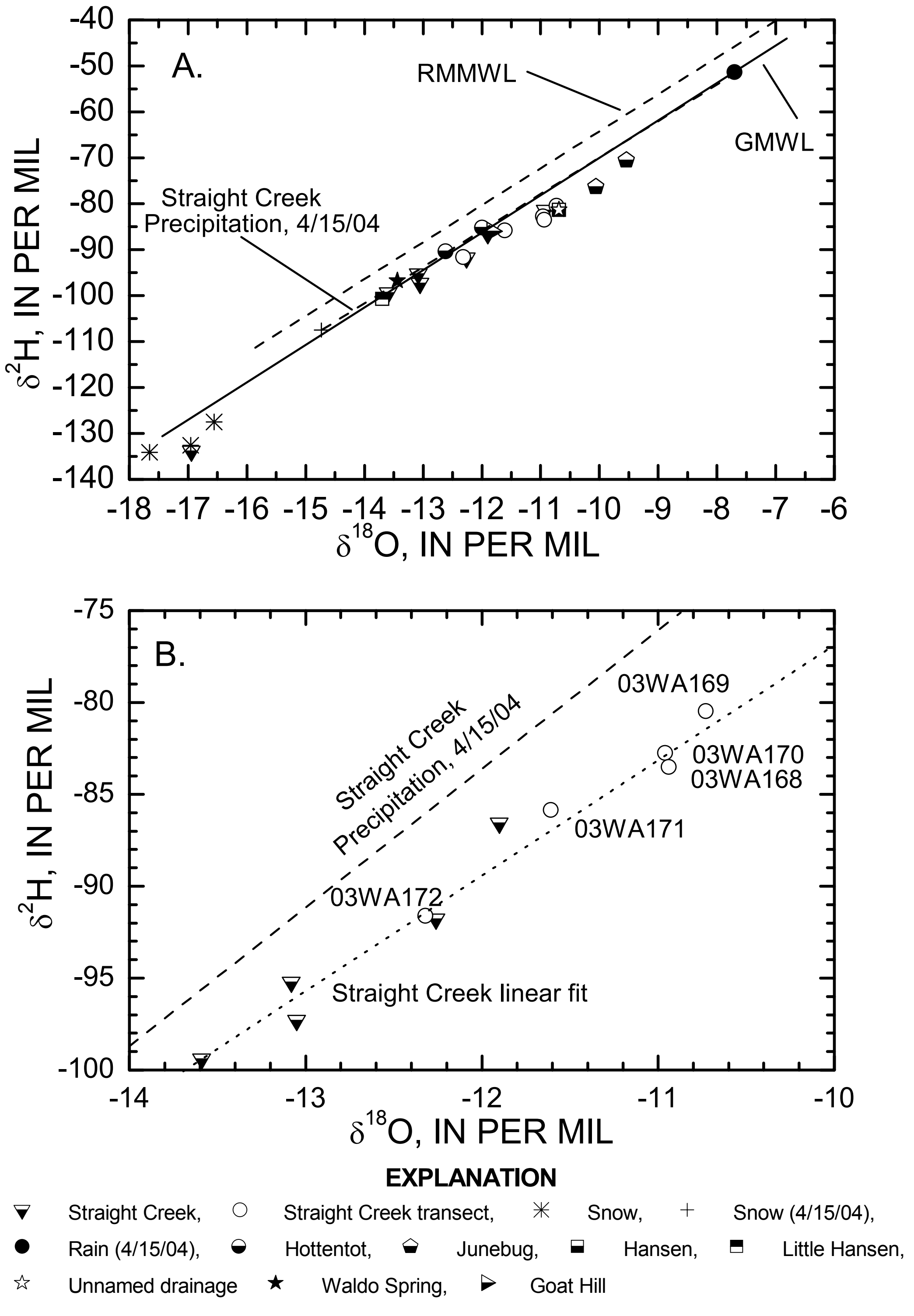


Figure 35. (A) Hydrogen isotopic composition in relation to oxygen isotopic composition of waters with precipitation line from Straight Creek, the Rocky Mountain meteoric water line (RMMWL), and the global meteoric water line (GMWL). (B) Enlarged view of Straight Creek transect samples.

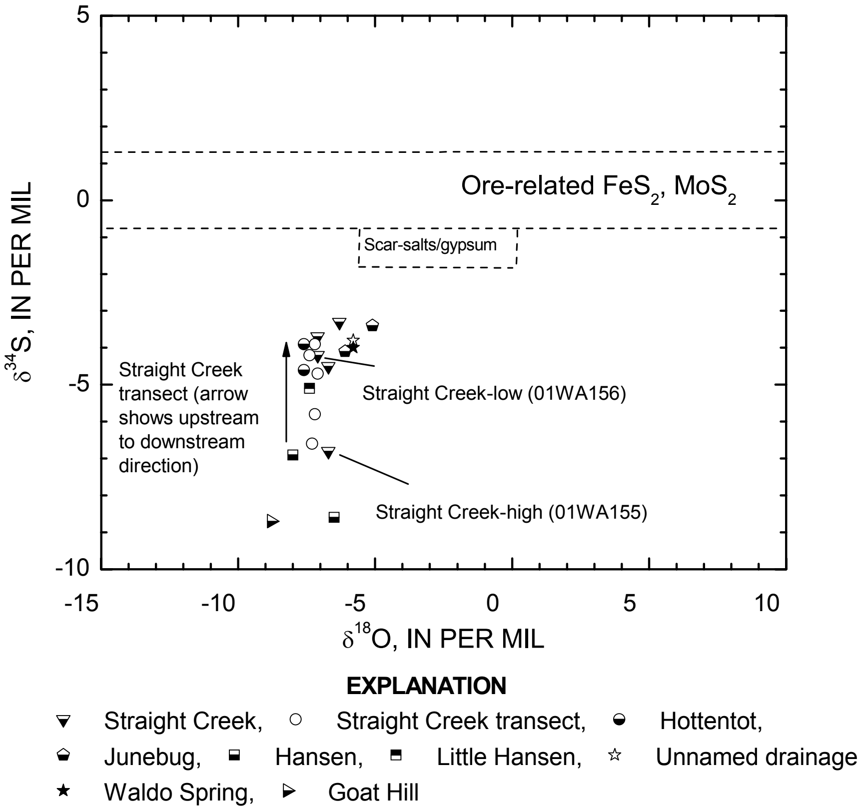


Figure 36. Sulfur isotopic composition in relation to oxygen isotopic composition of sulfate in waters. Isotopic data for solid phase fields from Field (1966), Stein (1985), Tuttle and others (2003), and Naus and others (2005).

A second set of calculations were done to evaluate if Straight Creek surface water is a likely initial water for water in the uppermost bedrock well (SC1B; fig. 4). Again, the most probable values from D. K. Nordstrom (U.S. Geological Survey, written commun., October 2005) for the Straight Creek and SC1B waters were used. Comparing the Straight Creek surface water and ground water in well SC1B, there is an increase in pH (2.98 to 6.75), calcium (349 to 503 mg/L), magnesium (113 to 215 mg/L), potassium (0.75 to 11.2 mg/L) and alkalinity (0-493 mg/L, as bicarbonate) and a decrease in sulfate (2,030 to 1,850 mg/L), silica (74.2 mg/L), aluminum (915 to 0.012 mg/L) and iron (65.0 to 1.85 mg/L). The modeling results are presented in table 10. Three models were found that satisfy chemical and mineralogical data. All the models call for the dissolution of dolomite, albite, illite, and chlorite, and the precipitation of kaolinite, gypsum, silica and goethite. The primary differences between the models are the sources of calcium and magnesium. In contrast to the surface-water results, these models call for the precipitation of gypsum to account for the decrease in sulfate concentration. This conclusion seems reasonable because supergene gypsum occurs throughout the watershed (Ludington and others, 2004).

Summary of Straight Creek Water Quality

The upper-most water sampled in Straight Creek, within 50 m of the drainage divide, had a pH of 2.66 and solute concentrations consistent with rain water reacting with underlying bedrock and colluvium. Much of the upper part of Straight Creek is intensely hydrothermally altered, and the quartz sericite-pyrite mineral assemblage provides minimal buffering capacity (Ludington and others, 2004). Stable isotopic

Table 9. Results of mass-balance modeling of Straight Creek surface water

[Positive values indicate mineral dissolution and negative values indicate mineral precipitation in units of millimoles of mineral per liter of water]

MODEL 1		MODEL 2	
PHASES	MASS	PHASES	MASS
Gypsum	+8.5	Pyrite	+8.7
Pyrite	+6.3	Dolomite	+4.7
Chlorite	+0.93	Gypsum	+3.9
Kaolinite	+0.56	Kaolinite	+1.5
Albite	+0.35	Albite	+0.35
Fluorite	+0.20	Fluorite	+0.20
Sphalerite	+0.12	Sphalerite	+0.12
Illite	+0.03	Illite	+0.03
Chalcopyrite	+0.03	Chalcopyrite	+0.03
Goethite	-5.2	Goethite	-7.5
Silica	-3.8	Silica	-2.9

Table 10. Results of mass-balance modeling of ground water in well SC1B

[Positive values indicate mineral dissolution and negative values indicate mineral precipitation in units of millimoles of mineral per liter of water]

MODEL 1		MODEL 2		MODEL 3	
PHASES	MASS	PHASES	MASS	PHASES	MASS
Dolomite	+3.8	Calcite	+3.8	Mg Calcite	+3.8
Epidote	+0.97	Dolomite	+2.0	Dolomite	+1.9
Albite	+0.56	Albite	+0.56	Albite	+0.56
Illite	+0.45	Illite	+0.45	Illite	+0.45
Chlorite	+0.04	Chlorite	+0.42	Chlorite	+0.43
Kaolinite	-3.5	Kaolinite	-2.7	Kaolinite	-2.7
Goethite	-2.0	Gypsum	-1.9	Gypsum	-1.9
Gypsum	-1.9	Goethite	-1.1	Goethite	-1.1
Silica	-0.06	Gibbsite	-0.51	Gibbsite	-0.51

results suggest that evaporation may play a minor role in the elevated solute concentrations.

During this study, water sampled at lower elevations in the catchment had a minimal range in pH (2.73 to 3.25) but a substantial range in many solutes; for example sulfate concentrations varied from 525 to 2,660 mg/L. Many elements covary with sulfate suggesting that dilution is the primary control of the range in solute concentrations.

Except during high-flow conditions, all of the Straight Creek surface water infiltrates into the upper part of the Straight Creek debris fan. This surface water appears to be the primary source of ground water to the uppermost alluvial well (SC1A). High-flow events correlate with increases in the static water level of SC1A (fig. 24). Mass-balance calculations show that interaction of Straight Creek surface water with the underlying bedrock can account for the chemistry of water in well SC1B.

Seeps and Tributaries, 2001-2004

To characterize waters emanating from the scar areas, a set of surface-water samples was collected during low-flow conditions, September 2001. Sampling occurred from September 10 to 18, in conjunction with the solid-phase sample collection reported in Briggs and others (2003). Whenever possible, water was sampled at the lowest and highest points in each tributary. In most all tributary basins water emerged from the bedrock or colluvium near the drainage divide and flowed over bedrock or ferricrete to the debris fan. Upon entering the channel in the upper portion of the debris fan, discharge decreased until all the surface water completely entered the streambed. The lowest and highest points were sampled in Hansen, Straight, and Hottentot Creeks; only the lowest point was sampled in Little Hansen Creek and the unnamed drainage to the west of Little Hansen Creek (table 1; fig. 1). Waldo Spring, located near the base of the unnamed drainage to the west of Little Hansen, also was sampled. Two tributaries draining the east and west sides of the Junebug scar were sampled at the base of the scar. In addition, a sample from Goat Hill Gulch was collected approximately 250 m upstream from the glory hole, and this sample was a mixture of scar seepage and waste-rock-pile seepage. Water emanating from the Capulin Canyon waste-rock-pile flows into a collection pond and then is pumped to Goat Hill Gulch above the sampling site. The water flows down the gulch and into the subsidence area, where the water then seeps into the underground workings. Water in the underground workings is collected and pumped to the tailings facility. Two samples from the Capulin Canyon scar area were collected in May 2004.

Figure 37 displays the variation in pH and sulfate for the low-flow tributary sample set. The pH values range from 2.60 to 7.71, and the sulfate concentrations range from 4,120 to 13,500 mg/L. The sulfate concentration of the Goat Hill Gulch sample (13,500 mg/L) is almost 10,000 milligrams per liter greater than the next most-concentrated sample (Little Hansen Creek with 3,700 mg/L). Water entering Goat Hill Gulch from the Capulin surface-water impoundment pipe, collected and analyzed in June, August, and November of 2001, had sulfate concentrations of 15,000, 9,300, and 18,000 mg/L (S.H. LoVetere, U.S. Geological Survey, written commun., March 2005). Many constituent concentrations in the Goat Hill Gulch sample were substantially greater than the rest of the tributary data and are not plotted because addition of this point expands the axes and obscures other trends. The unnamed drainage without a scar, west of Little Hansen Creek, had the highest pH value (7.71) and lowest sulfate concentration (412 mg/L). Waldo Spring had a slightly higher sulfate concentration (480 mg/L) and lower pH value (5.61). The pH values of the two Capulin Canyon scar water samples were similar to those of the other scar tributary waters (2.98 and 3.24), but the sulfate concentrations were substantially lower (668 and 746 mg/L)

For most tributary samples the dissolved iron concentration accounts for virtually all the iron in the unfiltered samples (fig. 38A). Two exceptions are samples from the unnamed drainage without a scar where the dissolved iron was low (0.01 mg/L) and accounted for 20 percent of the total iron, and from one of the Junebug sites where the dissolved iron was 0.70 mg/L and the total iron was 7.2 mg/L. Similar to Straight Creek surface waters and Straight Creek wells (Naus and others, 2005), the iron concentrations in the scar tributary water appear to be controlled by ferrihydrite saturation (fig. 28D) and ferric iron accounts for most of the dissolved iron in the waters from the other scar tributaries (fig. 38B). The Capulin Canyon scar

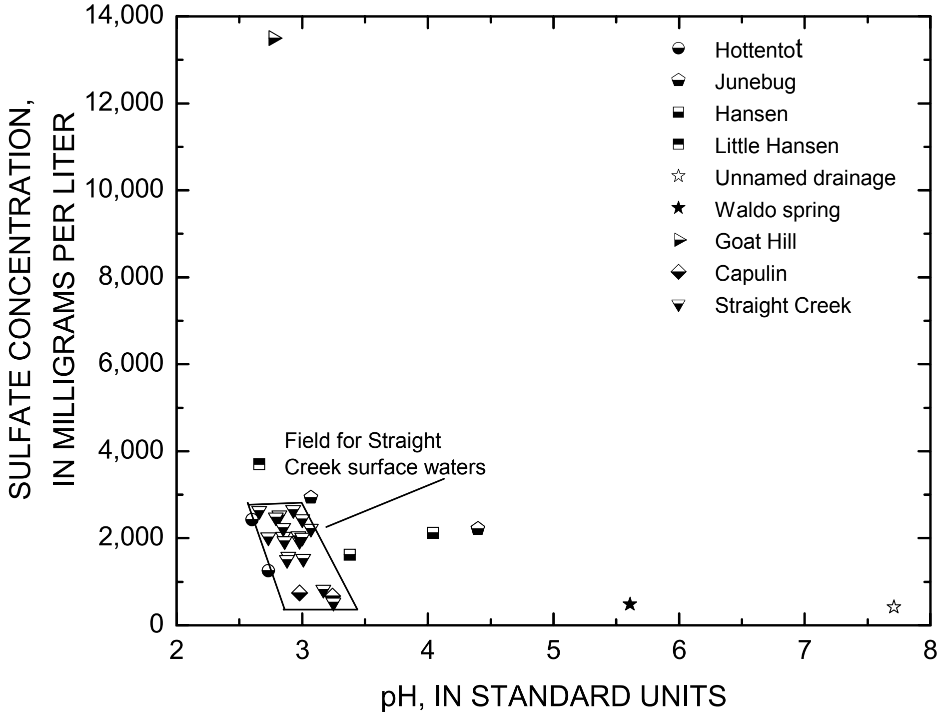


Figure 37. Sulfate concentration in relation to pH for Straight Creek and low-flow tributary samples.

samples are not included in this plot because no sample was collected for determination of iron redox species. The dissolved iron concentrations for the scar tributaries fall within the range of the Straight Creek samples with the exception of one Hottentot Creek sample collected in the upper scar area. Similar to the Straight Creek profile, the dissolved iron concentration in Hottentot Creek decreases from upstream to downstream.

These waters generally can be classified as calcium-sulfate type waters because calcium tends to be the dominant cation and sulfate the dominant anion. Figure 39A depicts calcium concentrations relative to sulfate concentrations, and many samples follow the trend of the Straight Creek samples. As discussed previously, samples which plot to the right of the gypsum dissolution line require an additional source of sulfate (pyrite) other than gypsum. The sample from the unnamed drainage without a scar, west of Little Hansen Creek, plots along the gypsum dissolution line. The samples from Capulin Canyon and Hottentot Creek plot well below the Straight Creek samples. Both these catchments contain substantial areas of rhyolite porphyry which tends to be pyrite-rich and calcium-poor.

For a given calcium concentration, most tributaries have greater strontium concentrations than those in the Straight Creek samples (fig. 39B). The two Junebug scar samples have the highest strontium concentrations (5.4 and 8.3 mg/L). Naus and others (2005) suggest that dissolution of carbonate minerals is the primary source of the strontium because waters with high calcium concentrations have high strontium concentrations.

Fluoride concentrations are elevated but variable in this dataset. Although dissolution of fluorite is likely the primary source of fluoride, calcium and fluoride concentrations are poorly correlated (fig. 39C). Additional sources of calcium, discussed above, result in this poor correlation. Fluoride also is associated with biotite and phlogopite in this mineral deposit type (Molling, 1989). Along with fluoride, beryllium and lithium are generally enriched in the Questa molybdenum deposit (Ludington and

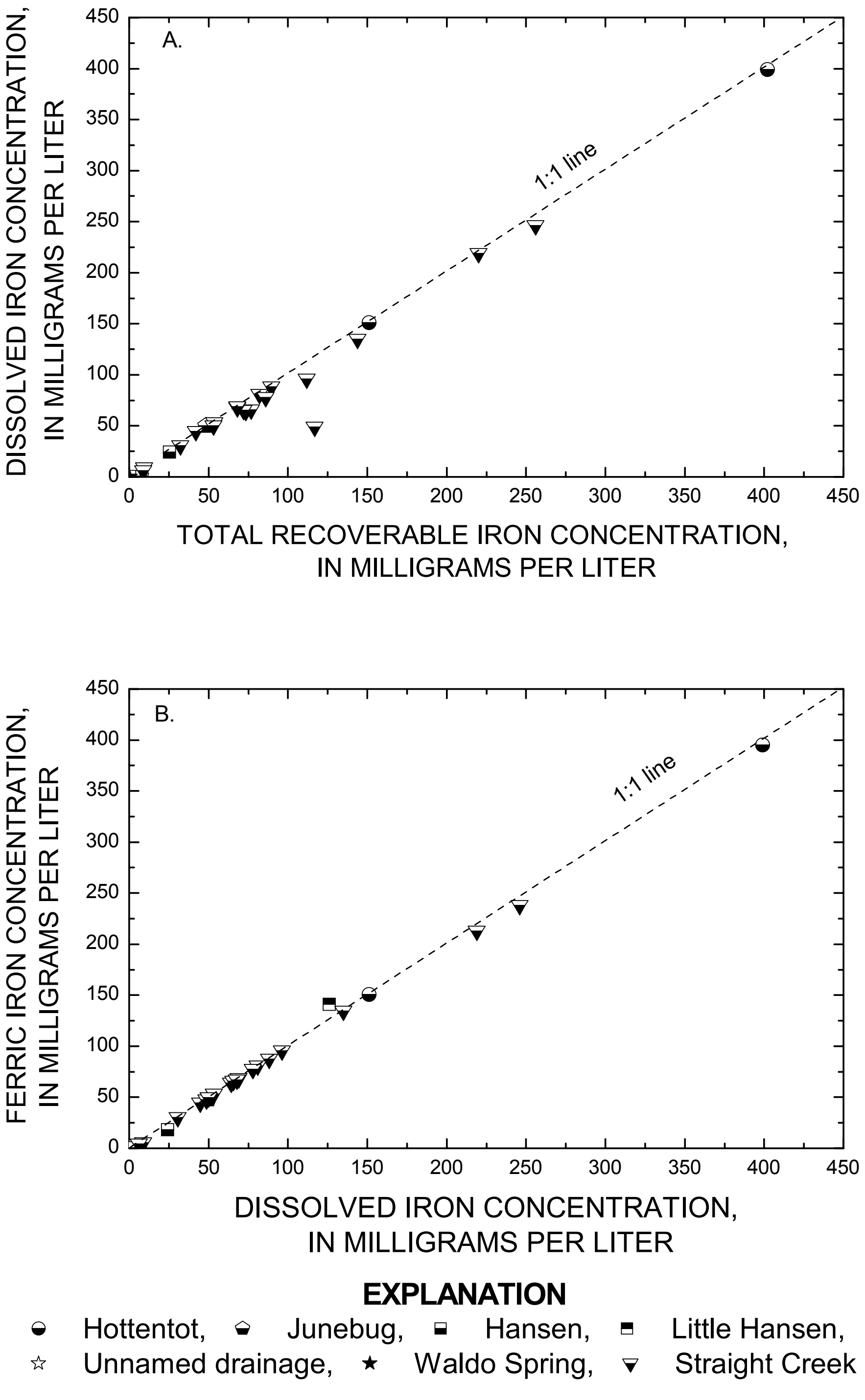


Figure 38. (A) Dissolved iron concentration in relation to total recoverable iron concentration and (B) ferric iron concentration in relation to dissolved iron concentration for Straight Creek and low-flow tributary samples.

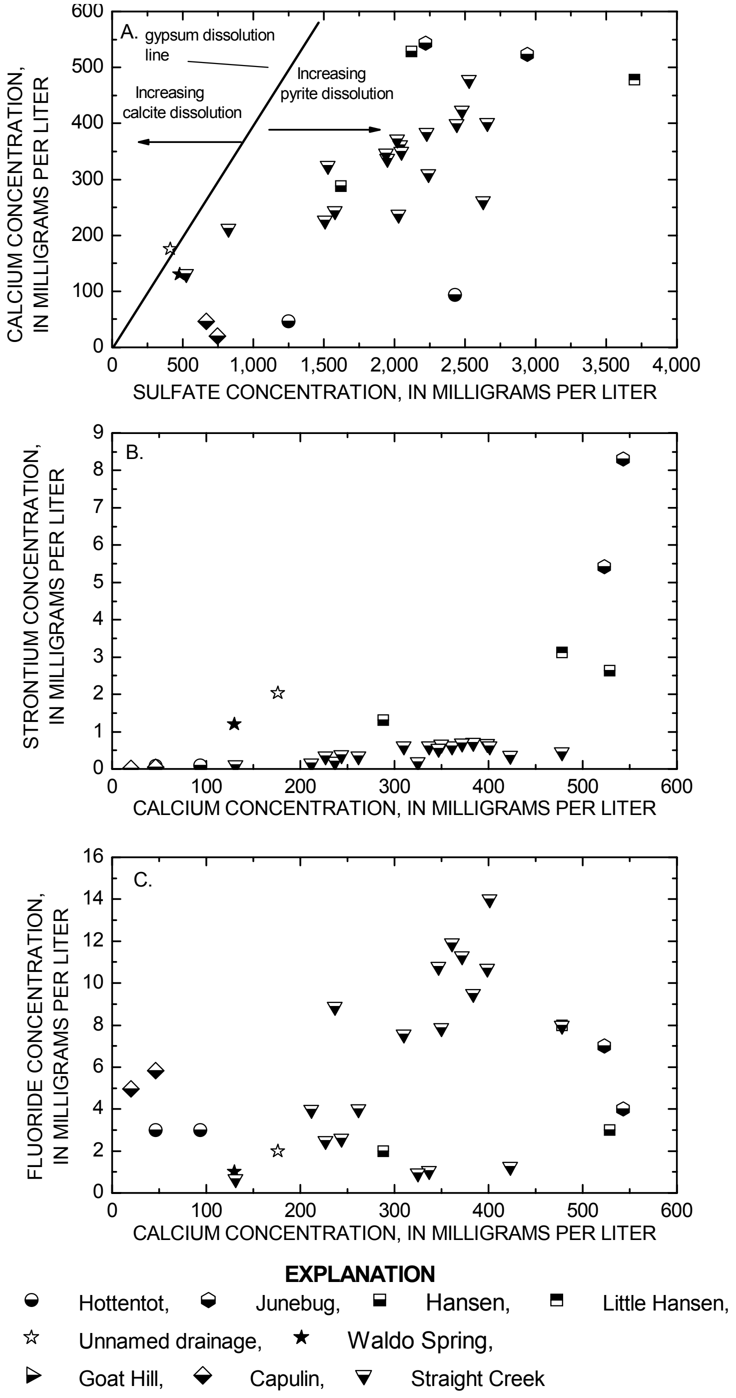


Figure 39. (A) Calcium concentration in relation to sulfate concentration, (B) strontium concentration in relation to calcium concentration, and (C) fluoride concentration in relation to calcium concentration for Straight Creek and low-flow tributary samples.

others, 2004), and these elements tend to covary in the tributary samples (figs. 40A and B).

For a given sulfate concentration, most of the tributary samples have lower zinc concentrations than those of most of the Straight Creek samples (fig. 41A). At this pH range both these constituents should be conservative, thus this difference is likely a source difference. A zinc anomaly, which tends to form a halo around the ore zone, has been identified at the Questa Molybdenum mine (Martineau and others, 1977). The higher zinc concentrations in the Straight Creek drainage may reflect the presence of another center of mineralization. Compared with Straight Creek waters, Hottentot and Junebug scar waters tend to have greater copper concentrations for a given zinc concentration (fig. 41B). Similar to Straight Creek waters the nickel and cobalt concentrations covary (fig. 41C).

Rare earth element concentrations were determined for all the scar tributary samples except the two Capulin Canyon samples. The REE concentrations tend to increase with decreasing pH (fig. 42). This has been documented in other studies and is believed to be a result of increased weathering of REE-bearing mineral phases at lower pH and the tendency for REEs to sorb to iron and aluminum precipitates at pH values between 5 and 6 (Verplanck and others, 2004). The REE patterns of these waters, when normalized to chondrite, display middle REE enrichment with either positive or negative Eu anomalies (figs. 43A and B). Samples with positive Eu anomalies include the two Junebug samples and the Little Hansen Creek sample. These two areas have a greater proportion of intermediate composition volcanic units (andesites and quartz latites) than the other scar tributaries. In higher-temperature environments Eu can have a +4 oxidation state during magma evolution, giving it a size and charge similar to those of calcium. Europium (IV) readily substitutes for calcium in plagioclase, which in turn produces an Eu enrichment relative to other REEs in plagioclase. Weathering of calcic plagioclase from the andesites and latites likely leads to the enrichment of Eu in these waters.

Stable Isotopes

The oxygen and hydrogen isotopic compositions of selected samples are plotted along with the global meteoric water line, the Rocky Mountain meteoric water line, and a snow and rain sample collected in April 2004 (fig. 35). The water isotopic composition of the scar tributary dataset overlap values from Straight Creek and plot along the line defined by precipitation data. Although some samples plot below the line, the trend parallels the precipitation, indicating that little if any evaporation has taken place.

The oxygen and sulfur isotopic compositions of sulfate in selected scar tributary samples are displayed along with the isotopic data for the Straight Creek samples (fig. 36). Most samples plot within the field defined by the Straight Creek dataset. The Hansen Creek and the Goat Hill Gulch samples have distinctly lower sulfur isotopic compositions. Interestingly, the upper Straight Creek samples also have distinctly lower sulfur isotopic compositions. The sulfur isotopic composition of the waste-rock-pile leachate from Capulin also had a sulfur isotopic composition of -8.1 (K. S. Smith, U.S. Geological Survey, written commun., January 2004). Water draining this waste-rock pile appears to be a large source of sulfate in Goat Hill Gulch.

Precipitation

Five samples of the seasonal snowpack were collected in March 2002 to determine the average chemistry of snowmelt (table 11). The pH value of these samples ranged from about 6.08 to 6.27, and as expected these samples are quite dilute, with specific conductance ranging from 8 to 15 μS/cm. Calcium (0.7 to 1.6 mg/L) and sulfate (<0.8 to 3.1 mg/L) are the only two constituents at concentrations greater than one milligram per liter. The oxygen and hydrogen isotopic composition of these samples has been discussed previously (Naus and others, 2005).

SUMMARY

Natural variations in water chemistry of streams and rivers are caused primarily by variations in hydrologic conditions, that is, changing proportions of inflows with contrasting compositions. Varying hydrologic conditions include snowmelt, rainstorms, and degree and

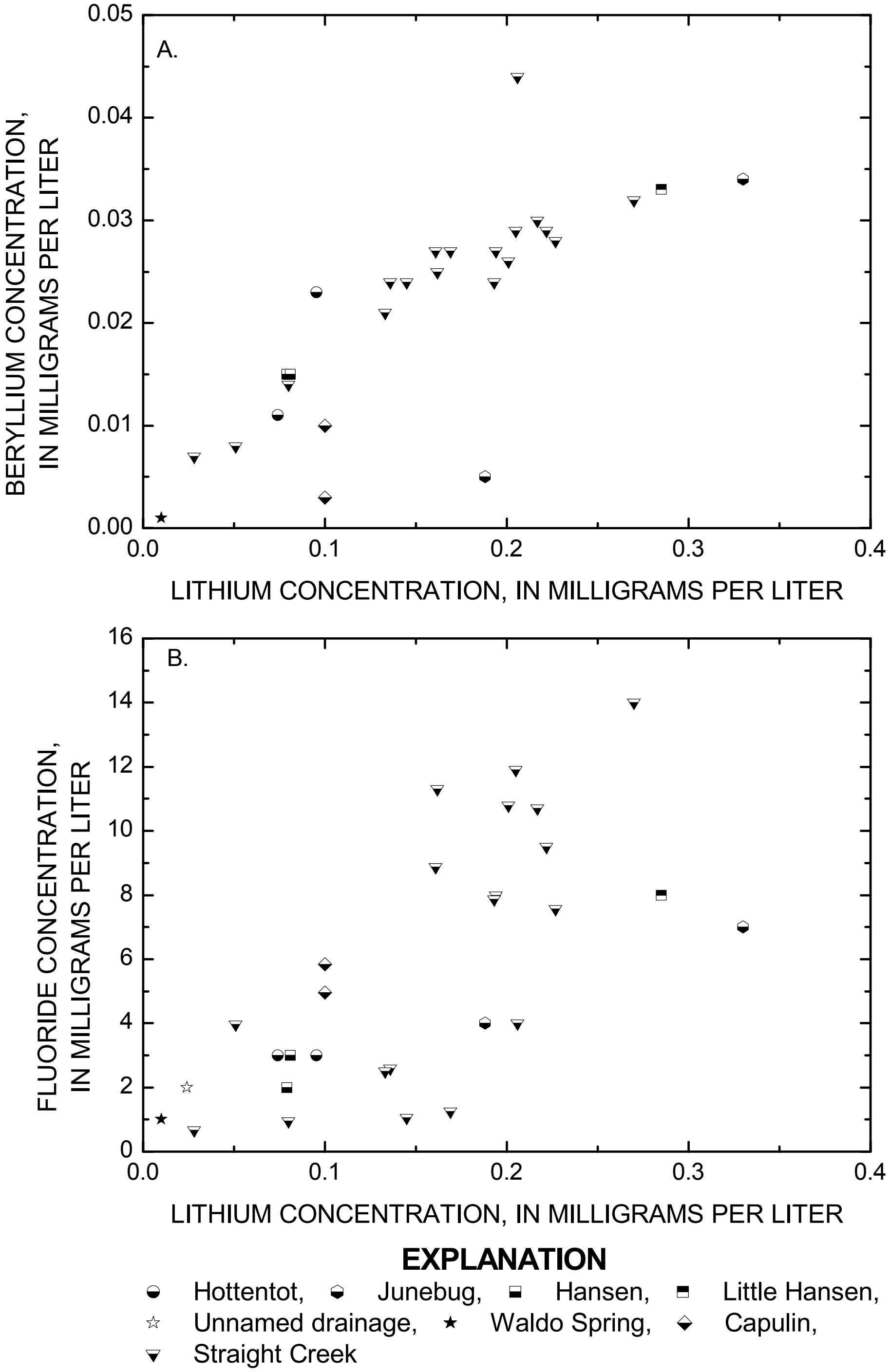


Figure 40. (A) Beryllium concentration in relation to lithium concentration, and (B) fluoride concentration in relation to lithium concentration for Straight Creek and low-flow tributary samples.

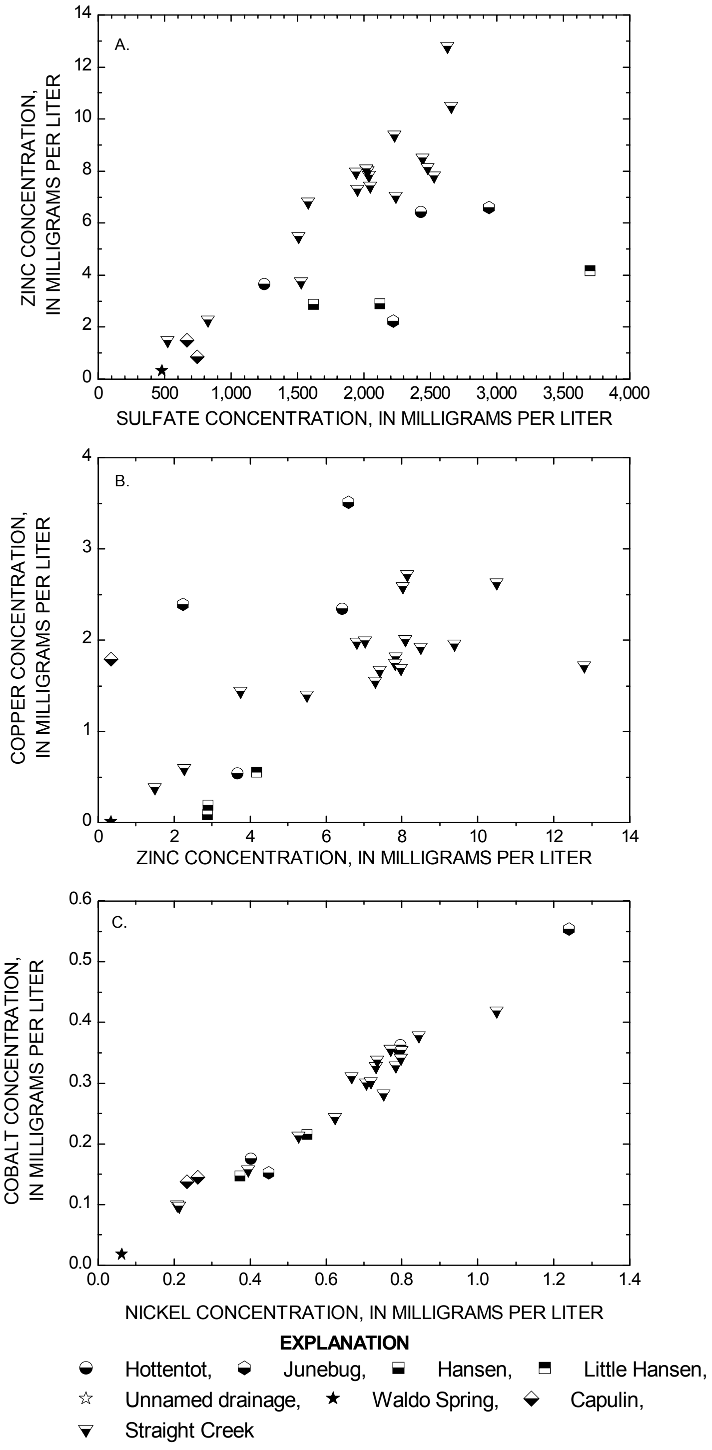


Figure 41. (A) Zinc concentration in relation to sulfate concentration, (B) copper concentration in relation to zinc concentration, and (C) cobalt concentration in relation to nickel concentration for Straight Creek and low-flow tributary samples.

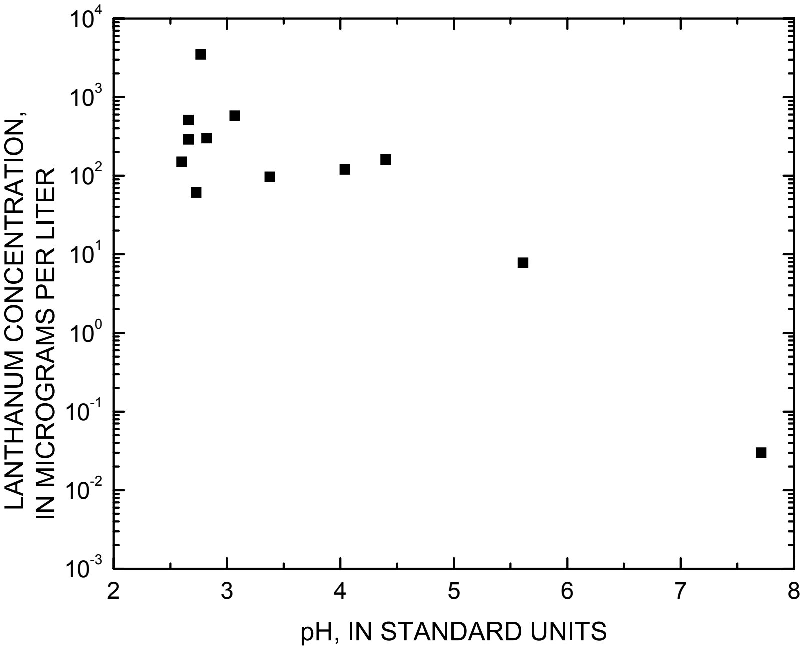


Figure 42. Lanthanum concentration in relation to pH for low-flow tributary samples.

length of dry periods. The Red River and the major scar-area tributaries in the Red River Valley were sampled between 2000 and 2004 to characterize water chemistry. Although seasonal variations in water quality are apparent, the most dramatic variation occurred during a late summer rainstorm event in 2002. In a matter of hours, the Red River discharge increased from 8 to 102 cubic feet per second and pH decreased from 7.80 to 4.83. Low-pH water derived from scar areas appears to be the primary source of acidity to the Red River during such events. The highest concentrations of many constituents, including sulfate and zinc, occurred during this storm event.

The year 2002 was one of the driest on record, and discharge in the Red River reflected the low seasonal snow pack. The traditional peak flow during late spring did not occur, and the highest flow of the year occurred during the late summer storm event described above. The year 2003 was more typical with low flows in the winter and early spring and a substantial snowmelt-derived peak in flow in early June. Snowmelt tends to dilute Red River water such that the lowest concentrations of many constituents occur during this period. The alkalinity values in the rising limb samples were slightly greater (50.6 and 56.6 mg/L as HCO_3^-) than the mean low-flow concentration (46.6 mg/L), and the concentration in the peak discharge sample also was greater (57.9 mg/L). Simple dilution of Red River water by melting snow can not account for this increase. Relatively high-alkalinity water needs to enter the Red River.

To evaluate the effect of solar radiation, two diel sampling events were undertaken during high-flow (May 2003) and low-flow (October 2003) conditions at two sites, the Questa Ranger Station gage and just upstream from the Molycorp Questa mine mill. At both sites during high flow and at the gage during low flow, concentrations of chemical constituents changed minimally and no diel cycle was observed. Upstream from the Questa mine mill during low-flow, a diel cycle was apparent, with pH increasing at night from 8.15

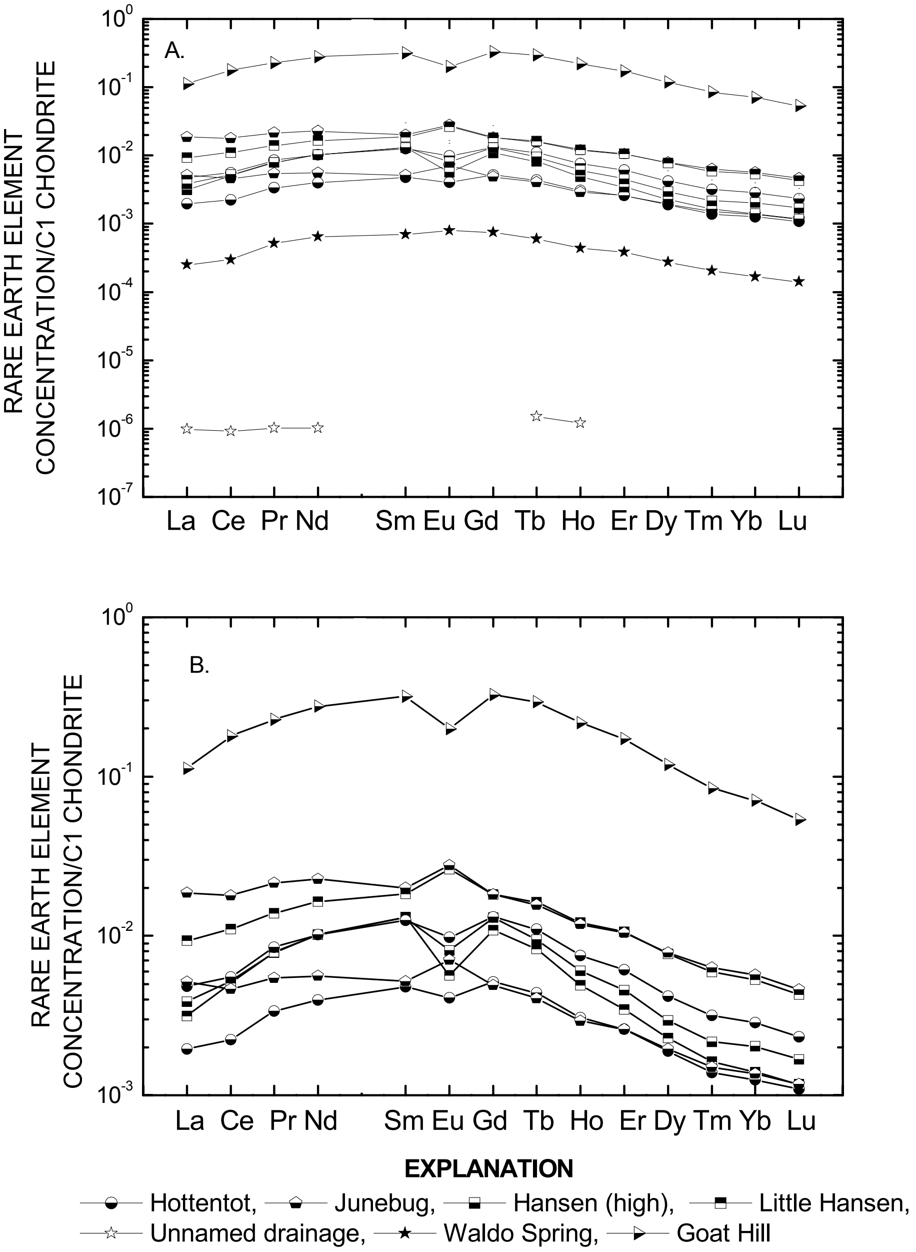


Figure 43. (A) Rare earth elements in selected waters with normalized concentrations ranging from 10^{-7} to 1, and (B) rare earth elements in selected waters with normalized concentrations ranging from 10^{-3} to 1. Concentrations normalized to C1 chondrite values from Anders and Ebihara (1982).

Table 11. Analyses of snow samples

[FA, filtered acidified; FU, filtered unacidified; meq/L, milliequivalents per liter; mg/L, milligrams per liter; µm, micrometer; µS/cm, microSiemens per centimeter; SC, specific conductance]

Sample Location	**North Side, North Facing**	**South Side, Elephant Rock**	**South Side, Bretts Steakhouse**	**Straight Creek**	**Hansen Creek**
Sample code number	**02WA107**	**02WA108**	**02WA109**	**02WA110**	**02WA111**
Collection Date	**3/19/2002**	**3/19/2002**	**3/19/2002**	**3/19/2002**	**3/19/2002**
Treatment	FA/FU - 0.1 µm	FA/FU - 0.1 µm	FA/FU - 0.1 µm	FA/FU - 0.1 µm	FA/FU - 0.1 µm
pH	6.21	6.27	6.28	6.13	6.08
SC (µS/cm)	8	15	13	11	15
Constituent, mg/L					
Ca	0.7	1.4	1.2	1.1	1.6
Mg	<0.1	0.1	<0.1	<0.1	<0.1
Sr	0.004	0.008	0.006	0.005	0.007
Ba	0.002	0.003	0.003	0.002	0.002
Na	0.10	0.34	0.22	0.12	0.13
K	0.14	0.44	0.26	0.11	0.28
Li	<0.002	<0.002	<0.002	<0.002	<0.002
SO_4	<0.8	1.2	<0.8	1.1	3.1
Alkalinity as HCO_3^-	<1	<1	<1	<1	<1
F	<0.1	0.26	0.22	0.1	0.22
Cl	0.3	0.6	0.5	0.3	0.4
Br	<0.1	<0.1	<0.1	<0.1	<0.1
NO_3	1.3	1.8	1.7	1.6	1.4
SiO_2	<0.05	<0.05	<0.05	<0.05	<0.05
B	<0.01	<0.01	<0.01	<0.01	<0.01
Al	<0.07	<0.07	<0.07	<0.07	<0.07
Fe(T)	<0.007	<0.007	<0.007	<0.007	0.01
Mn	0.010	0.021	0.018	0.018	0.030
Cu	<0.003	<0.003	<0.003	<0.003	<0.003
Zn	<0.005	<0.005	<0.005	<0.005	<0.005
Cd	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.002	<0.002	<0.002	<0.002	<0.002
Co	<0.003	<0.003	<0.003	<0.003	<0.003
Ni	<0.002	<0.002	<0.002	<0.002	<0.002
Pb	<0.008	<0.008	<0.008	<0.008	<0.008
Be	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
V	<0.002	<0.002	<0.002	<0.002	<0.002
Mo	<0.007	<0.007	<0.007	<0.007	<0.007
As	<0.04	<0.04	<0.04	<0.04	<0.04
Se	<0.05	<0.05	<0.05	<0.05	<0.05
Sum cations (meq/L)	0.04	0.11	0.08	0.06	0.09
Sum anions (meq/L)	0.03	0.08	0.05	0.06	0.11
Charge imbalance (percent)	35.1	23.9	36.5	-0.6	-14.6

to 8.34 due to photosynthetic consumption of CO_2. Only dissolved Zn and Mn concentrations had definite diel patterns, decreasing to a minimum at about noon and increasing to a maximum before sunrise during low-flow for the site upstream from the mill.

The Straight Creek subbasin was chosen as an analog site for evaluating pre-mining baseline conditions because of its geologic, topographic, and geomorphologic characteristics, and 11 alluvial and bedrock wells were installed to evaluate ground-water flow and chemistry. In this catchment, surface water appears to be the primary input to the debris-fan ground water because high-flow events correlate with increases in the static water level of well SC1A. Furthermore, mass-balance calculations show that interaction of Straight Creek surface water with the underlying bedrock can account for the chemistry of water in well SC1B.

Samples from other tributaries including Hottentot Creek, Junebug, Hansen Creek, Lower Hansen Creek, a relatively unaltered tributary west of Little Hansen Creek, and Goat Hill Gulch, were collected to characterize waters emanating from the scar areas. Water in Goat Hill Gulch had concentrations of most constituents substantially higher than those in water from other tributaries because waste-rock-pile seepage from upper Capulin Canyon is piped over to Goat Hill Gulch. Goat Hill Gulch water flows into the Molycorp glory hole where it enters the underground workings and is collected and piped to the tailings facility. Most constituents in the other scar tributary samples plot within the range of Straight Creek samples.

REFERENCES CITED

Aiken, G.R., 1992, Chloride interference in the analysis of dissolved organic carbon by wet oxidation method: Environmental Science and Technology, v. 26, p. 2435-2439.

Allen, B.D., Groffman, A.R., Molles, M.C. Jr., Anderson, R.Y., and Crossey, L.J., 1999, Geochemistry of the Red River stream system before and after open-pit mining, Questa Area, Taos County, N.M.: Santa Fe, New Mexico Office of the Natural Resources Trustee, October 1999.

American Public Health Association (APHA), 1985, Method 428C. Methylene blue method for sulfide, in Standard methods for the examination of water and wastewater (14th ed.): American Public Health Association, p. 403-405.

Anders, Edward, and Ebihara, Mitsuru, 1982, Solar-system abundances of the elements: Geochimica et Cosmochimica Acta, v. 46, p. 2362-2380.

Ball, J.W., Runkel, R.L., and Nordstrom, D.K., 2005, Questa baseline and pre-mining ground-water quality investigation. 12. Geochemical and reactive-transport modeling based on low-flow and snowmelt tracer studies for the Red River, New Mexico: U.S. Geological Survey Scientific Investigations Report 2005-5149, 68 p.

Barnard, W.R., and Nordstrom, D.K., 1980, Fluoride in precipitation – I. Methodology with the fluoride-selective electrode: Atmospheric Environment, v. 16, p. 99-103.

Barringer, J.L., and Johnsson, P.A., 1989, Theoretical considerations and a simple method for measuring alkalinity and acidity in low pH waters by Gran titration: U.S. Geological Survey Water-Resources Investigations Report 89-4029, 35 p.

Brick, C.M., and Moore, J.N., 1996, Diel variation of trace metals in the upper Clark Fork River, Montana: Environmental Science and Technology, v. 30, p. 1953-1960.

Briggs, P.H., Sutley, S.J., and Livo, K.E., 2003, Questa baseline and pre-mining ground-water quality investigation. 11. Geochemistry of alteration scars and waste piles: U.S. Geological Survey Open-File Report 03-458, 16 p.

Brinton, T.I., Antweiler, R.C., and Taylor, H.E., 1995, Method for the determination of dissolved chloride, nitrate, and sulfate in natural water using ion chromatography: U.S. Geological Survey Open-File Report 95-426A, 16 p.

Clark, I.D., and Fritz, Peter, 1999, Environmental Isotopes in Hydrogeology: Lewis Publishers, Boca Raton, 328 p.

Coplen, T.B., Wildman, J.D., and Chen, J., 1991, Improvements in the gaseous hydrogen-water equilibrium technique for hydrogen isotope ratio analysis: Analytical Chemistry, v. 63, p. 910-912.

Czamanski, G.K., Foland, K.A., Kubacher, F.A., and Allen, J.C., 1990, The ^{40}Ar/^{39}Ar chronology of caldera formation, intrusive activity, and Mo-ore deposition near Questa New Mexico; *in* Bauer, P.W., Lucas, S.G., Mawer, C.K., and McIntosh, W.C. eds., Tectonic development of the southern Sangre de Cristo Mountains, New Mexico: New Mexico Geological Society Guidebook, v. 41, p. 355-358.

Dzombak, D.A., and Morel, F.M.M., 1990, Surface Complexation Modelling: Hydrous Ferric Oxide: New York, John Wiley and Sons, 393 p.

Elston, W.E., 1994, Siliceous volcanic centers as guides to mineral exploration; review and summary: Economic Geology, v. 89, no. 8, p.1662-1686.

Epstein, S., and Mayeda, T., 1953, Variations of O18 contents of waters from natural sources: Geochimica et Cosmochimica Acta, v. 4, p. 213-224.

Field, C.W., 1966, Sulfur isotopic method for discriminating between sulfates of hypogene and supergene origin: Economic Geology, v. 61, p. 1478-1485.

Fuller, C.C., and Davis, J.A., 1989, Influence of coupling of sorption and photosynthesis processes on trace elements cycles in natural waters: Nature, v. 340, p. 52-54.

Garbarino, J.R., and Taylor, H.E., 1995, Inductively-coupled plasma-mass spectrometric method for the determination of dissolved trace elements in natural water: U.S. Geological Survey Open-File Report 94-358, 88 p.

Giesemann, A., Jäger, H.J., Norman, A.L., Krouse, H.R., and Brand, W.A., 1994, On-line sulfur-isotope determination using an elemental analyzer coupled to a mass spectrometer: Analytical Chemistry, v. 66, p. 2816-2819.

Ingersoll, G.P., 2000, Snowpack Chemistry at selected sites in Colorado and New Mexico during winter 1999-2000: U.S. Geological Survey Open-File Report 00-394, 9 p.

Johnson, C.M., and Lipman, P.W., 1988, Origins of metaluminous and alkaline volcanic rocks of the Latir volcanic field, northern Rio Grande rift, New Mexico: Contributions to Mineralogy and Petrology, v. 100, p. 107-128.

Jones, C.A., Nimick, D.A., and McCleskey, R.B., 2004, Relative effect of temperature and pH on diel cycling of dissolved trace elements in Prickly Pear Creek, Montana: Water, Air, and Soil Pollution, v. 153, p. 95-113.

Kennedy, V.C., Jenne, E.A., and Burchard, J.M., 1976, Backflushing filters for field processing of water samples prior to trace-element analyses: U.S. Geological Survey Open-File Report 76-126, 12 p.

Kimball, B.A., Nordstrom, D.K., Runkel, R.L., and Verplanck, P.L. (in press) Questa baseline and pre-mining ground-water quality investigation. 23. Quantification of solute mass loading for Red River, New Mexico: U.S. Geological Survey Scientific Investigations Report 2006-5004.

Leonardson, R.W., Dunlop, G., Starquist, V.L., Bratton, G.P., Meyer, J.W., Osborne, L.W., Atkins, S.A., Molling, P.A., Moore, R.F., and Olmore, S.D., 1983, Preliminary geology and molybdenum deposits at Questa, New Mexico, *in* The genesis of Rocky Mountain ore deposits-changes in time and tectonics: Proceedings of the Denver Region Exploration Geologist Society Symposium, Wheatridge, Colo., p. 151-156.

Lipman, P.W., and Reed, J.C., 1979, Geologic map of the Latir volcanic field and adjacent areas, northern New Mexico: U.S. Geological Survey Miscellaneous Investigations Map I-1907, scale 1:48,000.

Lipman, P.W., 1988, Evolution of silicic magma in the upper crust; the mid-Tertiary Latir volcanic field and its cogenetic granitic batholith, northern New Mexico, U.S.A.: Transactions of the Royal Society of Edinburgh, Earth Sciences, v. 79, p. 265-288.

Loucks, T.A., Phillips, J.S., and Newell, R.A., 1977, Exploration potential of the Questa East area:

unpublished report for Kennecott Copper Corporation.

LoVetere, S.H., Nordstrom, D.K., Maest, A.S., and Naus, C.A., 2004, Questa baseline and pre-mining ground-water quality investigation. 3. Historical ground-water quality for the Red River Valley, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 03-4186, 44 p.

Ludington, S., Plumlee, G.S., Caine, J.S., Bove, D.J., Holloway, J.M., and Livo, K.E., 2004, Questa baseline and pre-mining ground-water quality investigation. 10. Geological influences on ground and surface waters in the Red River watershed, New Mexico: U.S. Geological Survey Scientific Investigations Report 04-5245, 46 p.

Maest, A.S., Nordstrom, D.K., and LoVetere, S.H., 2004, Questa baseline and pre-mining ground-water quality investigation. 4. Historical surface-water quality for the Red River Valley, New Mexico 1965-2001: U.S. Geological Survey Scientific Investigations Report 2004-5063, 150 p.

Martineau, M.P., Heinemeyer, G.R., Craig, S.D. and McAndrews, K.P., 1977, Geological report, Questa project, 1975–1977: Questa Molybdenum Company, unpublished report, 161 p.

McCleskey, R.B., Nordstrom, D.K., and Naus, C.A., 2004, Questa baseline and pre-mining ground-water quality investigation. 16. Quality assurance and quality control for water analyses: U.S. Geological Survey Open-File Report 2004-1341, 105 p.

McCleskey, R.B., Nordstrom, D.K., and Ball, J.W., 2003a, Metal interferences and their removal prior to the determination of As(T) and As(III) in acid mine waters by hydride-generation atomic absorption spectrometry: U.S. Geological Survey Water-Resources Investigations Report 03-4117, 13 p.

McCleskey, R.B., Nordstrom, D.K., Steiger, J.I., Kimball, B.A., Verplanck, P.L., 2003b, Questa baseline and pre-mining ground-water-quality investigation. 2. Low-flow (2001) and snowmelt (2002) synoptic/tracer water chemistry for the Red River, New Mexico: U.S. Geological Survey Open-File Report 03-148, 166 p.

McKnight, D.M. and Bencala, K.E., 1988, Diel variations in iron chemistry in an acidic stream in the Colorado Rocky Mountains, USA: Arctic and Alpine Research, v. 20, no. 4, p. 492-500.

Meyer, J.W., and Leonardson, R.W., 1990, Tectonic, hydrothermal, and geomorphic controls on alteration scar formation near Questa, New Mexico: Guidebook-New Mexico Geological Society, v. 41, p. 417-422.

Meyer, J.W., 1991, Volcanic, plutonic, tectonic, and hydrothermal history of the southern Questa caldera, New Mexico: unpublished Ph.D. dissertation, University of California at Santa Barbara, 287 p.

Molling, P.A., 1989, Applications of the reaction progress variables to the hydrothermal alteration associated with the deposition of the Questa molybdenum deposit, New Mexico: unpublished Ph.D. dissertation, Johns Hopkins University, 229 p.

Moser, H., and Stichler, W., 1975, Deuterium and oxygen-18 contents as index of the properties of snow blankets, *in* Snow Mechanics, Proceedings of the Grindelwald Symposium, April 1974, IAHS Publication 14, 122-135.

Naus, C.A., McCleskey, R.B., Nordstrom, D.K., Donohoe, L.C., Paillet, Fred, and Verplanck, P.L., 2005, Questa baseline and pre-mining ground-water quality investigation. 5. Methods and results of well installation and development and data collection in the Straight Creek drainage basin, New Mexico, 2001-2003: U.S. Geological Survey Scientific Investigations Report 2005-5088, 220 p.

Nimick, D.A., Gammons, C.H., Cleasby, T.E., Madison, J.P., Skaar, Don, and Brick, C.M., 2003, Diel cycles in dissolved metal concentrations in streams: Occurrence and possible causes: Water Resources Research, v. 39, no. 9, p. 2.1-2.17.

Nimick, D.A., T.E. Cleasby, and McCleskey, R.B., 2005, Seasonality of diel cycles of dissolved metal concentrations in a Rocky Mountain stream: Environmental Geology, v. 47, p. 603-614.

Plumlee, G.S., Lowers, H., Ludington, S., Koenig, A., and Briggs, P.H., in press, Questa baseline and pre-mining ground-water quality investigation. 13. Mineral microscopy and chemistry of mined and unmined porphyry molybdenum mineralization along the Red River, New Mexico: Implications for ground- and surface-water: U.S. Geological Survey Open-File Report 2005-1442.

Plummer, L.N., Prestemon, E.C., and Parkhurst, D.L., 1994, An interactive code (NETPATH) for modeling net geochemical reactions along a flow path, version 2.0: U.S. Geological Survey Water-Resources Investigations Report 94-4169, 130 p.

Robertson GeoConsultants, Inc., 2001a, Integrated geochemical load balance for Straight Creek, Sangre de Cristo Mountains, New Mexico: Report number 052008/13, prepared for Molycorp Inc., 35 p.

Robertson GeoConsultants, Inc., 2001b, Interim geochemical load balance for Red River basin near Questa Mine, New Mexico: Report number 052008/18, prepared for Molycorp Inc., 38 p.

Roth, D.A., Taylor, H.E., Domagalski, J., Dileanis, P., Peart, D.B., Antweiler, R.C., and Alpers, C.N., 2001, Distribution of inorganic mercury in Sacramento River water and sediments: Archives of Environmental Contamination and Toxicology, v. 40, p. 161-172.

Smolka, L.R., and Tague, D.F., 1987, Intensive survey of the Red River, Taos County, New Mexico, August 18-21, 1986: New Mexico Environmental Improvement Division, Surveillance and Standards Section, Surface Water Quality Bureau, October 1987, 55 p.

Smolka, L.R., and Tague, D.F., 1989, Intensive survey of the Red River, Taos County, New Mexico, September 12-October 25, 1988: New Mexico Environmental Improvement Division, Surveillance and Standards Section, Surface Water Quality Bureau, May 1989, 89 p.

Stein, H.J., 1985, A lead, strontium, and sulfur isotope study of Laramide-Tertiary intrusions and mineralization in the Colorado mineral belt with emphasis on Climax-type porphyry molybdenum systems plus a summary of other newly acquired isotopic and rare earth element data: Ph.D. dissertation, University of North Carolina, Chapel Hill, 493 p.

Stookey, L.L., 1970, Ferrozine - a new spectrophotometric reagent for iron: Analytical Chemistry, v. 42, p. 779-781.

Taylor, H.E., and Garbarino, J.R., 1991, The measurement of trace metals in water resources: Monitoring samples by inductively coupled plasma-mass spectrometry: Spectrochimica Acta Reviews, v. 14, no. 1-2, p. 33-43.

Taylor, H.E., Berghoff, K., Andrews, E.D., Antweiler, R.C., Brinton, T.I., Miller, C., Peart, D.B., and Roth, D.A., 1997, Water quality of springs and seeps in Glen Canyon National Recreation Area: National Park Service Technical Report NPS/NRWRD/NRTR-97/128, 26 p.

To, T.B., Nordstrom, D.K., Cunningham, K.M., Ball, J.W., and McCleskey, R.B., 1999, New method for the direct determination of dissolved Fe(III) concentration in acid mine waters: Environmental Science and Technology, v. 33, p. 807-813.

Tuttle, M.L.W., Briggs, P.H., and Berry, C.J., 2003, A method to separate phases of sulfur in mine-waste and natural alteration zones, and to use sulfur isotopic compositions to investigate release of metals and acidity to the environment [abs]: *in* Proceedings of the 6th International Conference on Acid Rock Drainage, Queensland, Australia, July 14-17, 2003.

URS, 2001, Final report, Molycorp Questa site-wide comprehensive hydrologic characterization report: Denver, Colo., March, 2001, 95 p.

U.S. Geological Survey, 2003, Water quality samples for the Nation: accessed June 2003 at URL *http://nwis.waterdata.usgs.gov/nwis/qwdata* for site 08265000 (Red River near Questa, New Mexico).

U.S. Geological Survey, 2004, Daily streamflow for the nation, USGS 08265000 Red River near Questa, New Mexico: accessed July 22, 2004 at *http://nwis.waterdata.usgs.gov/nwis/discharge/.*

Vail Engineering, Inc., 2000, Analysis of acid rock drainage in the middle reach of the Red River, Taos, County, New Mexico: Interim report, July 4, 2000.

Verplanck, P.L., Antweiler, R.C., Nordstrom, D.K., and Taylor, H.E., 2001, Standard reference water samples for rare earth element determinations: Applied Geochemistry, v. 16, p. 231-244.

Verplanck, P.L., Nordstrom, D.K., Taylor, H.E. and Kimball, B.A., 2004, Rare earth element partitioning between iron oxyhydroxides and acid mine waters: Applied Geochemistry, v. 19, p. 1339-1354.

Western Regional Climate Center, 2003, Historical climate information: New Mexico climate summaries, Red River, New Mexico (297323), accessed July 17, 2003, at *http://www.wrcc.dri.edu/*.

Ward, J.R., and Harr, C.A., eds, 1990, Methods for collection and processing of surface-water and bed-sediment material samples for physical and chemical analyses: U.S. Geological Survey Open-File Report 90-140, 171 p.