Questa Baseline and Pre-Mining Ground-Water-Quality Investigation. 5. Well Installation, Water-Level Data, and Surface- and Ground-Water Geochemistry in the Straight Creek Drainage Basin, Red River Valley, New Mexico, 2001-03

Scientific Investigations Report 2005-5088

Prepared in cooperation with the
NEW MEXICO ENVIRONMENT DEPARTMENT

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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U.S. Geological Survey

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CONTENTS

FIGURES

Page

TABLES

CONVERSION FACTORS, DATUMS, AND ABBREVIATIONS

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Mass	
ton, short (2,000 lb)	0.9072	megagram (Mg)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
micrometer (µm)	0.00003937	inch (in.)
	Volume	
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
liter (L)	61.02	cubic inch (in^3)
	Flow rate	
liter per minute (L/min)	0.03532	cubic foot per minute (ft^3/min)

Ohm-meters (ohm-m) can be converted to microsiemens per centimeter (µS/cm) by the equation:
1/ohm-m (0.0001) = µS/cm

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

Temperature in degrees Fahrenheit (˚F) may be converted to degrees Celsius (˚C) as follows:
˚C = (˚F-32)/1.8

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

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

Explanation of Abbreviations and Acronyms

˚C (degrees Celsius)	ICP-OES (inductively coupled plasma-optical emission spectrometry)
AWWT (Advanced Waste Water Treatment)	mg/L (milligrams per liter)
cc (cubic centimeter)	µS/cm (microsiemens per centimeter)
CFC (chlorofluorocarbon)	mS/cm (millisiemens per centimeter)
DIW (deionized water)	mV (millivolts)
DOC (dissolved organic carbon)	PVC (polyvinyl chloride)
GFAAS (graphite furnace atomic absorption spectrometry)	QA/QC (quality assurance/quality control)
HNO_3 (nitric acid)	QSP (quartz-sericite-pyrite)
IAP (ion activity product)	SLAP (Standard Light Antarctic Precipitation)
IC (ion chromatography)	VSMOW (Vienna Standard Mean Ocean Water)
ICP-MS (inductively coupled plasma-mass spectrometry)	v/v (volume per volume)

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Abstract

The U.S. Geological Survey, in cooperation with the New Mexico Environment Department, is investigating the pre-mining ground-water chemistry at the Molycorp molybdenum mine in the Red River Valley, northern New Mexico. The primary approach is to determine the processes controlling ground-water chemistry at an unmined, off-site, proximal analog. The Straight Creek drainage basin, chosen for this purpose, consists of the same quartz-sericite-pyrite altered andesitic and rhyolitic volcanic rock of Tertiary age as the mine site. The weathered and rugged volcanic bedrock surface is overlain by heterogeneous debris-flow deposits that interfinger with alluvial deposits near the confluence of Straight Creek and the Red River. Pyritized rock in the upper part of the drainage basin is the source of acid rock drainage (pH 2.8-3.3) that infiltrates debris-flow deposits containing acidic ground water (pH 3.0-4.0) and bedrock containing water of circumneutral pH values (5.6-7.7).

Eleven observation wells were installed in the Straight Creek drainage basin. The wells were completed in debris-flow deposits, bedrock, and interfingering debris-flow and Red River alluvial deposits. Chemical analyses of ground water from these wells, combined with chemical analyses of surface water, water-level data, and lithologic and geophysical logs, provided information used to develop an understanding of the processes contributing to the chemistry of ground water in the Straight Creek drainage basin.

Surface- and ground-water samples were routinely collected for determination of total major cations and selected trace metals; dissolved major cations, selected trace metals, and rare-earth elements; anions and alkalinity; and dissolved-iron species. Rare-earth elements were determined on selected samples only. Samples were collected for determination of dissolved organic carbon, mercury, sulfur isotopic composition (^{34}S and ^{18}O of sulfate), and water isotopic composition (^{2}H and ^{18}O) during selected samplings. One set of ground-water samples was collected for helium-3/tritium and chlorofluorocarbon (CFC) age dating.

Several lines of evidence indicate that surface water is the primary input to the Straight Creek ground-water system. Straight Creek streamflow and water levels in wells closest to the apex of the Straight Creek debris fan and closest to Straight Creek itself appear to respond to the same seasonal inputs. Oxygen and hydrogen isotopic compositions in Straight Creek surface water and ground water are similar, and concentrations of most dissolved constituents in most Straight Creek surface-water and shallow (debris-flow and alluvial) aquifer ground-water samples correlate strongly with sulfate (concentrations decrease linearly with sulfate in a downgradient direction). After infiltration of surface water, dilution along the flow path is the dominant mechanism controlling ground-water chemistry. However, concentrations of some constituents can be higher in ground water than can be accounted for by concentrations in Straight Creek surface water, and additional sources of these constituents must therefore be inferred.

Constituents for which concentrations in ground water can be high relative to surface water include calcium, magnesium, strontium, silica, sodium, and potassium in ground water from debris-flow and alluvial aquifers and manganese, calcium, magnesium, strontium, sodium, and potassium in ground water from the bedrock aquifer. All ground water is a calcium sulfate type, often at or near gypsum saturation because of abundant gypsum in the aquifer material developed from co-existing calcite and pyrite mineralization. Calcite dissolution, the major buffering mechanism for bedrock aquifer ground water, also contributes to relatively higher calcium concentrations in some ground water. The main source of the second most abundant cation, magnesium, is probably dissolution of magnesium-rich carbonates or silicates. Strontium may also be derived from carbonate dissolution. Feldspars are likely sources of silica, sodium, and potassium. Other possible sources of silica are sericite, biotite, phlogopite, chlorite, epidote, and kaolinite. Manganese in bedrock aquifer ground water may be derived from rhodochrosite or manganese oxides. Although not striking from comparison of lithium or beryllium to sulfate concentrations in surface and ground water, strong correlations between beryllium and lithium in surface water and shallow ground water indicate that a beryllium-lithium association in the mineralization also is imparted to ground water.

Aluminum, fluoride, silica, lithium, copper, and beryllium in samples from wells near the mouth of the debris fan often do not follow the common dilution trend of decreasing concentrations with sulfate in a downgradient direction. The departure is greatest for aluminum and silica. Aluminum is leached from minerals in the debris flow under acidic conditions, but its concentration is a function of pH and decreases substantially above a pH of 5. The data indicate that precipitation of both aluminum

and silica can occur at a pH of around 4. An alternate explanation for the departure of these constituents from the dilution trend is the lack of a direct flow path from upgradient debris-flow aquifer wells to the wells closer to the Red River. However, linear best-fit lines on plots of some constituents do include the discrepant wells.

Mixing among debris-flow, bedrock, and alluvial aquifer ground water in the Straight Creek drainage basin is evident from the chemical data. High pH in some samples of debris-flow aquifer ground water is an indication of the influence of more neutral bedrock or Red River alluvial aquifer water. Similarly, mixing of bedrock and debris-flow aquifer ground water is indicated by low pH in samples from some bedrock aquifer wells. Mixing of water from these two aquifers also is indicated on various plots of concentrations of almost all constituents. In the lower part of the Straight Creek debris fan, mixing of ground water in alluvial, debris-flow, and bedrock aquifers is indicated by results of helium-3/tritium and CFC age-dating analyses; evidence of dilution of bedrock and debris-flow aquifer ground water by alluvial aquifer water; and high pH and low specific conductance in debris-flow aquifer ground water in wells close to the Red River. Ground water in this area also appears to be mixing with submodern (predating 1940's) ground water, the source of which may be discharge from deeper bedrock associated with mountain-block recharge.

Helium-3/tritium dating yielded ages of shallow ground water ranging from less than 0.5 to about 23 years and of bedrock aquifer water from about 15 to greater than 60 years; ground water from wells completed in alluvium and debris-flow deposits is almost always younger than that from bedrock aquifer wells. CFC dates for alluvial and debris-flow aquifer wells ranged from approximately 10 to 45 years and for bedrock aquifer wells ranged from approximately 20 to 47 years. CFC dating yielded considerably different ages for CFC-11, CFC-12, and CFC-113, almost all of which are older than helium-3/tritium ages, probably because of microbial degradation of CFC's in anaerobic conditions.

Introduction

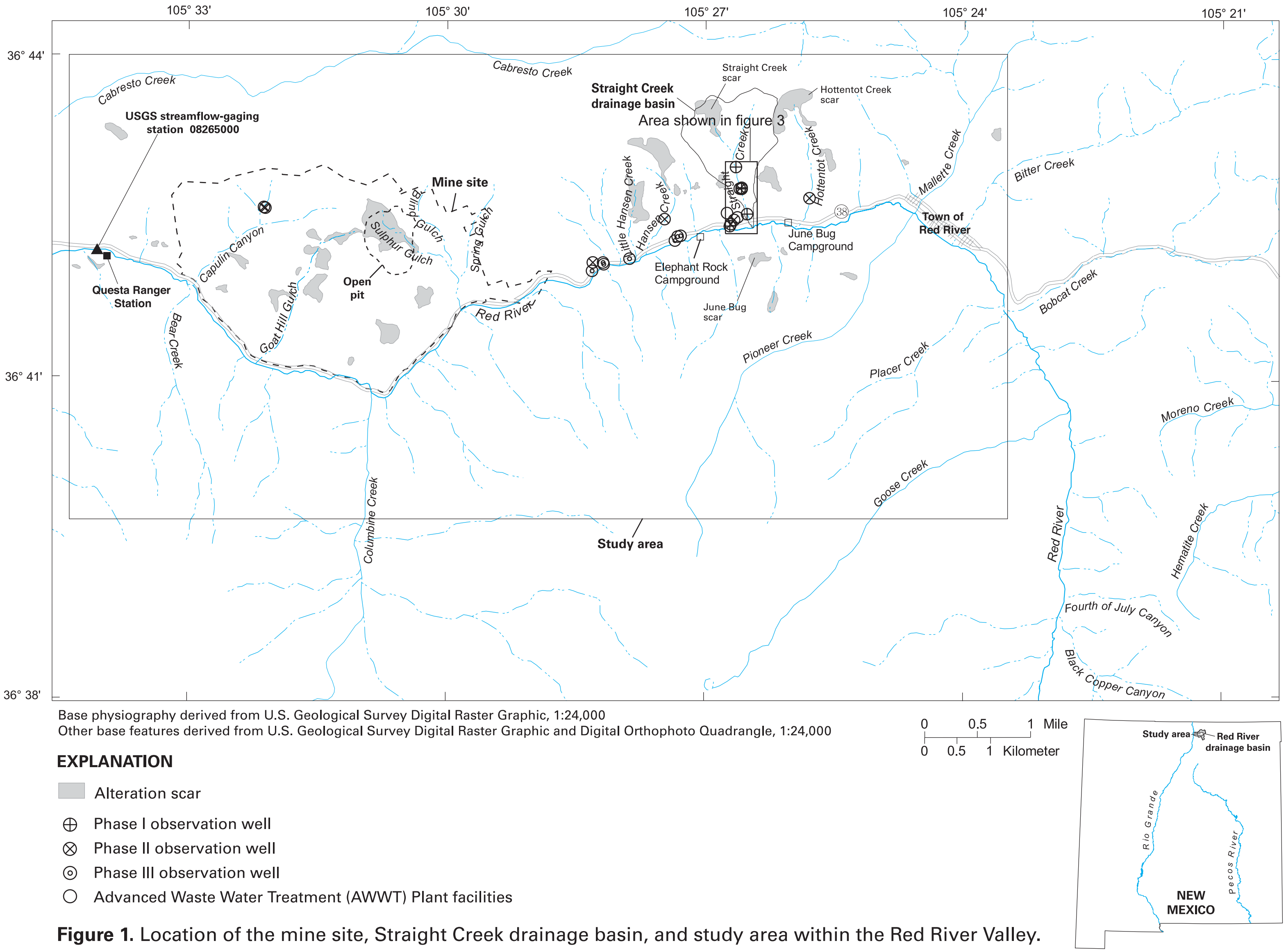
In April 2001, the U.S. Geological Survey (USGS) and the New Mexico Environment Department began a cooperative study to infer the pre-mining ground-water chemistry at the Molycorp molybdenum mine site in the Red River Valley (fig. 1). This study was prompted by the New Mexico State Water Quality Act (§§74-6-1 and following sections, New Mexico Statutes Annotated 1978), under the jurisdiction of the New Mexico Water Quality Control Commission, which requires an operator to develop and complete an approved closure plan that prevents the exceedence of (1) standards set forth in New Mexico Water Quality Control Commission Regulations (§20.6.2.3103 New Mexico Administrative Code) or (2) natural background concentrations.

The Molycorp molybdenum mine has been in operation since the 1920's, and ground-water measurements and chemical analyses were not obtained prior to mining. To infer the pre-mining ground-water chemistry, analogous off-site areas are being studied. These analog sites are often disturbed by other non-mining, anthropogenic activities, including exploration drilling, road construction, power and telephone line construction, U.S. Forest Service construction and maintenance, and residential, commercial, and municipal development. The existing conditions of these analog sites are referred to as "baseline conditions," from which, when combined with data for mined areas, pre-mining conditions of the mine site can be inferred.

The Straight Creek drainage basin (fig. 1) was selected as the primary analog site for this study because of its similar terrain and geology to the mine site, accessibility, potential for well construction, and minimal anthropogenic activity. Straight Creek flows perennially in the upper reach (west fork) and ephemerally and intermittently in the lower reach (fig. 2). All streamflow typically infiltrates the debris-flow deposits upstream from the confluence of the east and west forks of the drainage. The stream discharges into the Red River only during periods of peak snowmelt runoff and following intense precipitation. The lower reach of the natural streambed shown in figure 2 has been diverted around the east side of the Advanced Waste Water Treatment (AWWT) Plant facility, which is operated by the town of Red River.

As part of this study, 29 observation wells and piezometers were installed in the Red River Valley (figs. 1-3). The wells and piezometers were drilled, constructed, and developed in three phases. Eight observation wells were installed in the Straight Creek drainage basin during Phase I of the drilling program (November 2001 through February 2002). Eight wells and three piezometers were installed in the Red River Valley, including three wells and one piezometer in and near the Straight Creek Basin, during Phase II (October 2002 to January 2003), and 10 piezometers were installed during Phase III (December 2003). This report discusses only those wells in the Straight Creek drainage basin.

Observation-well locations within the Straight Creek drainage basin (fig. 3) were designed to be along the hypothesized path of ground-water flow from the upper part of the basin to the confluence of Straight Creek and the Red River. The relatively higher rate of ground-water flow within the Red River alluvial aquifer compared with the rate of flow within the Straight Creek debris-flow deposits was expected to cause ground water to begin flowing in a southwestward direction as it merges with the Red River alluvial aquifer. Wells SC-7A and SC-8A were installed in an effort to intercept this ground-water mixing zone, and well SC-7A was screened across an interval of approximately 90 feet to allow samples to be collected at selected depths within the postulated mixing zone.



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

EXPLANATION

▨ Alteration scar

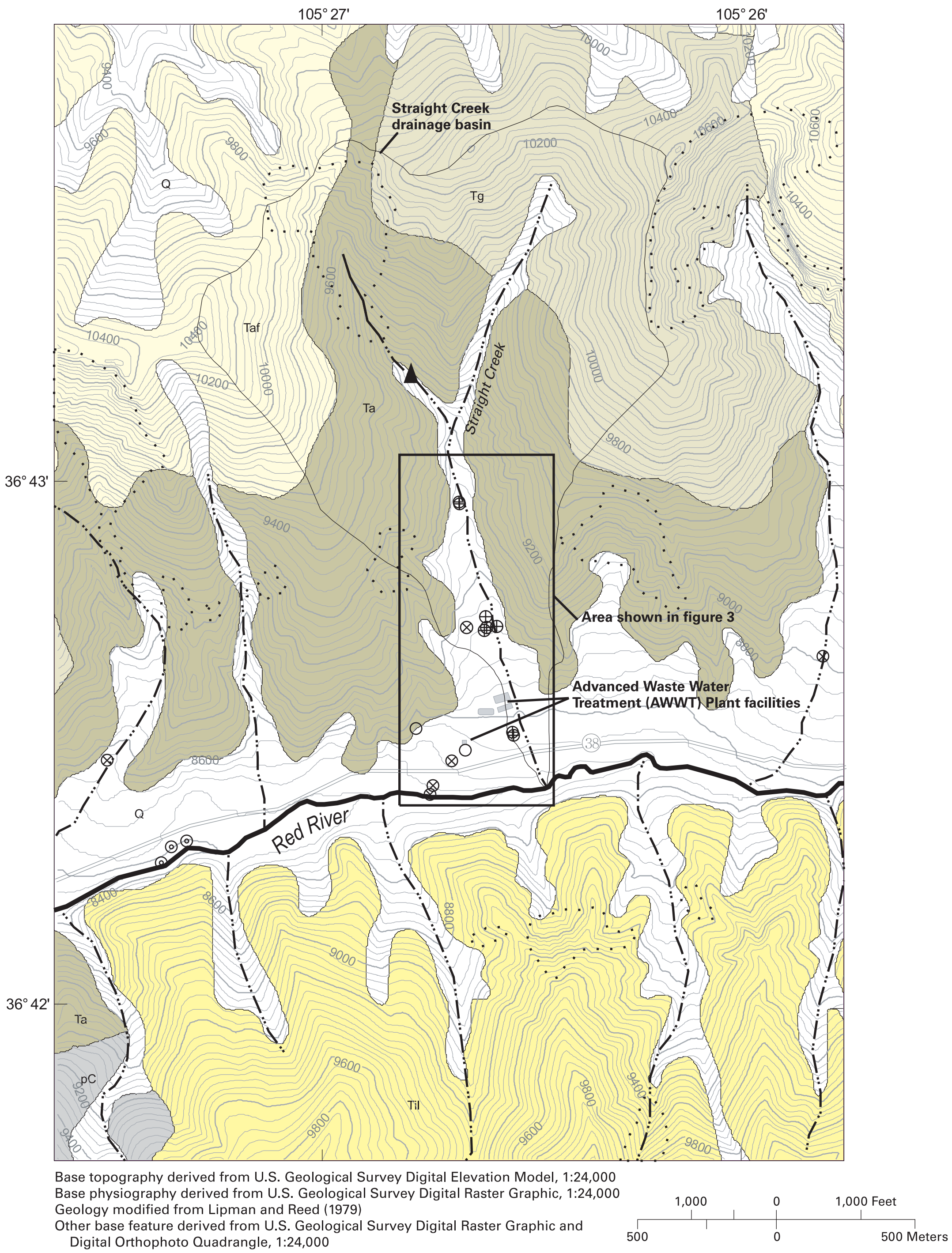
⊕ Phase I observation well

⊗ Phase II observation well

◎ Phase III observation well

○ Advanced Waste Water Treatment (AWWT) Plant facilities

Figure 1. Location of the mine site, Straight Creek drainage basin, and study area within the Red River Valley.



Base topography derived from U.S. Geological Survey Digital Elevation Model, 1:24,000
Base physiography derived from U.S. Geological Survey Digital Raster Graphic, 1:24,000
Geology modified from Lipman and Reed (1979)
Other base feature derived from U.S. Geological Survey Digital Raster Graphic and Digital Orthophoto Quadrangle, 1:24,000

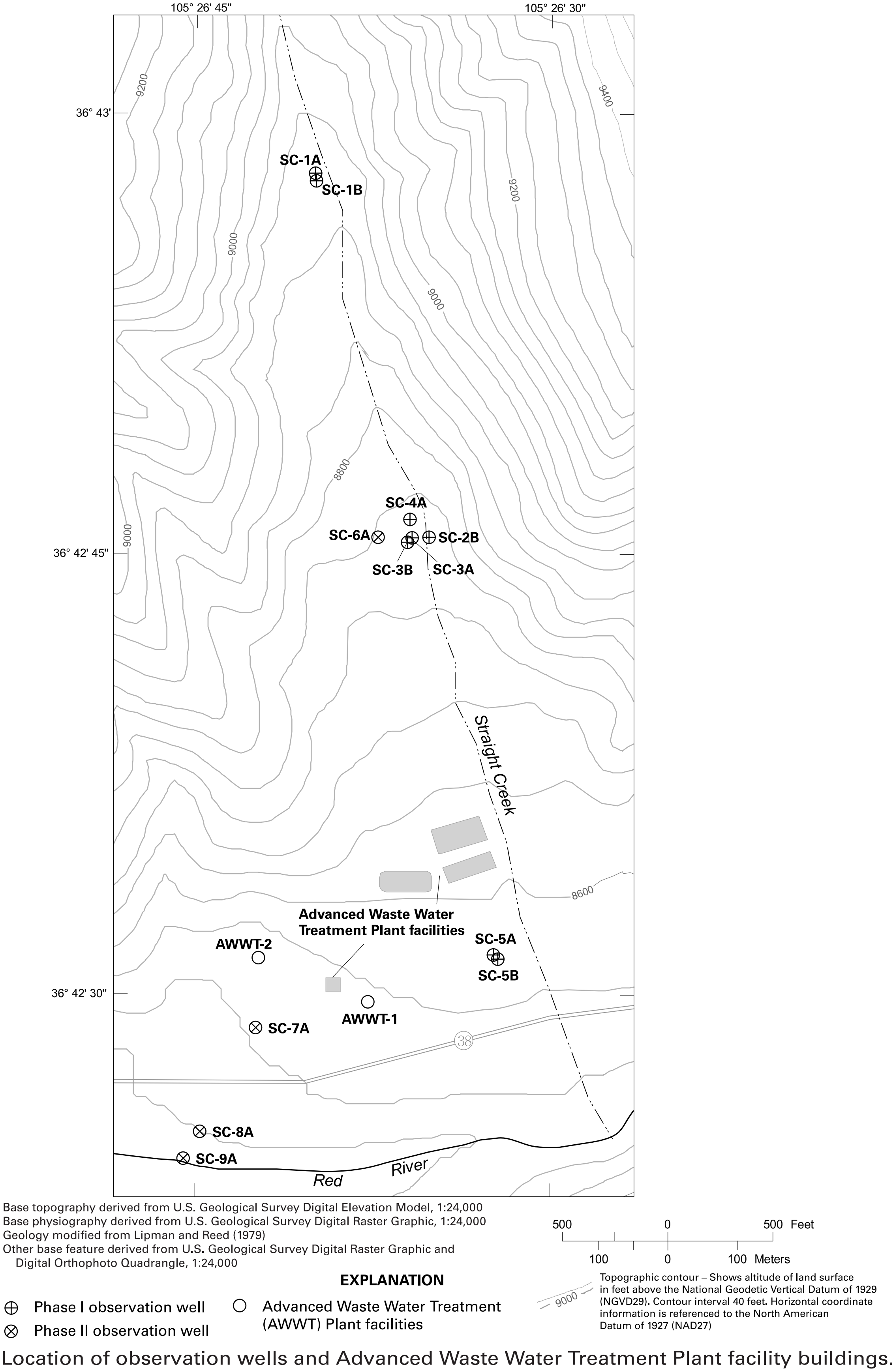
EXPLANATION

GEOLOGIC UNITS

Q	Surficial deposits, undivided debris flow and alluvial (Quaternary)
Ta	Andesite (Tertiary)
Taf	Amalia Tuff (Tertiary)
Tg	Granite (Tertiary)
Til	Latite (Tertiary)
pC	Proterozoic rocks, undivided

⁘	Alteration scar
10400	Topographic contour – Shows altitude of land surface in feet above the National Geodetic Vertical Datum of 1929 (NGVD29). Contour interval 40 feet. Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27)
⊕	Phase I observation well
⊗	Phase II observation well
◎	Phase III observation well
○	Advanced Waste Water Treatment (AWWT) Plant facilities
▲	Approximate location of surface-water sampling site

Figure 2. Topography, physiography, and generalized geology of the Straight Creek drainage basin and surrounding area and location of observation wells.



Base topography derived from U.S. Geological Survey Digital Elevation Model, 1:24,000
Base physiography derived from U.S. Geological Survey Digital Raster Graphic, 1:24,000
Geology modified from Lipman and Reed (1979)
Other base feature derived from U.S. Geological Survey Digital Raster Graphic and Digital Orthophoto Quadrangle, 1:24,000

EXPLANATION

⊕ Phase I observation well

⊗ Phase II observation well

○ Advanced Waste Water Treatment (AWWT) Plant facilities

9000 Topographic contour – Shows altitude of land surface in feet above the National Geodetic Vertical Datum of 1929 (NGVD29). Contour interval 40 feet. Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27)

Figure 3. Location of observation wells and Advanced Waste Water Treatment Plant facility buildings.

Purpose and Scope

This report documents methods and results of Phase I well installation, water-level and water-chemistry data collection, water sample analyses, and interpretation of the geochemistry of surface and ground water in the Straight Creek drainage basin. Data presented include lithologic logs, geophysical logs, and water-level and water-chemistry data obtained from the eight Phase I Straight Creek observation wells; water-chemistry data and minimal well-construction information for three Phase II observation wells in and near the Straight Creek drainage basin (to facilitate interpretation of Straight Creek ground-water chemistry data); geophysical logs, water-level data, and water-chemistry data obtained from two pre-existing observation wells near the AWWT facility; and surface-water-chemistry data obtained from Straight Creek. In addition, the stable isotopic composition of five precipitation samples and a few solid samples are presented. Water-chemistry data are presented for February 2002 through October 2003, and water-level data are presented for March 2002 through December 2003.

Because of the size and complexity of the study area, this report is one in a series of reports that will be used to infer pre-mining ground-water concentrations at the mine site. The results of these studies will ultimately guide decision makers in establishing appropriate remedial actions at the Molycorp mine.

Physical Description of Study Area

The Red River, a tributary to the Rio Grande within the Carson National Forest, is located in Taos County in north-central New Mexico (fig. 1). The area is a rugged and altered terrain with steep slopes and V-shaped valleys. The main area of study within the Red River Valley extends from the town of Red River to the USGS streamflow-gaging station near Questa (08265000, Red River near Questa) and includes approximately 63 square miles of the drainage basin and approximately 12 miles of river reach. The Molycorp, Inc. Questa Molybdenum mine, referred to as the mine site, is located east of the Ranger Station on the north side of State Highway 38 and the Red River. The mine site is approximately 6 square miles in area (U.S. Department of Agriculture Forest Service, 2001); it encompasses three tributary valleys to the Red River: Capulin Canyon, Goat Hill Gulch, and Sulphur Gulch, from west to east, respectively (fig. 1).

Mining activities produced extensive underground workings and an open pit approximately 3,000 feet in diameter (covering approximately 162 acres) near or in Sulphur Gulch (URS, 2001). Waste-rock piles cover steep slopes on the north side of the Red River between Capulin Canyon and Spring Gulch (a tributary valley of Sulphur Gulch). Hydrothermally altered bedrock is found in Capulin, Goat Hill, Sulphur, Hansen, Straight, and Hottentot drainages (fig. 1). Weathering of extensively altered rock has resulted in steep, highly erosive, sparsely vegetated "scars" that are clearly visible from the ground and in aerial photographs.

Climate and Vegetation

The Red River Valley is located within a semiarid desert that receives precipitation throughout the year and sustains moderate biodiversity. Between 1915 and 2002, the annual average temperature was 4 ˚C and the annual average precipitation and snowfall were approximately 20.5 and 146 inches, respectively. Daily temperatures generally fluctuated by 18 ˚C throughout the year (Western Regional Climate Center, 2003).

Climate and vegetation vary greatly within short distances, primarily because of differences in topography. Topography in the study area is steep, rising rapidly from the basin floor altitude of approximately 7,450 feet at the streamflow-gaging station near Questa to ridge crests at altitudes exceeding 10,500 feet. Orographic effects of mountainous topography lead to precipitation on the windward slopes and localized storms within tributary valleys. Thunderstorms are responsible for mass wasting in hydrothermally altered areas, producing debris flows that form debris fans at the mouths of most tributaries to the Red River (K. Vincent, U.S. Geological Survey, written commun., 2003). Winter snowpack contributes to ground-water recharge through snowmelt infiltration and runoff.

Prevalent vegetation in the Red River Valley is representative of the following altitude zones: piñon-juniper woodland (6,000-7,500 feet in altitude), mixed conifer woodland (7,500-9,000 feet), and spruce-fir woodland (9,000-12,000 feet) (Knight, 1990). Willows, cottonwoods, shrubs, perennial grasses, and flowering vegetation are common near the banks of the Red River. Extending from the river are widely spaced piñon pines and junipers. Gains in altitude give rise to an abundance of ponderosa pines and limber pines, and douglas and white fir can be found at higher altitudes. This typical montane community, although diverse, is dominated by ponderosa pines (L. Gough, U.S. Geological Survey, oral commun., 2003).

Hydrogeology

Ground water passes though, and may geochemically interact with, the various types of earth materials in the Red River Valley. This section describes the major rock types, minerals, and water-yielding units in the valley and presents generalized aquifer and ground-water-chemistry information. Previous studies of the geology and mineralogy of the Red River Valley include those described by Schilling (1956), Rehrig (1969), Lipman (1981), and Meyer and Leonardson (1990, 1997). Information in this section draws largely from these sources, with additional information from Ludington and others (2004) and other USGS scientists participating in this study.

The Red River Valley is located along the southern edge of the Questa Caldera and contains complex structural features (Caine, 2003) and extensive hydrothermal alteration. The geology of the basin consists of volcanic and intrusive rocks of Tertiary age that are underlain by metamorphic rocks of Precambrian age that were intruded by granitic stocks. The volcanic rocks are primarily intermediate to felsic composition (andesite to rhyolite); granites and porphyries have intruded the volcanics and are the apparent source of hydrothermal fluids and molybdenite mineralization.

The mineral deposits in the Red River Valley are considered Climax-type deposits, which are associated with silica- and fluorine-rich rhyolite porphyry and granitic intrusives. Climax-type hydrothermal alteration produces zones of alteration assemblages, with a central zone of fluorine-rich potassic alteration, a quartz-sericite-pyrite zone (often with a carbonate-fluorite veinlet overprint), and a propylitic zone. In the potassic zone, rocks are altered to a mixture of biotite, potassium feldspar, quartz, fluorite, and molybdenite; these rocks usually contain less than 3 percent sulfide (including molybdenite). Quartz-sericite-pyrite (QSP) alteration, as the name implies, produces a mixture of quartz, pyrite (as much as 10 percent), and fine-grained mica (sericite) or illite. Chlorite, epidote, albite, and calcite typically are found in the propylitic assemblages.

In the Red River Valley, ore deposits contain quartz, molybdenite, pyrite, fluorite, calcite, manganiferous calcite, dolomite, and rhodochrosite. Lesser amounts of galena, sphalerite, chalcopyrite, magnetite, and hematite also are present. The hydrothermal alteration related to mineralization overprints an older, regional propylitic alteration. In these areas, rocks can contain a mixture of quartz, pyrite, and illite clays replacing feldspars, chlorite, carbonates, and epidote. Abundant minerals in waste rock produced by mining activities include chlorite, gypsum, illite, illite-smectite, jarosite, kaolinite, and muscovite (Gale and Thompson, 2001).

Scar-area bedrock outcrops are composed of andesite volcanic and volcaniclastic rocks, rhyolitic tuff, quartz latite, and rhyolite porphyry. The dominant alteration type in all scars is QSP; carbonates also are found in all scar areas. Most of the andesite and quartz latite has been propylitically altered and contains plagioclase feldspar and chlorite, with fewer QSP alteration minerals. Rhyolite porphyry and tuff do not seem to have been substantially affected by propylitization. In Straight Creek, unweathered bedrock exposed in the creek bottom is propylitized andesite with a QSP overprint. Other dominant rock types include rhyolite porphyry and rhyolitic tuff. Depending on location within the weathering profile, altered rocks contain variable amounts of quartz, illite, chlorite, and plagioclase feldspar, with smaller amounts of pyrite, gypsum, rutile, jarosite, and goethite (Livo and Clark, 2002; Ludington and others, 2004).

Debris fans are composed of sediments shed from their watersheds, which are tributary to the Red River. Where the tributary watersheds contain scars, the debris fans are large and active and contain both coarse- and fine-grained debris-flow sediments. The chemistry of these sediments likely reflects the chemistry of their rapidly eroding and altered erosion scars. Sediments deposited by the Red River (alluvium), in contrast, generally consist of well-washed sandy gravel and are composed of a mix of the lithologies found in the entire Red River Basin. The largest debris fans caused the Red River to aggrade behind the fans during the Quaternary Period. Thus water flowing in the shallow aquifers likely passes alternately through Red River alluvium and debris-flow deposits (K. Vincent, U.S. Geological Survey, written commun., 2003). Major types of water-yielding units in the Red River Valley include fractured and weathered bedrock, debris-flow deposits, and Red River alluvium. Bedrock constitutes the largest aquifer in the study area in terms of rock mass, but probably contains only small amounts of ground water because of low porosity and hydraulic conductivity that are controlled by fractures. Although debris-flow deposits and Red River alluvium are restricted in areal extent compared to bedrock aquifers, they contain most of the ground water in the valley. Debris fans and the Red River alluvium are less than 1,000 feet wide and less than 200 feet thick (K. Vincent, U.S. Geological Survey, written commun., 2003).

Whereas chemical analyses of ground water were not obtained prior to mining in the Red River Valley, a substantial amount of historical data are available (LoVetere and others, 2004). Most wells developed in the Red River Valley were installed to monitor water quality downgradient from mining operations (waste rock and tailings piles) and (or) scar areas. Bedrock, debris-flow, and alluvial aquifer ground water is dominantly a calcium sulfate type water.

Surface Water

The Red River originates at an altitude of approximately 12,000 feet near Wheeler Peak and flows roughly 35 miles to its confluence with the Rio Grande at an altitude of 6,600 feet. Total basin drainage area is 190 square miles; the drainage area upstream from the Questa Ranger Station gaging station is 113 square miles. Streamflow usually peaks from late May to mid-June; snowmelt-related flows begin in late March and increase through mid-April. Summer thunderstorms are prevalent in July and August. Between 1930 and 2001, the mean annual discharge of the Red River at the Questa Ranger Station gage ranged from 12.8 to 103 cubic feet per second (ft^3/s), and the average daily discharge ranged from 2.5 to 750 ft^3/s with an average of 46.8 ft^3/s (U.S. Geological Survey, 2004a).

Springs and shallow alluvial aquifer ground water discharge to the Red River, rendering it a gaining stream over much of its length (Smolka and Tague, 1989). Between the town of Red River and the gaging station near Questa, there are roughly 25 ephemeral seeps and springs along the banks of the Red River and approximately 20 intermittent seeps and springs in tributary drainages on the north side of the river (South Pass Resources, Inc., 1995; Steffen Robertson & Kirsten, 1995; Robertson GeoConsultants, Inc., 2001). Most seeps and springs are acidic (pH 2-4) with high conductance, dissolved solids, and metal concentrations. Aluminum hydroxide often precipitates from springs downgradient from scar and mined areas on the north side of the Red River, affecting the color and turbidity of the river (Vail Engineering, Inc. 1989).

Mining History

A pair of prospectors first discovered molybdenite in Sulphur Gulch in 1914. Underground mining operations occurred between 1919 and 1958; there were more than 35 miles of underground mine workings by 1954 (Robertson GeoConsultants, 2000b; U.S. Environmental Protection Agency, 2000). Molycorp began removing the rock overburden at Sulphur Gulch in 1964, and the first molybdenite ore was extracted from the open pit in 1965. Overburden and waste rock from open-pit mining was deposited at several locations on the south-facing slopes north of the Red River between Capulin Canyon and Spring Gulches (Robertson GeoConsultants, 2000b, 2000c; URS, 2001). Tailings were transported by pipeline from the mine to the tailings facility near Questa. Water used in the mill operation was produced from the Red River and the Red River alluvial aquifer (URS, 2002).

In 1983, Molycorp ceased open-pit mining and initiated a new phase of underground mining in Goat Hill Gulch. The switch effectively stopped the dumping of waste rock in Capulin Canyon; along the north slope of the Red River; and in Goat Hill, Sulphur, and Spring Gulches and increased the volume of tailings slurry transported by pipeline to the tailings impoundment. An estimated 328 million tons of waste rock were deposited between 1964 and 1983 (Steffen Robertson & Kirsten, 1995; Slifer, 1996; Robertson GeoConsultants, Inc., 2000a, 2000b). Low market values for molybdenum caused the mine to shut down between 1986 and 1989 and again in 1992. From 1992 to 1995, while the underground mine was shut down, pumping of ground water from the underground mine stopped and the workings were allowed to flood. After mine dewatering and repair, production resumed in late 1996 and development of a new ore body began in 1998 (Molycorp, Inc., n.d.).

Well-Labeling System

Two separate systems of labeling wells are used in this report, a project-specific system and a standardized New Mexico system. The system more commonly used for this study is the project-specific system, in which all wells installed in the Straight Creek drainage basin are labeled SC (Straight Creek) and given a number. Numbering generally begins at the top of the drainage basin and increases toward the mouth of the drainage basin. Paired debris-flow and bedrock aquifer wells were given the same number and a suffix of A or B depending on whether the well was screened within debris-flow (“alluvial”) deposits or bedrock. For example, well SC-1A is the northernmost well in the Straight Creek drainage basin and is screened within debris-flow deposits, and well SC-1B is paired with SC-1A and is screened in bedrock.

The system of numbering wells in New Mexico is used to designate the location of well sites in this report. The system is based on the common subdivision of public lands into sections (fig. 4). The well number, in addition to designating the well, locates its position to the nearest 10-acre tract in the land network. This number is divided into four segments. The first segment denotes the township (T.) north (N.) or south (S.) of the New Mexico base line, the second denotes the range (R.) east (E.) or west (W.) of the New Mexico principal meridian, and the third denotes the section. The fourth segment of the number consists of three digits and denotes the 160-, 40-, and 10-acre tracts within the section, respectively. The section is divided into four quarters, numbered 1, 2, 3, and 4 in the normal reading order, for the northwest, northeast, southwest, and southeast quarters. The first digit of the fourth segment denotes the quarter section, which is a tract of 160 acres. Similarly, the quarter section is divided into four 40-acre tracts numbered in the same manner, and the second digit denotes the 40-acre tract. Finally, the 40-acre tract is divided into four 10-acre tracts, and the third digit denotes the 10-acre tract. For example, well SC-1A is designated 29N.14E.28.441; therefore, SC-1A is in the NW 1/4 of the SE 1/4 of the SE 1/4 of section 28, T.29 N., R.14 E. Letters A, B, C, and so on are added to the fourth segment to designate the second, third, fourth, and succeeding wells in the same 10-acre tract.

Acknowledgments

The authors are grateful to the project advisory committee for their contributions to the design and implementation of the study. Advisory committee members represent Amigos Bravos, Molycorp and its consultants, and the New Mexico Environment Department. Advice and cooperation from the U.S. Environmental Protection Agency Region 6 and the U.S. Forest Service are gratefully acknowledged. The authors also acknowledge Jim Ball and Ann Maest (USGS) for providing extensive technical assistance in development of the ground-water field sampling plan. Assistance with data compilation, report preparation, and sample collection activities from Caroline Myer (USGS) is greatly appreciated. Finally, the authors thank Russell Church (Plant Supervisor, AWWT facility, Town of Red River) and other AWWT facility staff for providing access to their monitoring wells and assisting with field activity logistics.

Well Installation, Development, and Logging

From November 2001 through February 2002, eight observation wells were installed in the Straight Creek drainage basin. This section presents lithologic and geophysical logs for these Phase I Straight Creek wells, geophysical logs for the AWWT wells, and well-completion data for Phase I, Phase II, and AWWT wells. Lithologic logs were constructed from field and laboratory examination of borehole cuttings. Types of geophysical logs acquired include caliper, natural gamma, single- and dual-detector neutron, induction conductivity, fluid-column resistivity, fluid-column temperature, and borehole television.

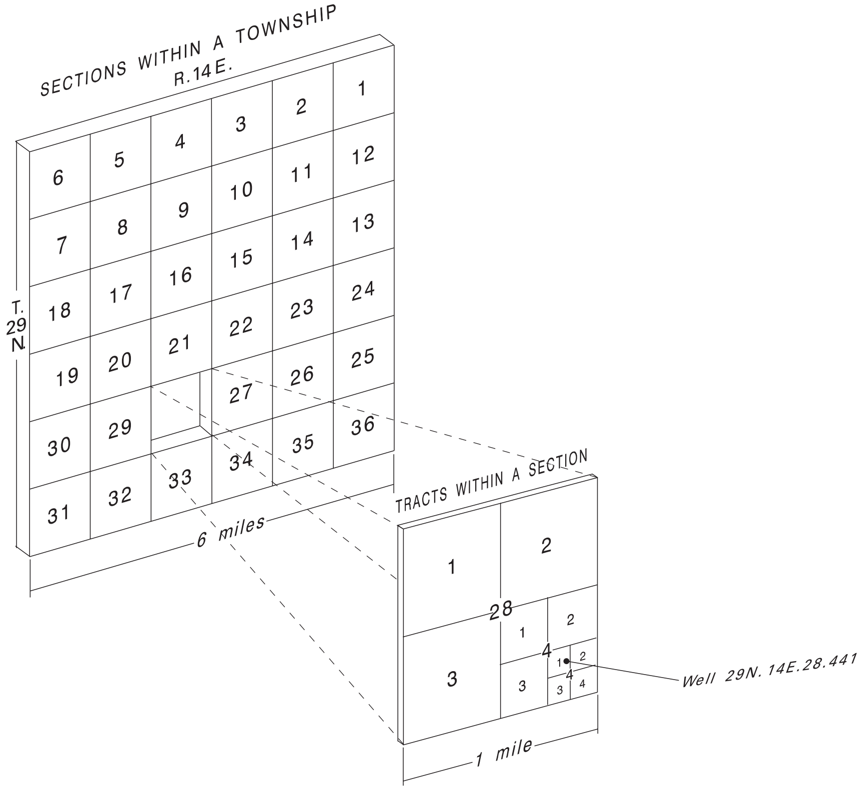


Figure 4. Well-numbering system in New Mexico.

Well Installation and Development

WDC Drilling Company (formerly THF Drilling Company) of Phoenix, Arizona, under the direction of Souder, Miller, and Associates hydrogeologists and USGS hydrologists, drilled, constructed, and developed the Straight Creek observation wells (fig. 3). Six of the observation wells are debris-flow aquifer / bedrock aquifer well pairs (SC-1A / SC-1B, SC-3A / SC-3B, and SC-5A / SC-5B). Well SC-2B was intended to be completed within debris-flow deposits, but because the debris-flow material was not saturated at the SC-2B location, the well was screened within bedrock. Well SC-4A and the three Phase II wells in the Straight Creek drainage basin (SC-6A, SC-7A, and SC-8A) were completed within debris-flow deposits. Red River alluvial deposits probably interfinger with debris-flow deposits in the vicinity of wells SC-5A and 5B, SC-7A, and SC-8A. Although the screened interval in wells SC-1A, SC-3A, and SC-4A includes bedrock, pump intakes were placed in the part of the screened interval that includes only debris-flow material. Water samples, therefore, are representative of the chemistry of debris-flow aquifer ground water, and wells SC-1A, SC-3A, and SC-4A are referred to as debris-flow aquifer wells in this report. Detailed well-installation information is not included in this report for the Phase II wells for which water chemistry data are presented in this report (SC-6A, SC-7A, and SC-8A).

Wells SC-1A, SC-2B, SC-3A, SC-4A, and SC-5A were installed using a drilling rig equipped with dual-wall drive casing (9-inch outer diameter, 6-inch inner barrel, center sample return), a diesel top-drive hammer, and an on-board air compressor.

Wells SC-1B, SC-3B, and SC-5B were installed using an air-rotary/hammer drilling rig equipped with a casing-advance system and an on-board air compressor (an auxiliary compressor provided additional air capacity as needed). Boreholes were advanced to the debris-flow/bedrock contact with air rotary using the casing-advance system to temporarily case unconsolidated material overlying bedrock. Six-inch-diameter steel conductor casing was permanently set to prevent debris-flow aquifer water from entering the bedrock aquifer, then boreholes were advanced into bedrock.

Wells SC-1A, SC-2B, SC-3A, SC-4A, and SC-5A were constructed of new, flush-threaded, 4-inch-diameter, schedule 80 polyvinyl chloride (PVC) casing. Wells SC-1B, SC-3B, and SC-5B were constructed of new, flush-threaded, 3-inch-diameter, schedule 80 PVC casing. All wells were constructed with factory-cut, 0.010-inch slot size PVC screens and threaded end caps. Filter packs (10/20 silica sand) were emplaced from the bottom of the well to a minimum of 2 feet above the top of the screen and surged for at least 20 minutes. Drill casing was decontaminated with phosphate-free detergent and tap water after completion of each well.

Wells SC-1A, SC-2B, SC-3A, SC-4A, and SC-5A were developed by mechanical surging and pumping. Wells SC-1B, SC-3B, and SC-5B were developed by mechanical surging and bailing. During development of well SC-1B, the bottom of the PVC casing was broken and a rubber plug was installed. Each well was pumped or bailed until a minimum of three well volumes was removed and then until pH, temperature, and specific conductance stabilized, with the exception of well SC-2B. Specific conductance and pH were not measured during development of well SC-2B. Stabilization criteria were: pH, ±0.1 unit; temperature, ±0.5 °C; and specific conductance, ±10 percent.

Site information, borehole and well depths, screened intervals, and initial water-level data are presented in table 1. For Straight Creek wells, latitude, longitude, and altitude data were acquired by Molycorp using a Trimble 5800 Real Time Kinematic Rover™ with Trimble 5700 Global Positioning System (GPS) Total Station™ base; accuracy of the system is +/- 5 millimeters horizontally and +/- 0.1 foot vertically (B.M. Walker, Molycorp, written commun., 2003). Unless otherwise noted in table 1, all other information for Straight Creek wells was collected at the time of drilling and well installation. Latitude and longitude for AWWT wells were acquired using a Garmin eTrex® 12-parallel-channel GPS receiver. Land-surface altitude at well AWWT-1 was estimated by rough leveling from a nearby surveyed well. For well AWWT-2, land-surface altitude was estimated from a USGS 7 1/2-minute topographic quadrangle map (scale 1:24,000). AWWT-1 completion date, borehole depth, and water level (at time of well completion) were compiled from the New Mexico Office of the State Engineer (NMOSE) well record. The completion date for well AWWT-2 was compiled from the NMOSE Water Administration Technical Engineering Resource System (WATERS). Because of incomplete well-completion data, borehole television logs were acquired for wells AWWT-1 and AWWT-2 to provide screened interval locations (table 1).

Well Logging

Lithologic logs and geophysical logs for Phase I wells are presented with well-completion diagrams in figure 5. No well-completion diagrams are presented for the AWWT wells because data are either unavailable or unreliable. The available well-completion information for AWWT wells is presented in table 1. Logging methods and results are described in this section.

Lithologic Logs

Lithologic logs for newly installed wells were constructed from field and laboratory examination of borehole cuttings. During drilling of wells SC-1A, SC-2B, SC-3A, SC-4A, and SC-5A, cuttings were collected from land surface to the debris-flow/bedrock contact. For wells SC-1B, SC-3B, and SC-5B, cuttings were collected from the debris-flow/bedrock contact to total depth. Cuttings were collected from sampling cyclones in 5-gallon plastic containers at 5-foot intervals. Representative samples from each 5-foot interval were examined in the field with a hand lens. The level of detail in field logging of samples was dictated by the condition of the sample (wet or dry, fine or coarse) and the time available for inspection. Marked sample containers were sealed and stored for later analysis. Detailed analyses of drill cuttings conducted by the USGS are documented in Ludington and others (2004).

The cuttings for wells SC-1A, SC-2B, SC-3A, SC-4A, and SC-5A were relatively undisturbed (in situ particle-size distribution was largely retained) compared with cuttings from wells SC-1B, SC-3B, and SC-5B. Upon completion of the drilling program, Souder, Miller, and Associates (2002) described the petrology and mineralogy of representative samples from each 5-foot interval for wells SC-1A, SC-2B, SC-3A, SC-4A, and SC-5A. Souder, Miller, and Associates (2002) also determined grain-size distribution, based on the Udden-Wentworth (Wentworth, 1922) scale, in samples from these wells.

Blow counts were recorded about every 10 feet for wells SC-2B, SC-3A, and SC-5A. Blow counts, which refer to the number of hammer blows needed to drive the casing 6 inches, are indicative of sediment packing and density. Penetration of harder formations requires more hammer blows than softer formations do (Harvey and others, 2002), so blow counts were useful in identifying the transition from debris-flow material to bedrock in some Straight Creek wells.

Geophysical Logs

Geophysical logging occurred in January and February 2002 for the Straight Creek wells and in October 2003 for the AWWT wells. Types of geophysical logs acquired include caliper, natural gamma, single- and dual-detector neutron, induction conductivity, fluid-column resistivity, fluid-column temperature, and borehole television (table 2). The two primary quality-control measures used in the collection of geophysical logs were (1) assuring a valid depth scale by verifying that the depth indicator on the log recorded a value within 2 centimeters of zero when the probe was returned to the measurement reference point at the end of logging and (2) obtaining duplicate sections for nuclear (gamma and neutron) logs to ensure that logs repeated the same formation signature with only minor changes related to nuclear statistics.

In theory, the most useful geophysical logs and most complete suite of measurements would be obtained by logging open boreholes filled with natural formation water. In practice, logistics and borehole conditions dictated that logs be obtained in wells at varying stages of completion. Because of the high probability of borehole collapse, wells SC-1A, SC-2B, SC-3A, SC-4A, and SC-5A were logged after being fully completed. Boreholes for wells SC-1B, SC-3B, and SC-5B were logged after steel conductor casing was installed. For wells SC-1B and SC-3B, geophysical logging of the open portion of the bedrock borehole occurred after boreholes were drilled to total depth and before PVC casing was installed. Because of the limited time

Table 1. Site and construction information and initial water-level data.

[NGVD29, National Geodetic Vertical Datum of 1929; ---, not available]

Well (fig. 3)	U.S. Geological Survey site identification number	Well location	Latitude	Longitude	Land-surface altitude (feet above NGVD 29)	Date completed	Borehole depth (feet below land surface)	Well depth (feet below land surface)	Screened interval (feet below land surface)	Water level (feet below land surface)	Water altitude (feet above NGVD-29)	Date water level measured
SC-1A	364258105264001	29N.14E.28.441	36˚42' 58.07"	105˚26' 42.06'"	8,958.6	1/29/2002	74.5	74	54-74	49.50	8,909.1	3/18/2002
SC-1B	364258105263901	29N.14E.28.441A	36˚42' 57.81"	105˚26' 42.01"	8,956.0	2/3/2002	146	140	130-140	55.86	8,900.2	3/18/2002
SC-2B	364245105263501	29N.14E.33.221	36˚42' 45.69"	105˚26' 37.18"	8,791.5	2/4/2002	86	85.5	60.5-85.5	68.08	8,723.4	3/19/2002
SC-3A	364245105263502	29N.14E.33.221A	36˚42' 45.66"	105˚26' 37.91"	8,790.0	2/7/2002	112.5	112	82-112	68.21	8,721.8	3/19/2002
SC-3B	364245105263601	29N.14E.33.221B	36˚42' 45.52"	105˚26' 38.09"	8,789.5	1/23/2002	200	191	161-191	153.84	8,635.7	3/19/2002
SC-4A	364246105263501	29N.14E.28.443	36˚42' 46.29"	105˚26' 37.98"	8,799.8	1/20/2002	114.5	114	94-114	74.63	8,725.2	3/18/2002
SC-5A	364231105263201	29N.14E.33.242	36˚42' 31.47"	105˚26' 34.39"	8,613.4	2/15/2002	197	197	172-187	151.74	8,461.7	3/19/2002
SC-5B	364231105263202	29N.14E.33.242A	36˚42' 31.32"	105˚26' 34.20"	8,612.1	1/17/2002	420	348	338-348	150.27	8,461.9	3/19/2002
SC-6A	364245105263901	29N.14E.33.221D	36˚42' 45.67"	105˚26' 39.33"	8,793.6	11/12/2002	150	149	129-149	132.12	8,661.4	11/26/2002
SC-7A	364228105264301	29N.14E.33.241	36˚42' 28.25"	105˚26' 43.04"	8,561.0	12/7/2002	196	195	107-195	109.27	8,451.7	12/8/2002
SC-8A	364225105264501	29N.14E.33.234	36˚42' 25.42"	105˚26' 45.66"	8,522.4	11/24/2002	98	98	87-97	71.05	8,451.3	12/8/2002
AWWT-1	364229105263901	29N.14E.33.241	36˚42' 29.38"	105˚26' 39.01"	8,580.0	4/13/1982	220	210	190-210	133	8,447.0	---
AWWT-2	364231105264601	29N.14E.33.232	36˚42' 31.90"	105˚26' 46.07"	8,560.0	7/24/1992	---	156	77-117 135-154	---	---	---

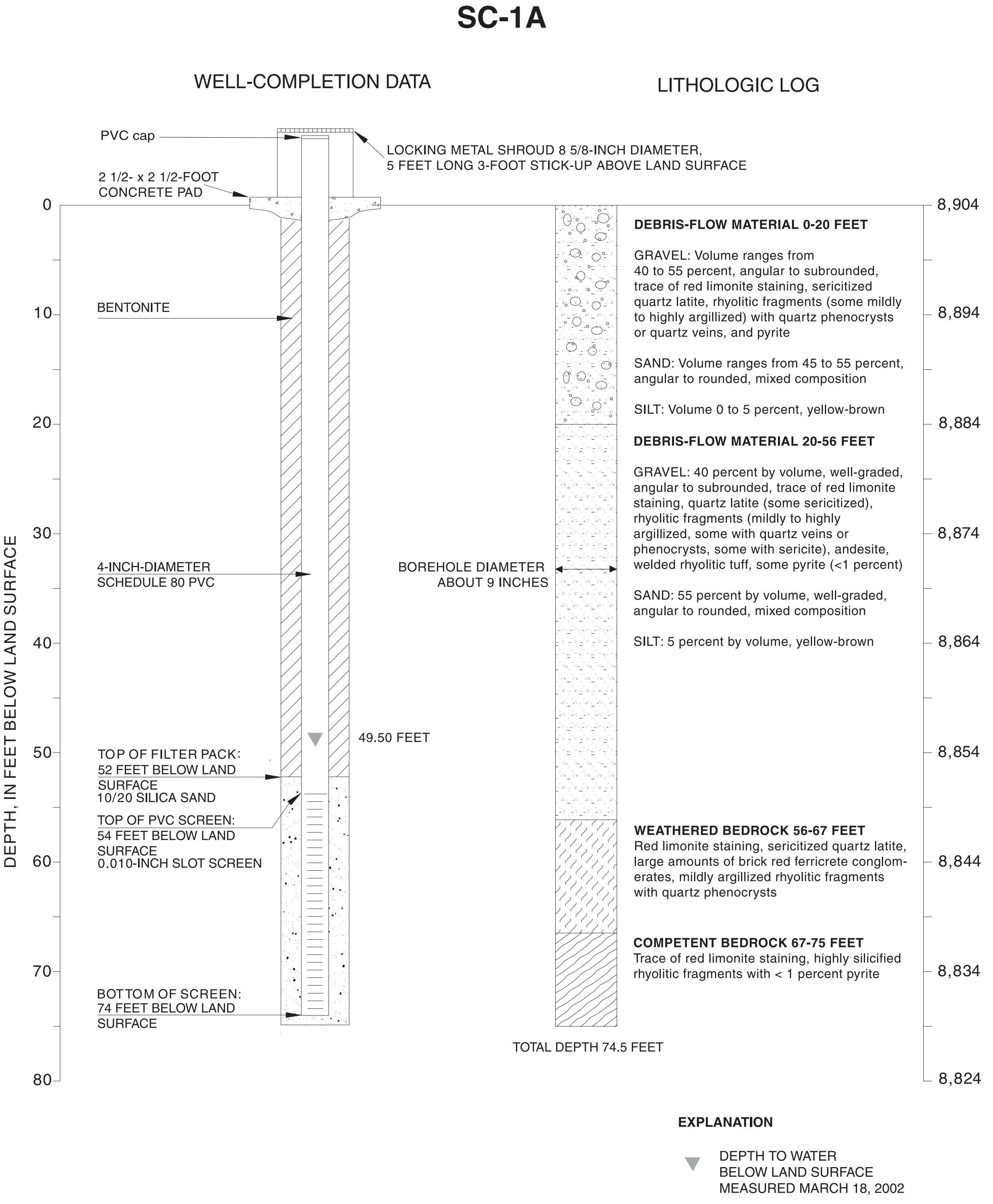


Figure 5A. Well-completion data, lithologic log, and geophysical logs for SC-1A (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).

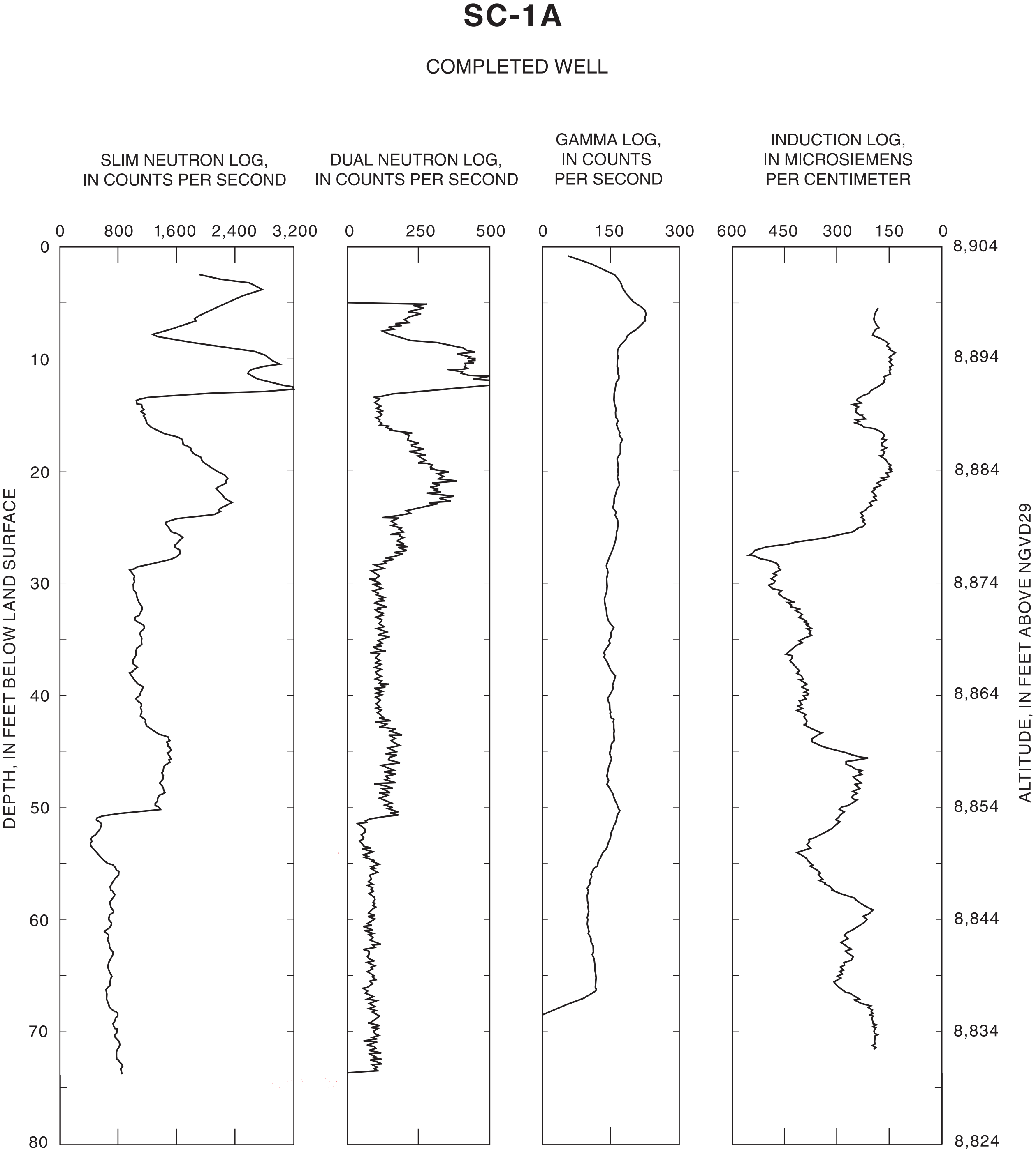


Figure 5A. Well-completion data, lithologic log, and geophysical logs for SC-1A (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).

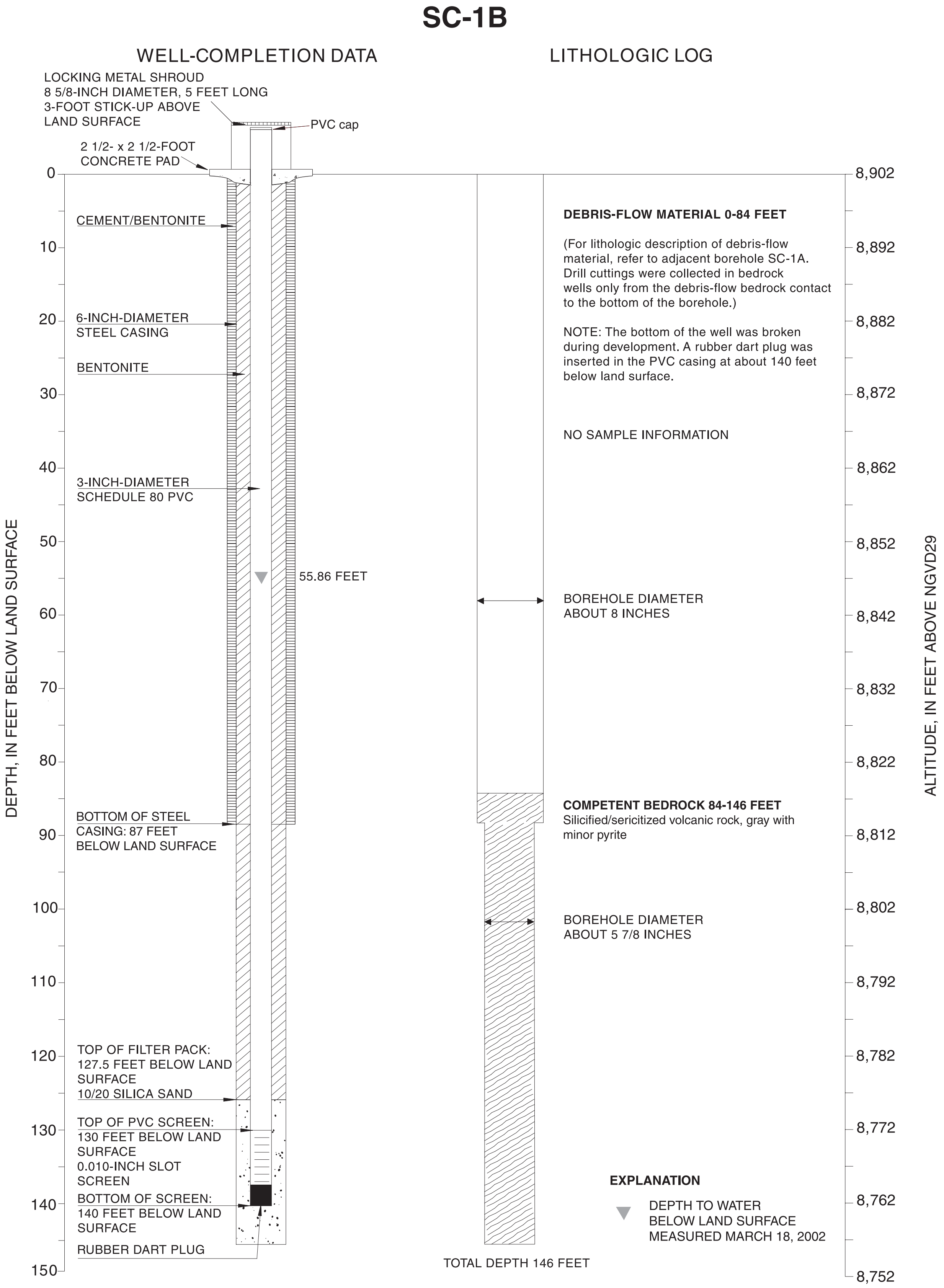


Figure 5B. Well-completion data, lithologic log, and geophysical logs for SC-1B (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).

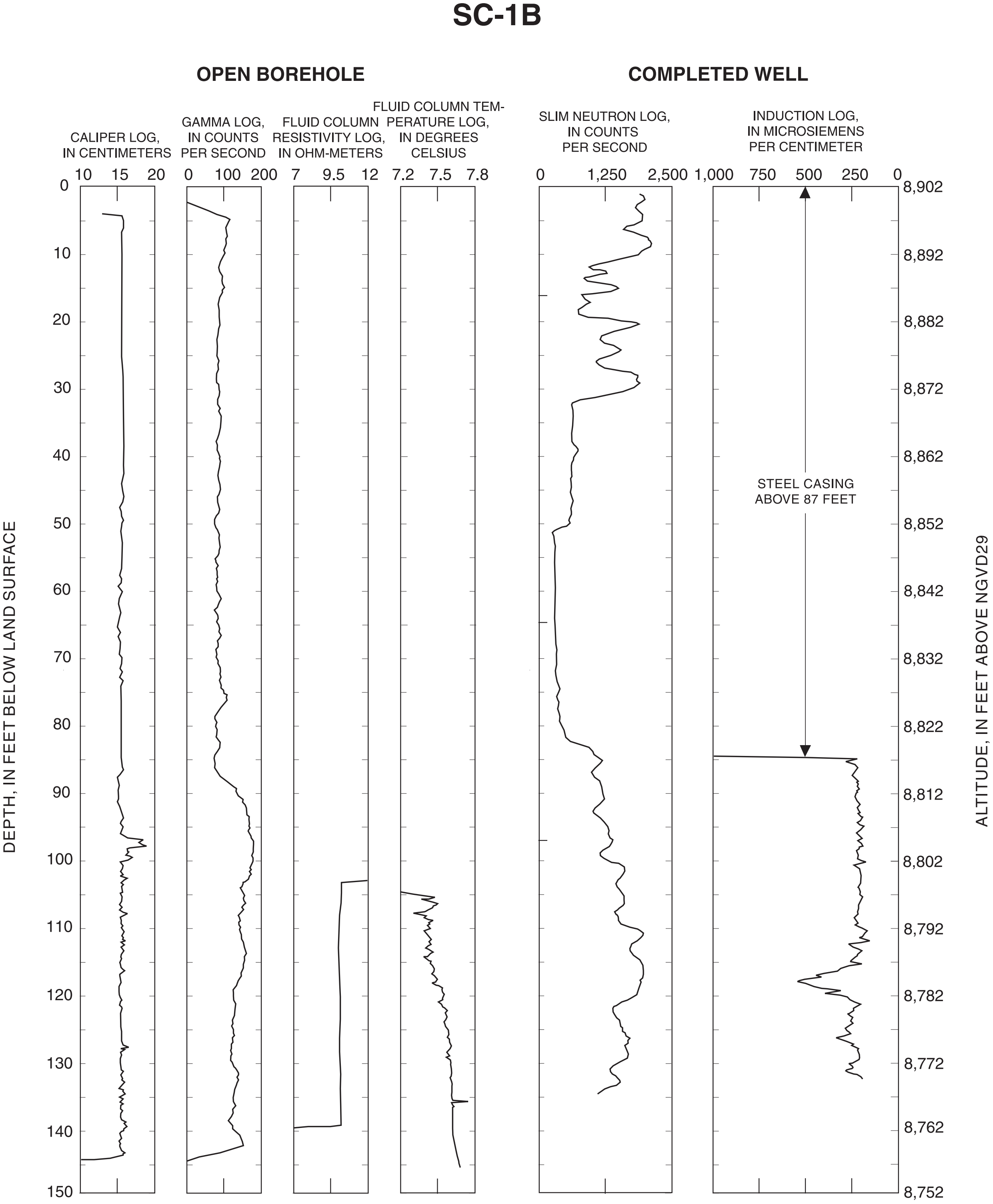
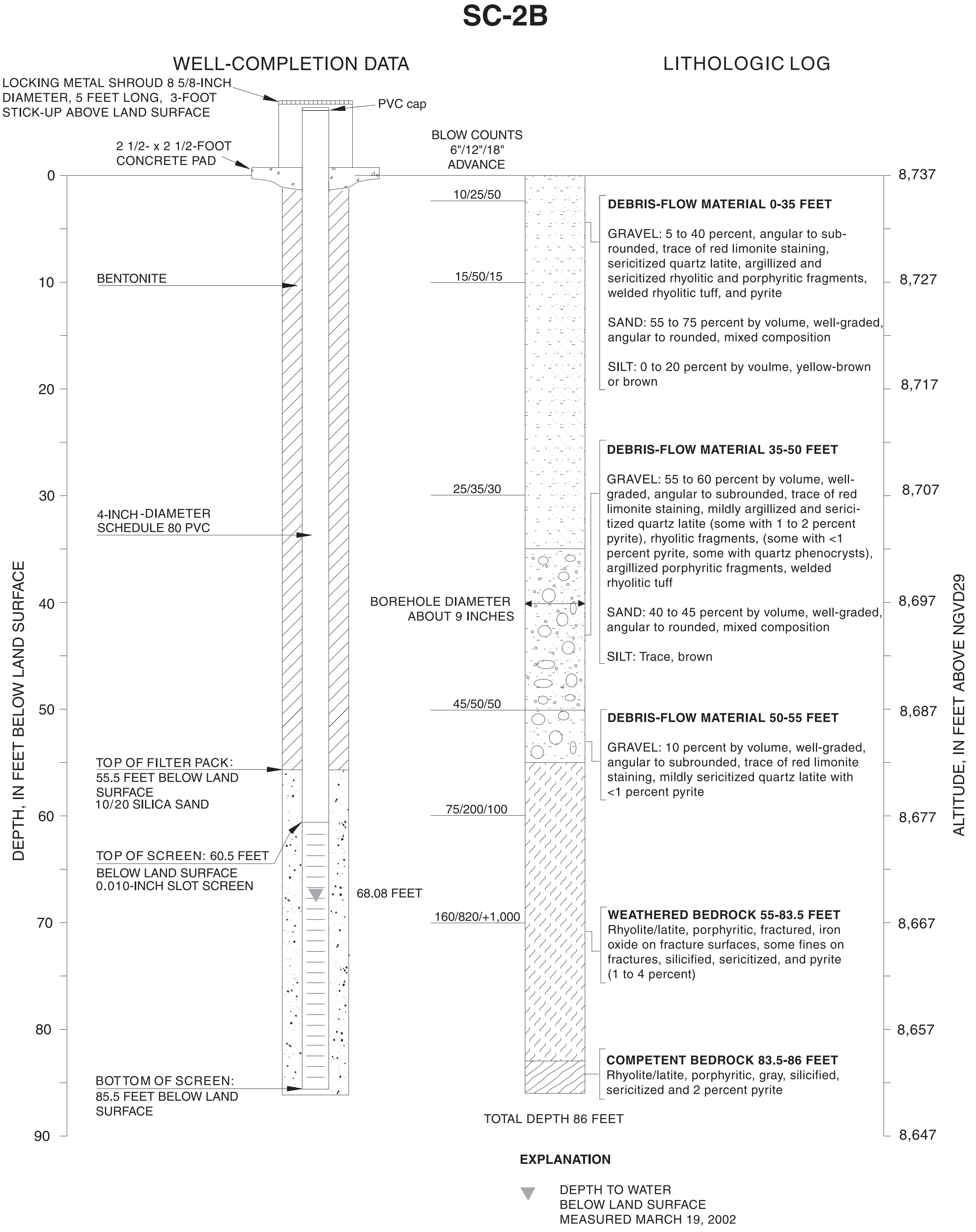


Figure 5B. Well-completion data, lithologic log, and geophysical logs for SC-1B (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).



DEBRIS-FLOW MATERIAL 0-35 FEET

GRAVEL: 5 to 40 percent, angular to subrounded, trace of red limonite staining, sericitized quartz latite, argillized and sericitized rhyolitic and porphyritic fragments, welded rhyolitic tuff, and pyrite

SAND: 55 to 75 percent by volume, well-graded, angular to rounded, mixed composition

SILT: 0 to 20 percent by voulme, yellow-brown or brown

DEBRIS-FLOW MATERIAL 35-50 FEET

GRAVEL: 55 to 60 percent by volume, well-graded, angular to subrounded, trace of red limonite staining, mildly argillized and sericitized quartz latite (some with 1 to 2 percent pyrite), rhyolitic fragments, (some with <1 percent pyrite, some with quartz phenocrysts), argillized porphyritic fragments, welded rhyolitic tuff

SAND: 40 to 45 percent by volume, well-graded, angular to rounded, mixed composition

SILT: Trace, brown

DEBRIS-FLOW MATERIAL 50-55 FEET

GRAVEL: 10 percent by volume, well-graded, angular to subrounded, trace of red limonite staining, mildly sericitized quartz latite with <1 percent pyrite

WEATHERED BEDROCK 55-83.5 FEET
Rhyolite/latite, porphyritic, fractured, iron oxide on fracture surfaces, some fines on fractures, silicified, sericitized, and pyrite (1 to 4 percent)

COMPETENT BEDROCK 83.5-86 FEET
Rhyolite/latite, porphyritic, gray, silicified, sericitized and 2 percent pyrite

Figure 5C. Well-completion data, lithologic log, and geophysical logs for SC-2B (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).

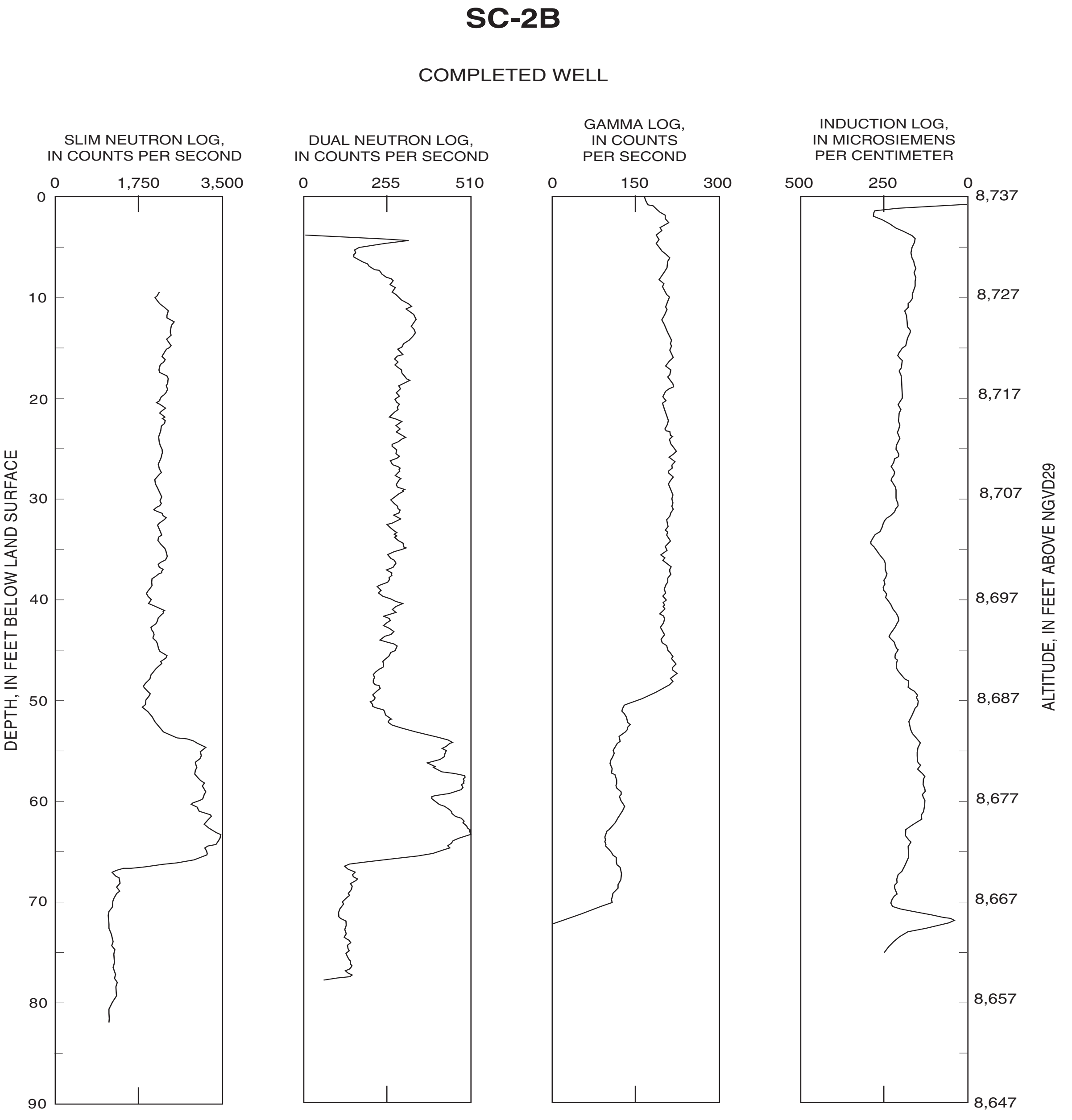
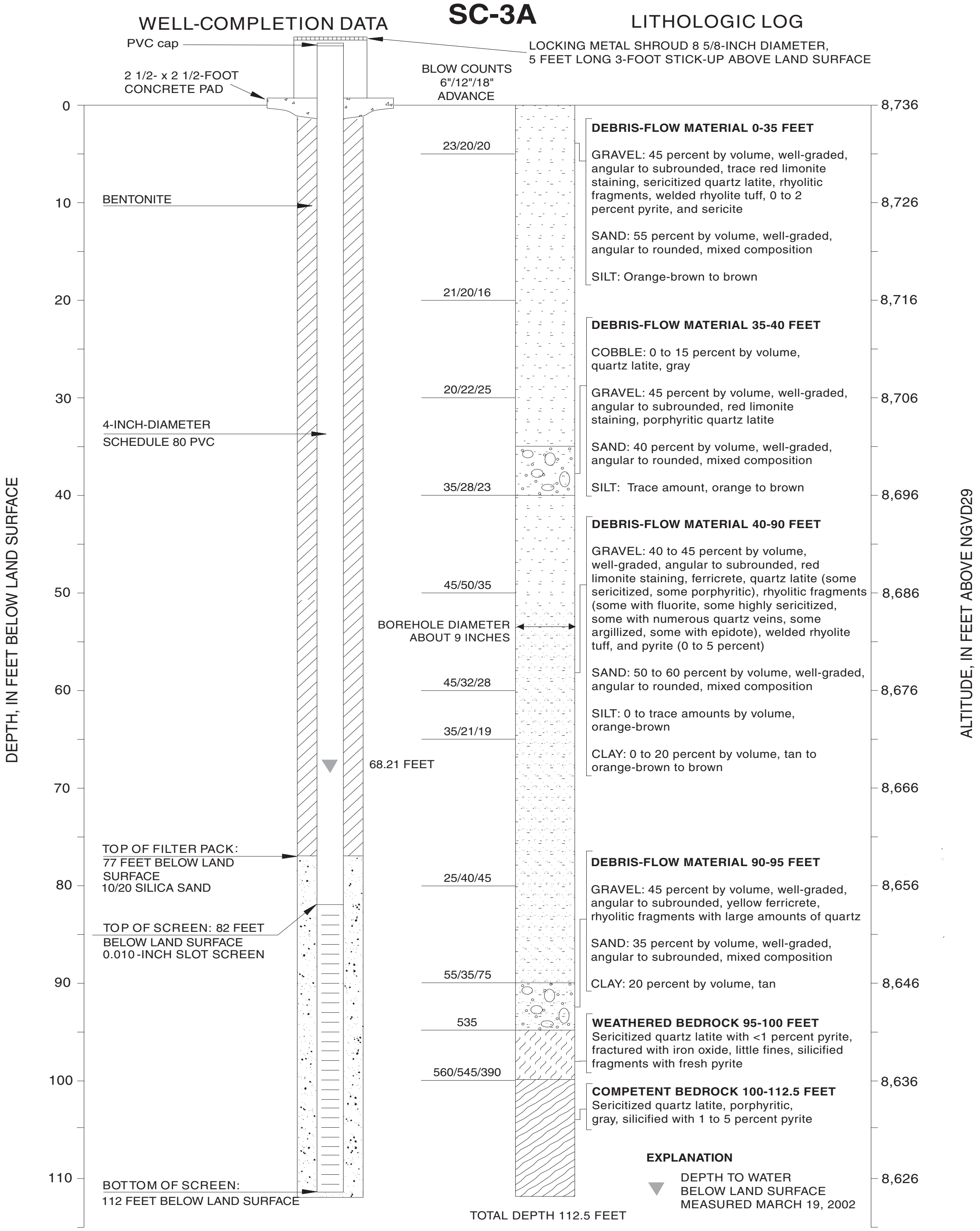


Figure 5C. Well-completion data, lithologic log, and geophysical logs for SC-2B (well completion data and lithologic log modified from Souder, Miller and Associates, 2002)--Concluded.



DEBRIS-FLOW MATERIAL 0-35 FEET

GRAVEL: 45 percent by volume, well-graded, angular to subrounded, trace red limonite staining, sericitized quartz latite, rhyolitic fragments, welded rhyolite tuff, 0 to 2 percent pyrite, and sericite

SAND: 55 percent by volume, well-graded, angular to rounded, mixed composition

SILT: Orange-brown to brown

DEBRIS-FLOW MATERIAL 35-40 FEET

COBBLE: 0 to 15 percent by volume, quartz latite, gray

GRAVEL: 45 percent by volume, well-graded, angular to subrounded, red limonite staining, porphyritic quartz latite

SAND: 40 percent by volume, well-graded, angular to rounded, mixed composition

SILT: Trace amount, orange to brown

DEBRIS-FLOW MATERIAL 40-90 FEET

GRAVEL: 40 to 45 percent by volume, well-graded, angular to subrounded, red limonite staining, ferricrete, quartz latite (some sericitized, some porphyritic), rhyolitic fragments (some with fluorite, some highly sericitized, some with numerous quartz veins, some argillized, some with epidote), welded rhyolite tuff, and pyrite (0 to 5 percent)

SAND: 50 to 60 percent by volume, well-graded, angular to rounded, mixed composition

SILT: 0 to trace amounts by volume, orange-brown

CLAY: 0 to 20 percent by volume, tan to orange-brown to brown

DEBRIS-FLOW MATERIAL 90-95 FEET

GRAVEL: 45 percent by volume, well-graded, angular to subrounded, yellow ferricrete, rhyolitic fragments with large amounts of quartz

SAND: 35 percent by volume, well-graded, angular to subrounded, mixed composition

CLAY: 20 percent by volume, tan

WEATHERED BEDROCK 95-100 FEET
Sericitized quartz latite with <1 percent pyrite, fractured with iron oxide, little fines, silicified fragments with fresh pyrite

COMPETENT BEDROCK 100-112.5 FEET
Sericitized quartz latite, porphyritic, gray, silicified with 1 to 5 percent pyrite

Figure 5D. Well-completion data, lithologic log, and geophysical logs for SC-3A (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).

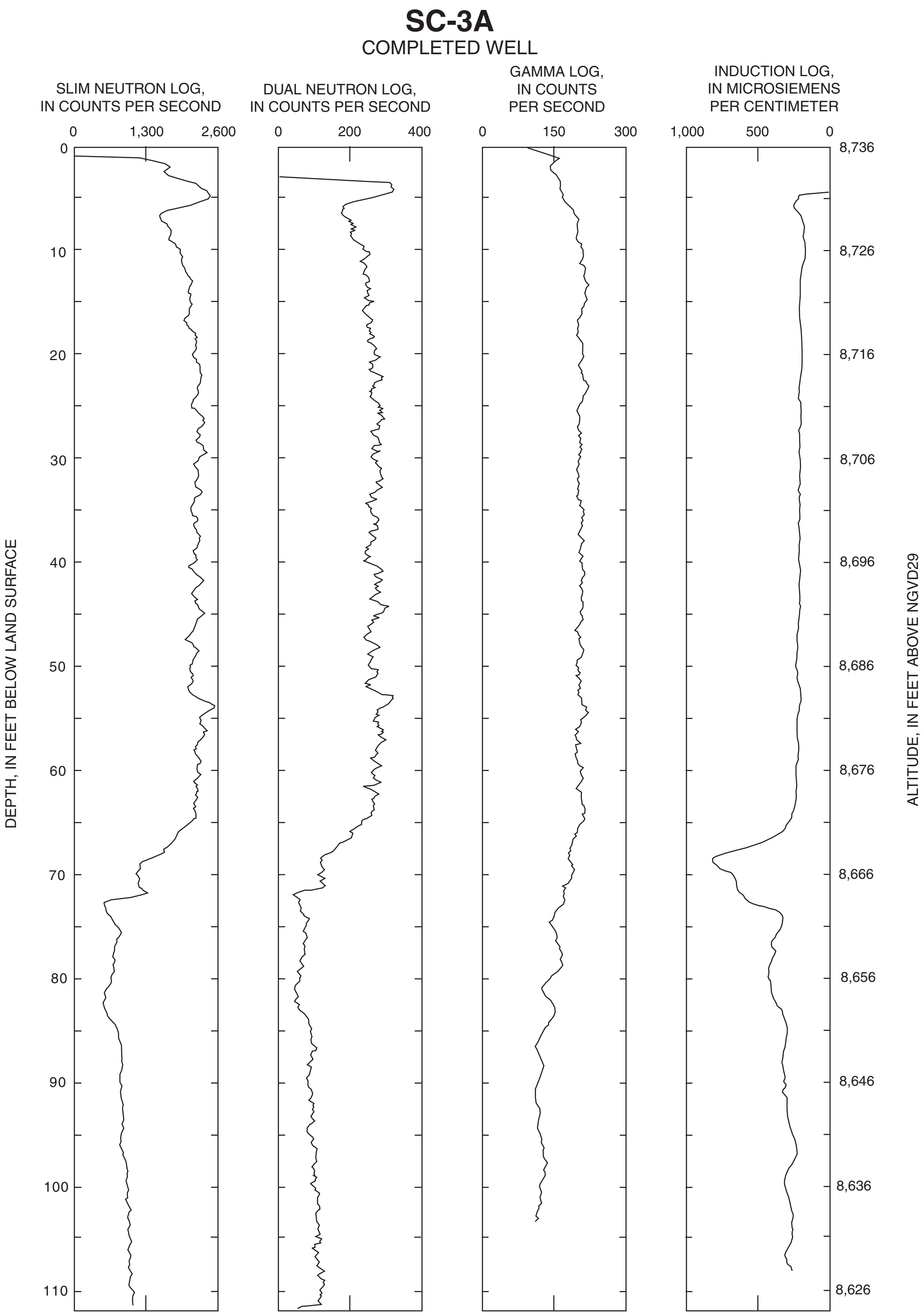


Figure 5D. Well-completion data, lithologic log, and geophysical logs for SC-3A (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002)--Concluded.

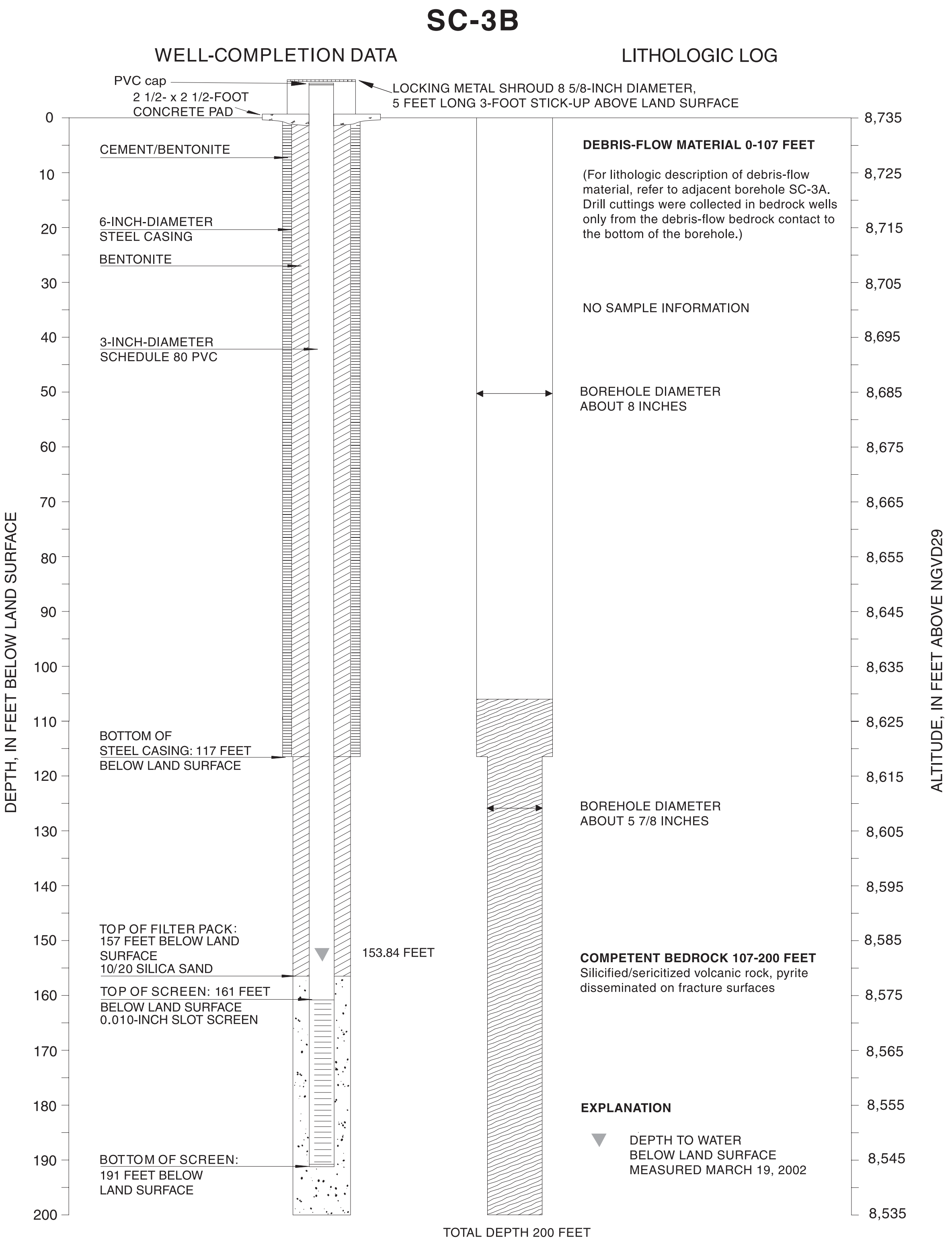


Figure 5E. Well-completion data, lithologic log, and geophysical logs for SC-3B (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).

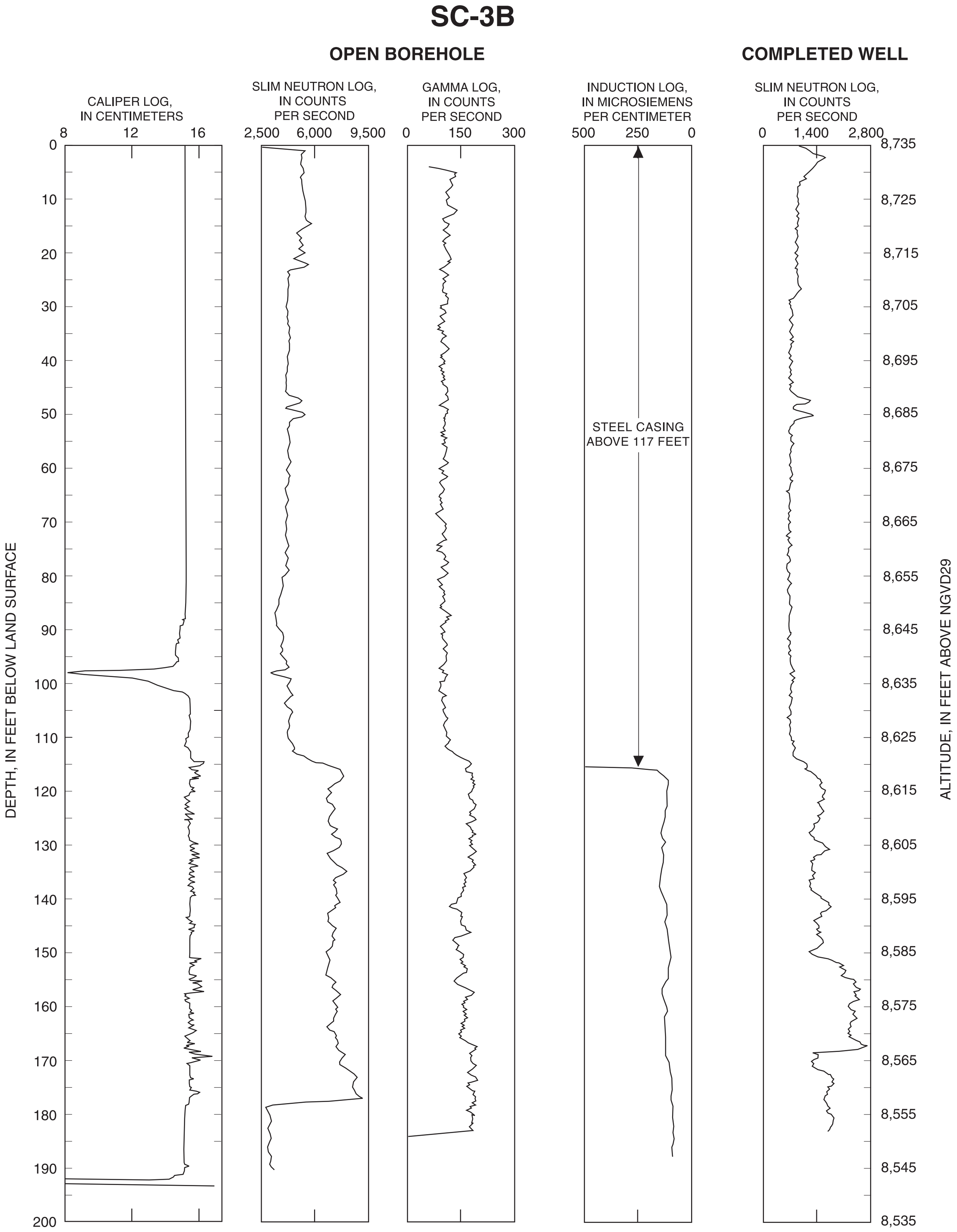
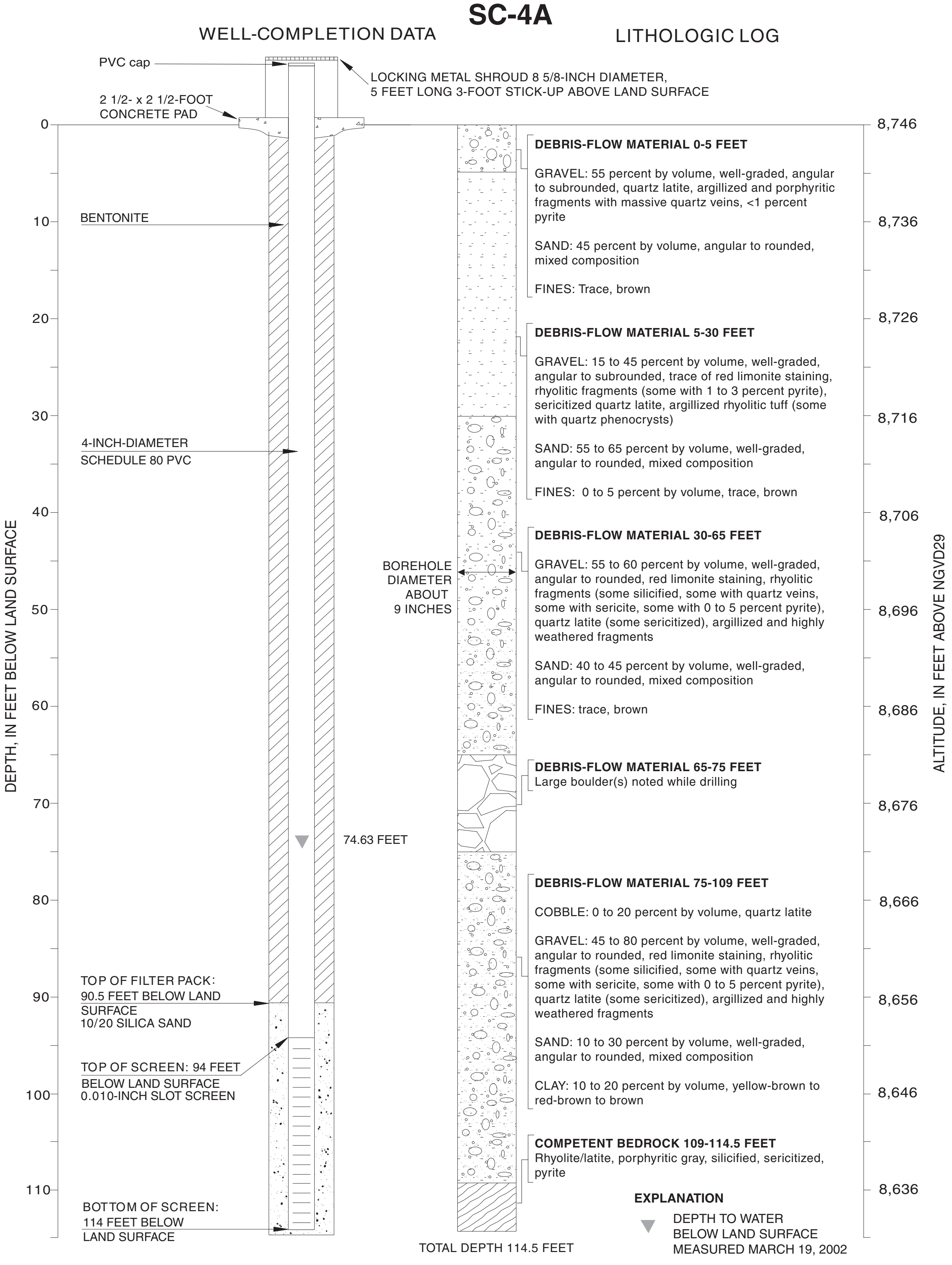


Figure 5E. Well-completion data, lithologic log, and geophysical logs for SC-3B (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002)--Concluded.



SC-4A

DEBRIS-FLOW MATERIAL 0-5 FEET

GRAVEL: 55 percent by volume, well-graded, angular to subrounded, quartz latite, argillized and porphyritic fragments with massive quartz veins, <1 percent pyrite

SAND: 45 percent by volume, angular to rounded, mixed composition

FINES: Trace, brown

DEBRIS-FLOW MATERIAL 5-30 FEET

GRAVEL: 15 to 45 percent by volume, well-graded, angular to subrounded, trace of red limonite staining, rhyolitic fragments (some with 1 to 3 percent pyrite), sericitized quartz latite, argillized rhyolitic tuff (some with quartz phenocrysts)

SAND: 55 to 65 percent by volume, well-graded, angular to rounded, mixed composition

FINES: 0 to 5 percent by volume, trace, brown

DEBRIS-FLOW MATERIAL 30-65 FEET

GRAVEL: 55 to 60 percent by volume, well-graded, angular to rounded, red limonite staining, rhyolitic fragments (some silicified, some with quartz veins, some with sericite, some with 0 to 5 percent pyrite), quartz latite (some sericitized), argillized and highly weathered fragments

SAND: 40 to 45 percent by volume, well-graded, angular to rounded, mixed composition

FINES: trace, brown

DEBRIS-FLOW MATERIAL 65-75 FEET
Large boulder(s) noted while drilling

DEBRIS-FLOW MATERIAL 75-109 FEET

COBBLE: 0 to 20 percent by volume, quartz latite

GRAVEL: 45 to 80 percent by volume, well-graded, angular to rounded, red limonite staining, rhyolitic fragments (some silicified, some with quartz veins, some with sericite, some with 0 to 5 percent pyrite), quartz latite (some sericitized), argillized and highly weathered fragments

SAND: 10 to 30 percent by volume, well-graded, angular to rounded, mixed composition

CLAY: 10 to 20 percent by volume, yellow-brown to red-brown to brown

COMPETENT BEDROCK 109-114.5 FEET
Rhyolite/latite, porphyritic gray, silicified, sericitized, pyrite

Figure 5F. Well-completion data, lithologic log, and geophysical logs for SC-4A (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).

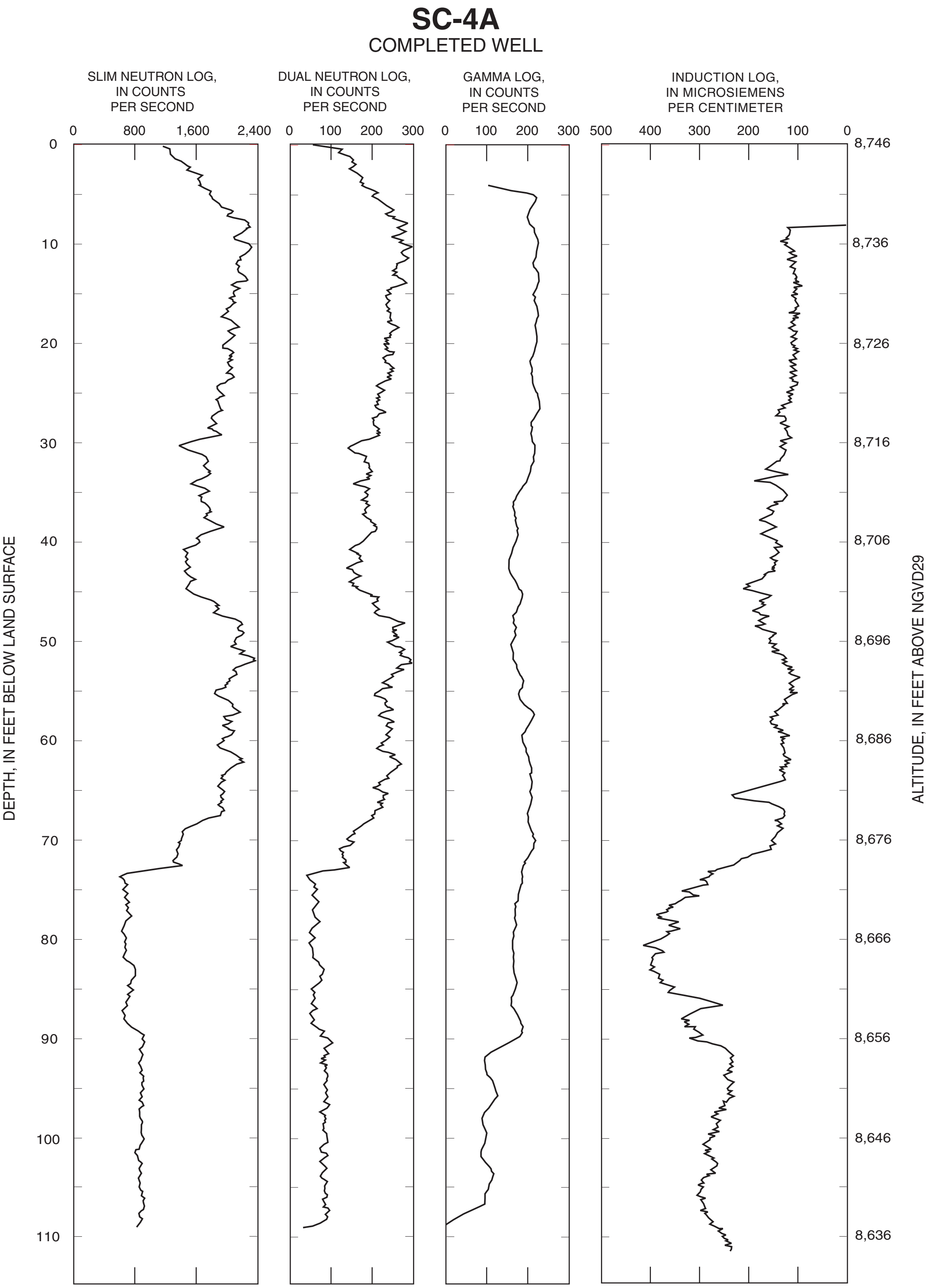
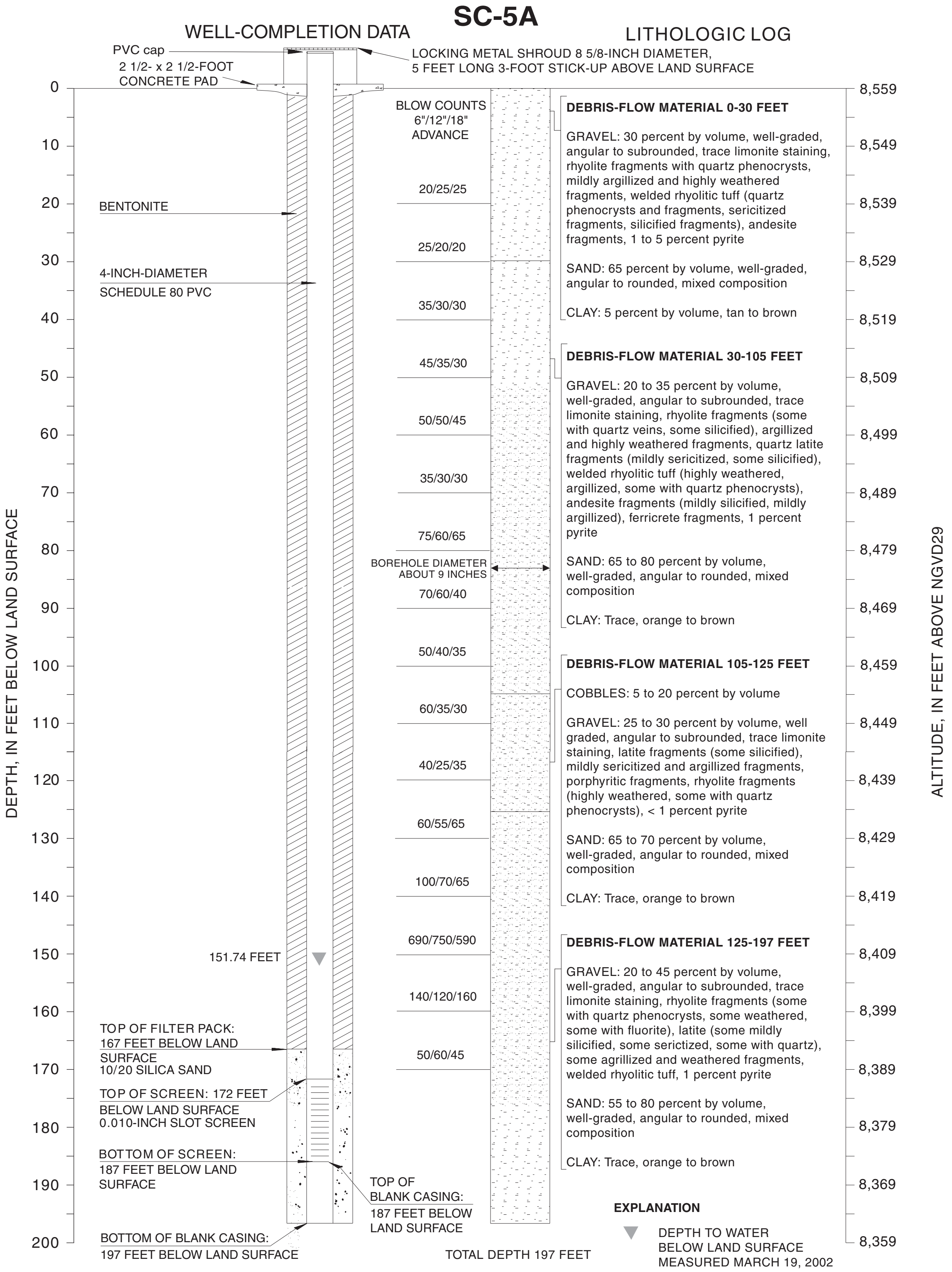


Figure 5F. Well-completion data, lithologic log, and geophysical logs for SC-4A (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002)--Concluded.



DEBRIS-FLOW MATERIAL 0-30 FEET

GRAVEL: 30 percent by volume, well-graded, angular to subrounded, trace limonite staining, rhyolite fragments with quartz phenocrysts, mildly argillized and highly weathered fragments, welded rhyolitic tuff (quartz phenocrysts and fragments, sericitized fragments, silicified fragments), andesite fragments, 1 to 5 percent pyrite

SAND: 65 percent by volume, well-graded, angular to rounded, mixed composition

CLAY: 5 percent by volume, tan to brown

DEBRIS-FLOW MATERIAL 30-105 FEET

GRAVEL: 20 to 35 percent by volume, well-graded, angular to subrounded, trace limonite staining, rhyolite fragments (some with quartz veins, some silicified), argillized and highly weathered fragments, quartz latite fragments (mildly sericitized, some silicified), welded rhyolitic tuff (highly weathered, argillized, some with quartz phenocrysts), andesite fragments (mildly silicified, mildly argillized), ferricrete fragments, 1 percent pyrite

SAND: 65 to 80 percent by volume, well-graded, angular to rounded, mixed composition

CLAY: Trace, orange to brown

DEBRIS-FLOW MATERIAL 105-125 FEET

COBBLES: 5 to 20 percent by volume

GRAVEL: 25 to 30 percent by volume, well graded, angular to subrounded, trace limonite staining, latite fragments (some silicified), mildly sericitized and argillized fragments, porphyritic fragments, rhyolite fragments (highly weathered, some with quartz phenocrysts), < 1 percent pyrite

SAND: 65 to 70 percent by volume, well-graded, angular to rounded, mixed composition

CLAY: Trace, orange to brown

DEBRIS-FLOW MATERIAL 125-197 FEET

GRAVEL: 20 to 45 percent by volume, well-graded, angular to subrounded, trace limonite staining, rhyolite fragments (some with quartz phenocrysts, some weathered, some with fluorite), latite (some mildly silicified, some serictized, some with quartz), some agrillized and weathered fragments, welded rhyolitic tuff, 1 percent pyrite

SAND: 55 to 80 percent by volume, well-graded, angular to rounded, mixed composition

CLAY: Trace, orange to brown

Figure 5G. Well-completion data, lithologic log, and geophysical logs for SC-5A (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).

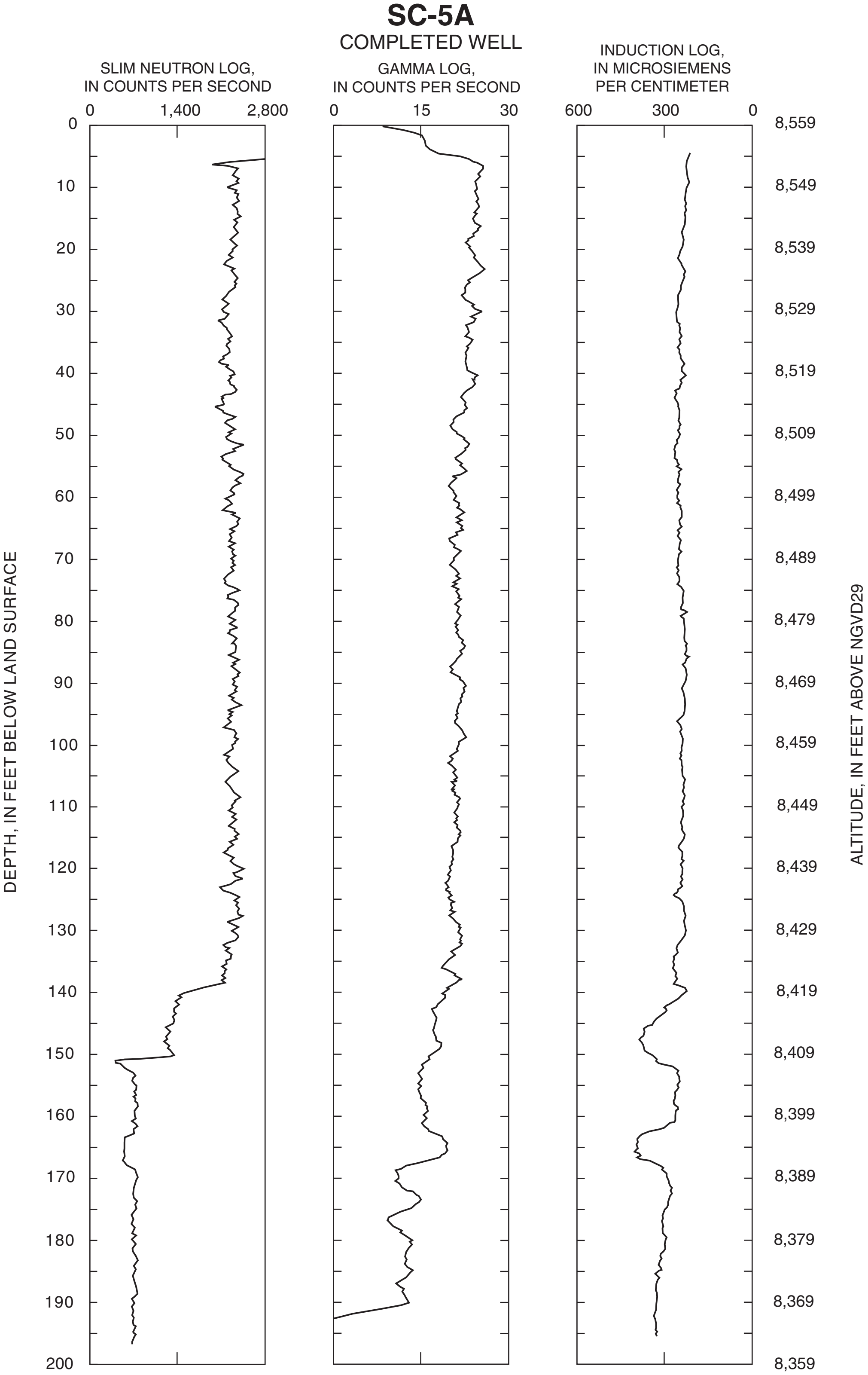


Figure 5G. Well-completion data, lithologic log, and geophysical logs for SC-5A (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002)--Concluded.

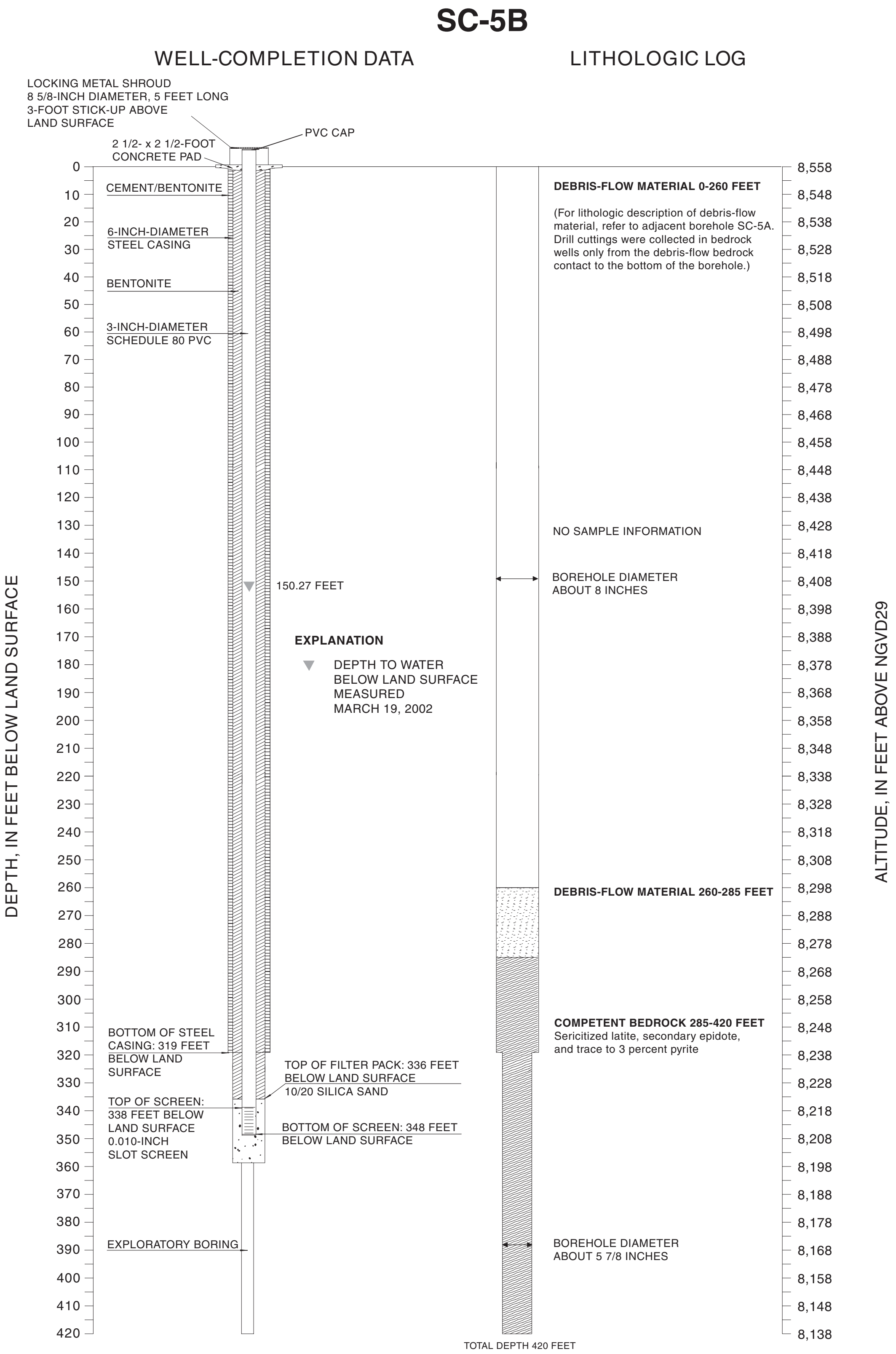


Figure 5H. Well-completion data, lithologic log, and geophysical logs for SC-5B (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002).

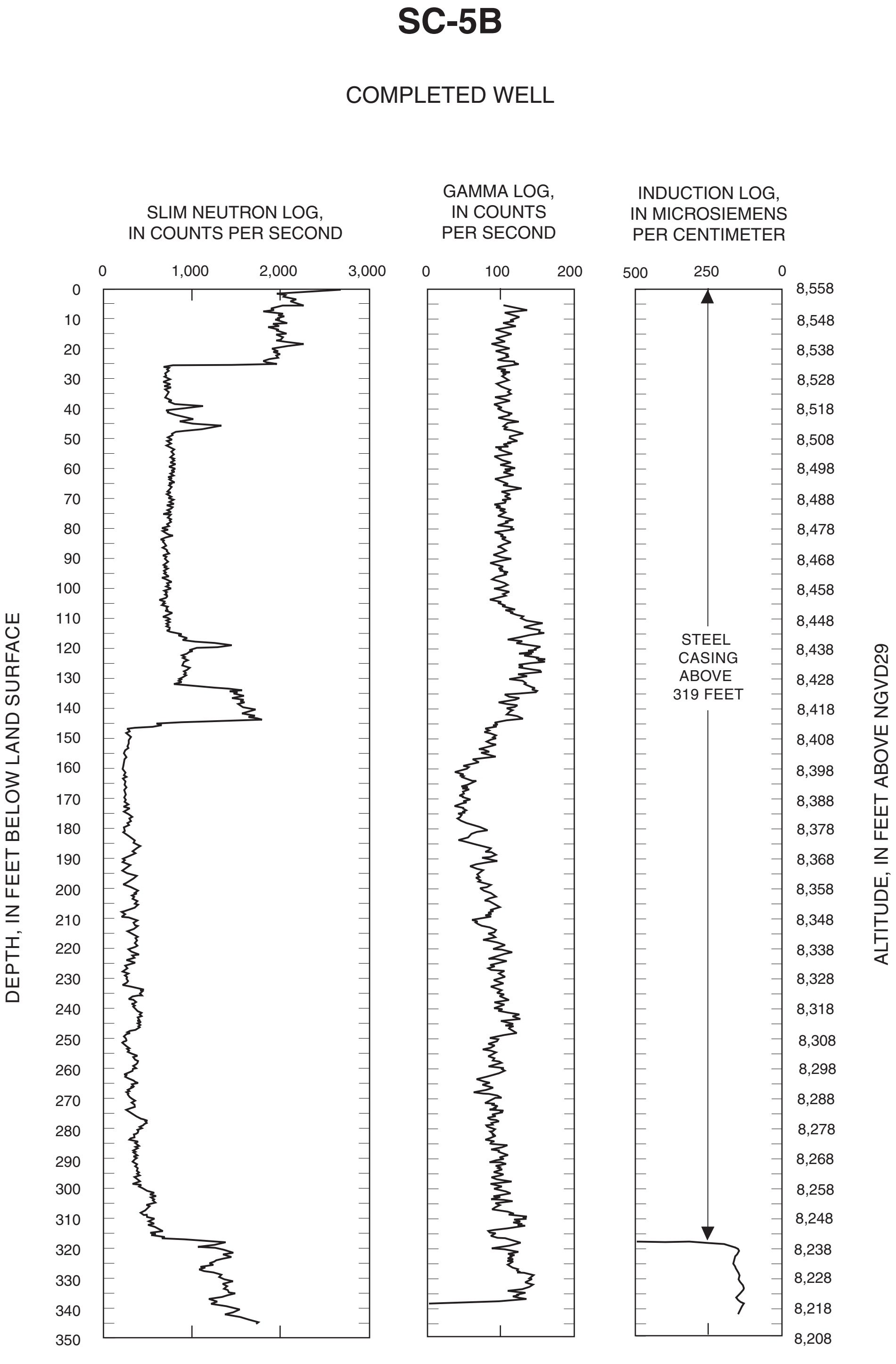


Figure 5H. Well-completion data, lithologic log, and geophysical logs for SC-5B (well-completion data and lithologic log modified from Souder, Miller and Associates, 2002)--Concluded.

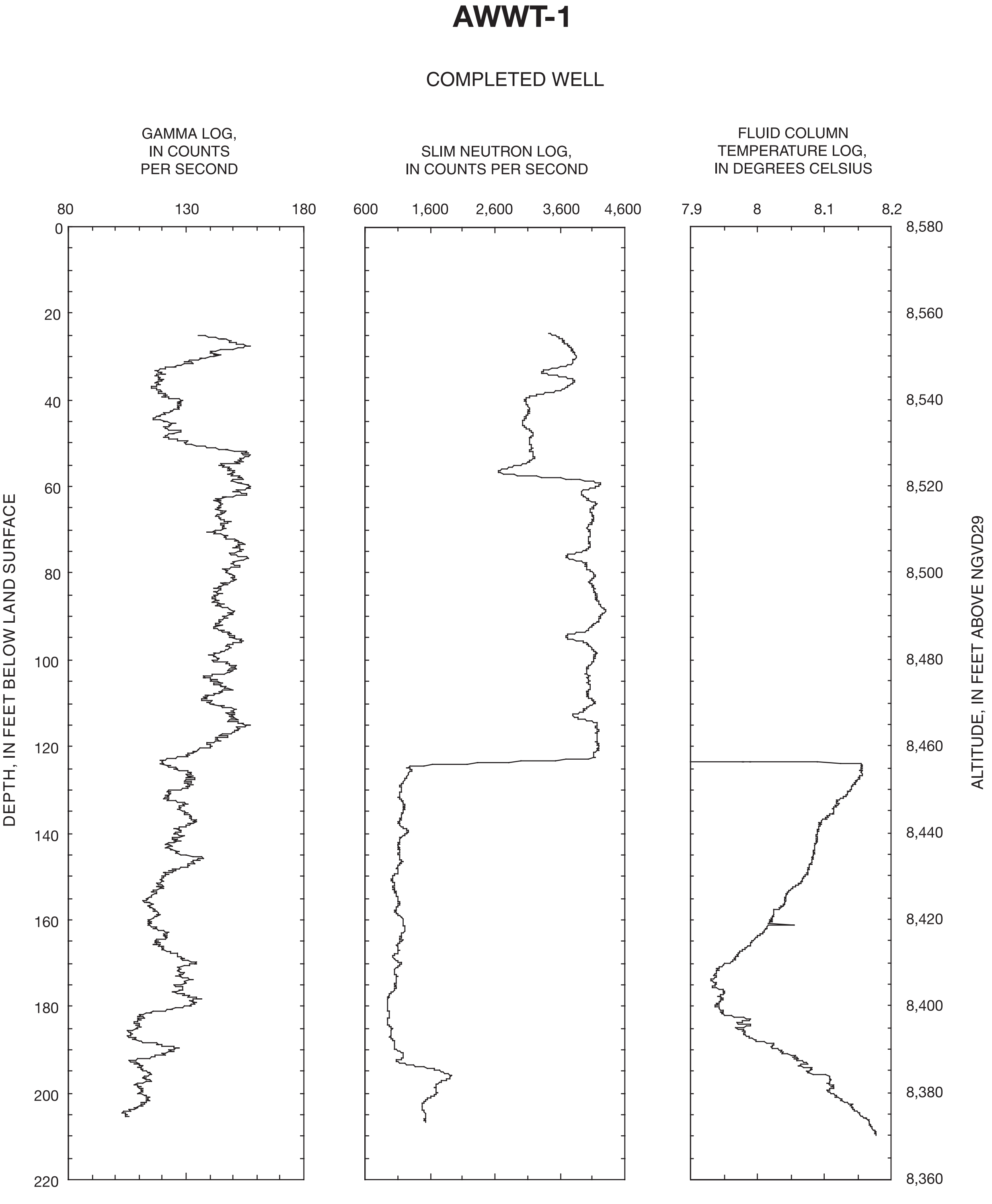


Figure 5I. Geophysical logs for AWWT-1.

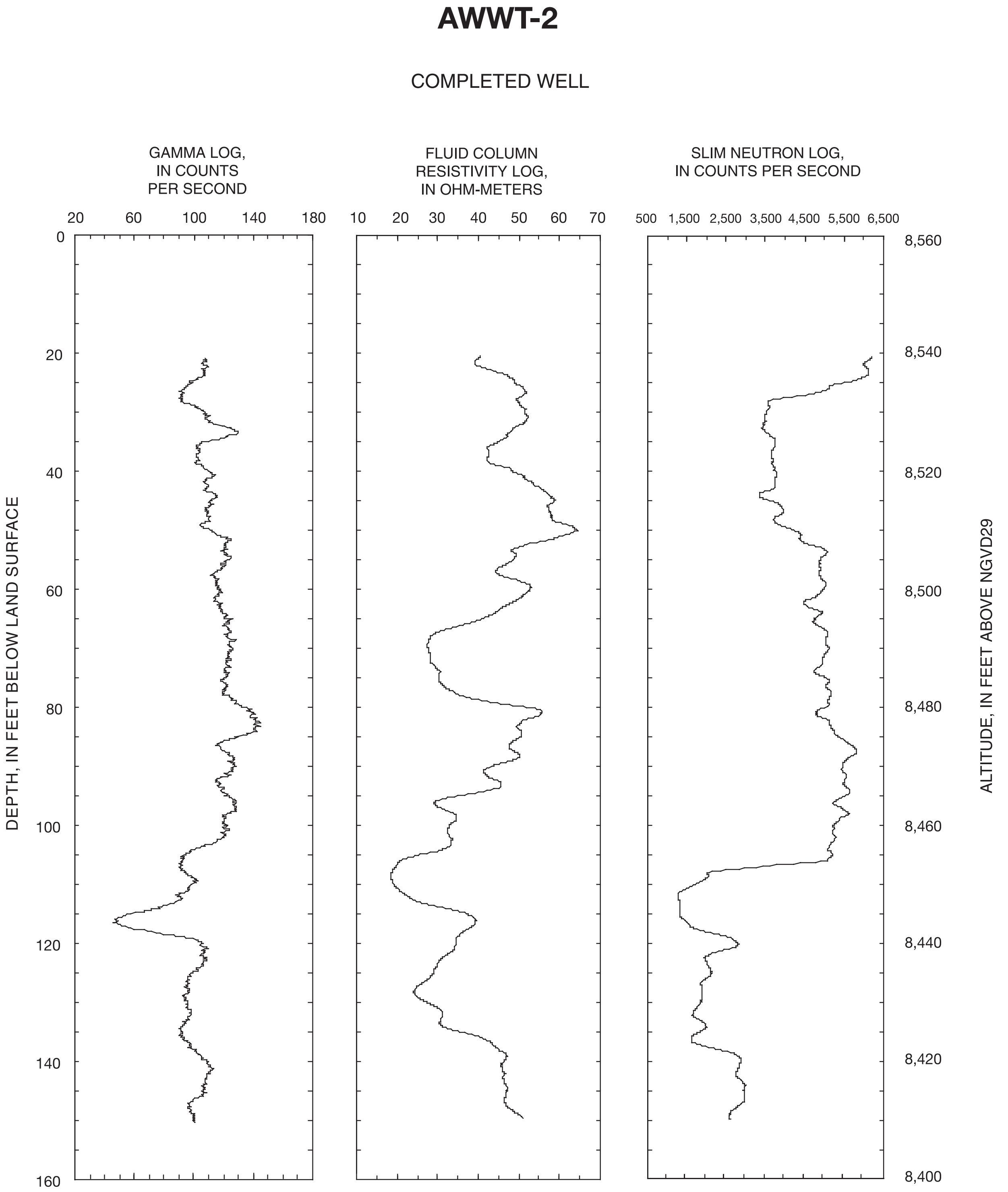


Figure 5J. Geophysical logs for AWWT-2.

Table 2. Types of geophysical well logs acquired.

Well (fig. 3)	Caliper, in centimeters	Natural gamma, in counts per second	Single-detector (slim) neutron, in counts per second	Dual-detector neutron, in counts per second	Induction conductivity, in microsiemens per centimeter	Fluid column resistivity, in ohm-meters	Fluid column temperature, in degrees Celsius	Borehole television
SC-1A		X	X	X	X			
SC-1B	X	X	X		X	X	X	
SC-2B		X	X	X	X			
SC-3A		X	X	X	X			
SC-3B	X	X	X		X			
SC-4A		X	X	X	X			
SC-5A		X	X		X			
SC-5B		X	X		X			
AWWT-1		X	X				X	X
AWWT-2		X	X			X		X

available for logging, open bedrock boreholes were only partly filled with water during logging. Geophysical logging of well SC-5B occurred after installation of PVC casing because logistics precluded logging the bedrock borehole prior to casing installation. Wells AWWT-1 and AWWT-2 were installed prior to this study and were logged within their existing well casings.

Some wells were logged shortly after completion and again several weeks later to verify that no temporary changes in the borehole environment had been induced by well construction. There was little difference between geophysical logs collected shortly after wells were completed and those collected several weeks later. Because of negligible differences between logs collected on different dates, a log that was run more than once is only shown once in this report. The exception is SC-3B, for which neutron logs are shown for the open borehole and the completed well.

The types of geophysical logs acquired are described in the following paragraphs. Additional background on geophysical logging in ground-water-investigation applications was provided by Keys (1986, 1990), Jorgensen (1991), Paillet and Crowder (1996), and Hearst and others (2000).

Caliper. Caliper logs provide a continuous record of the borehole diameter. Changes in borehole diameter may be related to drilling technique (change in bit size, enlargement of borehole from reentry or circulation of drilling fluids), well construction (casing size and joints), lithology (smaller holes in more competent rock), and secondary porosity (fractures and solution openings). Caliper logs can be important in interpreting other logs that are affected by changes in borehole diameter.

Single-Detector Neutron. Single-detector neutron (hereafter referred to as “slim neutron”) logs use a neutron source to generate a flux of neutrons and measure the rate at which those neutrons are scattered back to a detector on the probe. Log interpretation assumes that the neutrons are absorbed by the aquifer materials through the collision of neutrons with hydrogen atoms. On that basis, the neutron log signal is assumed to be inversely proportional to the total amount of water around the probe in the region surrounding the detector. This relation suppresses deflection of the neutron counts at the high-porosity limit, so that the range of the log, in counts per second, may be the same over the 30- to 40-percent porosity range as it is over the 2- to 5-percent porosity range. The neutron log reflects the total amount of water present in the volume of the 20-inch-diameter depth of investigation surrounding the detector. The response for a saturated formation differs, depending on whether water or air is filling the casing. Neutron logs in saturated formations respond to the total of effective (drainable) and non-effective (undrainable and often filled with geochemically bound water) porosity. The slim neutron log does not indicate porosity in an unsaturated formation. The slim neutron log is run decentralized and can be run in a cased borehole

Natural Gamma. Natural gamma (hereafter referred to as “gamma”) logs measure the gamma activity (radiation) produced by the naturally occurring isotopes of uranium, potassium, and thorium. The gamma log indicates variations in the lithology of aquifer materials, and gamma log interpretations generally relate the relative gamma activity to the proportion of clay minerals or the proportion of unweathered mineral grains. Well casing and borehole fluid affect the gamma log by attenuating the gamma flux from the radiation source to the detector in the logging probe, thereby potentially reducing the measured count rates. Logs are run with the probe "decentralized," meaning that the probe is not mechanically centered in the borehole or casing and may hang in proximity to the side of the borehole.

Dual-Detector Neutron. Dual-detector neutron (hereafter referred to as “dual neutron”) probes use a neutron source and a pair of detectors to reduce the effect of the borehole environment on log response and to allow calibration of porosity quantitatively. Because the calibration data apply to uncased, water-filled boreholes, the dual neutron log calibration could not be applied to cased boreholes at Straight Creek. For cased boreholes, the dual neutron log is presented by plotting the far-detector response as a measurement less likely to be affected by well construction than the near detector. Because of the diameter of the dual neutron probe, it can be used only in wells with 4-inch-diameter (or greater) casing. The dual neutron log is run with centralizers to hold the probe in the center of the borehole.

Induction Conductivity. Induction conductivity (hereafter referred to as “induction”) logs measure the electrical conductivity of aquifer materials surrounding the borehole. Measurements are made after the probe electronics have reached thermal equilibrium with the borehole environment and are automatically corrected for the ability of the formation to shield itself from the probe signal (the skin effect). The induction log is unaffected by the borehole fluid and can be run in open or PVC-cased boreholes. The probe is run decentralized in the borehole. Formation conductivity is often given in units of millimhos per meter, but units have been converted to microsiemens per centimeter at 25 degrees Celsius (µS/cm) here to allow direct comparison with the electrical conductivity of water samples.

Fluid-Column Resistivity. Fluid-column resistivity probes measure the electrical resistivity of the fluid in the borehole.

Fluid-Column Temperature. Fluid-column temperature logs measure the temperature of the fluid in the borehole. In ground-water studies, fluid-column temperature logs are often used to interpret locations where water enters or exits the borehole.

Borehole Television. Borehole television logs are acquired using a probe that contains a small, waterproof camera and a light source. Television logs are useful for assessing the integrity and construction of existing wells, including screen location and condition, casing joint locations, and the presence of offset and cracked well casing. Borehole television logging also can be used to visually inspect the geology of open boreholes, including identification of fractured intervals. The light required for television restricts application to boreholes or wells containing clear water and clean walls.

Results

Lithologic logs (fig. 5A-H) were constructed using information generalized from data presented in Souder, Miller, and Associates (2002). Intervals in which the percentage of gravel-sized fragments exceeded the percentage of sand-sized or finer fragments are indicated on the logs for wells SC-1A, SC-2B, SC-3A, SC-4A, and SC-5A. Blow counts are included for wells SC-2B, SC-3A, and SC-5A.

Geophysical logs (fig. 5A-H) are plotted using the standard conventions of borehole geophysics. Logs that indicate porosity and permeability are plotted so that larger values are shown as deflections toward the left. For example, low neutron counts are considered to correspond to high porosity, so the neutron log shows decreasing counts per second toward the left. In contrast, increasing formation conductivity is generally associated with increasing porosity and permeability, thus the induction log is plotted with conductivity increasing toward the left. These conventions cause logs to show the same general shape in composite plots of logs, helping to highlight depth intervals with similar hydraulic or water-chemistry properties of interest.

In general, the induction and neutron logs were the most useful. The effect of borehole environment on induction logs is minimal, allowing straightforward interpretation for open, PVC-cased, water-filled, or air-filled boreholes. Both slim and dual neutron logs were strongly affected by borehole environment, requiring consideration of the effects of casing and annulus materials in neutron log interpretation. The principle used in this analysis is that wherever the environment is the same, the neutron log will fluctuate around a "baseline" determined by that condition. For example, the top of the neutron log for wells completed within debris-flow deposits can be represented by a baseline corresponding to PVC casing, bentonite chips in the annulus, an air-filled borehole, and an unsaturated formation. The bottoms of these wells correspond to PVC screen, sand in the annulus, water in the borehole, and a saturated formation.

SC-1A. The lithologic log for well SC-1A (fig. 5A) indicates a zone of higher percentage gravel from land surface to a depth of 20 feet. A zone of weathered bedrock extends from 56 to 67 feet below land surface, and competent bedrock begins 67 feet below land surface.

Slim and dual neutron logs for well SC-1A were run in the completed well, and both indicated perched water in the debris-flow deposits. As indicated by the neutron logs, the water level in the well at the time of logging was approximately 50 feet below land surface. The transition to an air-filled well casing above 50 feet results in increasing neutron counts. The debris-flow deposits remain saturated up to about 29 feet below land surface. Above 29 feet, the neutron logs indicate intervals of partial saturation. Intervals of perched water are indicated by deflections to the left (low neutron counts) on the logs. The perched intervals generally correspond to the extent of the more gravelly zone indicated on the lithologic log.

A systematic upward increase in formation conductivity is shown in the induction log from the bottom of the log to about

28 feet below land surface. The deflections to the left within the saturated interval below about 28 feet on the induction log probably correspond to increases in permeability within a zone of approximately uniform water quality. In contrast, the thin perched water zone in the interval between about 12.5 and 17.5 feet is less conductive and is indicative of water with smaller dissolved solids content.

SC-1B. Geophysical logs for well SC-1B (fig. 5B) were run in the open bedrock borehole while ground water was entering the borehole, then run again in the completed bedrock well. During collection of the first suite of logs, water was filling the well at a rate of about 1.5 liters per minute and the water level in the well was at a depth of about 105 feet as shown by the fluid column resistivity and temperature logs. The fluid-column temperature log indicated inflow from a fracture or fracture zone around 136 feet, and the well screen was set to extend across this zone. The fluid-column resistivity log indicated a water conductivity of about 1,000 µS/cm, or about 700 milligrams per liter (mg/L) dissolved solids.

Logs acquired in the completed well indicated the water level to be at about 50 feet in depth. The neutron log baseline changes at the bottom of the steel casing because the water of hydration of the cement sharply reduces neutron counts above about 85 feet and above about 50 feet because the transition to an air-filled borehole increases neutron counts. The neutron log indicates intervals of partial saturation above 32 feet, similar to the intervals of perched water indicated by the SC-1A logs. A comparison of lithologic logs for wells SC-1A (fig. 5A) and SC-1B (fig. 5B) indicates that the depth to the top of competent bedrock (67 and 84 feet below land surface, respectively) can vary considerably over a short distance.

SC-2B. Geophysical logs for well SC-2B (fig. 5C) were run in the completed well. Both slim and dual neutron logs indicate intervals of partial saturation above about 50 feet in depth. The neutron logs indicate that the water level in the formation around the casing was the same as that in the well at the time of logging (about 67 feet). The induction log indicates rather low conductivity water throughout. The spike in formation resistivity (low conductivity) near 72 feet is not indicated on either neutron log, possibly because of the presence of a thin cemented zone. There is, however, no indication of such a zone on the lithologic log. The relatively large counts on the neutron log and the low electrical conductivity in the screened interval indicate a low-permeability formation, consistent with the placement of the well screen entirely within saturated bedrock as indicated on the well-completion log. Intervals of higher percentage gravel (35 to 55 feet) and weathered bedrock (55 to 83.5 feet) shown on the lithologic log were not identified on the geophysical logs.

SC-3A. In well SC-3A, geophysical logs, including both slim and dual neutron, were acquired in the completed well (fig. 5D). The neutron logs show an increase in porosity just below 72 feet and above the screen. Above 72 feet, the neutron log deflects to the right because of lack of water in the borehole. Above 65 feet, the neutron logs trend slightly to the left, indicating that the porosity of the formation increases upward. Changes in porosity indicated by the geophysical logs are not evident on the lithologic log, which shows intervals containing higher percentages of gravel from 35 to 40 and 90 to 95 feet. The upper gravelly zone in SC-3A begins at the same depth as a similar zone in well SC-2B (fig. 5C), but the length is shorter in SC-3A. Depths of weathered and competent bedrock are deeper in well SC-3A than in well SC-2B, presumably because well SC-3A is located closer to the center of the Straight Creek drainage basin. Blow counts were particularly useful for identifying the depth to competent bedrock (100 feet below land surface) in well SC-3A.

SC-3B. Geophysical logs for well SC-3B (fig. 5E) were first acquired within a few hours after drilling and before installation of the PVC casing. At that time, water was filling the borehole at a rate of about 0.5 liter per minute by inflow assumed to originate from the fractured zone indicated near the bottom of the caliper log (approximately 167 to 170 feet). The slow rate of inflow was attributed to low fracture-zone permeability. One unusual effect indicated by the caliper log is the partial blockage at about 98 feet, which appeared to be a partial bentonite plug on the basis of material on the surface of the probes after logging. The neutron log run in the open bedrock borehole also shows a deflection to the left at about 98 feet in depth. The slim neutron log acquired in the completed well a few weeks later does not deflect to the left at 98 feet in depth, indicating that the partial blockage was cleared during well installation.

The neutron log run in the open borehole indicates a long interval of saturation above the competent bedrock surface; the log also indicates a trend to higher count rates below about 165 feet in depth that could correspond to less porous bedrock. This shift correlates with a shift to slightly higher counts on the gamma log and to a change in character on the caliper log. All these effects could be attributed to either a change to less fractured bedrock or to a lithologic contact. However, no change in character of the bedrock is shown at this depth on the lithologic log. The depth to competent bedrock is 107 feet below land surface, similar to that in well SC-3A.

SC-4A. The lithologic log for well SC-4A (fig. 5F) shows a long interval (from 30 to 109 feet below land surface) dominated by gravel. The depth to the top of this zone is essentially the same as in wells SC-2B and SC-3A. The percentage of gravel in the 30- to 109-foot interval ranges from 45 to 80 percent and in the screened interval between 105 and 109 feet is 80 percent (Souder, Miller, and Associates, 2002). This well was noted to be much more productive than other nearby wells during drilling and sampling. The top of competent bedrock is at a depth of 109 feet below land surface, essentially the same as in wells SC-3A and SC-3B.

Geophysical logging of well SC-4A occurred shortly after completion and again about 4 weeks later. The neutron logs and the induction log show a trend of increasing porosity and permeability up to the water level in the well at the time of logging (about 74 feet) that is not evident on the lithologic log. A "step" in the neutron log at about 67 to 69 feet shows that the water level in the formation was higher than the water level in the borehole. This indicates a downward vertical hydraulic-head gradient in the region of the well, consistent with water altitudes in the nearby well pair (SC-3A and SC-3B; table 1). The neutron log also indicates a perched water zone in the 30- to 45-foot depth interval. This perched zone is probably as permeable as the lower part of the aquifer, as indicated by the similarity of the neutron values in the perched zone to those of the "step" near the water level in the well and by the extent of the interval of higher percentage gravel on the lithologic log. Formation conductivity in the perched zone is about 150 µS/cm, considerably lower than in the lower part of the aquifer where formation conductivity is as high as about 400 µS/cm. Therefore, concentrations of dissolved solids in water in the perched zone are apparently lower than in the fully saturated part of the formation.

SC-5A. Geophysical logs for well SC-5A (fig. 5G) were acquired in the completed well. The slim neutron log indicates that the water level in the formation outside the casing was about 140 feet below land surface. Depth to water in the well at the time of logging was about 151 feet, indicating a downward head gradient. However, this may be a localized head gradient because water-level altitudes (table 1) indicate a slight upward head gradient from SC-5B to SC-5A. The trend in the neutron log (after taking into account the baseline shift at water level) indicates two zones of higher permeability (163 to 167 feet and 145 to 150 feet), which is supported by the presence of two high-permeability zones on the induction log.

No gravel-dominated intervals are shown on the lithologic log for well SC-5A because the percentage of gravel-sized particles (by volume) was always less than that of sand-sized particles and smaller. Zones of slightly higher percentage gravel-sized particles (30 to 35 percent) are interspersed within intervals generally containing 20 to 25 percent gravel (Souder, Miller, and Associates, 2002) and may be indicative of interlayered Red River alluvial deposits. The percentage of gravel-sized particles increases to 45 percent below 160 feet (Souder, Miller, and Associates, 2002), which corresponds to the interval of higher permeability from 163 to 167 feet indicated on the neutron log. However, the 145- to 150-foot interval on the neutron log corresponds to a 20-percent gravel zone.

SC-5B. Although lithologic logging above the top of bedrock generally was not done for bedrock aquifer wells that are paired with a shallow well, some logging was conducted below 260 feet during drilling of well SC-5B. Well logs presented in Souder, Miller, and Associates (2002) indicate an interval from 270 to 275 feet below land surface containing 75 percent gravel by volume (not shown in figure 5H because of scale), which seems to be strong evidence for the interfingering of Red River alluvial deposits within the debris flow. Similar unlogged zones could exist above 260 feet.

Geophysical logs for well SC-5B (fig. 5H) were acquired in the completed well shortly after drilling and again 2 weeks later. The neutron log is dominated by the effects of steel and cement and by water level, producing sharp shifts in the log baseline near 150 feet (approximate water level at time of logging) and 320 feet (approximately the bottom of steel casing) in depth. There also are sharp deflections in the log between about 115 and 150 feet and about 37 to 50 feet. The shift to the right in the log (decreasing saturation) above about 25 feet probably indicates the baseline for the top of the well (casing, cement, and unsaturated formation). The log then defines another baseline extending from about 25 feet to the water level that probably corresponds to casing, cement, and partially saturated formation. The deflections to the right probably represent intervals where there is no cement in the annulus.

Overall, the neutron and gamma logs are the only logs that could be run effectively in the completed well. Neither indicates any obvious "break" representative of the contact between alluvium and bedrock. The weak changes in character of the gamma log between depths of about 110 and 165 feet could indicate a lithologic contact. Otherwise, the neutron log indicates a slow but steady trend of decreasing porosity with increasing depth, with the trend accelerating below about 275 feet. The top of the competent bedrock, as shown in the lithologic log, begins at 285 feet below land surface, which may explain the decreasing porosity with depth indicated by the neutron log.

AWWT-1. Well AWWT-1 is constructed of 7-inch-diameter steel casing and is screened from 190 to 210 feet below land surface (table 1). The NMOSE well record for AWWT-1 describes the aquifer material as “hard yellow rock” from 190 to 198 feet below land surface, “fractured yellow rock” from 198 to 200 feet below land surface, “yellow rock” from 200 to 208 feet below land surface, and “granite red in color” from 208 to 210 feet below land surface. This description indicates that the lower 2 feet of screen is within bedrock, whereas the upper 18 feet of the screen is within debris-flow material, Red River alluvial deposits, or perhaps both.

The presence of steel casing in well AWWT-1 precluded the use of electric logs and measurement of formation resistivity. Consequently, logs were limited to natural gamma, neutron, and fluid-column temperature (fig. 5I).

The unusual temperature reversal with depth displayed in the temperature log may represent the movement of cold ground water flowing horizontally by the casing. Because this flow is centered at about 175 feet and above the screen, the water does not appear to enter the well but simply to cool the borehole fluid as it flows by. The neutron log across this zone is substantially suppressed by both the water in the saturated formation and the steel casing; it therefore does not display any appreciable variation near 175 feet that would indicate an interval of higher relative porosity. However, the gamma log does show higher activity at this depth than in intervals above and below, possibly corresponding to a change in lithology. Because of the steel casing, the magnitudes of the gamma counts and the neutron counts are suppressed slightly compared with values measured in PVC-cased wells. The small deflections seen at approximately 20-foot intervals on the neutron log represent casing joints that further reduce the count rate. The water level in the well was clearly delineated at 123 feet from the temperature and neutron logs. The interval from about 58 feet down to the water level displays high gamma activity and high counts in the neutron log (greater than 4,000 counts per second), even with the presence of steel casing. These high neutron counts represent an interval about 65 feet thick that is composed of relatively dry material. Above 58 feet, neutron counts return to more typical values associated with moist, partially saturated deposits. The slight increase in neutron counts below 190 feet represents the top of the screened interval.

The temperature profile becomes monotonic and gradually warmer with depth in the screened interval below 190 feet. This trend indicates a slow return to conditions imposed by the background geothermal gradient and, therefore, less fluid movement within the screened section. Thus, interpretation of the temperature log suggests that the top of the screen was placed too deep to intercept the transmissive zone in this well.

AWWT-2. No driller's log is available for well AWWT-2, and little is known about the details of construction. The well is constructed of 4-inch-diameter schedule 40 PVC casing that is screened from 77 to 117 feet and again from 135 to 154 feet (table 1). No lithologic information is available.

Natural gamma, fluid-column resistivity, and neutron logs were recorded in well AWWT-2 (fig. 5J). The water level at the time of logging was 107 feet, as seen by the marked shift in the neutron log; consequently, most of the upper screened interval is above the water table. The relatively high resistivities and high neutron counts (for saturated materials) in the saturated deposits approximately coincide with the lower screened interval (135 to 154 feet), indicating that the screen penetrates a dense, low-porosity formation. High neutron counts above the water table (greater than 4,000 counts per second) remain relatively high almost up to the surface; values do not return to about 2,500 counts per second, which is indicative of moist, partially saturated soils. Thus, the neutron profile reflects the presence of continuously dry materials above the water table and up to the surface.

Water-Level Data

Each Phase I Straight Creek observation well was instrumented with a differential-pressure transducer to measure ground-water levels. Transducers were connected to electronic data loggers powered by 12-volt batteries and solar panels, and water levels were routinely recorded at 15-minute intervals. Ground-water levels were periodically measured manually to confirm the accuracy of pressure transducers. Manual water-level measurements using steel or electric tape were recorded to the nearest 0.01 foot and were repeated until the precision was within 0.02 foot. Corrections were applied to the transducer data if measurements differed from manual measurements by more than 0.1 foot and the manual measurements were considered accurate.

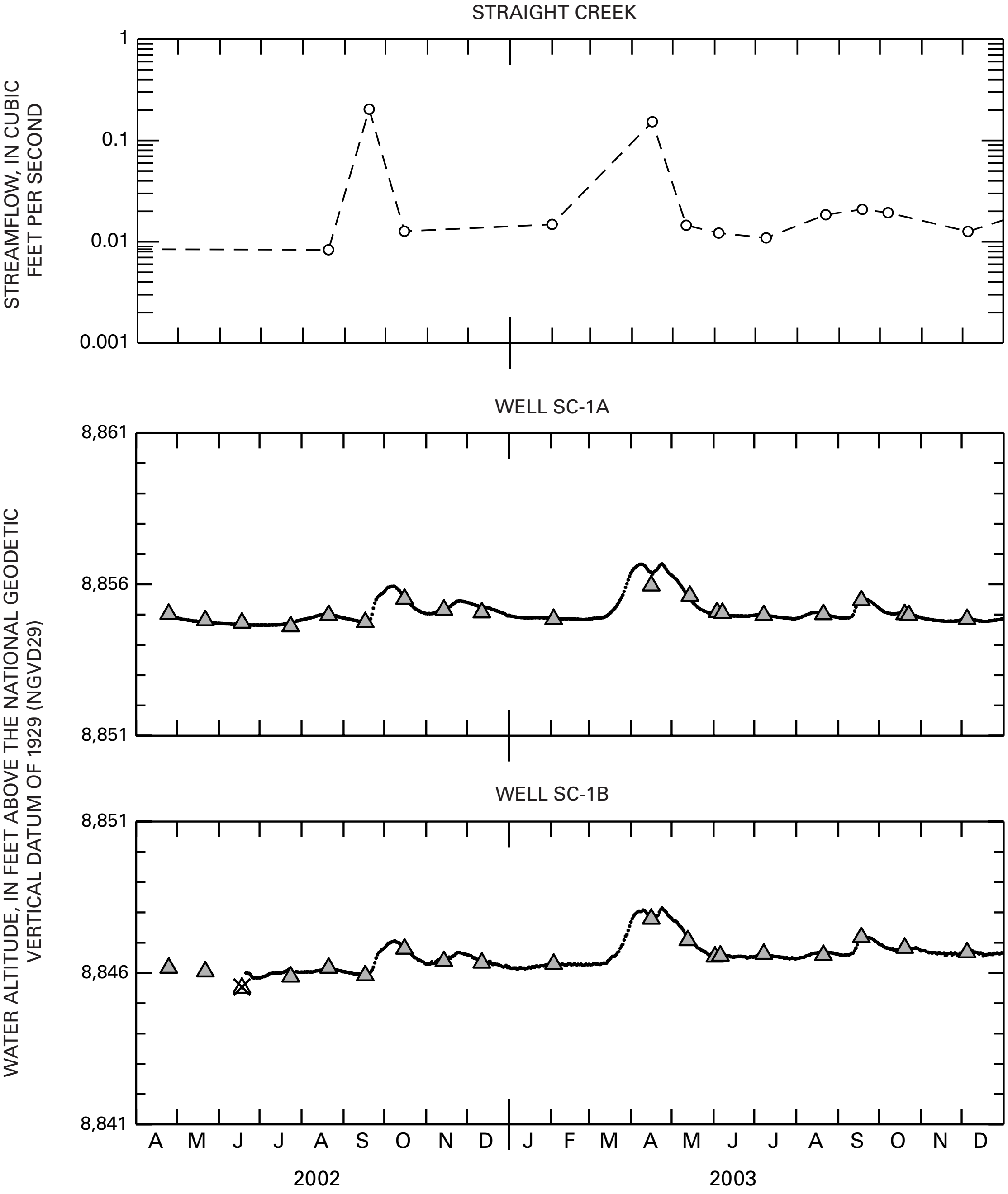
The observation-well locations and altitudes (table 1) were used to establish horizontal and vertical datums for long-term data collection. Permanent reference points for water-level measurements were established, enabling measurements to be referenced to the land-surface altitude at each well site. The surveyed altitude of land surface was used to adapt water levels to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Hydrographs showing static ground-water altitudes (fig. 6) were constructed using values calculated from land-surface altitudes (table 1), manually measured water levels, and water levels recorded at 15-minute intervals by pressure transducers and subsequently corrected for differences from manually measured water levels. Transducers in wells SC-1B and SC-2B did not function properly, resulting in a loss of data early in the period of record. Other gaps in the transducer record reflect loss of data due to data logger failure or time periods during which data loggers were intentionally disconnected from the power source.

Three manually measured water levels are thought to be in error (fig. 6). The measurement made in well SC-1B on June 18, 2002, is believed to be erroneous because water levels in SC-1A and SC-1B usually correlate well, but this SC-1B measurement indicates a downward trend in water level that is not corroborated by the trend observed in SC-1A. The water level manually measured in SC-5A on September 17, 2002, is thought to be in error because the difference between the measured water level and that recorded by the transducer was 0.50 foot, an anomalously large difference compared with differences in August (0.12 foot) and October (0.16 foot) 2002. In addition, the electronic tape used for the September measurement was not the tape normally used to measure water levels for this project. The measured water level in SC-5B on April 26, 2002, like the September SC-5A measurement, appears erroneous because it differed from the recorded water level by 0.89 foot, compared with no difference on April 22 and a difference of 0.02 foot on May 23, 2002.

Water-level measurements, both manual and automated with 15-minute data recording intervals, made from March 2002 to December 2003 indicate that water levels in wells respond to the seasonal infiltration of surface water or spring snowmelt water (fig. 6). Straight Creek streamflow and water levels in wells located nearest the apex of the Straight Creek debris fan and closest to Straight Creek itself (wells SC-1A and SC-1B) appear to respond to the same seasonal inputs. The timing of changes in water levels in downgradient wells SC-2B, SC-3A, and SC-4A shows the same general pattern as in SC-1A and SC-1B, but peaks in the hydrographs lag behind those in the upgradient wells. Water-level trends in well SC-3B are attenuated compared with other wells in the middle well cluster.

Water levels in wells located closest to the Red River apparently respond to the same seasonal influences that affect flow in the river, especially during snowmelt runoff (March-May) in 2003. The 2003 snowmelt runoff-influenced peaks occur later for wells SC-5A, SC-5B, and AWWT-1 than for the upgradient wells, a result of relatively higher altitudes in the Red River headwater areas and a corresponding later snowmelt. Water-level altitude data for well pairs show downward hydraulic gradients within the system except at the SC-5A / SC-5B well pair, where there is a slight upward gradient.



EXPLANATION

○ STREAMFLOW

● TRANSDUCER DATA

△ MANUAL MEASUREMENT

☒ MANUAL MEASUREMENT BELIEVED TO BE ERRONEOUS

Figure 6. Hydrographs of Straight Creek, observation wells, and Red River.

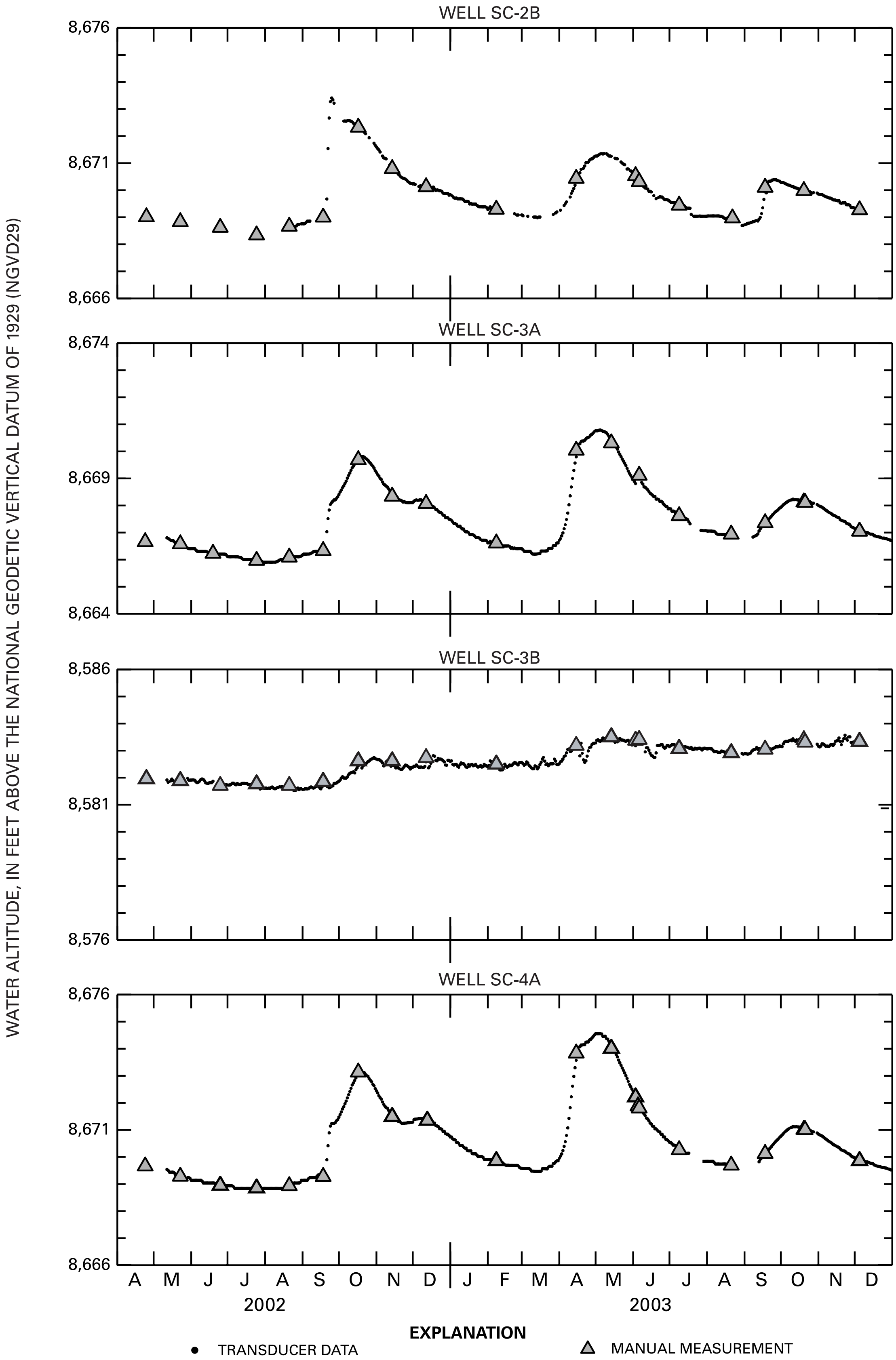


Figure 6. Hydrographs of Straight Creek, observation wells, and Red River--Continued.

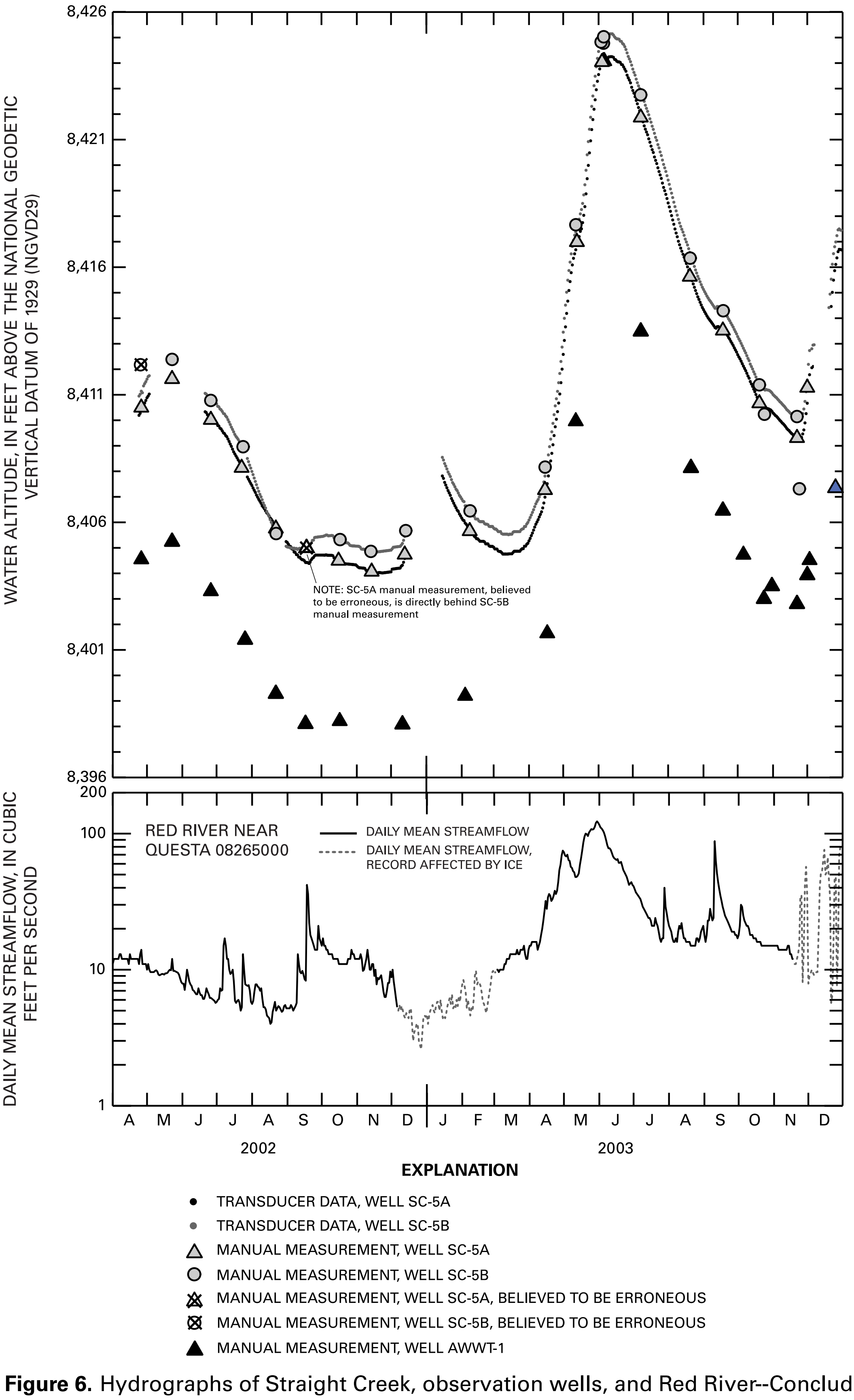


Figure 6. Hydrographs of Straight Creek, observation wells, and Red River--Concluded.

Surface- and Ground-Water Geochemistry

Several types of water-chemistry data were collected to help determine ground-water ages, geochemical signatures of solute sources in aquifer materials, and processes contributing to the chemistry of ground water in the Straight Creek drainage basin. For ground-water age dating, samples were collected for determination of chlorofluorocarbon (CFC), dissolved-gas, and tritium concentrations. The stable isotopic composition of water and solid samples was determined to help establish geochemical signatures of solute sources in alluvial, debris-flow, and bedrock aquifers and to constrain water/rock interactions. To provide further information about the processes controlling ground-water chemistry, samples were collected for determination of total recoverable major cations and selected trace metals; dissolved major cations, selected trace metals, and rare-earth elements; anions and alkalinity; dissolved-iron redox species; dissolved organic carbon; and mercury. Total recoverable metal concentrations are operationally defined as metals that are determined in an unfiltered sample acidified with concentrated HNO_3 (1 percent v/v) and, therefore, include both leachable particulates and dissolved metals. This section describes the methods used to collect and analyze samples and the results of water-chemistry investigations.

Water Sample Collection

Procedures for collecting samples from observation wells and surface water were modified slightly from the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997-99). Sampling procedures are described in detail in the project field sampling plans (C.A. Naus, U.S. Geological Survey, unpublished data, 2001). This section summarizes procedures used to monitor water-quality parameters and collect samples and presents results of water-quality-parameter monitoring for Phase I wells and well AWWT-1.

Ground Water

Dedicated bladder pumps designed specifically for purging and sampling at low flow rates were installed in the Straight Creek drainage basin observation wells. The pumps, constructed of PVC with Teflon® bladders, were equipped with dedicated discharge tubing for collection of samples.

A portable, low-flow bladder pump was used to collect samples from the AWWT observation wells. Tubing was dedicated to each well for sample collection, and samples were collected approximately 24 hours after pump and tubing installation. Both dedicated and portable pumps are operated by compressed gas and an electronic bladder-pump control unit.

Water-Quality-Parameter Monitoring

The standard USGS procedure for purging (Gibs and Wilde, 1999) requires monitoring water-quality parameters to determine when water withdrawn from the well is representative of water flowing through the aquifer and when sampling should begin. A sufficient volume has been purged from the well when the variability in sequential field measurements is within prescribed criteria for stability. Water-quality parameters measured for this study were pH, specific conductance, redox potential (Eh), dissolved oxygen, temperature, and turbidity. Sensors for all measurements except turbidity were housed in a 250-cc in-line flow-through cell. Water-quality-parameter measurement equipment (fig. 7), stabilization criteria, and guidelines for instrument calibration are listed in table 3. In general, manufacturers' recommendations and USGS guidelines (Wilde and Radtke, 1998) for testing, calibration, and calibration checks were followed.

Dissolved ferrous iron [Fe(II)] and total dissolved iron [ferrous and ferric; Fe(T)] concentrations were determined and monitored in the field as an additional indication of water-quality stability in March and April 2002 for each of the Phase I Straight Creek observation wells and well AWWT-1. Well AWWT-2 was sampled only once and field iron concentrations were not determined. Because iron and other solute concentrations can change during purging and affect trace metal concentrations without a corresponding change in standard field parameters, the use of field-determined iron concentrations provided unique real-time monitoring during purging. Iron concentrations can be used as a proxy for other ions, and changes in iron (II/III) concentrations during purging provide information about changes in the ground-water redox potential.

Samples for field iron determinations were collected in opaque, high-density polyethylene bottles and acidified with hydrochloric acid to a pH less than 2. The time between sample collections ranged from 1 to 54 minutes depending on the variability of the other monitored parameters. The total monitoring time for individual wells ranged from 11 to 144 minutes. Immediately after sample collection, Fe(T) and Fe(II) were measured on site in a mobile laboratory vehicle using a modification of the FerroZine colorimetric method (Stookey, 1970; To and others, 1999).

A unique stabilization/purging time for each well (table 4) was established on the basis of water-quality-parameter stabilization (including field-determined iron concentrations) during the March and April 2002 samplings (figs. 8 and 9). Wells were purged for the established time, and if necessary, additionally purged until water-quality parameters stabilized according to the criteria in table 3.

Samples collected for field iron determinations were analyzed later at the USGS laboratory in Boulder, Colorado, for selected constituents (figs. 8 and 9). Concentrations of Mg, Ca, Na, SiO_2, Mn, Zn, Al, Sr, Co, Cu, and Ni were determined using inductively coupled plasma-optical emission spectrometry (ICP-OES).

Table 3. Water-quality parameters, measurement equipment, stabilization criteria, and calibration guidelines.

[± , plus or minus; >, greater than; <, less than; <=, less than or equal to; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mV, millivolts; NTU, nephelometric turbidity units]

Parameter	Equipment used	Stabilization criteria (variability should be within the value shown)	Calibration guidelines
pH	Beckman 265 pH meter or Orion model 1230 multi-parameter meter with Orion Ross 815600, Orion 9107 Triode, or WTW SenTix 41-3 electrode	±0.1 unit[1,2]	Calibrate each morning. Check calibration at each sample site; recalibrate if not within 0.05 standard pH unit.
Specific conductance	Orion model 1230 multi-parameter meter with Orion 013010 DuraProbe or WTW TetraCon 325 conductivity cell	$\leq$ 100 µS/cm: ±5 percent[1] > 100 µS/cm: ±3 percent[1,2]	Calibrate each morning.
Eh[3]	Orion model 1230 multi-parameter meter with Orion 96-78-00 or WTW SenTix ORP electrode	±10 mv or <10 mV drift in 10 minutes[4]	Check using ZoBell's solution at the start and end of each trip (more often if necessary) (ZoBell, 1946; Nordstrom, 1977b).
Dissolved oxygen	Orion model 1230 multi-parameter meter with Orion 083010 or WTW CellOx 325 galvanic dissolved oxygen probe	±0.3 milligram per liter[1]	Calibrate each morning. Inspect electrode for bubbles under membrane at each sample site; replace if necessary.
Temperature	Thermistors included in pH electrodes or dissolved oxygen probes	±0.2 degree Celsius[1]	Calibrate annually; check calibration quarterly.
Turbidity[5]	Hach 2100P turbidimeter	±10 percent[1,2] if turbidity is less than 10 NTU; cease monitoring turbidity when turbidity is less than 10 NTU	Calibrate with a primary standard on a quarterly basis. Check calibration against secondary standards at the beginning of each trip.

[1] U.S. Geological Survey recommendation (Wilde and Radtke, 1998).

[2] U.S. Environmental Protection Agency recommendation (Puls and Barcelona, 1996).

[3] Eh should not be a limiting factor in determining stability prior to monitoring.

[4] This report.

[5] Turbidity criteria should not be too stringent to avoid excessive purge times (Puls and Barcelona, 1996) and should not be a limiting factor in determining stability prior to monitoring.

Figure 7. Sampling equipment, including flow-through cell and water-quality-parameter measurement instruments.

Table 4. Well-specific stabilization/purge times.

[n/a, not applicable]

Well (fig. 3)	Minimum purge time (minutes)
AWWT-1	15
AWWT-2[1]	n/a
SC-1A	15
SC-1B	40
SC-2B	30
SC-3A	40
SC-3B	20
SC-4A	20
SC-5A	40
SC-5B	20

[1] Minimum purge time was not established for AWWT-2 because the well was sampled only once.

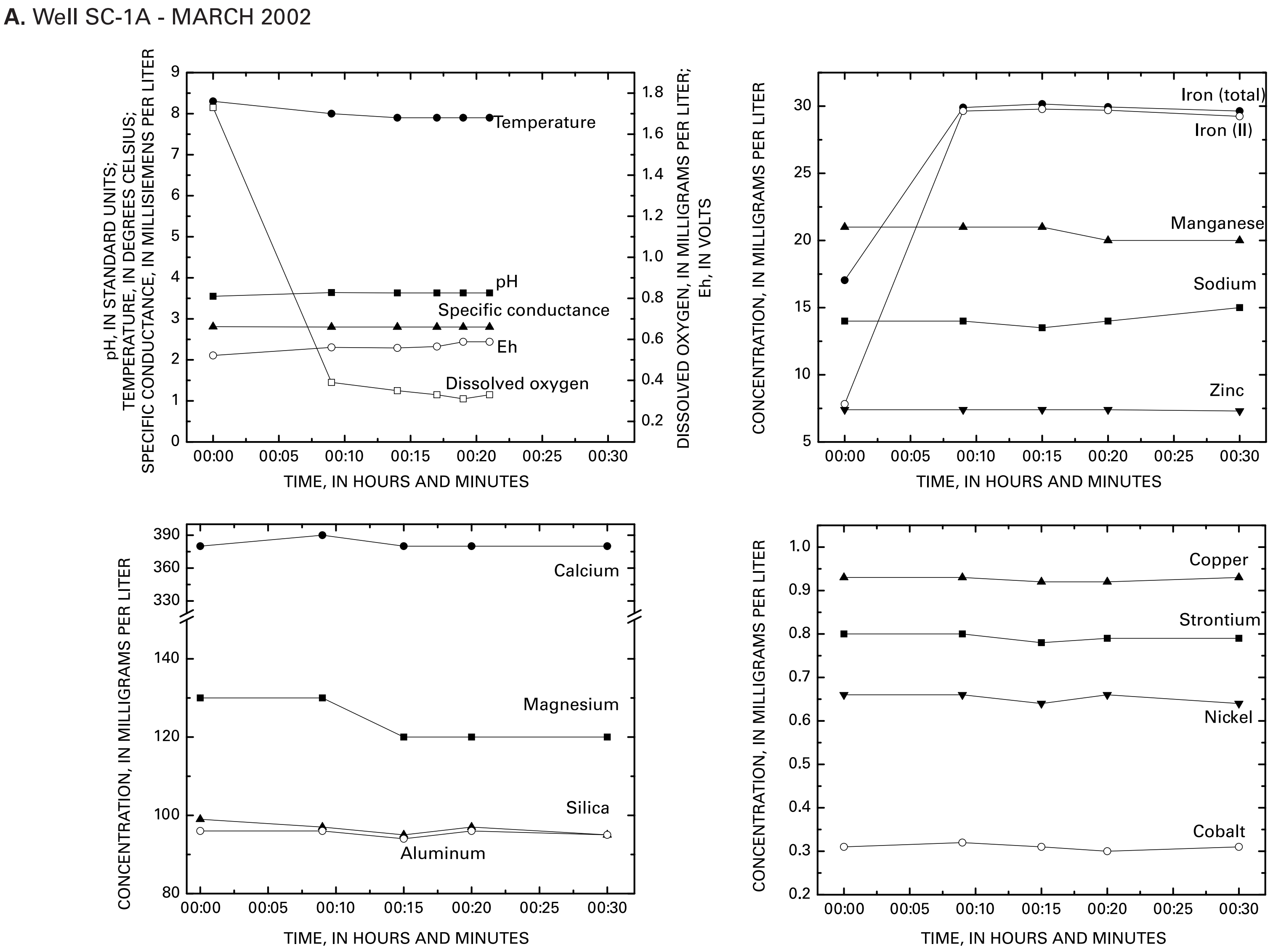


Figure 8. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1.

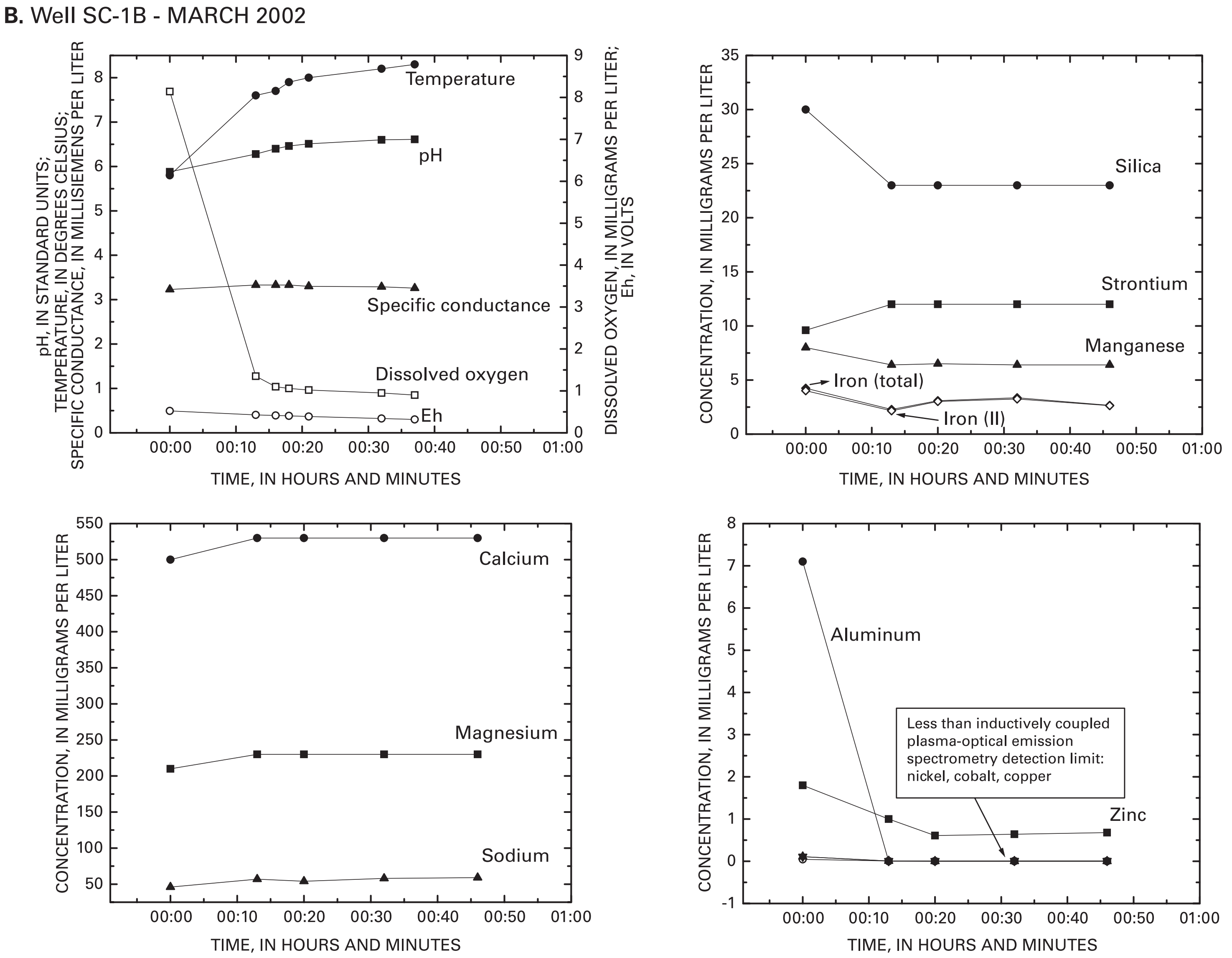


Figure 8. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

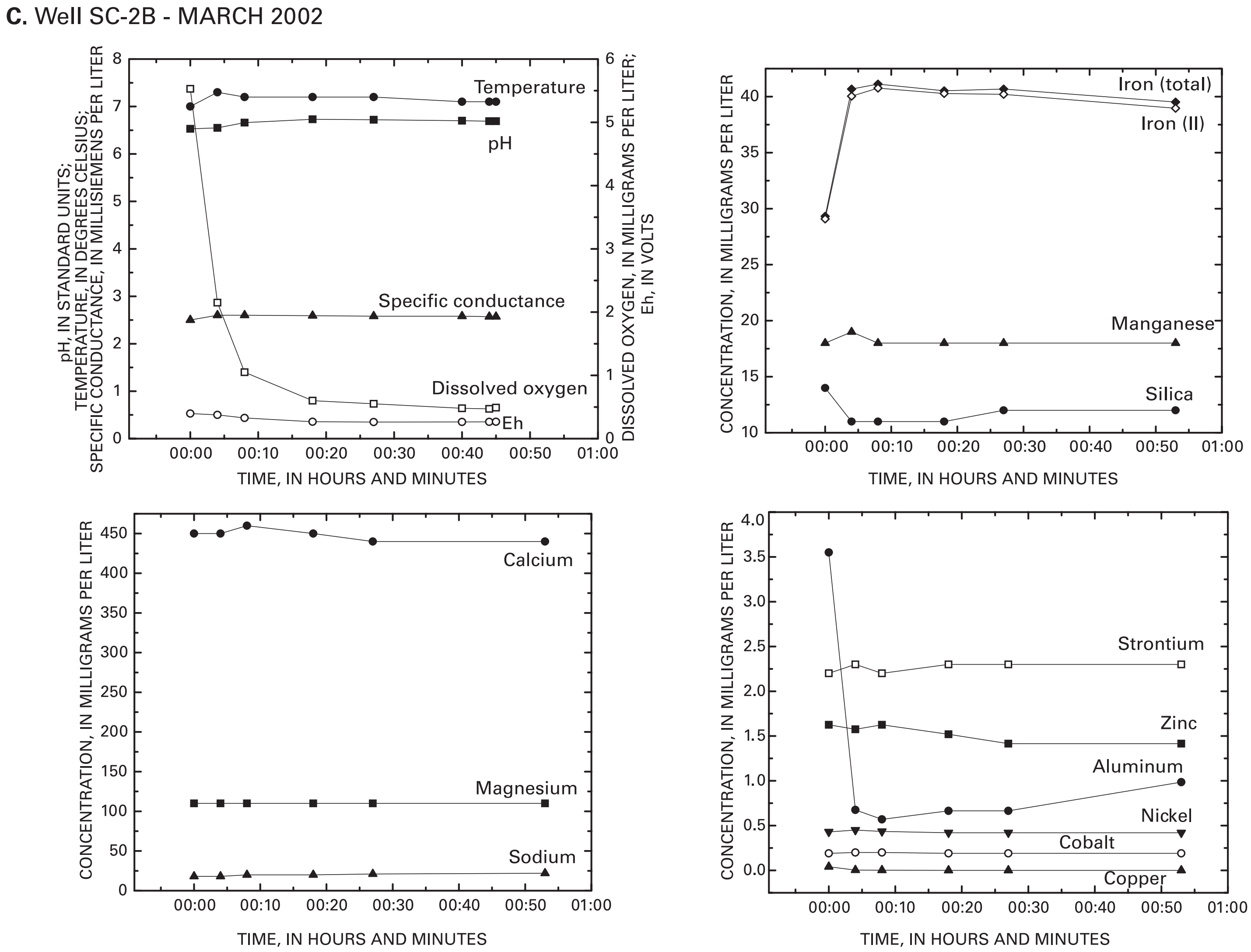


Figure 8. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

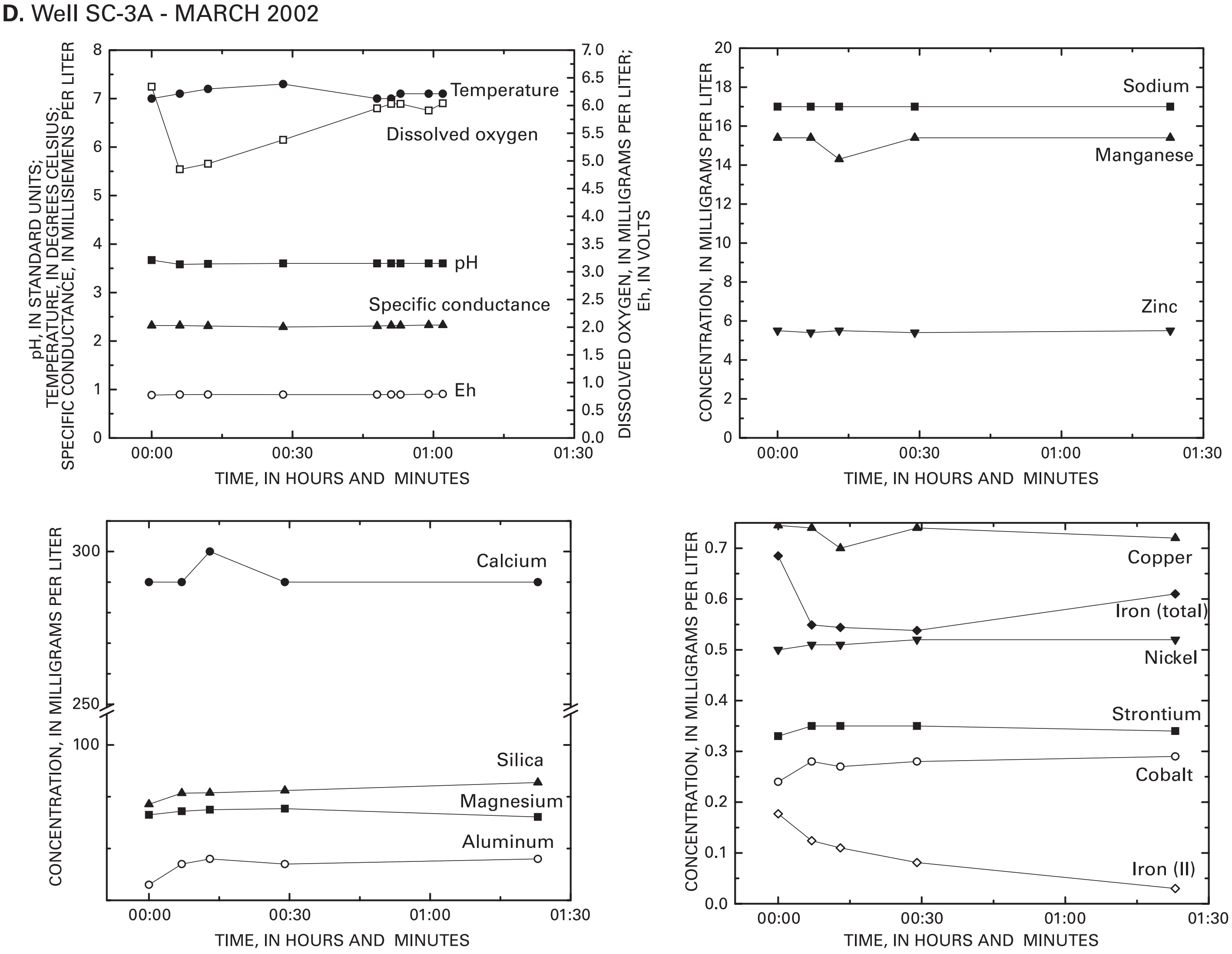


Figure 8. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

E. Well SC-3B - MARCH 2002

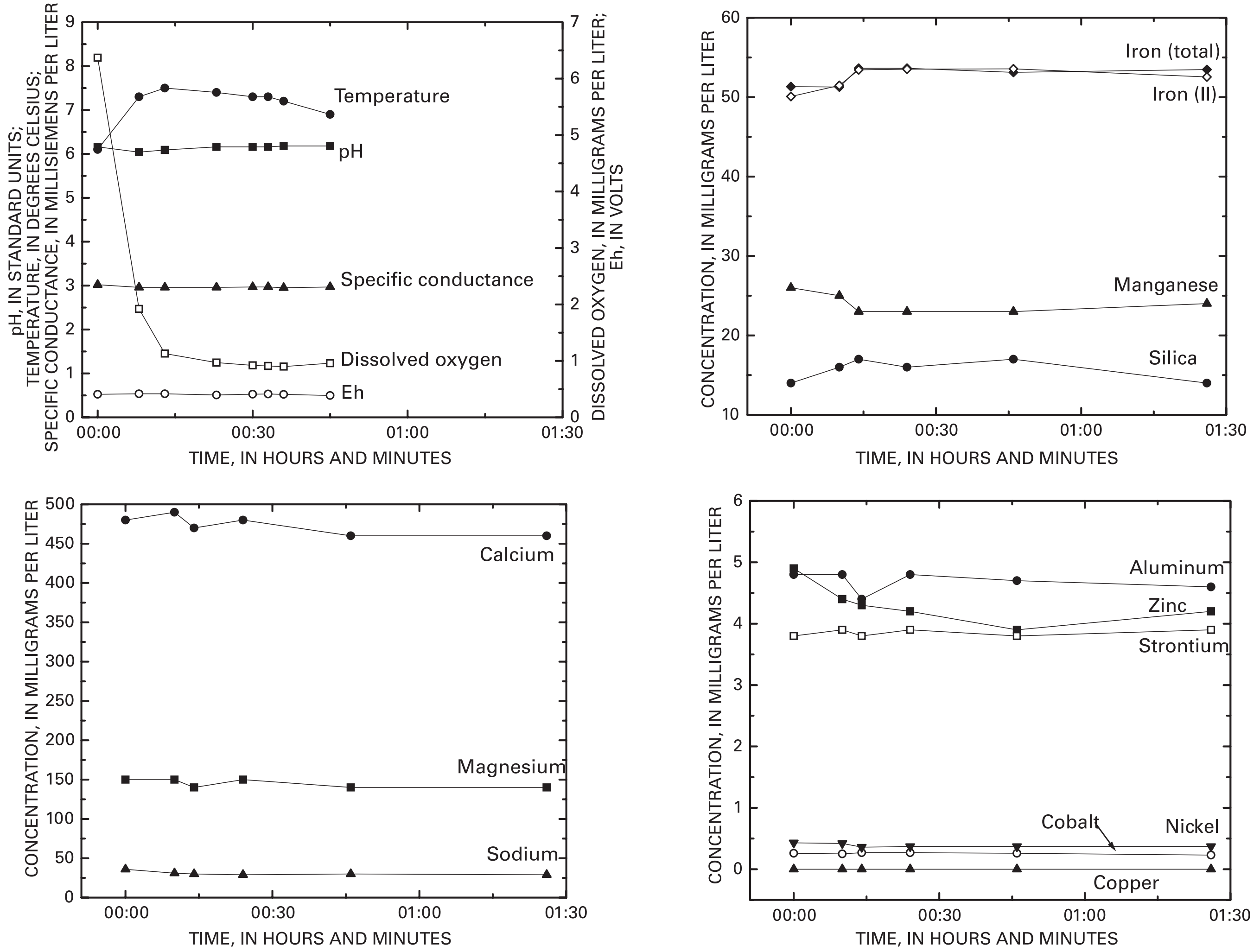


Figure 8. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

F. Well SC-4A - MARCH 2002

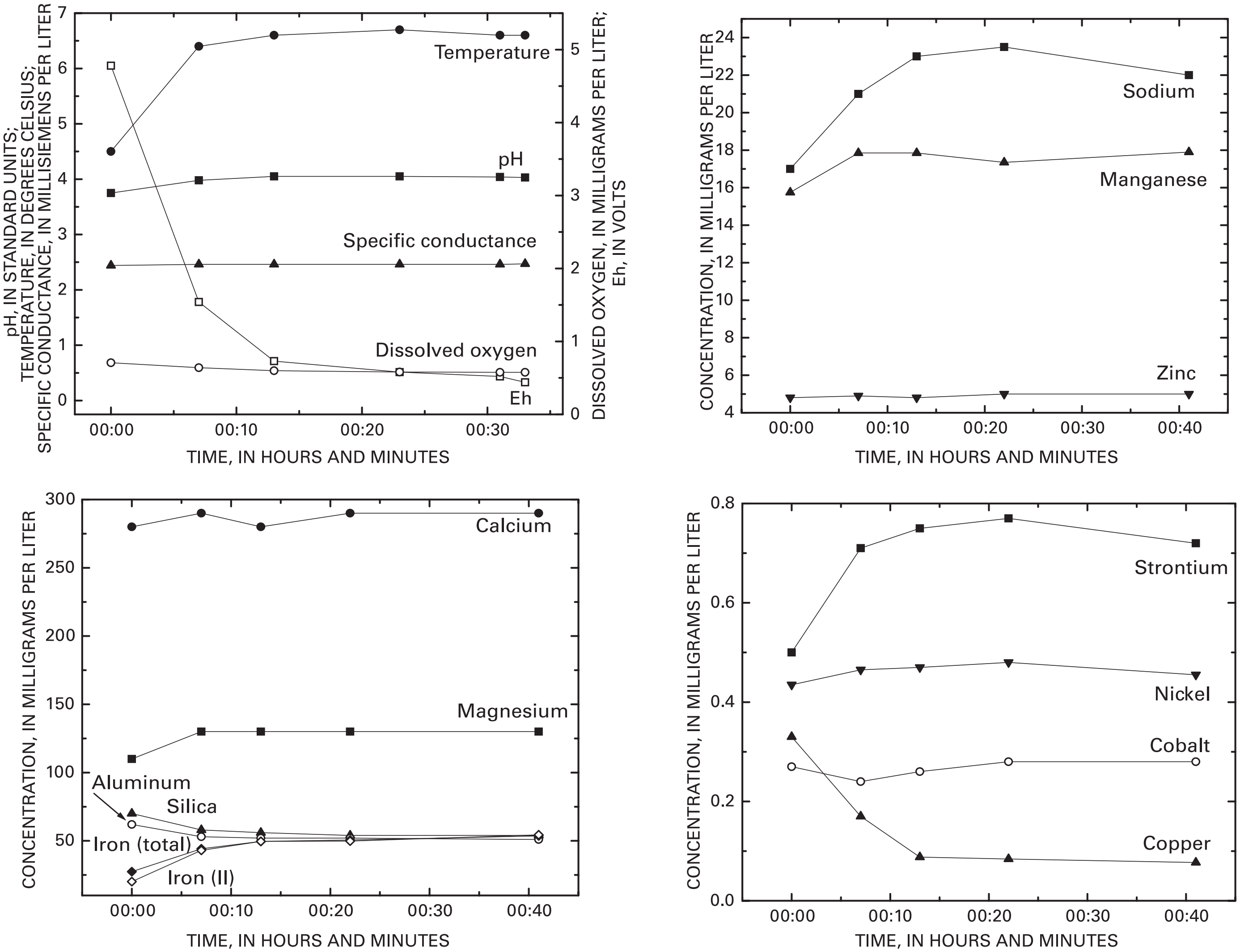


Figure 8. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

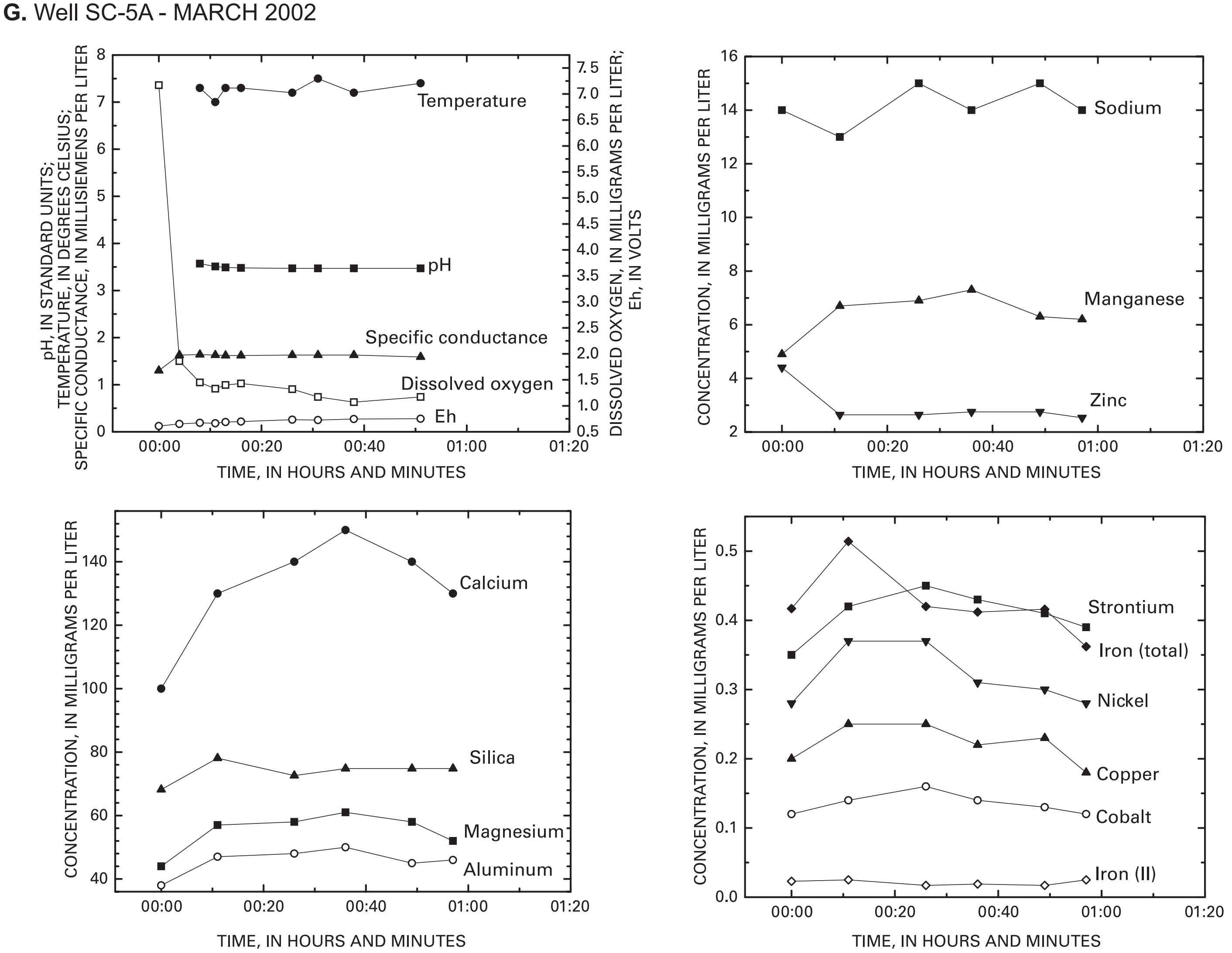

G. Well SC-5A - MARCH 2002

Figure 8. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

H. Well SC-5B - MARCH 2002

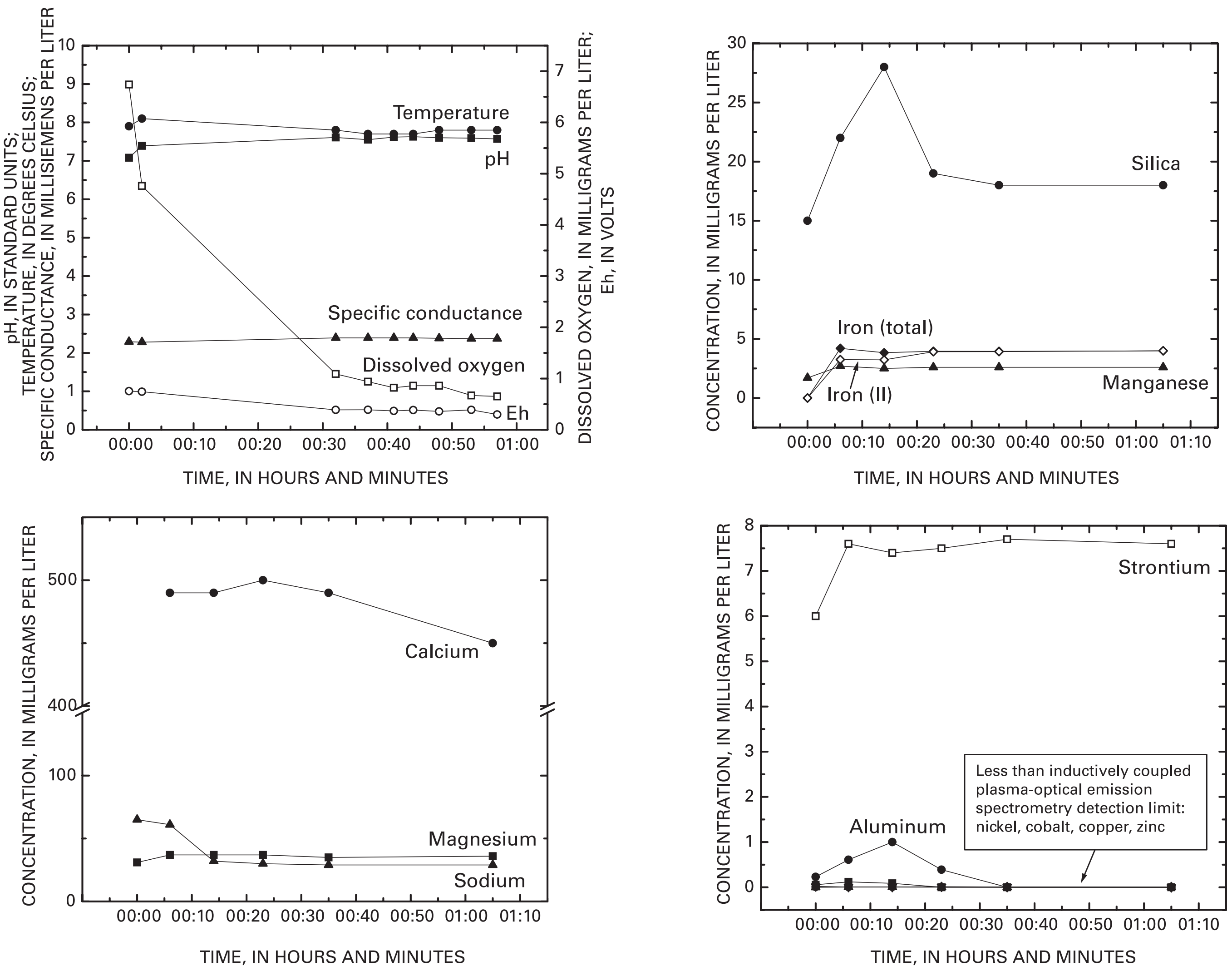


Figure 8. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

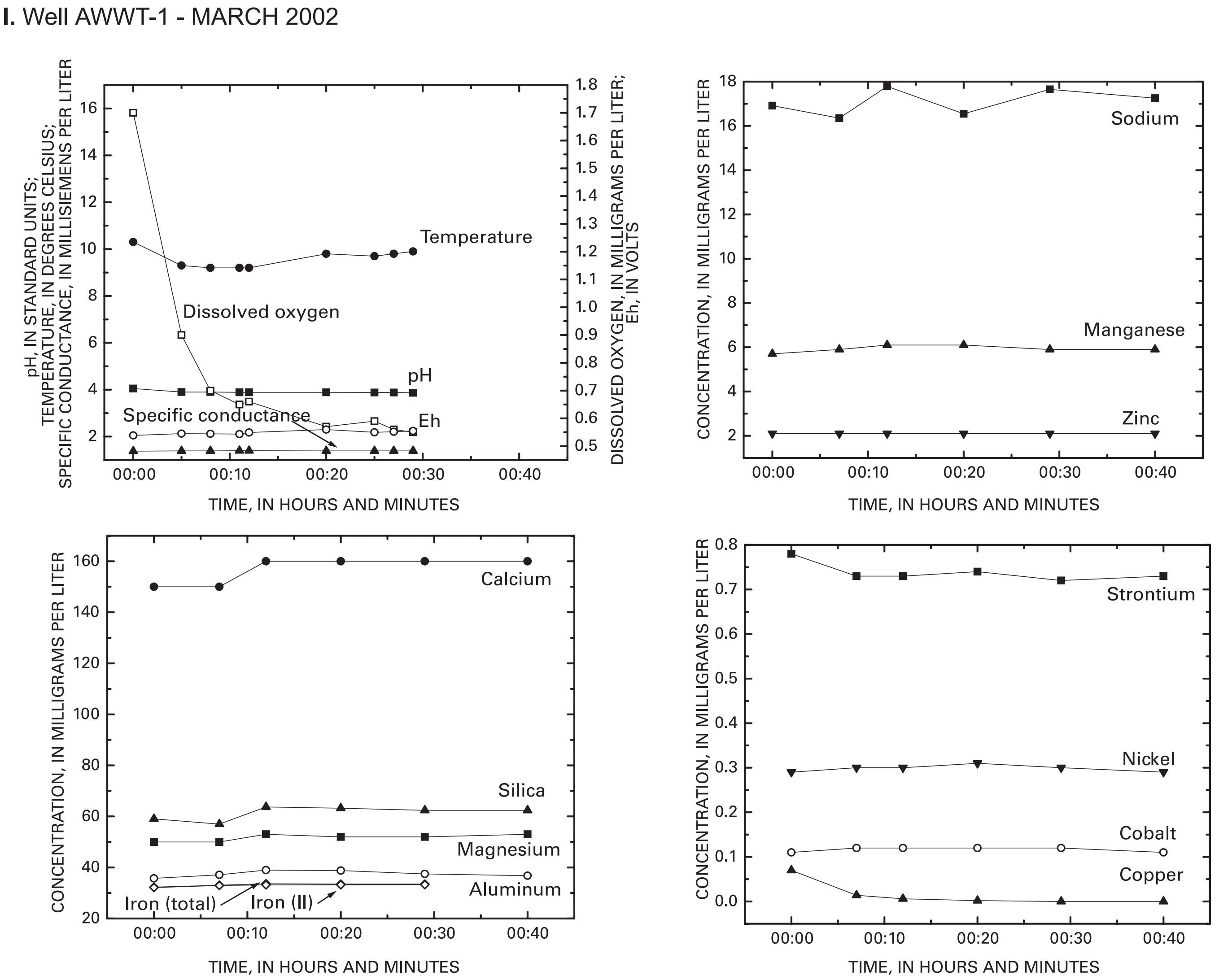
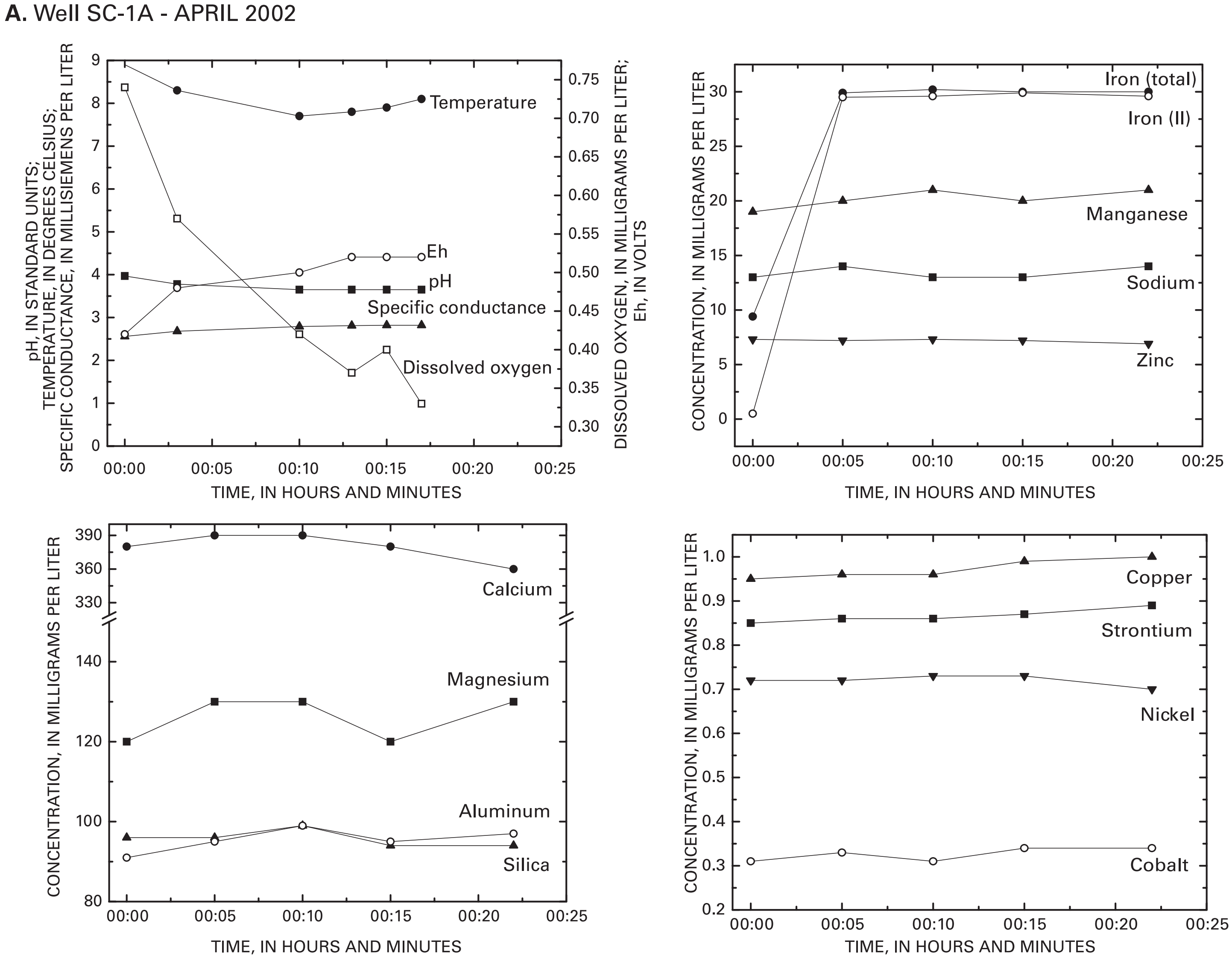
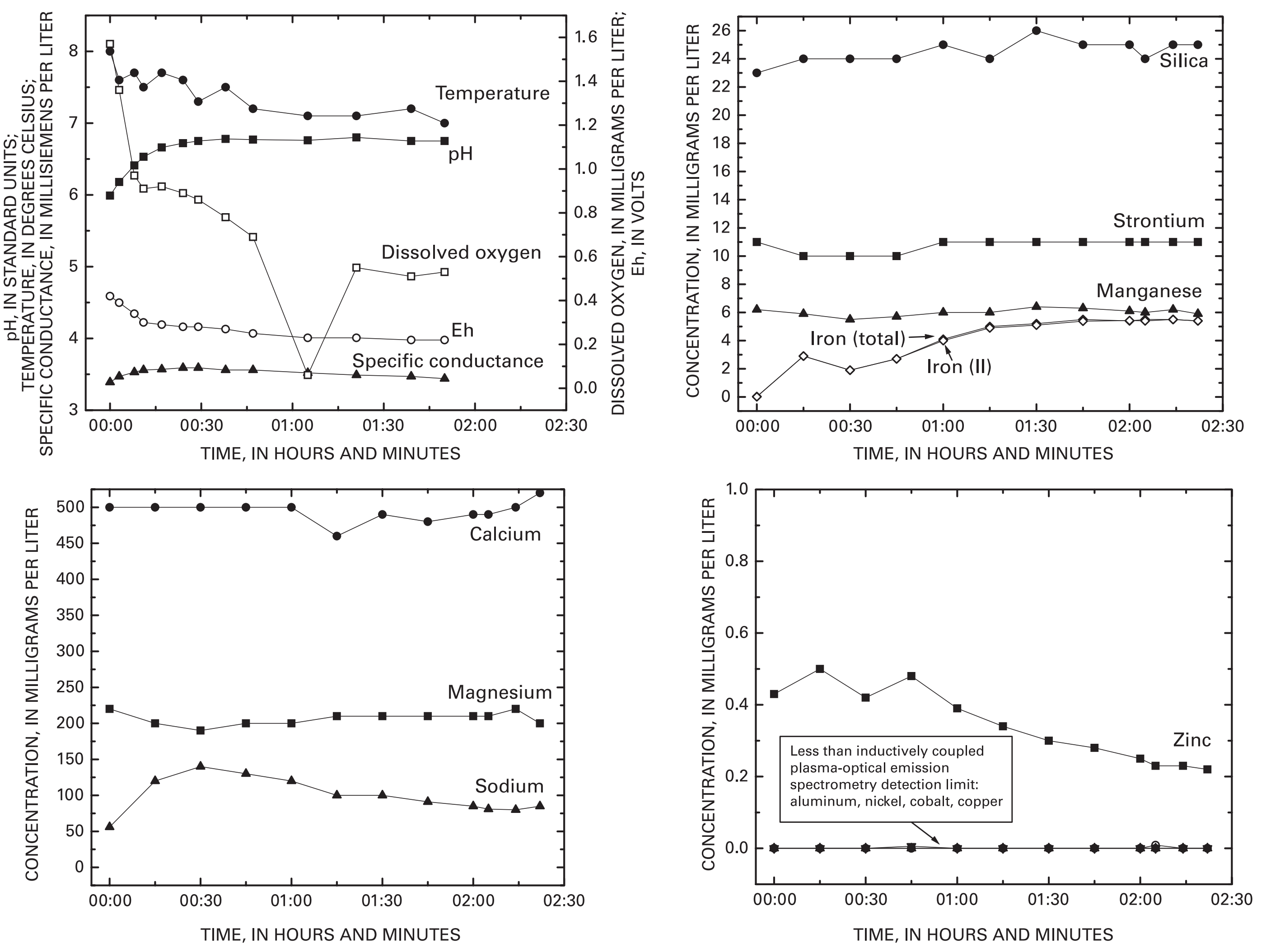


Figure 8. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Concluded.



A. Well SC-1A - APRIL 2002

Figure 9. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during April 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1.



B. Well SC-1B - APRIL 2002

Figure 9. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

C. Well SC-2B - APRIL 2002

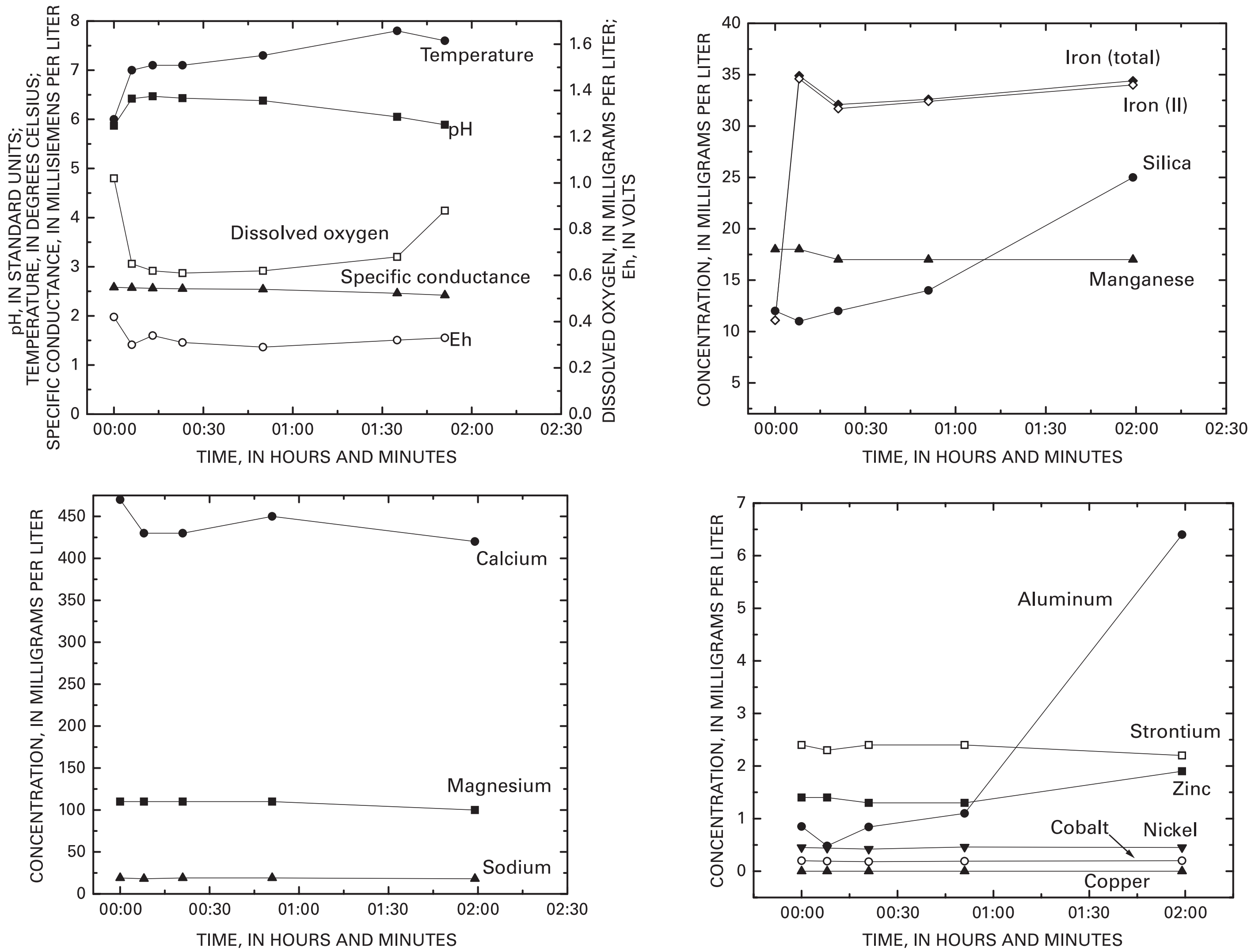


Figure 9. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

D. Well SC-3A - APRIL 2002

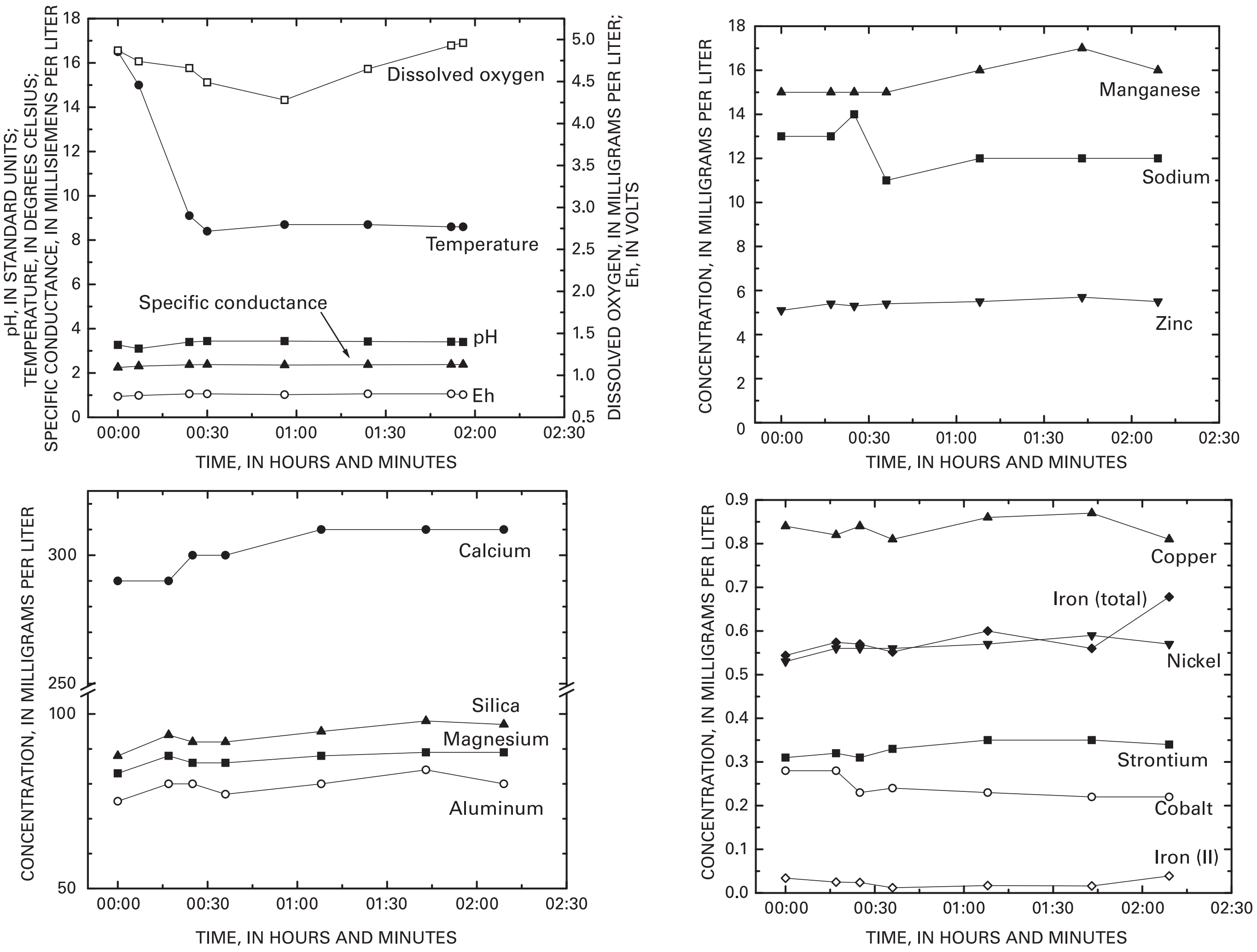


Figure 9. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

E. Well SC-3B - APRIL 2002

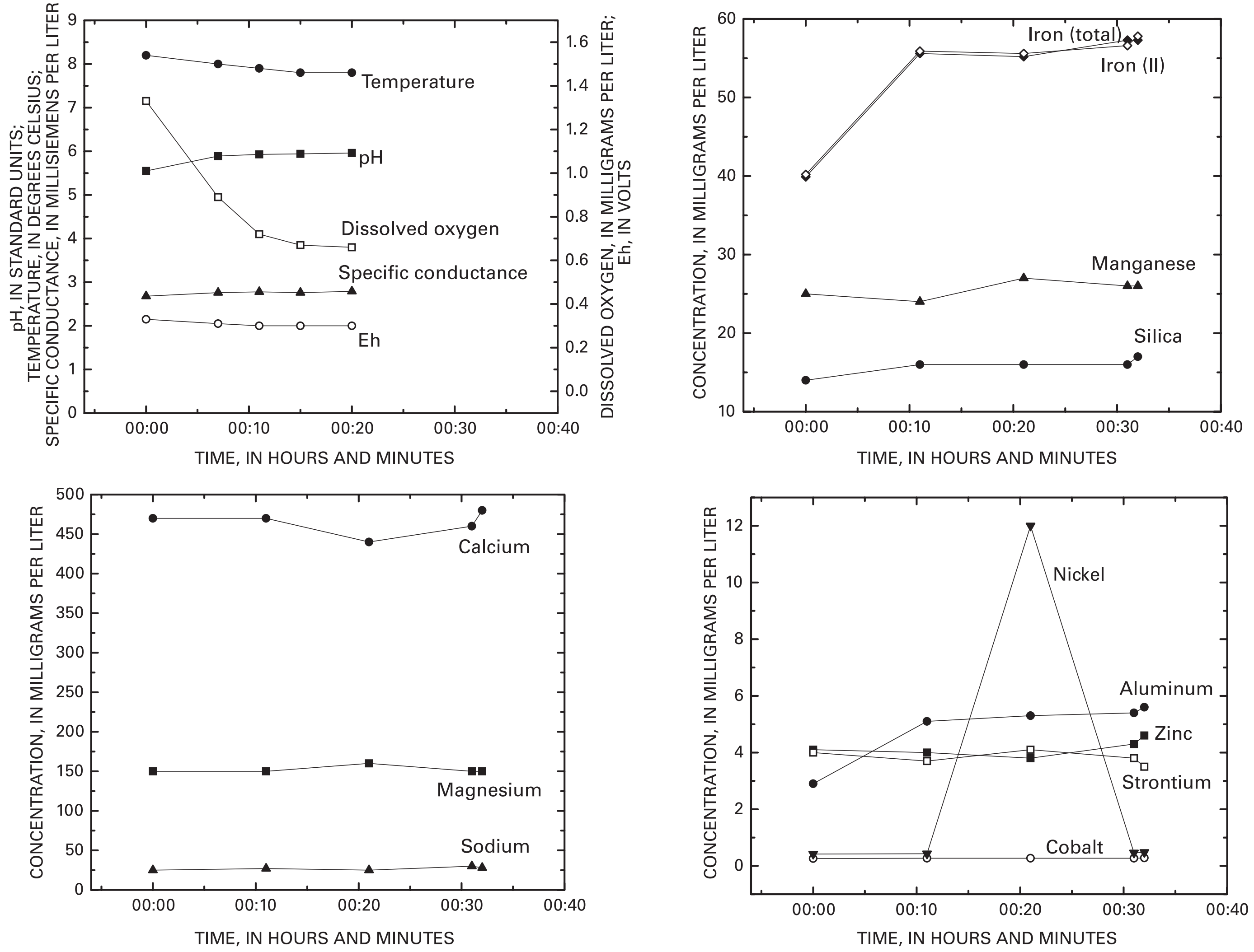


Figure 9. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

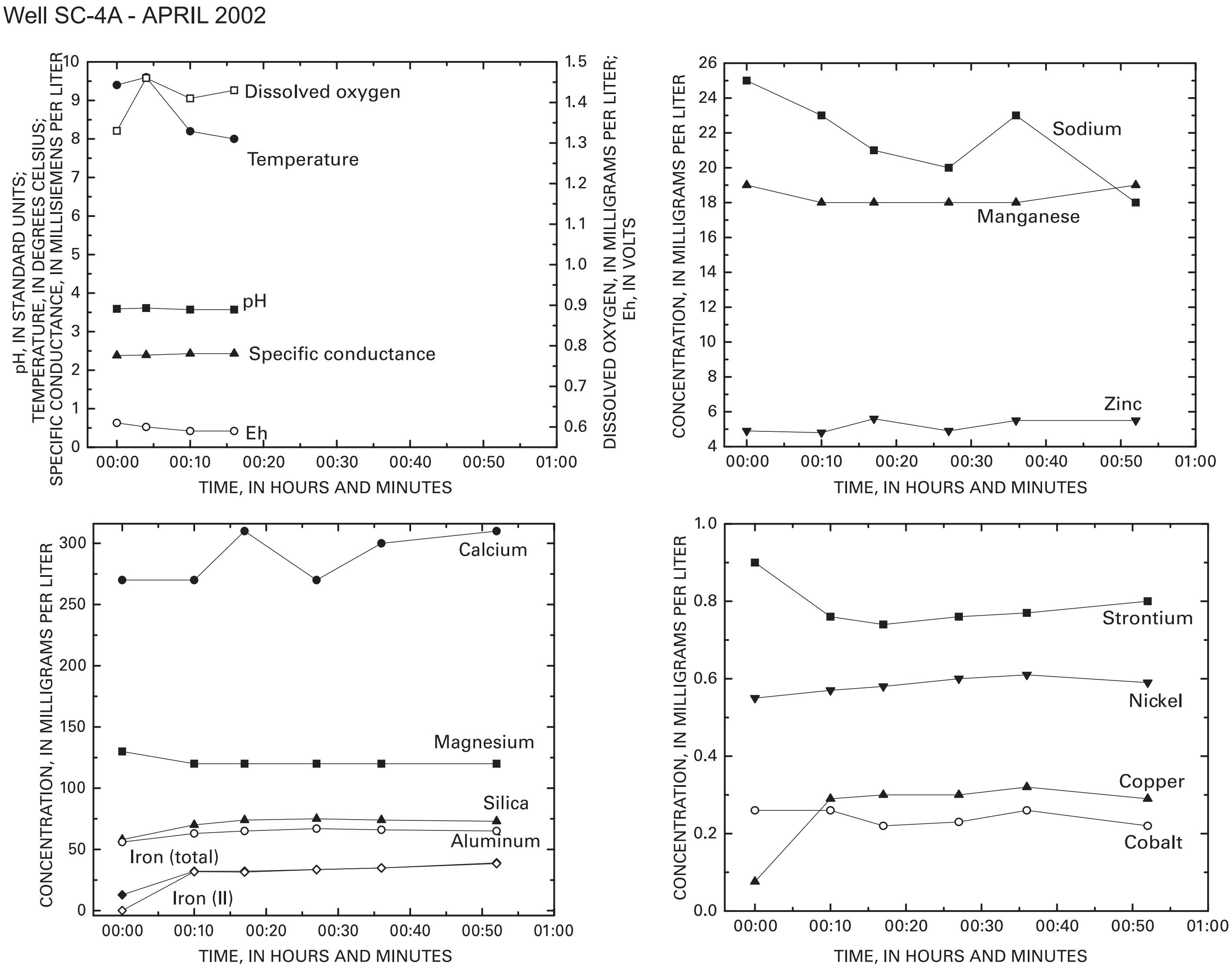

F. Well SC-4A - APRIL 2002

Figure 9. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

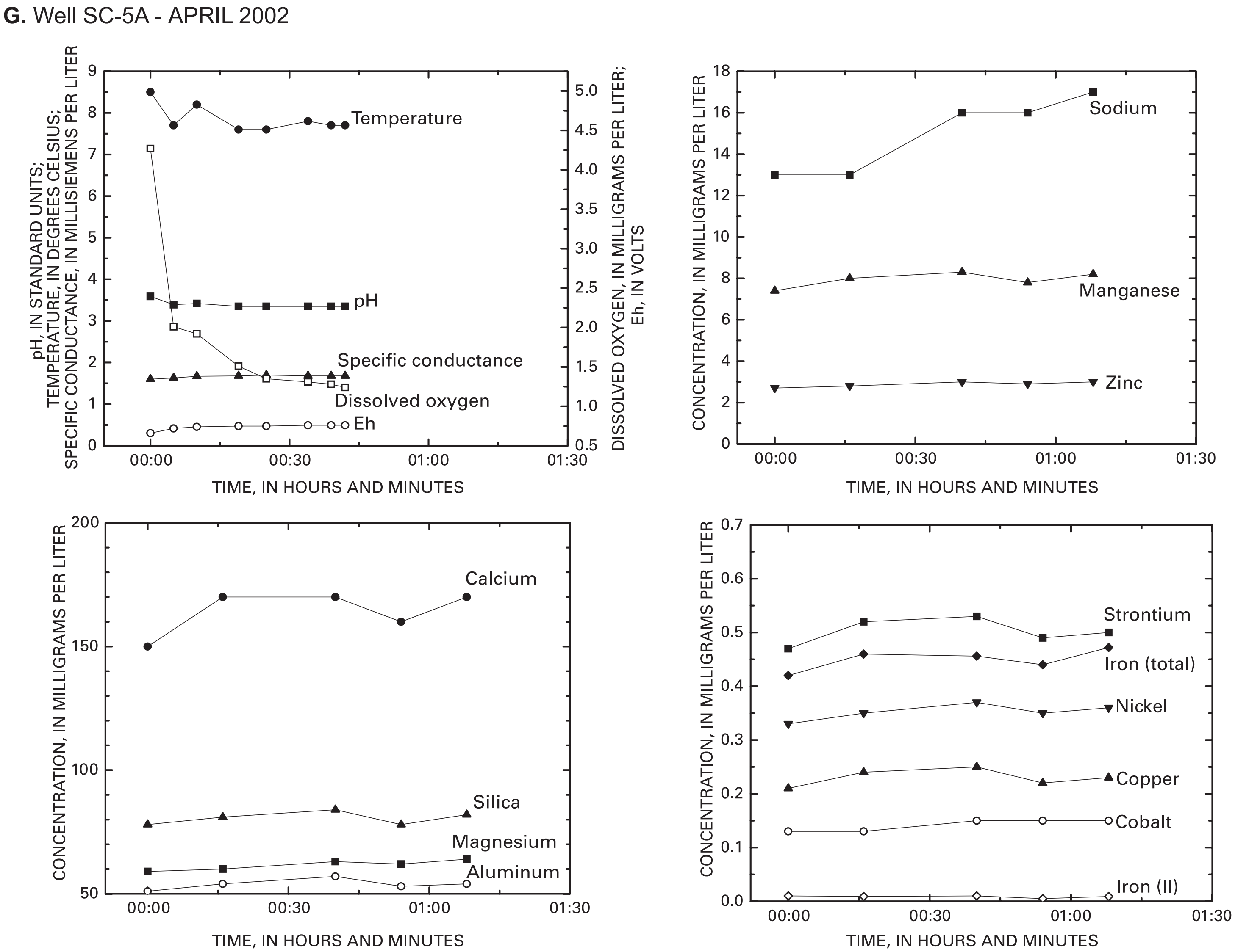
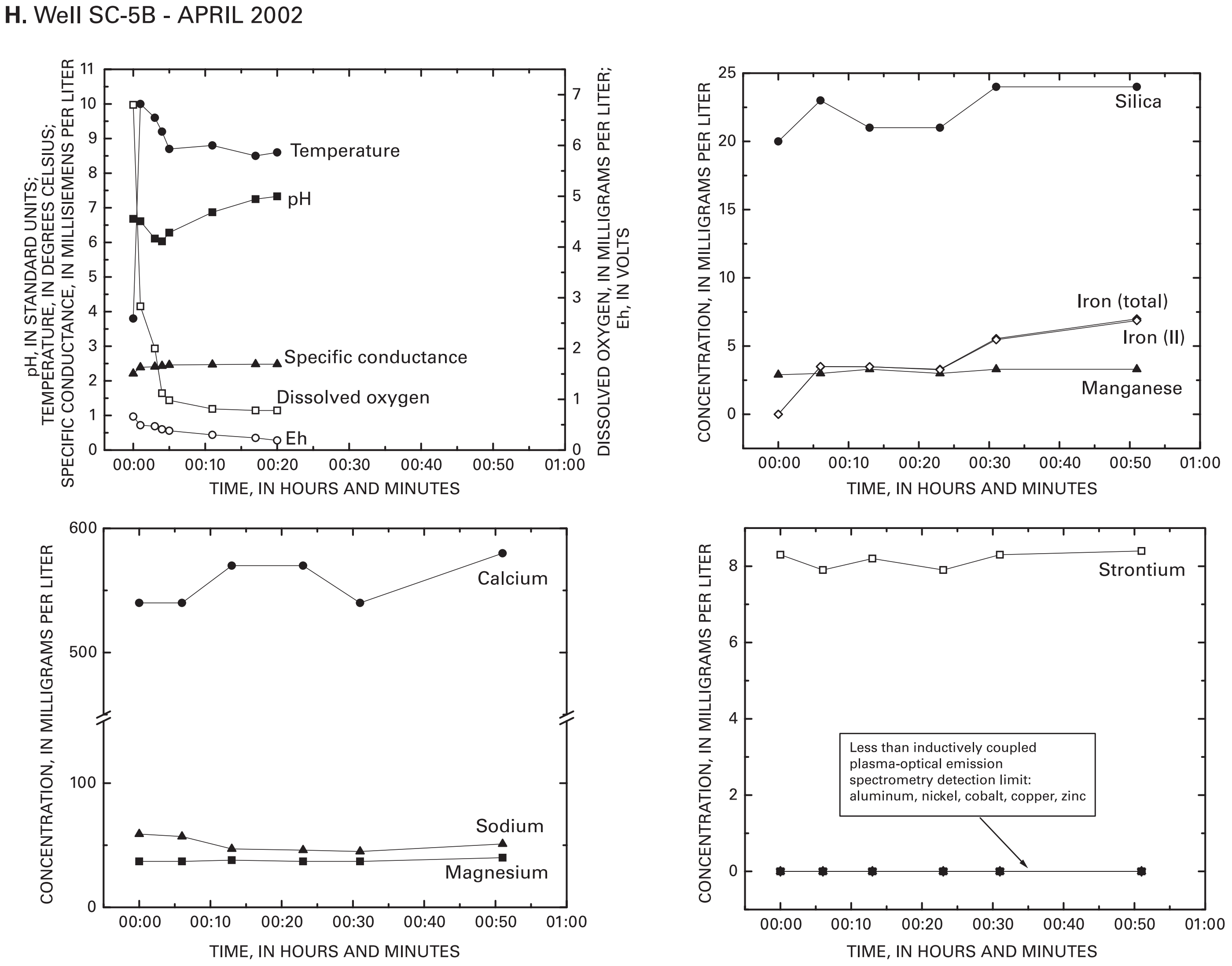


Figure 9. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.


H. Well SC-5B - APRIL 2002

Less than inductively coupled plasma-optical emission spectrometry detection limit: aluminum, nickel, cobalt, copper, zinc

Figure 9. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Continued.

I. Well AWWT-1 - APRIL 2002

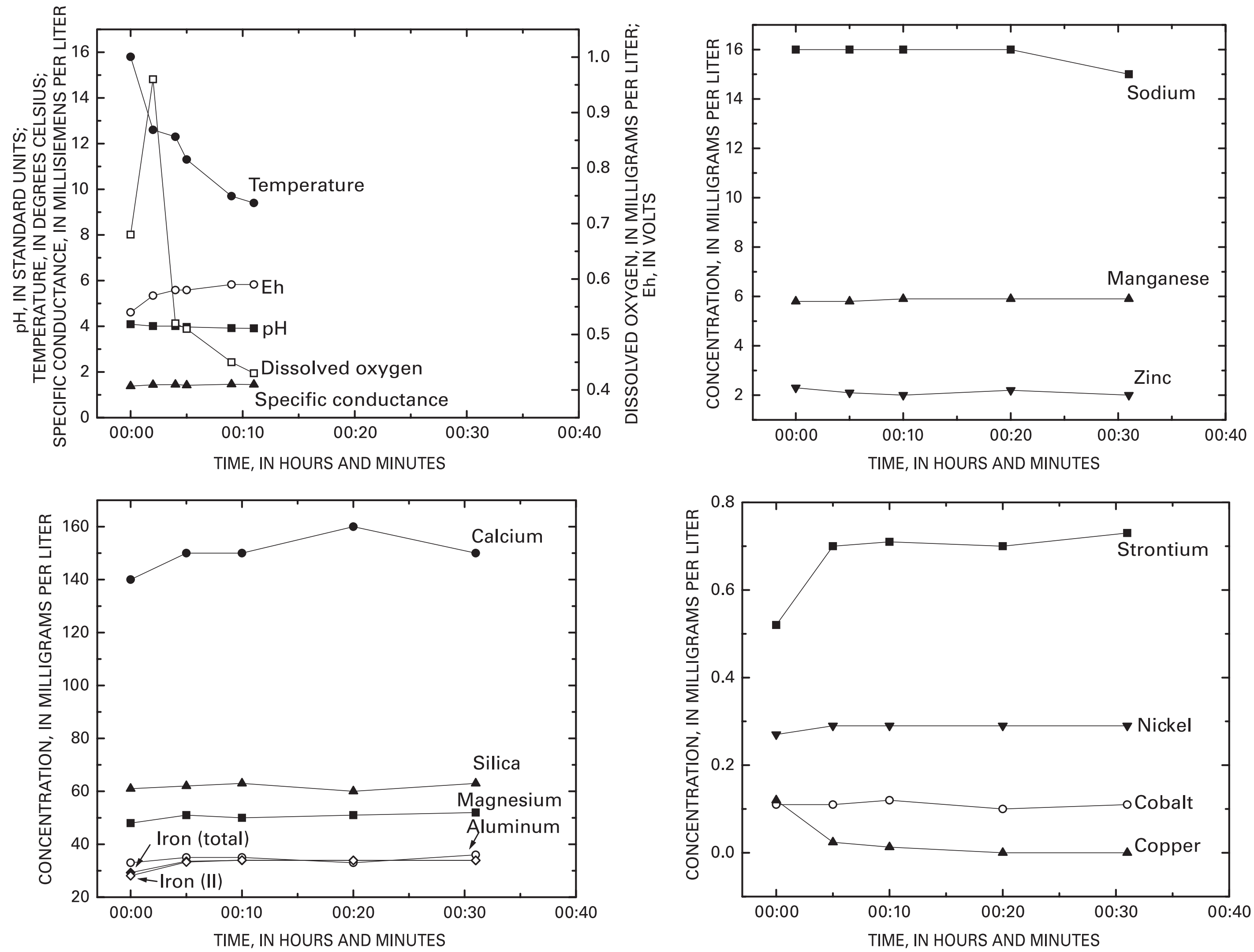


Figure 9. Stabilization of ground-water-quality parameters, including iron and other solute concentrations, with elapsed time during March 2002 sample collections in well (A) SC-1A, (B) SC-1B, (C) SC-2B, (D) SC-3A, (E) SC-3B, (F) SC-4A, (G) SC-5A, (H) SC-5B, and (I) AWWT-1--Concluded.

By using a target rate of less than 0.5 liter per minute, pump flow rates were optimized during the first several months of sampling and were kept as constant as possible thereafter. The water level (drawdown) was continuously monitored during purging to avoid dewatering the well screen, if applicable. The following information was recorded to document well purging activities: pumping rate, drawdown, and volume purged; water-quality parameter values; visual evaluation of purge-water turbidity and particulates; and any deviations from standard well-purging procedures and anomalies, difficulties, and adjustments.

Dissolved oxygen and temperature measurements made in the flow-through cell may not be representative of in situ ground-water properties. The sensitivity of these water-quality parameters to the measurement methods used and a technique used to test the degree of this sensitivity are discussed in the following paragraphs.

During each cycle of the bladder pump, water pumped through the well discharge tubing enters the base of the flow-through cell, flows past the sensors, and exits from the top of the flow-through cell. Each pump cycle consists of refill and discharge periods during which water enters into and is expelled from the pump bladder. The lengths of refill and discharge time periods were specified for each well on the basis of pump flow-rate optimization. For all wells, there is a time lag between discharge cycles, and although the flow-through cell is always full, the water does not continuously flow past the sensors. Measured dissolved oxygen concentrations therefore fluctuate with the pump cycles, and the recorded value depends on when the value was recorded during the cycle. Therefore, each time water-quality parameters were recorded, the dissolved oxygen concentrations were observed for a complete pump cycle, and the highest and lowest concentrations were recorded. The lowest concentrations correspond to the flow of water past the dissolved oxygen sensor and are most representative of actual dissolved oxygen concentrations.

The dissolved oxygen sensor is placed immediately adjacent to the inlet from the well discharge tubing at the base of the cell, which helps preclude measurement of the dissolved oxygen concentration in water that has contacted air. However, head space can exist at the top of the flow-through cell and could affect these dissolved oxygen concentrations. To test the effect of head space, dissolved oxygen concentrations were measured again after sample collection by placing the sensor and well discharge tubing in a graduated cylinder and allowing the cylinder to overflow, thereby eliminating headspace. The lowest recorded flow-through-cell dissolved oxygen concentrations were compared with the graduated cylinder dissolved oxygen concentrations (fig. 10A). These dissolved oxygen tests were conducted on some wells in March and all wells from April through August 2002.

The temperature of water in the flow-through cell could be affected by air temperature, especially during summer and winter months. Water temperature also was measured in the flow-through cell during purging and in the graduated cylinder during dissolved oxygen tests (or in a beaker when no dissolved oxygen tests were conducted), and the temperatures were compared (fig. 10B). Dissolved oxygen concentrations and temperatures measured in the graduated cylinder are considered more accurate because the graduated cylinder method eliminates the possibility of ground water contacting oxygen in the head space in the flow-through cell and of air temperature warming or cooling water in the flow-through cell.

Temporal trends are evident in the field parameter data (fig. 11). In wells SC-1B and SC-5B, dissolved oxygen concentrations and Eh values generally decreased during the sampling period. Iron concentrations in SC-1B and SC-5B are lower than in other bedrock aquifer wells, presumably because of the presence of hydrogen sulfide (H_2S). Evidence of H_2S was noted in the field and laboratory while collecting and processing samples from wells SC-1B and SC-5B. During the December 2002 and subsequent sample collections, a slight H_2S odor was noted in the field while samples were collected from SC-1B, and water appeared light gray in color. Similarly, the H_2S odor was noted in the mobile laboratory when samples from SC-5B were processed in April 2002. During the September 2002 and subsequent samplings, a strong H_2S odor was noted in the field and water pumped from SC-5B appeared gray to black in color. The H_2S concentration was measured in Straight Creek wells and well AWWT-1 during purging in May 2003 to verify the presence of H_2S in wells SC-1B and SC-5B (table 5).

The pH values in water from wells completed within debris-flow and Red River alluvial deposits are distinctly different from values in water from wells completed in bedrock (fig. 12); alluvial and debris-flow aquifer ground water is more acidic than bedrock aquifer ground water. The lowest pH of all bedrock aquifer wells is in water from well SC-3B, perhaps an indication of mixing with debris-flow aquifer ground water. Among Phase I wells completed within alluvial and debris-flow deposits and well AWWT-1, the least acidic ground water generally is from AWWT-1. This may reflect the influence of more neutral water in the Red River alluvial aquifer or the bedrock aquifer. Straight Creek surface-water pH values are similar to, but consistently lower than, values in water from wells completed within alluvial and debris-flow deposits.

Specific conductance is notably lower in ground water from wells AWWT-1 and SC-5A than in water from all other Phase I wells and Straight Creek surface water (fig. 13). The less conductive water could be caused by more neutral water in the Red River or its alluvial aquifer.

Sampling Procedures

Ground-water samples were routinely collected for determination of total major cations and selected trace metals; dissolved major cations, selected trace metals, and rare-earth elements; anions and alkalinity; and dissolved-iron species. Rare-earth elements were determined on selected samples only. Samples were collected for determination of dissolved organic carbon (DOC), mercury, sulfur isotopic composition (^{34}S and ^{18}O of sulfate), and water isotopic composition (^{2}H and ^{18}O) during selected samplings. One set of samples was collected for helium-3/tritium and CFC age dating. The type and size of bottles used and cleaning, treatment, and preservation methods for each sample type are presented in table 6.

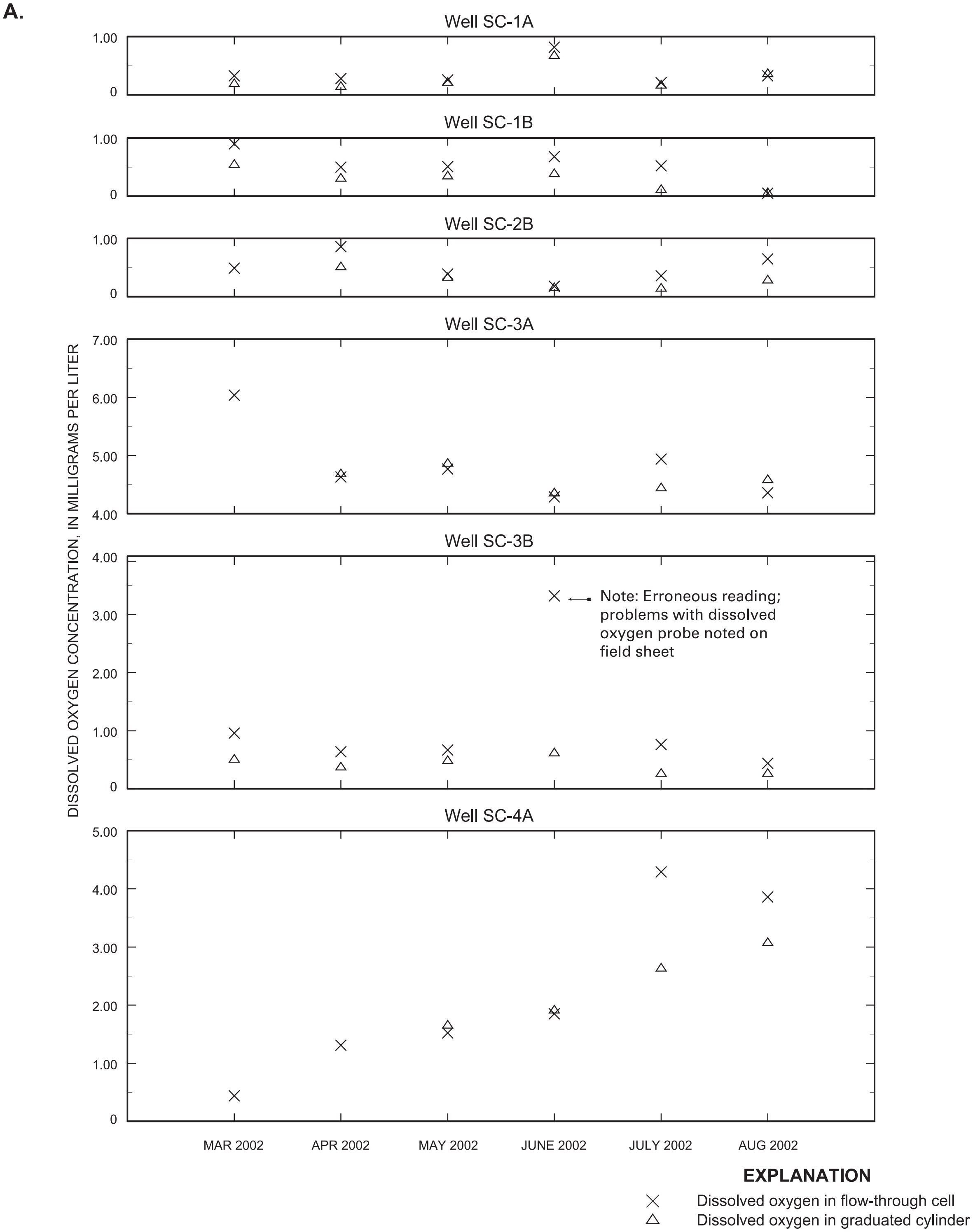


Figure 10. (A) Comparison of dissolved oxygen concentrations in ground water in the flow-through cell to dissolved oxygen concentrations in ground water in the graduated cylinder and (B) comparison of ground-water temperature in the flow-through cell to ground-water temperature in the graduated cylinder.

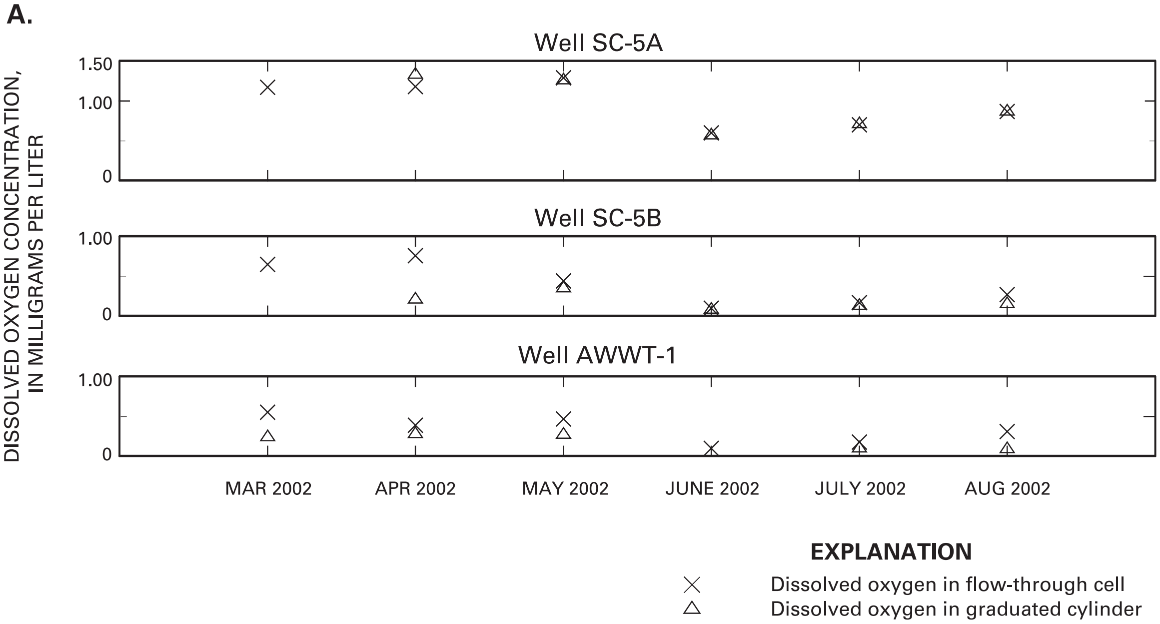


Figure 10. (A) Comparison of dissolved oxygen concentrations in ground water in the flow-through cell to dissolved oxygen concentrations in ground water in the graduated cylinder and (B) comparison of ground-water temperature in the flow-through cell to ground-water temperature in the graduated cylinder--Continued.

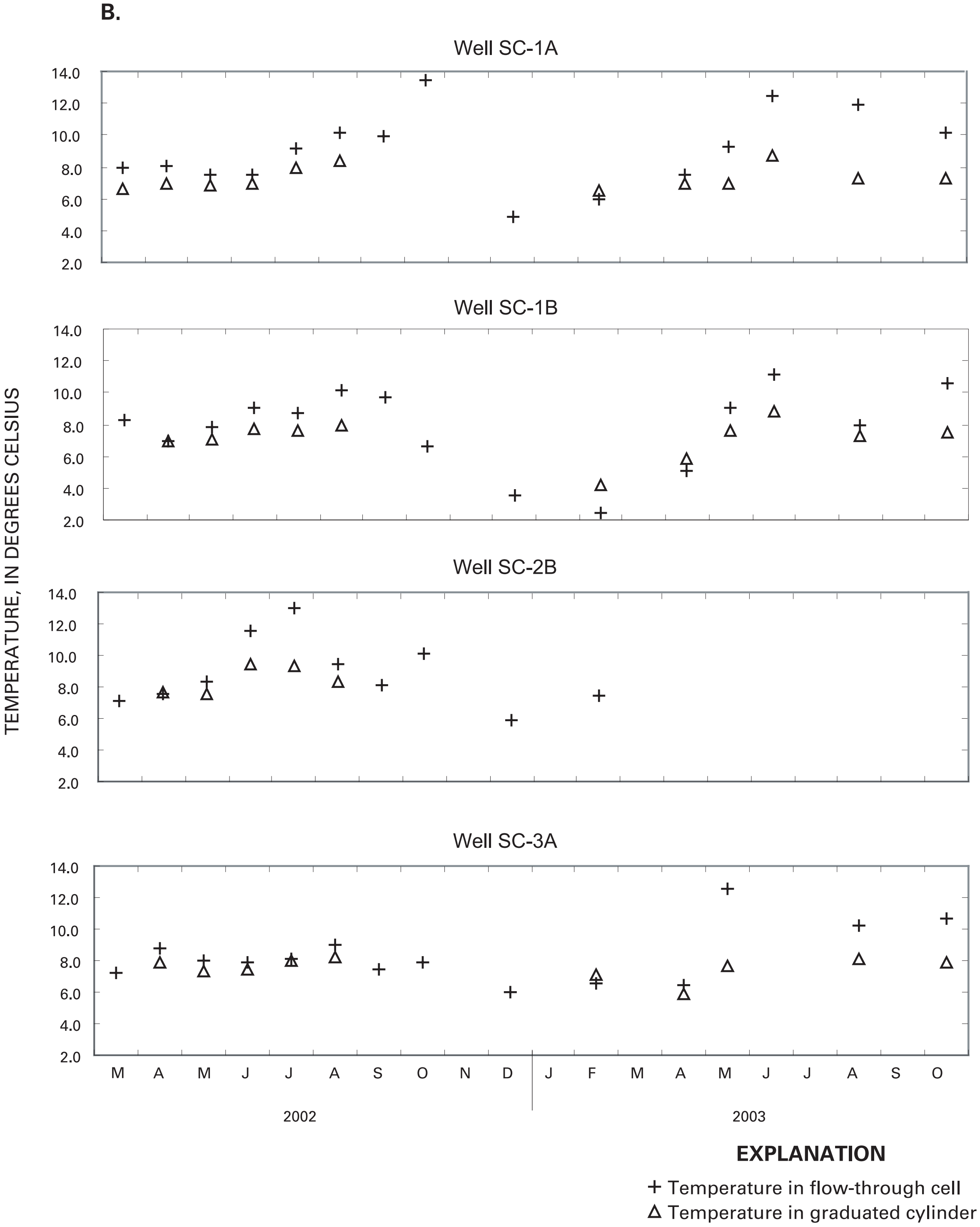


Figure 10. (A) Comparison of dissolved oxygen concentrations in ground water in the flow-through cell to dissolved oxygen concentrations in ground water in the graduated cylinder and (B) comparison of ground-water temperature in the flow-through cell to ground-water temperature in the graduated cylinder--Continued.

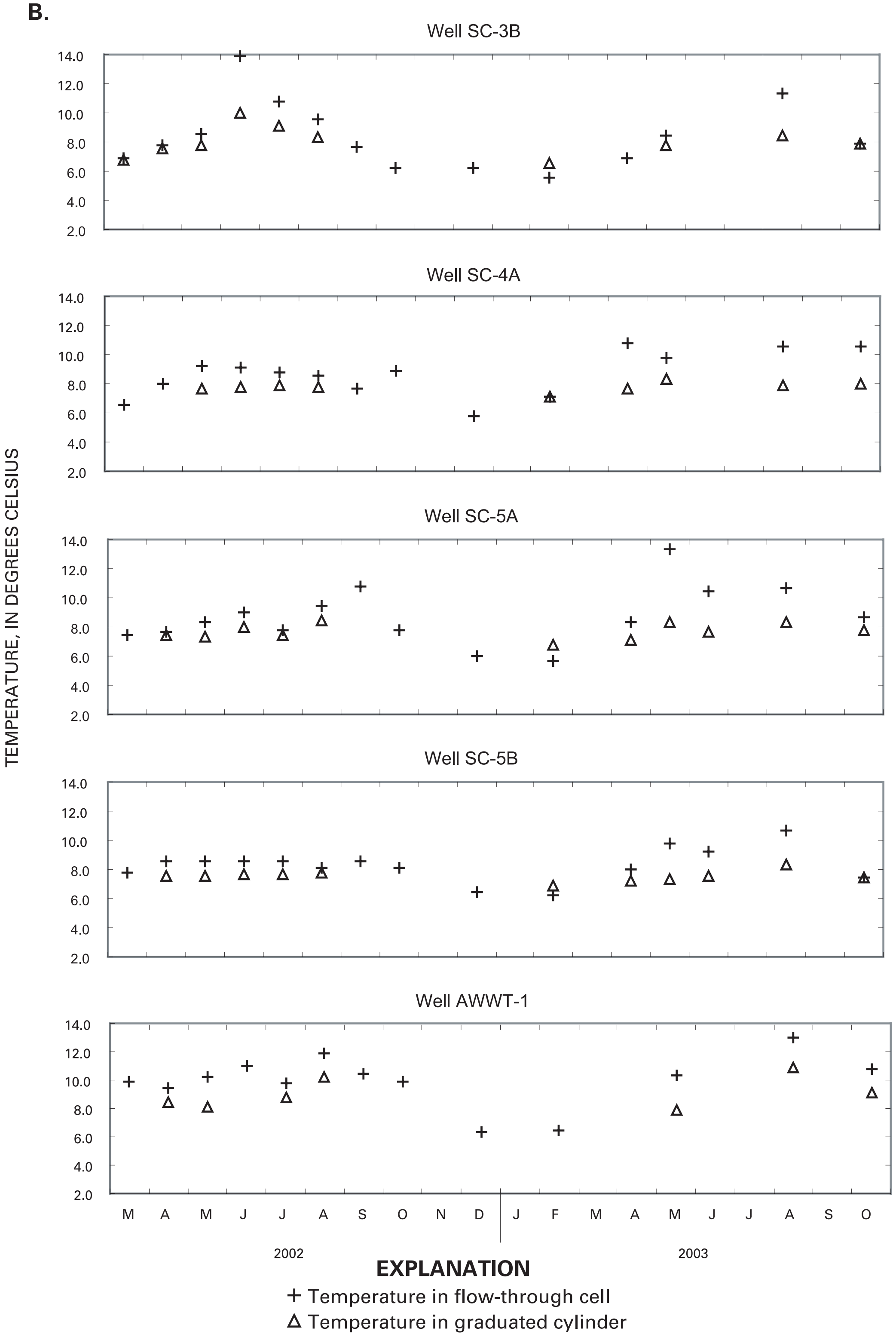


Figure 10. (A) Comparison of dissolved oxygen concentrations in ground water in the flow-through cell to dissolved oxygen concentrations in ground water in the graduated cylinder and (B) comparison of ground-water temperature in the flow-through cell to ground-water temperature in the graduated cylinder--Concluded.

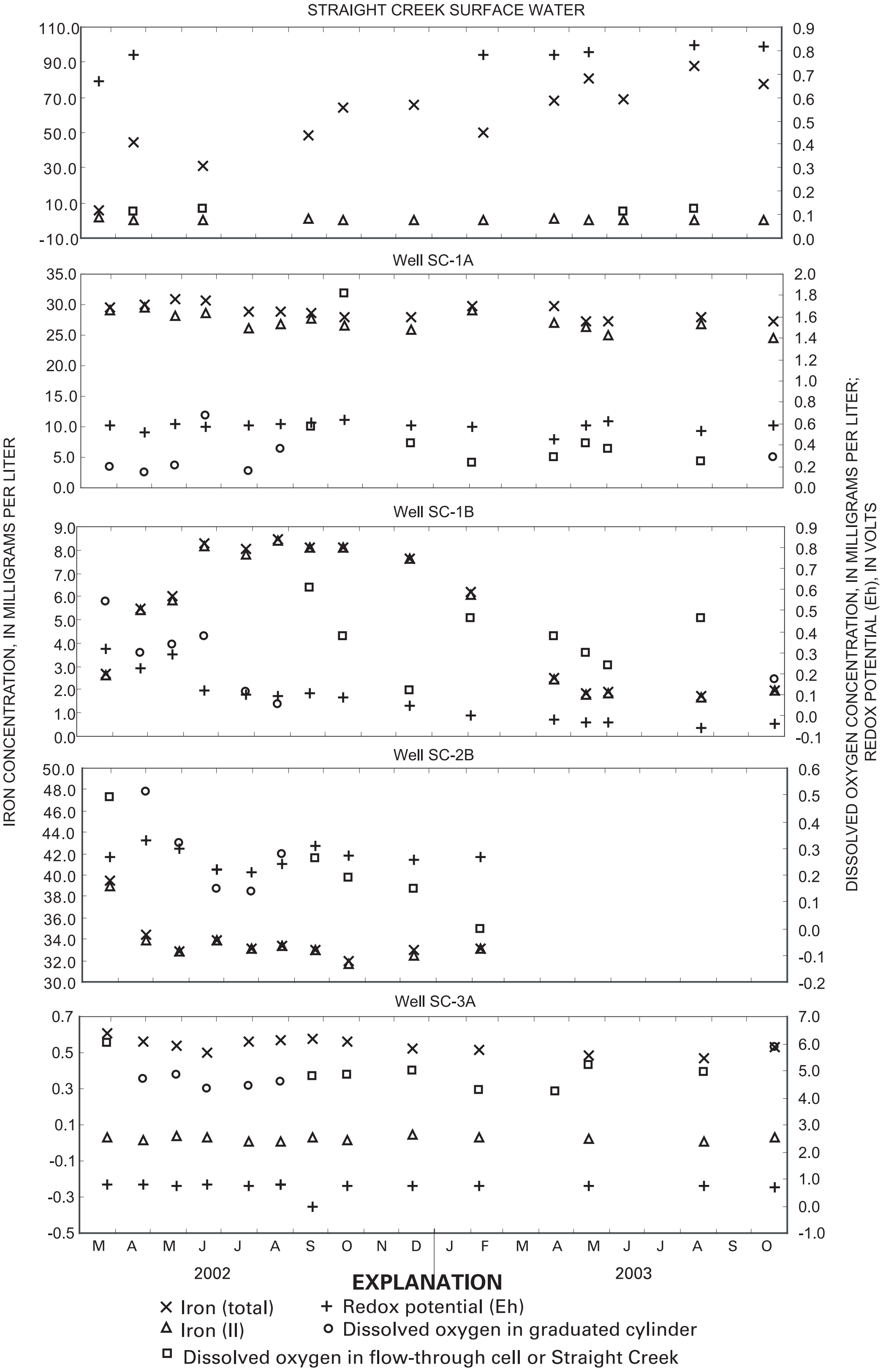


Figure 11. Final field parameter values for dissolved oxygen (graduated cylinder values if available; flow-through cell values otherwise) and Eh, and iron concentrations in Straight Creek surface water and ground water from observation wells.

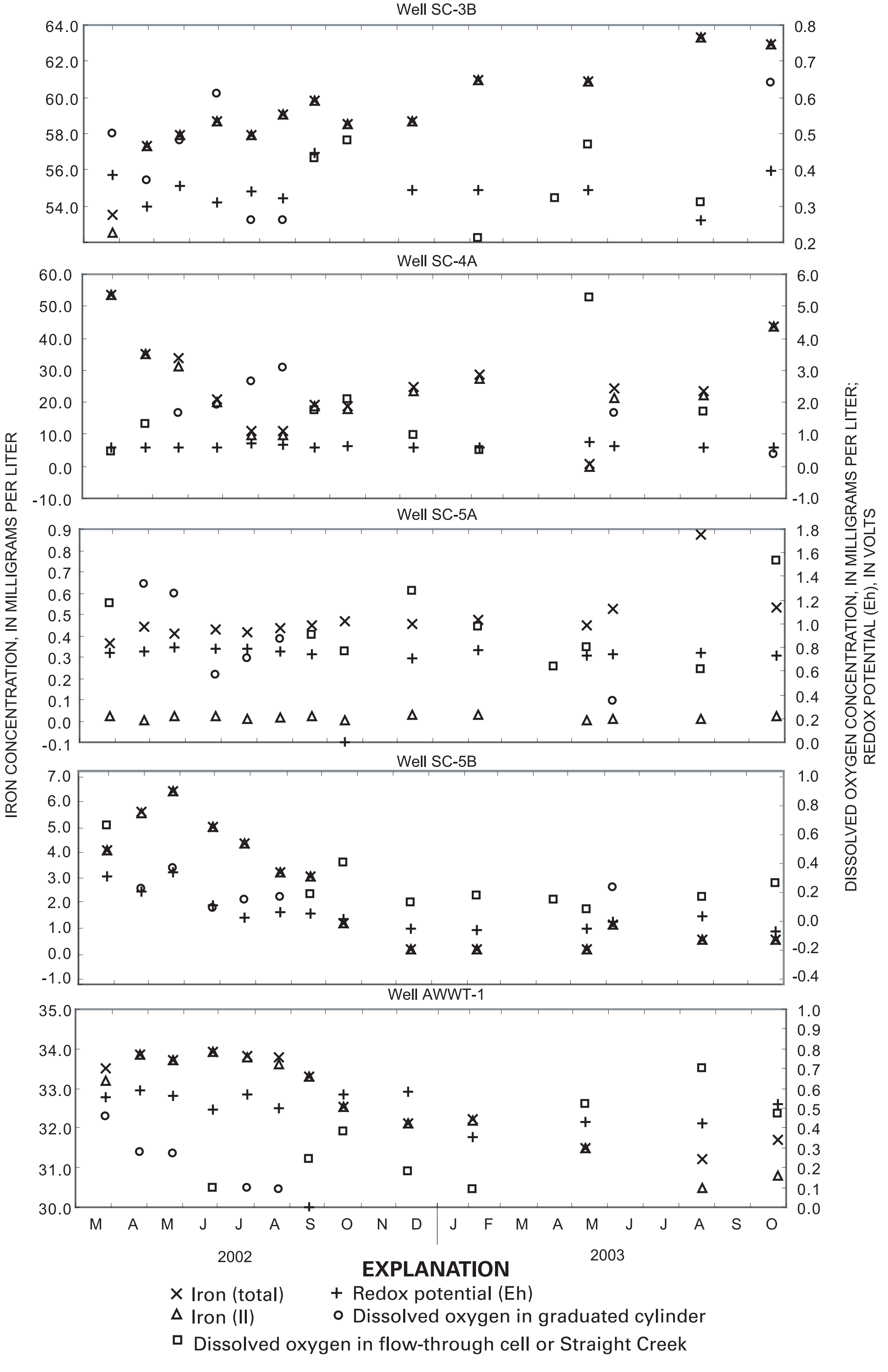


Figure 11. Final field parameter values for dissolved oxygen (graduated cylinder values if available; flow-through cell values otherwise) and Eh, and iron concentrations in Straight Creek surface water and ground water from observation wells--Concluded.

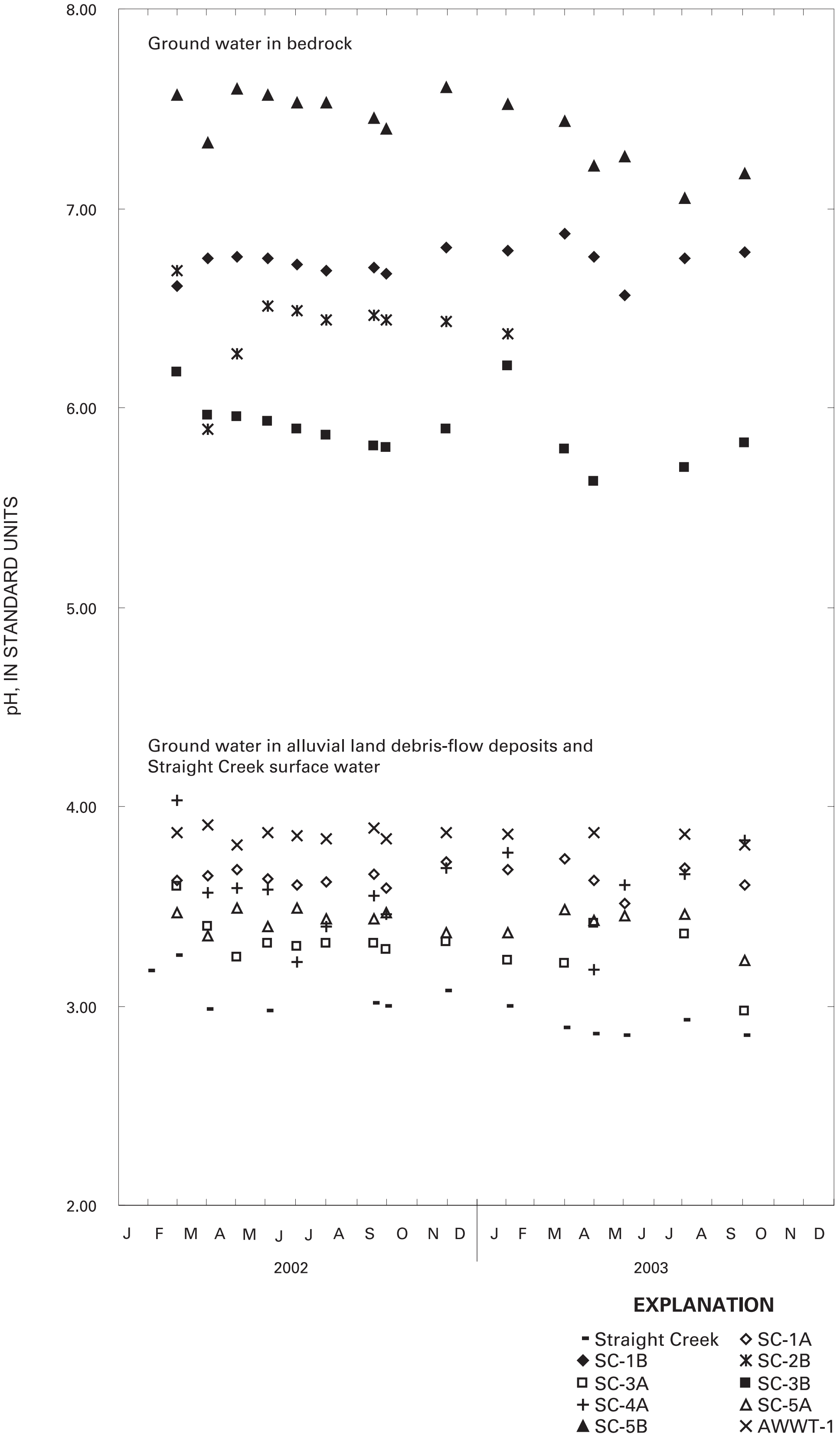


Figure 12. pH as a function of time in Straight Creek surface water and ground water from observation wells.

Table 5. Field-determined hydrogen sulfide (H_2S) concentrations.

[mg/L, milligrams per liter; <, less than; ± , plus or minus; N.D., non-detect]

Well (fig. 3)	Date	H_2S (mg/L)
SC-1A	5/13/2003	<0.002
SC-1B	5/13/2003	7.4 ± 0.5
SC-3A	5/14/2003	N.D.
SC-3B	5/14/2003	N.D.
SC-4A	5/14/2003	N.D.
SC-5A	5/13/2003	N.D.
SC-5B	5/13/2003	5.4 ± 0.8
AWWT-1	5/12/2003	N.D.

Both unfiltered (raw) and filtered samples were routinely collected. Disposable capsule filters with a nominal pore size of 0.45 micrometer (µm) were used for routine filtration. Because fine colloidal material may pass through a 0.45-µm filter membrane (Kennedy and others, 1974, 1976; Laxen and Chandler, 1982), duplicate samples were collected from selected wells by filtering the sample through a plate filter with a 0.1-µm membrane. Filters were connected inline with the sample tubing to collect samples directly from the well.

Field-data forms and sample bottle labels included the sample identification, collection date and time, preservation and filtration information, and analyses requested. All sample bottles were placed in sealed plastic storage bags and stored at about 4 °C for transport to the laboratory. For shipment to the laboratory, samples were placed in a cooler with ice (double bagged in sealed plastic bags) and protective packing material if appropriate to prevent breakage.

Equipment in contact with water from more than one well during a sampling trip (non-dedicated equipment) was decontaminated in the laboratory prior to each sampling trip and in the field between well visits. The portable bladder pump was decontaminated using one of two methods. From March 2002 to April 2003, the pump was cleaned by disassembling the pump, soaking the pump housing and fittings in (and scrubbing with, if necessary) non-phosphate laboratory detergent, and rinsing with deionized water (DIW). Beginning in May 2003, the portable pump was decontaminated by disassembling the pump and rinsing with sulfuric acid and DIW. Bladders were dedicated to each well and did not require decontamination. The electric water-level tape was decontaminated in the field by spraying it with DIW and in the laboratory by soaking it in (and scrubbing with, if necessary) non-phosphate laboratory detergent and rinsing with DIW. Equipment that did not contact sample water did not require decontamination between well visits unless it became visibly dirty or clogged with sediment. Dedicated pumps and tubing required no decontamination. In October 2002, samples also were collected for determination of the chlorofluorocarbons (CFC's) CFC-11, CFC-12, and CFC-113; dissolved gases (He, Ne, Ar, N_2, O_2, and CH_4) and isotopes of He and Ne (^{3}He, ^{4}He, ^{20}Ne, ^{21}Ne, and ^{22}Ne); and tritium. Ground-water samples for CFC analyses were collected in glass ampoules using an all-metal apparatus that prevents the contamination of water with halocarbons. The ampoules were flame sealed in the field. Five replicates were collected, and at least three ampoules per site were analyzed (U.S. Geological Survey, 2004c). Dissolved-gas samples were collected in 3/8-inch-diameter copper tubes and sealed with refrigeration clamps. Care was taken to ensure that the samples were bubble free and not exposed to the atmosphere. Tritium samples were collected after collection of the dissolved-gas sample and were sealed, free of bubbles, with a polyethylene cap (Solomon and Cook, 2000). Additional information regarding sample containers and cleaning, filtration, and preservation methods is presented in table 6.

Surface Water

Surface-water samples were collected from Straight Creek at a location upstream from the point where surface water completely infiltrates to the subsurface. Samples were collected routinely for total major cations and selected trace metals; dissolved major cations, selected trace metals, and rare-earth elements; anions and alkalinity; and dissolved-iron species. Rare-earth elements were determined for selected samples. Occasionally, samples were collected and analyzed for DOC, mercury, ^{34}S and ^{18}O of sulfate, ^{2}H, and ^{18}O. The type and size of bottles used and cleaning, filtration, and preservation methods for each sample type are the same as those used for ground-water samples (table 6). Samples were collected using a peristaltic pump and silicone tubing. Tubing was decontaminated in the laboratory between samplings.

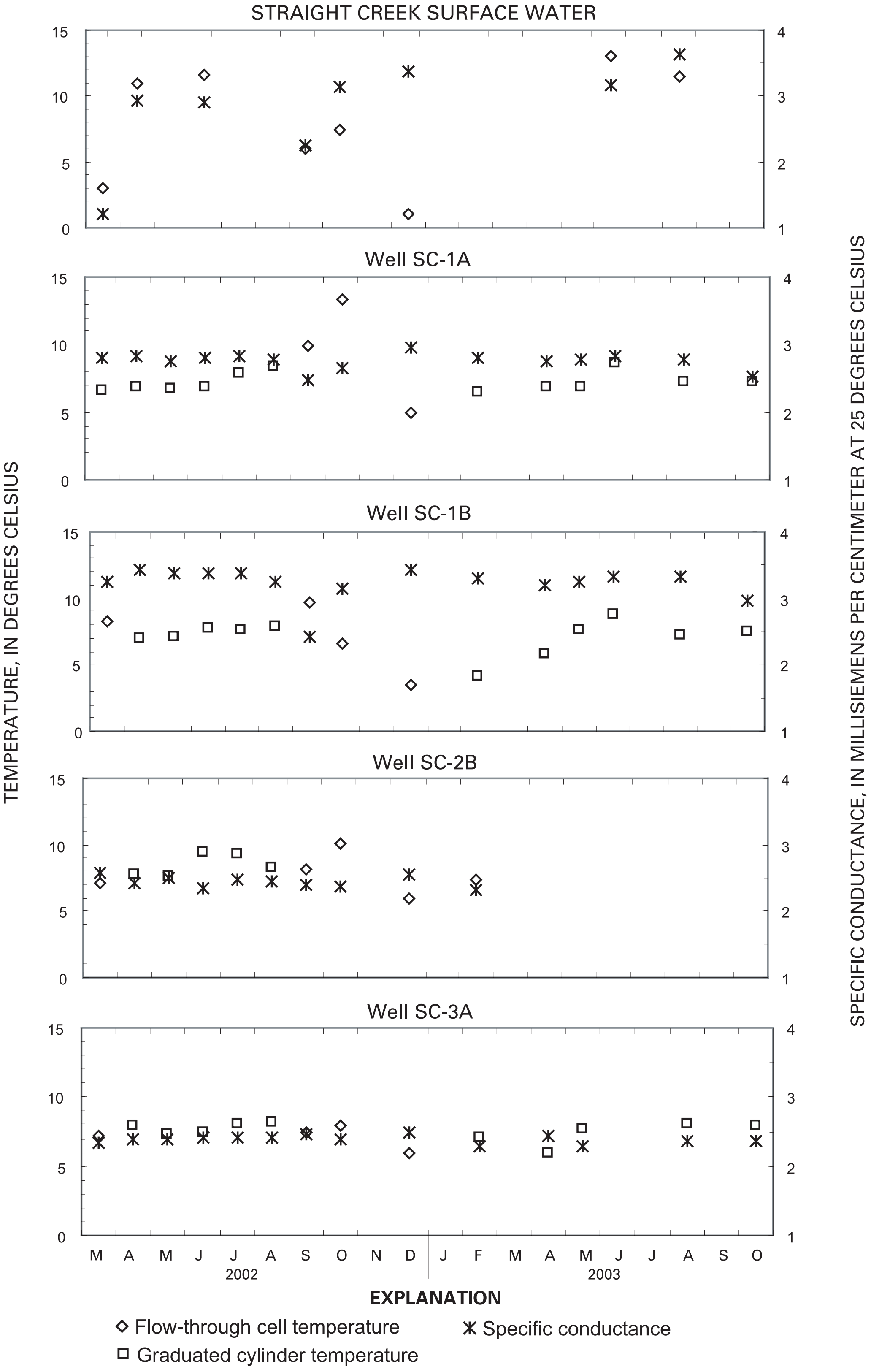


Figure 13. Temperature (graduated cylinder values if available; flow-through cell values otherwise) and specific conductance in Straight Creek surface water and ground water from observation wells.

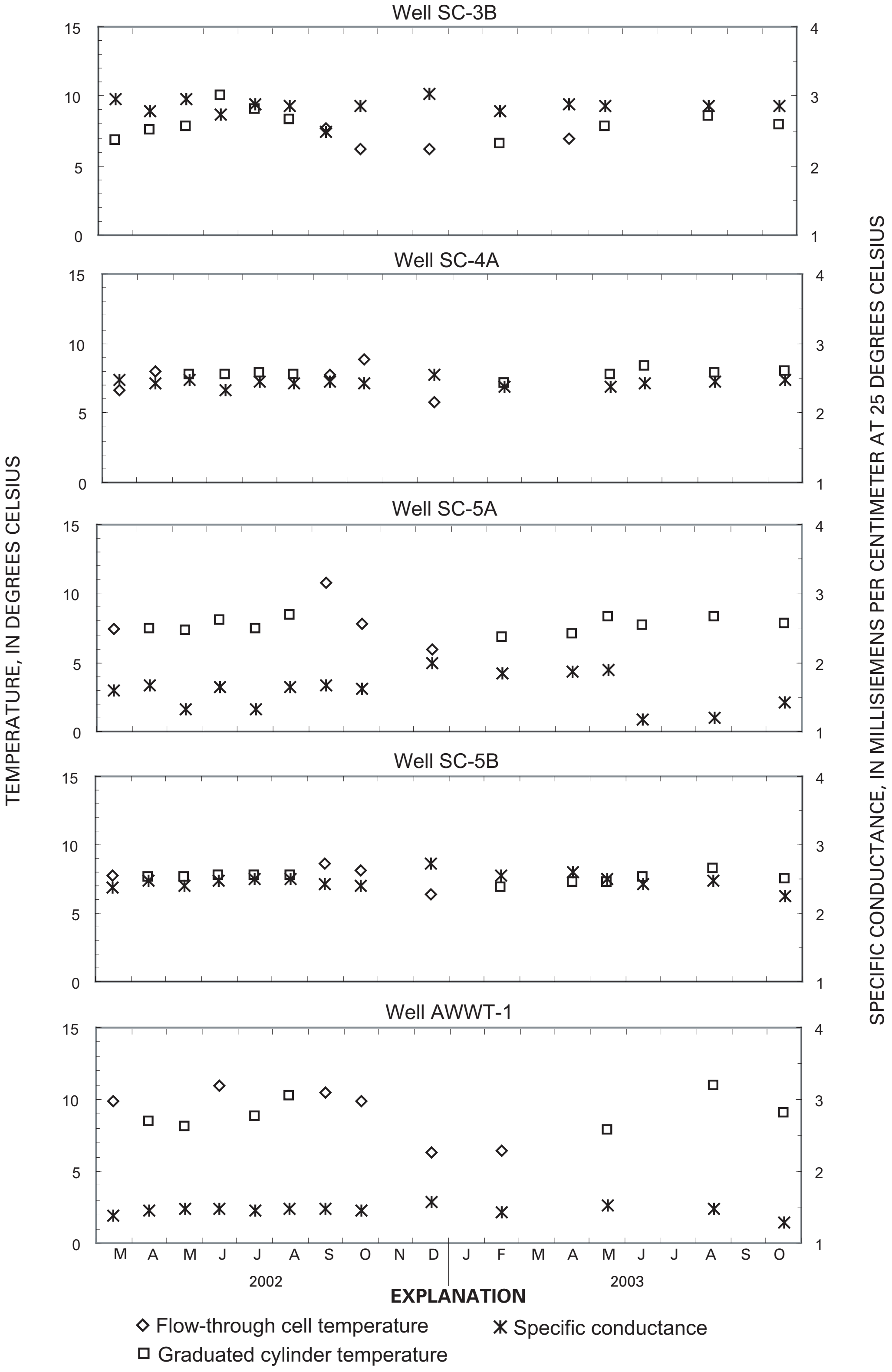


Figure 13. Temperature (graduated cylinder values if available; flow-through cell values otherwise) and specific conductance in Straight Creek surface water and ground water from observation wells--Concluded.

Water Sample Analyses and Results

The USGS Noble Gas Laboratory in Denver, Colorado, analyzed the dissolved-gas and tritium samples. CFC determinations were performed by the USGS Chlorofluorocarbon Laboratory in Reston, Virginia. Stable water isotope samples were analyzed by the USGS Stable Isotope Laboratory in Reston, Virginia, and stable isotopic compositions of sulfur and oxygen in dissolved sulfate, sulfate minerals, and sulfide minerals were determined at the USGS Stable Isotope Laboratory in Denver. All other samples were analyzed by the USGS Branch of Regional Research laboratory in Boulder, Colorado. Analytical techniques, detection limits or typical precision, equipment used, and analytical method references are summarized in table 7.

Ground-Water Age Dating

Samples were collected for determination of CFC, dissolved-gas, and tritium concentrations for ground-water age dating. This section presents background information regarding ground-water age dating, methods of sample analysis, and results.

Ground-water age dating refers to the process of measuring the time that has lapsed since a parcel of ground water was isolated from the atmosphere (residence time). Generally, the actual dating of water relies on measurement of a specific tracer that is introduced to ground water by a known physiochemical or biological process. The parcel of water then becomes isolated from the atmosphere with subsequent recharge and thus begins to “age” (Clark and Fritz, 1999). This measured time component should be considered a mean residence time for ground water in an aquifer and can be used to estimate recharge and discharge rates of water in the aquifer, horizontal and vertical flow velocities, and even kinetic reaction rates associated with bedrock weathering.

Table 6. Analysis type; constituents determined; bottle types, sizes, and cleaning; and sample treatment and preservation.

[mL, milliliter; HDPE, high-density polyethylene; RA, raw-acidified; HNO_3, nitric acid; <, less than; FA, filtered-acidified; DIW, deionized water; FU, filtered-unacidified; ºC, degrees Celsius; HCl, hydrochloric acid; DDW, double-distilled water; w/v, weight-volume; $K_2Cr_2O_7$, potassium dichromate; RU, raw-unacidified. See table 7 for constituent abbreviations]

Analysis Type	Constituents determined	Bottle type and size	Cleaning	Treatment identification and preservative
Total major cations and trace metals	Ca, Mg, Na, K, SiO_2, Al, Fe(T), B, Li, Sr, Ba, Mn, Zn, Pb, Ni, Cu, Cd, Cr, Co, Be, Mo, V, As, Se	125-mL HDPE	Acid clean (from supplier), field rinse	RA-HNO_3: HNO_3 to pH <2
Dissolved major cations and trace metals	Ca, Mg, Na, K, SiO_2, Al, B, Li, Sr, Ba, Mn, Zn, Pb, Ni, Cu, Cd, Cr, Co, Be, Mo, V, As, Se	250-mL HDPE	Acid clean (from supplier), field rinse	FA-HNO_3: HNO_3 to pH <2
Anions	SO_4, F, Cl, Br	250-mL HDPE	DIW soak overnight and rinse, field rinse	FU: on ice, 4 ^{o}C

Table 6. Analysis type; constituents determined; bottle types, sizes, and cleaning; and sample treatment and preservation--Concluded.

Analysis Type	Constituents determined	Bottle type and size	Cleaning	Treatment identification and preservative
Alkalinity	Alkalinity as bicarbonate	In anions bottle	DIW soak overnight and rinse, field rinse	FU: on ice, 4 °C
Dissolved-iron species	Fe(T), Fe(II)	250-mL opaque HDPE	10% HCl soak overnight, rinse 3x w/ DDW, field rinse	FA-HCl: HCl to pH <2, on ice, 4 °C
Dissolved organic carbon[1]	Organic carbon	60-mL amber glass	Baked (from supplier), field rinse	FU: on ice, 4 °C
Water isotopes[1]	$\delta^{18}O$, $\delta^{2}H$	Borosilicate glass	Field rinse	FU: on ice, 4 °C
Sulfur isotopes[1]	$\delta\,^{34}S$, $\delta^{18}O_{sulfate}$	1-liter HDPE	Field rinse	FU: on ice, 4 °C
Dissolved mercury[1]	Hg	125-mL borosilicate glass	Acid clean (from supplier), field rinse	FA; 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)
Rare earth elements[1]	Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sm, Tb, Tm, Yb	In dissolved major cations / trace metals bottle	Acid clean (from supplier), field rinse	FA-HNO_3: HNO_3 to pH <2
Additional trace metals[1]	Bi, Cs, Hf, Rb, Re, Sb, Ta, Te, Th, Tl, U, W, Y, Zr	In dissolved major cations / trace metals bottle	Acid clean (from supplier), field rinse	FA-HNO_3: HNO_3 to pH <2
Chlorofluorocarbons (CFC's)[1]	CFC-11, CFC-12, CFC-113	60-mL borosilicate-glass ampoule	Field rinse	RU; ampoules purged of air with ultrapure nitrogen and flame welded
Tritium[1]	^{3}H	500-mL glass	Field rinse	RU
Dissolved gases[1]	Ar, CH_4, He, N_2, Ne, O_2, ^{3}He, ^{4}He, ^{20}Ne, ^{21}Ne, and ^{22}Ne	3/8-inch copper tubes	Field rinse	RU

[1] Constituents were determined only on a selected subset of samples.

Table 7. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references

[N, normal; ICP-OES, inductively coupled plasma-optical emission spectrometry; mg/L, milligrams per liter; nm, nanometer; IC, ion chromatography; mM, millimolar; ISE, ion-selective electrode; GFAAS, graphite furnace atomic absorption spectrometry; µg, microgram; ICP-MS, inductively coupled plasma-mass spectrometry; ºC, degrees Celsius; HGAAS, hydride generation atomic absorption spectrometry; TOC, total organic carbon; MS, mass spectrometry; CVAFS, cold-vapor atomic fluorescence spectrometry; µg/L, micrograms per liter; cc/kg, cubic centimeters per kilogram; µcc/kg, microcubic centimeters per kilogram; pcc/kg, picocubic centimeters per kilogram]

Constituent	Analytical technique	Detection limit[1]	Equipment used	References and comments
pH (laboratory)	Potentiometry	0.02 pH unit[2]	Beckman 265 pH meter with an Orion Ross combination electrode	Two- or three-buffer calibration at sample temperature using two or three of 10.00-, 7.00-, 4.01-, 2.00-, and 1.68-pH buffers
Specific conductance (laboratory)	Conductometry	~0.5 percent[3]	Orion Research model 1230 multiparameter meter with conductivity electrode	Automatic temperature correction, calibration with 0.0100 N KCl
Calcium (Ca)	ICP-OES	0.4 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 315.887 nm, view: radial
Magnesium (Mg)	ICP-OES	0.04 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 280.270 nm, view: axial
Sodium (Na)	ICP-OES	0.05 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 589.592 nm, view: radial
Potassium (K)	ICP-OES	0.02 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 766.490 nm, view: axial
Sulfate (SO_4)	IC	0.3 mg/L	Dionex model 2010i ion chromatograph with AG4A guard and AS4A separator columns and Anion Self-Regenerating Suppres-	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	Orion Research model 960/940 autotitrator; potentiometric detection; end-point determined by the first derivative technique	Barringer and Johnsson (1989); Fishman and Friedman (1989)
Fluoride (F)	F-ISE	0.05 mg/L	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	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)

Table 7. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references--Continued.

Constituent	Analytical technique	Detection limit[1]	Equipment used	References and comments
Bromide (Br)	IC	0.1 mg/L	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	Leeman Labs Direct Reading Echelle	Sample diluted 1:10 in field, analytical wavelength: 251.611 nm, view: axial
Aluminum (Al)	ICP-OES or	0.07 mg/L	Leeman Labs Direct Reading Echelle or	ICP-OES: analytical wavelength: 308.215 nm, view: axial
	GFAAS[4]	0.001 mg/L	Perkin-Elmer model 4110ZL	GFAAS: analytical wavelength: 309.3 nm, modifier: 15 µg $Mg(NO_3)_2$, atomization temperature: 2,300 ˚C
Total iron (Fe(T))	ICP-OES or	ICP-OES: 0.07 mg/L	Leeman Labs Direct Reading Echelle or	ICP-OES: analytical wavelength: 238.204 nm, view: axial
	colorimetry	Colorimetry: 0.001 mg/L	Hewlett-Packard model 8452A diode array spectrometer with 1- and 5-cm cells	Colorimetry: FerroZine method (Stookey, 1970; To and others, 1999)
Ferrous iron (Fe(II))	Colorimetry	0.002 mg/L	Hewlett-Packard model 8452A diode array spectrometer with 1- and 5-cm cells	FerroZine method (Stookey, 1970; To and others, 1999)
Boron (B)	ICP-OES	ICP-OES: 0.010 mg/L	ICP-OES: Leeman Labs Direct Reading Echelle	ICP-OES: Analytical wavelength: 249.678 nm, view: axial
	ICP-MS[5]	ICP-MS: 0.002 mg/L	ICP-MS: Perkin-Elmer SCIEX ELAN 6000	Isotope: 11 (Taylor and Garbarino, 1991; Garbarino and Taylor, 1995)
Lithium (Li)	ICP-OES	0.001 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 670.784 nm, view: axial
Strontium (Sr)	ICP-OES	0.0003 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 421.552 nm, view: axial
Barium (Ba)	ICP-OES	0.0008 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 455.403 nm, view: axial
Manganese (Mn)	ICP-OES	0.002 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 257.610 nm, view: axial
Zinc (Zn)	ICP-OES	0.005 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 206.200 nm, view: radial

Table 7. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references--Continued.

Constituent	Analytical technique	Detection limit[1]	Equipment used	References and comments
Lead (Pb)	ICP-OES or	ICP-OES: 0.008 mg/L	Leeman Labs Direct Reading Echelle or	ICP-OES: analytical wavelength: 220.353 nm, view: axial
	GFAAS[4]	GFAAS: 0.0003 mg/L	Perkin-Elmer model 4110ZL	GFAAS: analytical wavelength: 283.3 nm, view: axial, modifier: 50 µg PO_4 + 3 µg $Mg(NO_3)_2$, atomization temperature: 1,600 ˚C
Nickel (Ni)	ICP-OES or	ICP-OES: 0.002 mg/L	Leeman Labs Direct Reading Echelle or	ICP-OES: analytical wavelength: 231.604 nm, view: axial
	GFAAS[4]	GFAAS: 0.0005 mg/L	Perkin-Elmer model 4110ZL	GFAAS: analytical wavelength: 231.604 nm, view: axial, atomization temperature: 2,300 ˚C
Copper (Cu)	ICP-OES or	ICP-OES: 0.002 mg/L	Leeman Labs Direct Reading Echelle or	ICP-OES: analytical wavelength: 324.754 nm, view: axial
	GFAAS[4]	GFAAS: 0.0005 mg/L	Perkin-Elmer model 4110ZL	GFAAS: analytical wavelength: 324.8 nm, modifier: 5 µg Pd + 3 µg $Mg(NO_3)_2$, atomization temperature: 2,000 ˚C
Cadmium (Cd)	ICP-OES or	ICP-OES: 0.002 mg/L	Leeman Labs Direct Reading Echelle or	ICP-OES: analytical wavelength: 214.428 nm, view: axial
	GFAAS[4]	GFAAS: 0.0002 mg/L	Perkin-Elmer model 4110ZL	GFAAS: analytical wavelength: 228.8 nm, modifier: 50 µg PO_4 + 3 µg $Mg(NO_3)_2$, atomization temperature: 1,500 ˚C
Chromium (Cr)	ICP-OES or	ICP-OES: 0.002 mg/L	Leeman Labs Direct Reading Echelle or	ICP-OES: analytical wavelength: 206.149 nm, view: axial
	GFAAS[4]	GFAAS: 0.0005 mg/L	Perkin-Elmer model 4110ZL	GFAAS: analytical wavelength: 357.9 nm, modifier: 15 µg $Mg(NO_3)_2$, atomization temperature: 2,300 ˚C
Cobalt (Co)	ICP-OES or	ICP-OES: 0.007 mg/L	Leeman Labs Direct Reading Echelle or	ICP-OES: analytical wavelength: 228.616 nm, view: axial
	GFAAS[4]	GFAAS: 0.0008 mg/L	Perkin-Elmer model 4110ZL	GFAAS: analytical wavelength: 242.5 nm, modifier: 15 µg $Mg(NO_3)_2$, atomization temperature: 2,400 ˚C

Table 7. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references--Continued.

Constituent	Analytical technique	Detection limit[1]	Equipment used	References and comments
Beryllium (Be)	ICP-OES	0.001 mg/L	Leeman Labs Direct Reading Echelle	Analytical wavelength: 313.042 nm, view: axial
Molybdenum (Mo)	ICP-OES	ICP-OES: 0.007 mg/L	ICP-OES: Leeman Labs Direct Reading Echelle	Analytical wavelength: 277.540 nm, view: axial
	ICP-MS[4]	ICP-MS: 0.0005 mg/L	ICP-MS: Perkin-Elmer SCIEX ELAN 6000	Isotope: 95 (Garbarino and Taylor, 1995)
Vanadium (V)	ICP-OES	ICP-OES: 0.002 mg/L	ICP-OES: Leeman Labs Direct Reading Echelle	Analytical wavelength: 292.401 nm, view: axial
	ICP-MS[4]	ICP-MS: 0.0003 mg/L	ICP-MS: Perkin-Elmer SCIEX ELAN 6000	Isotope: 51 (Garbarino and Taylor, 1995)
Arsenic (As)	ICP-OES or	ICP-OES: 0.04 mg/L	Leeman Labs Direct Reading Echelle or	ICP-OES: analytical wavelength: 188.977 nm, view: axial
	HGAAS	HGAAS: 0.0001 mg/L	Perkin-Elmer AAnalyst 300 atomic absorption spectrometer with an FIAS-100 flow-injection analysis system, quartz cell, and furnace	HGAAS: pre-reduction of As(V) using KI + ascorbic acid + HCl (McCleskey and others, 2003)
Selenium (Se)	ICP-OES or	ICP-OES: 0.04 mg/L	ICP-OES: Leeman Labs Direct Reading Echelle	Analytical wavelength: 196.026 nm, view: axial
	GFAAS[4]	GFAAS: 0.001 mg/L	Perkin-Elmer model 4110ZL	GFAAS: analytical wavelength: 196.0 nm, modifier: 5 µg Pd + 3 µg $Mg(NO_3)_2$, atomization temperature: 1,300 ˚C
	ICP-MS[5]	ICP-MS: 0.0002 mg/L	ICP-MS: Perkin-Elmer SCIEX ELAN 6000	Isotope: 77 (Garbarino and Taylor, 1995)
Dissolved organic carbon (DOC)	TOC	0.1 mg/L	Oceanography International Model 700 TOC Analyzer	Wet oxidation method (Aiken, 1992)
Oxygen-18 ($\delta^{18}O$)	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 Antarctic Precipitation (SLAP) ($\delta^{18}O$ = -55.5 per mil) (Epstein and Mayeda, 1953)

Table 7. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references--Continued.

Constituent	Analytical technique	Detection limit[1]	Equipment used	References and comments
Sulfur–34 ($\delta^{34}S$)	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
Oxygen-18 of sulfate ($\delta^{18}O_{sulfate}$)	MS	0.1 per mil[2]	Micromass Optima mass spectrometer	Sulfate ion removed from the samples using barium sulfate precipitation method
Mercury	CVAFS	0.4 mg/L	PS Analytical, model Galahad, direct cold-vapor atomic fluorescence spectrometry	Taylor and others (1997); Roth and others (2001)
Hydrogen sulfide (H_2S)	Colorimetry	0.002 mg/L	Hach model DR-2000 ultraviolet - visible spectrometer and Hach method # 8131 reagents	Methylene Blue Method based on American Public Health Association (1985)
Bismuth (Bi)	ICP-MS[5]	0.001 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 209
Cerium (Ce)	ICP-MS[5]	0.0004 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 140 (Verplanck and others, 2001)
Cesium (Cs)	ICP-MS[5]	0.002 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 133
Dysprosium (Dy)	ICP-MS[5]	0.0004 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 163 (Verplanck and others, 2001)
Erbium (Er)	ICP-MS[5]	0.0004 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 167 (Verplanck and others, 2001)
Europium (Eu)	ICP-MS[5]	0.001 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 151 Problems with Ba interference (Verplanck and others, 2001)
Gadolinium (Gd)	ICP-MS[5]	0.0006 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 158 (Verplanck and others, 2001)
Hafnium (Hf)	ICP-MS[5]	0.0005 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 178
Holmium (Ho)	ICP-MS[5]	0.0002 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 165 (Verplanck and others, 2001)
Lanthanum (La)	ICP-MS[5]	0.0004 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 139 (Verplanck and others, 2001)
Lutetium (Lu)	ICP-MS[5]	0.0002 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 175 (Verplanck and others, 2001)

Table 7. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references--Continued.

Constituent	Analytical technique	Detection limit[1]	Equipment used	References and comments
Neodymium (Nd)	ICP-MS[5]	0.0008 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 146 (Verplanck and others, 2001)
Lead (Pb)	ICP-MS[5]	0.01 µg/L	Perkin-Elmer SCIEX ELAN 6000	A weighted average of the 206, 207, and 208 isotopes is used (Taylor and Garbarino, 1991; Garbarino and Taylor, 1995)
Praseodymium (Pr)	ICP-MS[5]	0.0002 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 141 (Verplanck and others, 2001)
Rubidium (Rb)	ICP-MS[5]	0.001 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 85
Rhenium (Re)	ICP-MS[5]	0.0007 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 187
Antimony (Sb)	ICP-MS[5]	0.004 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 121 (Taylor and Garbarino, 1991; Garbarino and Taylor, 1995)
Samarium (Sm)	ICP-MS[5]	0.0008 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 147 (Verplanck and others, 2001)
Tantalum (Ta)	ICP-MS[5]	0.002 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 181
Terbium (Tb)	ICP-MS[5]	0.0002 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 159 (Verplanck and others, 2001)
Tellurium (Te)	ICP-MS[5]	0.008 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 126
Thorium (Th)	ICP-MS[5]	0.001 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 232
Thallium (Tl)	ICP-MS[5]	0.004 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 205 (Taylor and Garbarino, 1991; Garbarino and Taylor, 1995)
Thulium (Tm)	ICP-MS[5]	0.0002 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 169 (Verplanck and others, 2001)
Uranium (U)	ICP-MS[5]	0.0005 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 238 (Taylor and Garbarino, 1991; Garbarino and Taylor, 1995)
Tungsten (W)	ICP-MS[5]	0.006 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 182
Yttrium (Y)	ICP-MS[5]	0.0003 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 89
Ytterbium (Yb)	ICP-MS[5]	0.0005 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 174 (Verplanck and others, 2001)
Zirconium (Zr)	ICP-MS[5]	0.001 µg/L	Perkin-Elmer SCIEX ELAN 6000	Isotope: 90

Table 7. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references--Concluded.

Constituent	Analytical technique	Detection limit[1]	Equipment used	References and comments
CFC-11, CFC-12, CFC-113	Gas chromatography	0.5-1.0 picogram/kilogram	Shimadzu GC-8AIE gas chromatograph (GC) with an electron capture detector (ECD), Agilent model 6890A GC with an ECD	(U.S. Geological Survey, 2004b)
Dissolved gases (CH_4, N_2, O_2, Ar)	Quadrupole mass spectrometry	0.005 cc/kg	Prisma quadrupole mass spectrometer	(Solomon and others, 1995)
Dissolved-gas isotopes (^{3}He, ^{4}He, Ne)	Magnetic sector-field mass spectrometry	^{3}He: 0.07 µcc/kg ^{4}He: 0.05 pcc/kg Ne: 0.2 µcc/kg	Mass Analyzer Products 215-50 mass spectrometer	(Bayer and others, 1989; Solomon and others, 1995)
Tritium (^{3}H)	^{3}He in-growth technique	0.05 tritium unit	Mass Analyzer Products 215-50 mass spectrometer	(Clark and others, 1976; Bayer and others; 1989)

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[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 10 times the undiluted detection limit reported in this table).

[2] These values are expressions of precision or range, rather than relative standard deviation, of pH and isotope determinations.

[3] Percent relative standard deviation.

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

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

A simple system for classification of ground-water ages within a flow system is commonly used. “Modern” ground water is considered to have been recharged within the past few decades and is considered part of the active hydrologic cycle. “Submodern” water is considerably older (predating 1940’s) and is defined by its lack of measurable tritium.

Chlorofluorocarbons

CFC’s are stable synthetic organic compounds that were first produced in the 1930’s and are of purely anthropogenic origin. CFC’s have accumulated in the atmosphere at a quantifiable rate since the 1930’s, resulting in a relation between CFC concentration and age of modern ground water. Concentrations of CFC’s in water are controlled by the partial pressure (altitude and mole fraction) of the constituent CFC and the recharge temperature of the ground water. By measuring the concentration of a CFC in a sample, an atmospheric concentration can be computed and compared with a known atmospheric concentration profile to estimate an age for the sample. This analysis ideally produces three complementary ages, each associated with a common CFC (CFC-11, CFC-12, or CFC-113). The strengths of the technique are the conservative nature of CFC’s as ground-water tracers in aerobic conditions and the relative ease of analysis (Plummer and Busenberg, 2000). Physical degradation of CFC’s in anaerobic conditions and the effect of mixing with other water on age (concentration) are drawbacks of the technique.

Helium-3 / Tritium Dating

Tritium (^{3}H) is the radioactive isotope of hydrogen, which decays by beta decay to helium-3 (^{3}He) with a half-life of 12.43 years. ^{3}H in the atmosphere is mainly associated with atmospheric testing of nuclear devices that began in 1952 and peaked in 1963-64. The nature of the ^{3}H input to the atmosphere produces a spike-like input associated with the nuclear testing peak and a decay curve as the initial input undergoes radioactive decay. The ^{3}H age-dating technique is similar to CFC dating in that a measured concentration can be used to estimate age by comparison to a historical input curve. The technique is improved by using separate measurements of ^{3}He and ^{3}H in ground water to produce an absolute age, independent of the ^{3}H input curve, based on radioactive decay of ^{3}H to ^{3}He. This technique requires two separate samples, one for the measurement of the total amount of ^{3}He ($^3\mathrm{He}_{total}$) and the calculation of tritiogenic ^{3}He (^{3}He from ^{3}H decay, denoted as ^{3}He*) contained as a dissolved gas in the ground water and the second for the calculation of ^{3}H by the ^{3}He in-growth technique (Clark and others, 1976; Bayer and others, 1989).

Discrimination of ^{3}He* from $^3\mathrm{He}_{total}$ in the dissolved-gas samples requires not only measurement of the $^3\mathrm{He}_{total}$ concentration and the isotopic composition of He but also measurement of Ne, Ar, and N_2 concentrations. The data derived from these analyses facilitate separation of the various sources of ^{3}He contained in the sample. Sources of He within ground water include ^{3}He associated with atmospheric solubility ($^3\mathrm{He}_{solubility}$), ^{3}He from excess air ($^3\mathrm{He}_{exair}$), and excess ^{3}He from primordial and crustal (nucleogenic) sources ($^3\mathrm{He}_{terrigenic}$) as well as ^{3}He from ^{3}H decay.

$^3\mathrm{He}_{solubility}$ results from the equilibrium solubility of ^{3}He with the atmosphere, which is temperature and pressure (altitude) related. The measured $^3\mathrm{He}_{total}$ concentration (along with concentrations of the other atmospherically derived gases Ne, Ar, and N_2) often is much higher than the $^3\mathrm{He}_{solubility}$ concentration predicted by atmospheric solubility. One common explanation for this supersaturation of gas in a sample is that it is derived from entrapment of air below wetting fronts during recharge to an aquifer. The air is forced into solution, creating a gas component in excess of that of atmospheric solubility (excess air), which contains any $^3\mathrm{He}_{exair}$.

$^3\mathrm{He}_{terrigenic}$ is associated with an extrinsic source of helium, such as the rock through which ground water flows or a basal flux that is migrating into the ground-water-flow system. This excess component can be derived from two sources, primordial and crustal. Primordial sources of ^{3}He include ^{3}He incorporated into the Earth’s mantle during planetary accretion; crustal sources of helium refer to He produced in situ in the Earth’s crust by decay of the uranium (U)-thorium (Th) series elements (Kendall and McDonnell, 1998; Clark and Fritz, 1999). U-Th series radiogenic decay produces helium-4 (^{4}He) by alpha decay, and ^{3}He is produced as a result of fission reactions with lithium-6 (nucleogenic production). The production ratio of ^{3}He to ^{4}He (^{3}He/^{4}He) is typically about 1.0×10^{-8} or 0.02 R/R_A. This production ratio is conventionally expressed in terms of ^{3}He/^{4}He ratios, R/R_A; where R is the ^{3}He/^{4}He ratio in the sample and R_A is the ^{3}He/^{4}He ratio in air ($R_{air} = 1.384 \times 10^{-6}$; Ozima and Podosek, 1983). For this investigation, the main source of terrigenic He was considered to be from crustal production (radiogenic/nucleogenic) rather than primordial (mantle-derived) sources.

To properly use the ^{3}He/^{3}H age-dating technique, the sources of ^{3}He must be resolved. Accounting for these various sources, the tritiogenic ^{3}He (^{3}He*) is found by:

$$^3\mathrm{He}^* = {}^3\mathrm{He}_{total} - {}^3\mathrm{He}_{solubility} - {}^3\mathrm{He}_{exair} - {}^3\mathrm{He}_{terrigenic} \qquad (1)$$

where $^3\mathrm{He}_{total}$ is the total ^{3}He in the sample; $^3\mathrm{He}_{solubility}$ is ^{3}He produced by atmospheric solubility; $^3\mathrm{He}_{exair}$ is ^{3}He associated with excess air; and $^3\mathrm{He}_{terrigenic}$ is associated with an extrinsic source of He.

The $^3\mathrm{He}_{solubility}$ component is modeled using recharge temperature and altitude estimates derived from an excess air model and measured Ne, Ar, and N_2 concentrations. Procedures for estimating recharge temperature and altitude were outlined by Aeschbach-Hertig and others (1999) and Ballentine and Hall (1999). The $^3\mathrm{He}_{exair}$ component is modeled using the temperature and solubility estimates along with measured Ne concentrations, and the $^3\mathrm{He}_{terrigenic}$ component is modeled using He, Ne, Ar, and N_2 concentrations. The total ^{3}He in the sample ($^3\mathrm{He}_{total}$) can be either measured or modeled; modeled $^3\mathrm{He}_{total}$ is derived from measurements of the ^{3}He/^{4}He production ratio and modeled estimates of the concentration of helium in the sample produced by atmospheric solubility and excess air.

The ^{3}He in-growth method of measuring ^{3}H allows for determinations as low as 0.05 tritium unit (TU), where 1 TU equals 1 ^{3}H atom per 10^{18} hydrogen atoms. The method involves degassing a sample of water and sealing it off from the atmosphere within a measuring vessel for approximately 2 months. The sample is then analyzed for the amount of ^{3}He produced by ^{3}H decay over the 2-month period (^{3}He in-growth), and the amount of ^{3}H is then calculated.

Using the data from both the dissolved-gas measurement (^{3}He*; eq. 1) and the ^{3}He in-growth method (^{3}H), the apparent age of the sample is derived from:

$$t = (T_{1/2}/\ln 2)\ \ln(1+ (^3\mathrm{He}^*/^3\mathrm{H})) \qquad (2)$$

where t is apparent age, in years; $T_{1/2}$ is the half-life of ^{3}H, in years; and ^{3}He*/^{3}H is the ratio of ^{3}He* and ^{3}H. The advantage of this technique is that the age of the sample is determined as a function of the daughter-to-parent isotope ratio. This method is insensitive to mixing with submodern water, and in the case of mixing with modern water, it produces an average age of the two mixing systems. Another advantage of this technique is that recharge temperature of, and excess air in, the sample are determined from measurements of other dissolved gases; these are typically estimated using other techniques. Disadvantages of this age-dating technique are its limit to about 60 years of measurement, the need for a specialty laboratory (noble gas mass spectrometer with ultrahigh vacuum extraction system) for measurements, and the time required for the ^{3}He in-growth analysis.

Analysis

CFC's were analyzed using a gas chromatograph fitted with an electron capture detector (table 7), which can measure CFC-11, CFC-12, and CFC-113 to concentrations as low as 0.5-1.0 picogram/kilogram. The concentrations of CFC-11, CFC-12, and CFC-113 were calculated from the measured concentrations in the water sample, water temperature, and volumes of water and head space in the ampoules. Details of the measurements, including descriptions of the equipment used to collect samples and measure CFC concentrations, measurement procedures, and quality assurance/quality control methods, are provided at the USGS CFC Laboratory website (U.S. Geological Survey, 2004d). The analytical procedures also are described in detail by Bullister (1984) and Bullister and Weiss (1988).

Ground-water ages were interpolated from measured concentrations by curve matching to CFC concentration curves from Niwot Ridge, Colorado. Ages were corrected using recharge temperature and excess air values determined from the measured dissolved-gas concentrations using the ^{3}He/^{3}H dating method (Plummer and Busenberg, 2000). For wells SC-1A, SC-1B, SC-2B, SC-3A, SC-3B, SC-4A, SC-5A, SC-5B, and AWWT-1, the recharge altitude was assumed to be 9,000 feet. Recharge altitude estimates for wells SC-6A, SC-7A, and SC-8A were derived from an excess air model and measured dissolved-gas data.

For analysis, the dissolved gases were separated from the water within an ultrahigh vacuum extraction system. Concentrations of the major gas components (Ar, N_2, O_2, and CH_4) were measured using a quadrupole mass spectrometer, and He and Ne were further separated from the sample gas and analyzed for the isotopic composition of He (^{3}He and ^{4}He) and total concentration of Ne with a magnetic sector-field mass spectrometer.

The ^{3}H concentrations were determined using the ^{3}He in-growth technique (Clark and others, 1976; Bayer and others, 1989). Each sample was transferred to an extraction vessel, completely degassed under low vacuum for 30 minutes, and sealed within the extraction flask. The flask was stored at room temperature for no less than 2 months to allow for the production of ^{3}He from the decay of ^{3}H in the sample. The evolved head-space gas was then analyzed for ^{3}He, and the amount of ^{3}H was calculated on the basis of the amount of time stored.

Results

The range of recharge temperatures (table 8) estimated from dissolved-gas data (table 9) is consistent with the average annual air temperature of 4 ˚C between 1915 and 2002 in the Red River Valley. For many wells (SC-1A, SC-1B, SC-3B, SC-4A, SC-5A, and SC-6A), recharge altitudes estimated from dissolved-gas data appear reasonable compared with land-surface altitudes in the upper Straight Creek drainage basin (fig. 2). Estimated recharge altitudes for wells SC-2B, SC-3A, SC-5B, SC-7A, SC-8A, and AWWT-1 are lower than recharge altitudes estimated for other wells, perhaps because of uncertainties in the excess air model used to estimate recharge altitudes. Mixing of debris-flow and alluvial aquifer water also could explain lower estimated recharge altitudes for samples from wells in the lower part of the Straight Creek drainage basin. The estimated recharge altitude of 8,500 feet for wells SC-5B, SC-8A, and AWWT-1 is similar to the altitude of the Red River and its alluvial aquifer in this area, which could indicate the influence of Red River alluvial aquifer water. The estimated recharge altitude for water from well SC-7A, also in the lower Straight Creek drainage basin, is 9,000 feet. The higher estimated recharge altitude for this well compared with those for wells SC-5B, SC-8A, and AWWT-1 could indicate less mixing with Red River alluvial aquifer water in this well. Similarly, the estimated recharge altitude of 9,500 feet for SC-5A could indicate the predominance of debris-flow aquifer water in this well.

Concentrations of ^{3}He associated with different ^{3}He sources (table 8) indicate that samples have variable amounts of excess air. Measured and modeled $^3\mathrm{He}_{total}$ concentrations (table 8) compare well in samples from wells SC-1A, SC-1B, SC-5B, and AWWT-1. Differences between measured and modeled $^3\mathrm{He}_{total}$ concentrations in samples from other wells could be a result of sampling, analytical procedures, or uncertainties in the excess air model. Alternatively, differences between measured and modeled $^3\mathrm{He}_{total}$ concentrations could indicate ground-water mixing. Water from different ground-water flow systems likely would have different dissolved-gas chemistry (different excess air and solubility components). Mixing of dissolved-gas components in a sample composed of a mixture of water from different ground-water flow systems would cause an error in the determination of recharge temperature and amount of excess air, resulting in a less accurate approximation of the various components of ^{3}He in the sample.

To resolve ^{3}He*, both the modeled and measured $^3He_{total}$ concentrations were used in equation 1, and their difference provided additional error analysis for ^{3}He*. The average of the ^{3}He* values calculated using the two different (measured and modeled) $^3He_{total}$ concentrations is reported in table 8. Samples from three wells, SC-1B, SC-3A, and SC-8A, have almost no detectable ^{3}He*, indicating that sampled water is either young (less than 0.5 year) or associated with pre-nuclear-age water (older than 60 years).

The ^{3}H concentration in water from well SC-1B is less than 0.2 TU (“tritium dead”) (table 8), and water from this well contains some excess terrigenic ^{4}He (table 9). Sources of excess terrigenic ^{4}He are typically associated with water with long residence times (much greater than 60 years) within the ground-water flow system. Helium accumulates in the water because of extrinsic or intrinsic sources such as a basal He flux or accumulation by radiogenic decay of U-Th series elements in the aquifer (Solomon and others, 1996). The amount of excess ^{4}He and lack of ^{3}H indicate that ground water from well SC-1B is submodern and may represent a deep flow component associated with the deep bedrock flow system.

^{3}H in water from well SC-3B is detectable (7.36 TU), having a value similar to that in well SC-3A (7.17 TU). The similarity of SC-3A and SC-3B ^{3}H concentrations indicates that ground water in well SC-3B may be affected by mixing with more recently recharged water in the debris-flow material. This conclusion is corroborated by the relatively low pH in well SC-3B compared with other bedrock aquifer wells. However, water in well SC-3B is considerably older than that in well SC-3A (table 8).

Ages derived from the ^{3}He analysis (table 8) show that ground water in most alluvial and debris-flow aquifer wells is younger than that in bedrock aquifer wells, with the exception of water from wells SC-7A and AWWT-1. A plausible explanation for older water in wells SC-7A and AWWT-1 is that debris-flow and Red River alluvial deposits may be receiving recharge from deeper (and older) bedrock on adjacent valley walls. This explanation is consistent with the upward hydraulic gradient from well SC-5B to SC-5A and with estimated recharge altitudes that indicate ground-water mixing in the lower part of the Straight Creek Basin. Another indication of mixing of debris-flow and Red River alluvial aquifer water with a deeper, submodern component of ground water in the lower part of the Straight Creek drainage basin is the presence of excess terrigenic ^{4}He in wells SC-5B, SC-7A, and AWWT-1 (table 9).

Water samples from wells SC-5A and SC-5B were estimated to be 13.7 and 14.7 years old, respectively (table 8). The estimated ages of water from wells SC-7A and AWWT-1 are 21.5 and 22.6 years, respectively, and water from well SC-8A was estimated to be less than 0.5 year old. Water from well SC-5B was estimated to be younger than water from other bedrock wells, which may be an indication of mixing with debris-flow aquifer water. The younger ground-water age estimated for the sample from well SC-5A relative to estimated ages of water

Table 8. Measured gas data for helium-3/tritium dating analyses.

[μcc/kg, microcubic centimeter (cc) per kilogram; R/R_A, helium-3/helium-4 isotope ratio[1]; <, less than]

Well (fig. 3)	Date sampled	He (μcc/kg)	R/R_A[1]	^{4}He terrigenic (mcc/kg)	Ne (mcc/kg)	Ar (cc/kg)	N_2 (cc/kg)
SC-1A	10/16/02	35.1	1.131	< 0.5	158.3	0.247	12.6
SC-1B	10/16/02	58.7	0.676	19.5	174.0	0.298	13.5
SC-2B	10/16/02	44.8	1.743	< 0.5	211.5	0.374	16.7
SC-3A	10/17/02	35.1	1.014	< 0.5	160.1	0.195	12
SC-3B	10/17/02	42.9	1.649	< 0.5	188.7	0.350	15.2
SC-4A	10/17/02	34.0	1.065	< 0.5	157.5	0.302	12.8
SC-5A	10/16/02	53.9	1.336	< 0.5	229.1	0.260	15.2
SC-5B	10/16/02	146.7	0.497	94.7	220.7	0.351	16.6
AWWT-1	10/17/02	72.5	1.440	11.9	246.9	0.211	16.4

[1] For helium isotope ratios expressed as R/R_A, R is the $^3He/^4He$ ratio in the sample and R_A is the $^3He/^4He$ ratio in air ($R_{air} = 1.384 \times 10^{-6}$; Ozima and Podosek (1983)).

Table 9. Measured dissolved-gas data for helium-3/tritium dating analyses.

[TU, tritium units; ˚C, degrees Celsius; NGVD29, National Geodetic Vertical Datum of 1929; σ, standard deviation; ±, plus or minus; <, less than; >, greater than; for ^{3}He components expressed in TU, one TU equals one ^{3}He atom per 10^{18} H atom]

Well (fig. 3)	^{3}He total (measured) (TU)	^{3}He total (modeled) (TU)	Recharge temperature (˚C)	Recharge altitude (feet above NGVD-29)	^{3}He solubility (TU)	^{3}He excess air (TU)	^{3}He terrigenic (TU)	^{3}He tritiogenic (TU)	+1σ error (TU)	^{3}H (TU)	+1σ error (TU)	Estimated age (years)	Estimated recharge year	±
SC-1A	22.10	21.98	2.0	9,501	19.12	0.10		2.82	0.19	6.64	0.10	6.31	1996.52	0.42
SC-1B	22.08	22.08	1.2	9,501	19.21	2.37	0.22	0.28	0.01	< 0.2		> 60		
SC-2B	43.48	48.09	1.1	8,622	19.83	7.55		18.41	3.91	10.19	0.15	18.36	1984.47	2.83
SC-3A	19.81	20.50	6.1	8,501	19.35	0.65		0.16	0.49	7.17	0.11	0.38	2002.45	1.39
SC-3B	39.36	40.90	5.0	9,501	18.79	5.81		15.53	1.63	7.36	0.11	20.19	1982.64	1.48
SC-4A	20.13	20.66	2.5	9,501	19.06	0.12		1.22	0.41	6.65	0.10	2.99	1999.84	1.08
SC-5A	40.10	41.61	4.1	9,501	18.88	12.05		9.92	1.42	8.52	0.13	13.73	1989.10	1.59
SC-5B	40.55	40.55	0.5	8,501	19.99	8.73	1.05	10.79	0.38	8.40	0.13	14.69	1988.14	0.44
AWWT-1	58.07	58.07	3.7	8,501	19.60	13.90	0.13	24.44	0.86	9.55	0.14	22.59	1980.24	0.56

from wells SC-7A and AWWT-1 may indicate that well SC-5A contains a greater portion of ground water recharged further upgradient in the Straight Creek drainage basin where there may be less influence from deep bedrock recharge. Ground water in wells SC-5A and SC-5B may also be mixing with Red River alluvial aquifer water. Ground water from well SC-8A is estimated to be very young relative to other wells in the lower part of the Straight Creek drainage basin, which could indicate that water in this well is a mixture containing very little, if any, deep, submodern, bedrock water. It is probable that ground water in well SC-8A is predominantly water of the Red River alluvial aquifer flow system rather than water of the Straight Creek flow system.

This mixing of end components is purely speculative based on the dissolved-gas components, but the interpretation is consistent with the interpretation of estimated recharge altitudes and with the specific conductance and pH (app. 1) of ground water from wells in the lower part of the Straight Creek drainage basin. Ground water from well SC-8A is of near-neutral pH, and ground water from wells AWWT-1 and SC-7A is of generally slightly higher pH than water from SC-5A and other debris-flow aquifer wells. The specific conductance of ground water from well SC-8A is lower than that of ground water from any other well. The specific conductance of water from wells SC-5A, SC-7A, and AWWT-1 is higher than that of SC-8A water but lower than those of water from other wells. Both the specific conductance and pH results indicate that water in well SC-8A may be mostly Red River alluvial aquifer water. The pH values provide evidence that ground water contains greater percentages of debris-flow aquifer water as distance upgradient from well SC-8A increases, with the highest percentage of debris-flow aquifer water in well SC-5A. Water from well SC-5B is slightly lower in specific conductance than water from other bedrock wells, also indicative of mixing with alluvial aquifer water.

To further investigate mixing relations, the sum of $^3He^*$ and ^3H concentrations was compared to the recharge year calculated from the measured age, and the results were compared to a known ^3H input curve (fig. 14). Data for the ^3H input curve (1962-2000) were obtained from the International Atomic Energy Database of precipitation in Albuquerque, New Mexico. The average ^3H input concentration for each year was computed and is shown with the standard deviation to indicate annual variation within the signal. Points that plot close to the input curve display a conservative age typical for mixing of water in the flow system.

Measured concentrations compare well with the input curve for all samples except those for wells SC-2B, SC-3B, SC-6A, SC-7A, and AWWT-1 (because input data for years later than 2000 were not available, no comparison can be made for SC-3A and SC-8A). Differences between the measured $^3He^* + {}^3H$ values and the ^3H input curve for samples from wells SC-2B, SC-3B, SC-6A, and SC-7A may represent mixed water; however, the error associated with the age dates for these samples indicates that the measured $^3He^* + {}^3H$ values could plot within the ^3H input curve. The AWWT-1 sample plots well above the ^3H input curve and the discrepancy cannot be explained by possible errors in the age of the sample. This sample probably represents mixed water, but whether the sample is mixed with younger or older water is unclear from this analysis.

In the CFC data set, there is an explanation for the apparent ambiguity between ages determined from the various CFC components (table 10; fig. 15). With the exception of well SC-1B (not plotted in fig. 15), water from all wells is younger in CFC-12 age than in CFC-113 age. For all wells, the CFC-113 age is younger than the CFC-11 age. Almost all CFC ages are older than the $^3He/^3H$ ages. These older CFC ages likely result from degradation of CFC's under anaerobic conditions (less than 1.0 mg/L dissolved O_2), which exist in some Straight Creek wells (fig. 10; app. 1). Microbial degradation of CFC's commonly occurs under anaerobic conditions in the presence of sulfate-reducing bacteria, preferentially degrading CFC-11 relative to CFC-12 (Plummer and others, 1998; Plummer and Busenberg, 2000). Depending on DOC and sulfate concentrations in the water under reducing conditions, the degradation sequence for CFC's is expected to be CFC-11, followed by CFC-113, then CFC-12. In some wells, CFC-11 and CFC-113 may be entirely removed from the system.

The CFC-12 ages correlate reasonably well to the $^3He/^3H$ ages in the older samples (fig. 15) and seem to be least affected by degradation. Samples from wells SC-7A and AWWT-1 appear to be enriched in CFC-12 (younger age) compared to the $^3He/^3H$ age; this could be a result of water mixing with a young ground-water component with some CFC degradation in the older water. This interpretation is consistent with other evidence of ground-water mixing in these wells.

Oxygen, Hydrogen, and Sulfur Isotopes

To help determine geochemical signatures of solute sources in alluvial, debris-flow, and bedrock aquifers and to constrain water/rock interactions, the stable isotopic composition of a suite of samples was determined. Types of samples collected included Straight Creek surface water and ground water, two precipitation samples, three snowpack samples, and five solid samples from scar areas and the underground mine workings. Methods and results of sample analyses are described in this section.

In this report, "delta notation" (δ) is used to describe the isotopic concentration of water and sulfur isotopes. In delta notation, the ratio between heavy and light isotopes of a sample is compared to that of a reference standard, VSMOW (Vienna Standard Mean Ocean Water), for oxygen, hydrogen, and troilite (FeS) of the Canyon Diablo iron meteorite (Clark and Fritz, 1999). For the example of $^{18}O/^{16}O$ ratios, delta notation is:

$$^{18}O/^{16}O_{\text{standard}}\ \delta^{18}O_{\text{sample}} = {}^{18}O/^{16}O_{\text{sample}} - {}^{18}O/^{16}O_{\text{standard}} \qquad (3)$$

where ‰ is per mil, which is equivalent to parts per thousand.

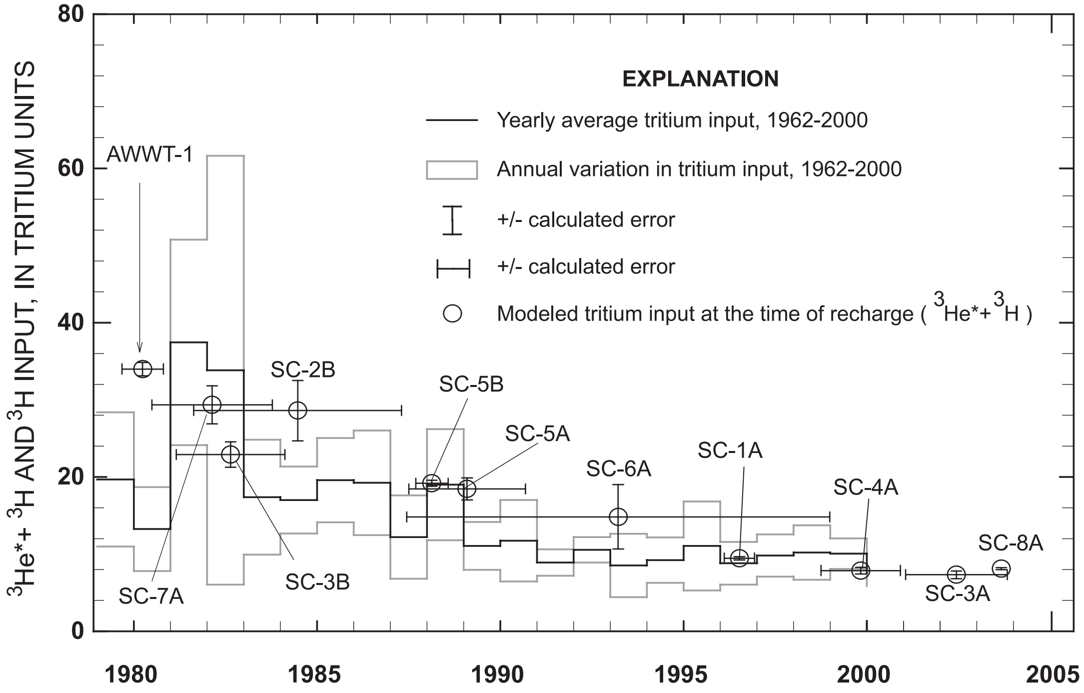

Figure 14. Tritium input curve from Albuquerque, New Mexico, and modeled tritium input at the time of recharge ($^3He^* + ^3H$) for ground-water samples.

Table 10. Chlorofluorocarbon data.

[CFC, chlorofluorocarbon; pg/kg, picograms per kilogram]

Well (fig. 3)	Date sampled	CFC concentrations			CFC ages[1]		
		CFC-11 (pg/kg)	CFC-12 (pg/kg)	CFC-113 (pg/kg)	CFC-11 (years)	CFC-12 (years)	CFC-113 (years)
SC-1A	10/16/2002	442.2	312.9	67.6	23.9	9.5	15.5
SC-1B	10/16/2002	79.1	29.8	6.8	37.5	40.5	33.2
SC-2B	10/16/2002	23.1	226.3	6.9	44.4	19.5	33
SC-3A	10/17/2002	538.8	294.8	74.5	19.9	12.9	14.9
SC-3B	10/17/2002	14.6	162.5	8.3	46.5	25.9	31.5
SC-4A	10/17/2002	610.9	268	63.6	25.5	15.4	16.2
SC-5A	10/16/2002	348.9	301.8	45.8	27.2	13.2	19
SC-5B	10/16/2002	14.9	197.1	8.1	46.4	22.4	32.2
AWWT-1	10/17/2002	133	270.2	24.2	34.2	15.9	24

[7] CFC ages calculated using recharge altitude of 9,000 feet and recharge temperatures and excess air values taken from dissolved-gas data.

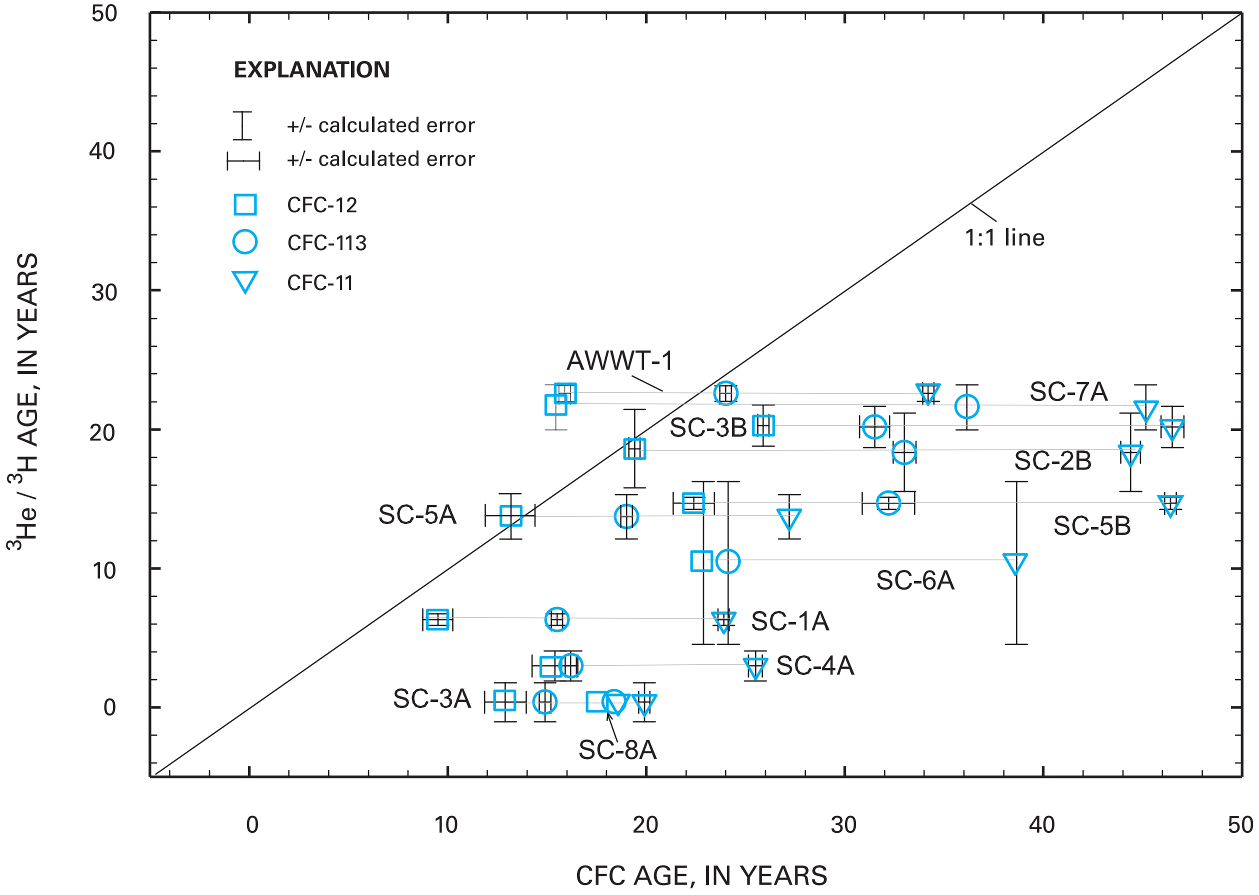

Figure 15. Comparison of chlorofluorocarbon (CFC) and tritium / helium-3 ages for ground-water samples.

Analysis

Water samples for oxygen isotope ratio determination were analyzed using the carbon dioxide-water equilibration technique of Epstein and Mayeda (1953). Every third water sample was analyzed in duplicate. The standard deviation was calculated on duplicate analyses; if the deviation was larger than 0.15 ‰, the samples were reanalyzed until the 2-sigma (2 standard deviations) uncertainty of the result was better than 0.2 ‰ (U.S. Geological Survey, 2004b).

Water samples for hydrogen isotope ratio determination were analyzed using the gaseous hydrogen equilibration procedure of Coplen and others (1991). Every water sample was analyzed in duplicate. If the standard deviation was larger than 1.55 ‰, the sample was reanalyzed until the 2-sigma uncertainty of the result was better than 2 ‰ (U.S. Geological Survey, 2004b).

Oxygen and hydrogen isotopic results are normalized (Coplen, 1994) on scales so that the oxygen and hydrogen isotopic values of Standard Light Antarctic Precipitation (SLAP) are -55.5 ‰ and -428 ‰, respectively. The 2-sigma uncertainties of oxygen and hydrogen isotopic results are 0.2 ‰ and 2 ‰, respectively. Hence, if the same sample were resubmitted for isotopic analysis, the newly measured value is expected to lie within the uncertainty bounds 95 percent of the time. Analysis of two sets of field replicate samples yielded differences in oxygen and hydrogen isotopic results of less than 0.1 per mil and less than 1 per mil, respectively (table 11).

Stable isotopic compositions of sulfur and oxygen in dissolved sulfate, sulfate minerals, and sulfide minerals were determined using the procedures described in Nordstrom and others (2004). The 1-sigma standard deviations of sulfur and oxygen isotopic results are ±0.2 ‰ and 0.3 ‰, respectively. In addition, a sequential extraction experiment was conducted on composite sulfide samples from the Hottentot Creek, Straight Creek, and June Bug alteration scars (fig. 1) to determine the variation in sulfur isotopic compositions during weathering. This procedure is described in Tuttle and others (2003).

Results

Results of sample collection and analyses for stable isotopic composition include (1) ^{2}H and ^{18}O of Straight Creek surface water and ground water, two precipitation samples, and three snow samples (table 11); (2) the ^{34}S and ^{18}O of dissolved sulfate for Straight Creek surface water and ground water (table 12); and (3) the ^{34}S and ^{18}O of five solid samples (table 12), including gypsum and sulfate salts from the scar areas and anhydrite collected from the underground mine workings.

Determining the average oxygen and hydrogen isotopic composition of local precipitation is a substantial task and was beyond the scope of this project. A small set of precipitation

Table 11. Water isotope data.

[_R, field replicate]

Site	Date collected	δ^2H (per mil)	$\delta^{18}O$ (per mil)
Red River precipitation	4/15/2003	-51.34	-7.7
Red River precipitation	4/15/2003	-107.46	-14.73
Snow composite	3/19/2002	-134.12	-17.66
Snow composite	3/19/2002	-127.52	-16.56
Snow composite	3/19/2002	-132.61	-16.96
Straight Creek	9/12/2001	-86.56	-11.9
Straight Creek	2/24/2002	-133.86	-16.94
Straight Creek	4/24/2002	-97.29	-13.05
Straight Creek	12/11/2002	-95.23	-13.08
Straight Creek	4/16/2003	-99.4	-13.59
Straight Creek	8/21/2003	-91.78	-12.26
SC-1A	4/25/2002	-96.8	-13.08
SC-1B	4/25/2002	-100.06	-13.37
SC-1B_R	4/25/2002	-99.16	-13.44
SC-2B	4/25/2002	-94.62	-12.9
SC-2B	2/8/2003	-94.4	-12.89
SC-2B	5/23/2002	-94.49	-12.88
SC-3A	4/24/2002	-94.24	-13.04
SC-3A	2/8/2003	-95.56	-13.07
SC-3A	5/14/2003	-95.77	-12.98
SC-3B	4/25/2002	-93.03	-12.59
SC-3B	2/8/2003	-92.69	-12.62
SC-3B	5/17/2003	-92.61	-12.58
SC-4A	4/24/2002	-93.92	-12.87
SC-4A	2/8/2003	-94.55	-12.91
SC-4A	5/14/2003	-95.55	-13.03
SC-5A	4/25/2002	-97.27	-13.33
SC-5A	2/8/2003	-98.31	-13.21
SC-5A	5/13/2003	-97.22	-13.24
SC-5A	8/20/2003	-98.44	-13.52
SC-5B	4/25/2002	-97.44	-13.24
SC-5B	2/8/2003	-97.38	-13.25
SC-5B_R	2/8/2003	-96.22	-13.3
SC-5B	5/13/2003	-97.23	-13.32
SC-5B	8/22/2003	-94.39	-12.77
AWWT-1	4/25/2002	-98.93	-13.42
AWWT-1	2/24/2003	-98.83	-13.44
AWWT-1	5/12/2003	-98.43	-13.46
AWWT-1	8/21/2003	-99.08	-13.44
AWWT-2	12/13/2002	-92.12	-12.38

Table 11. Water isotope data--Concluded.

Site	Date collected	δ^2H (per mil)	δ^{18}O (per mil)
SC-6A	2/7/2003	-96.86	-13.18
SC-6A	5/14/2003	-97.56	-13.18
SC-6A_R	5/14/2003	-96.82	-13.18
SC-7A_1	2/4/2003	-97.38	-13.41
SC-7A_1	5/12/2003	-98.93	-13.35
SC-7A_1	8/18/2003	-96.64	-13.44
SC-7A_4	2/4/2003	-97.74	-13.51
SC-7A_4	5/12/2003	-97.36	-13.45
SC-7A_4	8/20/2003	-97.86	-13.48
SC-8A	2/4/2003	-97.51	-13.55
SC-8A	5/12/2003	-97.46	-13.46
SC-8A	8/18/2003	-97.91	-13.66

Table 12. Sulfur isotope data.

[_R, field replicate; _DUP, duplicate analysis; --, no data]

Site	Sample collection date	$\delta\ ^{34}$S (per mil)	$\delta^{18}O_{sulfate}$ (per mil)
WATER SAMPLES			
Straight Creek	9/12/2001	-4.2	-7.1
Straight Creek	3/20/2002	-3.3	-6.3
Straight Creek	4/24/2002	-4.5	-6.7
SC-1A	4/25/2002	-4.2	-6.2
SC-1A_R	4/25/2002	-3.9	-5.6
SC-1B	4/25/2002	-5.1	-6.3
SC-1B_R	4/25/2002	-4.9	-6.3
SC-2B	4/25/2002	-3.5	-5.4
SC-3A	4/24/2002	-3.7	-6.0
SC-3A_R	4/24/2002	-3.7	-6.3
SC-3B	4/25/2002	-3.1	-4.3
SC-4A	4/24/2002	-3.2	-5.0
SC-5A	4/25/2002	-3.4	-5.2
AWWT-1	4/25/2002	-3.6	-5.9
SOLID SAMPLES			
Junebug scar (gypsum)	9/14/2001	-1.1	-1.0
Straight Creek (gypsum)	6/28/2001	-1.0	-5.4
Straight Creek (sulfate salt)	6/28/2001	-1.0	-4.7
Hansen Creek (sulfate salt)	9/11/2001	-1.3	-3.8
Lower Hansen Creek (sulfate salt)	9/12/2001	-1.7	-4.3
Anhydrite1	--	10.3	6.1
Anhydrite1_DUP	--	--	5.6
Anhydrite2	--	10.4	6.1

samples was collected to compare with results of a larger USGS study to determine the oxygen and hydrogen isotopic composition of precipitation in the Rocky Mountains (Nordstrom and others, 2004). During March 2002, three samples were collected to determine the isotopic composition of snowpack. Snowpack at sites where snow accumulates during the entire winter provides an integrated isotopic composition of the entire snow history for that year. Storms have variable isotopic compositions, depending on the source area of the storm, the path of the storm, and variations in atmospheric temperature. A temperature profile of the snowpack at the sampling site was measured immediately prior to sampling to determine whether melting had begun. A heterogeneous temperature profile is consistent with a snowpack that has not begun to melt, whereas a homogeneous temperature profile is a sign that melting has begun. Because the melting of snow imparts an isotopic fractionation, samples were collected only at sites with a heterogeneous temperature profile. A composite sample of the entire thickness of the snow profile was collected. In addition, two precipitation samples were collected on April 15, 2003, in lower Straight Creek next to the Red River; one sample of rain was collected in the morning at the onset of a storm, and a second sample of snow was collected in the afternoon near the end of the storm. These five samples provide some data on the isotopic composition of local precipitation, but they are not sufficient to define the average isotopic composition of precipitation in the Red River Valley.

Although the two April 2003 precipitation samples from lower Straight Creek were collected from the same storm, they are of different oxygen and hydrogen isotopic compositions (fig. 16). The large change in isotopic composition reflects Rayleigh distillation, a fractionation process by which the heavy water isotopes condense and “rain out,” leaving the residual water vapor depleted in oxygen-18 (^{18}O) and deuterium (^{2}H). As precipitation continues, or if temperature drops and rain turns to snow, the rainout becomes progressively lighter (more negative) in isotopic composition. The two April 2003 samples form a line that is parallel to, but slightly below, a meteoric water line for Rocky Mountain precipitation proposed by Nordstrom and others (2004). The Rocky Mountain meteoric water line, the linear best fit generated from more than 400 precipitation samples collected from 1993 to 2000 at high-altitude sites from northern New Mexico to Montana, is parallel to, but slightly above, the global meteoric water line. One storm is not likely to be representative of the isotopic composition of annual recharge because of the substantial variability of individual storms.

The three snowpack samples were collected from north-facing slopes in the upper part of the study area at altitudes of 8,660, 8,830, and 9,425 feet above NGVD29. The slightly different isotopic compositions among the three samples correlate with altitude; with increasing altitude, ^{18}O and ^{2}H become more negative (fig. 16). The oxygen and hydrogen isotopic compositions are lighter in the snowpack samples than in the two precipitation samples collected from Straight Creek on April 15, 2003 (fig. 16). Because the snow samples represent an integration of winter precipitation, they may be more representative of recharge than the single storm of April 15, 2003.

The oxygen and hydrogen isotopic compositions of six Straight Creek surface-water samples were compared with those of ground-water samples (fig. 17). The samples were collected upstream from the point where surface water completely infiltrates to the subsurface as part of the routine water-quality sampling schedule for Straight Creek. The oxygen and hydrogen isotopic compositions of five of the six surface-water samples encompass those of the ground-water samples (fig. 17 and table 11). The single surface-water sample with isotopic compositions distinctly different from the other five samples was collected in February 2002 (table 11; not shown in fig. 17 because of scale) when recent snow was melting in the lower part of Straight Creek. The ^{18}O and ^{2}H values for this sample are similar to those for the three snowpack samples collected in March 2002. The major ion chemistry of this sample is distinctly different from that of most other Straight Creek surface-water samples (app. 1). For example, the sulfate in other Straight Creek surface-water samples varied from 1,510 to 2,660 mg/L (with the exception of the March 2002 sample containing 525 mg/L sulfate), whereas the February 2002 sample contained 825 mg/L sulfate. The low sulfate content and depleted oxygen and hydrogen isotopic compositions are consistent with inclusion of a substantial portion of snowmelt-derived water in the spring 2002 samples.

The similarity of oxygen and hydrogen isotopic compositions of ground-water samples from wells in the Straight Creek drainage basin and Straight Creek surface-water samples indicates that ground water in the Straight Creek drainage basin is derived primarily from local precipitation and runoff. Most sample compositions, including Straight Creek surface water, plot below the local precipitation line derived from one storm in April 2003, indicating that this storm may not represent average precipitation (fig. 17). The slope of a linear fit of snowpack and Straight Creek surface-water samples is similar to that of the April 15, 2003, precipitation sample line and defines a field that is consistent for most ground-water samples (fig. 17). A linear fit of all ground-water samples is distinctly shallower in slope than the April 15, 2003, precipitation line and the best fit of the snowpack and surface-water samples. This variation in slope is consistent with the ground water from some Straight Creek wells containing an evaporated water component.

Few analyses of the sulfur isotopic compositions of mineral phases from the Questa Molycorp mine have been published. Field (1966) reported ^{34}S values of -0.4 and 1.4 for pyrite and supergene gypsum, respectively. Laughlin and others (1969) reported ^{34}S values of 1.1 and 9.8 for molybdenite and hypogene gypsum, respectively. Both phases were collected from veins in the open pit. These results are displayed as horizontal (dashed) lines and shaded fields in figure 18 because no oxygen isotopic results were reported. Stein (1985) reported ^{34}S values of 1.0, 1.0, and 1.1 from vein and massive molybdenite along the 8,520-foot bench in the open pit. New results from the study described in this report include ^{34}S and ^{18}O values for hypogene anhydrite collected from the underground mine

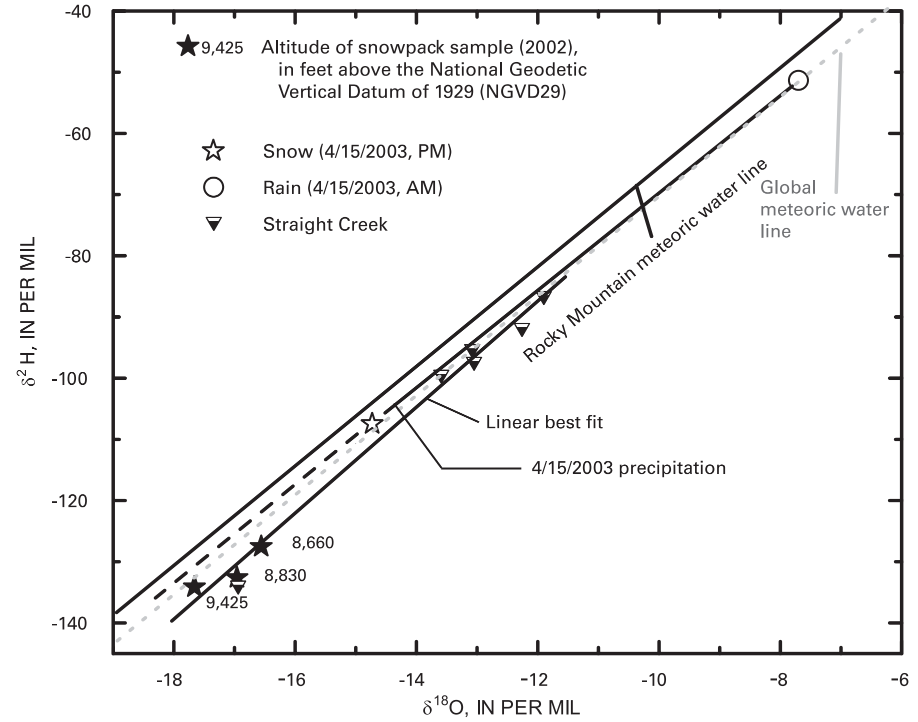

Figure 16. Hydrogen and oxygen isotopic composition of Straight Creek surface water and precipitation in the Red River Valley compared to the Rocky Mountain and global meteoric water lines.

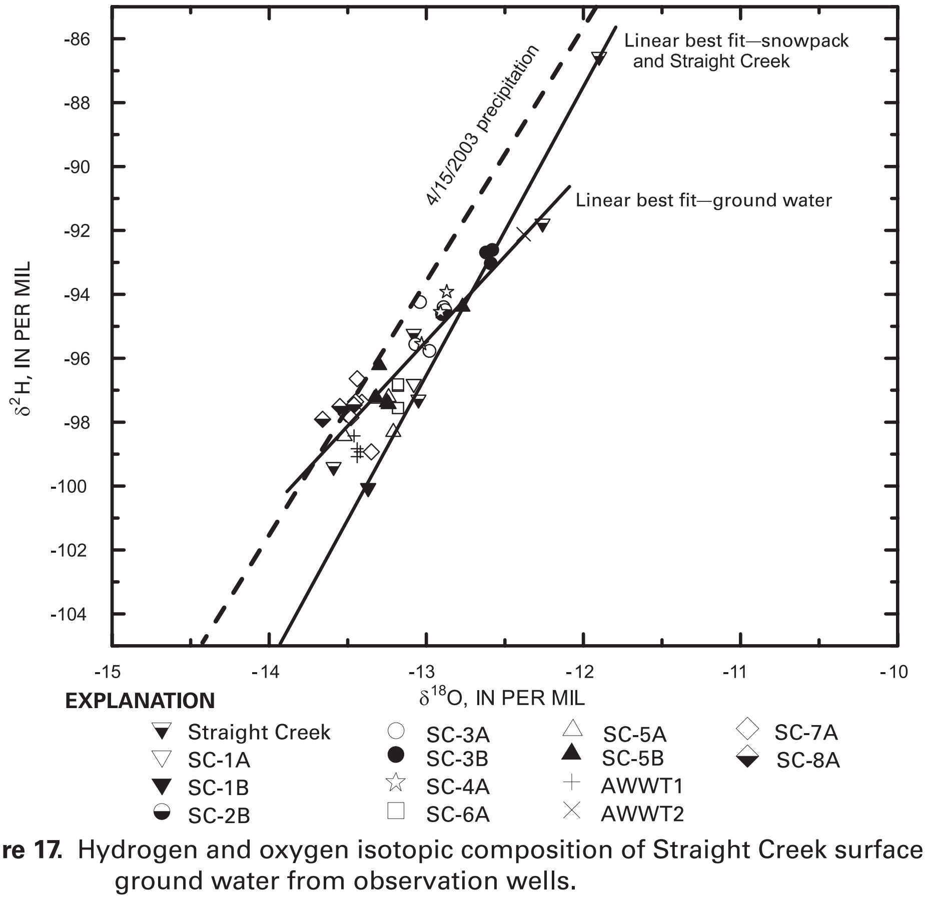

Figure 17. Hydrogen and oxygen isotopic composition of Straight Creek surface water and ground water from observation wells.

workings, supergene gypsum collected from the Straight Creek drainage basin and June Bug scar, and sulfate salts collected from the Straight, Hansen, and Lower Hansen Creek drainages (table 12; fig. 18).

The sequential extraction experiment conducted on composite solid samples from the Hottentot Creek, Straight Creek, and June Bug alteration scars (fig. 1) yielded an acid-volatile component and a disulfide component. Interpretation of these two components is in progress, but in general the acid-volatile component represents sulfides that evolve hydrogen sulfide in hydrochloric acid (for example galena, sphalerite, and pyrrhotite), and the disulfide component represents pyrite and marcasite. The ^{34}S sequential extraction results include the acid-volatile compositions of -7.2 and -7.7 (Hottentot Creek), -4.3 (June Bug), and -1.3 (Straight Creek) and the disulfide component of -3.6 and -4.6 (Hottentot Creek), -3.6 and -4.1 (June Bug), and -1.0 and -1.1 (Straight Creek).

Values of ^{34}S and ^{18}O for gypsum and sulfate salts are consistent with those in ground water but much lower than corresponding values for anhydrite from the underground workings. Values of ^{34}S and ^{18}O for hypogene anhydrite and gypsum are substantially higher than corresponding values for supergene gypsum because supergene gypsum is derived from pyrite oxidation. The ^{34}S values for leachates of sulfides collected on the surface in the scar areas tend to be more negative than for the sulfides collected from the ore zone. The ground-water samples from Straight Creek wells are of isotopic composition similar to Straight Creek surface water. The overall trend of water in figure 18 results from the mixing of sulfate derived from sulfide oxidation (lighter ^{34}S values) with sulfate derived from gypsum (heavier ^{34}S values).

Other Constituents

Samples were collected for determination of several other constituents to provide information about the processes controlling ground-water chemistry in the Straight Creek analog site. Ground-water samples were collected routinely for determination of total recoverable major cations and selected trace metals; dissolved major cations, selected trace metals, and rare-earth elements; anions and alkalinity; and dissolved-iron redox species. Rare-earth elements were determined only for selected samples. Samples were collected for determination of DOC and mercury during selected samplings.

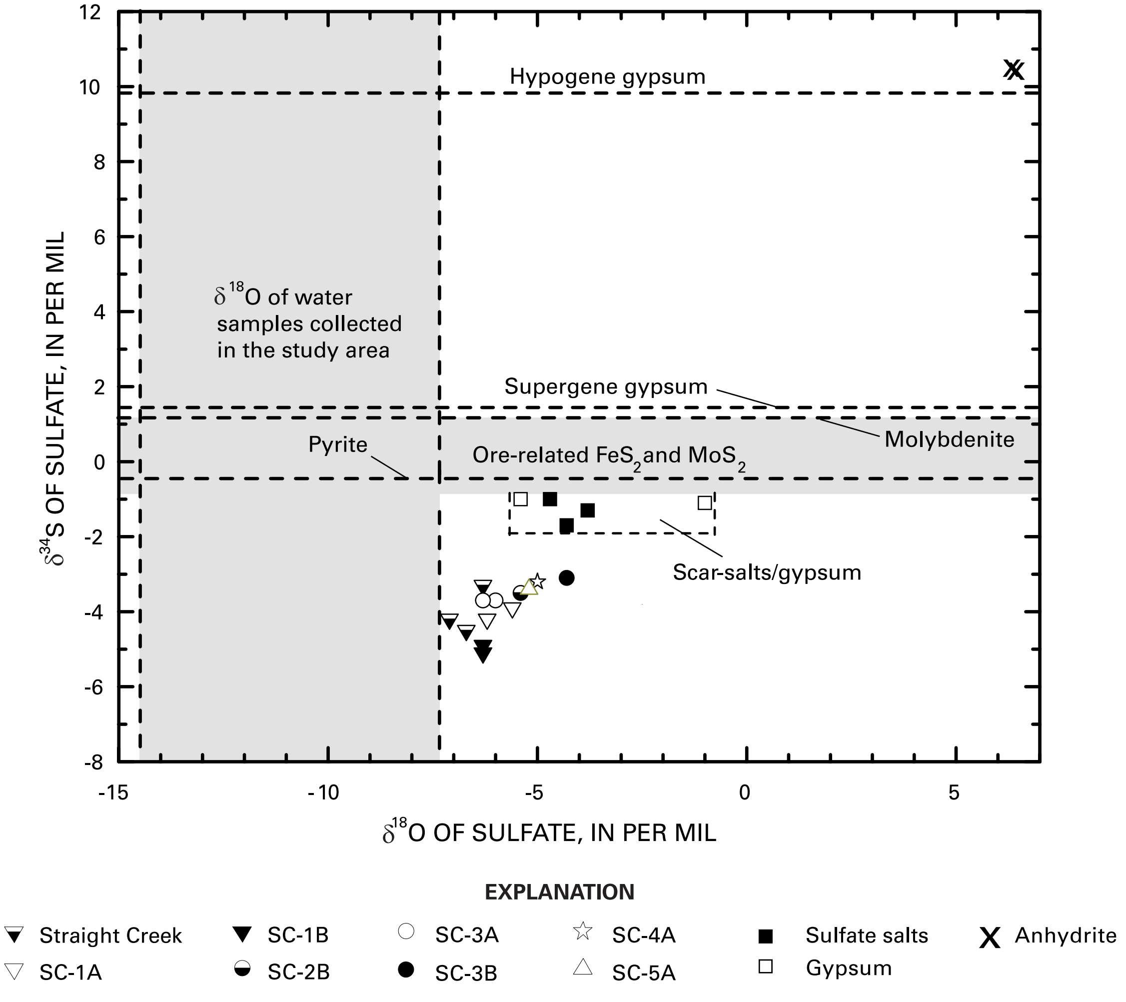

Figure 18. Stable isotopic composition of dissolved sulfate in Straight Creek surface water, ground water from observation wells, and sulfate and sulfide materials.

Analysis

The USGS Branch of Regional Research laboratory used reagents of purity at least equal to the reagent-grade standards of the American Chemical Society to analyze samples. Double distilled or deionized water and redistilled or trace-metal-grade acids were used in all preparations. Each sample was analyzed in at least duplicate for major cations and trace metals. Samples were diluted as necessary to bring the constituent concentration within the optimal range of the method. Analytical techniques, detection limits, typical precision, equipment used, and analytical method references are summarized in table 7.

Quality-assurance/quality-control (QA/QC) samples included equipment blanks, field blanks, trip blanks, and replicate samples. Techniques used to assure the quality of analytical data included use of charge imbalance (C.I.); standard reference water samples; analyses of the same constituents by different analytical techniques, different laboratories, and different instruments; laboratory blanks; and replicate analyses. The use of C.I. to select samples for speciation calculations is described below. Further details regarding methods and results of other QA/QC sampling and analyses were documented in McCleskey and others (2004).

Charge imbalances were calculated using the program WATEQ4F (Ball and Nordstrom, 1991) according to the following equation:

$$\text{C.I. (percent)} = \frac{100 \text{ x (sum cations - sum anions)}}{\text{(sum cations + sum anions)/2}} \tag{4}$$

where sum cations is the sum of the cations, in milliequivalents per liter, and sum anions is the sum of the anions, in milliequivalents per liter. The charge "imbalances" are twice the value normally reported as charge balances because the denominator contains the average of the cation plus anion sum rather than the cation plus anion sum. C.I., sum cations, and sum anions for each sample are included in the table of chemical analyses of water samples (app. 1). The distribution of the C.I. is shown in figure 19A along with the normal (or Gaussian) distribution fit for 179 samples and the limits for 2 standard deviations. One hundred seventy-four values fall within ± 11.2 percent C.I. (2 standard deviations) and are considered to be of high enough quality for speciation calculations.

Aqueous speciation, ionic strength, saturation index, and redox potential calculations based on Fe(II)/Fe(III) determinations were obtained with the program WATEQ4F (Ball and Nordstrom, 1991). The saturation index, SI, is defined as the logarithm of the ratio of the ion-activity product, IAP, to the solubility product constant, K_{sp}:

$$SI = \log\left[\frac{IAP}{K_{sp}}\right] . \tag{5}$$

If the solution is in equilibrium with a mineral, the IAP = K_{sp} and the SI = 0. If the SI is greater than 0, the solution is supersaturated and the mineral tends to precipitate; if the SI is less than 0, the solution is undersaturated and the mineral tends to dissolve.

A considerable range of dissolved-solids concentration and ionic strength was detected in ground water from the Straight Creek drainage basin. The range in effective and total ionic strength for this water is shown in figure 19B. "Effective ionic strength" is the computed ionic strength after speciation using WATEQ4F, and "total ionic strength" is the computed ionic strength before speciation. Both are computed according to the following equation:

$$I = \frac{1}{2}\sum_i m_i z_i \tag{6}$$

where I is the ionic strength, m_i is the molality of the ith ion, and z_i is the electronic charge on the ith ion. The upper end of the range of total ionic strength in figure 19B is as much as nearly 0.12 molal, but effective ionic strength does not increase at the same rate as total ionic strength. Effective ionic strength for this water reaches a maximum of about 0.065 molal, about half of total ionic strength. This water is much lower in effective ionic strength than that of sea water, which is considered to be the upper limit for application of the ion association model for speciation (Nordstrom and Munoz, 1994). Hence, the ion association model should be applicable for this water.

The ionic strength plot in figure 19B also shows that bedrock aquifer ground water is of higher effective ionic strength than shallow (debris-flow aquifer and Red River alluvial aquifer) ground water. This difference is related to high aluminum and iron concentrations in the acidic water of the debris-flow aquifer. These ions complex strongly with sulfate, thereby reducing the overall concentration of charged ions in solution in debris-flow aquifer ground water.

The range of pH values in Straight Creek surface water, shallow well water, and bedrock aquifer well water (app. 1) is shown in figure 19C. Straight Creek contains the most acidic water in the basin (pH of 2.7-3.2) and because Straight Creek is the main input to the debris-flow aquifer, some neutralization occurs when this water reacts with debris-flow material to increase the pH in ground water (pH of 3.2-4.0). All bedrock aquifer water is of circumneutral pH, indicating neutralization by carbonate-rich bedrock. Several lines of evidence support this hypothesis.

The double-ended arrow (fig. 19C) indicates a trend in which SC-4A water appears to be a mixture of SC-3A and SC-3B water. This indication of mixing does not mean that water in SC-3A actually mixes with water in SC-3B to produce water in SC-4A, merely that these types of debris-flow and bedrock aquifer ground water are mixing somewhere in the subsurface before reaching well SC-4A.

The correlation is strong between specific conductance and sulfate concentration (fig. 19D) as is expected for water in which sulfate is the only dominant anion. Specific conductance of bedrock aquifer water tends to be higher than that of debris-flow aquifer water with the same sulfate concentration because iron and aluminum concentrations are higher in debris-flow aquifer water, resulting in more ion pairing with sulfate to lower the specific conductance of the solution. This reduction in specific conductance is consistent with the reduced ionic strength in shallow ground water (fig. 19B).

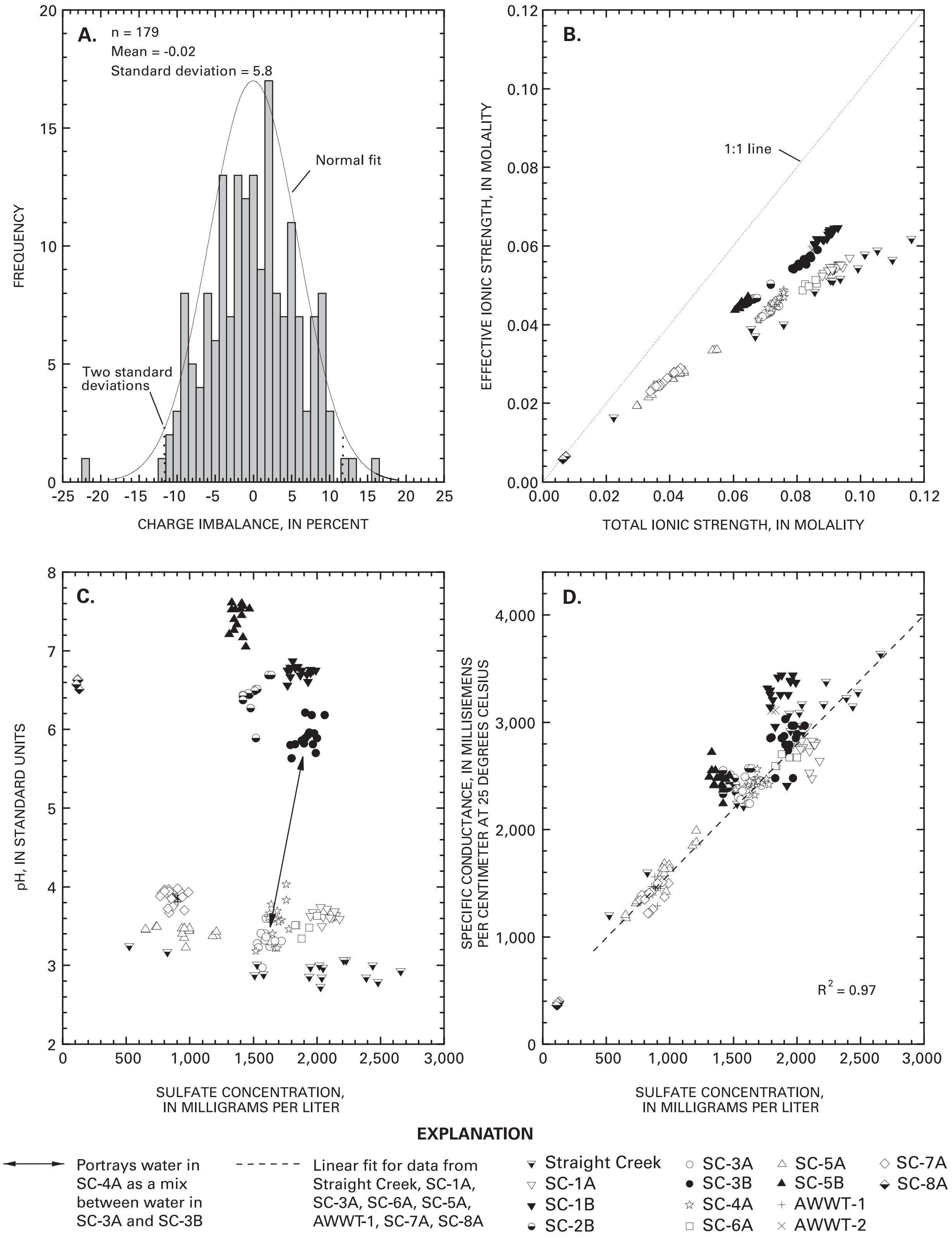

Figure 19. (A) Frequency of distribution of charge imbalance using equation 4. Comparison of (B) effective ionic strength to total ionic strength, (C) pH to sulfate concentrations, and (D) specific conductance to sulfate concentrations.

Results

Water-chemistry data (app. 1; tables 13-14) for analyses done by colorimetry, ICP-OES, inductively coupled plasma-mass spectrometry (ICP-MS), ion chromatography (IC), and graphite furnace atomic absorption spectrometry (GFAAS) are reported to a maximum of three significant figures depending on the constituent concentration and its proximity to the method detection limit (see table 7 for analytical techniques and detection limits). Three significant figures often are reported because the third digit is needed to avoid loss of information and eliminate internal inconsistencies, and for subsequent calculations. Constituent concentrations are not reported to more digits than the order of magnitude of the detection limit. For example, if a constituent's detection limit is 0.01 mg/L, the maximum number of decimal places reported would be two regardless of the constituent concentration or number of significant figures. Depending on the concentration, the example constituent could be reported as 0.05, 0.52, 5.24, or 52.4 mg/L.

Results of analyses done by ICP-MS for a selected subset of samples are included in table 14 for constituents (with the exception of boron) not included in appendix 1. Boron is reported in both appendix 1 and table 14 because it was generally below the ICP-OES detection limit and no alternative analysis technique was routinely used. In appendix 1, constituent concentrations less than the detection limit are reported as such. In plots created for the purpose of interpreting the chemistry (figs. 19-45), however, constituent concentrations were set to zero for water samples in which concentrations of the constituent of interest were less than the method detection limit. Total iron concentrations reported in appendix 1 can be either total recoverable concentrations (unfiltered samples) or total dissolved concentrations (Fe(II) + Fe(III); filtered samples). Total recoverable metal concentrations are operationally defined as metals that are determined in an unfiltered sample acidified with concentrated HNO_3 (1 percent v/v) and, therefore, include both leachable particulates and dissolved metals.

Table 13. Dissolved mercury data.

[Hg, mercury; ng/L, nanograms per liter]

Site	Sample collection date	Hg (ng/L)
Straight Creek	10/23/2003	2.2
SC-1A	10/23/2003	0.4
SC-1B	10/23/2003	0.2
SC-3A	10/21/2003	0.8
SC-3B	10/21/2003	0.5
SC-4A	10/21/2003	0.9
SC-5A	10/24/2003	0.9
SC-5B	10/24/2003	0.9
AWWT-1	10/24/2003	0.8

Redox Potentials and Iron Chemistry

As a check on both speciation calculations and the equilibrium Nernstian response of the platinum electrode (an electrode is said to behave "Nernstially" if the equilibrium electrode potential obeys the Nernst equation) for iron-rich ground water, the field-measured redox potential was compared with the redox potential calculated from Fe(II/III) determinations and speciation using WATEQ4F. These comparisons, along with an analysis of the effect of Fe(III) detection limits, are shown in figure 20A-D.

Figure 20A shows the Eh, or redox potential, measured in the field with a platinum electrode and the Eh calculated from a complete water analysis with Fe(II) and Fe(T) determinations. Samples with low or non-detectable Fe(III) were included; the detection limit was used when Fe(III) was non-detectable. Many of the values agree and many do not. Non-detectable Fe(III) concentrations (found by the difference between Fe(II) and Fe(T) concentrations) were identified by plotting the difference (Δ) between measured and calculated Eh as a function of the Fe(II)/Fe(T) ratio (fig. 20B). Samples with Fe(II)/Fe(T) ratios greater than 0.97 were considered to have Fe(III) concentrations too low to be detectable relative to the combined error from the Fe(II) and the Fe(T) determinations and were not considered further. Next, the ΔEh was compared to the Fe(III) concentration (fig. 20C) and any samples that were less than 0.1 mg/L, a concentration that is too low for dissolved iron to be electroactive (Morris and Stumm, 1967), were eliminated. The final, revised plot is shown in figure 20D; the variance of the values has narrowed considerably.

A frequency distribution plot of final ΔEh values (fig. 21A) illustrates the close match between measured and calculated Eh. The mean and median ΔEh values are both near zero and 1 standard deviation is ±35 millivolts (mV); only 2 of 70 values lie outside 2 standard deviations. Thus, when sufficient iron (Fe(II) and Fe(III)) concentrations are present in water, the platinum electrode responds with an equilibrium potential that closely approximates that of the Fe(II/III) redox couple. The quality of this comparison confirms the reliability of the field redox measurements and the speciation calculations. Furthermore, this analysis demonstrates that expected combined errors from field potential measurements and thermodynamic data should be within ±35 mV.

Only samples with ΔEh values within 2 standard deviations of zero should be used for calculations of saturation indices for ferric iron minerals. An important mineral group for checking these saturation indices is the hydrous ferric oxides, especially ferrihydrite and goethite (fig. 21B). In figure 21B, freshly precipitated hydrous ferric oxide (the upper solubility for ferrihydrite of $\log K_{sp} = 4.9$) is shown as providing an upper limit to ferric iron concentrations. Potential formation of ferric hydroxysulfate particles, such as schwertmannite, does not change the essence of these conclusions because the composition is still closely approximated by $Fe(OH)_3$ or FeOOH stoichiometry.

Table 14. Chemical analyses of water samples by inductively coupled plasma-mass spectrometry.

[µg/L, micrograms per liter; <, less than]

Site	Straight Creek	Straight Creek	SC-1A	SC-1B	SC-1B_R	SC-2B	SC-3A	SC-3B	SC-4A	SC-5A	SC-5B	AWWT-1
Date collected	3/20/2002	4/24/2002	4/25/2002	4/25/2002	4/25/2002	4/25/2002	4/24/2002	4/25/2002	4/24/2002	4/25/2002	4/25/2002	4/25/2002
Constituent (µg/L):												
Boron (B)	<5	5	7	16	18	12	9	5	7	<5	10	<5
Bismuth (Bi)	0.02	<0.03	<0.03	<0.05	<0.05	<0.03	<0.03	<0.03	<0.03	<0.02	<0.03	0.02
Cerium (Ce)	94	720	710	0.67	0.70	31	450	420	350	110	0.15	63
Cesium (Cs)	0.11	0.11	0.20	0.59	0.68	0.15	0.19	0.23	0.25	0.18	0.12	0.26
Dysprosium (Dy)	6.5	44	45	0.077	0.058	2.3	34	31	33	16	0.009	11
Erbium (Er)	2.3	15	16	0.055	0.064	1.1	12	10	13	6.2	0.007	4.1
Europium (Eu)	2.6	17	20	0.006	0.009	0.75	14	13	13	6.5	0.002	4.0
Gadolinium (Gd)	11	77	80	0.058	0.051	3.5	58	51	51	25	0.009	16
Hafnium (Hf)	0.044	0.32	0.34	0.008	0.024	0.029	0.28	0.26	0.29	0.096	0.007	0.065
Holmium (Ho)	0.98	6.6	7.2	0.018	0.019	0.45	5.2	4.8	5.5	2.6	0.002	1.7
Lanthanum (La)	33	270	250	0.27	0.26	14	130	170	130	26	0.076	17
Lutetium (Lu)	0.18	1.1	1.2	0.010	0.008	0.077	0.93	0.69	1.0	0.50	0.0017	0.33
Molybdenum (Mo)	0.6	1.5	1.8	11	10	1.4	1.6	3.3	1.0	<0.5	5.8	<0.5
Neodymium (Nd)	64	460	490	0.19	0.16	18	340	270	260	110	0.04	67
Lead (Pb)	0.27	1.5	1.3	0.34	0.26	0.19	2.2	19	0.14	0.09	0.15	0.11
Praseodymium (Pr)	14	110	110	0.045	0.046	4.2	76	62	56	22	0.012	14
Rubidium (Rb)	1.2	1.2	5.3	14	13	5.6	8.1	6.1	7.9	5.7	8.2	5.8
Rhenium (Re)	0.27	1.4	1.0	0.19	0.17	0.37	0.81	0.17	0.56	0.22	0.25	0.11
Antimony (Sb)	0.05	<0.03	0.03	0.18	0.18	<0.03	0.14	0.27	<0.03	<0.04	0.26	<0.04
Selenium (Se)	2.0	11	11	1.6	<1	2.0	10	7.0	8.0	5.9	0.8	2.0
Samarium (Sm)	13	94	94	0.02	0.02	2.9	69	54	53	26	<0.009	15
Tantalum (Ta)	<0.006	<0.005	<0.005	<0.009	<0.009	<0.005	<0.005	<0.005	<0.005	<0.006	<0.005	<0.006
Terbium (Tb)	1.4	9.7	10	0.009	0.009	0.45	7.3	6.6	6.8	3.4	0.002	2.2
Tellurium (Te)	0.16	0.72	<0.04	<0.07	<0.07	<0.04	0.15	0.17	0.04	<0.05	<0.04	<0.05
Thorium (Th)	1.1	9.9	0.49	0.07	0.07	0.25	1.5	0.12	0.60	0.33	0.04	0.12
Thallium (Tl)	0.04	0.04	0.06	<0.05	<0.05	0.06	0.08	<0.03	0.09	0.07	<0.03	0.03
Thulium (Tm)	0.25	1.7	1.8	0.0093	0.0100	0.12	1.3	1.1	1.5	0.72	0.0013	0.47
Uranium (U)	3.8	17	17	5.3	5.3	0.45	12	0.90	5.0	4.3	1.3	1.9
Vanadium (V)	<0.9	<0.6	2.3	<1	<1	0.7	<0.6	<0.6	1.2	<0.9	<0.6	<0.9
Tungsten (W)	<0.02	<0.02	<0.02	0.14	0.13	<0.02	0.02	<0.02	<0.02	<0.02	0.12	<0.02
Yttrium (Y)	26	170	180	1.0	1.0	18	140	140	160	77	0.21	52
Ytterbium (Yb)	1.4	9.2	10	0.065	0.060	0.59	7.6	5.9	8.3	3.9	0.013	2.6
Zirconium (Zr)	0.11	0.38	0.21	0.54	0.49	0.52	0.19	0.45	0.48	0.084	0.25	0.087

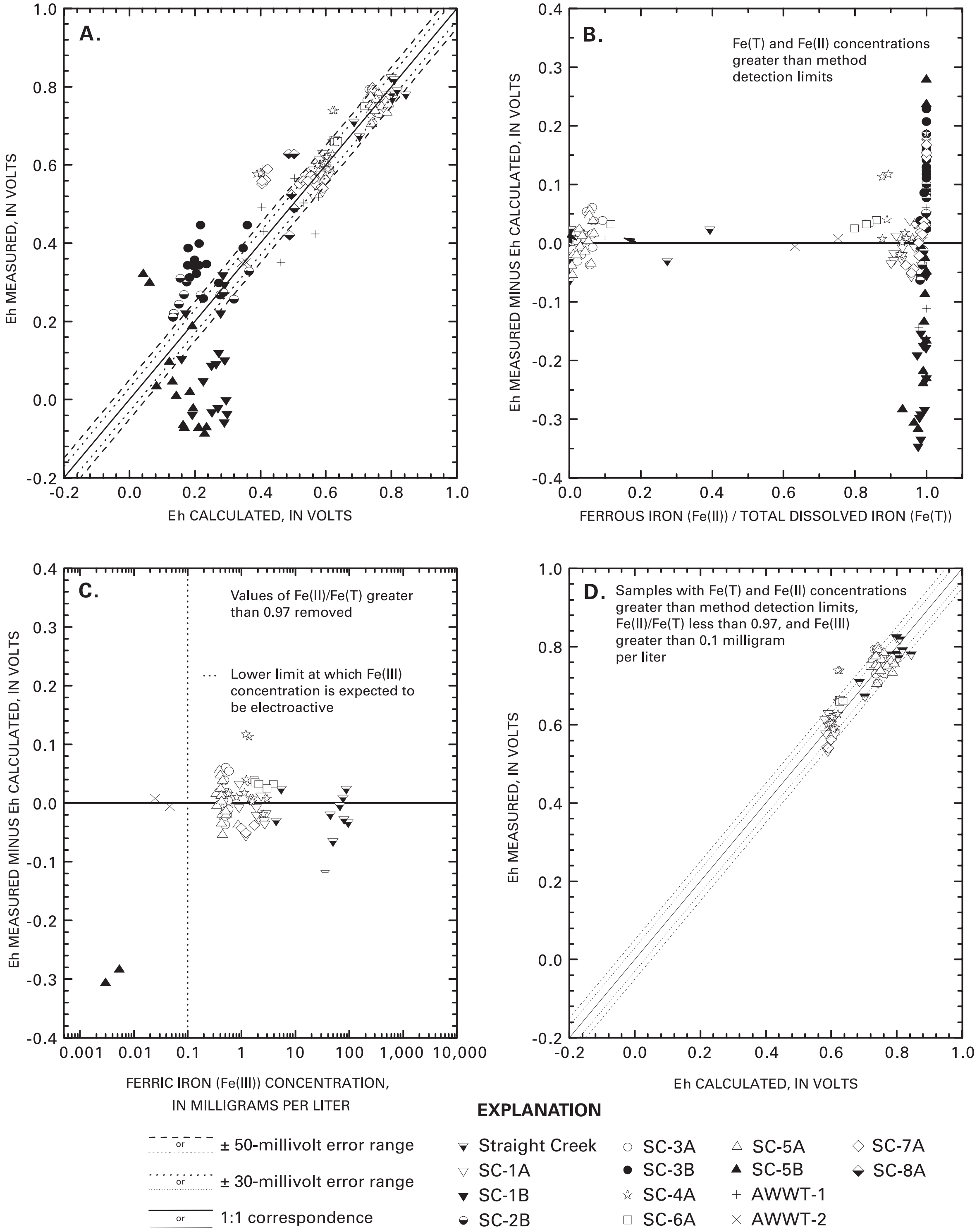

Figure 20. Comparison of (A) measured Eh to calculated Eh for all samples, (B) difference between measured and calculated Eh to ferrous iron/total dissolved iron (Fe(II)/Fe(T)) ratio for samples with total dissolved iron and ferrous iron greater than method detection limits, (C) difference between measured and calculated Eh to ferric iron (Fe(III)) concentrations, and (D) revised plot of figure 20A minus data points containing non-detectable and non-electroactive ferric iron concentrations.

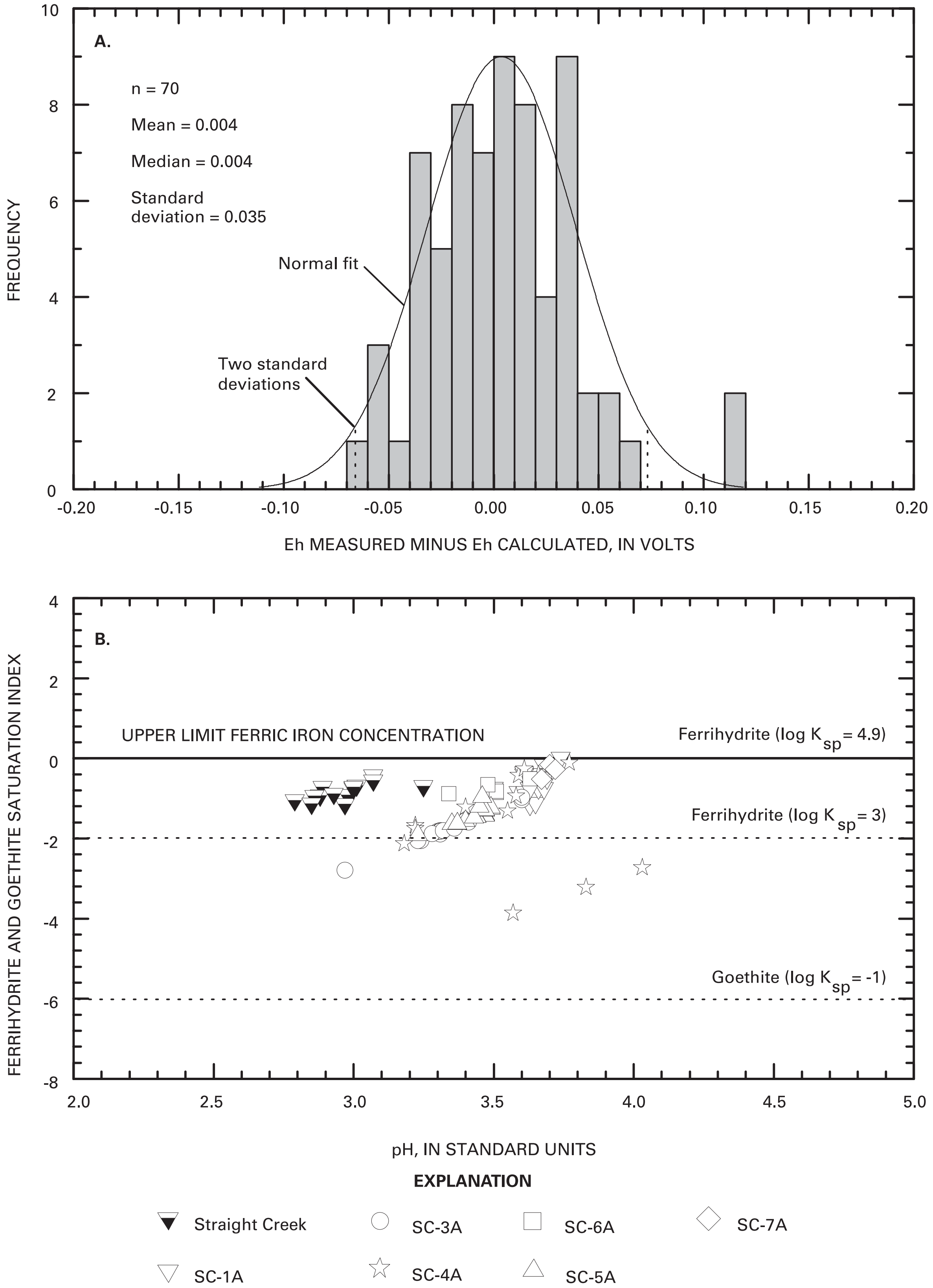

Figure 21. (A) Frequency distribution of Δ Eh showing normal fit, mean, median, and standard deviation and (B) saturation index for hydrous ferric oxides (ferrihydrite and goethite) as a function of pH.

Although most dissolved constituents in shallow ground water from the Straight Creek drainage basin linearly decrease in concentration with sulfate in a downgradient direction, total dissolved-iron concentrations do not, except in a qualitative manner with poor correlation (fig. 22A). Furthermore, at low total dissolved-iron concentrations (fig. 22B), water from wells SC-1B and SC-5B varies widely in dissolved-iron concentrations at constant sulfate concentrations. Iron concentrations in water from wells SC-1B and SC-5B both increase from the first collected sample to a maximum value (8.47 mg/L for SC-1B and 6.32 mg/L for SC-5B), then decrease to minimum values (1.72 mg/L for SC-1B and 0.063 mg/L for SC-5B) over time (fig. 23A). Only these two wells contained dissolved hydrogen sulfide (table 5). Water that is undergoing sulfate reduction is expected to produce hydrogen sulfide that will affect iron concentrations. Hydrogen sulfide was not noticed until after monitoring had begun. Sulfate reduction may have been initiated by the use of excessive amounts of organic chemicals (methanol antifreeze, phosphate-free detergent, or vegetable oil-based rock drill lubricant) used to overcome problems with well construction. The plug in well SC-1B and the detergent used as a lubricant to emplace it are unique to this well, which contains the highest concentration of hydrogen sulfide. Iron concentrations would be expected first to increase in response to increased anoxia-causing iron reduction, then to decrease in response to hydrogen sulfide reacting with reduced iron to form relatively insoluble iron sulfides.

Dissolved-iron concentrations are compared with total recoverable iron concentrations in figure 23B. Total recoverable metal concentrations are operationally defined as metals that are determined in an unfiltered sample acidified with concentrated HNO_3 (1 percent v/v) and, therefore, include both leachable particulates and dissolved metals. Straight Creek surface water and SC-5B ground water often have a large proportion of leachable particulate iron. In figure 23C, dissolved-iron concentrations are compared with total recoverable iron concentrations for ground water. The R^2 value of a linear fit line is 0.99 and its intercept is lower than the 1:1 correspondence line, indicating that the concentration of iron in the total recoverable sample is consistently higher than its dissolved counterpart. The deviation of the linear fit line from the 1:1 correspondence line is small, indicating very little particulate iron, which is not surprising at these high concentrations of dissolved iron.

When iron data are compared as Fe(II), or ferrous iron, concentrations with total iron (fig. 24A), or sulfate concentration (fig. 24C), trends are evident. All ground-water samples contain predominantly ferrous iron, an observation demonstrated by a strong correlation between ferrous iron and total dissolved iron concentrations (fig. 24A). Straight Creek surface water, however, contains predominantly ferric iron (fig. 24B and D). Analysis of oxygen and hydrogen isotopic compositions of ground-water samples from Straight Creek (fig. 16) indicates that ground water in the Straight Creek drainage basin is derived primarily from local precipitation and runoff. If, as hypothesized, Straight Creek surface water is the primary input to SC-1A ground water, then no additional iron is dissolved upon interaction with debris-flow material, and the main process contributing to the evolution of iron chemistry is reduction of ferric to ferrous iron. Again, the chemistry of water from SC-4A appears to be a mixture of the types of water collected from wells SC-3A and SC-3B (fig. 24C).

The only two reactions that appear to limit iron concentrations in ground water in the Straight Creek drainage basin are the solubilities of hydrous ferric oxide ($Fe(OH)_3$ or microcrystalline FeOOH) and siderite ($FeCO_3$). The saturation indices for siderite as a function of pH and of calcium concentration, respectively, relative to poorly crystallized, disordered siderite and to crystalline siderite are shown in figure 25A and B. Carbonate mineral solubilities are sensitive to pH; low pH conditions promote dissolution so solubility equilibrium cannot be reached. Bedrock aquifer water with near-neutral pH reaches siderite saturation (fig. 25A), which likely provides a maximum limit to ferrous iron concentrations. Siderite saturation accompanies high calcium concentrations, and the driving force to reach siderite equilibrium probably results from calcite dissolution rather than siderite dissolution (fig. 25B). That is, siderite solubility equilibrium is reached by a high ferrous iron water (derived from pyrite oxidation and (or) ferric iron reduction upgradient) mixing with a high calcium carbonate water derived from dissolution of a calcitic bedrock. This interpretation is further corroborated by comparisons of the saturation index for gypsum to calcium and sulfate concentrations, which are discussed in the calcium chemistry section.

Manganese Chemistry

Manganese and iron are chemically similar in that there are two main manganese oxidation states, Mn(II) and Mn(IV), and manganese is more soluble under anoxic reducing conditions and less soluble under oxidizing conditions. The correlation is strong for manganese concentration with sulfate concentration in shallow well water but not bedrock aquifer well water (fig. 26). Furthermore, manganese concentrations in Straight Creek surface water correlate with manganese concentrations in the shallow ground water, indicating Straight Creek as the likely main source of manganese in this ground water. Again, the chemistry of water in well SC-4A appears to be a mixture of the types of water collected from wells SC-3A and SC-3B. With the exception of SC-8A, samples from shallow wells in the lower part of the Straight Creek drainage basin (SC-5A, SC-7A, and AWWT-1) are grouped together along the linear correlation line. The sample from well SC-8A is much more dilute, probably because of a large component of Red River alluvial aquifer water in this well. The manganese concentrations for bedrock aquifer ground water seem highly variable; however, an explanation is evident when the saturation indices for rhodochrosite ($MnCO_3$) are plotted (fig. 27).

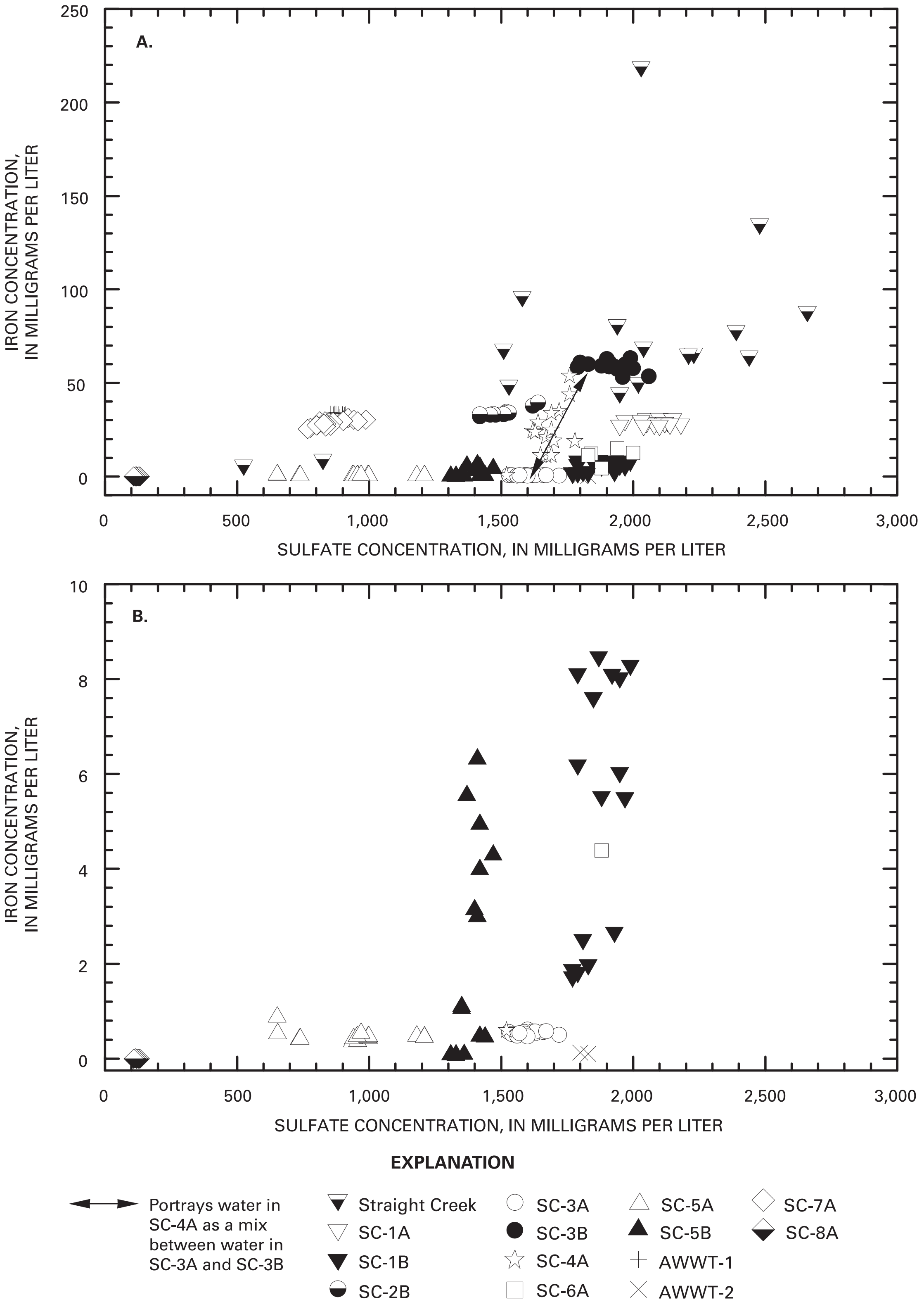

Figure 22. Comparison of (A) total dissolved iron concentrations to dissolved sulfate concentrations for all ground-water samples from the Straight Creek drainage basin and (B) total dissolved iron concentrations to dissolved sulfate concentrations for concentrations ranging from 0 to 10 milligrams per liter iron.

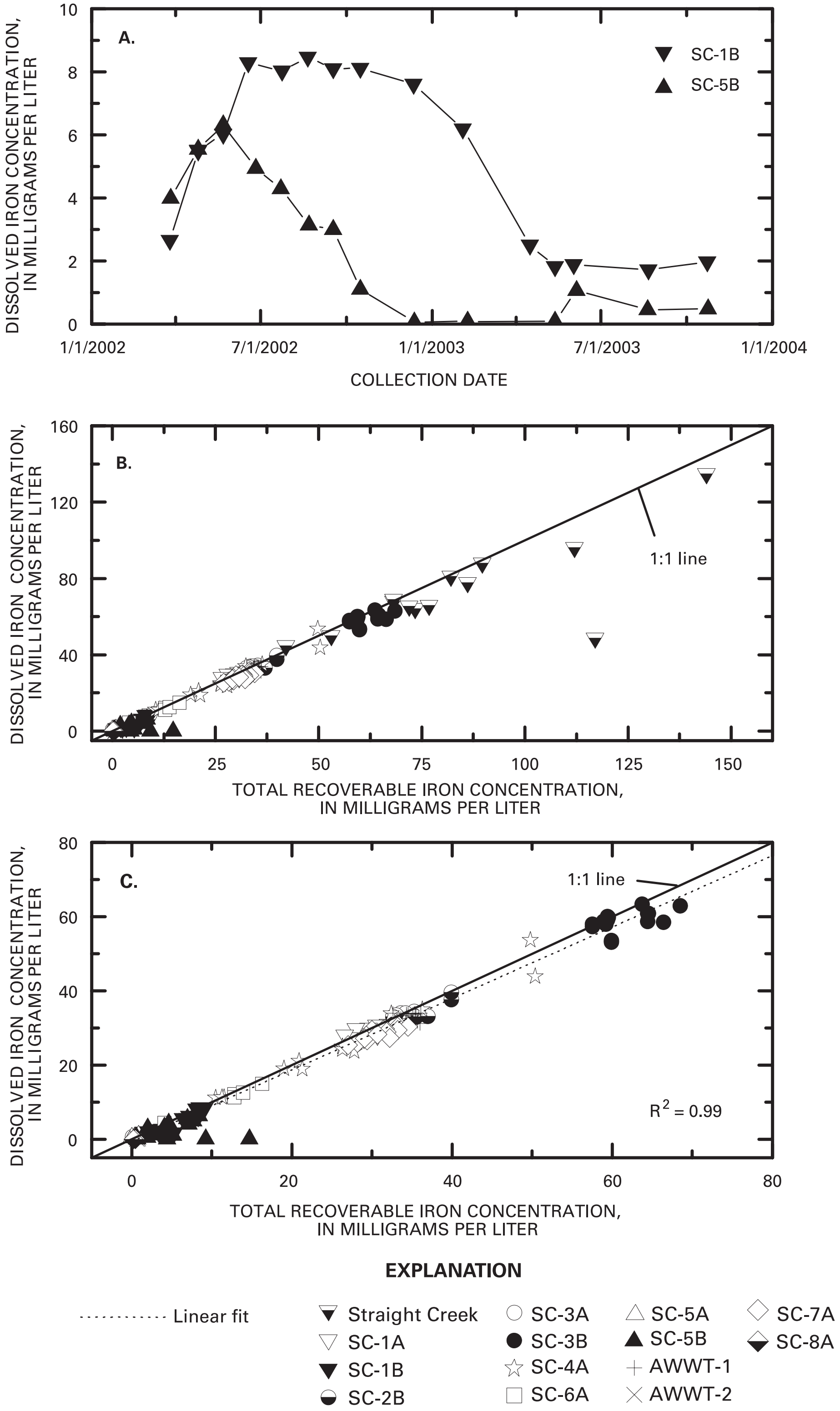

Figure 23. Comparison of (A) total dissolved-iron concentrations over time for samples from wells SC-1B and SC-5B, (B) dissolved-iron concentrations to total recoverable iron concentrations for surface-water and ground-water samples, and (C) dissolved-iron concentrations to total recoverable iron concentrations only for ground-water samples.

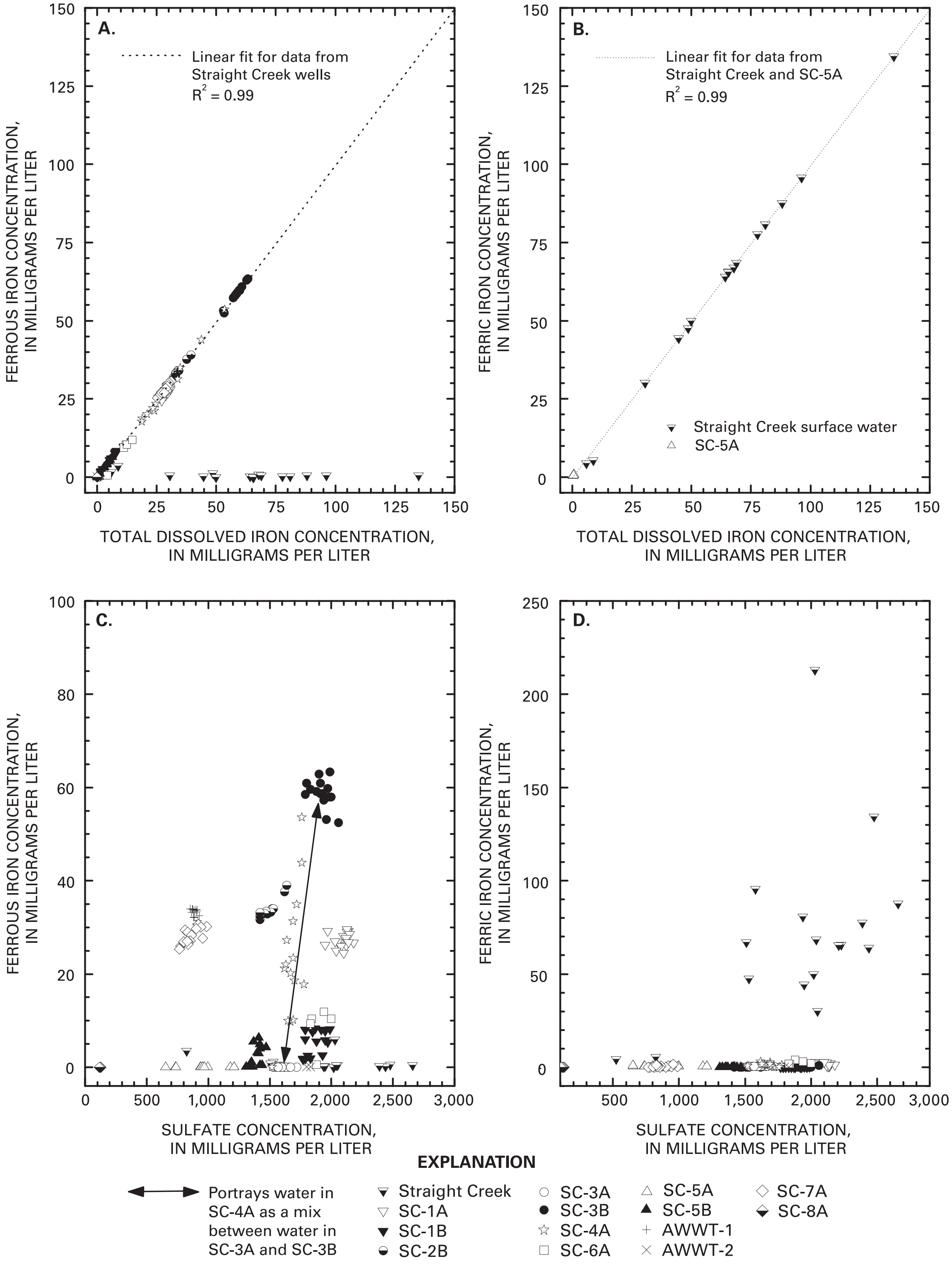

Figure 24. Comparison of (A) ferrous iron concentrations to total dissolved iron concentrations, (B) ferric iron concentrations to total dissolved iron concentrations, (C) ferrous iron concentrations to sulfate concentrations, and (D) ferric iron concentrations to sulfate concentrations.
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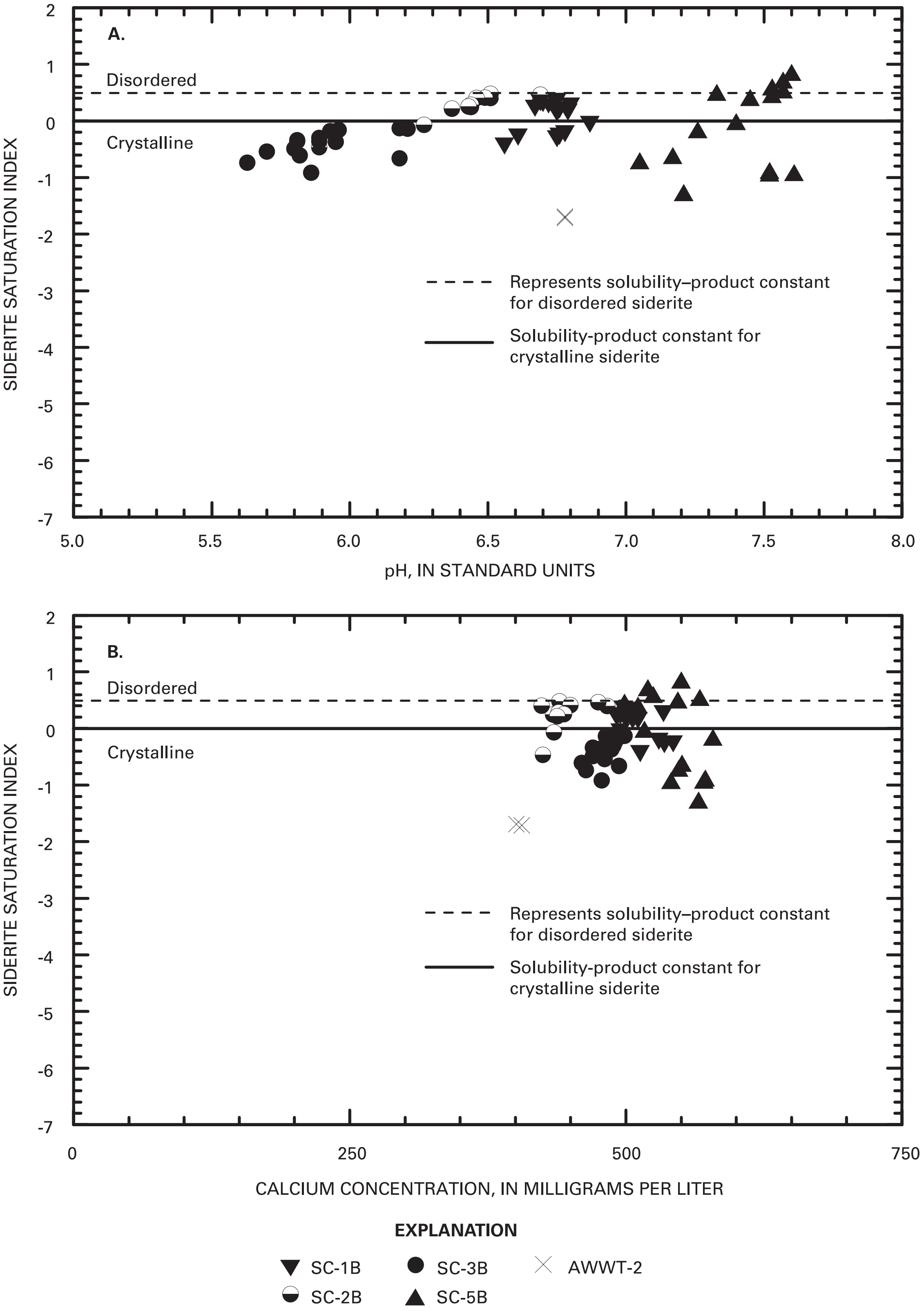

Figure 25. Comparison of (A) saturation indices for crystalline and disordered siderite as a function of pH and (B) siderite saturation indices as a function of calcium concentration for ground-water samples of circumneutral pH from Straight Creek wells.

In plots comparing rhodochrosite saturation indices to dissolved inorganic carbon concentration (fig. 27A) and pH (fig. 27B), the bedrock aquifer ground water reflects solubility equilibrium except in SC-3B. The pH values for SC-3B ground water appear to be too low for equilibrium to be reached, which is why manganese concentrations in this well water are the highest. Manganese concentrations in SC-3B water are higher than those in Straight Creek (fig. 26). Hence, additional manganese must be dissolving from the aquifer material, either from rhodochrosite or manganese oxides (G.S. Plumlee, U.S. Geological Survey, written commun., 2004).

Aluminum Chemistry

Aluminous particles might be present in some ground water from Straight Creek wells. One method of determining their presence is to compare dissolved aluminum with total recoverable aluminum concentrations (fig. 28A). The absence of bias in the strong correlation demonstrates that no substantial amounts of aluminous particles are detectable. The few outlying data points are to be expected and do not indicate any consistent trend. Although the linear correlation is dominated by the acidic debris-flow aquifer ground water, it also includes the circumneutral ground water.

The difference between aluminum concentrations in bedrock aquifer ground water and those in debris-flow aquifer ground water is more evident in figure 28B in which aluminum concentrations are compared to sulfate concentrations. A strong correlation exists for debris-flow aquifer water from wells SC-1A, SC-3A, SC-5A, and SC-6A, but bedrock aquifer water plots much lower and does not correlate well. The difference in aluminum concentrations between debris-flow aquifer water and bedrock aquifer water is directly related to the difference in pH.

Nordstrom and Ball (1986) have shown that aluminum in acidic surface water with pH less than about 4.5 tends to behave conservatively, whereas in the pH range of 4.5-5.0 aluminum begins to precipitate from acidic, aluminum-rich water and decreases substantially in concentration. Aluminum precipitates near a pH of 5.0 because aluminum precipitation cannot begin until hydrolysis occurs, and hydrolysis does not start until the pH approaches the first hydrolysis constant, pK_1, of 5.0 (Hem and Roberson, 1990; Nordstrom and May, 1996). Aluminum reactions in ground water may be somewhat different because of the much larger exposed surface area and longer residence times compared with surface water. In figure 28C, the logarithm of the free aluminum-ion activity is compared to pH for Straight Creek surface water and ground water to test the relative reactivity of aluminum. Similar to aluminum behavior in surface water, a shallow slope reflecting simple dilution is shown for acidic water, and a distinct change in slope consistent with microcrystalline to amorphous $Al(OH)_3$ solubility is shown for pH values higher than 5. The range of solubility from

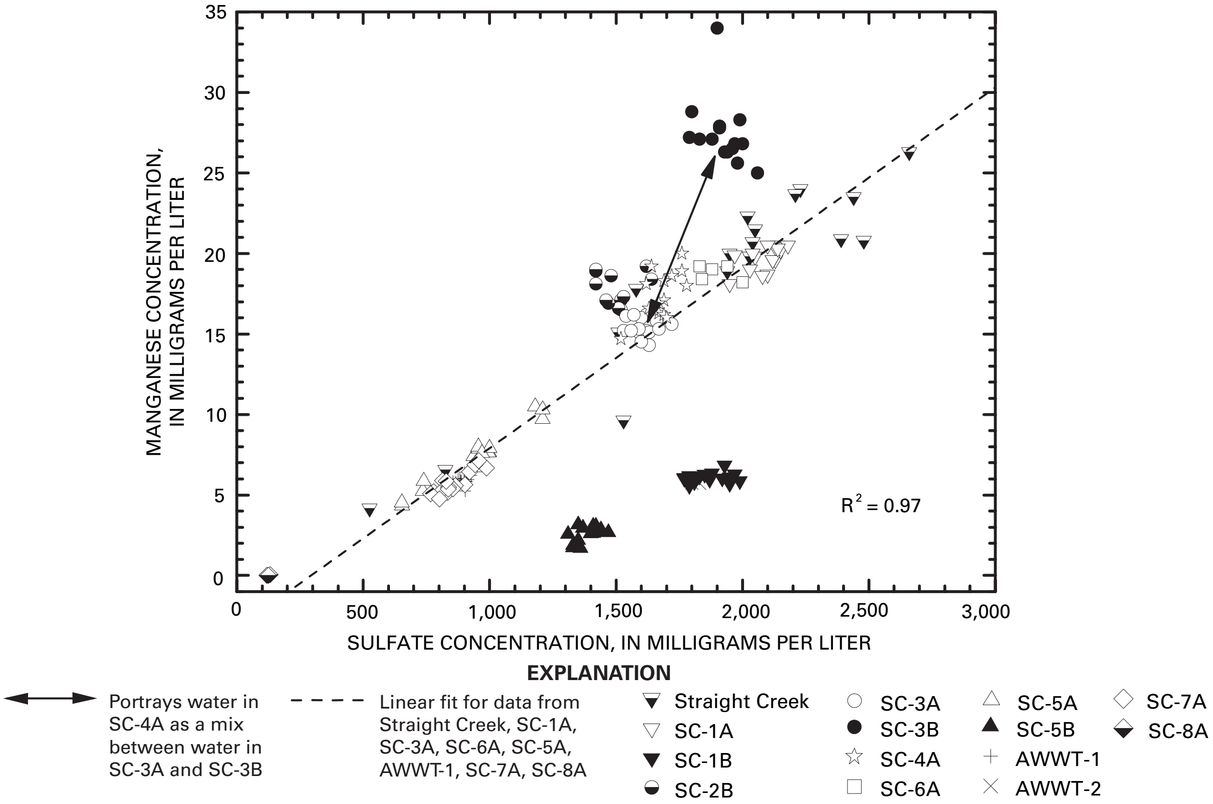

Figure 26. Comparison of manganese concentrations to sulfate concentrations.

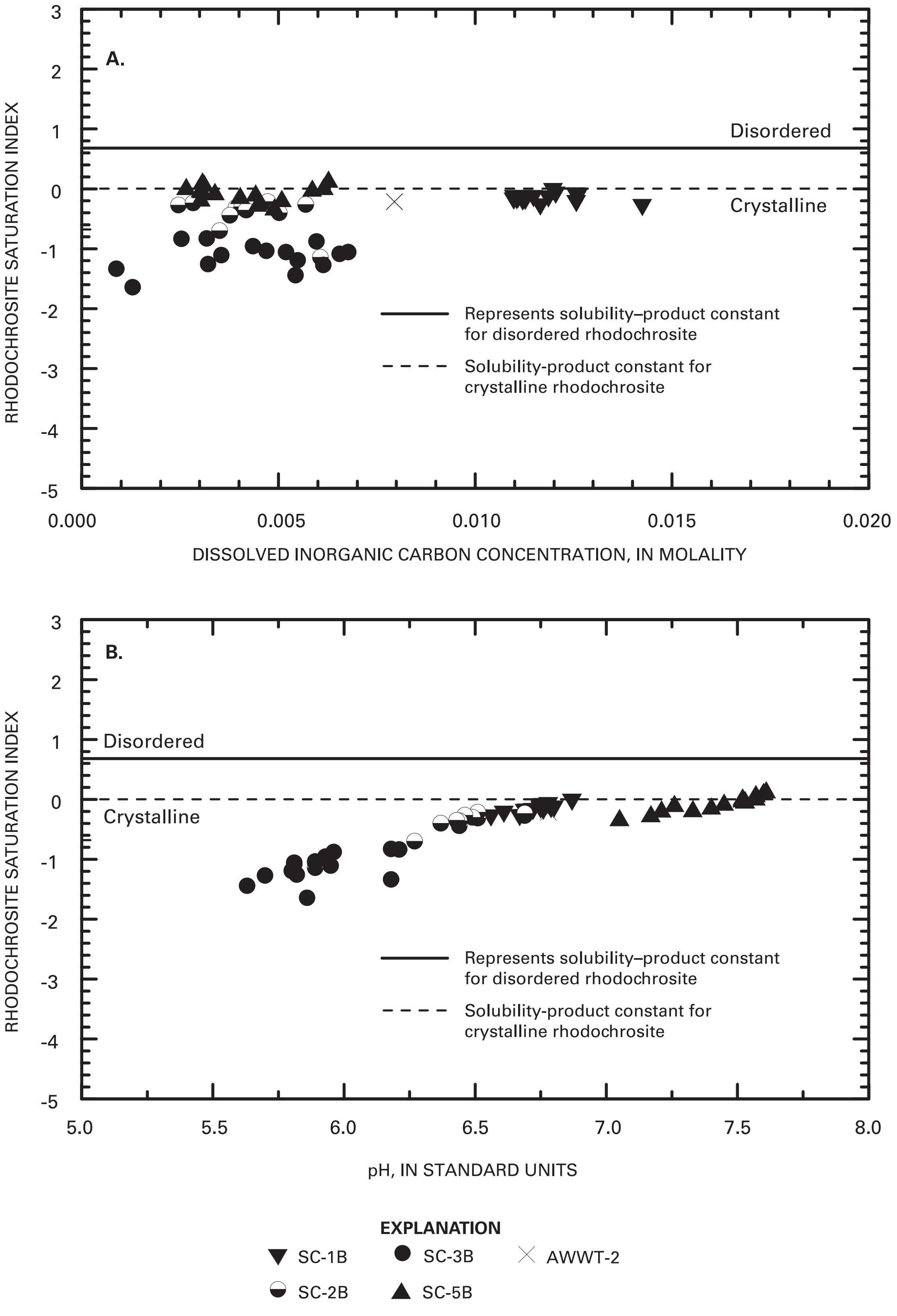

Figure 27. (A) Saturation indices for rhodochrosite to dissolved inorganic carbon and (B) saturation indices for rhodochrosite to pH.

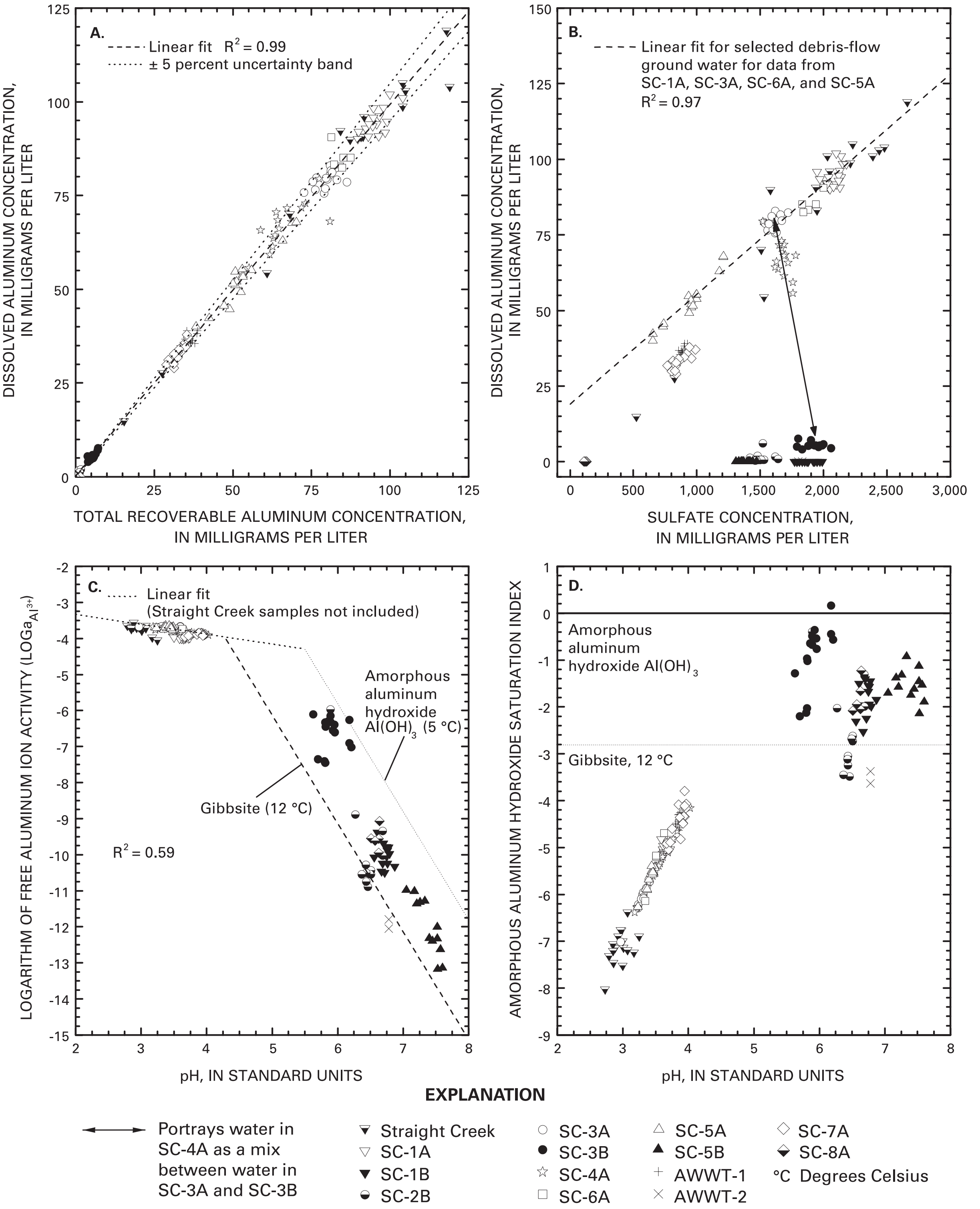

Figure 28. Comparison of (A) dissolved aluminum concentrations to total recoverable aluminum concentrations, (B) dissolved aluminum concentrations to dissolved sulfate concentrations showing linear fit for selected debris-flow ground water, (C) logarithm of free aluminum-ion activity to pH with the degree of fit for water with pH less than 5 and the range of solubility limits for gibbsite to amorphous aluminum hydroxide for the temperature of ground-water samples, and (D) saturation indices to pH.

microcrystalline gibbsite to amorphous $Al(OH)_3$ also is shown for the temperature range of the samples (about 5-12 ºC). Saturation indices for amorphous $Al(OH)_3$ compared to pH (fig. 28D) show behavior analogous to that demonstrated in figure 28C. Figures 28C and 28D indicate that aluminum hydrolysis is effectively reducing aluminum concentrations in higher pH ground water.

One other observation is noteworthy. In figure 28B, the best-fit line for some of the acidic ground water from SC-1A, SC-3A, SC-5A, and SC-6A does not correlate with the aluminum concentrations in water from SC-7A, SC-8A, and AWWT-1 and the lowest concentration samples from Straight Creek. There appears to be a gap between the aluminum concentrations from SC-5A and those from SC-7A that is not seen for most other constituents. The slightly higher pH in SC-7A (nearly pH 4) may be just enough to initiate some aluminum hydrolysis. Another possibility is that ground water does not flow from SC-5A to SC-7A, although the close similarity in most constituent concentrations indicates that the ground water is essentially the same type of water. As indicated by interpretation of age-dating data, proportions of Red River alluvial aquifer water in wells in the lower part of the drainage basin may increase in a downgradient direction, which could explain the differences in aluminum concentrations in wells SC-5A, SC-7A, SC-8A, and AWWT-1. Finally, aluminum concentrations in SC-4A ground water again indicate a mixture between SC-3A and SC-3B (fig. 28B).

Calcium Chemistry

The predominant dissolved cation in all ground-water samples from the Straight Creek drainage basin is calcium, which generally constitutes 50 percent or more of the cation concentration. The main source of dissolved calcium is the dissolution of gypsum ($CaSO_4 \cdot 2H_2O$). Gypsum occurs in mineralized areas throughout the Red River Valley, and small crystals can be found on the surface of the Straight Creek debris flow. By comparing calcium concentrations to sulfate concentrations (fig. 29), the extent to which gypsum dissolution influences ground-water chemistry can be discerned. Calcium and sulfate concentrations range widely, from gypsum-saturated to dilute water, and correlate well in figure 29. If gypsum were the only source of calcium and sulfate, the data points should plot along the stoichiometric gypsum dissolution line. However, only a few ground-water samples from SC-5B and the near-neutral dilute water from SC-8A plot on this line. Most values plot to the right of the gypsum dissolution line; that is, they display sulfate enrichment relative to simple gypsum dissolution. Because these samples also are the most acidic, excess sulfate is likely derived from pyrite oxidation. Most bedrock aquifer ground water has reached gypsum saturation. Gypsum saturation in the mixed electrolyte solutions of this ground water is slightly less than that shown by stoichiometric saturation of gypsum in pure water because the additional electrolytes reduce the free-ion activities of calcium and sulfate. However, these samples are at saturation when speciation and ionic strength effects are included (fig. 30A).

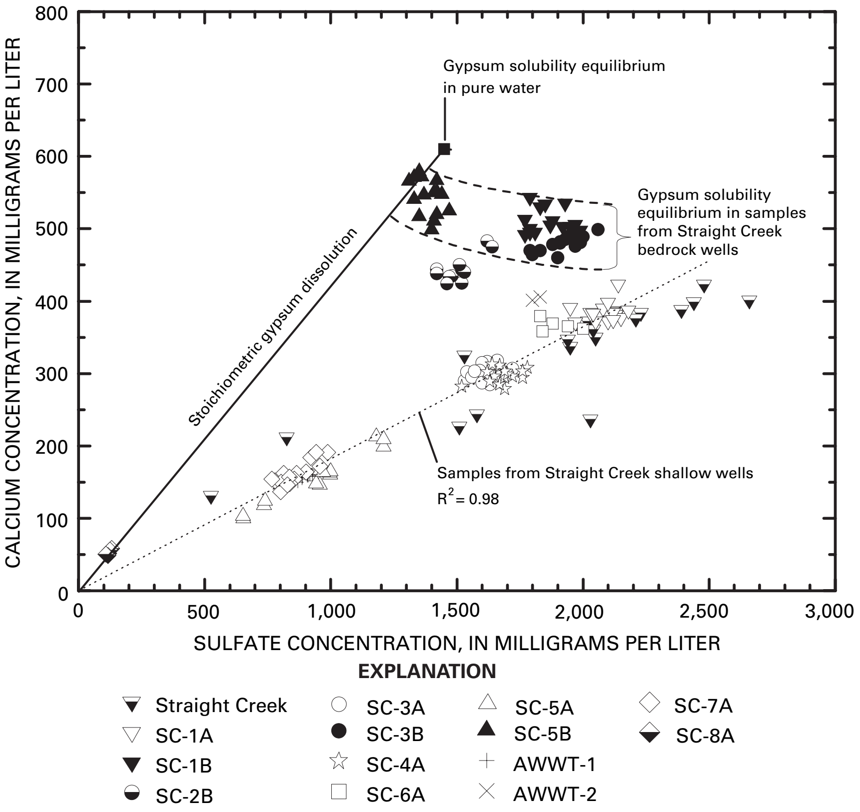

Figure 29. Comparison of calcium concentrations to sulfate concentrations.

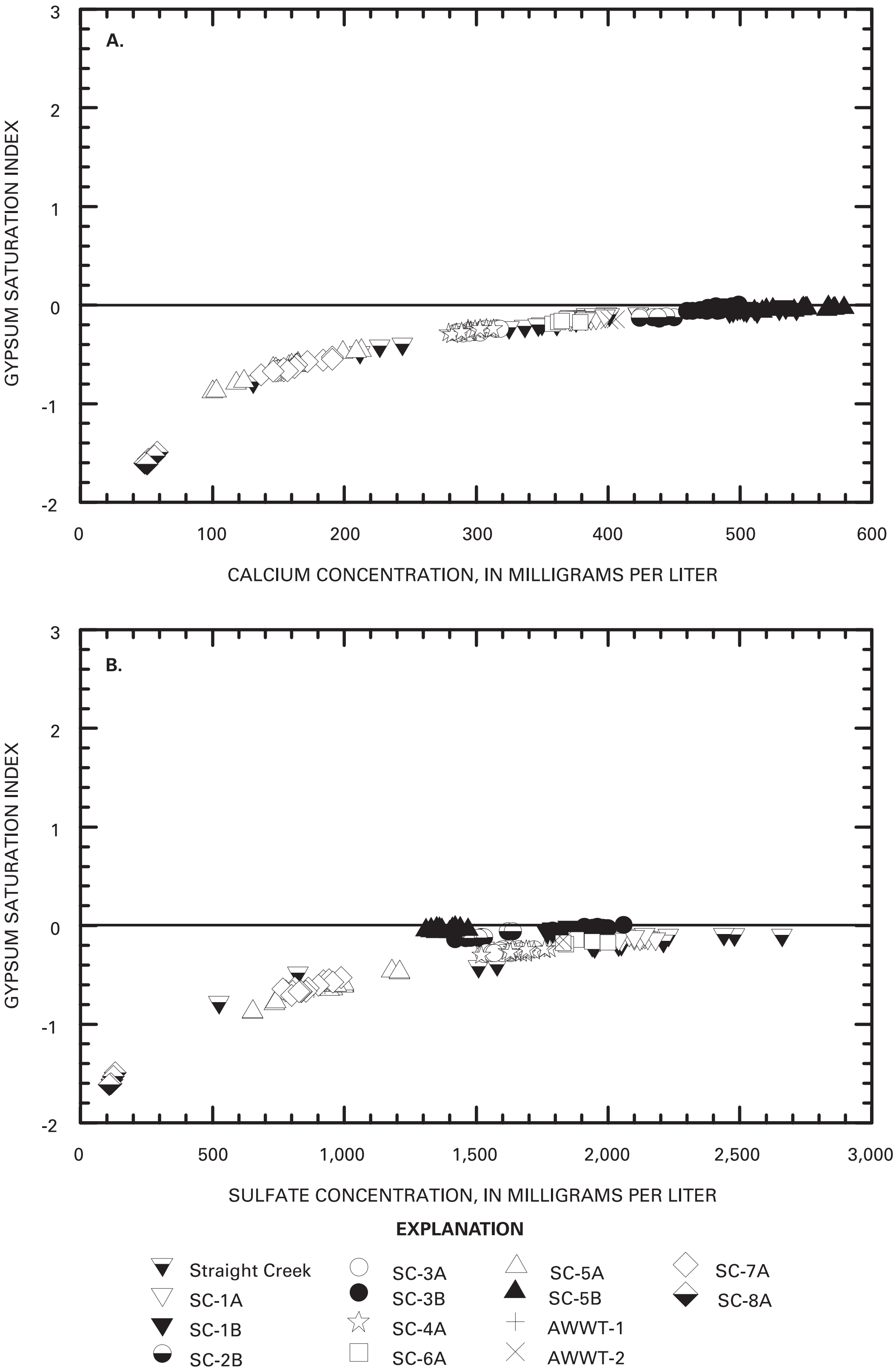

Figure 30. Comparison of (A) saturation indices for gypsum to calcium concentrations and (B) saturation indices for gypsum to sulfate concentrations.

Calcium concentrations in bedrock aquifer ground water are higher than those in Straight Creek surface water; hence, an additional source of calcium must be inferred. This source is most likely calcite dissolution. Only a slight enrichment in calcium for debris-flow aquifer ground water might be inferred by comparison to Straight Creek surface water. Again, the sample from well SC-8A is more dilute than samples from other wells in the lower part of the drainage basin because of a probable large component of Red River alluvial aquifer water.

Gypsum saturation indices compared to calcium concentrations indicate a progression to gypsum saturation with increasing calcium concentrations (fig. 30A). Comparing figure 30A to a plot of gypsum saturation indices and sulfate concentrations (fig. 30B) shows that increasing calcium concentrations are driving bedrock aquifer ground water toward gypsum saturation. Calcite, the main mineral component in bedrock, is generally absent in the scar area and in debris-flow material. Calcite also is the main source of neutralizing capacity that gives bedrock aquifer ground water circumneutral pH. Dissolution of calcite in the bedrock could reasonably be the primary source of additional calcium forcing the water toward gypsum saturation. Debris-flow aquifer ground water is too acidic for calcite to be stable.

Calcite occurs throughout the Red River Valley, including in the Straight Creek drainage basin, as a common alteration mineral produced during regional propylitization and in hydrothermal veins (Schilling, 1956; Livo and Clark, 2002; S. Ludington and G.S. Plumlee, U.S. Geological Survey, oral commun., 2002-03). To test the saturation state of bedrock aquifer ground water with respect to calcite, saturation indices were compared to pH (fig. 31). The results indicate that SC-1B water is at calcite saturation and SC-5B water is saturated to supersaturated. The highest calcium concentrations are found in wells SC-1B and SC-5B, the highest pH values of all ground water are found in well SC-5B, and the highest alkalinity in all ground water is found in well SC-1B. These observations are consistent with calcite dissolution as the major buffering mechanism for bedrock aquifer ground water. Calcite also can contain trace elements, thus calcite dissolution likely contributes other trace elements to ground water.

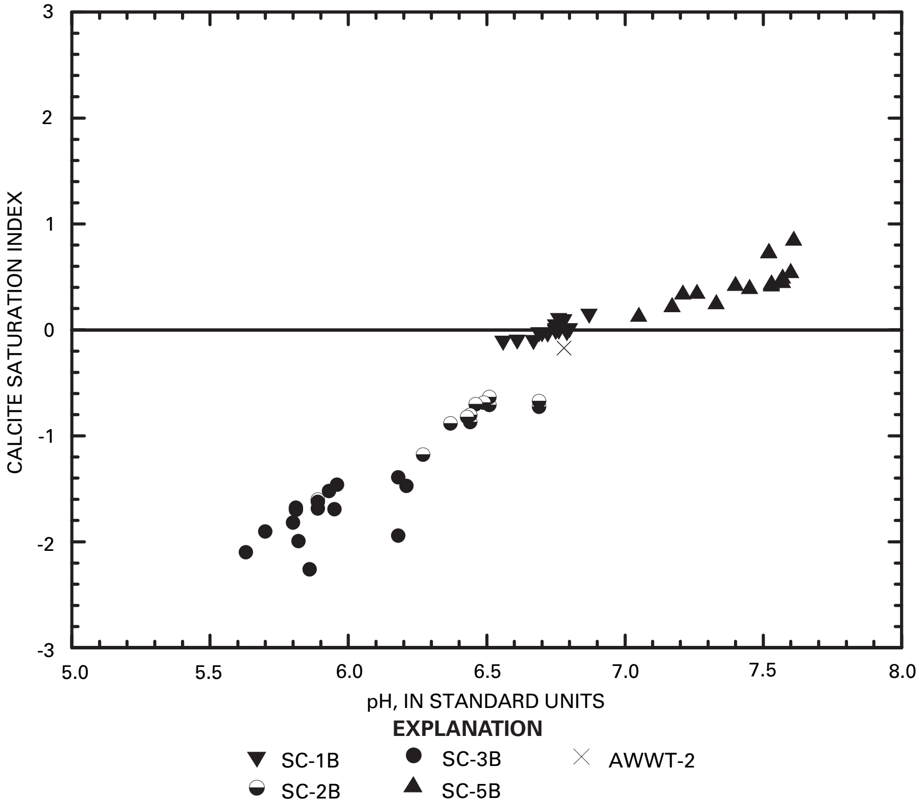

Figure 31. Comparison of calcite saturation indices to pH.

Another source of calcium in ground water is dissolution of fluorite (CaF_2). Fluorite dissolution also may be the major source of fluoride in ground water. Fluoride concentrations and saturation indices allow better understanding of the geochemical processes governing fluoride mobility. Fluoride concentrations and calcium concentrations (fig. 32A) show a strong correlation for debris-flow aquifer ground water but not for bedrock aquifer ground water. The plot of fluoride concentrations and sulfate concentrations (fig. 32B) indicates a similarly strong correlation for debris-flow aquifer, but not bedrock aquifer, ground water. In both plots, points for wells SC-7A and AWWT-1 plot slightly below the best-fit line for debris-flow aquifer wells. Plots of fluorite saturation indices compared to calcium concentrations (fig. 32C) and to pH (fig. 32D) indicate that water from SC-5B and possibly SC-1B reaches saturation but that water from AWWT-2 and from SC-2B is supersaturated. The main difference in general chemistry between SC-3B (all undersaturated with respect to fluorite) and SC-2B (nearly all supersaturated with respect to fluorite) is that SC-2B contains about 0.5-2 mg/L of aluminum, whereas SC-3B contains 4-7 mg/L of aluminum. Although this difference in aluminum concentration is small, it is enough, along with the difference in pH, to produce considerably more aluminum-fluoride complexing in SC-3B, which reduces the free fluoride ion activity enough to result in undersaturation. This example demonstrates the sensitivity of the fluorite saturation index to aluminum concentrations in the pH range of 5-7.

Magnesium Chemistry

Magnesium concentrations compared to sulfate concentrations (fig. 33A) exhibit the strong correlation observed for other elements in shallow ground-water samples (except SC-4A); SC-4A concentrations plot along a mixing line between SC-3A and SC-3B samples. Again, the concentrations in the sample from well SC-8A indicate a large component of Red River alluvial aquifer water. Straight Creek surface-water sample concentrations fit separately to a linear correlation and indicate their deficiency in magnesium relative to shallow ground water. Consequently, Mg-carbonates or Mg-silicates must be dissolving in debris-flow aquifer ground water, and considerable Mg-carbonates must be dissolving to yield SC-1B and AWWT-2 ground-water composition. In contrast to these samples, SC-5B water appears to reflect calcite dissolution but little Mg-carbonate dissolution. However, this interpretation is speculative unless it can be confirmed by saturation indices. Magnesium is the second most abundant cation in ground water in Straight Creek aquifers; both shallow and bedrock aquifer ground water is a calcium sulfate type water. Ground water with high magnesium concentrations usually is found only in terrains containing mafic to ultramafic rocks or in dolostone terrains. Early literature made no mention of dolomite (for example, Schilling, 1956), but more recent investigations have confirmed the presence of dolomite as a hydrothermal mineral accompanying calcite (G.S. Plumlee, U.S. Geological Survey, oral commun., 2003; B.M. Walker, Molycorp, oral commun., 2003). Hence, dolomite and (or) magnesium-rich calcite dissolution is the most likely primary source of magnesium in ground water. Because detailed information on the composition of carbonates in the Straight Creek drainage basin is not available, these magnesium-rich carbonates are called “Mg-carbonates” in this report. Magnesium also could be weathered from fine-grained chlorite that is abundant in most rocks in the valley, and differentiating the relative proportions by mass-balance calculations might be possible (Bricker and others, 2004).

In a plot of magnesium concentrations and calcium concentrations (fig. 33B), the correlation is strong for all concentrations in debris-flow aquifer water (except SC-4A concentrations, which were a bit discrepant) and SC-3B water. Water from SC-2B also was not far from the best fit. This strong correlation indicates one main source of magnesium for debris-flow and bedrock aquifer ground water. The exceptions are water from wells SC-1B, SC-5B, and AWWT-2. Concentrations of magnesium in SC-1B and AWWT-2 water are considerably higher than the best-fit line, indicating that Mg-carbonates in the bedrock are dissolved as surface water infiltrates to bedrock. Magnesium concentrations in water from SC-3B and SC-2B may be lower than in SC-1B and AWWT-2 water because of admixed debris-flow aquifer water (relatively low pH in SC-3B (fig. 33C) indicates mixing with debris-flow aquifer water) or loss of magnesium during downgradient flow. In contrast to magnesium concentrations in SC-1B and AWWT-2, magnesium concentrations in SC-5B ground water are considerably lower than the best-fit line for debris-flow aquifer ground water. To understand why magnesium concentrations in SC-5B ground water are so low relative to water in other bedrock aquifer wells, saturation indices must be examined.

In a plot of saturation indices of dolomite and pH (fig. 33C), dolomite saturation is reached for ground water from wells SC-1B, SC-5B, and AWWT-2. This result and the data in figures 33A and B present strong evidence for hydrothermal dolomite dissolution in the bedrock at Straight Creek. Because water from SC-5B is at or near saturation with respect to dolomite, there may be no tendency to dissolve Mg-carbonates and the water cannot increase in magnesium concentration any further. However, this does not explain why magnesium concentrations are so low. Sulfate concentrations in SC-5B water may provide an explanation. Although at gypsum saturation, sulfate concentrations in water from SC-5B are lower than those in SC-1B and SC-3B by about 25 percent (fig. 29B). Hence, some of the decreased magnesium may be caused by dilution. Interpretation of the helium-3/tritium age-dating results indicates that SC-5B water contains a high proportion of water from the Red River alluvial aquifer; this interpretation is supported by the location of the observation well. Diluted SC-5B ground water should therefore have lower magnesium concentrations and still be at gypsum, calcite, and dolomite saturation because of the minerals in debris-flow material and the highest calcium concentrations in well SC-5B. In a plot of dolomite saturation indices and calcium concentrations (fig. 33D), dolomite saturation is reached in water having the highest calcium concentrations. Another factor that accounts for dolomite saturation at lower magnesium concentrations in SC-5B water than in SC-1B water is the consistently higher pH in SC-5B water. Higher pH will produce saturation for carbonates at lower solute concentrations.

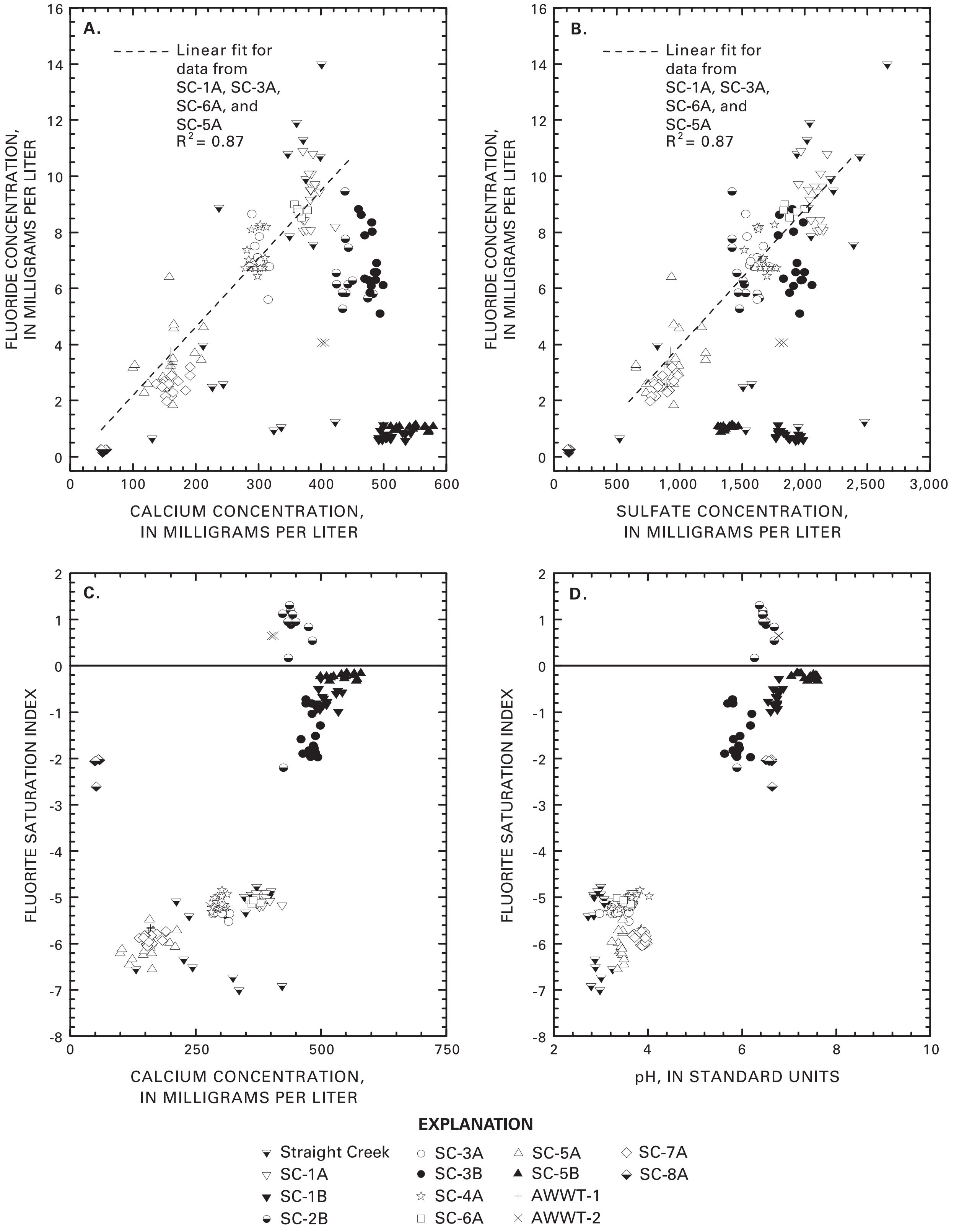

Figure 32. Comparison of (A) fluoride concentrations to calcium concentrations, (B) fluoride concentrations to sulfate concentrations, (C) fluorite saturation indices to calcium concentrations, and (D) fluorite saturation indices to pH.

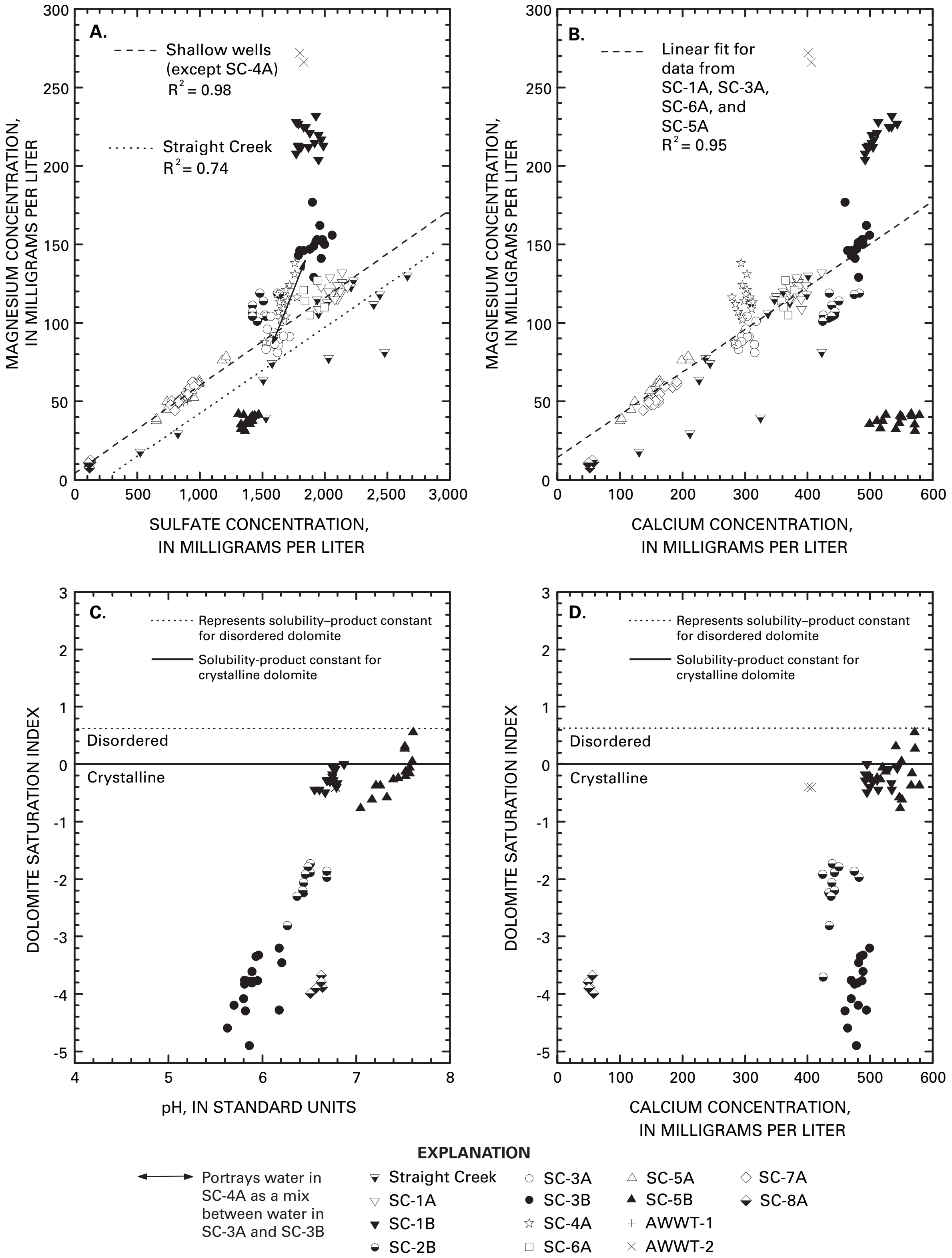

Figure 33. Comparison of (A) magnesium concentrations to sulfate concentrations, (B) magnesium concentrations to calcium concentrations, (C) dolomite saturation indices to pH, and (D) dolomite saturation indices to calcium concentrations.

Strontium Chemistry

Strontium concentrations should be related to other alkaline earth element geochemistry, especially to that of calcium, and to the dissolution of carbonate minerals. In figure 34A, strontium concentrations are low in shallow ground water but increase dramatically and continuously with increasing calcium concentration in bedrock aquifer ground water. This trend strongly implicates carbonate dissolution as the source of most of the strontium in ground water.

In a plot of strontium and sulfate concentrations (fig. 34B), strontium concentrations in shallow ground water are again low and do not correlate well, whereas concentrations in bedrock aquifer ground water increase with increasing sulfate concentrations. Celestite ($SrSO_4$) saturation is reached in ground water from wells SC-1B, SC-5B, and AWWT-2 but not in other ground-water samples (fig. 34C). Strontianite ($SrCO_3$) saturation is not reached in any ground-water samples (fig. 34D). Celestite precipitation may limit the concentrations of strontium in bedrock aquifer ground water.

These saturation-state results are strikingly similar to those found by Plummer and others (1990) for the regional Madison Limestone aquifer. They found that calcite, celestite, and anhydrite saturations were reached in ground water with the highest sulfate concentrations and that strontianite saturation was never reached. They explained that application of the Gibbs phase rule did not allow simultaneous equilibria of all four phases, and they calculated a saturation index for strontianite of -1.4 from thermodynamic data when calcite, anhydrite, and celestite were all at equilibrium. Values of strontianite saturation indices averaged -1.2 ± 0.2 from field data, in good agreement with their prediction. Strontianite saturation indices from Straight Creek ground-water data range from -1.5 to -0.5. The average saturation index for SC-1B water is -1.09 ± 0.08 and for SC-5B water is -0.75 ± 0.19. These results are in substantive agreement with those from the study by Plummer and others (1990). The thermodynamic data for this grouped equilibrium (calcite, anhydrite, and celestite) were recalculated on the basis of updated thermodynamic data from Nordstrom and others (1990), using gypsum instead of anhydrite and using an average ground-water temperature of 7 ºC. The resulting strontianite saturation index is -1.15, which is more similar to strontianite saturation indices averaged from field data than to the saturation index (-1.4) calculated by Plummer and others (1990).

Silica Chemistry

Reactions involving silica are complicated by multiple sources for possible silica dissolution (numerous aluminosilicates), variable silica dissolution rates, and rates of silicate precipitation that can vary widely depending on temperature, pH, and the mineral phase precipitating. Nevertheless, the considerable range of silica concentrations in ground-water samples from the Straight Creek drainage basin is explicable when several trends are recognized.

A plot of silica and sulfate concentrations is shown in figure 35; three lines indicate dilution or mixing trends. The correlation of debris-flow aquifer ground water from wells SC-1A, SC-3A, SC-5A, and SC-6A is consistent with dilution trends for other constituents in this water. Ground water from wells SC-7A and AWWT-1 plots below the best-fit line for debris-flow aquifer wells, and water from SC-8A is much more dilute than water from other shallow wells. Water from SC-4A again appears along a mixing line between SC-3A and SC-3B. Most Straight Creek surface water also follows a downgradient dilution trend but at lower concentrations than debris-flow aquifer ground water.

In addition to these dilution/mixing trends, several other aspects are important to the interpretation. Bedrock aquifer ground water contains consistently lower silica concentrations (less than 30 mg/L) than concentrations in debris-flow aquifer ground water (55-105 mg/L). Furthermore, if water that is similar in composition to Straight Creek surface water is the main type of water infiltrating to both debris-flow and bedrock aquifers, then silica must be dissolving in acidic debris-flow aquifer ground water and precipitating from circumneutral bedrock aquifer ground water. Several possible sources of silicates that might dissolve in acidic ground water are feldspar, sericite, biotite, phlogopite, chlorite, epidote, and kaolinite. Because all these minerals contain aluminum, aluminum concentrations also would be expected to increase from Straight Creek surface-water composition to that of debris-flow aquifer ground water. However, figure 28B indicates that rather than increasing, aluminum concentrations decrease on the same dilution trend as that for Straight Creek surface water. This difference in behavior between silica and aluminum was unexpected but possibly could be explained if aluminum remained associated with the mineral phase but silica did not. For example, an aluminum hydroxysulfate mineral phase of low solubility may form on the surface of the dissolving aluminosilicate. The high sulfate concentrations may enhance this secondary mineral formation, preventing aluminum from leaving the surface but not affecting silica dissolution. Another possibility is silica-sulfate complexing (Marshall and Chen, 1982), but this complex has not been confirmed and is unlikely to be important at low pH and low temperature.

Finally, silica concentrations in ground water from wells AWWT-1 and SC-7A, like aluminum concentrations (fig. 28B), are considerably lower than those in well SC-5A and do not correlate with those in the other debris-flow aquifer wells. No other constituents as clearly indicate this decrease in concentrations in samples from well SC-5A to those in samples from wells SC-7A and AWWT-1. The pH of water in SC-7A and AWWT-1 is 3.9 or close to 4.0, whereas the pH of water from SC-5A is less than 3.5 (fig. 28C). This pH increase from less than 3.5 to nearly 4 may be critical for initiating aluminum and silica precipitation. An alternative hypothesis, mentioned previously, is that ground water may not flow along a path from well SC-5A to wells SC-7A and AWWT-1. Variable proportions of Red River alluvial aquifer water in wells SC-5A, SC-7A, SC-8A, and AWWT-1 also could explain differences in silica concentrations in water from these wells.

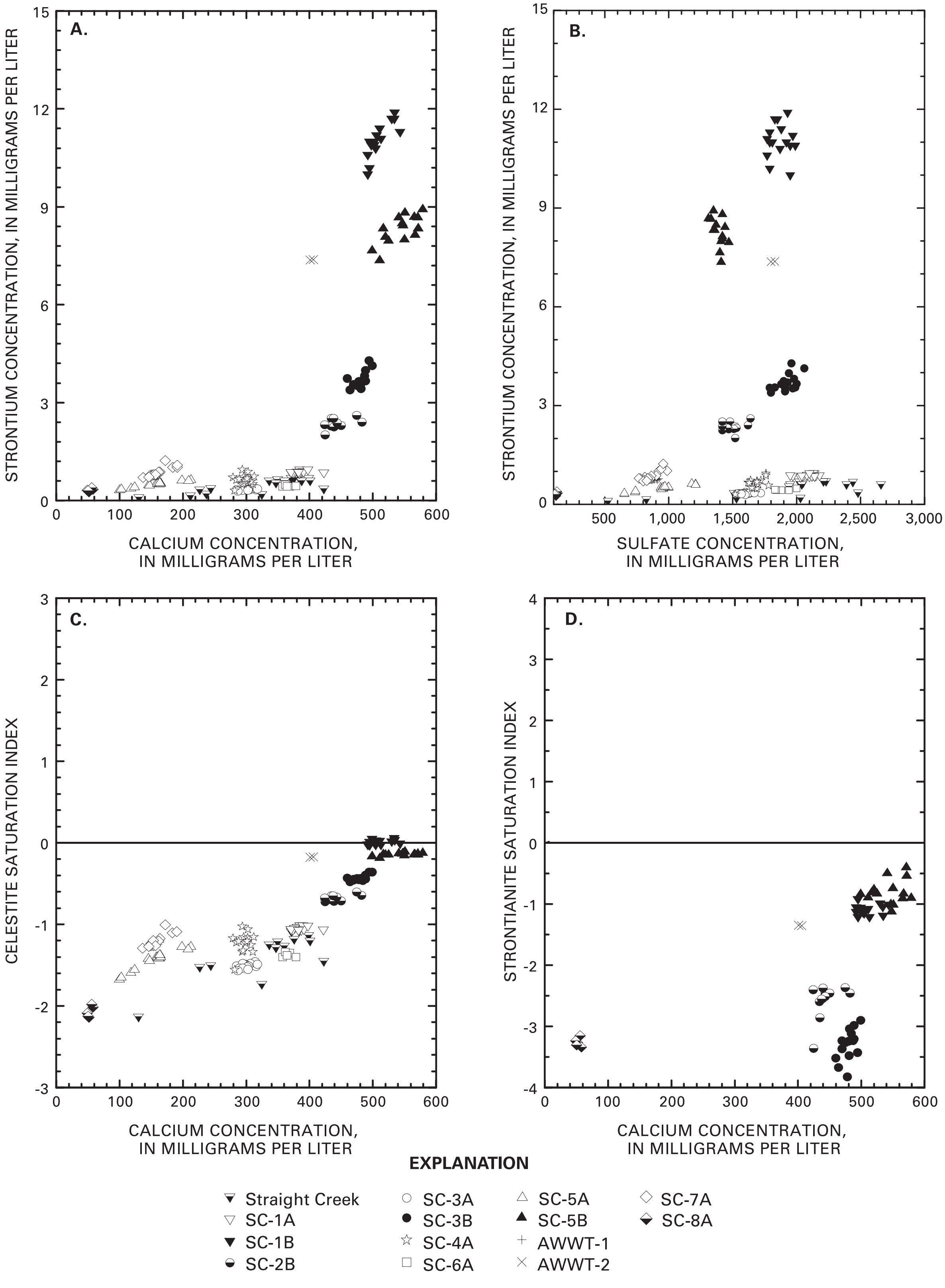

Figure 34. Comparison of (A) strontium concentrations to calcium concentrations, (B) strontium concentrations to sulfate concentrations, (C) celestite saturation indices to calcium concentrations, and (D) strontianite saturation indices to calcium concentrations.

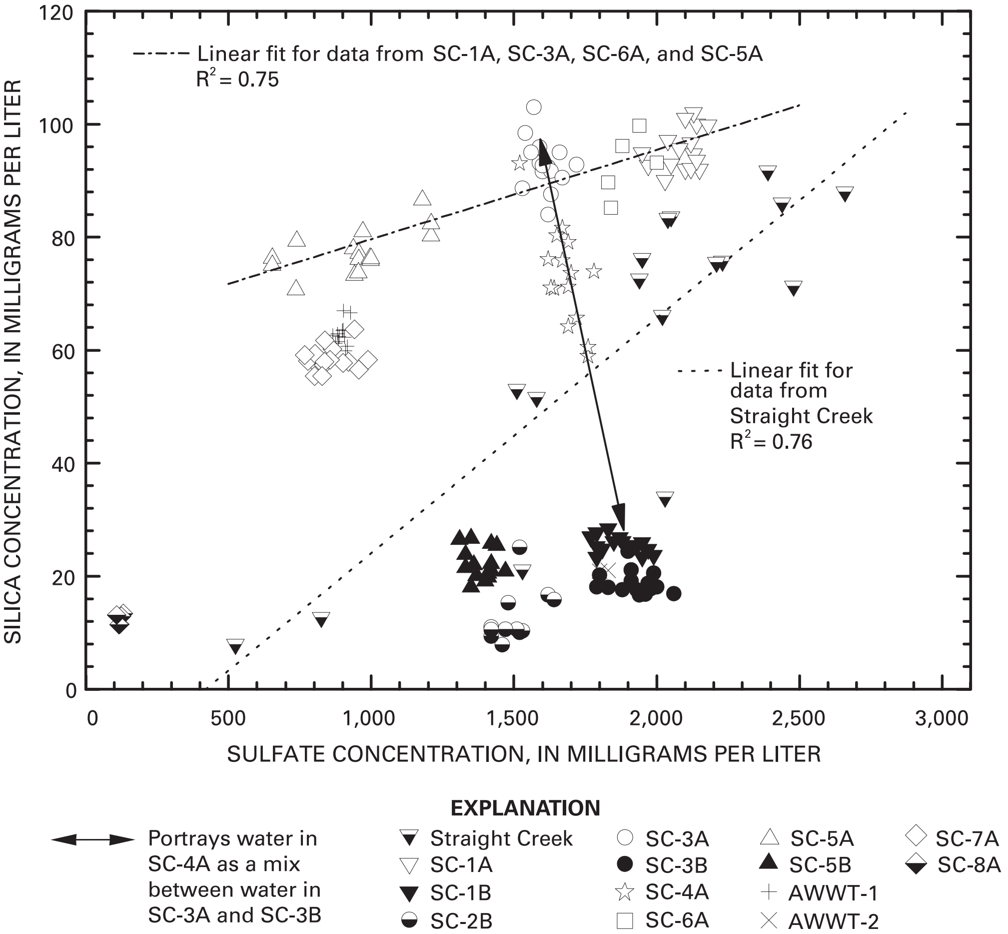

Figure 35. Comparison of silica concentrations to sulfate concentrations.

Alkali Metal Chemistry

Lithium. Lithium is found in phyllosilicates such as micas, some clay minerals such as smectites, and in spodumene. The pyroxene spodumene is not known to occur in the Straight Creek area, thus micas and their altered or weathered counterparts are the most likely source of lithium. Lithium is a conservative element in water; the linear fit for lithium and sulfate concentrations in debris-flow aquifer ground water (fig. 36) reflects this non-reactive characteristic. Lithium concentrations in Straight Creek surface water are similar to those in debris-flow aquifer ground water, indicating no substantial addition of lithium as the water infiltrates. Water from SC-4A is consistent with mixing along a trend from water in SC-3A to water in SC-3B. The highest lithium concentrations in bedrock aquifer ground water are in water from well SC-2B, and the lowest concentrations relative to sulfate are in water from well SC-5B. These low concentrations in water from well SC-5B support the hypothesis of substantial dilution by water from the Red River alluvial aquifer. The high concentrations in water from well SC-2B are unusual and may reflect a local anomaly in leachable source rock.

Sodium. Sodium is leached from alkali feldspars, micas, and some clay minerals and can be derived from septic-tank leachate or road salt applications. Sodium concentrations in water from wells SC-1B and SC-5B (fig. 37A) are much higher and more variable than concentrations in water from all other wells. This range is not normal for ground water and indicates some anthropogenic influence. Sodium concentrations in water from well SC-1B reached a peak in early summer of 2002; concentrations in water from well SC-5B reached a broader peak in late summer to early winter of 2002 (fig. 37B). A plot of sodium and chloride concentrations, in milliequivalents per liter (fig. 37C), exhibits a correlation at high concentrations that indicates the source of the sodium in water from wells SC-1B and SC-5B to be partly sodium chloride. The correlation coefficient and slope for the linear regression of the SC-1B data are 0.90 and 2.4, respectively. The correlation coefficient for a linear regression of the data for wells SC-1B and SC-5B was 0.65 because the data for well SC-5B are more scattered, but the slope of 2.6 is nearly identical to that for the regression of SC-1B data only. Either slope is greater than one, indicating that another source of soluble sodium besides sodium chloride must be present. It is unreasonable to assume that sodium chloride or another sodium salt is leaching from the bedrock when the rest of the chemistry, except for iron and hydrogen sulfide, is constant. Wells SC-1B and SC-5B were the only bedrock aquifer wells that developed hydrogen sulfide and had iron concentrations that varied over time. It was therefore concluded that sodium chloride and one or more additional soluble sodium salts were components of the additives introduced into these wells.

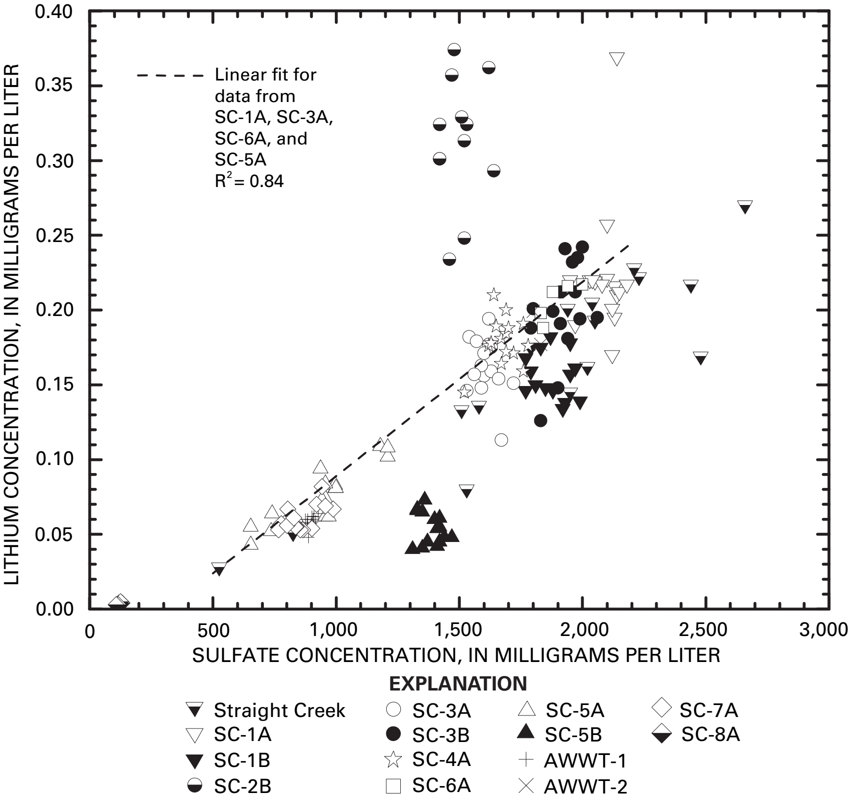

Figure 36. Comparison of lithium concentrations to sulfate concentrations.

Hence, the lowest sodium concentration measured for each well is probably the most reliable value for interpreting water/rock interactions. The close correspondence of sodium concentration in AWWT-2 with the lowest concentrations in SC-1B and SC-5B lends credibility to this hypothesis. Comparison of sodium concentrations in all ground-water samples with sodium concentrations in Straight Creek surface-water samples indicates that additional sodium is weathered from both the debris flow and the bedrock. The most likely source is plagioclase feldspar, primarily albite. Three observations may be drawn from the plot in figure 37D: (1) lithium concentrations are generally unrelated to sodium concentrations, (2) the highest lithium concentrations occur at the lowest sodium concentrations, and (3) the largest variability in lithium is in bedrock aquifer ground water.

Potassium. Potassium leaches from rocks to a lesser extent than sodium because potassium minerals are less soluble than their sodium counterparts. For example, albite ($NaAlSi_3O_8$) weathers more readily than microcline ($KAlSi_3O_8$); paragonite ($NaAl_3Si_3O_{10}(OH)_2$) weathers more readily than muscovite ($KAl_3Si_3O_{10}(OH)_2$); and sodic jarosite ($NaFe_3(SO_4)_2(OH)_6$) weathers more readily than potassic jarosite ($KFe_3(SO_4)_2(OH)_6$). Hence, potassium concentrations in water are nearly always lower than sodium concentrations. The water in the Straight Creek drainage basin is no exception. Although potassium concentrations consistently increase with increasing sodium concentrations, sodium concentrations are always higher (fig. 38A). Trends in a plot of potassium and sulfate concentrations (fig. 38B) are similar to those in a plot of sodium and sulfate concentrations (fig. 37A). Potassium also must be leaching out of both debris-flow and bedrock aquifers because the concentrations of potassium in all ground water are higher than concentrations in Straight Creek surface water. High potassium concentrations in wells SC-1B and SC-5B may indicate that some potassium accompanied the contaminants that were introduced into these wells. An alternative possibility is that wells SC-1B and SC-5B penetrated localized organic matter that is decomposing and contributing additional potassium.

Trace Element Chemistry

Zinc. Zinc is usually a conservative element during transport in aquatic systems until rather high pH is reached. In shallow ground water, zinc follows the same distinct dilution trend with respect to sulfate as other constituents, and no zinc addition from the debris-flow or Red River alluvial aquifers is needed to achieve that composition (fig. 39A). Zinc concentrations in all bedrock aquifer ground water, however, are lower than those in Straight Creek surface water or shallow ground water. Because the primary source of zinc in the Straight Creek drainage basin likely is oxidative weathering of sphalerite (ZnS), the lack of zinc in the bedrock aquifer indicates little sulfide oxidation. Alternatively, zinc may have been at higher ini-

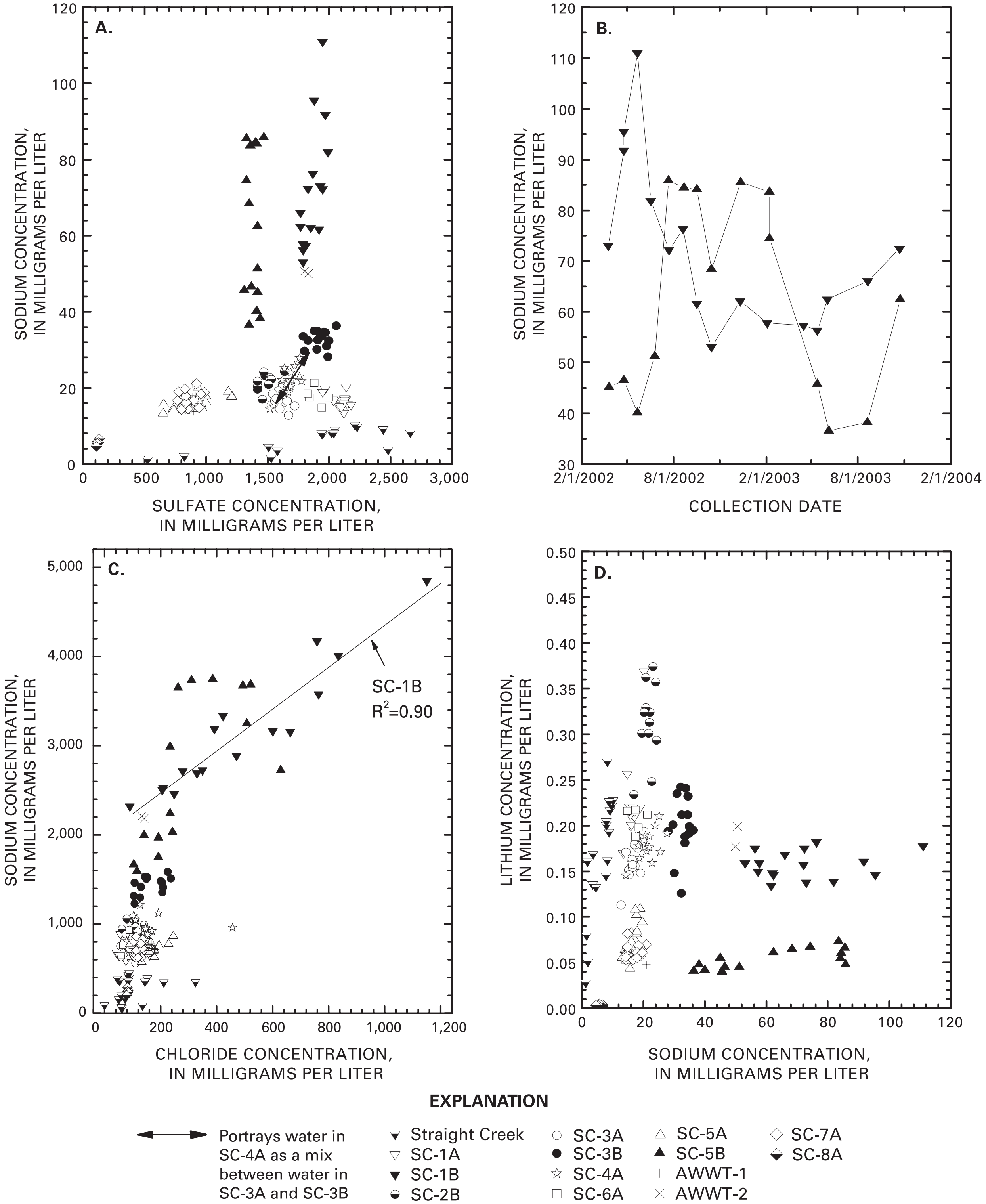

Figure 37. Comparison of (A) sodium concentrations to sulfate concentrations, (B) sodium concentrations over time for wells SC-1B and SC-5B, (C) sodium concentrations to chloride concentrations, and (D) lithium concentrations to sodium concentrations.

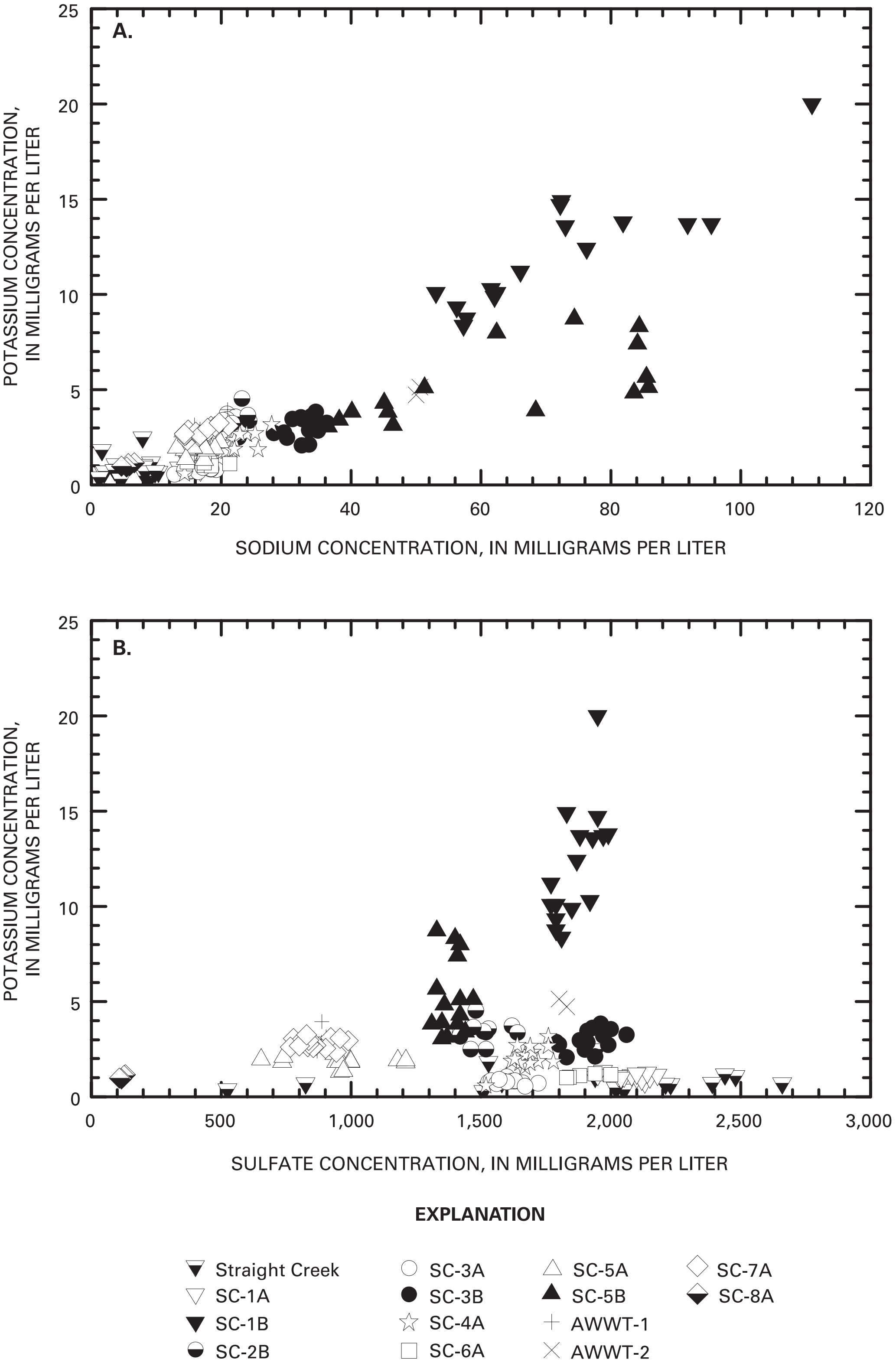

Figure 38. Comparison of (A) potassium concentrations to sodium concentrations and (B) potassium concentrations to sulfate concentrations.

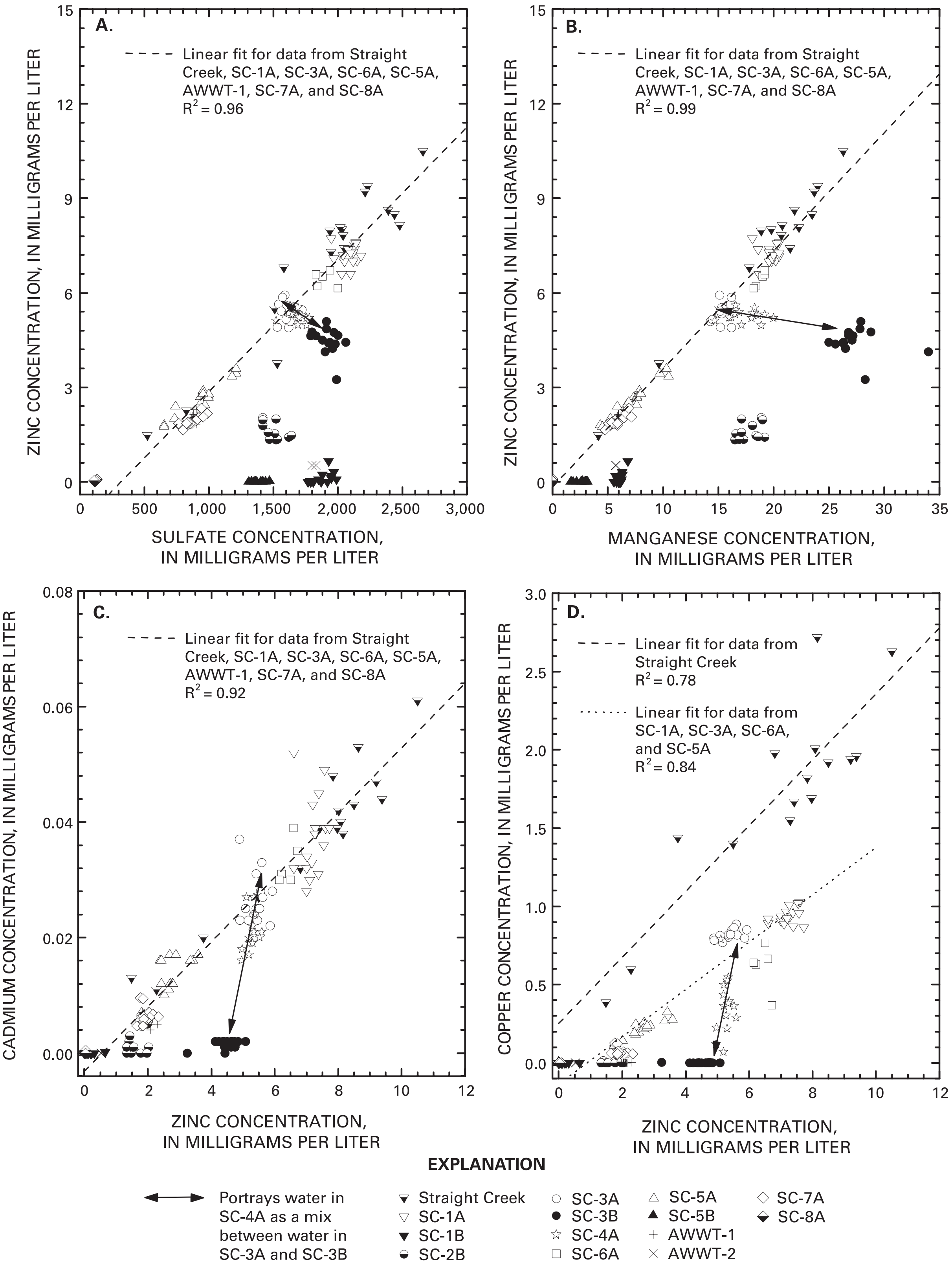

Figure 39. Comparison of (A) zinc concentrations to sulfate concentrations, (B) zinc concentrations to manganese concentrations, (C) cadmium concentrations to zinc concentrations, and (D) copper concentrations to zinc concentrations.

tial concentrations in the recharge area but sorbed onto aquifer surfaces during transport. The latter possibility seems unlikely because pH values are not very high. Zinc concentrations in water from well SC-3B are the highest of any bedrock aquifer well, corroborating the hypothesis that the bedrock aquifer at SC-3B may have some hydraulic connection with the debris-flow aquifer.

When another trace metal such as manganese is used instead of sulfate for correlation (fig. 39B), the linear fit is even better than it is with sulfate for shallow ground water. This improved fit is probably related to the greater accuracy and precision of zinc and manganese determinations than of sulfate determinations. Ground water from SC-4A follows a mixing trend between water from SC-3A and SC-3B (fig. 39).

Zinc and cadmium have similar chemical properties and when sphalerite oxidation is the main source of zinc, it also is likely the main source of cadmium. Furthermore, cadmium-to-zinc weight ratios in sphalerite are often near 1:200 regardless of the type of mineral deposit (Fleischer, 1955), and the same ratio is often observed in acid drainage water from the same mine site (for example, Nordstrom, 1977a). The close correlation of cadmium with zinc (fig. 39C) is similar to that for zinc with sulfate and for zinc with manganese. Furthermore, the cadmium to zinc weight ratio for this water also is about 1:200. All shallow ground water (except SC-4A) and Straight Creek surface water plot together along the same linear dilution trend. Again, the mixing trend of water from SC-4A between that from SC-3A and SC-3B is evident.

Copper. Copper is not conservative (fig. 39D). A dilution correlation for copper is evident in debris-flow aquifer water, but concentrations are all lower relative to Straight Creek surface-water concentrations. This trend also is evident in a plot of copper and sulfate concentrations (fig. 40). This decrease is strong evidence for sorption or reactive removal of copper from water in the debris-flow aquifer, although substantial removal of copper seems unusual and is unlikely to be caused by sorption at these pH values (3-4) and these copper concentrations (1-3 mg/L). A considerable amount of clay and hydrous ferric oxides undoubtedly exists within the debris-flow aquifer and could affect adsorption. Because there apparently is a dilution trend, however, the sorption would all have to occur between the infiltration of Straight Creek surface water and well SC-1A,

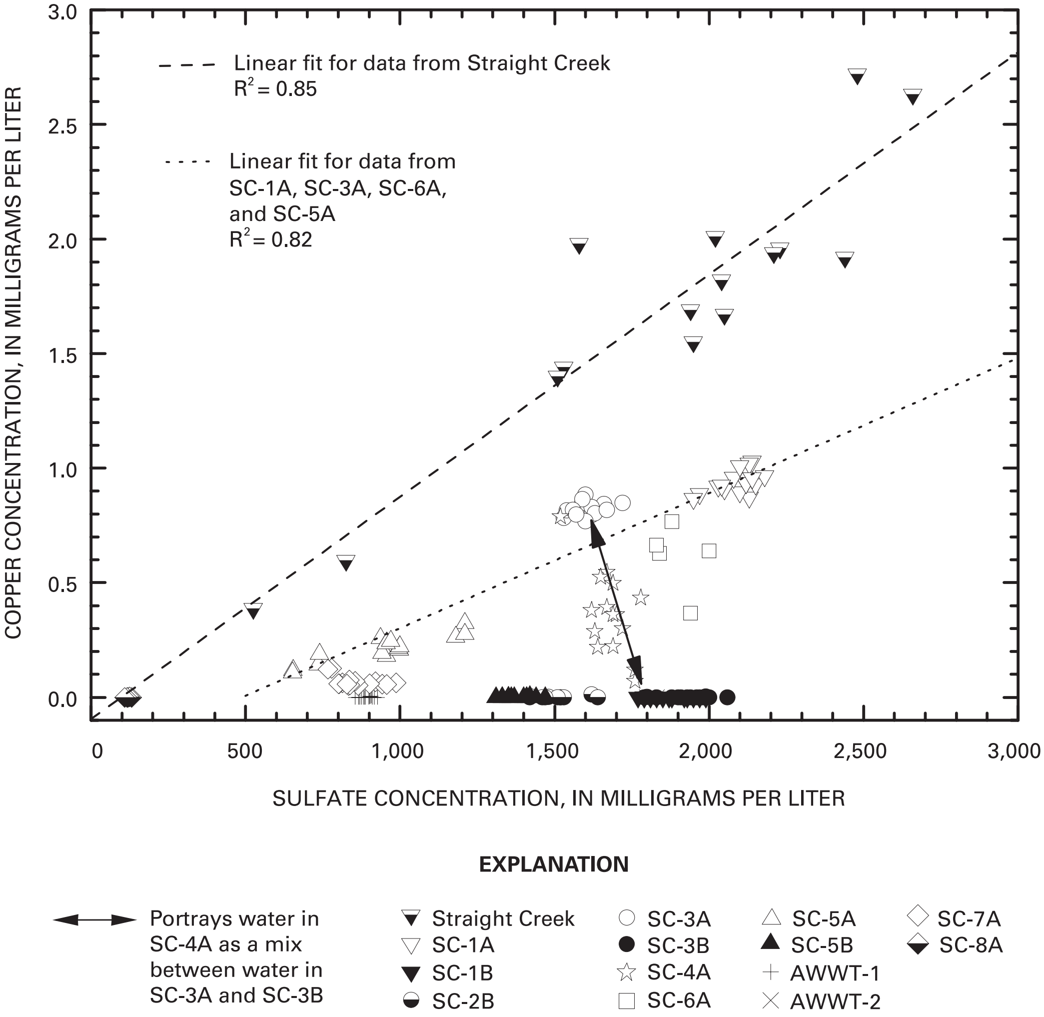

Figure 40. Comparison of copper concentrations to sulfate concentrations.

a scenario that seems unlikely. Another possibility is that sulfate concentrations increase from gypsum dissolution without any change in copper concentrations along this flow path, again unlikely because calcium concentrations increase only slightly and sulfate concentrations either do not change or decrease slightly along the flow path from Straight Creek surface water to SC-1A ground water (fig. 29). Ferrous iron concentrations considerably increase along this flow path, apparently because of reductive iron dissolution rather than pyrite oxidation because sulfate concentrations do not change (fig. 24C). Reductive iron dissolution requires organic matter as the driving force. In this rapidly eroding debris flow, evergreen trees often are uprooted by physical erosion during floods. Numerous trees of considerable size have been observed as deadfall lying across Straight Creek and buried in the debris, and woody material was occasionally found in drill-return material. Buried in the debris-flow sediments are broken branches, log stumps, and major portions of trees that likely provide the necessary organic material for reductive iron dissolution. Copper is easily reduced and can form reduced insoluble copper compounds and even elemental copper in buried trees found in sediments. This is the preferred viable hypothesis at present.

Nickel and cobalt. Nickel and cobalt are two other trace elements found at relatively high concentrations in Straight Creek ground water. A plot of nickel and sulfate concentrations (fig. 41A) shows a strong correlation in shallow ground water, and the dilution trend is congruent with Straight Creek surface water. Even concentrations in water from well SC-2B plots directly on the same trend. Cobalt and nickel are chemically and geochemically similar, and figure 41B reflects a strong correlation between these two elements; no substantial change in concentration, other than that caused by dilution, is evident along the flow path from Straight Creek surface water to ground water. Higher cobalt concentrations in well SC-3B than concentrations in other bedrock aquifer ground water are not readily explicable unless water from the debris-flow aquifer, such as that in wells SC-3A and SC-4A, is hydraulically connected with bedrock aquifer ground water in SC-3B, as previously postulated.

Barium. Barium concentrations should be extremely low in high sulfate water because of the common-ion effect and the insolubility of barite ($BaSO_4$). This assumption is confirmed in a plot of barium and sulfate concentrations (fig. 42A). No dilution trend is evident for shallow ground water. Indeed, the opposite trend can be discerned: barium concentrations increase with decreasing sulfate concentrations as is expected if barite solubility equilibrium controls barium concentrations. Bedrock aquifer ground water is on a separate trend, also of increasing barium concentration with decreasing sulfate concentration but at higher sulfate concentrations. A plot of barite saturation indices and pH (fig. 42B) indicates that pH is a controlling factor in barite solubility. All bedrock aquifer and SC-8A ground water is saturated to supersaturated with respect to barite, whereas all debris-flow aquifer ground water is saturated to undersaturated. The higher pH in ground water from bedrock aquifer wells and SC-8A is related to the supersaturation effect. When barite saturation indices and barium concentrations are plotted (fig. 42C), barium concentrations range widely, as can be seen for the most supersaturated samples from SC-5B. Freshly precipitated barite is more soluble than aged or well-crystallized barite (Linke and Seidell, 1958; Hina and Nancollas, 2000). Thus, the supersaturation could be real and caused by the particle-size effect on solubility. Another factor related to particle-size effect is the ability to remove barite colloids by filtration. In a plot of dissolved barium concentrations and total recoverable barium concentrations (fig. 42D), a clear bias toward higher total recoverable barium concentrations is shown. This bias indicates barium-rich particles in ground water, some of which may not be filterable using 0.45-µm-pore-size filters.

Beryllium. Beryllium is generally present at concentrations less than 0.01 mg/L in most water because of low solubility and low abundance. In the Red River Valley, however, the range of dissolved beryllium concentrations is considerable. For Straight Creek surface-water and ground-water samples, a plot of beryllium and sulfate concentrations (fig. 43A) illustrates that beryllium concentrations are as high as about 0.04 mg/L. Again, the dilution trend is evident for debris-flow aquifer ground water, and beryllium concentrations are consistent with those in Straight Creek surface water. Concentrations in samples from wells SC-7A and AWWT-1 plot slightly below the best-fit line for the debris-flow aquifer wells, and concentrations in samples from well SC-8A are substantially lower than in other samples. Concentrations of beryllium in bedrock aquifer ground water are either near the top or bottom of the beryllium concentration range. In water from wells SC-1B and SC-5B, beryllium concentrations are at or lower than the 0.001-mg/L beryllium detection limit. In contrast, beryllium concentrations in water from wells SC-2B and SC-3B are some of the highest in all water samples. This result indicates that water in wells SC-2B and SC-3B is influenced either by debris-flow aquifer water or by local contributions from the rock. Beryllium concentrations and aluminum concentrations are plotted in figure 43B because beryllium often substitutes for aluminum in minerals. A striking bimodal distribution in which beryllium concentrations in SC-2B and SC-3B water are high at low aluminum concentrations is shown. In contrast, beryllium and aluminum concentrations in water from other wells are well correlated. This plot indicates that beryllium is soluble at neutral pH, whereas aluminum is not.

Beryllium is strongly associated with lithium and fluoride in pegmatitic and hydrothermal ore deposits (Rankama and Sahama, 1950; Griffitts, 1973). Substantial complexing between beryllium and fluoride is thought to be important in maintaining high concentrations of beryllium in hydrothermal fluids. Two typical examples of the strong beryllium-lithium-fluoride association are the hydrothermal beryllium deposits at Spor Mountain, Utah (Lindsey and others, 1973) and the pegmatite deposits in the Black Hills, South Dakota (Norton and others, 1964). Mineralization in the Red River Valley also contains high concentrations of beryllium, lithium, and fluoride, indicating a possible relation between beryllium and lithium concentrations in ground water from the Straight Creek drainage basin. The correlation is strong between beryllium and lithium in Straight Creek surface water and shallow ground water (fig. 44), and beryllium concentrations decrease (lithium concentrations increase) along the hypothesized flow path from surface to ground water. Plots shown previously of lithium and

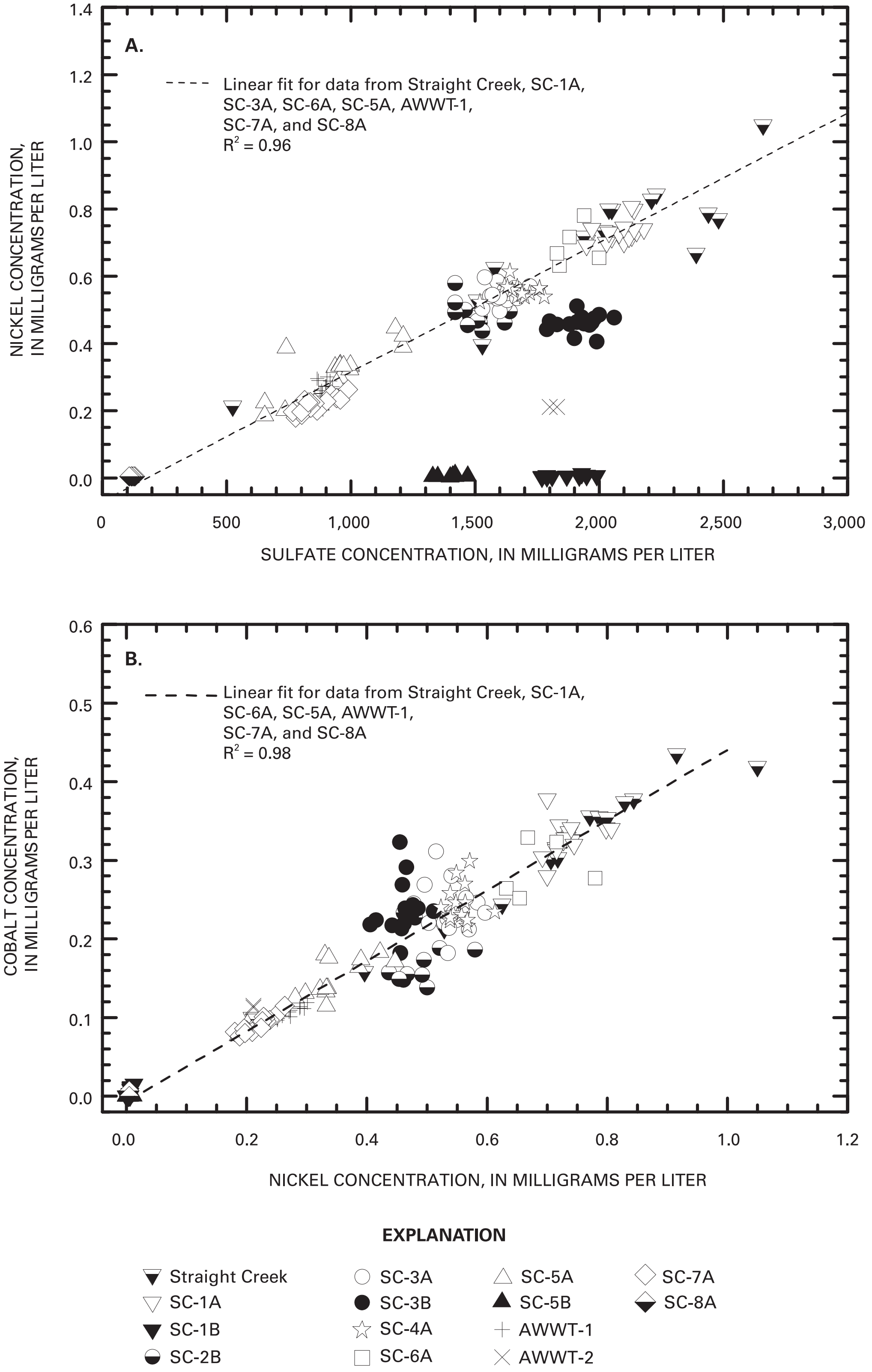

Figure 41. Comparison of (A) nickel concentrations to sulfate concentrations and (B) cobalt concentrations to nickel concentrations.

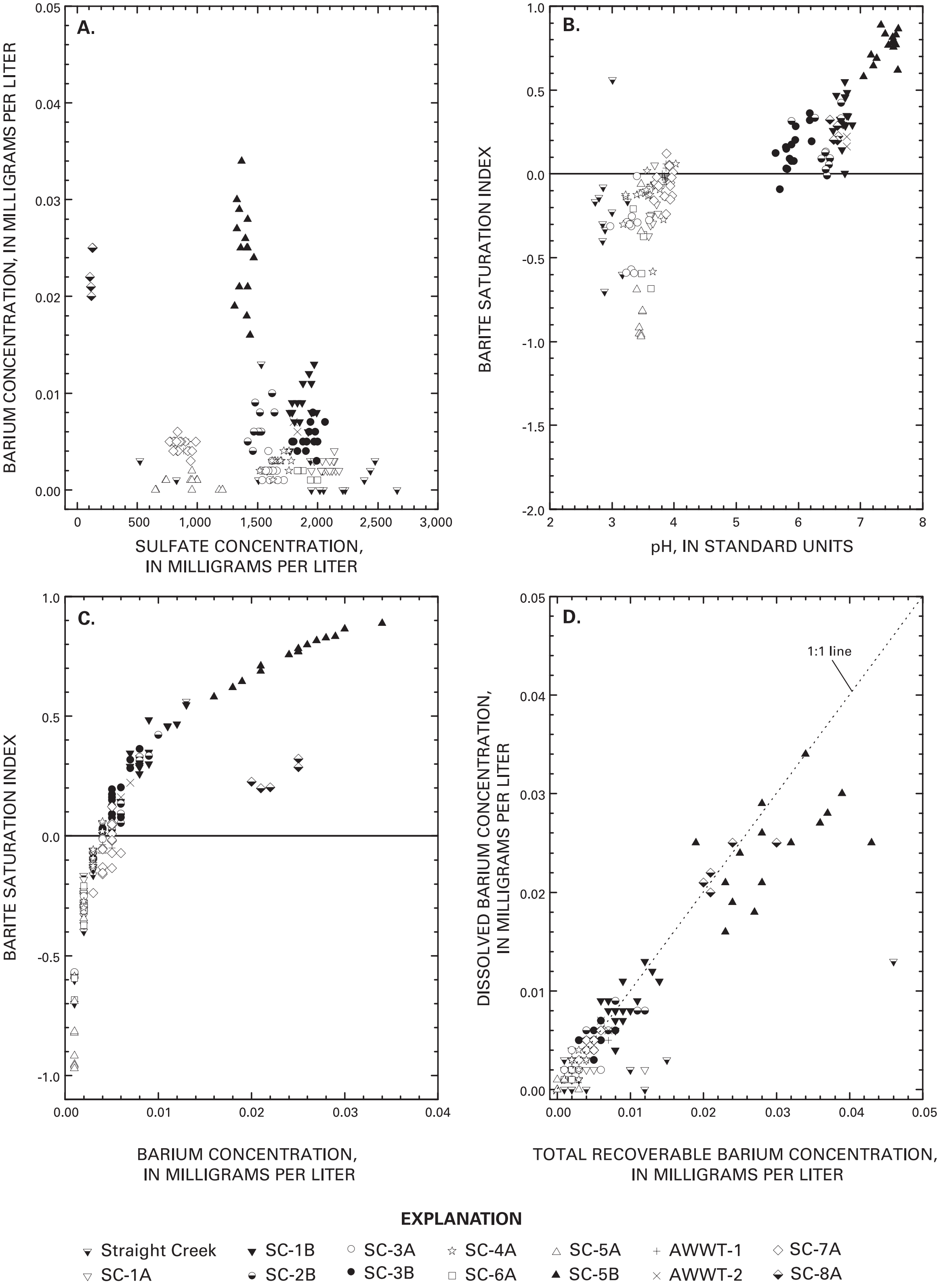

Figure 42. Comparison of (A) barium concentrations to sulfate concentrations, (B) barite saturation indices to pH, (C) barite saturation indices to barium concentrations, and (D) dissolved barium concentrations to total recoverable barium concentrations.

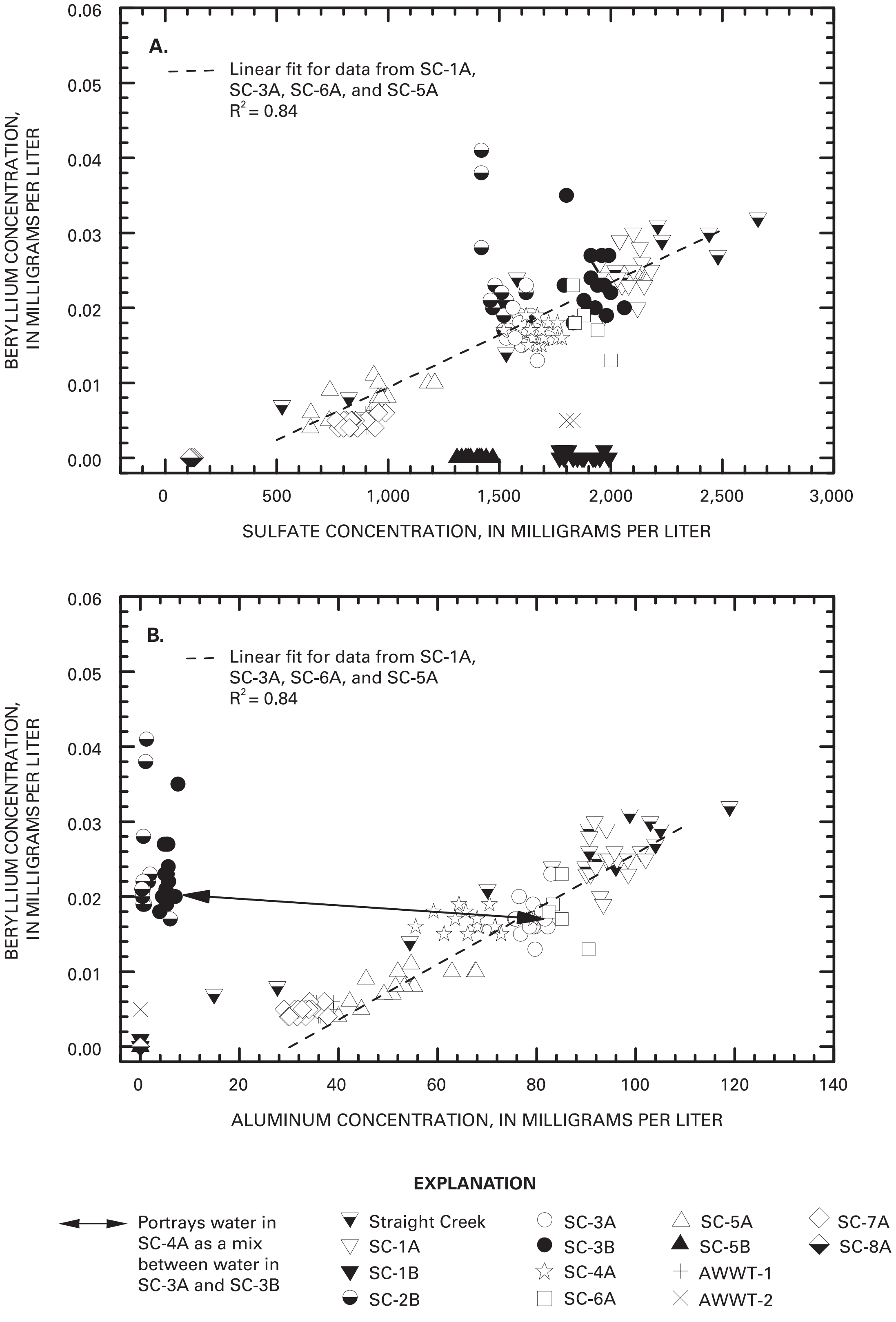

Figure 43. Comparison of (A) beryllium concentrations to sulfate concentrations and (B) beryllium concentrations to aluminum concentrations.

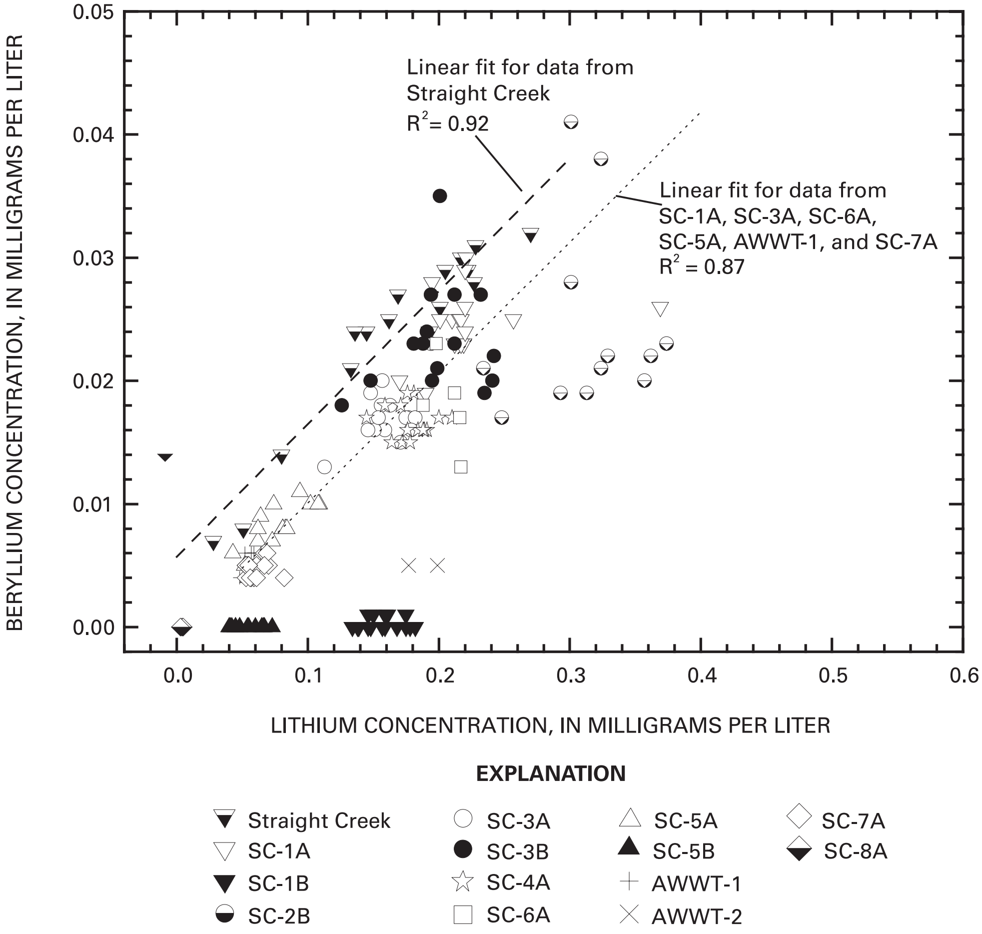

Figure 44. Comparison of beryllium concentrations to lithium concentrations.

sulfate concentrations (fig. 36) and beryllium and sulfate concentrations (fig. 43A) indicate that lithium is more likely elevated in the shallow ground water relative to Straight Creek surface water rather than beryllium being depleted. The strong correlation between beryllium and lithium indicates that the beryllium-lithium association in the mineralization is imparted to ground water during weathering.

Dissolved Organic Carbon. DOC concentrations in Straight Creek surface and ground water generally are low and typical of most natural water (approximately 1 mg/L). In water from SC-1B and SC-5B, however, DOC concentrations are as high as 33 mg/L (fig. 45A), whereas concentrations in water from all other wells were less than 5 mg/L. Water from wells SC-1B and SC-5B also contains high concentrations of hydrogen sulfide and the highest iron concentrations for circumneutral pH bedrock aquifer wells. These results support active sulfate reduction through carbon utilization. Furthermore, DOC concentrations temporally change in water from wells SC-1B and SC-5B (fig. 45B), decreasing gradually in water from SC-1B from nearly 20 to about 6 mg/L over about a 1-year period. DOC concentrations in water from SC-5B follow almost the same temporal trend with the exception of a 33-mg/L DOC concentration in a sample collected on August 22, 2002. The iron concentrations for these two wells also increase, then decrease, over this same time period (fig. 23A). These coincident trends support the argument that these two wells were contaminated with organic compounds introduced during well construction and that they were gradually returning to normal ground-water chemistry after 1 year.

Summary

In April 2001, the USGS and the New Mexico Environment Department began a cooperative study to infer the premining ground-water quality at the Molycorp molybdenum mine site in the Red River Valley in northern New Mexico. This study was prompted by the Water Quality Act, under the jurisdiction of the Water Quality Control Commission, which requires an operator to develop and complete an approved closure plan that prevents the exceedence of (1) standards set forth in the New Mexico Water Quality Control Commission Regulations (§20.6.2.3103 NMAC) or (2) the natural background concentrations.

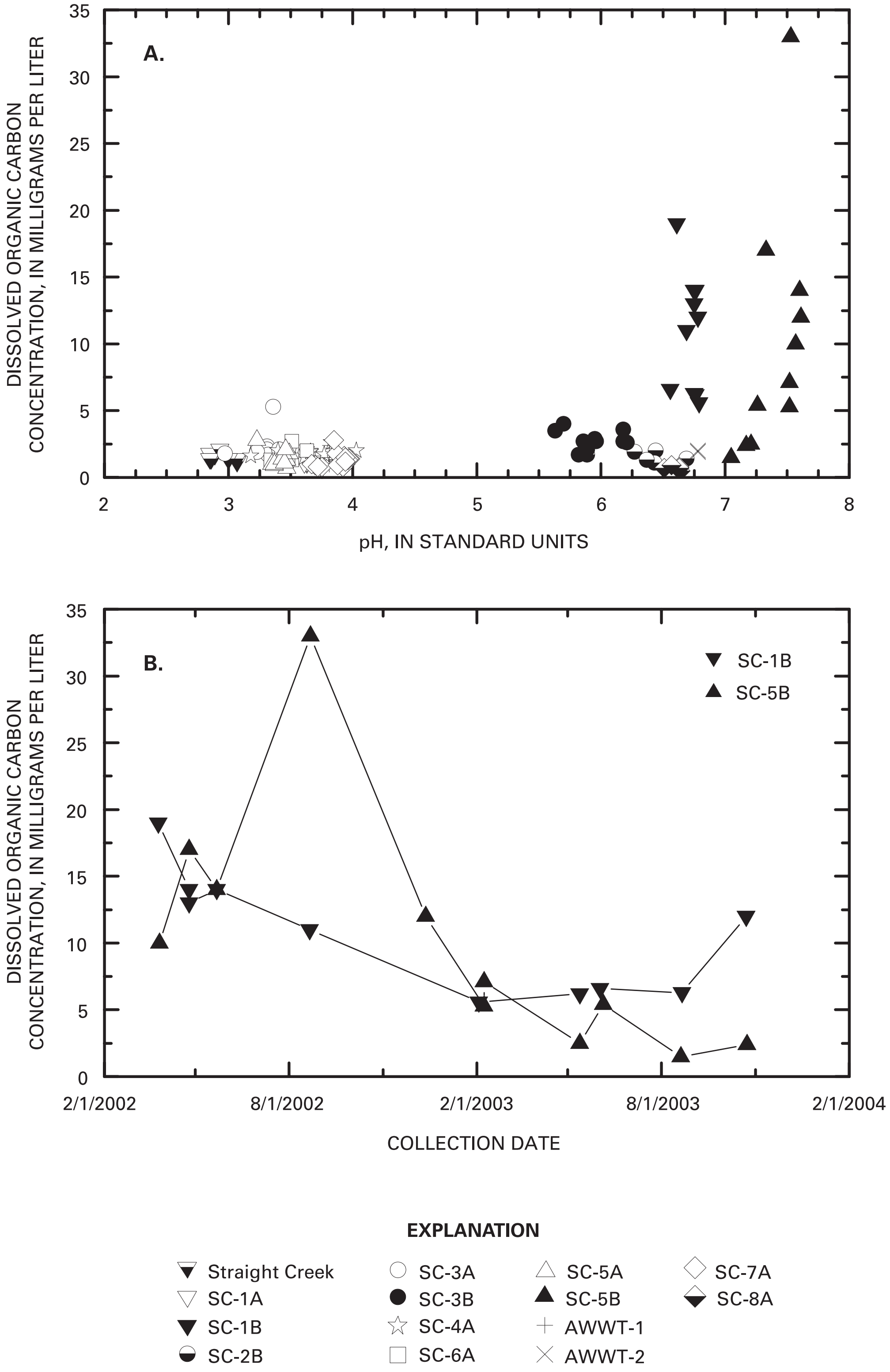

Figure 45. Comparison of (A) dissolved organic carbon concentrations to pH and (B) dissolved organic carbon concentrations over time for wells SC-1B and SC-5B.

The primary approach of the study is to determine the processes controlling ground-water chemistry at an unmined, off-site, proximal analog. The Straight Creek drainage basin, chosen for this purpose, consists of the same QSP altered andesitic and rhyolitic volcanic rock of Tertiary age as the mine site. The weathered and rugged volcanic bedrock surface is overlain by heterogeneous debris-flow deposits that interfinger with alluvial deposits near the confluence of Straight Creek and the Red River. Pyritized rock in the upper part of the drainage basin is the source of acid rock drainage (pH 2.8-3.3) that infiltrates debris-flow deposits containing acidic ground water (pH 3.0-4.0) and bedrock containing water of circumneutral pH values (5.6-7.7).

As part of this study, 29 observation wells and piezometers were installed in the Red River Valley. Eleven observation wells were installed in the Straight Creek drainage basin, which is the primary analog site from which pre-mining chemistry will be inferred. Six of the observation wells are debris-flow aquifer/bedrock aquifer well pairs (SC-1A / SC-1B, SC-3A / SC-3B, and SC-5A / SC-5B). SC-1A and SC-3A are completed entirely within debris-flow deposits, whereas the debris-flow deposits in which well SC-5A was completed probably interfinger with Red River alluvial deposits. Of the five additional wells in Straight Creek, well SC-2B was completed in bedrock, wells SC-4A and SC-6A were completed in debris-flow deposits, and wells SC-7A and SC-8A were completed in interfingering debris-flow and Red River alluvial deposits. In addition to the wells installed for this study, data were collected from two pre-existing wells, AWWT-1 and AWWT-2, in the Straight Creek Basin. Chemical analyses of ground water from these wells, combined with chemical analyses of surface water, water-level data, and lithologic and geophysical logs, provided information used to develop an understanding of the processes contributing to the chemistry of ground water in the Straight Creek drainage basin.

Lithologic logging identified the location of the debris-flow/bedrock contact, intervals of weathered bedrock, zones containing higher percentages of gravel within the debris-flow material, and probable interfingering of Red River alluvial and debris-flow deposits. The thickness and extent of the weathered bedrock are spatially variable, and the depth to the top of competent bedrock can vary considerably over a short distance. Depth to competent bedrock is very similar in wells SC-3A, SC-3B, and SC-4A, all of which are near the center of the drainage basin. The debris-flow material is heterogeneous, but the depth to the top of a gravel-dominated zone is consistent in wells SC-2B, SC-3A, and SC-4A.

Geophysical logs also were successful in identifying hydrogeologic structure in the debris-flow deposits. Logs for wells SC-1A, SC-1B, SC-2B, SC-4A, and AWWT-1 show the presence of intervals of partial saturation above the water table. Comparison of neutron logs made shortly after well completion with those obtained several weeks later indicated that perched zones are not an artifact of the well-completion process. The combined interpretation of induction and neutron logs, when available, indicates that some of the perched zones may contain water with considerably lower conductivity than that in the saturated zone and that bedrock aquifer water in well SC-1B is of higher conductivity than that in debris-flow aquifer wells. Logs in wells SC-1A, SC-3A, SC-4A, and SC-5A identified zones of relatively high permeability. Logs in bedrock aquifer wells and boreholes did not identify the contact between alluvial deposits and bedrock but did provide some information about the character of bedrock in the deep wells. Logs in SC-5B indicate a gradual change in bedrock properties with depth, and logs run in wells SC-2B, SC-3B, SC-5B, and AWWT-2 identified zones of low or decreasing porosity and permeability.

Water levels measured from March 2002 to December 2003 indicate that water levels in wells respond to the seasonal infiltration of surface water or spring snowmelt water. Straight Creek streamflow and water levels in wells closest to the apex of the Straight Creek debris fan and closest to Straight Creek itself appear to respond to the same seasonal inputs, and water-level trends in wells closest to the Red River apparently respond to the same seasonal influences that affect riverflow. The timing of water-level changes in wells SC-2B, SC-3A, and SC-4A is of the same general pattern as in SC-1A and SC-1B, but peaks in the hydrographs lag behind those in the upgradient wells. Water-altitude data for well pairs indicate downward hydraulic gradients within the system except at the SC-5A / SC-5B well pair, where the gradient is upward.

Several types of water-chemistry data were collected from March 2002 to October 2003 to help determine ground-water ages, geochemical signatures of solute sources in the aquifer materials, and processes contributing to the chemistry of ground water in the Straight Creek drainage basin. For ground-water age dating, ground-water samples were collected for determination of CFC and dissolved-gas and tritium concentrations. The stable isotopic composition of water and solid samples was determined to help establish geochemical signatures of solute sources in alluvial, debris-flow, and bedrock aquifers and to constrain water/rock interactions. To provide further information about the processes controlling ground-water chemistry, samples were collected for determination of total recoverable major cations and selected trace metals; dissolved major cations, selected trace metals, and rare-earth elements; anions and alkalinity; dissolved-iron redox species; dissolved organic carbon; and mercury.

Surface-water samples were collected using a peristaltic pump. Ground-water samples were collected from observation wells using bladder pumps capable of low flow rates (less than 0.5 liter/minute). Monitored field parameters included pH, temperature, specific conductance, dissolved oxygen, redox potential, turbidity, and (for the first two samplings) field-determined iron concentrations. A unique stabilization/purging time was established for each well based on stabilization of these parameters.

Analysis of monthly final field parameter measurements and selected analytical data revealed a few important trends and relations. In wells SC-1B and SC-5B, dissolved oxygen concentrations and Eh values decreased over time. Iron concentrations in these wells were lower than in other bedrock aquifer wells, presumably because of the documented presence of hydrogen sulfide (H_2S). The pH in water from wells completed in alluvial deposits (except well SC-8A) was considerably lower (3-4) than the pH in bedrock aquifer ground water (5.6-7.6). The relatively low pH of water from well SC-3B compared with that from other bedrock aquifer wells could indicate mixing with debris-flow aquifer ground water. Water from wells SC-7A, SC-8A, and AWWT-1 is of relatively high pH compared with water from other shallow (alluvial and debris-flow aquifer) wells, an indication of the influence of more neutral ground water in bedrock or Red River alluvial aquifers. Specific conductance is notably lower in ground water from wells SC-5A, SC-7A, SC-8A, and AWWT-1 than in that from all other wells and Straight Creek, which also indicates the influence of more dilute water in the Red River or its alluvial aquifer. Straight Creek surface-water pH values are similar to, but consistently lower than, those of water in wells completed in debris-flow deposits.

Helium-3/tritium dating yielded ages of shallow ground water ranging from less than 0.5 to about 23 years and of bedrock aquifer water from about 15 to greater than 60 years. These modeled ages show that ground water from wells completed in alluvial and debris-flow deposits is younger than that from bedrock aquifer wells, with the exception of wells SC-7A and AWWT-1. The age of water from wells SC-7A and AWWT-1 and the presence of excess helium-4 in wells SC-5B, SC-7A, and AWWT-1 indicate mixing with deeper, submodern (predating 1940's) ground water in the lower part of the Straight Creek drainage basin. The source of this submodern component may be deep bedrock discharge associated with mountain-block recharge in the area. Estimated recharge altitudes for samples from wells in the lower part of the Straight Creek drainage basin indicate that mixtures of debris-flow and alluvial aquifer water contain increasingly smaller proportions of debris-flow aquifer water in a downgradient direction. The distribution of ground-water ages in these wells also supports this conclusion and indicates that there may be less influence from deep bedrock recharge in the vicinity of wells SC-5A and SC-5B than near wells SC-7A and AWWT-1. The very young (less than 0.5 year) estimated age of ground water from well SC-8A indicates that water in this well is a mixture containing very little, if any, deep, submodern, bedrock water, possibly because ground water in well SC-8A is predominantly water of the Red River alluvial aquifer flow system rather than water of the Straight Creek flow system.

CFC ages for alluvial and debris-flow aquifer wells ranged from approximately 10 to 45 years and for bedrock aquifer wells ranged from approximately 20 to 47 years. CFC dating yielded considerably different ages for CFC-11, CFC-12, and CFC-113, almost all of which are older than helium-3/tritium ages, probably because of microbial degradation of CFC's in anaerobic conditions. The CFC-12 ages correlate reasonably well to the helium-3/tritium ages in the older samples and appear to be least affected by degradation, whereas younger samples appear to be more affected by degradation. Water from wells SC-7A and AWWT-1 appears to be enriched in CFC-12 (younger age) compared to the helium-3/tritium age, which could be a result of mixing with a young ground-water component with some CFC degradation occurring in the older end member. This interpretation is consistent with other evidence of ground-water mixing in these wells.

The stable isotopic composition of a suite of water and solid samples was determined. The results include (1) the oxygen and hydrogen isotopic composition of Straight Creek surface water and ground water and a few precipitation samples, (2) the ^{34}S and ^{18}O of dissolved sulfate in Straight Creek surface and ground water, and (3) the ^{34}S and ^{18}O of gypsum and sulfate salts from scar areas and anhydrite collected from the underground mine workings.

The five precipitation samples provide some data on the isotopic composition of local precipitation but by themselves are not sufficient to define the average isotopic composition of Red River precipitation. Three snow samples, each providing an integrated isotopic composition of the entire snow history for 2002, may be more representative of recharge than the two samples collected during a single storm in April 2003.

The oxygen and hydrogen isotopic compositions of Straight Creek surface water are similar to those of ground-water samples, except for one surface-water sample that probably represents a substantial portion of snowmelt-derived water. The similarity of surface- and ground-water isotopic compositions indicates that ground water in the Straight Creek drainage basin is derived primarily from local precipitation and runoff. A linear fit of all ground-water samples is of distinctly shallower slope than the best fit of precipitation, surface water, and Rocky Mountain and global meteoric water lines, which is consistent with evaporated water as a component of ground water in some of the Straight Creek wells.

As a check on speciation calculations and on the response of the platinum electrode for iron-rich ground water such as that in Straight Creek, the field-measured redox potential was compared with the redox potential calculated from Fe(II/III) determinations and speciation calculations. It was concluded that when sufficient iron (Fe(II) and Fe(III)) concentrations are present in water, the electrode responds with an equilibrium potential that matches the Fe(II/III) redox couple. The quality of this comparison confirms the reliability of the field redox measurements and the speciation calculations. Only samples with properly confirmed Eh values should be used for calculations of saturation indices of ferric iron minerals. This analysis also shows that expected combined errors from field potential measurements and thermodynamic data should result in a range of ± 35 mV. Values of ^{34}S and ^{18}O for gypsum and sulfate salts are consistent with those in ground water but much lower than the values for anhydrite from the underground workings. Because supergene gypsum is derived from pyrite oxidation, values of ^{34}S and ^{18}O for supergene gypsum are substantially lighter (more negative) than hypogene anhydrite and gypsum. The ^{34}S values of leachates of sulfides collected on the surface in the scar areas tend to be lighter than the sulfides in the ore zone. Isotopic compositions in ground-water samples from the Straight Creek drainage basin are similar to those in Straight Creek surface-water samples. Stable isotopic compositions of sulfur and oxygen in dissolved sulfate in ground-water samples indicate mixing of sulfate derived from sulfide oxidation (lighter isotopes) with sulfate derived from gypsum (heavier isotopes).

At low concentrations of iron, water from wells SC-1B and SC-5B varies widely in dissolved iron at constant sulfate concentration because of sulfate reduction initiated by the use of excessive amounts of organic chemicals to overcome problems with well construction. Sodium and chloride concentrations in these wells also are indicative of anthropogenic influences.

All ground-water samples from the Straight Creek drainage basin contain predominantly ferrous iron, but Straight Creek surface water contains predominantly ferric iron. If, as indicated by oxygen and hydrogen isotopes, Straight Creek surface water is the primary input to ground water, then no additional iron is dissolved upon interaction with debris-flow material, and the main process is reduction of ferric to ferrous iron. The only two reactions that appear to limit iron concentrations in ground water are the solubility of hydrous ferric oxide ($Fe(OH)_3$ or microcrystalline FeOOH) and the solubility siderite ($FeCO_3$).

The strong correlation of most dissolved constituents with sulfate (concentrations decrease linearly with sulfate in a downgradient direction) in Straight Creek surface water and shallow ground water indicates that Straight Creek surface water is the primary input to the ground-water system and that dilution along the flow path is the dominant mechanism controlling ground-water chemistry. Exceptions include calcium, magnesium, strontium, silica, sodium, and potassium. Concentrations of these constituents can be higher in shallow ground water than can be accounted for by concentrations in Straight Creek surface water; thus, additional sources of these constituents must be inferred. Although not striking from comparison of lithium or beryllium to sulfate concentrations in shallow ground water, the strong correlation between beryllium and lithium concentrations indicates that the beryllium-lithium association in the mineralization also is imparted to ground water. Concentrations of manganese, calcium, magnesium, strontium, sodium, and potassium in some bedrock aquifer ground water indicate additional sources of these constituents when compared with concentrations in Straight Creek surface water.

All ground water in samples from the Straight Creek drainage basin is a calcium sulfate type, often at or near gypsum saturation because of abundant gypsum in the aquifer material developed from co-existing calcite and pyrite mineralization. Calcite dissolution, the major buffering mechanism for bedrock aquifer ground water, also contributes to relatively higher calcium concentrations in some ground water. The main source of the second most abundant cation, magnesium, is probably dissolution of magnesium-rich carbonates or silicates. Strontium also may be derived from carbonate dissolution. Feldspars are likely sources of silica, sodium, and potassium. Other possible sources of silica are sericite, biotite, phlogopite, chlorite, epidote, and kaolinite. Manganese in bedrock aquifer ground water may be derived from rhodochrosite or manganese oxides.

Aluminum, fluoride, silica, lithium, copper, and beryllium in samples from wells SC-7A, AWWT-1, and sometimes SC-8A often do not follow the common dilution trend of decreasing concentrations with sulfate in a downgradient direction. Water samples from these wells also do not follow trends in plots of sulfate and fluoride against calcium, magnesium against calcium, and copper against zinc. The departure from the best-fit lines is greatest in plots of aluminum and silica; these differences in concentrations could be due to precipitation of aluminum and silica induced by slightly higher pH values. The data indicate that both aluminum and silica can precipitate at a pH of around 4. An alternate explanation is the lack of a direct flow path from SC-5A to AWWT-1 and SC-7A. However, linear best-fit lines on plots of some constituents do include wells AWWT-1, SC-7A, and sometimes SC-8A. As indicated by pH, specific conductance, and age-dating data, water in the lower part of the Straight Creek drainage basin is mixing among debris-flow, bedrock, and Red River alluvial aquifers. Mixtures containing different amounts of water from these aquifers could explain the departure of water from wells AWWT-1, SC-7A, and SC-8A from the common dilution trend. Plots of various constituents support the concept of increasing proportions of Red River alluvial aquifer water in a downgradient direction from well SC-5A to well SC-8A.

On various plots of concentrations of almost all constituents, the chemistry of water from well SC-4A appears to be a mixture of ground water similar to that in wells SC-3A and SC-3B. In well SC-3B, magnesium, zinc, cobalt, and beryllium concentrations indicate the mixing of bedrock aquifer and debris-flow aquifer ground water. Magnesium, sulfate, and lithium concentrations in well SC-5B are low compared with those in other bedrock aquifer wells, indicating mixing with less concentrated water in the Red River alluvial aquifer.

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Appendix 1. Chemical analyses of water samples

Appendix 1. Chemical analyses of water samples.

[_R, field replicate; ---, no data; SC, specific conductance; ∝S/cm, microsiemens per centimeter at 25 degrees Celsius; D.O., dissolved oxygen; mg/L, milligrams per liter; ºC, degrees Celsius; Eh, redox potential; ∝m, micrometer; mm, millimeter; RA, unfiltered-acidified; <, less than; meq/L, milliequivalents per liter]

Site	**Straight Creek**	**Straight Creek**	**Straight Creek**	**Straight Creek**
Collection date	**2/24/2002**	**2/24/2002**	**3/20/2002**	**3/20/2002**
pH, field / lab [1]	3.17 / ---	--- / ---	3.25 / ---	--- / ---
SC (∝S/cm), field / lab [1]	1,600 / ---	--- / ---	1,200 / ---	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	---	---	---	---
Temperature (˚C), flow-through cell / graduated cylinder [1]	0.6	---	3.0	---
Eh (volts)	0.711	---	0.674	---
Treatment [2]	0.1-∝m, 142-mm plate	RA	0.1-∝m, 142-mm plate	RA
Constituent (mg/L)				
Calcium (Ca)	212	210	131	142
Magnesium (Mg)	29.6	27.8	17.9	19.8
Sodium (Na)	2.07	2.22	1.25	1.44
Potassium (K)	0.715	0.812	0.402	0.406
Sulfate (SO_4)	825	---	525	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	3.97	---	0.664	---
Chloride (Cl)	<0.2	---	2.2	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	12.7	14.3	7.92	8.98
Aluminum (Al)	27.7	27.6	14.9	15.5
Total iron (Fe)	8.97	9.37	6.01	9.00
Ferrous iron (Fe(II))	3.53	---	1.65	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.051	0.055	0.028	0.032
Strontium (Sr)	0.158	0.170	0.107	0.134
Barium (Ba)	0.001	0.003	0.003	0.001
Manganese (Mn)	6.56	6.34	4.17	4.49
Zinc (Zn)	2.27	2.21	1.49	1.64
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.209	0.235	0.213	0.258
Copper (Cu)	0.597	0.598	0.386	0.391
Cadmium (Cd)	0.011	0.012	0.013	0.016
Chromium (Cr)	0.012	0.015	0.014	0.017
Cobalt (Co)	0.100	0.117	0.098	0.117
Beryllium (Be)	0.008	0.008	0.007	0.009
Molybdenum (Mo)	<0.007	<0.007	<0.007	0.019
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon		---		---
Sum cations (meq/L)	13.4	---	8.6	---
Sum anions (meq/L)	12.9	---	8.6	---
Charge imbalance (percent)	3.8	---	-1.1	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	Straight Creek	Straight Creek	Straight Creek	Straight Creek
Collection date	4/24/2002	4/24/2002	6/19/2002	6/19/2002
pH, field / lab [1]	2.98 / ---	--- / ---	2.97 / ---	--- / ---
SC (∝S/cm), field / lab [1]	2,920 / ---	--- / ---	2,910 / ---	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	---	---	---	---
Temperature (˚C), flow-through cell / graduated cylinder [1]	10.9	---	11.6	---
Eh (volts)	0.782	---	---	---
Treatment [2]	0.1-∝m, 142-mm plate	RA	0.1-∝m, 142-mm plate	RA
Constituent (mg/L)				
Calcium (Ca)	337	337	350	358
Magnesium (Mg)	106	103	117	119
Sodium (Na)	7.93	8.25	8.99	10.0
Potassium (K)	2.50	2.84	0.381	0.423
Sulfate (SO_4)	1,950	---	2,050	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	1.06	---	7.86	---
Chloride (Cl)	7.5	---	5.4	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	76.2	75.5	83.6	80.0
Aluminum (Al)	83.1	83.9	96.0	91.8
Total iron (Fe)	44.7	42.1	30.7	32.2
Ferrous iron (Fe(II))	0.256	---	0.487	---
Boron (B)	0.011	0.013	<0.01	<0.01
Lithium (Li)	0.145	0.157	0.193	0.206
Strontium (Sr)	0.612	0.611	0.657	0.643
Barium (Ba)	<0.0008	0.002	<0.0008	0.001
Manganese (Mn)	20.0	19.0	21.5	20.7
Zinc (Zn)	7.30	6.99	7.42	7.46
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.706	0.690	0.798	0.796
Copper (Cu)	1.55	1.54	1.67	1.66
Cadmium (Cd)	0.038	0.038	0.039	0.037
Chromium (Cr)	0.038	0.035	0.041	0.039
Cobalt (Co)	0.301	0.294	0.341	0.349
Beryllium (Be)	0.024	0.025	0.024	0.022
Molybdenum (Mo)	<0.007	<0.007	0.012	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0002	<0.0001	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon		---		---
Sum cations (meq/L)	25.8	---	27.2	---
Sum anions (meq/L)	26.3	---	27.7	---
Charge imbalance (percent)	-2.0	---	-1.8	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	Straight Creek	Straight Creek	Straight Creek	Straight Creek
Collection date	9/18/2002	9/18/2002	9/20/2002	9/20/2002
pH, field / lab [1]	3.01 / ---	--- / ---	2.79 / ---	--- / ---
SC (∝S/cm), field / lab [1]	2,240 / ---	--- / ---	3,280 / ---	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	---	---	---	---
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.0	---	10.7	---
Eh (volts)	---	---	---	---
Treatment [2]	0.1-∝m, 142-mm plate	RA	0.1-∝m, 142-mm plate	RA
Constituent (mg/L)				
Calcium (Ca)	325	306	423	422
Magnesium (Mg)	39.7	39.4	81.4	78.1
Sodium (Na)	1.62	1.90	3.74	4.55
Potassium (K)	1.83	3.50	1.09	1.50
Sulfate (SO_4)	1,530	---	2,480	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	0.945	---	1.25	---
Chloride (Cl)	2.1	---	2.6	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	21.1	33.0	71.3	75.6
Aluminum (Al)	54.4	60.9	104	119
Total iron (Fe)	48.8	117	135	144
Ferrous iron (Fe(II))	1.24	---	0.535	---
Boron (B)	<0.01	0.012	0.014	0.013
Lithium (Li)	0.080	0.094	0.169	0.192
Strontium (Sr)	0.194	0.227	0.363	0.344
Barium (Ba)	0.013	0.046	0.003	0.015
Manganese (Mn)	9.64	9.51	20.8	21.5
Zinc (Zn)	3.76	3.63	8.15	7.73
Lead (Pb)	0.010	0.051	0.012	0.015
Nickel (Ni)	0.396	0.398	0.771	0.731
Copper (Cu)	1.44	1.42	2.72	2.50
Cadmium (Cd)	0.020	0.021	0.038	0.040
Chromium (Cr)	0.039	0.070	0.064	0.068
Cobalt (Co)	0.158	0.165	0.356	0.325
Beryllium (Be)	0.014	0.014	0.027	0.029
Molybdenum (Mo)	<0.007	0.019	0.026	0.027
Vanadium (V)	<0.002	0.035	<0.002	0.004
Arsenic (As)	<0.04	<0.04	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon		---		---
Sum cations (meq/L)	19.8	---	30.2	---
Sum anions (meq/L)	21.5	---	31.2	---
Charge imbalance (percent)	-8.2	---	-3.4	---

Appendix 1. Chemical analyses of water samples--Continued.

Site **Collection date**	**Straight Creek** **10/15/2002**	**Straight Creek** **10/15/2002**	**Straight Creek** **12/11/2002**	**Straight Creek** **12/11/2002**
pH, field / lab [1]	3.00 / 2.87	--- / ---	3.07 / 2.85	--- / ---
SC (∝S/cm), field / lab [1]	3,150 / 3,150	--- / ---	3,380 / 3,200	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	---	---	---	---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.5	---	1.0	---
Eh (volts)	---	---	---	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	399	443	384	377
Magnesium (Mg)	118	133	127	127
Sodium (Na)	9.20	9.90	9.78	9.06
Potassium (K)	1.19	1.14	0.661	0.685
Sulfate (SO_4)	2,440	---	2,230	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	10.7	---	9.50	---
Chloride (Cl)	3.1	---	3.0	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	86.0	91.6	75.7	75.7
Aluminum (Al)	103	105	105	104
Total iron (Fe)	64.3	73.4	65.8	76.8
Ferrous iron (Fe(II))	0.217	---	<0.001	---
Boron (B)	0.012	<0.01	0.012	0.012
Lithium (Li)	0.217	0.208	0.222	0.206
Strontium (Sr)	0.685	0.762	0.706	0.700
Barium (Ba)	0.002	0.002	<0.0008	0.004
Manganese (Mn)	23.5	26.2	24.0	24.2
Zinc (Zn)	8.50	9.62	9.39	9.34
Lead (Pb)	0.022	0.038	<0.008	0.130
Nickel (Ni)	0.787	0.912	0.844	0.830
Copper (Cu)	1.92	1.92	1.96	1.93
Cadmium (Cd)	0.043	0.044	0.044	0.049
Chromium (Cr)	0.043	0.044	0.041	0.051
Cobalt (Co)	0.355	0.324	0.378	0.368
Beryllium (Be)	0.030	0.030	0.029	0.030
Molybdenum (Mo)	0.020	<0.007	0.016	0.020
Vanadium (V)	<0.002	<0.002	<0.002	0.005
Arsenic (As)	0.002	0.003	0.001	0.004
Selenium (Se)	<0.04	<0.04	0.002	<0.04
Dissolved organic carbon		---	1.2	---
Sum cations (meq/L)	29.5	---	31.1	---
Sum anions (meq/L)	33.1	---	30.3	---
Charge imbalance (percent)	-11.3	---	2.8	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**Straight Creek_R**	**Straight Creek_R**	**Straight Creek**	**Straight Creek**
Collection date	**12/11/2002**	**12/11/2002**	**2/3/2003**	**2/3/2003**
pH, field / lab [1]	3.07 / 2.84	--- / ---	3.00 / ---	--- / ---
SC (∝S/cm), field / lab [1]	3,170 / 3,210	--- / ---	3,090 / ---	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	4.83	---	---	---
Temperature (˚C), flow-through cell / graduated cylinder [1]	13.0	---	0.0	---
Eh (volts)	---	---	---	---
Treatment [2]	0.45-∝m, capsule	RA	0.1-∝m, 142-mm plate	RA
Constituent (mg/L)				
Calcium (Ca)	376	381	372	373
Magnesium (Mg)	123	127	113	106
Sodium (Na)	10.3	10.3	8.31	8.20
Potassium (K)	0.693	0.732	0.474	0.791
Sulfate (SO_4)	2,210	---	2,020	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	9.90	---	11.3	---
Chloride (Cl)	3.1	---	3.0	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	75.5	74.7	66.1	69.1
Aluminum (Al)	98.8	104	92.2	84.3
Total iron (Fe)	65.5	72.0	50.0	53.1
Ferrous iron (Fe(II))	<0.001	---	0.029	---
Boron (B)	0.012	0.011	<0.01	<0.01
Lithium (Li)	0.228	0.236	0.162	0.174
Strontium (Sr)	0.703	0.696	0.693	0.685
Barium (Ba)	<0.0008	0.002	<0.0008	0.012
Manganese (Mn)	23.7	24.5	22.3	23.4
Zinc (Zn)	9.21	9.19	8.09	8.57
Lead (Pb)	0.0050	0.023	<0.008	0.024
Nickel (Ni)	0.829	0.820	0.736	0.810
Copper (Cu)	1.94	1.92	2.01	1.92
Cadmium (Cd)	0.047	0.046	0.040	0.049
Chromium (Cr)	0.046	0.045	0.037	0.039
Cobalt (Co)	0.374	0.361	0.338	0.358
Beryllium (Be)	0.031	0.030	0.025	0.026
Molybdenum (Mo)	0.023	0.017	0.017	0.012
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0007	0.0010	0.0003	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.4	---	1.4	---
Sum cations (meq/L)	28.9	---	29.2	---
Sum anions (meq/L)	29.1	---	28.0	---
Charge imbalance (percent)	-0.60	---	4.1	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**Straight Creek**	**Straight Creek**	**Straight Creek**	**Straight Creek**
Collection date	**4/16/2003**	**4/16/2003**	**4/16/2003**	**4/16/2003**
pH, field / lab [1]	2.89 / ---	--- / ---	2.88 / ---	--- / ---
SC (µS/cm), field / lab [1]	2,220 / ---	--- / ---	2,410 / ---	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	---	---	---	---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.9	---	9.8	---
Eh (volts)	0.771	---	0.780	---
Treatment [2]	0.1-µm, 142-mm plate	RA	0.22-µm, syringe	RA
Constituent (mg/L)				
Calcium (Ca)	244	246	227	233
Magnesium (Mg)	74.5	74.5	63.7	64.6
Sodium (Na)	3.57	3.27	4.57	4.06
Potassium (K)	0.788	0.970	0.318	0.315
Sulfate (SO_4)	1,580	---	1,510	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.60	---	2.50	---
Chloride (Cl)	1.8	---	2.1	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	51.6	53.8	53.0	55.2
Aluminum (Al)	89.9	87.3	70.1	68.2
Total iron (Fe)	96.2	112	67.9	68.2
Ferrous iron (Fe(II))	0.504	---	0.855	---
Boron (B)	<0.01	<0.01	0.011	<0.01
Lithium (Li)	0.136	0.136	0.133	0.113
Strontium (Sr)	0.372	0.367	0.344	0.367
Barium (Ba)	0.002	0.010	0.001	0.002
Manganese (Mn)	17.8	18.2	15.1	15.0
Zinc (Zn)	6.81	6.61	5.50	5.36
Lead (Pb)	0.018	0.024	<0.008	<0.008
Nickel (Ni)	0.625	0.611	0.529	0.551
Copper (Cu)	1.98	1.84	1.40	1.60
Cadmium (Cd)	0.032	0.032	0.027	0.027
Chromium (Cr)	0.039	0.040	0.032	0.030
Cobalt (Co)	0.244	0.253	0.213	0.209
Beryllium (Be)	0.024	0.024	0.021	0.020
Molybdenum (Mo)	0.020	0.020	0.009	0.008
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0010	<0.04	0.0004	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.7	---		---
Sum cations (meq/L)	23.7	---	19.9	---
Sum anions (meq/L)	20.3	---	20.6	---
Charge imbalance (percent)	15.5	---	-3.2	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	Straight Creek	Straight Creek	Straight Creek	Straight Creek
Collection date	**5/11/2003**	**5/11/2003**	**6/4/2003**	**6/4/2003**
pH, field / lab [1]	2.86 / 2.66	--- / ---	2.85 / 2.67	--- / ---
SC (∝S/cm), field / lab [1]	3,080 / 3,120	--- / ---	3,170 / 3,240	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	---	---	4.83	---
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.3	---	13.0	---
Eh (volts)	0.791	---	---	---
Treatment [2]	0.1-∝m, 142-mm plate	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	347	341	361	359
Magnesium (Mg)	115	117	120	120
Sodium (Na)	8.03	9.25	8.12	8.10
Potassium (K)	1.05	1.09	0.961	1.04
Sulfate (SO_4)	1,940	---	2,040	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	10.8	---	11.9	---
Chloride (Cl)	11.5	---	5.1	---
Bromide (Br)	<0.1	---	0.13	---
Silica (SiO_2)	72.6	70.3	83.3	80.8
Aluminum (Al)	90.7	91.4	90.6	90.8
Total iron (Fe)	81.1	82.1	69.0	68.2
Ferrous iron (Fe(II))	0.204	---	0.470	---
Boron (B)	0.010	0.015	0.012	0.013
Lithium (Li)	0.201	0.220	0.205	0.199
Strontium (Sr)	0.548	0.557	0.612	0.622
Barium (Ba)	0.003	0.002	0.002	0.002
Manganese (Mn)	18.9	19.2	20.7	20.9
Zinc (Zn)	7.98	8.21	7.84	7.75
Lead (Pb)	0.017	0.011	0.0074	0.0083
Nickel (Ni)	0.718	0.711	0.800	0.805
Copper (Cu)	1.69	1.69	1.82	1.84
Cadmium (Cd)	0.039	0.042	0.048	0.046
Chromium (Cr)	0.036	0.043	0.046	0.039
Cobalt (Co)	0.303	0.327	0.354	0.362
Beryllium (Be)	0.026	0.028	0.029	0.028
Molybdenum (Mo)	0.012	0.017	0.017	0.014
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.04	0.0005	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.4	---	1.8	---
Sum cations (meq/L)	29.3	---	28.9	---
Sum anions (meq/L)	25.8	---	26.7	---
Charge imbalance (percent)	12.9	---	8.0	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**Straight Creek**	**Straight Creek**	**Straight Creek**	**Straight Creek**
Collection date	**8/22/2003**	**8/22/2003**	**10/22/2003**	**10/22/2003**
pH, field / lab [1]	2.93 / 2.70	--- / ---	2.85 / ---	--- / ---
SC (∝S/cm), field / lab [1]	3,640 / 3,550	--- / ---	3,230 / ---	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	6.34	---	---	---
Temperature (˚C), flow-through cell / graduated cylinder [1]	11.5	---	10.8	---
Eh (volts)	0.824	---	0.819	---
Treatment [2]	0.45-∝m, capsule	RA	0.1-∝m, 142-mm plate	RA
Constituent (mg/L)				
Calcium (Ca)	401	415	310	340
Magnesium (Mg)	130	139	112	126
Sodium (Na)	8.30	8.40	8.92	8.01
Potassium (K)	0.718	0.819	0.587	0.526
Sulfate (SO_4)	2,660	---	2,240	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	14.0	---	7.56	---
Chloride (Cl)	1.9	---	1.6	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	88.0	90.7	91.7	93.4
Aluminum (Al)	119	118	101	104
Total iron (Fe)	88.1	89.7	77.9	86.1
Ferrous iron (Fe(II))	0.480	---	0.279	---
Boron (B)	<0.01	<0.01	0.017	0.011
Lithium (Li)	0.270	0.270	0.227	0.205
Strontium (Sr)	0.611	0.608	0.613	0.613
Barium (Ba)	<0.0008	0.003	0.002	0.002
Manganese (Mn)	26.3	28.1	20.9	21.0
Zinc (Zn)	10.5	10.4	7.04	6.81
Lead (Pb)	0.009	0.015	<0.008	0.014
Nickel (Ni)	1.05	1.04	0.668	0.716
Copper (Cu)	2.63	2.60	1.99	1.89
Cadmium (Cd)	0.061	0.055	0.042	0.044
Chromium (Cr)	0.065	0.065	0.044	0.046
Cobalt (Co)	0.419	0.436	0.311	0.362
Beryllium (Be)	0.032	0.034	0.028	0.033
Molybdenum (Mo)	<0.007	<0.007	0.012	0.019
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0008	<0.04	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	2.1	---	1.4	---
Sum cations (meq/L)	31.3	---	25.8	---
Sum anions (meq/L)	35.0	---	28.9	---
Charge imbalance (percent)	-10.9	---	-11.3	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-1A**	**SC-1A**	**SC-1A_R**	**SC-1A_R**
Collection date	**3/26/2002**	**3/26/2002**	**3/26/2002**	**3/26/2002**
pH, field / lab [1]	3.63 / 3.15	--- / ---	3.63 / 3.14	--- / ---
SC (∝S/cm), field / lab [1]	2,800 / 2,890	--- / ---	2,800 / 2,900	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.33 / 0.19	--- / ---	0.33 / 0.19	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.9 / 6.6	--- / ---	7.9 / 6.6	--- / ---
Eh (volts)	0.589	---	0.589	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	386	381	385	382
Magnesium (Mg)	126	124	124	124
Sodium (Na)	17.2	17.2	17.3	16.9
Potassium (K)	1.14	1.18	1.18	1.17
Sulfate (SO_4)	2,140	---	2,130	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	9.64	---	10.1	---
Chloride (Cl)	2.9	---	3.0	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	100	98.2	102	98.1
Aluminum (Al)	94.1	95.7	96.2	96.7
Total iron (Fe)	29.6	32.5	29.5	32.7
Ferrous iron (Fe(II))	29.2	---	29.1	---
Boron (B)	0.008	0.009	0.005	0.010
Lithium (Li)	0.210	0.217	0.216	0.217
Strontium (Sr)	0.943	0.932	0.951	0.933
Barium (Ba)	0.003	0.004	0.003	0.004
Manganese (Mn)	20.5	20.4	20.4	20.2
Zinc (Zn)	7.60	7.79	7.54	7.65
Lead (Pb)	0.010	<0.008	0.011	0.011
Nickel (Ni)	0.798	0.838	0.807	0.890
Copper (Cu)	1.03	1.02	1.02	0.999
Cadmium (Cd)	0.039	0.039	0.036	0.040
Chromium (Cr)	0.033	0.035	0.037	0.034
Cobalt (Co)	0.340	0.374	0.340	0.339
Beryllium (Be)	0.025	0.025	0.025	0.025
Molybdenum (Mo)	<0.007	<0.007	0.014	<0.007
Vanadium (V)	0.002	0.002	0.001	0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.001	<0.001	<0.04	<0.001
Dissolved organic carbon	1.1	---	1.1	---
Sum cations (meq/L)	28.2	---	28.3	---
Sum anions (meq/L)	30.0	---	29.8	---
Charge imbalance (percent)	-5.9	---	-5.2	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-1A**	**SC-1A**	**SC-1A**	**SC-1A**
Collection date	**4/25/2002**	**4/25/2002**	**5/22/2002**	**5/22/2002**
pH, field / lab [1]	3.65 / 3.15	--- / ---	3.68 / 3.16	--- / ---
SC (∝S/cm), field / lab [1]	2,820 / 2,880	--- / ---	2,730 / 2,890	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.28 / 0.14	--- / ---	0.26 / 0.21	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.1 / 6.9	--- / ---	7.5 / 6.8	--- / ---
Eh (volts)	0.524	---	0.591	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	381	396	372	371
Magnesium (Mg)	119	123	115	118
Sodium (Na)	16.8	16.0	15.5	15.5
Potassium (K)	0.748	0.843	1.01	0.910
Sulfate (SO_4)	2,130	---	2,100	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	10.1	---	8.07	---
Chloride (Cl)	6.4	---	5.9	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	94.7	98.2	92.0	95.6
Aluminum (Al)	90.7	93.1	91.8	98.5
Total iron (Fe)	30.0	32.0	30.9	32.0
Ferrous iron (Fe(II))	29.6	---	28.1	---
Boron (B)	0.009	0.010	0.010	<0.01
Lithium (Li)	0.195	0.191	0.221	0.201
Strontium (Sr)	0.890	0.913	0.841	0.903
Barium (Ba)	0.003	0.003	0.003	0.002
Manganese (Mn)	19.6	20.0	18.7	20.0
Zinc (Zn)	7.39	7.56	6.60	6.92
Lead (Pb)	<0.008	<0.008	0.013	<0.008
Nickel (Ni)	0.720	0.761	0.700	0.737
Copper (Cu)	0.871	0.987	0.895	0.984
Cadmium (Cd)	0.045	0.044	0.052	0.035
Chromium (Cr)	0.038	0.039	0.041	0.031
Cobalt (Co)	0.345	0.334	0.378	0.339
Beryllium (Be)	0.028	0.027	0.030	0.022
Molybdenum (Mo)	<0.007	<0.007	0.013	0.012
Vanadium (V)	<0.002	0.003	0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.8	---	---	---
Sum cations (meq/L)	27.3	---	26.8	---
Sum anions (meq/L)	30.2	---	29.7	---
Charge imbalance (percent)	-10.2	---	-10.3	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-1A**	**SC-1A**	**SC-1A**	**SC-1A**
Collection date	**6/17/2002**	**6/17/2002**	**7/24/2002**	**7/24/2002**
pH, field / lab [1]	3.64 / 3.15	--- / ---	3.61 / 3.18	--- / ---
SC (∝S/cm), field / lab [1]	2,810 / 2,880	--- / ---	2,830 / 2,880	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.82 / 0.67	--- / ---	0.21 / 0.16	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.5 / 6.9	--- / ---	9.2 / 7.9	--- / ---
Eh (volts)	0.575	---	0.581	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	377	377	384	388
Magnesium (Mg)	124	123	124	120
Sodium (Na)	15.8	15.9	16.1	16.6
Potassium (K)	1.02	1.01	0.993	1.11
Sulfate (SO_4)	2,150	---	2,120	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	8.08	---	8.08	---
Chloride (Cl)	6.1	---	5.9	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	92.0	90.7	96.7	96.0
Aluminum (Al)	98.5	97.9	94.7	99.1
Total iron (Fe)	30.7	30.6	28.8	29.8
Ferrous iron (Fe(II))	28.6	---	26.2	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.212	0.204	0.201	0.211
Strontium (Sr)	0.866	0.850	0.860	0.885
Barium (Ba)	0.002	0.002	0.002	0.004
Manganese (Mn)	20.2	19.9	19.6	19.1
Zinc (Zn)	7.02	7.10	7.29	7.10
Lead (Pb)	<0.008	<0.008	0.009	<0.008
Nickel (Ni)	0.733	0.721	0.737	0.740
Copper (Cu)	0.929	0.910	0.936	0.955
Cadmium (Cd)	0.034	0.034	0.039	0.036
Chromium (Cr)	0.032	0.032	0.030	0.028
Cobalt (Co)	0.329	0.325	0.336	0.327
Beryllium (Be)	0.023	0.023	0.025	0.025
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	0.002	0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	28.0	---	27.9	---
Sum anions (meq/L)	30.1	---	29.5	---
Charge imbalance (percent)	-7.3	---	-5.5	---

Appendix 1. Chemical analyses of water samples--Continued.

Site Collection date	SC-1A 8/21/2002	SC-1A 8/21/2002	SC-1A 9/17/2002	SC-1A 9/17/2002
pH, field / lab [1]	3.62 / 3.18	--- / ---	3.66 / 3.17	--- / ---
SC (∝S/cm), field / lab [1]	2,770 / 2,860	--- / ---	2,480 / 2,860	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.33 / ---	--- / ---	0.57 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	10.1 / 8.4	--- / ---	9.9 / ---	--- / ---
Eh (volts)	0.594	---	0.614	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	372	377	374	374
Magnesium (Mg)	118	120	120	119
Sodium (Na)	17.2	18.4	13.5	12.5
Potassium (K)	1.07	1.17	0.926	0.834
Sulfate (SO_4)	2,050	---	2,120	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	8.44	---	8.44	---
Chloride (Cl)	4.2	---	2.7	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	92.9	94.0	92.1	91.7
Aluminum (Al)	90.1	89.7	92.9	92.3
Total iron (Fe)	28.8	29.4	28.7	28.8
Ferrous iron (Fe(II))	26.9	---	27.8	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.219	0.251	0.170	0.152
Strontium (Sr)	0.864	0.871	0.859	0.854
Barium (Ba)	0.002	0.002	0.002	0.005
Manganese (Mn)	19.8	19.9	19.6	19.7
Zinc (Zn)	7.00	6.95	7.00	7.07
Lead (Pb)	<0.008	<0.008	<0.008	0.009
Nickel (Ni)	0.715	0.725	0.716	0.712
Copper (Cu)	0.908	0.947	0.936	0.938
Cadmium (Cd)	0.032	0.032	0.028	0.027
Chromium (Cr)	0.025	0.025	0.024	0.022
Cobalt (Co)	0.316	0.317	0.313	0.318
Beryllium (Be)	0.023	0.022	0.020	0.018
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	0.003	0.003	<0.002	0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	0.003	<0.04
Dissolved organic carbon	1.9	---	---	---
Sum cations (meq/L)	26.9	---	26.9	---
Sum anions (meq/L)	28.6	---	29.6	---
Charge imbalance (percent)	-6.0	---	-9.7	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-1A**	**SC-1A**	**SC-1A**	**SC-1A**
Collection date	**10/16/2002**	**10/16/2002**	**12/12/2002**	**12/12/2002**
pH, field / lab [1]	3.59 / 3.21	--- / ---	3.72 / 3.20	--- / ---
SC (∝S/cm), field / lab [1]	2,640 / 2,840	--- / ---	2,960 / 2,830	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	1.82 / ---	--- / ---	0.41 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	13.4 / ---	--- / ---	4.9 / ---	--- / ---
Eh (volts)	0.630	---	0.580	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	387	373	390	389
Magnesium (Mg)	123	120	115	124
Sodium (Na)	15.6	15.8	15.2	16.5
Potassium (K)	1.15	1.04	1.13	1.10
Sulfate (SO_4)	2,180	---	2,080	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	10.8	---	9.64	---
Chloride (Cl)	1.5	---	3.2	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	99.8	96.3	95.6	94.5
Aluminum (Al)	98.4	94.8	90.9	96.4
Total iron (Fe)	28.0	30.7	27.9	29.6
Ferrous iron (Fe(II))	26.7	---	26.0	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.217	0.207	0.217	0.213
Strontium (Sr)	0.881	0.881	0.896	0.889
Barium (Ba)	0.002	0.002	0.002	0.003
Manganese (Mn)	20.5	20.1	18.6	20.2
Zinc (Zn)	7.17	7.06	7.38	7.37
Lead (Pb)	<0.008	<0.008	<0.0003	<0.008
Nickel (Ni)	0.740	0.746	0.727	0.732
Copper (Cu)	0.966	0.928	0.959	0.959
Cadmium (Cd)	0.033	0.032	0.031	0.032
Chromium (Cr)	0.027	0.025	0.027	0.028
Cobalt (Co)	0.326	0.322	0.325	0.323
Beryllium (Be)	0.025	0.023	0.023	0.023
Molybdenum (Mo)	<0.007	0.009	<0.007	<0.007
Vanadium (V)	0.003	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	1.0	---
Sum cations (meq/L)	27.6	---	27.7	---
Sum anions (meq/L)	29.9	---	29.6	---
Charge imbalance (percent)	-8.3	---	-6.5	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-1A**	**SC-1A**	**SC-1A**	**SC-1A**
Collection date	**2/3/2003**	**2/3/2003**	**4/16/2003**	**4/16/2003**
pH, field / lab [1]	3.68 / 3.17	--- / ---	3.74 / 3.14	--- / ---
SC (∝S/cm), field / lab [1]	2,800 / 2,850	--- / ---	2,750 / 2,850	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.23 / ---	--- / ---	0.28 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.0 / 6.5	--- / ---	7.5 / 6.9	--- / ---
Eh (volts)	0.565	---	---	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	371	377	384	376
Magnesium (Mg)	123	126	120	120
Sodium (Na)	19.8	18.4	17.0	17.0
Potassium (K)	1.37	1.25	1.10	1.20
Sulfate (SO_4)	1,970	---	2,030	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	10.9	---	9.53	---
Chloride (Cl)	2.9	---	2.8	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	92.7	96.6	90.0	97.0
Aluminum (Al)	93.5	94.5	92.0	90.0
Total iron (Fe)	29.9	29.6	29.8	28.0
Ferrous iron (Fe(II))	29.2	---	27.0	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.190	0.226	0.220	0.210
Strontium (Sr)	0.867	0.864	0.830	0.840
Barium (Ba)	0.003	0.002	0.002	0.002
Manganese (Mn)	19.9	20.1	19.0	18.0
Zinc (Zn)	7.10	7.03	6.60	6.60
Lead (Pb)	0.0050	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.741	0.744	0.700	0.720
Copper (Cu)	0.888	0.919	0.920	0.970
Cadmium (Cd)	0.030	0.034	0.032	0.032
Chromium (Cr)	0.029	0.030	0.025	0.025
Cobalt (Co)	0.325	0.330	0.280	0.280
Beryllium (Be)	0.019	0.020	0.024	0.023
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.2	---	---	---
Sum cations (meq/L)	28.3	---	28.0	---
Sum anions (meq/L)	27.6	---	28.4	---
Charge imbalance (percent)	2.6	---	-1.5	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-1A	SC-1A	SC-1A	SC-1A
Collection date	**5/13/2003**	**5/13/2003**	**6/2/2003**	**6/2/2003**
pH, field / lab [1]	3.63 / 3.06	--- / ---	3.50 / 3.15	--- / ---
SC (∝S/cm), field / lab [1]	2,780 / 2,830	--- / ---	2,830 / 2,810	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.42 / ---	--- / ---	0.37 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.3 / 6.9	--- / ---	8.7 / 12.5	--- / ---
Eh (volts)	0.578	---	0.623	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	391	405	383	390
Magnesium (Mg)	109	118	129	125
Sodium (Na)	19.0	21.0	16.7	16.1
Potassium (K)	1.17	1.40	1.01	1.00
Sulfate (SO_4)	1,950	---	2,040	---
Alkalinity as bicarbonate	---	---		---
Fluoride (F)	9.72	---	9.17	---
Chloride (Cl)	4.0	---	4.8	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	94.9	91.0	97.1	96.3
Aluminum (Al)	95.8	94.7	94.1	93.3
Total iron (Fe)	27.2	29.0	27.3	27.8
Ferrous iron (Fe(II))	26.3	---	25.0	---
Boron (B)	0.010	0.013	<0.01	0.012
Lithium (Li)	0.220	0.228	0.220	0.202
Strontium (Sr)	0.882	0.973	0.872	0.853
Barium (Ba)	0.002	0.003	0.003	0.002
Manganese (Mn)	18.1	18.2	20.0	19.7
Zinc (Zn)	7.72	7.46	7.2	6.95
Lead (Pb)	<0.0003	<0.0003	0.0006	0.0014
Nickel (Ni)	0.692	0.692	0.730	0.739
Copper (Cu)	0.867	0.866	0.925	0.905
Cadmium (Cd)	0.039	0.039	0.043	0.045
Chromium (Cr)	0.032	0.032	0.034	0.034
Cobalt (Co)	0.304	0.322	0.328	0.327
Beryllium (Be)	0.026	0.026	0.029	0.026
Molybdenum (Mo)	0.017	0.011	0.013	0.013
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.2	---	1.2	---
Sum cations (meq/L)	28.3	---	28.7	---
Sum anions (meq/L)	27.1	---	28.2	---
Charge imbalance (percent)	4.1	---	1.6	---

Appendix 1. Chemical analyses of water samples--Continued.

Site Collection date	SC-1A 8/21/2003	SC-1A 8/21/2003	SC-1A 10/23/2003	SC-1A 10/23/2003
pH, field / lab [1]	3.69 / 3.12	--- / ---	3.61 / 3.11	--- / ---
SC (∝S/cm), field / lab [1]	2,790 / 2,810	--- / ---	2,530 / 2,820	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.25 / ---	--- / ---	0.31 / 0.28	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	11.9 / 7.3	--- / ---	10.2 / 7.3	--- / ---
Eh (volts)	0.533	---	0.578	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	423	419	398	398
Magnesium (Mg)	132	131	124	124
Sodium (Na)	20.3	18.2	14.9	14.6
Potassium (K)	1.27	1.24	1.23	1.38
Sulfate (SO_4)	2,140	---	2,100	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	8.21	---	9.46	---
Chloride (Cl)	2.0	---	1.8	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	93.6	91.5	101	102
Aluminum (Al)	101	104	102	100
Total iron (Fe)	28.0	26.6	27.2	29.5
Ferrous iron (Fe(II))	26.8	---	24.5	---
Boron (B)	0.017	0.013	0.013	0.013
Lithium (Li)	0.369	0.241	0.257	0.267
Strontium (Sr)	0.856	0.833	0.946	0.934
Barium (Ba)	0.004	0.002	0.002	0.002
Manganese (Mn)	20.3	21.2	20.5	21.1
Zinc (Zn)	7.57	7.66	7.27	7.66
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.740	0.713	0.745	0.777
Copper (Cu)	0.957	1.10	1.01	1.02
Cadmium (Cd)	0.049	0.035	0.038	0.035
Chromium (Cr)	0.043	0.025	0.031	0.031
Cobalt (Co)	0.341	0.356	0.320	0.317
Beryllium (Be)	0.026	0.026	0.025	0.022
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.5	---	1.1	---
Sum cations (meq/L)	30.8	---	29.3	---
Sum anions (meq/L)	29.3	---	29.0	---
Charge imbalance (percent)	5.1	---	1.0	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC1B**	**SC1B**	**SC1B**	**SC1B**
Collection date	**3/26/2002**	**3/26/2002**	**4/25/2002**	**4/25/2002**
pH, field / lab [1]	6.61 / 7.98	--- / ---	6.75 / 7.96	--- / ---
SC (∝S/cm), field / lab [1]	3,260 / 2,900	--- / ---	3,440 / 3,010	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.9 / 0.54	--- / ---	0.50 / 0.30	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.3 / ---	--- / ---	7.0 / 7.0	--- / ---
Eh (volts)	0.319	---	0.222	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	535	520	506	509
Magnesium (Mg)	232	225	217	221
Sodium (Na)	73.0	70.6	91.8	89.3
Potassium (K)	13.6	13.6	13.7	13.7
Sulfate (SO_4)	1,930	---	1,970	---
Alkalinity as bicarbonate	493	---	494	---
Fluoride (F)	0.575	---	0.740	---
Chloride (Cl)	13.9	---	29.6	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	25.3	25.2	24.7	25.5
Aluminum (Al)	0.033	0.116	0.047	0.133
Total iron (Fe)	2.66	3.85	5.50	6.96
Ferrous iron (Fe(II))	2.63	---	5.42	---
Boron (B)	0.021	0.033	0.027	0.029
Lithium (Li)	0.138	0.125	0.161	0.152
Strontium (Sr)	11.9	11.4	11.2	11.4
Barium (Ba)	0.012	0.012	0.013	0.013
Manganese (Mn)	6.84	6.82	6.29	6.28
Zinc (Zn)	0.653	0.740	0.313	0.322
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.013	0.016	<0.003	0.010
Copper (Cu)	<0.0005	<0.0005	<0.003	0.0014
Cadmium (Cd)	0.0002	0.0003	<0.001	<0.0002
Chromium (Cr)	<0.0005	0.0009	<0.003	0.0008
Cobalt (Co)	0.015	0.014	<0.002	<0.0007
Beryllium (Be)	<0.001	<0.001	0.001	0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0002	<0.0001	0.0004	0.0005
Selenium (Se)	<0.04	0.002	<0.04	<0.04
Dissolved organic carbon	19	---	14	---
Sum cations (meq/L)	36.0	---	34.7	---
Sum anions (meq/L)	34.7	---	36.6	---
Charge imbalance (percent)	3.6	---	-5.2	---

Appendix 1. Chemical analyses of water samples--Continued.

Site Collection date	SC1B_R 4/25/2002	SC1B_R 4/25/2002	SC1B 5/22/2002	SC1B 5/22/2002
pH, field / lab [1]	6.75 / 7.98	--- / ---	6.76 / 7.96	--- / ---
SC (∝S/cm), field / lab [1]	3,440 / 2,940	--- / ---	3,390 / 3,040	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.50 / 0.30	--- / ---	0.51 / 0.34	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.0 / 7.0	--- / ---	7.8 / 7.1	--- / ---
Eh (volts)	0.222	---	0.294	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	511	511	492	496
Magnesium (Mg)	221	219	204	209
Sodium (Na)	95.5	94.8	111	110
Potassium (K)	13.7	14.7	20.0	22.7
Sulfate (SO_4)	1,880	---	1,950	---
Alkalinity as bicarbonate	484	---	481	---
Fluoride (F)	0.625	---	0.600	---
Chloride (Cl)	26.9	---	40.8	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	26.1	25.4	23.4	26.8
Aluminum (Al)	0.052	0.135	0.014	0.271
Total iron (Fe)	5.52	6.42	6.03	8.28
Ferrous iron (Fe(II))	5.52	---	5.87	---
Boron (B)	0.024	0.025	0.024	0.024
Lithium (Li)	0.146	0.153	0.178	0.151
Strontium (Sr)	11.4	11.2	10.0	10.8
Barium (Ba)	0.011	0.012	0.011	0.014
Manganese (Mn)	6.35	6.21	5.70	6.04
Zinc (Zn)	0.235	0.248	0.190	0.214
Lead (Pb)	<0.008	<0.008	<0.008	0.008
Nickel (Ni)	<0.003	0.010	0.0080	0.0090
Copper (Cu)	<0.003	0.0012	0.0008	0.0046
Cadmium (Cd)	<0.001	<0.0002	<0.0002	<0.0002
Chromium (Cr)	<0.003	0.0009	<0.0005	0.0030
Cobalt (Co)	<0.002	0.004	0.012	0.013
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0004	0.0002	0.0002	0.0003
Selenium (Se)	<0.04	<0.001	<0.001	<0.04
Dissolved organic carbon	13	---	14	---
Sum cations (meq/L)	35.8	---	34.3	---
Sum anions (meq/L)	34.7	---	36.6	---
Charge imbalance (percent)	2.9	---	-6.6	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC1B	SC1B	SC1B	SC1B
Collection date	**6/18/2002**	**6/18/2002**	**7/24/2002**	**7/24/2002**
pH, field / lab [1]	6.75 / 8.02	--- / ---	6.72 / 7.92	--- / ---
SC (∝S/cm), field / lab [1]	3,370 / 2,940	--- / ---	3,380 / 3,030	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.68 / 0.38	--- / ---	0.52 / 0.11	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.1 / 7.7	--- / ---	8.7 / 7.6	--- / ---
Eh (volts)	0.120	---	0.101	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	498	499	503	502
Magnesium (Mg)	213	225	220	207
Sodium (Na)	81.9	89.1	72.2	73.8
Potassium (K)	13.8	15.5	14.7	14.7
Sulfate (SO_4)	1,990	---	1,950	---
Alkalinity as bicarbonate	484	---	469	---
Fluoride (F)	0.600	---	0.805	---
Chloride (Cl)	27.1	---	23.5	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	23.7	25.4	25.9	25.6
Aluminum (Al)	0.010	0.119	0.006	0.153
Total iron (Fe)	8.29	9.10	8.03	8.51
Ferrous iron (Fe(II))	8.16	---	7.82	---
Boron (B)	0.028	0.019	0.023	0.022
Lithium (Li)	0.139	0.147	0.157	0.151
Strontium (Sr)	10.9	11.2	10.9	10.6
Barium (Ba)	0.008	0.009	0.008	0.010
Manganese (Mn)	5.87	6.13	6.10	5.93
Zinc (Zn)	0.077	0.086	0.125	0.070
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.0070	0.0070	0.0070	0.0080
Copper (Cu)	<0.0005	0.0019	<0.0005	0.0016
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	0.0003
Chromium (Cr)	<0.0005	0.0008	<0.0005	0.0012
Cobalt (Co)	0.008	0.011	0.011	0.012
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	0.0002	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	33.4	---	33.9	---
Sum anions (meq/L)	36.5	---	35.4	---
Charge imbalance (percent)	-9.0	---	-4.3	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC1B**	**SC1B**	**SC1B**	**SC1B**
Collection date	**8/21/2002**	**8/21/2002**	**9/17/2002**	**9/17/2002**
pH, field / lab [1]	6.69 / 7.97	--- / ---	6.70 / 7.93	--- / ---
SC (∝S/cm), field / lab [1]	3,260 / 2,930	--- / ---	2,410 / 2,940	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.05 / 0.05	--- / ---	0.61 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	10.2 / 7.9	--- / ---	9.7 / ---	--- / ---
Eh (volts)	0.091	---	0.104	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	505	507	503	500
Magnesium (Mg)	212	213	215	215
Sodium (Na)	76.3	76.3	61.6	61.4
Potassium (K)	12.4	12.0	10.3	9.94
Sulfate (SO_4)	1,870	---	1,920	---
Alkalinity as bicarbonate	473	---	478	---
Fluoride (F)	0.680	---	0.680	---
Chloride (Cl)	15.0	---	11.7	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	26.8	25.8	25.4	24.3
Aluminum (Al)	0.008	0.071	0.027	0.047
Total iron (Fe)	8.47	8.48	8.10	8.11
Ferrous iron (Fe(II))	8.38	---	8.10	---
Boron (B)	0.022	0.023	0.015	0.011
Lithium (Li)	0.182	0.187	0.134	0.099
Strontium (Sr)	10.8	10.8	11.0	10.9
Barium (Ba)	0.009	0.009	0.006	0.006
Manganese (Mn)	5.96	5.92	6.04	5.88
Zinc (Zn)	<0.005	0.013	<0.005	<0.005
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.0060	0.0050	0.0060	0.0080
Copper (Cu)	<0.0005	0.0007	<0.0005	<0.0005
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (Cr)	0.0036	0.0006	<0.0005	0.0007
Cobalt (Co)	0.003	0.011	<0.0007	0.012
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.001	<0.04
Dissolved organic carbon	11	---	---	---
Sum cations (meq/L)	33.7	---	32.9	---
Sum anions (meq/L)	33.8	---	34.6	---
Charge imbalance (percent)	-0.32	---	-5.0	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC1B**	**SC1B**	**SC1B**	**SC1B**
Collection date	**10/16/2002**	**10/16/2002**	**12/12/2002**	**12/12/2002**
pH, field / lab [1]	6.67 / 7.78	--- / ---	6.80 / 7.81	--- / ---
SC (∝S/cm), field / lab [1]	3,140 / 3,020	--- / ---	3,420 / 3,010	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.38 / ---	--- / ---	0.12 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.6 / ---	--- / ---	3.5 / ---	--- / ---
Eh (volts)	0.087	---	0.048	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	495	520	534	529
Magnesium (Mg)	212	211	225	221
Sodium (Na)	53.1	61.2	62.1	64.1
Potassium (K)	10.1	11.0	9.89	9.86
Sulfate (SO_4)	1,790	---	1,850	---
Alkalinity as bicarbonate	471	---	477	---
Fluoride (F)	0.926	---	0.800	---
Chloride (Cl)	3.2	---	9.9	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	23.3	26.8	26.1	26.6
Aluminum (Al)	0.008	0.010	0.011	0.029
Total iron (Fe)	8.11	8.74	7.61	8.47
Ferrous iron (Fe(II))	8.08	---	7.60	---
Boron (B)	0.023	0.024	0.023	0.023
Lithium (Li)	0.159	0.162	0.148	0.160
Strontium (Sr)	10.2	10.7	11.7	11.3
Barium (Ba)	0.008	0.008	0.007	0.008
Manganese (Mn)	5.57	6.27	6.28	6.27
Zinc (Zn)	<0.005	<0.005	0.075	0.031
Lead (Pb)	<0.008	<0.008	<0.008	<0.0003
Nickel (Ni)	0.0070	0.0070	<0.003	<0.003
Copper (Cu)	<0.0005	<0.0005	<0.003	<0.003
Cadmium (Cd)	<0.0002	<0.0002	<0.001	<0.001
Chromium (Cr)	<0.0005	0.0005	<0.003	<0.0005
Cobalt (Co)	0.009	<0.0007	<0.002	<0.002
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	0.001	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	33.0	---	36.0	---
Sum anions (meq/L)	32.6	---	33.8	---
Charge imbalance (percent)	1.0	---	6.4	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC1B	SC1B	SC1B	SC1B
Collection date	2/3/2003	2/3/2003	4/16/2003	4/16/2003
pH, field / lab [1]	6.79 / 7.91	--- / ---	6.87 / 7.97	--- / ---
SC (∝S/cm), field / lab [1]	3,300 / 2,750	--- / ---	3,210 / 2,930	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.46 / ---	--- / ---	0.38 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	2.4 / 4.2	--- / ---	5.1 / 5.8	--- / ---
Eh (volts)	-0.001	---	-0.021	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	500	502	495	470
Magnesium (Mg)	213	213	212	206
Sodium (Na)	57.8	57.9	57.3	55.2
Potassium (K)	8.76	8.82	8.37	8.48
Sulfate (SO_4)	1,790	---	1,810	---
Alkalinity as bicarbonate	505	---	550	---
Fluoride (F)	1.13	---	0.927	---
Chloride (Cl)	7.4	---	7.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	27.7	27.0	24.8	25.8
Aluminum (Al)	0.034	0.022	0.012	0.028
Total iron (Fe)	6.19	7.21	2.51	2.67
Ferrous iron (Fe(II))	6.07	---	2.47	---
Boron (B)	0.024	0.018	0.022	0.023
Lithium (Li)	0.159	0.140	0.150	0.154
Strontium (Sr)	11.0	10.7	11.0	10.3
Barium (Ba)	0.009	0.008	0.007	0.007
Manganese (Mn)	6.19	6.09	5.81	5.83
Zinc (Zn)	<0.005	<0.005	<0.005	<0.005
Lead (Pb)	0.0008	<0.0003	0.0009	<0.008
Nickel (Ni)	0.0035	0.0039	0.0042	<0.003
Copper (Cu)	0.0007	<0.0005	<0.0005	<0.003
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	<0.001
Chromium (Cr)	0.0010	0.0005	<0.0005	<0.003
Cobalt (Co)	<0.0007	<0.0007	<0.0007	0.004
Beryllium (Be)	0.001	<0.001	0.001	0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	5.6	---	---	---
Sum cations (meq/L)	33.9	---	33.0	---
Sum anions (meq/L)	33.8	---	34.5	---
Charge imbalance (percent)	0.29	---	-4.6	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC1B**	**SC1B**	**SC1B**	**SC1B**
Collection date	**5/13/2003**	**5/13/2003**	**6/2/2003**	**6/2/2003**
pH, field / lab [1]	6.76 / 7.56	--- / ---	6.56 / 7.68	--- / ---
SC (∝S/cm), field / lab [1]	3,260 / 2,940	--- / ---	3,320 / 2,760	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.30 / ---	--- / ---	0.24 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.1 / 7.6	--- / ---	11.1 / 8.8	--- / ---
Eh (volts)	-0.032	---	-0.036	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	543	526	513	516
Magnesium (Mg)	227	222	228	228
Sodium (Na)	56.3	50.7	62.4	62.6
Potassium (K)	9.32	8.70	10.1	9.82
Sulfate (SO_4)	1,790	---	1,770	---
Alkalinity as bicarbonate	547	---	537	---
Fluoride (F)	0.843	---	0.714	---
Chloride (Cl)	8.8	---	12.4	---
Bromide (Br)	<0.1	---	0.10	---
Silica (SiO_2)	25.2	24.6	26.9	27.4
Aluminum (Al)	0.011	0.013	0.011	0.015
Total iron (Fe)	1.82	3.38	1.88	2.47
Ferrous iron (Fe(II))	1.81	---	1.85	---
Boron (B)	0.025	0.029	0.025	0.026
Lithium (Li)	0.175	0.175	0.146	0.144
Strontium (Sr)	11.3	11.2	11.1	11.1
Barium (Ba)	0.008	0.009	0.008	0.008
Manganese (Mn)	6.10	5.99	6.01	6.06
Zinc (Zn)	0.023	0.211	<0.005	<0.005
Lead (Pb)	0.0014	<0.0003	0.0014	<0.0003
Nickel (Ni)	0.0029	<0.0005	0.0038	0.0019
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007
Beryllium (Be)	0.001	0.001	0.001	0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	6.2	---	6.6	---
Sum cations (meq/L)	35.8	---	34.9	---
Sum anions (meq/L)	33.3	---	33.0	---
Charge imbalance (percent)	7.3	---	5.5	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC1B	SC1B	SC1B	SC1B
Collection date	8/21/2003	8/21/2003	10/23/2003	10/23/2003
pH, field / lab [1]	6.75 / 7.97	--- / ---	6.78 / 7.59	--- / ---
SC (∝S/cm), field / lab [1]	3,320 / 2,930	--- / ---	2,960 / 2,910	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.46 / ---	--- / ---	0.12 / 0.17	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.0 / 7.3	--- / ---	10.6 / 7.5	--- / ---
Eh (volts)	-0.057	---	-0.038	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	492	492	530	506
Magnesium (Mg)	208	206	225	219
Sodium (Na)	66.1	63.1	72.4	70.4
Potassium (K)	11.2	10.3	14.9	14.1
Sulfate (SO_4)	1,770	---	1,830	---
Alkalinity as bicarbonate	544	---	531	---
Fluoride (F)	0.680	---	0.859	---
Chloride (Cl)	16.7	---	21.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	27.0	27.1	28.4	28.7
Aluminum (Al)	0.021	0.113	0.031	0.017
Total iron (Fe)	1.72	5.27	1.98	2.05
Ferrous iron (Fe(II))	1.68	---	1.98	---
Boron (B)	<0.01	<0.01	0.032	0.039
Lithium (Li)	0.168	0.162	0.175	0.122
Strontium (Sr)	10.6	10.4	11.7	10.7
Barium (Ba)	0.004	0.007	0.009	0.008
Manganese (Mn)	6.07	5.94	6.16	5.87
Zinc (Zn)	<0.005	0.047	<0.005	<0.005
Lead (Pb)	<0.0003	0.0009	0.0012	0.016
Nickel (Ni)	0.0019	0.0039	<0.0005	0.0031
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (Cr)	<0.0005	0.0017	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	6.3	---	12	---
Sum cations (meq/L)	33.0	---	35.9	---
Sum anions (meq/L)	33.9	---	34.2	---
Charge imbalance (percent)	-2.7	---	4.7	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-2B**	**SC-2B**	**SC-2B**	**SC-2B**
Collection date	**3/25/2002**	**3/25/2002**	**3/25/2002**	**4/25/2002**
pH, field / lab [1]	6.69 / ---	6.69 / 6.96	--- / ---	5.89 / 5.90
SC (∝S/cm), field / lab [1]	2,570 / ---	2,570 / 2,570	--- / ---	2,420 / 2,280
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.49 / ---	--- / ---	--- / ---	0.86 / 0.51
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.1 / ---	--- / ---	--- / ---	7.6 / 7.7
Eh (volts)	0.267	0.267	---	0.328
Treatment [2]	0.1-∝m, 142-mm plate	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	483	475	484	425
Magnesium (Mg)	119	118	114	105
Sodium (Na)	20.9	24.3	24.9	22.7
Potassium (K)	3.73	3.36	3.38	2.51
Sulfate (SO_4)	1,620	1,640	---	1,520
Alkalinity as bicarbonate	102	117	---	92.0
Fluoride (F)	5.80	5.64	---	6.14
Chloride (Cl)	2.6	2.8	---	5.0
Bromide (Br)	<0.1	<0.1	---	<0.1
Silica (SiO_2)	16.7	15.8	16.2	25.1
Aluminum (Al)	1.66	0.864	1.08	6.05
Total iron (Fe)	37.6	39.5	39.9	34.4
Ferrous iron (Fe(II))	37.6	39.0	---	34.0
Boron (B)	0.013	0.015	0.011	0.012
Lithium (Li)	0.362	0.293	0.287	0.248
Strontium (Sr)	2.40	2.61	2.58	2.01
Barium (Ba)	0.010	0.008	0.011	0.008
Manganese (Mn)	19.2	18.4	18.5	17.1
Zinc (Zn)	1.41	1.47	1.52	1.99
Lead (Pb)	0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.461	0.495	0.497	0.480
Copper (Cu)	0.013	<0.0005	0.011	<0.003
Cadmium (Cd)	0.002	<0.001	<0.001	0.005
Chromium (Cr)	0.0040	<0.0005	<0.0005	0.0080
Cobalt (Co)	0.233	0.173	0.184	0.227
Beryllium (Be)	0.022	0.019	0.019	0.017
Molybdenum (Mo)	0.010	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0003	<0.0001	0.0002	0.0001
Selenium (Se)	<0.04	<0.001	<0.04	<0.04
Dissolved organic carbon	---	1.4	---	1.7
Sum cations (meq/L)	26.5	26.2	---	23.8
Sum anions (meq/L)	25.0	25.8	---	23.9
Charge imbalance (percent)	5.8	1.7	---	-0.23

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-2B**	**SC-2B**	**SC-2B**	**SC-2B**
Collection date	**4/25/2002**	**5/23/2002**	**5/23/2002**	**6/25/2002**
pH, field / lab [1]	--- / ---	6.27 / 7.49	--- / ---	6.51 / 7.89
SC (∝S/cm), field / lab [1]	--- / ---	2,510 / 2,300	--- / ---	2,350 / 2,300
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.39 / 0.32	--- / ---	0.18 / 0.15
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	8.3 / 7.6	--- / ---	11.6 / 9.5
Eh (volts)	---	0.300	---	0.220
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	426	435	446	443
Magnesium (Mg)	106	119	110	105
Sodium (Na)	24.5	23.2	20.3	22.1
Potassium (K)	2.52	4.54	3.61	3.40
Sulfate (SO_4)	---	1,480	---	1,520
Alkalinity as bicarbonate	---	95.9	---	144
Fluoride (F)	---	5.27	---	6.14
Chloride (Cl)	---	3.9	---	3.9
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	24.9	15.3	15.0	10.0
Aluminum (Al)	6.43	1.94	1.62	0.532
Total iron (Fe)	35.3	32.9	35.5	33.9
Ferrous iron (Fe(II))	---	32.9	---	33.9
Boron (B)	0.011	0.015	<0.01	<0.01
Lithium (Li)	0.268	0.374	0.295	0.313
Strontium (Sr)	1.97	2.51	2.28	2.36
Barium (Ba)	0.011	0.009	0.012	0.006
Manganese (Mn)	16.9	18.6	17.1	16.5
Zinc (Zn)	1.97	1.43	1.38	1.33
Lead (Pb)	<0.008	<0.0003	0.0040	0.0060
Nickel (Ni)	0.473	0.478	0.466	0.461
Copper (Cu)	0.0040	0.0020	0.015	<0.0005
Cadmium (Cd)	0.005	0.003	<0.001	<0.001
Chromium (Cr)	<0.0005	0.0075	0.011	0.0075
Cobalt (Co)	0.230	0.245	0.151	0.148
Beryllium (Be)	0.017	0.023	0.014	0.019
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	0.003	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.001	<0.001	<0.04
Dissolved organic carbon	---	1.9	---	---
Sum cations (meq/L)	---	25.1	---	23.8
Sum anions (meq/L)	---	23.0	---	24.5
Charge imbalance (percent)	---	8.7	---	-2.6

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-2B**	**SC-2B_R**	**SC-2B_R**	**SC-2B**
Collection date	**6/25/2002**	**6/25/2002**	**6/25/2002**	**7/25/2002**
pH, field / lab [1]	--- / ---	6.51 / 7.82	--- / ---	6.49 / 7.59
SC (∝S/cm), field / lab [1]	--- / ---	2,350 / 2,310	--- / ---	2,480 / 2,330
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.18 / 0.15	--- / ---	0.36 / 0.14
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	11.6 / 9.5	--- / ---	13.0 / 9.3
Eh (volts)	---	0.220	---	0.210
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	442	440	440	450
Magnesium (Mg)	105	104	104	114
Sodium (Na)	22.2	22.2	20.7	20.9
Potassium (K)	3.56	3.58	3.43	3.43
Sulfate (SO_4)	---	1,530	---	1,510
Alkalinity as bicarbonate	---	174	---	149
Fluoride (F)	---	5.83	---	6.28
Chloride (Cl)	---	3.9	---	4.0
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	10.4	10.3	10.1	10.6
Aluminum (Al)	0.640	0.566	0.625	0.566
Total iron (Fe)	33.6	34.0	34.2	33.2
Ferrous iron (Fe(II))	---	34.0	---	33.2
Boron (B)	0.018	0.010	<0.01	0.011
Lithium (Li)	0.323	0.324	0.314	0.329
Strontium (Sr)	2.29	2.32	2.31	2.29
Barium (Ba)	0.008	0.006	0.007	0.006
Manganese (Mn)	17.1	17.3	16.5	16.6
Zinc (Zn)	1.29	1.34	1.34	1.53
Lead (Pb)	0.0010	<0.0003	<0.008	<0.008
Nickel (Ni)	0.439	0.437	0.452	0.467
Copper (Cu)	0.0010	<0.0005	0.0010	<0.0005
Cadmium (Cd)	<0.001	<0.001	<0.001	0.001
Chromium (Cr)	0.0094	0.0074	0.0089	0.0076
Cobalt (Co)	0.155	0.157	0.147	0.155
Beryllium (Be)	0.021	0.021	0.020	0.022
Molybdenum (Mo)	0.010	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0008	0.0006	0.0002	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	---	23.6	---	24.6
Sum anions (meq/L)	---	25.1	---	24.1
Charge imbalance (percent)	---	-6.2	---	2.2

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-2B**	**SC-2B**	**SC-2B**	**SC-2B**
Collection date	**7/25/2002**	**8/21/2002**	**8/21/2002**	**9/18/2002**
pH, field / lab [1]	--- / ---	6.44 / 7.75	--- / ---	6.46 / 7.75
SC (∝S/cm), field / lab [1]	--- / ---	2,440 / 2,280	--- / ---	2,390 / 2,310
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.65 / 0.28	--- / ---	0.26 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	9.5 / 8.3	--- / ---	8.1 / ---
Eh (volts)	---	0.244	---	0.310
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	461	434	429	424
Magnesium (Mg)	109	103	102	101
Sodium (Na)	20.7	24.1	22.1	17.0
Potassium (K)	3.13	3.67	3.41	2.49
Sulfate (SO_4)	---	1,470	---	1,460
Alkalinity as bicarbonate	---	127	---	192
Fluoride (F)	---	5.84	---	6.55
Chloride (Cl)	---	3.9	---	3.6
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	10.2	10.6	9.92	7.83
Aluminum (Al)	0.308	0.506	0.491	0.344
Total iron (Fe)	33.1	33.4	33.0	33.0
Ferrous iron (Fe(II))	---	33.4	---	33.0
Boron (B)	0.011	<0.01	<0.01	<0.01
Lithium (Li)	0.299	0.357	0.321	0.234
Strontium (Sr)	2.29	2.28	2.27	2.32
Barium (Ba)	0.006	0.006	0.006	0.004
Manganese (Mn)	16.6	16.9	16.5	17.1
Zinc (Zn)	1.38	1.34	1.32	1.56
Lead (Pb)	<0.008	<0.0003	0.0004	<0.0003
Nickel (Ni)	0.468	0.454	0.448	0.500
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium (Cd)	0.001	0.001	0.001	0.001
Chromium (Cr)	0.0082	0.0073	0.0077	0.0080
Cobalt (Co)	0.160	0.149	0.144	0.138
Beryllium (Be)	0.024	0.020	0.019	0.021
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0002	0.0002	<0.0001	0.0002
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	2.0	---	---
Sum cations (meq/L)	---	23.8	---	23.0
Sum anions (meq/L)	---	23.6	---	24.8
Charge imbalance (percent)	---	0.85	---	-7.3

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-2B**	**SC-2B**	**SC-2B**	**SC-2B**
Collection date	**9/18/2002**	**10/17/2002**	**10/17/2002**	**12/12/2002**
pH, field / lab [1]	--- / ---	6.44 / 6.76	--- / ---	6.43 / 7.84
SC (∝S/cm), field / lab [1]	--- / ---	2,380 / 2,330	--- / ---	2,550 / 2,240
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.19 / ---	--- / ---	0.15 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	10.1 / ---	--- / ---	5.9 / ---
Eh (volts)	---	0.274	---	0.256
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	433	439	453	444
Magnesium (Mg)	106	111	115	107
Sodium (Na)	15.1	19.6	20.2	20.3
Potassium (K)	2.17	3.17	3.34	3.39
Sulfate (SO_4)	---	1,420	---	1,420
Alkalinity as bicarbonate	---	142	---	159
Fluoride (F)	---	7.76	---	7.45
Chloride (Cl)	---	3.3	---	2.7
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	7.01	9.41	10.9	11.0
Aluminum (Al)	0.346	0.636	1.12	1.07
Total iron (Fe)	32.6	32.0	34.7	33.0
Ferrous iron (Fe(II))	---	31.7	---	32.4
Boron (B)	<0.01	<0.01	0.011	0.010
Lithium (Li)	0.207	0.301	0.290	0.324
Strontium (Sr)	2.25	2.25	2.39	2.37
Barium (Ba)	0.004	0.005	0.005	0.005
Manganese (Mn)	17.4	18.1	18.7	18.9
Zinc (Zn)	1.57	1.78	1.70	2.03
Lead (Pb)	<0.008	<0.0003	0.0020	<0.008
Nickel (Ni)	0.496	0.492	0.509	0.521
Copper (Cu)	<0.0005	0.0010	0.0050	<0.0005
Cadmium (Cd)	<0.001	<0.001	<0.001	0.001
Chromium (Cr)	0.0083	0.0073	0.0079	0.0076
Cobalt (Co)	0.127	0.154	0.172	0.188
Beryllium (Be)	0.021	0.028	0.029	0.038
Molybdenum (Mo)	<0.007	<0.007	<0.007	0.008
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	0.0002	<0.0001	0.0003
Selenium (Se)	<0.04	<0.001	<0.001	<0.04
Dissolved organic carbon	---	---	---	1.1
Sum cations (meq/L)	---	24.5	---	24.9
Sum anions (meq/L)	---	22.9	---	23.6
Charge imbalance (percent)	---	6.8	---	5.2

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-2B**	**SC-2B**	**SC-2B**	**SC-3A**
Collection date	**12/12/2002**	**2/8/2003**	**2/8/2003**	**3/25/2002**
pH, field / lab [1]	--- / ---	6.37 / 7.36	--- / ---	3.60 / 3.46
SC (∝S/cm), field / lab [1]	--- / ---	2,330 / 2,290	--- / ---	2,330 / 2,290
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.00 / ---	--- / ---	6.04 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	7.4 / ---	--- / ---	7.2 / ---
Eh (volts)	---	0.268	---	0.793
Treatment [2]	RA	0.45-∝m, capsule	RA	0.1-∝m, 142-mm plate
Constituent (mg/L)				
Calcium (Ca)	450	438	445	316
Magnesium (Mg)	107	104	110	81.2
Sodium (Na)	18.4	21.7	20.7	20.2
Potassium (K)	3.00	3.24	3.16	1.24
Sulfate (SO_4)	---	1,420	---	1,620
Alkalinity as bicarbonate	---	153	---	---
Fluoride (F)	---	9.45	---	5.60
Chloride (Cl)	---	2.2	---	2.7
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	10.3	10.5	10.1	84.0
Aluminum (Al)	1.17	1.23	1.27	82.9
Total iron (Fe)	35.4	33.1	37.0	0.542
Ferrous iron (Fe(II))	---	33.1	---	0.035
Boron (B)	0.010	<0.01	<0.01	0.012
Lithium (Li)	0.280	0.301	0.301	0.194
Strontium (Sr)	2.38	2.51	2.52	0.321
Barium (Ba)	0.006	0.005	0.005	0.003
Manganese (Mn)	19.4	19.0	19.1	16.2
Zinc (Zn)	2.04	1.97	2.14	4.89
Lead (Pb)	<0.008	0.0010	0.0008	<0.008
Nickel (Ni)	0.523	0.580	0.587	0.515
Copper (Cu)	0.0070	0.0042	0.019	0.796
Cadmium (Cd)	0.001	<0.0002	0.0001	0.037
Chromium (Cr)	<0.0005	<0.0005	<0.0005	0.027
Cobalt (Co)	0.185	0.186	0.193	0.311
Beryllium (Be)	0.039	0.041	0.041	0.023
Molybdenum (Mo)	0.009	0.010	0.017	0.014
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0006	0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	1.3	---	1.9
Sum cations (meq/L)	---	24.3	---	22.8
Sum anions (meq/L)	---	23.4	---	23.1
Charge imbalance (percent)	---	4.1	---	-1.2

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3A**	**SC-3A**	**SC-3A**	**SC-3A**
Collection date	**3/25/2002**	**3/25/2002**	**4/24/2002**	**4/24/2002**
pH, field / lab [1]	3.60 / 3.46	--- / ---	3.40 / 3.52	--- / ---
SC (∝S/cm), field / lab [1]	2,330 / 2,270	--- / ---	2,380 / 2,260	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	--- / ---	4.63 / 4.68	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	--- / ---	8.8 / 7.9	--- / ---
Eh (volts)	0.793	---	0.775	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	315	314	299	299
Magnesium (Mg)	86.3	90.0	94.1	88.1
Sodium (Na)	17.3	17.0	19.2	18.1
Potassium (K)	1.04	1.04	0.802	0.793
Sulfate (SO_4)	1,600	---	1,590	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	6.78	---	7.09	---
Chloride (Cl)	2.7	---	3.5	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	91.6	92.3	95.9	90.2
Aluminum (Al)	80.6	81.0	79.3	80.1
Total iron (Fe)	0.610	0.109	0.560	0.768
Ferrous iron (Fe(II))	0.030	---	0.016	---
Boron (B)	0.007	0.006	0.021	<0.01
Lithium (Li)	0.156	0.154	0.148	0.152
Strontium (Sr)	0.368	0.370	0.339	0.330
Barium (Ba)	0.002	0.003	0.004	0.003
Manganese (Mn)	16.0	15.8	15.1	15.3
Zinc (Zn)	5.59	5.61	5.93	5.38
Lead (Pb)	<0.008	0.011	<0.008	<0.008
Nickel (Ni)	0.496	0.591	0.584	0.536
Copper (Cu)	0.884	0.907	0.848	0.822
Cadmium (Cd)	0.033	0.030	0.028	0.041
Chromium (Cr)	0.027	0.025	0.024	0.036
Cobalt (Co)	0.269	0.260	0.246	0.330
Beryllium (Be)	0.018	0.018	0.019	0.022
Molybdenum (Mo)	0.009	0.008	0.018	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	0.002	<0.04	<0.04
Dissolved organic carbon	1.9	---	1.8	---
Sum cations (meq/L)	22.9	---	22.9	---
Sum anions (meq/L)	22.8	---	22.6	---
Charge imbalance (percent)	0.23	---	1.0	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3A**	**SC-3A**	**SC-3A**	**SC-3A**
Collection date	**5/23/2002**	**5/23/2002**	**6/19/2002**	**6/19/2002**
pH, field / lab [1]	3.24 / 3.43	--- / ---	3.31 / 3.42	--- / ---
SC (∝S/cm), field / lab [1]	2,400 / 2,280	--- / ---	2,410 / 2,300	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	4.77 / 4.86	--- / ---	4.29 / 4.35	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.0 / 7.3	--- / ---	7.9 / 7.5	--- / ---
Eh (volts)	0.730	---	0.773	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	285	287	307	305
Magnesium (Mg)	85.8	84.0	91.3	90.7
Sodium (Na)	16.1	15.6	15.2	19.4
Potassium (K)	0.816	0.762	0.717	0.891
Sulfate (SO_4)	1,630	---	1,720	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	6.78	---	6.78	---
Chloride (Cl)	5.3	---	5.4	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	87.6	87.9	92.8	94.4
Aluminum (Al)	79.6	79.7	82.3	82.8
Total iron (Fe)	0.537	0.449	0.501	0.533
Ferrous iron (Fe(II))	0.035	---	0.034	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.159	0.156	0.151	0.189
Strontium (Sr)	0.324	0.322	0.342	0.344
Barium (Ba)	0.002	0.002	0.001	0.002
Manganese (Mn)	14.3	14.7	15.6	15.7
Zinc (Zn)	5.08	5.02	5.46	5.41
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.529	0.527	0.570	0.560
Copper (Cu)	0.813	0.830	0.848	0.869
Cadmium (Cd)	0.025	0.024	0.023	0.025
Chromium (Cr)	0.021	0.018	0.020	0.020
Cobalt (Co)	0.221	0.208	0.212	0.238
Beryllium (Be)	0.016	0.015	0.016	0.017
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.001	<0.04	<0.04	<0.04
Dissolved organic carbon	2.3	---	---	---
Sum cations (meq/L)	21.7	---	22.7	---
Sum anions (meq/L)	23.6	---	24.7	---
Charge imbalance (percent)	-8.3	---	-8.5	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3A**	**SC-3A**	**SC-3A**	**SC-3A**
Collection date	**7/25/2002**	**7/25/2002**	**8/21/2002**	**8/21/2002**
pH, field / lab [1]	3.30 / 3.42	--- / ---	3.31 / 3.42	--- / ---
SC (∝S/cm), field / lab [1]	2,420 / 2,300	--- / ---	2,240 / 2,310	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	4.94 / 4.44	--- / ---	4.36 / 4.58	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.1 / 8.0	--- / ---	9.0 / 8.2	--- / ---
Eh (volts)	0.766	---	0.772	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	318	319	299	293
Magnesium (Mg)	101	102	91.5	88.7
Sodium (Na)	16.5	15.7	18.4	18.5
Potassium (K)	0.744	0.734	0.821	0.862
Sulfate (SO_4)	1,660	---	1,620	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	6.78	---	7.10	---
Chloride (Cl)	4.8	---	2.5	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	95.0	95.7	92.4	89.3
Aluminum (Al)	81.7	81.2	75.6	79.0
Total iron (Fe)	0.565	0.517	0.569	0.531
Ferrous iron (Fe(II))	0.010	---	0.011	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.154	0.152	0.177	0.189
Strontium (Sr)	0.348	0.350	0.346	0.342
Barium (Ba)	0.002	0.002	0.002	0.002
Manganese (Mn)	15.8	15.7	15.2	15.2
Zinc (Zn)	5.55	5.49	5.42	5.19
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.565	0.560	0.558	0.545
Copper (Cu)	0.842	0.829	0.830	0.807
Cadmium (Cd)	0.028	0.027	0.025	0.024
Chromium (Cr)	0.022	0.021	0.018	0.018
Cobalt (Co)	0.252	0.239	0.233	0.223
Beryllium (Be)	0.017	0.017	0.017	0.017
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	0.0002	0.0005	<0.0001
Selenium (Se)	0.003	<0.04	<0.04	<0.001
Dissolved organic carbon	---	---	2.3	---
Sum cations (meq/L)	24.1	---	22.3	---
Sum anions (meq/L)	23.5	---	23.2	---
Charge imbalance (percent)	2.6	---	-3.8	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-3A_R	SC-3A_R	SC-3A	SC-3A
Collection date	8/21/2002	8/21/2002	9/18/2002	9/18/2002
pH, field / lab [1]	3.31 / 3.41	--- / ---	3.31 / 3.41	--- / ---
SC (∝S/cm), field / lab [1]	2,240 / 2,310	--- / ---	2,460 / 2,310	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	4.36 / 4.58	--- / ---	4.81 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.0 / 8.2	--- / ---	7.4 / ---	--- / ---
Eh (volts)	0.772	---	---	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	298	300	295	293
Magnesium (Mg)	89.6	89.5	91.4	91.4
Sodium (Na)	18.3	19.0	12.8	11.6
Potassium (K)	0.855	0.878	0.547	0.534
Sulfate (SO_4)	1,630	---	1,670	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	6.80	---	7.50	---
Chloride (Cl)	5.7	---	3.9	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	91.7	92.6	90.5	91.1
Aluminum (Al)	75.8	72.6	79.7	76.6
Total iron (Fe)	0.573	0.514	0.580	0.413
Ferrous iron (Fe(II))	0.006	---	0.033	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.175	0.185	0.113	0.104
Strontium (Sr)	0.343	0.346	0.340	0.340
Barium (Ba)	0.002	0.002	0.001	0.001
Manganese (Mn)	15.1	15.1	15.3	15.3
Zinc (Zn)	5.35	5.10	5.34	5.34
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.549	0.553	0.535	0.546
Copper (Cu)	0.803	0.838	0.817	0.830
Cadmium (Cd)	0.024	0.022	0.020	0.021
Chromium (Cr)	0.017	0.017	0.015	0.016
Cobalt (Co)	0.224	0.214	0.182	0.181
Beryllium (Be)	0.017	0.016	0.013	0.013
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	2.1	---	---	---
Sum cations (meq/L)	22.1	---	22.1	---
Sum anions (meq/L)	23.5	---	24.2	---
Charge imbalance (percent)	-5.9	---	-8.7	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3A**	**SC-3A**	**SC-3A**	**SC-3A**
Collection date	**10/17/2002**	**10/17/2002**	**12/12/2002**	**12/12/2002**
pH, field / lab [1]	3.28 / 3.41	--- / ---	3.32 / 3.41	--- / ---
SC (∝S/cm), field / lab [1]	2,380 / 2,290	--- / ---	2,490 / 2,270	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	4.86 / ---	--- / ---	4.99 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.9 / ---	--- / ---	6.0 / ---	--- / ---
Eh (volts)	0.734	---	0.765	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	290	296	304	302
Magnesium (Mg)	83.0	84.4	91.3	89.9
Sodium (Na)	15.4	16.0	16.4	15.9
Potassium (K)	0.767	0.784	0.771	0.753
Sulfate (SO_4)	1,530	---	1,590	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	8.65	---	6.78	---
Chloride (Cl)	5.5	---	3.1	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	88.6	88.6	93.1	90.2
Aluminum (Al)	79.2	83.1	81.1	81.6
Total iron (Fe)	0.562	0.555	0.524	0.460
Ferrous iron (Fe(II))	0.019	---	0.049	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.146	0.170	0.163	0.158
Strontium (Sr)	0.315	0.332	0.321	0.313
Barium (Ba)	0.002	0.002	0.002	0.002
Manganese (Mn)	15.2	15.5	15.3	15.1
Zinc (Zn)	4.91	5.42	5.52	5.47
Lead (Pb)	<0.008	<0.008	<0.008	<0.0003
Nickel (Ni)	0.503	0.521	0.534	0.533
Copper (Cu)	0.784	0.788	0.864	0.836
Cadmium (Cd)	0.023	0.025	0.025	0.024
Chromium (Cr)	0.019	0.017	0.019	0.019
Cobalt (Co)	0.220	0.219	0.226	0.224
Beryllium (Be)	0.016	0.017	0.018	0.017
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0004	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.001	<0.04
Dissolved organic carbon	---	---	1.7	---
Sum cations (meq/L)	22.0	---	23.2	---
Sum anions (meq/L)	22.1	---	22.8	---
Charge imbalance (percent)	-0.14	---	1.6	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3A**	**SC-3A**	**SC-3A**	**SC-3A**
Collection date	**2/8/2003**	**2/8/2003**	**5/14/2003**	**5/14/2003**
pH, field / lab [1]	3.23 / 3.39	--- / ---	3.41 / 3.31	--- / ---
SC (∝S/cm), field / lab [1]	2,300 / 2,270	--- / ---	2,280 / 2,190	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	4.27 / ---	--- / ---	5.21 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.6 / 7.1	--- / ---	12.6 / 7.7	--- / ---
Eh (volts)	0.754	---	0.749	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	302	304	295	297
Magnesium (Mg)	96.0	87.0	88.2	88.0
Sodium (Na)	18.4	18.3	16.5	16.6
Potassium (K)	0.838	0.834	0.696	0.737
Sulfate (SO_4)	1,540	---	1,560	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	7.85	---	6.83	---
Chloride (Cl)	3.0	---	3.2	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	98.4	96.5	95.0	98.3
Aluminum (Al)	78.7	75.5	76.5	76.2
Total iron (Fe)	0.517	0.475	0.484	0.419
Ferrous iron (Fe(II))	0.033	---	0.023	---
Boron (B)	<0.01	<0.01	<0.01	0.011
Lithium (Li)	0.182	0.176	0.157	0.161
Strontium (Sr)	0.328	0.315	0.313	0.312
Barium (Ba)	0.001	0.002	0.002	0.002
Manganese (Mn)	16.1	16.2	15.2	15.2
Zinc (Zn)	5.63	5.25	5.42	5.43
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.597	0.567	0.541	0.545
Copper (Cu)	0.815	0.847	0.818	0.842
Cadmium (Cd)	0.027	0.027	0.031	0.030
Chromium (Cr)	0.020	0.021	0.025	0.024
Cobalt (Co)	0.233	0.241	0.280	0.269
Beryllium (Be)	0.017	0.017	0.020	0.020
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.9	---	2.1	---
Sum cations (meq/L)	23.7	---	22.1	---
Sum anions (meq/L)	21.9	---	22.4	---
Charge imbalance (percent)	7.8	---	-1.4	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3A**	**SC-3A**	**SC-3A**	**SC-3A**
Collection date	**8/21/2003**	**8/21/2003**	**10/21/2003**	**10/21/2003**
pH, field / lab [1]	3.36 / 3.32	--- / ---	2.97 / 3.31	--- / ---
SC (∝S/cm), field / lab [1]	2,370 / 2,220	--- / ---	2,360 / 2,240	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	4.95 / ---	--- / ---	5.09 / 5.86	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	10.2 / 8.1	--- / ---	10.7 / 7.9	--- / ---
Eh (volts)	0.731	---	0.706	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	287	292	303	306
Magnesium (Mg)	86.4	89.1	104	102
Sodium (Na)	14.4	13.2	17.2	16.5
Potassium (K)	0.777	0.633	0.919	0.814
Sulfate (SO_4)	1,600	---	1,570	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	6.77	---	6.96	---
Chloride (Cl)	2.1	---	2.0	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	92.7	95.8	103	103
Aluminum (Al)	76.8	79.4	78.6	86.3
Total iron (Fe)	0.470	0.583	0.533	0.550
Ferrous iron (Fe(II))	0.011	---	0.031	---
Boron (B)	0.011	<0.01	<0.01	<0.01
Lithium (Li)	0.171	0.175	0.179	0.156
Strontium (Sr)	0.286	0.294	0.313	0.299
Barium (Ba)	0.001	0.001	0.002	0.001
Manganese (Mn)	14.5	14.3	16.2	16.1
Zinc (Zn)	5.16	5.70	5.86	4.99
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.537	0.550	0.545	0.449
Copper (Cu)	0.769	0.772	0.797	0.816
Cadmium (Cd)	0.023	0.027	0.022	0.025
Chromium (Cr)	0.021	0.021	0.020	0.019
Cobalt (Co)	0.214	0.225	0.233	0.230
Beryllium (Be)	0.015	0.014	0.016	0.015
Molybdenum (Mo)	0.016	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	5.3	---	1.8	---
Sum cations (meq/L)	21.5	---	24.7	---
Sum anions (meq/L)	23.1	---	22.0	---
Charge imbalance (percent)	-7.3	---	11.4	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3B**	**SC-3B**	**SC-3B**	**SC-3B**
Collection date	**3/26/2002**	**3/26/2002**	**3/26/2002**	**4/25/2002**
pH, field / lab [1]	6.18 / 4.98	6.18 / 4.70	--- / ---	5.96 / 4.10
SC (∝S/cm), field / lab [1]	2,970 / 2,740	2,970 / 2,790	--- / ---	2,790 / 2,810
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.96 / 0.50	--- / ---	--- / ---	0.64 / 0.37
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.9 / 6.8	--- / ---	--- / ---	7.8 / 7.6
Eh (volts)	0.387	0.387	---	0.298
Treatment [2]	0.1-∝m, 142-mm plate	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	494	499	510	489
Magnesium (Mg)	162	156	155	153
Sodium (Na)	34.6	36.3	37.1	33.5
Potassium (K)	3.84	3.27	2.88	2.11
Sulfate (SO_4)	1,960	2,060	---	1,940
Alkalinity as bicarbonate	21.5	77.0	---	105
Fluoride (F)	5.10	6.12	---	6.90
Chloride (Cl)	8.4	8.0	---	7.3
Bromide (Br)	<0.1	<0.1	---	<0.1
Silica (SiO_2)	16.8	16.9	17.1	16.7
Aluminum (Al)	4.86	4.48	4.78	5.39
Total iron (Fe)	53.1	53.5	59.9	57.3
Ferrous iron (Fe(II))	53.1	52.5	---	57.3
Boron (B)	0.020	0.014	0.010	0.015
Lithium (Li)	0.232	0.195	0.173	0.181
Strontium (Sr)	4.28	4.13	4.10	3.98
Barium (Ba)	0.008	0.007	0.006	0.007
Manganese (Mn)	26.5	25.0	25.4	26.3
Zinc (Zn)	4.24	4.42	4.53	4.43
Lead (Pb)	0.060	0.054	0.066	0.030
Nickel (Ni)	0.455	0.477	0.483	0.459
Copper (Cu)	<0.003	<0.0005	<0.0005	<0.003
Cadmium (Cd)	0.002	0.001	0.001	<0.001
Chromium (Cr)	0.008	0.008	0.008	0.008
Cobalt (Co)	0.323	0.243	0.236	0.269
Beryllium (Be)	0.027	0.020	0.019	0.023
Molybdenum (Mo)	0.025	0.023	0.024	<0.007
Vanadium (V)	<0.002	0.003	<0.002	<0.002
Arsenic (As)	0.0008	0.0007	0.0005	0.0007
Selenium (Se)	<0.04	<0.04	0.001	<0.04
Dissolved organic carbon	3.6	2.7	---	2.7
Sum cations (meq/L)	30.2	29.5	---	29.3
Sum anions (meq/L)	28.6	31.2	---	29.6
Charge imbalance (percent)	5.4	-5.7	---	-1.0

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3B**	**SC-3B**	**SC-3B**	**SC-3B**
Collection date	**4/25/2002**	**5/23/2002**	**5/23/2002**	**6/25/2002**
pH, field / lab [1]	--- / ---	5.95 / 4.05	--- / ---	5.93 / 4.37
SC (∝S/cm), field / lab [1]	--- / ---	2,970 / 2,800	--- / ---	2,740 / 2,780
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	--- / ---	--- / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	--- / ---	--- / ---	--- / ---
Eh (volts)	---	0.357	---	0.312
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	487	487	482	485
Magnesium (Mg)	152	153	152	152
Sodium (Na)	34.1	31.0	31.8	33.9
Potassium (K)	2.14	3.46	3.04	3.61
Sulfate (SO_4)	---	1,980	---	1,930
Alkalinity as bicarbonate	---	62.3	---	80.4
Fluoride (F)	---	6.31	---	6.58
Chloride (Cl)	---	7.3	---	7.1
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	16.6	17.8	16.4	17.6
Aluminum (Al)	5.75	5.36	5.16	5.36
Total iron (Fe)	57.5	57.9	57.5	58.7
Ferrous iron (Fe(II))	---	57.9	---	58.7
Boron (B)	0.015	0.015	0.012	0.015
Lithium (Li)	0.169	0.235	0.202	0.241
Strontium (Sr)	3.87	3.81	3.84	3.70
Barium (Ba)	0.006	0.006	0.006	0.006
Manganese (Mn)	26.3	25.6	26.0	26.3
Zinc (Zn)	4.55	4.37	4.13	4.40
Lead (Pb)	0.035	0.016	0.027	0.011
Nickel (Ni)	0.450	0.474	0.443	0.478
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium (Cd)	<0.001	0.002	0.002	0.002
Chromium (Cr)	0.009	0.005	0.008	0.006
Cobalt (Co)	0.270	0.230	0.270	0.240
Beryllium (Be)	0.022	0.019	0.025	0.020
Molybdenum (Mo)	<0.007	<0.007	0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0004	0.0004	0.0003	0.0003
Selenium (Se)	<0.04	0.002	<0.04	<0.04
Dissolved organic carbon	---	2.9	---	---
Sum cations (meq/L)	---	28.9	---	28.5
Sum anions (meq/L)	---	29.5	---	28.4
Charge imbalance (percent)	---	-2.0	---	0.42

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3B**	**SC-3B**	**SC-3B**	**SC-3B**
Collection date	**6/25/2002**	**7/25/2002**	**7/25/2002**	**8/21/2002**
pH, field / lab [1]	--- / ---	5.89 / 4.04	--- / ---	5.86 / 4.13
SC (∝S/cm), field / lab [1]	--- / ---	2,890 / 2,800	--- / ---	2,850 / 2,750
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	--- / ---	--- / ---	0.44 / 0.26
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	--- / ---	--- / ---	9.6 / 8.3
Eh (volts)	---	0.340	---	0.322
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	487	489	501	478
Magnesium (Mg)	150	150	147	147
Sodium (Na)	34.0	32.3	32.3	35.0
Potassium (K)	3.59	3.56	2.77	2.96
Sulfate (SO_4)	---	2,000	---	1,880
Alkalinity as bicarbonate	---	77.5	---	19.8
Fluoride (F)	---	6.58	---	5.84
Chloride (Cl)	---	7.4	---	5.1
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	18.3	18.1	18.3	17.6
Aluminum (Al)	5.89	5.74	5.39	5.17
Total iron (Fe)	58.9	57.9	59.2	59.1
Ferrous iron (Fe(II))	---	57.9	---	59.1
Boron (B)	0.016	0.016	0.015	0.010
Lithium (Li)	0.238	0.242	0.190	0.199
Strontium (Sr)	3.73	3.66	3.56	3.65
Barium (Ba)	0.008	0.005	0.005	0.005
Manganese (Mn)	26.6	26.8	25.9	27.1
Zinc (Zn)	4.50	4.65	4.76	4.50
Lead (Pb)	0.039	0.012	0.018	0.011
Nickel (Ni)	0.468	0.485	0.461	0.458
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium (Cd)	0.002	0.002	0.002	0.002
Chromium (Cr)	0.006	0.006	0.006	0.004
Cobalt (Co)	0.241	0.239	0.248	0.213
Beryllium (Be)	0.021	0.022	0.023	0.021
Molybdenum (Mo)	<0.007	0.011	0.012	0.010
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0002	0.0002	<0.0001	0.0005
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	2.7
Sum cations (meq/L)	---	28.6	---	28.7
Sum anions (meq/L)	---	29.9	---	27.2
Charge imbalance (percent)	---	-4.4	---	5.6

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3B**	**SC-3B**	**SC-3B**	**SC-3B_R**
Collection date	**8/21/2002**	**9/18/2002**	**9/18/2002**	**9/18/2002**
pH, field / lab [1]	--- / ---	5.81 / 4.09	--- / ---	5.81 / 4.18
SC (∝S/cm), field / lab [1]	--- / ---	2,480 / 2,780	--- / ---	2,480 / 2,800
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.43 / ---	--- / ---	0.43 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	7.7 / ---	--- / ---	7.7 / ---
Eh (volts)	---	0.446	---	0.446
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	476	476	468	470
Magnesium (Mg)	144	141	142	146
Sodium (Na)	36.4	34.5	33.4	32.4
Potassium (K)	3.39	3.21	2.11	2.07
Sulfate (SO_4)	---	1,970	---	1,830
Alkalinity as bicarbonate	---	88.8	---	91.9
Fluoride (F)	---	6.29	---	6.34
Chloride (Cl)	---	5.3	---	4.6
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	18.1	18.7	18.1	18.0
Aluminum (Al)	5.58	5.41	3.88	3.96
Total iron (Fe)	59.4	59.8	59.5	60.0
Ferrous iron (Fe(II))	---	59.8	---	59.6
Boron (B)	0.011	<0.01	<0.01	<0.01
Lithium (Li)	0.228	0.212	0.137	0.126
Strontium (Sr)	3.59	3.52	3.43	3.55
Barium (Ba)	0.005	0.005	0.004	0.004
Manganese (Mn)	26.3	26.8	26.4	27.1
Zinc (Zn)	4.48	4.74	4.58	4.63
Lead (Pb)	0.011	0.012	0.011	0.008
Nickel (Ni)	0.458	0.462	0.448	0.456
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium (Cd)	0.002	0.002	0.002	0.002
Chromium (Cr)	0.003	0.004	0.004	0.004
Cobalt (Co)	0.215	0.219	0.175	0.182
Beryllium (Be)	0.022	0.023	0.019	0.018
Molybdenum (Mo)	0.008	0.013	0.008	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	0.0002	<0.0001	0.0003
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	---	28.1	---	28.5
Sum anions (meq/L)	---	30.1	---	27.8
Charge imbalance (percent)	---	-7.1	---	2.4

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-3B_R	SC-3B	SC-3B	SC-3B
Collection date	9/18/2002	10/17/2002	10/17/2002	12/12/2002
pH, field / lab [1]	--- / ---	5.80 / 4.61	--- / ---	5.89 / 4.64
SC (∝S/cm), field / lab [1]	--- / ---	2,850 / 2,760	--- / ---	3,030 / 2,760
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.48 / ---	--- / ---	0.85 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	6.2 / ---	--- / ---	6.2 / ---
Eh (volts)	---	---	---	0.343
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	470	470	471	480
Magnesium (Mg)	144	143	150	149
Sodium (Na)	32.1	33.5	30.9	34.9
Potassium (K)	2.01	2.88	3.25	2.86
Sulfate (SO_4)	---	1,790	---	1,910
Alkalinity as bicarbonate	---	70.9	---	79.0
Fluoride (F)	---	7.89	---	6.09
Chloride (Cl)	---	3.8	---	5.4
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	17.7	18.1	18.7	19.1
Aluminum (Al)	3.97	4.95	5.61	5.61
Total iron (Fe)	59.4	58.5	66.4	58.7
Ferrous iron (Fe(II))	---	58.5	---	58.7
Boron (B)	<0.01	<0.01	0.012	0.015
Lithium (Li)	0.123	0.188	0.226	0.191
Strontium (Sr)	3.51	3.54	3.70	3.53
Barium (Ba)	0.004	0.005	0.005	0.005
Manganese (Mn)	27.2	27.2	29.0	27.9
Zinc (Zn)	4.59	4.63	5.03	5.09
Lead (Pb)	0.011	0.008	0.008	<0.008
Nickel (Ni)	0.451	0.442	0.470	0.464
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium (Cd)	0.002	0.001	0.001	0.002
Chromium (Cr)	0.003	0.004	0.004	0.006
Cobalt (Co)	0.182	0.217	0.226	0.239
Beryllium (Be)	0.018	0.023	0.027	0.024
Molybdenum (Mo)	0.015	0.008	0.025	0.021
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	0.0002	<0.0001	0.0002
Selenium (Se)	0.001	<0.04	<0.04	0.001
Dissolved organic carbon	---	---	---	2.1
Sum cations (meq/L)	---	28.7	---	29.2
Sum anions (meq/L)	---	27.0	---	29.0
Charge imbalance (percent)	---	6.1	---	0.81

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3B**	**SC-3B**	**SC-3B**	**SC-3B**
Collection date	**12/12/2002**	**2/8/2003**	**2/8/2003**	**5/14/2003**
pH, field / lab [1]	--- / ---	6.21 / 3.95	--- / ---	5.63 / 4.20
SC (∝S/cm), field / lab [1]	--- / ---	2,790 / 2,750	--- / ---	2,860 / 2,740
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.21 / ---	--- / ---	0.47 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	5.6 / 6.6	--- / ---	8.4 / 7.8
Eh (volts)	---	0.343	---	0.346
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	486	482	486	464
Magnesium (Mg)	152	129	140	146
Sodium (Na)	34.1	32.5	32.2	29.7
Potassium (K)	3.05	3.47	3.23	2.75
Sulfate (SO_4)	---	1,910	---	1,800
Alkalinity as bicarbonate	---	62.8	---	52.9
Fluoride (F)	---	8.02	---	8.63
Chloride (Cl)	---	4.6	---	4.5
Bromide (Br)	---	<0.1	---	0.10
Silica (SiO_2)	19.3	21.1	20.8	20.2
Aluminum (Al)	5.67	5.56	5.73	7.59
Total iron (Fe)	64.4	60.9	64.5	60.9
Ferrous iron (Fe(II))	---	60.9	---	60.9
Boron (B)	0.014	0.010	0.012	0.020
Lithium (Li)	0.190	0.212	0.197	0.201
Strontium (Sr)	3.63	3.43	3.27	3.39
Barium (Ba)	0.006	0.005	0.005	0.005
Manganese (Mn)	28.1	27.8	29.3	28.8
Zinc (Zn)	5.30	4.85	5.19	4.75
Lead (Pb)	0.028	<0.0003	0.0018	0.0003
Nickel (Ni)	0.464	0.511	0.510	0.466
Copper (Cu)	<0.0005	<0.0005	0.0013	0.0022
Cadmium (Cd)	0.002	0.002	0.002	0.001
Chromium (Cr)	0.005	0.008	0.006	0.007
Cobalt (Co)	0.240	0.235	0.247	0.291
Beryllium (Be)	0.023	0.027	0.025	0.035
Molybdenum (Mo)	0.018	0.020	0.021	0.024
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0002	0.0002	<0.04	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	2.6	---	3.5
Sum cations (meq/L)	---	27.9	---	28.6
Sum anions (meq/L)	---	29.0	---	26.7
Charge imbalance (percent)	---	-4.0	---	7.0

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3B**	**SC-3B**	**SC-3B**	**SC-3B**
Collection date	**5/14/2003**	**8/21/2003**	**8/21/2003**	**10/21/2003**
pH, field / lab [1]	--- / ---	5.70 / 4.69	--- / ---	5.82 / 4.33
SC (∝S/cm), field / lab [1]	--- / ---	2,850 / 2,700	--- / ---	2,870 / 2,690
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.31 / ---	--- / ---	0.80 / 0.64
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	11.3 / 8.5	--- / ---	7.9 / 7.9
Eh (volts)	---	0.259	---	0.399
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	464	481	496	460
Magnesium (Mg)	148	151	138	177
Sodium (Na)	31.8	28.1	31.6	30.1
Potassium (K)	3.33	2.73	2.79	2.47
Sulfate (SO$_4$)	---	1,990	---	1,900
Alkalinity as bicarbonate	---	69.4	---	44.9
Fluoride (F)	---	8.35	---	8.83
Chloride (Cl)	---	3.8	---	3.7
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO$_2$)	21.5	20.5	22.5	24.4
Aluminum (Al)	7.09	5.32	4.73	7.02
Total iron (Fe)	64.4	63.3	63.7	62.9
Ferrous iron (Fe(II))	---	63.3	---	62.9
Boron (B)	0.021	<0.01	<0.01	0.018
Lithium (Li)	0.219	0.194	0.219	0.148
Strontium (Sr)	3.38	3.55	3.76	3.74
Barium (Ba)	0.005	0.003	0.003	0.004
Manganese (Mn)	28.7	28.3	25.6	34.0
Zinc (Zn)	4.78	3.25	4.14	4.13
Lead (Pb)	<0.0003	0.0006	<0.0003	0.0003
Nickel (Ni)	0.461	0.406	0.391	0.415
Copper (Cu)	0.0036	0.0023	0.0050	<0.0005
Cadmium (Cd)	0.002	<0.001	<0.001	0.002
Chromium (Cr)	0.008	<0.003	0.003	0.005
Cobalt (Co)	0.276	0.218	0.198	0.224
Beryllium (Be)	0.030	0.027	0.024	0.020
Molybdenum (Mo)	0.026	0.010	0.032	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	0.0001	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	4.0	---	1.7
Sum cations (meq/L)	---	28.5	---	30.3
Sum anions (meq/L)	---	29.8	---	27.7
Charge imbalance (percent)	---	-4.4	---	8.8

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-3B**	**SC-4A**	**SC-4A**	**SC-4A**
Collection date	**10/21/2003**	**3/25/2002**	**3/25/2002**	**4/24/2002**
pH, field / lab [1]	--- / ---	4.03 / 3.01	--- / ---	3.57 / 3.09
SC (∝S/cm), field / lab [1]	--- / ---	2,470 / 2,710	--- / ---	2,430 / 2,580
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.44 / ---	--- / ---	1.31 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	6.6 / ---	--- / ---	8.0 / ---
Eh (volts)	---	0.577	---	0.588
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	475	294	288	296
Magnesium (Mg)	151	138	136	124
Sodium (Na)	27.8	27.8	27.6	25.7
Potassium (K)	2.95	3.18	3.25	1.86
Sulfate (SO_4)	---	1,760	---	1,720
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	6.72	---	6.72
Chloride (Cl)	---	4.5	---	6.8
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	23.5	58.9	58.1	65.7
Aluminum (Al)	6.97	55.6	55.1	65.7
Total iron (Fe)	68.5	53.6	49.8	34.9
Ferrous iron (Fe(II))	---	53.6	---	34.9
Boron (B)	0.018	0.013	0.012	0.015
Lithium (Li)	0.189	0.191	0.197	0.171
Strontium (Sr)	3.41	0.938	0.933	0.722
Barium (Ba)	0.005	0.004	0.004	0.004
Manganese (Mn)	30.3	20.0	19.6	18.6
Zinc (Zn)	3.98	5.20	5.19	5.28
Lead (Pb)	0.0009	<0.008	0.010	<0.008
Nickel (Ni)	0.348	0.563	0.556	0.549
Copper (Cu)	<0.0005	0.070	0.072	0.300
Cadmium (Cd)	0.001	0.017	0.017	0.022
Chromium (Cr)	0.007	0.012	0.012	0.017
Cobalt (Co)	0.219	0.270	0.251	0.284
Beryllium (Be)	0.023	0.016	0.016	0.018
Molybdenum (Mo)	0.012	0.013	0.007	<0.007
Vanadium (V)	<0.002	0.001	0.001	<0.002
Arsenic (As)	<0.04	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	0.002	0.003	<0.04
Dissolved organic carbon	---	2.0	---	1.5
Sum cations (meq/L)	---	25.1	---	24.5
Sum anions (meq/L)	---	25.7	---	24.8
Charge imbalance (percent)	---	-2.4	---	-1.3

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-4A**	**SC-4A**	**SC-4A**	**SC-4A**
Collection date	**4/24/2002**	**5/23/2002**	**5/23/2002**	**6/25/2002**
pH, field / lab [1]	--- / ---	3.59 / 3.10	--- / ---	3.58 / 3.21
SC (∝S/cm), field / lab [1]	--- / ---	2,480 / 2,550	--- / ---	2,320 / 2,450
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	1.52 / 1.65	--- / ---	1.85 / 1.91
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	9.2 / 7.7	--- / ---	9.1 / 7.8
Eh (volts)	---	0.587	---	0.599
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	299	279	279	285
Magnesium (Mg)	121	116	113	112
Sodium (Na)	24.9	21.1	21.8	20.1
Potassium (K)	1.84	2.24	2.38	2.18
Sulfate (SO_4)	---	1,690	---	1,670
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	6.72	---	7.02
Chloride (Cl)	---	6.0	---	5.6
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	65.2	64.2	66.2	75.9
Aluminum (Al)	58.8	61.3	62.7	70.5
Total iron (Fe)	36.3	33.8	32.4	21.0
Ferrous iron (Fe(II))	---	31.3	---	20.1
Boron (B)	0.013	0.013	0.012	0.012
Lithium (Li)	0.167	0.172	0.180	0.181
Strontium (Sr)	0.719	0.703	0.709	0.631
Barium (Ba)	0.004	0.003	0.003	0.003
Manganese (Mn)	19.2	17.1	17.2	16.9
Zinc (Zn)	5.30	4.97	4.94	5.37
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.542	0.551	0.542	0.539
Copper (Cu)	0.283	0.223	0.235	0.392
Cadmium (Cd)	0.021	0.018	0.016	0.024
Chromium (Cr)	0.019	0.013	0.012	0.014
Cobalt (Co)	0.276	0.230	0.219	0.258
Beryllium (Be)	0.018	0.015	0.014	0.019
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	1.4	---	---
Sum cations (meq/L)	---	22.7	---	23.0
Sum anions (meq/L)	---	24.6	---	24.1
Charge imbalance (percent)	---	-8.3	---	-4.5

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-4A**	**SC-4A**	**SC-4A**	**SC-4A_R**
Collection date	**6/25/2002**	**7/25/2002**	**7/25/2002**	**7/25/2002**
pH, field / lab [1]	--- / ---	3.22 / 3.31	--- / ---	3.22 / 3.30
SC (∝S/cm), field / lab [1]	--- / ---	2,450 / 2,360	--- / ---	2,450 / 2,380
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	4.29 / 2.63	--- / ---	4.29 / 2.63
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	8.8 / 7.9	--- / ---	8.8 / 7.9
Eh (volts)	---	0.738	---	0.738
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	289	311	312	294
Magnesium (Mg)	110	109	113	104
Sodium (Na)	19.9	18.8	18.9	20.3
Potassium (K)	2.08	1.54	1.56	1.77
Sulfate (SO_4)	---	1,670	---	1,690
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	7.08	---	6.72
Chloride (Cl)	---	5.3	---	5.4
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	72.6	81.6	82.0	79.1
Aluminum (Al)	63.8	72.9	73.2	71.7
Total iron (Fe)	20.9	11.1	10.5	11.3
Ferrous iron (Fe(II))	---	9.75	---	10.1
Boron (B)	0.011	0.010	<0.01	0.012
Lithium (Li)	0.172	0.164	0.165	0.184
Strontium (Sr)	0.605	0.491	0.523	0.484
Barium (Ba)	0.003	0.003	0.003	0.003
Manganese (Mn)	17.3	16.3	16.4	16.2
Zinc (Zn)	5.16	5.35	5.24	5.21
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.531	0.567	0.543	0.544
Copper (Cu)	0.395	0.546	0.544	0.497
Cadmium (Cd)	0.020	0.021	0.022	0.020
Chromium (Cr)	0.013	0.015	0.015	0.014
Cobalt (Co)	0.224	0.216	0.223	0.232
Beryllium (Be)	0.016	0.015	0.016	0.016
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	---	24.2	---	23.0
Sum anions (meq/L)	---	23.8	---	24.4
Charge imbalance (percent)	---	1.6	---	-5.6

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-4A_R**	**SC-4A**	**SC-4A**	**SC-4A**
Collection date	**7/25/2002**	**8/21/2002**	**8/21/2002**	**9/18/2002**
pH, field / lab [1]	--- / ---	3.40 / 3.30	--- / ---	3.55 / 3.25
SC (∝S/cm), field / lab [1]	--- / ---	2,430 / 2,380	--- / ---	2,450 / 2,430
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	3.86 / 3.07	--- / ---	1.73 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	8.6 / 7.8	--- / ---	7.7 / ---
Eh (volts)	---	0.660	---	0.599
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	302	296	298	299
Magnesium (Mg)	107	102	100	114
Sodium (Na)	19.6	20.8	21.3	22.0
Potassium (K)	1.72	1.77	1.83	2.35
Sulfate (SO_4)	---	1,650	---	1,700
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	6.72	---	6.43
Chloride (Cl)	---	4.8	---	5.2
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	79.9	80.3	79.3	73.6
Aluminum (Al)	71.9	71.6	67.3	68.4
Total iron (Fe)	11.5	11.2	11.3	19.0
Ferrous iron (Fe(II))	---	9.97	---	18.6
Boron (B)	0.010	<0.01	<0.01	<0.01
Lithium (Li)	0.179	0.189	0.192	0.188
Strontium (Sr)	0.490	0.502	0.492	0.605
Barium (Ba)	0.003	0.003	0.003	0.003
Manganese (Mn)	16.2	16.5	16.1	16.0
Zinc (Zn)	5.42	5.32	5.37	5.21
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.539	0.558	0.554	0.539
Copper (Cu)	0.514	0.525	0.522	0.362
Cadmium (Cd)	0.021	0.022	0.021	0.019
Chromium (Cr)	0.015	0.013	0.012	0.011
Cobalt (Co)	0.233	0.230	0.224	0.223
Beryllium (Be)	0.017	0.016	0.017	0.016
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.001
Dissolved organic carbon	---	2.0	---	---
Sum cations (meq/L)	---	22.9	---	23.6
Sum anions (meq/L)	---	23.8	---	24.6
Charge imbalance (percent)	---	-3.8	---	-4.2

Appendix 1. Chemical analyses of water samples--Continued.

Site Collection date	SC-4A 9/18/2002	SC-4A 10/17/2002	SC-4A 10/17/2002	SC-4A 12/13/2002
pH, field / lab [1]	--- / ---	3.46 / 3.24	--- / ---	3.69 / 3.20
SC (∝S/cm), field / lab [1]	--- / ---	2,420 / 2,460	--- / ---	2,560 / 2,470
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	2.08 / ---	--- / ---	0.96 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	8.9 / ---	--- / ---	5.8 / ---
Eh (volts)	---	0.620	---	0.606
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	296	308	320	303
Magnesium (Mg)	107	116	122	121
Sodium (Na)	14.6	21.7	20.8	23.9
Potassium (K)	1.45	1.84	2.07	2.65
Sulfate (SO_4)	---	1,780	---	1,690
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	6.72	---	6.72
Chloride (Cl)	---	5.2	---	3.9
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	73.5	73.9	84.0	71.2
Aluminum (Al)	64.4	68.1	80.9	68.0
Total iron (Fe)	19.0	18.9	21.3	24.9
Ferrous iron (Fe(II))	---	17.7	---	23.4
Boron (B)	<0.01	<0.01	<0.01	0.011
Lithium (Li)	0.117	0.176	0.191	0.200
Strontium (Sr)	0.614	0.573	0.633	0.682
Barium (Ba)	0.002	0.003	0.003	0.003
Manganese (Mn)	16.7	18.0	19.8	18.3
Zinc (Zn)	5.34	5.19	6.22	5.53
Lead (Pb)	<0.008	<0.008	<0.008	<0.0003
Nickel (Ni)	0.550	0.539	0.616	0.548
Copper (Cu)	0.376	0.434	0.443	0.361
Cadmium (Cd)	0.016	0.020	0.024	0.020
Chromium (Cr)	0.009	0.014	0.015	0.012
Cobalt (Co)	0.175	0.227	0.253	0.246
Beryllium (Be)	0.013	0.016	0.018	0.017
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	0.002	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	1.4
Sum cations (meq/L)	---	23.7	---	24.6
Sum anions (meq/L)	---	25.7	---	24.5
Charge imbalance (percent)	---	-7.8	---	0.55

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-4A**	**SC-4A**	**SC-4A**	**SC-4A**
Collection date	**12/13/2002**	**2/8/2003**	**2/8/2003**	**5/14/2003**
pH, field / lab [1]	--- / ---	3.77 / 3.12	--- / ---	3.18 / 3.25
SC (∝S/cm), field / lab [1]	--- / ---	2,370 / 2,490	--- / ---	2,370 / 2,250
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.51 / ---	--- / ---	5.27 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	7.1 / 7.1	--- / ---	10.8 / 7.7
Eh (volts)	---	0.603	---	0.767
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	307	313	311	282
Magnesium (Mg)	121	113	109	87.6
Sodium (Na)	21.9	25.2	26.0	14.4
Potassium (K)	2.37	2.70	2.96	0.588
Sulfate (SO_4)	---	1,640	---	1,520
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	8.18	---	7.37
Chloride (Cl)	---	3.7	---	3.2
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	72.2	70.9	71.5	93.0
Aluminum (Al)	68.7	63.6	62.9	79.4
Total iron (Fe)	26.3	28.8	32.7	0.593
Ferrous iron (Fe(II))	---	27.2	---	0.024
Boron (B)	0.013	0.013	<0.01	<0.01
Lithium (Li)	0.189	0.210	0.217	0.145
Strontium (Sr)	0.694	0.724	0.758	0.302
Barium (Ba)	0.003	0.003	0.004	0.002
Manganese (Mn)	18.4	19.2	19.1	14.7
Zinc (Zn)	5.65	5.30	5.53	5.11
Lead (Pb)	<0.008	<0.0003	0.0018	<0.0003
Nickel (Ni)	0.560	0.613	0.614	0.523
Copper (Cu)	0.368	0.219	0.220	0.788
Cadmium (Cd)	0.022	0.019	0.020	0.027
Chromium (Cr)	0.014	0.010	0.011	0.022
Cobalt (Co)	0.262	0.234	0.246	0.240
Beryllium (Be)	0.018	0.017	0.017	0.017
Molybdenum (Mo)	0.009	0.008	<0.007	0.013
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	0.002	<0.04	<0.04	<0.04
Dissolved organic carbon	---	1.7	---	1.6
Sum cations (meq/L)	---	24.4	---	22.2
Sum anions (meq/L)	---	23.7	---	21.8
Charge imbalance (percent)	---	2.9	---	2.1

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-4A**	**SC-4A**	**SC-4A**	**SC-4A**
Collection date	**5/14/2003**	**6/5/2003**	**6/5/2003**	**8/21/2003**
pH, field / lab [1]	--- / ---	3.61 / 3.07	--- / ---	3.66 / 3.10
SC (∝S/cm), field / lab [1]	--- / ---	2,420 / 2,490	--- / ---	2,450 / 2,480
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	1.99 / 1.66	--- / ---	1.69 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	9.8 / 8.3	--- / ---	10.6 / 7.9
Eh (volts)	---	0.627	---	0.604
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	296	302	299	289
Magnesium (Mg)	91.1	118	117	107
Sodium (Na)	14.7	22.0	21.6	18.5
Potassium (K)	0.642	1.88	1.95	1.98
Sulfate (SO_4)	---	1,620	---	1,630
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	8.18	---	8.10
Chloride (Cl)	---	16.2	---	2.8
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	91.7	76.1	77.9	71.0
Aluminum (Al)	77.5	64.3	63.5	66.1
Total iron (Fe)	0.687	24.2	26.3	23.6
Ferrous iron (Fe(II))	---	21.2	---	22.0
Boron (B)	<0.01	0.014	0.014	<0.01
Lithium (Li)	0.153	0.176	0.179	0.178
Strontium (Sr)	0.296	0.663	0.681	0.649
Barium (Ba)	0.002	0.003	0.003	0.001
Manganese (Mn)	15.1	18.1	17.6	16.6
Zinc (Zn)	5.29	5.35	5.50	5.59
Lead (Pb)	<0.0003	0.0021	0.0021	<0.0003
Nickel (Ni)	0.518	0.571	0.580	0.567
Copper (Cu)	0.784	0.380	0.404	0.287
Cadmium (Cd)	0.026	0.027	0.025	0.021
Chromium (Cr)	0.021	0.017	0.018	0.012
Cobalt (Co)	0.231	0.299	0.292	0.224
Beryllium (Be)	0.017	0.019	0.020	0.015
Molybdenum (Mo)	0.012	0.009	0.009	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.0001	<0.04	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	1.5	---	1.9
Sum cations (meq/L)	---	24.1	---	22.7
Sum anions (meq/L)	---	23.6	---	23.7
Charge imbalance (percent)	---	2.1	---	-4.2

Appendix 1. Chemical analyses of water samples--Continued.

Site **Collection date**	**SC-4A** **8/21/2003**	**SC-4A** **10/21/2003**	**SC-4A** **10/21/2003**	**SC-6A** **2/7/2003**
pH, field / lab [1]	--- / ---	3.83 / 2.98	--- / ---	3.34 / 3.33
SC (∝S/cm), field / lab [1]	--- / ---	2,470 / 2,630	--- / ---	2,700 / 2,560
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.41 / 0.39	--- / ---	1.17 / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	10.6 / 8.0	--- / ---	5.3 / 6.3
Eh (volts)	---	0.578	---	0.750
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	285	303	300	369
Magnesium (Mg)	102	131	124	105
Sodium (Na)	19.7	22.9	25.4	21.3
Potassium (K)	1.90	2.65	2.58	1.11
Sulfate (SO_4)	---	1,760	---	1,880
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	8.26	---	8.52
Chloride (Cl)	---	3.2	---	3.1
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	70.0	60.5	67.2	96.1
Aluminum (Al)	64.7	59.2	61.8	83.3
Total iron (Fe)	27.8	43.8	50.4	4.39
Ferrous iron (Fe(II))	---	43.8	---	0.514
Boron (B)	<0.01	0.018	0.018	<0.01
Lithium (Li)	0.186	0.159	0.172	0.212
Strontium (Sr)	0.665	0.876	0.931	0.429
Barium (Ba)	0.002	0.002	0.003	0.002
Manganese (Mn)	16.4	18.9	19.1	19.0
Zinc (Zn)	5.54	4.96	5.89	6.51
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.561	0.564	0.595	0.716
Copper (Cu)	0.276	0.119	0.119	0.767
Cadmium (Cd)	0.019	0.016	0.016	0.030
Chromium (Cr)	0.013	0.013	0.011	0.027
Cobalt (Co)	0.238	0.246	0.241	0.323
Beryllium (Be)	0.014	0.018	0.020	0.019
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.04	<0.04	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	2.6	---	1.3
Sum cations (meq/L)	---	24.6	---	26.3
Sum anions (meq/L)	---	25.5	---	26.7
Charge imbalance (percent)	---	-3.6	---	-1.7

Appendix 1. Chemical analyses of water samples--Continued.

Site **Collection date**	**SC-6A** **2/7/2003**	**SC-6A** **5/14/2003**	**SC-6A** **5/14/2003**	**SC-6A_R** **5/14/2003**
pH, field / lab [1]	--- / ---	3.51 / 3.22	--- / ---	3.51 / 3.24
SC (∝S/cm), field / lab [1]	--- / ---	2,590 / 2,640	--- / ---	2,590 / 2,640
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	0.45 / 0.63	--- / ---	0.45 / 0.63
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	11.6 / 7.8	--- / ---	11.6 / 7.8
Eh (volts)	---	0.664	---	0.664
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	368	358	360	379
Magnesium (Mg)	111	114	110	121
Sodium (Na)	20.8	17.4	17.7	18.5
Potassium (K)	1.04	1.02	1.00	0.998
Sulfate (SO_4)	---	1,840	---	1,830
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	8.99	---	8.78
Chloride (Cl)	---	3.5	---	3.5
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	92.6	85.2	87.5	89.7
Aluminum (Al)	82.2	82.4	84.8	85.1
Total iron (Fe)	4.06	12.1	12.8	11.2
Ferrous iron (Fe(II))	---	10.4	---	9.40
Boron (B)	<0.01	0.012	0.010	<0.01
Lithium (Li)	0.206	0.188	0.194	0.198
Strontium (Sr)	0.416	0.430	0.441	0.442
Barium (Ba)	0.002	0.002	0.002	0.002
Manganese (Mn)	19.0	18.4	17.7	19.2
Zinc (Zn)	6.41	6.22	6.31	6.59
Lead (Pb)	<0.0003	0.0013	<0.0003	0.0009
Nickel (Ni)	0.706	0.632	0.632	0.668
Copper (Cu)	0.725	0.627	0.627	0.663
Cadmium (Cd)	0.032	0.031	0.031	0.039
Chromium (Cr)	0.024	0.021	0.023	0.022
Cobalt (Co)	0.270	0.264	0.265	0.329
Beryllium (Be)	0.019	0.018	0.019	0.023
Molybdenum (Mo)	<0.007	0.016	0.014	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.0001	<0.04	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	1.3	---	2.7
Sum cations (meq/L)	---	25.8	---	27.4
Sum anions (meq/L)	---	25.6	---	25.0
Charge imbalance (percent)	---	0.87	---	9.3

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-6A_R	SC-6A	SC-6A	SC-6A
Collection date	5/14/2003	8/18/2003	8/18/2003	10/21/2003
pH, field / lab [1]	--- / ---	3.63 / 3.25	--- / ---	3.48 / 3.22
SC (∝S/cm), field / lab [1]	--- / ---	2,670 / 2,640	--- / ---	2,670 / 2,660
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	1.05 / ---	--- / ---	0.91 / 0.63
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	13.5 / 10.3	--- / ---	11.8 / 8.9
Eh (volts)	---	0.658	---	0.660
Treatment [2]	RA	0.45-∝m, capsule	RA	0.45-∝m, capsule
Constituent (mg/L)				
Calcium (Ca)	380	362	356	365
Magnesium (Mg)	121	110	111	127
Sodium (Na)	18.2	17.4	15.7	14.8
Potassium (K)	0.941	1.15	1.11	1.20
Sulfate (SO_4)	---	2,000	---	1,940
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	8.83	---	8.74
Chloride (Cl)	---	2.3	---	2.1
Bromide (Br)	---	<0.1	---	<0.1
Silica (SiO_2)	91.4	93.2	85.2	99.7
Aluminum (Al)	85.2	90.5	81.3	85.1
Total iron (Fe)	12.8	12.5	13.9	14.9
Ferrous iron (Fe(II))	---	10.4	---	11.9
Boron (B)	0.013	<0.01	0.020	<0.01
Lithium (Li)	0.186	0.217	0.220	0.216
Strontium (Sr)	0.460	0.482	0.451	0.426
Barium (Ba)	0.002	0.001	0.002	0.001
Manganese (Mn)	19.4	18.2	17.8	19.2
Zinc (Zn)	6.49	6.15	6.12	6.71
Lead (Pb)	<0.0003	0.0008	<0.0003	<0.0003
Nickel (Ni)	0.680	0.654	0.638	0.780
Copper (Cu)	0.689	0.639	0.579	0.367
Cadmium (Cd)	0.038	0.030	0.029	0.035
Chromium (Cr)	0.021	0.021	0.021	0.021
Cobalt (Co)	0.323	0.252	0.252	0.277
Beryllium (Be)	0.022	0.013	0.016	0.017
Molybdenum (Mo)	0.012	0.021	0.029	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.0001	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	2.0	---	1.4
Sum cations (meq/L)	---	25.3	---	27.0
Sum anions (meq/L)	---	27.8	---	27.0
Charge imbalance (percent)	---	-9.0	---	0.02

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-6A**	**SC-5A**	**SC-5A**	**SC-5A**
Collection date	**10/21/2003**	**3/27/2002**	**3/27/2002**	**3/27/2002**
pH, field / lab [1]	--- / ---	3.47 / 3.50	3.47 / 3.47	--- / ---
SC (∝S/cm), field / lab [1]	--- / ---	1,590 / 1,570	1,590 / 1,360	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	1.17 / ---	--- / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	7.4 / ---	--- / ---	--- / ---
Eh (volts)	---	0.752	0.752	---
Treatment [2]	RA	0.1-∝m, 142-mm plate	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	366	158	146	147
Magnesium (Mg)	119	61.3	52.3	52.3
Sodium (Na)	21.4	19.8	15.8	15.5
Potassium (K)	1.39	2.25	1.96	1.95
Sulfate (SO_4)	---	937	957	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	---	6.40	2.60	---
Chloride (Cl)	---	8.7	5.3	---
Bromide (Br)	---	<0.1	<0.1	---
Silica (SiO_2)	95.6	78.0	77.1	76.7
Aluminum (Al)	87.5	54.7	51.0	50.8
Total iron (Fe)	16.3	0.360	0.362	0.022
Ferrous iron (Fe(II))	---	0.011	0.025	---
Boron (B)	<0.01	0.008	0.006	0.005
Lithium (Li)	0.239	0.094	0.062	0.063
Strontium (Sr)	0.452	0.508	0.468	0.463
Barium (Ba)	0.001	0.004	0.002	0.002
Manganese (Mn)	16.6	7.40	6.72	6.74
Zinc (Zn)	6.25	2.69	2.43	2.48
Lead (Pb)	<0.0003	<0.008	<0.008	<0.008
Nickel (Ni)	0.701	0.330	0.298	0.293
Copper (Cu)	0.378	0.258	0.180	0.181
Cadmium (Cd)	0.031	0.017	0.012	0.011
Chromium (Cr)	0.021	0.010	0.009	0.009
Cobalt (Co)	0.260	0.180	0.131	0.126
Beryllium (Be)	0.020	0.011	0.007	0.007
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	1.3	0.7	---
Sum cations (meq/L)	---	15.1	13.4	---
Sum anions (meq/L)	---	14.4	14.8	---
Charge imbalance (percent)	---	5.0	-9.8	---

Appendix 1. Chemical analyses of water samples--Continued.

Site Collection date	SC-5A 4/25/2002	SC-5A 4/25/2002	SC-5A 5/22/2002	SC-5A 5/22/2002
pH, field / lab [1]	3.35 / 3.45	--- / ---	3.49 / 3.47	--- / ---
SC (∝S/cm), field / lab [1]	1,680 / 1,570	--- / ---	1,310 / 1,250	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	1.18 / 1.33	--- / ---	1.29 / 1.26	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.7 / 7.5	--- / ---	8.3 / 7.3	--- / ---
Eh (volts)	0.762	---	0.798	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	164	163	118	122
Magnesium (Mg)	61.7	60.0	44.9	51.1
Sodium (Na)	17.4	17.4	14.4	16.4
Potassium (K)	1.32	1.28	1.83	2.48
Sulfate (SO_4)	957	---	736	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	1.84	---	2.28	---
Chloride (Cl)	6.9	---	6.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	76.1	75.2	70.7	77.2
Aluminum (Al)	52.0	51.2	44.6	49.0
Total iron (Fe)	0.440	0.553	0.411	0.640
Ferrous iron (Fe(II))	0.005	---	0.024	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.074	0.073	0.052	0.072
Strontium (Sr)	0.497	0.481	0.365	0.384
Barium (Ba)	<0.0008	<0.0008	0.001	0.001
Manganese (Mn)	7.86	7.60	5.25	5.77
Zinc (Zn)	2.88	2.78	2.01	2.28
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.337	0.321	0.201	0.376
Copper (Cu)	0.238	0.245	0.142	0.204
Cadmium (Cd)	0.017	0.017	0.007	0.015
Chromium (Cr)	0.011	0.014	0.006	0.015
Cobalt (Co)	0.176	0.174	0.091	0.164
Beryllium (Be)	0.010	0.010	0.005	0.010
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	0.002	<0.04	<0.04
Dissolved organic carbon	1.0	---	1.8	---
Sum cations (meq/L)	15.1	---	11.8	---
Sum anions (meq/L)	14.5	---	11.5	---
Charge imbalance (percent)	4.6	---	2.9	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-5A**	**SC-5A**	**SC-5A**	**SC-5A**
Collection date	**6/26/2002**	**6/26/2002**	**7/23/2002**	**7/23/2002**
pH, field / lab [1]	3.40 / 3.46	--- / ---	3.49 / 3.47	--- / ---
SC (∝S/cm), field / lab [1]	1,640 / 1,510	--- / ---	1,330 / 1,240	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.60 / 0.57	--- / ---	0.70 / 0.71	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.0 / 8.0	--- / ---	7.8 / 7.4	--- / ---
Eh (volts)	0.791	---	0.784	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	148	161	124	124
Magnesium (Mg)	56.5	60.5	49.8	49.3
Sodium (Na)	16.1	18.9	14.1	14.6
Potassium (K)	1.84	2.05	2.10	2.35
Sulfate (SO_4)	942	---	740	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.84	---	2.60	---
Chloride (Cl)	6.2	---	5.2	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	73.3	75.7	79.3	79.2
Aluminum (Al)	49.2	52.6	45.6	47.2
Total iron (Fe)	0.428	0.561	0.418	0.643
Ferrous iron (Fe(II))	0.024	---	0.012	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.073	0.086	0.064	0.070
Strontium (Sr)	0.459	0.506	0.402	0.412
Barium (Ba)	0.001	0.001	0.001	0.001
Manganese (Mn)	6.90	7.61	5.87	5.89
Zinc (Zn)	2.53	2.73	2.39	2.24
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.281	0.334	0.387	0.377
Copper (Cu)	0.193	0.222	0.190	0.204
Cadmium (Cd)	0.010	0.012	0.016	0.016
Chromium (Cr)	0.008	0.009	0.014	0.013
Cobalt (Co)	0.125	0.142	0.164	0.160
Beryllium (Be)	0.007	0.008	0.009	0.010
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	0.001	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	13.7	---	12.5	---
Sum anions (meq/L)	14.5	---	11.4	---
Charge imbalance (percent)	-5.1	---	9.4	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-5A**	**SC-5A**	**SC-5A**	**SC-5A**
Collection date	**8/21/2002**	**8/21/2002**	**9/17/2002**	**9/17/2002**
pH, field / lab [1]	3.44 / 3.45	--- / ---	3.44 / 3.44	--- / ---
SC (∝S/cm), field / lab [1]	1,640 / 1,570	--- / ---	1,670 / 1,590	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.87 / 0.87	--- / ---	0.91 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.5 / 8.4	--- / ---	10.8 / ---	--- / ---
Eh (volts)	0.766	---	0.748	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	160	161	163	163
Magnesium (Mg)	61.4	60.8	63.3	61.6
Sodium (Na)	17.7	17.5	16.2	12.1
Potassium (K)	1.82	1.79	1.89	1.22
Sulfate (SO_4)	998	---	996	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	3.24	---	2.97	---
Chloride (Cl)	3.2	---	6.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	75.9	76.9	76.3	77.6
Aluminum (Al)	53.8	53.2	55.1	55.9
Total iron (Fe)	0.433	0.397	0.450	0.342
Ferrous iron (Fe(II))	0.016	---	0.024	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.081	0.078	0.083	0.053
Strontium (Sr)	0.507	0.501	0.507	0.515
Barium (Ba)	0.001	0.001	0.001	<0.0008
Manganese (Mn)	7.66	7.49	7.64	7.66
Zinc (Zn)	2.71	2.74	2.67	2.70
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.332	0.334	0.322	0.324
Copper (Cu)	0.207	0.207	0.215	0.158
Cadmium (Cd)	0.012	0.011	0.011	0.009
Chromium (Cr)	0.006	0.007	0.007	0.004
Cobalt (Co)	0.133	0.129	0.136	0.101
Beryllium (Be)	0.008	0.008	0.008	0.006
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.001	0.002
Dissolved organic carbon	1.8	---	---	---
Sum cations (meq/L)	14.8	---	15.0	---
Sum anions (meq/L)	15.0	---	14.9	---
Charge imbalance (percent)	-1.7	---	0.54	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-5A**	**SC-5A**	**SC-5A_R**	**SC-5A_R**
Collection date	**10/16/2002**	**10/16/2002**	**10/16/2002**	**10/16/2002**
pH, field / lab [1]	3.47 / 3.44	--- / ---	3.47 / 3.49	--- / ---
SC (∝S/cm), field / lab [1]	1,630 / 1,610	--- / ---	1,630 / 1,590	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.77 / ---	--- / ---	0.77 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.8 / ---	--- / ---	7.8 / ---	--- / ---
Eh (volts)	---	---	---	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	165	164	165	163
Magnesium (Mg)	61.8	60.8	62.1	60.6
Sodium (Na)	17.8	16.9	18.0	17.9
Potassium (K)	1.85	1.64	1.83	1.63
Sulfate (SO_4)	999	---	956	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	4.57	---	4.71	---
Chloride (Cl)	8.1	---	5.1	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	76.2	75.8	73.7	74.9
Aluminum (Al)	55.3	53.0	53.3	53.2
Total iron (Fe)	0.468	0.431	0.467	0.442
Ferrous iron (Fe(II))	0.006	---	0.007	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.081	0.079	0.084	0.074
Strontium (Sr)	0.521	0.499	0.514	0.502
Barium (Ba)	0.001	<0.0008	0.001	<0.0008
Manganese (Mn)	7.92	7.71	8.00	7.94
Zinc (Zn)	2.78	2.77	2.79	2.74
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.335	0.332	0.333	0.340
Copper (Cu)	0.222	0.214	0.234	0.211
Cadmium (Cd)	0.012	0.012	0.012	0.012
Chromium (Cr)	0.008	0.007	0.008	0.007
Cobalt (Co)	0.137	0.136	0.137	0.135
Beryllium (Be)	0.008	0.008	0.008	0.008
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	15.2	---	15.2	---
Sum anions (meq/L)	15.2	---	14.5	---
Charge imbalance (percent)	-0.49	---	4.9	---

Appendix 1. Chemical analyses of water samples--Continued.

Site Collection date	SC-5A 12/13/2002	SC-5A 12/13/2002	SC-5A 2/8/2003	SC-5A 2/8/2003
pH, field / lab [1]	3.37 / 3.45	--- / ---	3.37 / 3.48	--- / ---
SC (∝S/cm), field / lab [1]	1,990 / 1,800	--- / ---	1,850 / 1,690	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	1.28 / ---	--- / ---	0.97 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.0 / ---	--- / ---	5.7 / 6.8	--- / ---
Eh (volts)	0.704	---	0.775	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	199	200	213	214
Magnesium (Mg)	76.0	75.2	76.0	80.5
Sodium (Na)	17.8	16.9	19.0	19.9
Potassium (K)	1.80	1.74	1.91	1.88
Sulfate (SO_4)	1,210	---	1,180	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	3.70	---	4.62	---
Chloride (Cl)	4.5	---	4.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	80.2	80.5	86.6	86.5
Aluminum (Al)	67.6	69.0	62.9	65.9
Total iron (Fe)	0.456	0.421	0.476	0.484
Ferrous iron (Fe(II))	0.028	---	0.032	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.102	0.096	0.109	0.113
Strontium (Sr)	0.607	0.606	0.625	0.619
Barium (Ba)	<0.0008	<0.0008	<0.0008	<0.0008
Manganese (Mn)	9.72	9.54	10.5	10.5
Zinc (Zn)	3.43	3.40	3.34	3.50
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.390	0.387	0.447	0.440
Copper (Cu)	0.323	0.316	0.264	0.270
Cadmium (Cd)	0.016	0.015	0.016	0.017
Chromium (Cr)	0.010	0.009	0.009	0.010
Cobalt (Co)	0.174	0.159	0.171	0.169
Beryllium (Be)	0.010	0.009	0.010	0.009
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	0.9	---	1.0	---
Sum cations (meq/L)	18.1	---	18.4	---
Sum anions (meq/L)	18.0	---	17.4	---
Charge imbalance (percent)	0.47	---	5.7	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-5A**	**SC-5A**	**SC-5A**	**SC-5A**
Collection date	**5/13/2003**	**5/13/2003**	**6/5/2003**	**6/5/2003**
pH, field / lab [1]	3.43 / 3.40	--- / ---	3.45 / 3.40	--- / ---
SC (∝S/cm), field / lab [1]	1,880 / 1,790	--- / ---	1,170 / 1,120	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.80 / ---	--- / ---	1.62 / 0.35	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	13.3 / 8.3	--- / ---	10.4 / 7.7	--- / ---
Eh (volts)	0.733	---	0.749	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	209	213	100	100
Magnesium (Mg)	78.5	73.1	37.4	36.3
Sodium (Na)	17.5	17.5	15.7	15.7
Potassium (K)	1.93	1.66	1.96	1.92
Sulfate (SO_4)	1,210	---	654	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	3.45	---	3.16	---
Chloride (Cl)	4.9	---	5.7	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	82.4	81.3	76.3	75.6
Aluminum (Al)	67.8	70.2	42.3	42.5
Total iron (Fe)	0.450	0.721	0.525	0.599
Ferrous iron (Fe(II))	0.004	---	0.011	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.108	0.098	0.043	0.043
Strontium (Sr)	0.594	0.607	0.313	0.337
Barium (Ba)	<0.0008	<0.0008	<0.0008	<0.0008
Manganese (Mn)	10.3	10.1	4.33	4.29
Zinc (Zn)	3.59	3.38	1.80	1.75
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.422	0.410	0.224	0.215
Copper (Cu)	0.277	0.260	0.119	0.116
Cadmium (Cd)	0.017	0.017	0.007	0.007
Chromium (Cr)	0.013	0.012	0.008	0.008
Cobalt (Co)	0.183	0.182	0.095	0.091
Beryllium (Be)	0.010	0.010	0.006	0.006
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	0.0008	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.4	---	1.1	---
Sum cations (meq/L)	18.5	---	10.7	---
Sum anions (meq/L)	17.6	---	10.4	---
Charge imbalance (percent)	4.5	---	2.9	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-5A**	**SC-5A**	**SC-5A**	**SC-5A**
Collection date	**8/20/2003**	**8/20/2003**	**10/24/2003**	**10/24/2003**
pH, field / lab [1]	3.46 / 3.40	--- / ---	3.23 / 3.41	--- / ---
SC (∝S/cm), field / lab [1]	1,200 / 1,130	--- / ---	1,420 / 1,490	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.62 / ---	--- / ---	1.53 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	10.7 / 8.3	--- / ---	8.7 / 7.8	--- / ---
Eh (volts)	0.755	---	0.737	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	103	102	164	164
Magnesium (Mg)	39.0	38.5	60.9	59.4
Sodium (Na)	13.2	13.4	14.6	14.9
Potassium (K)	1.97	1.89	1.36	1.45
Sulfate (SO_4)	653	---	970	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	3.26	---	3.50	---
Chloride (Cl)	4.7	---	4.1	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	75.0	73.5	81.0	81.0
Aluminum (Al)	40.0	38.3	51.5	50.0
Total iron (Fe)	0.876	0.834	0.534	0.568
Ferrous iron (Fe(II))	0.007	---	0.024	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.055	0.051	0.062	0.065
Strontium (Sr)	0.334	0.333	0.539	0.538
Barium (Ba)	<0.0008	0.003	<0.0008	<0.0008
Manganese (Mn)	4.53	4.40	7.60	7.53
Zinc (Zn)	1.75	1.72	2.43	2.69
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.186	0.199	0.333	0.337
Copper (Cu)	0.108	0.111	0.246	0.261
Cadmium (Cd)	0.006	0.006	0.016	0.011
Chromium (Cr)	0.007	0.007	0.010	0.008
Cobalt (Co)	0.077	0.081	0.115	0.126
Beryllium (Be)	0.004	0.004	0.008	0.007
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	2.1	---	2.8	---
Sum cations (meq/L)	10.6	---	15.0	---
Sum anions (meq/L)	10.3	---	14.7	---
Charge imbalance (percent)	2.5	---	2.3	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-5B	SC-5B	SC-5B	SC-5B
Collection date	3/27/2002	3/27/2002	4/25/2002	4/25/2002
pH, field / lab [1]	7.57 / 7.98	--- / ---	7.33 / 8.03	--- / ---
SC (∝S/cm), field / lab [1]	2,370 / 2,220	--- / ---	2,480 / 2,270	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.65 / ---	--- / ---	0.76 / 0.21	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.8 / ---	--- / ---	8.6 / 7.6	--- / ---
Eh (volts)	0.298	---	0.187	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	567	563	547	542
Magnesium (Mg)	40.7	40.9	36.1	36.6
Sodium (Na)	45.1	45.4	46.5	45.6
Potassium (K)	4.30	4.47	3.15	3.51
Sulfate (SO_4)	1,420	---	1,370	---
Alkalinity as bicarbonate	154	---	167	---
Fluoride (F)	1.04	---	0.994	---
Chloride (Cl)	6.8	---	8.6	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	22.2	23.3	20.1	21.2
Aluminum (Al)	0.004	0.166	0.066	0.067
Total iron (Fe)	3.99	7.10	5.55	6.95
Ferrous iron (Fe(II))	3.99	---	5.46	---
Boron (B)	0.025	0.020	<0.01	<0.01
Lithium (Li)	0.055	0.056	0.045	0.044
Strontium (Sr)	8.14	8.28	8.49	8.50
Barium (Ba)	0.028	0.037	0.034	0.034
Manganese (Mn)	3.07	3.18	2.96	3.06
Zinc (Zn)	<0.005	<0.005	<0.005	<0.005
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.011	0.013	<0.003	0.007
Copper (Cu)	0.0048	0.0007	<0.003	<0.0005
Cadmium (Cd)	<0.0002	<0.0002	<0.001	<0.0002
Chromium (Cr)	<0.0005	0.0011	<0.003	<0.0005
Cobalt (Co)	<0.002	0.004	<0.002	<0.0007
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	0.0001	<0.0001
Selenium (Se)	<0.001	<0.001	<0.04	<0.04
Dissolved organic carbon	10	---	17	---
Sum cations (meq/L)	24.9	---	24.0	---
Sum anions (meq/L)	23.1	---	22.7	---
Charge imbalance (percent)	7.6	---	5.5	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-5B**	**SC-5B**	**SC-5B**	**SC-5B**
Collection date	**5/22/2002**	**5/22/2002**	**6/26/2002**	**6/26/2002**
pH, field / lab [1]	7.60 / 8.00	--- / ---	7.57 / 7.99	--- / ---
SC (∝S/cm), field / lab [1]	2,410 / 2,180	--- / ---	2,480 / 2,230	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.44 / 0.35	--- / ---	0.10 / 0.08	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.6 / 7.6	--- / ---	8.6 / 7.7	--- / ---
Eh (volts)	0.321	---	0.096	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	550	519	520	535
Magnesium (Mg)	39.6	37.2	37.4	42.1
Sodium (Na)	40.1	39.5	51.3	54.0
Potassium (K)	3.85	3.82	5.11	5.03
Sulfate (SO_4)	1,410	---	1,420	---
Alkalinity as bicarbonate	179	---	180	---
Fluoride (F)	1.04	---	1.04	---
Chloride (Cl)	6.8	---	8.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	20.5	21.0	21.0	19.3
Aluminum (Al)	0.002	0.159	<0.001	0.137
Total iron (Fe)	6.32	8.39	4.94	7.72
Ferrous iron (Fe(II))	6.32	---	4.92	---
Boron (B)	<0.01	0.011	<0.01	0.011
Lithium (Li)	0.042	0.041	0.045	0.054
Strontium (Sr)	7.99	8.03	8.07	8.40
Barium (Ba)	0.018	0.027	0.025	0.032
Manganese (Mn)	3.08	2.98	2.98	2.91
Zinc (Zn)	<0.005	0.023	<0.005	0.063
Lead (Pb)	0.012	<0.008	<0.008	<0.008
Nickel (Ni)	0.005	0.008	0.004	0.008
Copper (Cu)	<0.0005	0.0023	<0.0005	0.0006
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (Cr)	<0.0005	0.0014	<0.0005	0.0010
Cobalt (Co)	0.005	<0.0007	0.005	0.004
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	0.0002
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	14	---	---	---
Sum cations (meq/L)	24.0	---	23.1	---
Sum anions (meq/L)	23.4	---	24.0	---
Charge imbalance (percent)	2.3	---	-4.0	---

Appendix 1. Chemical analyses of water samples--Continued.

Site **Collection date**	**SC-5B** **7/23/2002**	**SC-5B** **7/23/2002**	**SC-5B** **8/22/2002**	**SC-5B** **8/22/2002**
pH, field / lab [1]	7.53 / 8.01	--- / ---	7.53 / 8.01	--- / ---
SC (∝S/cm), field / lab [1]	2,500 / 2,350	--- / ---	2,500 / 2,290	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.17 / 0.13	--- / ---	0.27 / 0.15	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.6 / 7.7	--- / ---	8.1 / 7.8	--- / ---
Eh (volts)	0.009	---	0.045	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	525	526	499	520
Magnesium (Mg)	41.5	40.3	35.6	34.2
Sodium (Na)	85.8	85.8	84.4	75.8
Potassium (K)	5.13	5.38	8.33	5.40
Sulfate (SO_4)	1,470	---	1,400	---
Alkalinity as bicarbonate	174	---	175	---
Fluoride (F)	1.08	---	1.08	---
Chloride (Cl)	13.7	---	18.5	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	20.9	21.2	19.1	17.9
Aluminum (Al)	0.001	0.089	<0.001	0.072
Total iron (Fe)	4.29	4.63	3.14	4.06
Ferrous iron (Fe(II))	4.27	---	3.12	---
Boron (B)	0.015	0.014	0.014	0.011
Lithium (Li)	0.048	0.047	0.060	0.066
Strontium (Sr)	7.96	7.92	7.65	8.37
Barium (Ba)	0.024	0.025	0.026	0.028
Manganese (Mn)	2.68	2.68	2.62	2.46
Zinc (Zn)	0.020	0.034	<0.005	0.005
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.006	0.007	0.003	0.006
Copper (Cu)	<0.0005	0.0005	<0.0005	0.0005
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (Cr)	<0.0005	0.0006	<0.0005	0.0005
Cobalt (Co)	<0.0007	0.005	<0.0007	0.006
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0002	<0.0001	0.0002	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	33	---
Sum cations (meq/L)	24.9	---	23.7	---
Sum anions (meq/L)	24.8	---	24.2	---
Charge imbalance (percent)	0.06	---	-2.1	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-5B	SC-5B	SC-5B	SC-5B
Collection date	**9/17/2002**	**9/17/2002**	**10/16/2002**	**10/16/2002**
pH, field / lab [1]	7.45 / 8.01	--- / ---	7.40 / 7.94	--- / ---
SC (∝S/cm), field / lab [1]	2,420 / 2,350	--- / ---	2,410 / 2,340	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.17 / ---	--- / ---	0.39 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.6 / ---	--- / ---	8.1 / ---	--- / ---
Eh (volts)	0.034	---	---	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	511	509	517	520
Magnesium (Mg)	37.4	36.8	32.7	32.4
Sodium (Na)	84.1	85.0	68.4	74.0
Potassium (K)	7.40	7.94	3.90	3.99
Sulfate (SO_4)	1,410	---	1,350	---
Alkalinity as bicarbonate	192	---	226	---
Fluoride (F)	1.08	---	0.942	---
Chloride (Cl)	17.5	---	8.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	19.8	20.1	18.1	18.6
Aluminum (Al)	0.003	0.003	0.002	0.079
Total iron (Fe)	3.00	1.98	1.10	2.10
Ferrous iron (Fe(II))	3.00	---	1.10	---
Boron (B)	0.011	<0.01	0.017	0.016
Lithium (Li)	0.054	0.035	0.065	0.057
Strontium (Sr)	7.36	7.75	8.33	8.55
Barium (Ba)	0.025	0.019	0.029	0.028
Manganese (Mn)	2.64	2.72	2.19	2.21
Zinc (Zn)	<0.005	0.015	<0.005	0.009
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.005	0.005	0.004	0.006
Copper (Cu)	<0.0005	<0.0005	0.0009	<0.0005
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (Cr)	<0.0005	<0.0005	<0.0005	0.0007
Cobalt (Co)	<0.0007	0.004	0.004	0.004
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0002	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.001	<0.001	<0.04	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	24.2	---	23.5	---
Sum anions (meq/L)	24.4	---	23.7	---
Charge imbalance (percent)	-1.0	---	-0.88	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-5B	SC-5B	SC-5B	SC-5B
Collection date	12/13/2002	12/13/2002	2/8/2003	2/8/2003
pH, field / lab [1]	7.61 / 7.77	--- / ---	7.52 / 7.61	--- / ---
SC (∝S/cm), field / lab [1]	2,720 / 2,400	--- / ---	2,550 / 2,260	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.11 / ---	--- / ---	0.16 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.4 / ---	--- / ---	6.2 / 6.9	--- / ---
Eh (volts)	-0.066	---	-0.072	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	571	583	572	591
Magnesium (Mg)	35.4	36.0	31.2	34.0
Sodium (Na)	85.5	80.2	83.6	90.3
Potassium (K)	5.67	5.12	4.84	5.03
Sulfate (SO_4)	1,330	---	1,360	---
Alkalinity as bicarbonate	363	---	335	---
Fluoride (F)	0.878	---	0.923	---
Chloride (Cl)	11.0	---	9.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	23.8	25.2	22.0	30.1
Aluminum (Al)	0.014	0.243	0.009	0.336
Total iron (Fe)	0.063	14.7	0.088	9.26
Ferrous iron (Fe(II))	0.063	---	0.087	---
Boron (B)	0.021	0.022	0.014	0.017
Lithium (Li)	0.066	0.065	0.073	0.071
Strontium (Sr)	8.67	9.12	8.33	8.89
Barium (Ba)	0.030	0.039	0.025	0.043
Manganese (Mn)	1.88	1.98	1.68	1.89
Zinc (Zn)	<0.005	0.115	<0.005	0.088
Lead (Pb)	<0.008	<0.008	<0.0003	0.0019
Nickel (Ni)	<0.003	0.006	<0.0005	0.0063
Copper (Cu)	<0.0005	<0.0005	<0.0005	0.0042
Cadmium (Cd)	<0.001	<0.001	<0.0002	<0.0002
Chromium (Cr)	<0.0005	0.011	<0.0005	0.0021
Cobalt (Co)	<0.002	0.007	<0.0007	<0.0007
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.002	0.0010	0.002	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	12	---	5.3	---
Sum cations (meq/L)	26.8	---	26.3	---
Sum anions (meq/L)	25.3	---	25.3	---
Charge imbalance (percent)	5.9	---	4.0	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-5B_R	SC-5B_R	SC-5B	SC-5B
Collection date	**2/8/2003**	**2/8/2003**	**5/13/2003**	**5/13/2003**
pH, field / lab [1]	7.52 / 7.57	--- / ---	7.21 / 7.69	--- / ---
SC (∝S/cm), field / lab [1]	2,550 / 2,290	--- / ---	2,490 / 2,240	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.16 / ---	--- / ---	0.07 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.2 / 6.9	--- / ---	9..8 / 7.3	--- / ---
Eh (volts)	-0.072	---	-0.071	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	541	551	566	549
Magnesium (Mg)	32.2	31.9	41.9	40.8
Sodium (Na)	74.4	83.0	45.7	46.2
Potassium (K)	8.72	5.73	3.83	4.36
Sulfate (SO_4)	1,330	---	1,310	---
Alkalinity as bicarbonate	352	---	271	---
Fluoride (F)	1.06	---	1.07	---
Chloride (Cl)	18.0	---	5.0	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	21.5	23.9	26.5	25.8
Aluminum (Al)	0.004	0.299	0.004	0.091
Total iron (Fe)	0.081	4.41	0.086	0.693
Ferrous iron (Fe(II))	0.076	---	0.083	---
Boron (B)	0.015	0.017	0.011	0.013
Lithium (Li)	0.067	0.075	0.040	0.045
Strontium (Sr)	8.67	8.22	8.68	8.63
Barium (Ba)	0.027	0.036	0.019	0.024
Manganese (Mn)	1.73	1.73	2.58	2.51
Zinc (Zn)	<0.005	0.044	<0.005	0.005
Lead (Pb)	<0.0003	0.0010	<0.0003	<0.0003
Nickel (Ni)	0.0046	0.0041	<0.0005	<0.0005
Copper (Cu)	<0.0005	0.0011	<0.0005	0.0049
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	0.001	<0.0007	<0.0007
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	0.0003	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	7.1	---	2.5	---
Sum cations (meq/L)	25.0	---	25.4	---
Sum anions (meq/L)	25.6	---	23.2	---
Charge imbalance (percent)	-2.5	---	8.9	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-5B**	**SC-5B**	**SC-5B**	**SC-5B**
Collection date	**6/5/2003**	**6/5/2003**	**8/20/2003**	**8/20/2003**
pH, field / lab ^{1}	7.26 / 7.70	--- / ---	7.05 / 7.78	--- / ---
SC (∝S/cm), field / lab ^{1}	2,420 / 2,160	--- / ---	2,470 / 2,250	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder ^{1}	0.31 / 0.22	--- / ---	0.15/ ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder ^{1}	9.2 / 7.6	--- / ---	10.7 / 8.3	--- / ---
Eh (volts)	-0.023	---	0.019	---
Treatment ^{2}	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	579	569	548	545
Magnesium (Mg)	41.1	40.2	40.8	36.8
Sodium (Na)	36.5	36.4	38.2	37.5
Potassium (K)	3.05	3.30	3.41	3.36
Sulfate (SO$_4$)	1,350	---	1,440	---
Alkalinity as bicarbonate	239	---	247	---
Fluoride (F)	1.08	---	1.06	---
Chloride (Cl)	4.1	---	3.7	---
Bromide (Br)	0.13	---	<0.1	---
Silica (SiO$_2$)	26.7	27.4	25.4	24.4
Aluminum (Al)	0.007	0.256	0.006	0.181
Total iron (Fe)	1.06	5.19	0.459	1.97
Ferrous iron (Fe(II))	1.05	---	0.459	---
Boron (B)	<0.01	0.012	<0.01	<0.01
Lithium (Li)	0.041	0.041	0.048	0.048
Strontium (Sr)	8.92	8.61	8.42	8.51
Barium (Ba)	0.021	0.028	0.016	0.023
Manganese (Mn)	3.17	3.12	2.84	2.67
Zinc (Zn)	0.004	0.065	<0.005	0.023
Lead (Pb)	<0.0003	0.0012	<0.0003	<0.0003
Nickel (Ni)	<0.0005	0.0043	<0.0005	0.0026
Copper (Cu)	<0.0005	0.0012	<0.0005	<0.0005
Cadmium (Cd)	<0.0002	<0.0002	<0.0002	<0.0002
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0002	<0.04	0.0003	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	5.4	---	1.5	---
Sum cations (meq/L)	25.3	---	23.6	---
Sum anions (meq/L)	23.2	---	25.0	---
Charge imbalance (percent)	8.7	---	-5.9	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-5B	SC-5B	AWWT-1	AWWT-1
Collection date	10/24/2003	10/24/2003	3/27/2002	3/27/2002
pH, field / lab [1]	7.17 / 7.80	--- / ---	3.87 / 3.06	--- / ---
SC (∝S/cm), field / lab [1]	2,240 / 2,290	--- / ---	1,390 / 1,650	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.25 / ---	--- / ---	0.55 / 0.46	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.5 / 7.5	--- / ---	9.9 / ---	--- / ---
Eh (volts)	-0.087	---	0.555	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	551	561	157	155
Magnesium (Mg)	39.6	40.5	51.6	50.9
Sodium (Na)	62.4	64.4	16.1	16.1
Potassium (K)	7.99	7.97	2.75	2.81
Sulfate (SO_4)	1,420	---	865	---
Alkalinity as bicarbonate	235	---	---	---
Fluoride (F)	1.13	---	2.49	---
Chloride (Cl)	22.3	---	5.5	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	25.8	27.0	62.6	62.8
Aluminum (Al)	0.008	0.013	35.5	35.5
Total iron (Fe)	0.476	0.541	33.5	35.5
Ferrous iron (Fe(II))	0.465	---	33.2	---
Boron (B)	0.016	0.022	0.007	0.009
Lithium (Li)	0.061	0.062	0.055	0.055
Strontium (Sr)	8.81	8.74	0.732	0.734
Barium (Ba)	0.021	0.023	0.005	0.005
Manganese (Mn)	2.70	2.76	5.80	5.80
Zinc (Zn)	<0.005	0.069	2.04	2.44
Lead (Pb)	<0.0003	<0.0003	0.011	<0.008
Nickel (Ni)	<0.0005	<0.0005	0.296	0.285
Copper (Cu)	<0.0005	<0.0005	<0.0005	0.100
Cadmium (Cd)	<0.0002	<0.0002	0.006	0.052
Chromium (Cr)	<0.0005	<0.0005	0.103	0.112
Cobalt (Co)	<0.0007	<0.0007	0.111	0.110
Beryllium (Be)	<0.001	<0.001	0.005	0.006
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	0.001	0.002
Arsenic (As)	<0.04	<0.04	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	2.4	---	0.8	---
Sum cations (meq/L)	25.0	---	13.6	---
Sum anions (meq/L)	25.1	---	13.4	---
Charge imbalance (percent)	-0.43	---	1.3	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	AWWT-1	AWWT-1	AWWT-1	AWWT-1
Collection date	**4/25/2002**	**4/25/2002**	**5/23/2002**	**5/23/2002**
pH, field / lab [1]	3.91 / 3.06	--- / ---	3.81 / 3.11	--- / ---
SC (∝S/cm), field / lab [1]	1,450 / 1,650	--- / ---	1,470 / 1,580	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.39 / 0.28	--- / ---	0.47 / 0.27	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.4 / 8.4	--- / ---	10.2 / 8.1	--- / ---
Eh (volts)	0.590	---	0.562	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	150	146	158	159
Magnesium (Mg)	49.2	49.9	52.6	54.6
Sodium (Na)	16.6	17.9	18.0	19.6
Potassium (K)	2.41	20.6	3.03	4.03
Sulfate (SO_4)	870	---	910	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.49	---	2.38	---
Chloride (Cl)	6.1	---	5.9	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	60.4	58.8	59.9	62.9
Aluminum (Al)	35.0	33.2	36.3	37.0
Total iron (Fe)	33.9	32.6	33.7	35.1
Ferrous iron (Fe(II))	33.9	---	33.7	---
Boron (B)	0.011	0.016	<0.01	0.011
Lithium (Li)	0.052	0.055	0.062	0.084
Strontium (Sr)	0.739	0.718	0.732	0.774
Barium (Ba)	0.005	0.005	0.005	0.007
Manganese (Mn)	5.73	5.61	5.82	6.09
Zinc (Zn)	1.97	1.95	2.08	2.20
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.289	0.290	0.221	0.365
Copper (Cu)	<0.003	0.036	<0.0005	0.074
Cadmium (Cd)	0.006	0.006	0.004	0.018
Chromium (Cr)	0.099	0.100	0.074	0.121
Cobalt (Co)	0.114	0.114	0.088	0.143
Beryllium (Be)	0.006	0.006	0.004	0.008
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	0.001	0.002
Dissolved organic carbon	1.0	---	1.5	---
Sum cations (meq/L)	13.7	---	13.7	---
Sum anions (meq/L)	13.6	---	14.1	---
Charge imbalance (percent)	0.24	---	-3.0	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**AWWT-1_R**	**AWWT-1_R**	**AWWT-1**	**AWWT-1**
Collection date	**5/23/2002**	**5/23/2002**	**6/26/2002**	**6/26/2002**
pH, field / lab [1]	3.81 / 3.05	--- / ---	3.87 / 3.09	--- / ---
SC (∝S/cm), field / lab [1]	1,470 / 1,620	--- / ---	1,470 / 1,650	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.47 / 0.27	--- / ---	0.10 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	10.2 / 8.1	--- / ---	11.0 / ---	--- / ---
Eh (volts)	0.562	---	0.492	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	157	157	157	159
Magnesium (Mg)	53.5	51.3	53.6	52.6
Sodium (Na)	16.4	16.6	16.2	19.1
Potassium (K)	2.58	2.79	2.78	3.16
Sulfate (SO_4)	855	---	875	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.60	---	2.49	---
Chloride (Cl)	6.4	---	6.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	61.2	60.7	61.2	63.5
Aluminum (Al)	36.8	36.4	36.3	37.2
Total iron (Fe)	34.0	36.1	33.9	35.4
Ferrous iron (Fe(II))	34.0	---	33.9	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.058	0.057	0.060	0.068
Strontium (Sr)	0.739	0.746	0.749	0.777
Barium (Ba)	0.004	0.004	0.005	0.005
Manganese (Mn)	5.86	5.94	6.00	6.03
Zinc (Zn)	2.09	2.05	2.09	2.09
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.244	0.215	0.251	0.275
Copper (Cu)	<0.0005	0.051	<0.0005	0.037
Cadmium (Cd)	0.005	0.007	0.006	0.007
Chromium (Cr)	0.081	0.069	0.079	0.094
Cobalt (Co)	0.099	0.086	0.101	0.112
Beryllium (Be)	0.005	0.005	0.005	0.006
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	0.001	<0.04	<0.04
Dissolved organic carbon	2.4	---	---	---
Sum cations (meq/L)	13.9	---	13.7	---
Sum anions (meq/L)	13.2	---	13.5	---
Charge imbalance (percent)	5.3	---	1.8	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	AWWT-1	AWWT-1	AWWT-1	AWWT-1
Collection date	7/26/2002	7/26/2002	8/22/2002	8/22/2002
pH, field / lab [1]	3.85 / 3.06	--- / ---	3.84 / 3.10	--- / ---
SC (∝S/cm), field / lab [1]	1,460 / 1,650	--- / ---	1,470 / 1,650	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.18 / 0.10	--- / ---	0.31 / 0.09	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.8 / 8.8	--- / ---	11.9 / 10.2	--- / ---
Eh (volts)	0.566	---	0.503	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	161	157	154	155
Magnesium (Mg)	56.9	62.0	52.0	52.9
Sodium (Na)	16.5	16.8	17.6	16.9
Potassium (K)	2.64	2.72	2.85	2.67
Sulfate (SO_4)	899	---	885	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.60	---	2.60	---
Chloride (Cl)	6.4	---	5.6	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	63.5	62.5	61.5	62.2
Aluminum (Al)	36.7	36.4	36.3	36.7
Total iron (Fe)	33.8	34.5	33.8	34.3
Ferrous iron (Fe(II))	33.8	---	33.6	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.057	0.059	0.060	0.057
Strontium (Sr)	0.762	0.791	0.758	0.749
Barium (Ba)	0.005	0.005	0.005	0.004
Manganese (Mn)	6.01	5.89	5.90	5.87
Zinc (Zn)	2.03	2.05	2.04	2.09
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.273	0.260	0.251	0.249
Copper (Cu)	<0.0005	0.040	<0.0005	0.045
Cadmium (Cd)	0.006	0.009	0.005	0.009
Chromium (Cr)	0.089	0.093	0.081	0.088
Cobalt (Co)	0.109	0.101	0.097	0.098
Beryllium (Be)	0.006	0.005	0.005	0.005
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.001	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	2.2	---
Sum cations (meq/L)	14.1	---	13.5	---
Sum anions (meq/L)	13.9	---	13.7	---
Charge imbalance (percent)	2.0	---	-1.4	---

Appendix 1. Chemical analyses of water samples--Continued.

Site **Collection date**	**AWWT-1** **9/17/2002**	**AWWT-1** **9/17/2002**	**AWWT-1** **10/17/2002**	**AWWT-1** **10/17/2002**
pH, field / lab [1]	3.89 / 3.07	--- / ---	3.84 / 3.14	--- / ---
SC (∝S/cm), field / lab [1]	1,480 / 1,640	--- / ---	1,450 / 1,620	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.24 / ---	--- / ---	0.38 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	10.5 / ---	--- / ---	9.9 / ---	--- / ---
Eh (volts)	---	---	0.570	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	158	156	160	160
Magnesium (Mg)	53.1	53.0	53.8	51.6
Sodium (Na)	16.7	16.1	18.4	18.0
Potassium (K)	2.92	1.84	3.11	2.78
Sulfate (SO_4)	907	---	927	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.49	---	3.77	---
Chloride (Cl)	6.0	---	3.5	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	62.3	60.5	66.6	61.5
Aluminum (Al)	35.9	36.5	39.0	35.4
Total iron (Fe)	33.3	34.3	32.5	33.6
Ferrous iron (Fe(II))	33.3	---	32.5	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.060	0.038	0.064	0.057
Strontium (Sr)	0.770	0.747	0.779	0.751
Barium (Ba)	0.005	0.003	0.005	0.005
Manganese (Mn)	5.86	5.84	6.21	5.92
Zinc (Zn)	2.04	2.10	2.10	2.11
Lead (Pb)	<0.008	<0.008	<0.008	<0.008
Nickel (Ni)	0.252	0.196	0.271	0.263
Copper (Cu)	0.0050	0.062	<0.0005	0.053
Cadmium (Cd)	0.006	0.010	0.006	0.014
Chromium (Cr)	0.081	0.068	0.085	0.080
Cobalt (Co)	0.099	0.075	0.107	0.099
Beryllium (Be)	0.005	0.004	0.006	0.005
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	---	---	---	---
Sum cations (meq/L)	13.6	---	14.0	---
Sum anions (meq/L)	14.1	---	14.3	---
Charge imbalance (percent)	-3.5	---	-1.9	---

Appendix 1. Chemical analyses of water samples--Continued.

Site Collection date	AWWT-1 12/11/2002	AWWT-1 12/11/2002	AWWT-1 2/4/2003	AWWT-1 2/4/2003
pH, field / lab [1]	3.87 / 3.14	--- / ---	3.86 / 3.07	--- / ---
SC (∝S/cm), field / lab [1]	1,560 / 1,610	--- / ---	1,430 / 1,660	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.18 / ---	--- / ---	0.09 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	6.3 / ---	--- / ---	6.4 / ---	--- / ---
Eh (volts)	0.582	---	0.351	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	159	157	156	156
Magnesium (Mg)	54.3	54.1	56.5	53.7
Sodium (Na)	16.2	18.0	21.0	20.4
Potassium (K)	2.67	2.99	3.96	3.27
Sulfate (SO_4)	882	---	887	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.49	---	3.20	---
Chloride (Cl)	4.7	---	4.7	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	62.9	61.0	62.4	63.0
Aluminum (Al)	36.7	34.7	36.0	36.0
Total iron (Fe)	32.1	34.2	32.2	34.9
Ferrous iron (Fe(II))	32.1	---	32.2	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.057	0.062	0.048	0.067
Strontium (Sr)	0.761	0.742	0.744	0.791
Barium (Ba)	0.005	0.005	0.004	0.004
Manganese (Mn)	6.00	5.85	5.90	6.00
Zinc (Zn)	2.15	2.22	2.03	1.94
Lead (Pb)	<0.008	<0.008	0.0003	<0.0003
Nickel (Ni)	0.259	0.256	0.202	0.230
Copper (Cu)	<0.0005	0.084	<0.0005	0.049
Cadmium (Cd)	0.006	0.019	0.005	0.011
Chromium (Cr)	0.076	0.075	0.063	0.070
Cobalt (Co)	0.102	0.102	0.080	0.088
Beryllium (Be)	0.005	0.006	0.004	0.005
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.2	---	1.3	---
Sum cations (meq/L)	14.0	---	14.2	---
Sum anions (meq/L)	13.8	---	13.9	---
Charge imbalance (percent)	1.6	---	2.4	---

Appendix 1. Chemical analyses of water samples--Continued.

Site **Collection date**	**AWWT-1** **5/12/2003**	**AWWT-1** **5/12/2003**	**AWWT-1** **8/21/2003**	**AWWT-1** **8/21/2003**
pH, field / lab [1]	3.87 / 2.99	--- / ---	3.86 / 3.00	--- / ---
SC (µS/cm), field / lab [1]	1,530 / 1,620	--- / ---	1,470 / 1,600	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.52 / ---	--- / ---	0.70 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	10.3 / 7.9	--- / ---	13.0 / 10.9	--- / ---
Eh (volts)	0.430	---	0.424	---
Treatment [2]	0.45-µm, capsule	RA	0.45-µm, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	160	161	164	167
Magnesium (Mg)	55.1	54.7	58.2	58.9
Sodium (Na)	17.0	17.0	13.8	14.3
Potassium (K)	2.72	2.74	2.52	2.52
Sulfate (SO_4)	916	---	901	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	3.38	---	3.30	---
Chloride (Cl)	4.9	---	4.3	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	60.7	62.9	63.6	65.1
Aluminum (Al)	35.5	37.9	38.2	38.5
Total iron (Fe)	31.5	34.9	31.2	36.0
Ferrous iron (Fe(II))	31.5	---	30.5	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.059	0.058	0.062	0.062
Strontium (Sr)	0.758	0.776	0.815	0.830
Barium (Ba)	0.005	0.005	0.004	0.004
Manganese (Mn)	5.95	6.14	6.41	6.48
Zinc (Zn)	2.14	2.09	2.30	2.35
Lead (Pb)	0.0002	0.0003	0.0001	<0.0003
Nickel (Ni)	0.288	0.282	0.273	0.277
Copper (Cu)	<0.0005	0.037	0.0036	0.039
Cadmium (Cd)	0.006	0.008	0.005	0.007
Chromium (Cr)	0.082	0.080	0.099	0.084
Cobalt (Co)	0.112	0.109	0.101	0.102
Beryllium (Be)	0.006	0.006	0.004	0.004
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.0003	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.3	---	1.2	---
Sum cations (meq/L)	13.8	---	14.2	---
Sum anions (meq/L)	14.3	---	13.7	---
Charge imbalance (percent)	-3.4	---	3.5	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**AWWT-1**	**AWWT-1**	**AWWT-2**	**AWWT-2**
Collection date	**10/24/2003**	**10/24/2003**	**12/13/2002**	**12/13/2002**
pH, field / lab [1]	3.81 / 3.00	--- / ---	6.78 / 7.78	--- / ---
SC (∝S/cm), field / lab [1]	1,290 / 1,590	--- / ---	3,110 / 2,880	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.47 / ---	--- / ---	0.54 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	10.8 / 9.1	--- / ---	8.7 / ---	--- / ---
Eh (volts)	0.518	---	0.351	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	161	165	401	400
Magnesium (Mg)	50.0	50.9	272	266
Sodium (Na)	15.9	14.7	50.6	50.1
Potassium (K)	3.15	1.85	5.14	4.55
Sulfate (SO_4)	903	---	1,800	---
Alkalinity as bicarbonate	---	---	352	---
Fluoride (F)	3.31	---	4.07	---
Chloride (Cl)	4.1	---	4.7	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	67.0	67.6	20.9	20.7
Aluminum (Al)	39.0	38.8	0.012	0.523
Total iron (Fe)	31.7	35.7	0.125	0.822
Ferrous iron (Fe(II))	30.8	---	0.079	---
Boron (B)	<0.01	0.011	0.013	0.014
Lithium (Li)	0.058	0.053	0.199	0.169
Strontium (Sr)	0.829	0.817	7.37	7.11
Barium (Ba)	0.005	0.005	0.007	0.006
Manganese (Mn)	5.24	5.55	5.74	5.64
Zinc (Zn)	1.83	2.05	0.517	0.599
Lead (Pb)	0.0005	<0.0003	<0.008	<0.008
Nickel (Ni)	0.301	0.303	0.211	0.210
Copper (Cu)	0.0038	0.029	<0.0005	<0.0005
Cadmium (Cd)	0.007	0.006	<0.001	<0.001
Chromium (Cr)	0.083	0.068	<0.0005	0.0011
Cobalt (Co)	0.119	0.108	0.113	0.112
Beryllium (Be)	0.005	0.006	0.005	0.005
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.04	<0.0001	<0.0001
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	0.9	---	1.9	---
Sum cations (meq/L)	13.7	---	32.4	---
Sum anions (meq/L)	14.0	---	30.9	---
Charge imbalance (percent)	-1.6	---	4.9	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**AWWT-2_R**	**AWWT-2_R**	**SC-7A_1**	**SC-7A_1**
Collection date	**12/13/2002**	**12/13/2002**	**2/4/2003**	**2/4/2003**
pH, field / lab [1]	6.78 / 7.93	--- / ---	3.94 / 3.10	--- / ---
SC (∝S/cm), field / lab [1]	3,110 / 2,860	--- / ---	1,530 / 1,700	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.54 / ---	--- / ---	0.78 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.7 / ---	--- / ---	7.4 / 7.0	--- / ---
Eh (volts)	0.351	---	0.570	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	406	402	184	182
Magnesium (Mg)	266	249	59.1	59.4
Sodium (Na)	50.0	50.4	21.1	19.5
Potassium (K)	4.74	4.82	3.10	2.87
Sulfate (SO_4)	1,830	---	921	---
Alkalinity as bicarbonate	353	---	---	---
Fluoride (F)	4.07	---	2.36	---
Chloride (Cl)	5.0	---	4.2	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	21.0	21.4	57.9	57.8
Aluminum (Al)	0.007	0.458	35.7	34.9
Total iron (Fe)	0.101	0.643	31.2	33.1
Ferrous iron (Fe(II))	0.076	---	30.6	---
Boron (B)	0.014	0.014	<0.01	<0.01
Lithium (Li)	0.177	0.179	0.070	0.070
Strontium (Sr)	7.38	6.79	1.01	1.01
Barium (Ba)	0.006	0.007	0.004	0.004
Manganese (Mn)	5.73	5.83	6.45	6.42
Zinc (Zn)	0.528	0.528	2.04	1.94
Lead (Pb)	<0.008	<0.008	<0.0003	<0.0003
Nickel (Ni)	0.211	0.213	0.249	0.210
Copper (Cu)	<0.0005	<0.0005	0.068	0.069
Cadmium (Cd)	<0.001	<0.001	0.0070	0.0069
Chromium (Cr)	<0.0005	<0.003	0.0047	0.0046
Cobalt (Co)	0.115	0.115	0.103	0.091
Beryllium (Be)	0.005	0.005	0.005	0.005
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.0001	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	2.0	---	1.0	---
Sum cations (meq/L)	32.1	---	15.3	---
Sum anions (meq/L)	31.5	---	14.1	---
Charge imbalance (percent)	1.9	---	8.1	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-7A_1**	**SC-7A_1**	**SC-7A_1**	**SC-7A_1**
Collection date	**5/12/2003**	**5/12/2003**	**8/18/2003**	**8/18/2003**
pH, field / lab [1]	3.93 / 3.08	--- / ---	3.87 / 3.10	--- / ---
SC (∝S/cm), field / lab [1]	1,621 / 1,710	--- / ---	1,510 / 1,640	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.47 / ---	--- / ---	0.50 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.8 / 7.8	--- / ---	10.9 / 9.7	--- / ---
Eh (volts)	0.551	---	0.575	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	191	187	191	187
Magnesium (Mg)	60.8	60.2	62.4	63.6
Sodium (Na)	18.9	17.8	14.8	13.8
Potassium (K)	2.95	2.76	2.34	2.45
Sulfate (SO_4)	988	---	942	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.90	---	3.20	---
Chloride (Cl)	4.2	---	3.7	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	58.3	58.6	63.7	58.9
Aluminum (Al)	37.1	35.8	37.9	35.4
Total iron (Fe)	30.3	33.2	30.3	34.5
Ferrous iron (Fe(II))	30.2	---	30.1	---
Boron (B)	<0.01	0.010	<0.01	<0.01
Lithium (Li)	0.067	0.063	0.082	0.082
Strontium (Sr)	1.02	1.01	1.08	1.07
Barium (Ba)	0.005	0.004	0.003	0.003
Manganese (Mn)	6.68	6.63	6.89	6.49
Zinc (Zn)	2.17	2.15	2.33	2.19
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.263	0.256	0.238	0.231
Copper (Cu)	0.062	0.063	0.057	0.059
Cadmium (Cd)	0.0067	0.0067	0.0063	0.0062
Chromium (Cr)	0.0052	0.0069	0.0050	0.0042
Cobalt (Co)	0.115	0.113	0.097	0.097
Beryllium (Be)	0.006	0.006	0.004	0.004
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.6	---	1.8	---
Sum cations (meq/L)	15.4	---	15.5	---
Sum anions (meq/L)	15.1	---	14.2	---
Charge imbalance (percent)	1.9	---	8.9	---

Appendix 1. Chemical analyses of water samples--Continued.

Site **Collection date**	**SC-7A_1** **10/24/2003**	**SC-7A_1** **10/24/2003**	**SC-7A_2** **2/4/2003**	**SC-7A_2** **2/4/2003**
pH, field / lab [1]	3.70 / 3.11	--- / ---	3.92 / 3.10	--- / ---
SC (∝S/cm), field / lab [1]	1,370 / 1,630	--- / ---	1,390 / 1,610	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.25 /	--- / ---	0.29 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.5 / 7.9	--- / ---	5.8 / 5.8	--- / ---
Eh (volts)	0.562	---	0.560	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	172	163	162	168
Magnesium (Mg)	59.6	52.4	49.2	52.9
Sodium (Na)	18.4	17.6	18.0	18.5
Potassium (K)	3.09	2.83	2.83	2.91
Sulfate (SO_4)	957	---	813	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.70	---	2.16	---
Chloride (Cl)	3.7	---	4.8	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	56.5	57.1	57.3	60.8
Aluminum (Al)	34.2	33.4	33.3	33.5
Total iron (Fe)	29.4	30.0	29.4	33.2
Ferrous iron (Fe(II))	27.7	---	29.4	---
Boron (B)	<0.01	0.015	<0.01	<0.01
Lithium (Li)	0.069	0.061	0.061	0.063
Strontium (Sr)	1.23	1.02	0.831	0.844
Barium (Ba)	0.004	0.004	0.005	0.005
Manganese (Mn)	7.13	5.94	5.89	5.91
Zinc (Zn)	2.06	1.83	1.80	1.94
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.233	0.233	0.231	0.230
Copper (Cu)	0.056	0.061	0.063	0.068
Cadmium (Cd)	0.0062	0.0064	0.0063	0.0066
Chromium (Cr)	0.0047	0.0046	0.0043	0.0043
Cobalt (Co)	0.095	0.112	0.099	0.099
Beryllium (Be)	0.006	0.006	0.005	0.005
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	0.9	---	0.8	---
Sum cations (meq/L)	14.5	---	13.7	---
Sum anions (meq/L)	14.8	---	12.7	---
Charge imbalance (percent)	-1.9	---	7.7	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-7A_2**	**SC-7A_2**	**SC-7A_2**	**SC-7A_2**
Collection date	**5/12/2003**	**5/12/2003**	**8/20/2003**	**8/20/2003**
pH, field / lab [1]	3.98 / 3.08	--- / ---	3.97 / 3.12	--- / ---
SC (∝S/cm), field / lab [1]	1,500 / 1,600	--- / ---	1,400 / 1,520	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.21 / ---	--- / ---	0.30 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	8.8 / ---	--- / ---	11.8 / 10.2	--- / ---
Eh (volts)	0.551	---	0.574	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	164	164	150	149
Magnesium (Mg)	54.7	54.2	48.9	47.6
Sodium (Na)	16.6	17.6	14.6	14.5
Potassium (K)	2.55	2.81	2.64	2.73
Sulfate (SO_4)	902	---	833	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.30	---	2.50	---
Chloride (Cl)	4.5	---	4.0	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	57.7	57.7	57.4	58.1
Aluminum (Al)	34.6	34.8	31.7	31.9
Total iron (Fe)	29.7	31.6	29.5	31.4
Ferrous iron (Fe(II))	29.7	---	29.0	---
Boron (B)	<0.01	0.011	<0.01	<0.01
Lithium (Li)	0.054	0.056	0.059	0.062
Strontium (Sr)	0.874	0.868	0.787	0.774
Barium (Ba)	0.005	0.005	0.004	0.005
Manganese (Mn)	5.65	5.57	5.15	5.14
Zinc (Zn)	1.95	1.93	1.79	1.75
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.228	0.240	0.210	0.196
Copper (Cu)	0.060	0.063	0.053	0.055
Cadmium (Cd)	0.0057	0.0057	0.0050	0.0052
Chromium (Cr)	0.0051	0.0043	0.0041	0.0043
Cobalt (Co)	0.101	0.102	0.085	0.081
Beryllium (Be)	0.005	0.005	0.004	0.004
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.4	---	1.4	---
Sum cations (meq/L)	13.8	---	12.6	---
Sum anions (meq/L)	14.0	---	13.0	---
Charge imbalance (percent)	-1.4	---	-3.1	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-7A_2**	**SC-7A_2**	**SC-7A_3**	**SC-7A_3**
Collection date	**10/24/2003**	**10/24/2003**	**2/4/2003**	**2/4/2003**
pH, field / lab [1]	3.75 / 3.11	--- / ---	3.90 / 3.13	--- / ---
SC (∝S/cm), field / lab [1]	1,260 / 1,530	--- / ---	1,350 / 1,490	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.27 /	--- / ---	0.00 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	12.0 / ---	--- / ---	5.4 / ---	--- / ---
Eh (volts)	0.549	---	0.562	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	162	161	152	151
Magnesium (Mg)	50.9	50.7	50.4	50.2
Sodium (Na)	14.4	14.2	19.0	19.3
Potassium (K)	2.70	3.00	3.05	3.11
Sulfate (SO_4)	864	---	778	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.90	---	2.16	---
Chloride (Cl)	3.8	---	4.8	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	60.2	59.5	58.1	58.2
Aluminum (Al)	33.3	32.6	31.7	31.5
Total iron (Fe)	28.9	31.8	26.0	28.2
Ferrous iron (Fe(II))	28.3	---	26.0	---
Boron (B)	0.010	0.012	0.015	<0.01
Lithium (Li)	0.053	0.063	0.057	0.057
Strontium (Sr)	0.868	0.839	0.783	0.779
Barium (Ba)	0.005	0.005	0.005	0.005
Manganese (Mn)	5.58	5.22	5.20	5.16
Zinc (Zn)	1.84	1.82	1.77	1.73
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.200	0.246	0.180	0.185
Copper (Cu)	0.052	0.053	0.126	0.121
Cadmium (Cd)	0.0053	0.0050	0.0096	0.0090
Chromium (Cr)	0.0045	0.0046	0.0040	0.0039
Cobalt (Co)	0.084	0.102	0.082	0.079
Beryllium (Be)	0.004	0.005	0.004	0.004
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	0.8	---	0.8	---
Sum cations (meq/L)	13.3	---	13.3	---
Sum anions (meq/L)	13.3	---	12.2	---
Charge imbalance (percent)	0.05	---	8.5	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-7A_3**	**SC-7A_3**	**SC-7A_3**	**SC-7A_3**
Collection date	**5/12/2003**	**5/12/2003**	**8/20/2003**	**8/20/2003**
pH, field / lab [1]	3.85 / 3.10	--- / ---	3.96 / 2.78	--- / ---
SC (∝S/cm), field / lab [1]	1,420 / 1,530	--- / ---	1,350 / 1,460	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.43 / ---	--- / ---	0.10 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	17.2 / 14.9	--- / ---	12.1 / 9.3	--- / ---
Eh (volts)	0.559	---	0.564	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	154	154	150	141
Magnesium (Mg)	51.5	51.7	47.9	47.5
Sodium (Na)	14.4	14.2	14.9	14.3
Potassium (K)	2.58	2.14	2.88	2.91
Sulfate (SO_4)	855	---	803	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.50	---	2.70	---
Chloride (Cl)	4.7	---	4.0	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	58.3	57.9	59.3	58.0
Aluminum (Al)	34.0	32.9	31.1	29.5
Total iron (Fe)	27.1	29.4	27.3	32.2
Ferrous iron (Fe(II))	27.1	---	26.7	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.053	0.048	0.067	0.069
Strontium (Sr)	0.780	0.782	0.748	0.724
Barium (Ba)	0.005	0.004	0.005	0.004
Manganese (Mn)	5.39	5.35	5.13	5.00
Zinc (Zn)	1.85	1.84	1.78	1.77
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.222	0.225	0.188	0.194
Copper (Cu)	0.070	0.071	0.059	0.061
Cadmium (Cd)	0.0064	0.0061	0.0047	0.0050
Chromium (Cr)	0.0040	0.0034	0.0038	0.0039
Cobalt (Co)	0.091	0.093	0.076	0.084
Beryllium (Be)	0.005	0.005	0.005	0.004
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	0.022	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	2.8	---	1.3	---
Sum cations (meq/L)	12.9	---	12.6	---
Sum anions (meq/L)	13.1	---	12.6	---
Charge imbalance (percent)	-1.8	---	0.27	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	SC-7A_3	SC-7A_3	SC-7A_4	SC-7A_4
Collection date	10/24/2003	10/24/2003	2/4/2003	2/4/2003
pH, field / lab [1]	3.67 / 3.12	--- / ---	3.88 / 3.12	--- / ---
SC (∝S/cm), field / lab [1]	1,220 / 1,470	--- / ---	1,340 / 1,570	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.33 /	--- / ---	0.15 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	11.7 / ---	--- / ---	2.7 / ---	--- / ---
Eh (volts)	0.544	---	0.590	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	148	151	154	152
Magnesium (Mg)	51.0	50.1	47.9	48.2
Sodium (Na)	16.1	16.9	16.7	17.3
Potassium (K)	2.76	2.84	2.62	2.78
Sulfate (SO_4)	838	---	767	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.60	---	1.98	---
Chloride (Cl)	4.0	---	4.8	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	61.7	58.6	59.1	58.3
Aluminum (Al)	29.0	31.3	31.8	32.4
Total iron (Fe)	27.9	29.3	25.3	27.0
Ferrous iron (Fe(II))	26.9	---	25.3	---
Boron (B)	<0.01	0.015	0.010	0.010
Lithium (Li)	0.055	0.052	0.053	0.056
Strontium (Sr)	0.752	0.737	0.791	0.778
Barium (Ba)	0.004	0.005	0.005	0.005
Manganese (Mn)	5.47	5.06	5.07	5.05
Zinc (Zn)	1.85	1.81	1.85	1.81
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.209	0.201	0.196	0.190
Copper (Cu)	0.054	0.061	0.122	0.127
Cadmium (Cd)	0.0048	0.0050	0.0094	0.0092
Chromium (Cr)	0.0042	0.0045	0.0038	0.0039
Cobalt (Co)	0.082	0.083	0.086	0.083
Beryllium (Be)	0.005	0.005	0.005	0.005
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.0	---	0.9	---
Sum cations (meq/L)	12.6	---	13.2	---
Sum anions (meq/L)	13.1	---	12.2	---
Charge imbalance (percent)	-4.1	---	8.5	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-7A_4**	**SC-7A_4**	**SC-7A_4**	**SC-7A_4**
Collection date	**5/12/2003**	**5/12/2003**	**8/20/2003**	**8/20/2003**
pH, field / lab [1]	3.94 / 3.11	--- / ---	3.94 / 3.13	--- / ---
SC (∝S/cm), field / lab [1]	1,410 / 1,500	--- / ---	1,350 / 1,460	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.26 / ---	--- / ---	0.37 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	15.4 / ---	--- / ---	11.3 / ---	--- / ---
Eh (volts)	0.560	---	0.560	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	157	157	137	135
Magnesium (Mg)	50.3	52.0	44.2	43.0
Sodium (Na)	17.9	18.1	14.3	13.8
Potassium (K)	2.97	3.22	2.68	2.78
Sulfate (SO_4)	836	---	801	---
Alkalinity as bicarbonate	---	---	---	---
Fluoride (F)	2.60	---	2.60	---
Chloride (Cl)	4.6	---	4.2	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	57.9	56.4	55.4	54.9
Aluminum (Al)	32.7	31.3	29.9	28.9
Total iron (Fe)	26.6	29.4	27.2	29.1
Ferrous iron (Fe(II))	26.4	---	26.9	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.055	0.056	0.056	0.057
Strontium (Sr)	0.793	0.783	0.703	0.688
Barium (Ba)	0.006	0.006	0.004	0.005
Manganese (Mn)	5.36	5.39	4.76	4.62
Zinc (Zn)	1.88	1.90	1.65	1.63
Lead (Pb)	0.0008	0.0015	<0.0003	<0.0003
Nickel (Ni)	0.226	0.208	0.197	0.200
Copper (Cu)	0.075	0.070	0.060	0.066
Cadmium (Cd)	0.0059	0.0060	0.0047	0.0050
Chromium (Cr)	0.0040	0.0037	0.0039	0.0040
Cobalt (Co)	0.095	0.090	0.080	0.082
Beryllium (Be)	0.005	0.005	0.004	0.004
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	0.0003	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	1.5	---	1.2	---
Sum cations (meq/L)	13.0	---	11.6	---
Sum anions (meq/L)	12.8	---	12.7	---
Charge imbalance (percent)	1.5	---	-8.9	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-7A_4**	**SC-7A_4**	**SC-8A**	**SC-8A**
Collection date	**10/24/2003**	**10/24/2003**	**2/5/2003**	**2/5/2003**
pH, field / lab [1]	3.72 / 3.11	--- / ---	6.64 / 7.77	--- / ---
SC (∝S/cm), field / lab [1]	1,220 / 1,490	--- / ---	362 / 353	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	0.26 /	--- / ---	5.03 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	9.5 / ---	--- / ---	4.1 / 5.9	--- / ---
Eh (volts)	0.540	---	0.420	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	146	144	51.6	50.8
Magnesium (Mg)	49.6	47.8	7.43	10.4
Sodium (Na)	19.7	19.2	5.88	5.82
Potassium (K)	3.25	3.13	1.01	1.04
Sulfate (SO_4)	828	---	119	---
Alkalinity as bicarbonate	---	---	71.2	---
Fluoride (F)	2.50	---	0.140	---
Chloride (Cl)	4.0	---	3.0	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	55.4	61.0	11.5	13.1
Aluminum (Al)	30.1	31.2	0.010	0.003
Total iron (Fe)	28.2	30.7	<0.001	<0.007
Ferrous iron (Fe(II))	27.0	---	<0.001	---
Boron (B)	0.015	<0.01	<0.01	<0.01
Lithium (Li)	0.061	0.060	0.004	0.003
Strontium (Sr)	0.717	0.738	0.263	0.302
Barium (Ba)	0.005	0.005	0.020	0.021
Manganese (Mn)	5.86	5.26	0.002	0.002
Zinc (Zn)	1.85	1.74	0.019	0.030
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.224	0.213	0.0039	0.0032
Copper (Cu)	0.057	0.062	<0.0005	<0.0005
Cadmium (Cd)	0.0047	0.0047	<0.0002	<0.0002
Chromium (Cr)	0.0043	0.0039	<0.0005	<0.0005
Cobalt (Co)	0.087	0.091	<0.0007	<0.0007
Beryllium (Be)	0.004	0.005	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.04	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	0.8	---	0.5	---
Sum cations (meq/L)	12.8	---	3.2	---
Sum anions (meq/L)	13.0	---	3.5	---
Charge imbalance (percent)	-1.9	---	-7.8	---

Appendix 1. Chemical analyses of water samples--Continued.

Site	**SC-8A**	**SC-8A**	**SC-8A**	**SC-8A**
Collection date	**5/12/2003**	**5/12/2003**	**8/18/2003**	**8/18/2003**
pH, field / lab [1]	6.51 / 7.98	--- / ---	6.63 / 8.04	--- / ---
SC (∝S/cm), field / lab [1]	398 / 374	--- / ---	384 / 365	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	5.20 / ---	--- / ---	6.51 / ---	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	7.3 / 6.7	--- / ---	8.2 / 7.5	--- / ---
Eh (volts)	0.489	---	0.628	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	58.3	65.3	56.0	56.9
Magnesium (Mg)	11.3	10.0	12.6	11.4
Sodium (Na)	6.57	6.20	5.67	6.50
Potassium (K)	1.17	1.11	1.12	1.22
Sulfate (SO_4)	131	---	125	---
Alkalinity as bicarbonate	63.0	---	63.0	---
Fluoride (F)	0.257	---	0.264	---
Chloride (Cl)	2.9	---	2.9	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	13.4	15.2	12.9	13.3
Aluminum (Al)	0.007	1.50	0.003	0.006
Total iron (Fe)	0.001	0.452	0.001	<0.007
Ferrous iron (Fe(II))	<0.001	---	<0.001	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.004	0.005	0.005	0.004
Strontium (Sr)	0.340	0.341	0.388	0.351
Barium (Ba)	0.025	0.024	0.025	0.030
Manganese (Mn)	0.058	0.284	0.002	<0.002
Zinc (Zn)	0.084	0.219	0.039	0.037
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.0040	0.0054	0.0045	0.0037
Copper (Cu)	<0.0005	<0.0005	0.0008	0.0018
Cadmium (Cd)	<0.0002	<0.0002	0.0005	0.0004
Chromium (Cr)	0.0010	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	0.007	0.001
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.0001	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	0.7	---	0.8	---
Sum cations (meq/L)	3.8	---	3.8	---
Sum anions (meq/L)	3.5	---	3.4	---
Charge imbalance (percent)	8.3	---	10.4	---

Appendix 1. Chemical analyses of water samples--Concluded.

Site	**SC-8A_R**	**SC-8A_R**	**SC-8A**	**SC-8A**
Collection date	**8/18/2003**	**8/18/2003**	**10/23/2003**	**10/23/2003**
pH, field / lab [1]	6.63 / 8.07	--- / ---	6.57 / 8.02	--- / ---
SC (∝S/cm), field / lab [1]	384 / 366	--- / ---	363 / 351	--- / ---
D.O. (mg/L), flow-through cell / graduated cylinder [1]	--- / ---	--- / ---	6.07 / 6.67	--- / ---
Temperature (˚C), flow-through cell / graduated cylinder [1]	--- / ---	--- / ---	8.3 / 6.9	--- / ---
Eh (volts)	0.628	---	0.524	---
Treatment [2]	0.45-∝m, capsule	RA	0.45-∝m, capsule	RA
Constituent (mg/L)				
Calcium (Ca)	48.8	49.1	50.6	51.0
Magnesium (Mg)	10.3	10.8	10.9	10.8
Sodium (Na)	5.40	5.47	4.66	4.43
Potassium (K)	0.930	0.916	0.984	0.855
Sulfate (SO_4)	116	---	108	---
Alkalinity as bicarbonate	63.6	---	63.9	---
Fluoride (F)	0.273	---	0.263	---
Chloride (Cl)	3.0	---	2.8	---
Bromide (Br)	<0.1	---	<0.1	---
Silica (SiO_2)	11.4	11.5	13.1	13.2
Aluminum (Al)	0.009	0.005	0.007	0.005
Total iron (Fe)	0.002	0.205	<0.001	<0.007
Ferrous iron (Fe(II))	<0.001	---	<0.001	---
Boron (B)	<0.01	<0.01	<0.01	<0.01
Lithium (Li)	0.003	0.003	0.003	0.004
Strontium (Sr)	0.311	0.302	0.304	0.304
Barium (Ba)	0.021	0.020	0.022	0.021
Manganese (Mn)	<0.002	<0.002	<0.002	<0.002
Zinc (Zn)	<0.005	<0.005	0.035	0.028
Lead (Pb)	<0.0003	<0.0003	<0.0003	<0.0003
Nickel (Ni)	0.0044	0.0021	0.0041	0.0039
Copper (Cu)	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium (Cd)	0.0061	<0.0002	<0.0002	<0.0002
Chromium (Cr)	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt (Co)	<0.0007	<0.0007	<0.0007	<0.0007
Beryllium (Be)	<0.001	<0.001	<0.001	<0.001
Molybdenum (Mo)	<0.007	<0.007	<0.007	<0.007
Vanadium (V)	<0.002	<0.002	<0.002	<0.002
Arsenic (As)	<0.0001	<0.04	<0.04	<0.04
Selenium (Se)	<0.04	<0.04	<0.04	<0.04
Dissolved organic carbon	0.7	---	0.9	---
Sum cations (meq/L)	3.3	---	3.4	---
Sum anions (meq/L)	3.3	---	3.1	---
Charge imbalance (percent)	-0.68	---	8.3	---

[1] Although field parameter values for ground-water samples are listed under the filtered column only, all field parameters were measured prior to sample collection and are not associated with a particular sample. For Straight Creek surface-water samples, all field parameters were measured either in the stream or in a beaker.

[2] 0.45-∝m and 0.1-∝m refer to filter pore sizes. All filtered samples are acidified except the anion sample.