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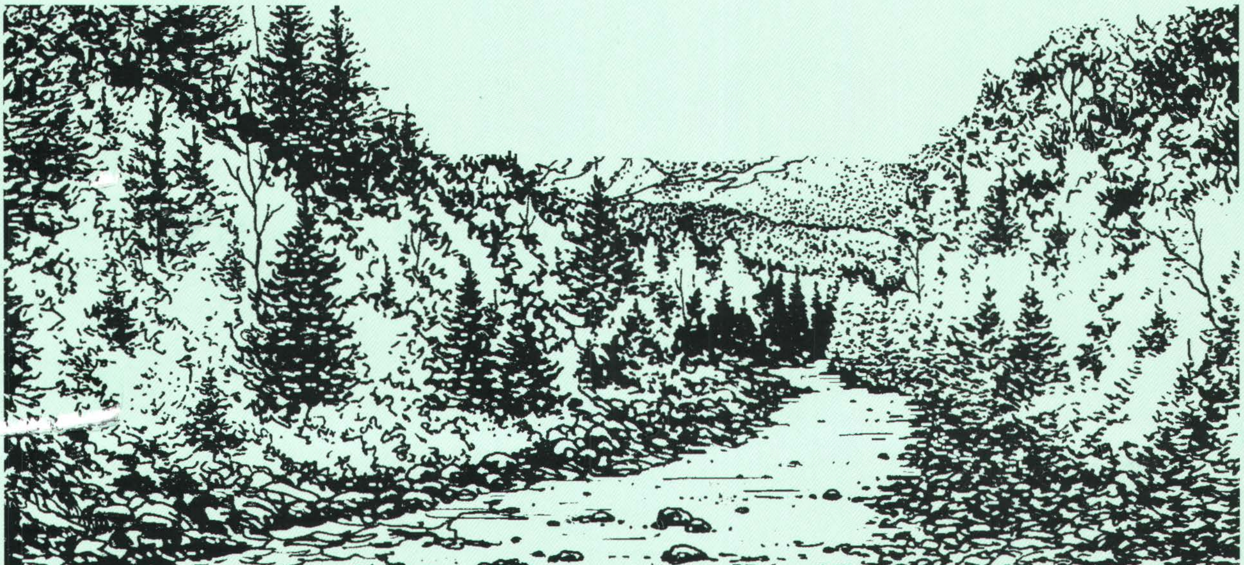
Environmental Characteristics and Water Quality of Hydrologic Benchmark Network Stations in the Western United States, 1963–95

Circular 1173–D



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Environmental Characteristics and Water Quality of Hydrologic Benchmark Network Stations in the Western United States, 1963–95

By M. Alisa Mast *and* David W. Clow

U.S. GEOLOGICAL SURVEY CIRCULAR 1173–D

U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

Reston, Virginia 2000

Free on application to the
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Library of Congress Cataloging-in-Publications Data

Mast, M. Alisa.
Environmental characteristics and water quality of hydrologic benchmark network stations in the western United States, 1963–95 / by M. Alisa Mast and David W. Clow.
p. cm. -- (U.S. Geological Survey circular ; 1173–D)
Includes bibliographical references (p.).
1. Hydrology--West (U.S.)--History. 2. Water quality--West (U.S.)--History. I. Clow, David W. II. Title. III. Series.
GB705.W3 M37 2000
551.48'0978--dc21
00–056161
ISBN 0–607–95104–4

FOREWORD

In 1962, Luna Leopold, Chief of the U.S. Geological Survey's Water Resources Division from 1957–66, stated "We are engaged in great national programs of water control and development. An expanding population demands ever-increasing supplies of the natural resources which are to be found in or upon the landscape—soil, water, minerals, food, timber, and fiber. By his works, by his extractions, man's mark upon his environment becomes ever deeper, his effects more indelible." He proposed that the Geological Survey "establish a network of 'hydrologic bench marks' in areas which are as free as possible from man-induced changes." In 1963, the U.S. Geological Survey established the Hydrologic Benchmark Network to provide long-term measurements of streamflow and water quality in areas that are minimally affected by human activities.

Circular 1173, titled "Environmental Characteristics and Water Quality of Hydrologic Benchmark Network Stations in the United States," consists of a series of four individual circulars that include stations in (A) Eastern, (B) Midwestern, (C) West-Central, and (D) Western United States. This series describes the hydrologic and chemical characteristics of each of the 58 stations that have been included in the Network. Trends in discharge, pH, and major dissolved ions also are examined. This circular is intended to provide information that will aid researchers and others in the application and interpretation of historical data collected as part of the Hydrologic Benchmark Network Program.

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
cubic meter per second (m^3/s)	35.31	cubic foot per second
hectare (ha)	2.471	acre
kilometer (km)	0.6214	mile
liter (L)	0.2642	foot
meter (m)	3.281	foot
meter per kilometer (m/km)	5.291	foot per mile
square kilometer (km^2)	0.386	square mile
microequivalent per liter alkalinity (µeq/L)	0.0500	milligram per liter alkalinity (as $CaCO_3$)
microequivalent per liter ammonium (µeq/L)	0.0140	milligram per liter ammonium (as N)
microequivalent per liter calcium (µeq/L)	0.0200	milligram per liter calcium
microequivalent per liter chloride (µeq/L)	0.0355	milligram per liter chloride
microequivalent per liter magnesium (µeq/L)	0.0122	milligram per liter magnesium
microequivalent per liter nitrite plus nitrate (µeq/L)	0.0140	milligram per liter nitrite plus nitrate (as N)
microequivalent per liter potassium (µeq/L)	0.0391	milligram per liter potassium
microequivalent per liter silica (µeq/L)	0.0602	milligram per liter silica
microequivalent per liter sodium (µeq/L)	0.0230	milligram per liter sodium
micromole per liter sulfate (µeq/L)	0.0480	milligram per liter sulfate

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = 9/5\ (°C) + 32.$$

Additional abbreviations used in this report:

cm/yr	centimeter per year (cm/yr)
$(m^3/s)/yr$	cubic meter per second per year
meq/100g	milliequivalent per 100 grams
mg/L	milligram per liter
(µeq/L)/yr	microequivalent per liter per year
µm	micrometer
(µmol/L)/yr	micromole per liter per year
µS/cm	microsiemens per centimeter at 25 degrees Celsius

Environmental Characteristics and Water Quality of Hydrologic Benchmark Network Stations in the Western United States, 1963–95

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Abstract

The Hydrologic Benchmark Network was established in 1963 to provide long-term measurements of streamflow and water quality in areas that are minimally affected by human activities. These data were used to study time trends and to serve as controls for separating natural from artificial changes in other streams. The network has consisted of as many as 58 drainage basins in 39 States. This report describes the environmental characteristics and water quality at 12 benchmark basins in the Western United States. The stations discussed in this report and their physiographic provinces are as follows: Wet Bottom Creek, Arizona, in the Southern Rocky Mountains; Elder Creek, California, in the Pacific Border Province; Merced River and Sagehen Creek, California, and Crater Lake, Oregon, in the Sierra-Cascade Mountains; Big Jacks Creek, Idaho, and Minam River, Oregon, in the Columbia Plateaus; Hayden Creek, Idaho, and Andrews Creek, Washington, in the Northern Rocky Mountains; South Twin River and Steptoe Creek, Nevada, in the Basin and Range; and Red Butte Creek, Utah, in the Middle Rocky Mountains. The information in this report was compiled to aid in the application and interpretation of historical water-quality data collected by the U.S. Geological Survey Hydrologic Benchmark Network program.

The Hydrologic Benchmark Network streams discussed in this report drain either forested areas or grasslands and have land-use activities that include recreational use, timber harvesting, grazing, and scientific research. Surface-water chemistry in the benchmark basins was controlled by the interaction of dilute precipitation with the underlying soils and bedrock, and land-use activities seemed to have a minimal effect on the major-ion and nutrient chemistry of stream water at the Hydrologic Benchmark Network stations. Temporal trends in water-quality constituents were observed at a number of the stations and were attributed to environmental and method-related factors. Trends in base cations and alkalinity at Elder Creek and Sagehen Creek, California, and Red Butte Creek, Utah, seemed to be associated with an extended period of drought that persisted from the late 1980's through the early 1990's in both regions of the country. Statistically significant upward trends in field pH and downward trends in sulfate that were observed at several of the stations were attributed to changes in field instrumentation and analytical techniques rather than environmental change.

INTRODUCTION

In 1962, L.B. Leopold, then Chief Hydrologist of the U.S. Geological Survey (USGS), proposed the establishment of a network of hydrologic benchmarks for making long-term measurements of various hydrologic characteristics in areas that were free from the effects of human activities (Leopold, 1962). The main purpose of the network was to provide a long-term hydrologic data base to be used to study temporal trends in hydrologic characteristics and to serve as controls for separating natural from manmade changes in other streams. The Hydrologic Benchmark Network (HBN) was started in 1963, and sites were selected on the basis of four criteria: (1) No manmade storage, regulation, or diversion was to exist in the basin; (2) ground water in the basin was not to be affected by pumping from wells; (3) conditions were to be favorable for accurate measurement of streamflow and water quality; and (4) the potential was to be small for special natural changes, such as beaver activity, overgrazing or overbrowsing, or extensive fire (Cobb and Biesecker, 1971). Most of the stations selected for the network were located in areas virtually free of human activities, such as national parks, wilderness areas, or nature preserves. However, such undisturbed areas no longer existed in many parts of the country, and the decision was made to include basins where logging or agriculture was practiced under the assumption that stations in such basins would still yield useful information as long as the land use did not change (Lawrence, 1987). Most stations in the HBN were established by the late 1960's and, after a few changes in the 1970's and 1980's, the network eventually consisted of 57 streamflow-HBN stations and one lake-stage station in 39 States (fig. 1). As a result of

Figure 1. Locations of gaging stations in the Hydrologic Benchmark Network.

an evaluation of the HBN program in the early 1990's, eight stations were discontinued and two stations were replaced for the following reasons: (1) The sites were operated as discharge-only stations during the period of record (Tallulah River, Ga.; Swiftcurrent Creek, Mont.; and Little Vermillion River, S. Dak.), (2) discharge records rated as poor were collected at the station (Honolii Stream, Hawaii, replaced by Kahakuloa Stream, Hawaii), (3) substantial changes in land use occurred during the period of record (Upper Three Runs, S.C.), or (4) water quality at the HBN station was strongly affected by upstream human activities (Esopus Creek, N.Y., replaced by Biscuit Brook, N.Y.; Falling Creek, Ga.; South Hogan Creek, Ind.; North Fork Whitewater River, Minn.; and Elk Creek, Iowa). Because of budgetary restrictions, water-quality sampling was decreased at all HBN stations in October 1986 and discontinued in October 1997.

The original network design to study temporal trends was first used to test whether changes in acidic deposition from the atmosphere were causing regional trends in surface-water chemistry (Smith and Alexander, 1983). This attempt to ascribe surface-water trends to environmental changes revealed a lack of ancillary data for the HBN, particularly for precipitation quality and quantity. Because temporal trends in surface-water chemistry may exist at many of the HBN stations, it is necessary to determine whether environmental factors, such as precipitation chemistry and land use, or changes in analytical techniques could have caused the observed trends. However, documentation of environmental characteristics and method-related effects is minimal for most HBN stations, and hydrologic characteristics other than stream discharge and chemistry were seldom measured. In addition, if the HBN is to be useful as a control for separating natural from manmade changes in other streams, an understanding of the natural and manmade factors that affect water quality in these basins is needed. In 1990, the USGS undertook an evaluation of the HBN program to provide detailed information for sites in the network and to determine the suitability of each site on the basis of the original design criteria.

Purpose and Scope

This report describes the environmental characteristics and water quality of 12 HBN stream basins in the Western United States. These stream basins, in order of presentation, are: Wet Bottom Creek, Arizona; Elder Creek, Merced River, and Sagehen Creek, California; Big Jacks Creek and Hayden Creek, Idaho; South Twin River and Steptoe Creek, Nevada; Crater Lake and Minam River, Oregon; Red Butte Creek, Utah; and Andrews Creek, Washington. The following information is presented for each HBN basin: (1) An overview of the basin characteristics, including physiography, geology, soils, vegetation, land ownership, basin access, and land use; (2) an analysis of the historical water-quality records for the HBN station in each basin for the period of record through water year 1995, including data quality, water-quality characteristics, and time-series trends; and (3) an interpretation of the intrabasin variability in surface-water chemistry for selected tributary streams in each basin that were sampled between January 1991 and April 1993. This report is intended to provide a framework of information to aid in the application and interpretation of water-quality data collected as part of the HBN program.

Previous Work

Although the HBN has been in existence for more than 30 years, only a few studies have assessed or analyzed data for the entire network. Brief descriptions of the HBN drainage basins and water-quality characteristics of the streams were compiled by Cobb and Biesecker (1971). Biesecker and Leifeste (1975) compared water-quality constituents for undisturbed HBN stations with constituents for major streams that drain similar hydrologic regions of the United States. Smith and Alexander (1983) examined time trends in pH, alkalinity, and sulfate at 47 HBN stations to investigate the long-term effects of acidic deposition on water quality in undeveloped basins. Lins (1986) used a principal-component analysis to determine whether patterns in stream sulfate at 30 HBN stations in the network could be used as analogues for regional patterns in sulfate deposition from the atmosphere. Lawrence (1987) presented a compilation of streamflow characteristics for 58 HBN stations, including an analysis of time trends in streamflow for the period of record through water year 1980.

Few process-level investigations have been conducted by the USGS in the individual HBN drainage basins. One exception is for McDonalds Branch in New Jersey, which was the site of an acidic deposition study from 1984 through 1988 (Lord and others, 1990; Johnsson and Barringer, 1993). The Biscuit Brook Basin, N.Y., which replaced the Esopus Creek Basin in 1991, has been the site of several biogeochemical investigations (Murdoch, 1991; Murdoch and Stoddard, 1993). Site-specific investigations were more limited in scope at other HBN stations. Hainly and Ritter (1986) collected samples from tributary streams in the Esopus Creek Basin, N.Y., and Young Womans Creek Basin, Pa., to determine the representativeness of water quality at the basin outlet compared to water quality in headwater areas of these basins. Several observation wells and rain gages were installed in the Holiday Creek Basin, Va., in the early 1970's to investigate rainfall-runoff relations, but the project was not completed (Edward Knuckles, U.S. Geological Survey, oral commun., 1994). Buell (1985) investigated time-series trends in water-quality constituents at Falling Creek, Ga., to evaluate the effects of land use on water quality in similar basins.

Acknowledgments

The authors express their appreciation to employees of the U.S. Forest Service, the Bureau of Land Management, the National Park Service, the Nature Conservancy, and the USGS who provided information for this study. The authors also express gratitude to USGS employees Donald H. Campbell, Kathleen K. Fitzgerald, George P. Ingersoll, Wendy Meyer, Anthony J. Ranalli, Norman E. Spahr, and Amy Swancar for technical assistance and data collection.

METHODS

Historical water-quality records for stations in the HBN are available from the USGS National Water Information System (NWIS). Water measurements made at HBN stations have included a comprehensive suite of about 85 characteristics, including physical properties, major dissolved constituents, trace elements, radiochemical constituents, nutrients, and biological constituents (Alexander and others, 1996). Data for 63 of these characteristics were recently compiled on a CD-ROM for 1962 through 1994 (Alexander and others, 1996). The parameter codes used in NWIS and the periods of record of physical properties and water-quality constituents retrieved for this report are listed in table 1. The following modifications were made to the data before statistical and graphical analyses were performed: (1) Alkalinity concentrations stored under parameter code 00410 before 1981 were combined with alkalinity concentrations stored under parameter code 90410 to obtain a continuous record of laboratory alkalinities; (2) dissolved and total nitrite plus nitrate and dissolved and total ammonium were combined to obtain more continuous records for these two nutrient species (Office of Water Quality Technical Memorandum No. 93.04, *Discontinuation of the National Water Quality Laboratory determinations for "total" nitrite, "total" nitrite plus nitrate, "total" ammonium, and "total" orthophosphate*, issued December 2, 1992, at URL http://water.usgs.gov/admin/memo/); (3) concentrations reported as less than were set equal to the analytical reporting limit for the time-series plots and charge-balance calculations; (4) concentrations reported as zero were retained in the data files; (5) concentrations were converted from units of milligrams per liter to microequivalents per liter, except silica, aluminum, and iron, which were converted to units of micromoles per liter by using the conversion factors listed at the front of this report; and (6) outliers greater than five standard deviations from the mean were removed from the data sets. All periods of record discussed in this report refer to the water year defined as October 1 through September 30 unless otherwise indicated.

The quality of the chemical analyses was checked on the basis of ion balance, which was calculated as the total cation charge minus the total anion

Table 1. Parameter codes and periods of record for physical properties and water-quality constituents retrieved from the U.S. Geological Survey National Water Information System

Parameter	Parameter code	Period of record
Discharge, instantaneous	00060, 00061	Entire period
Specific conductance, field	00095	Entire period
Specific conductance, laboratory	90095	After 1980
pH, field	00400	Entire period
pH, laboratory	00403	After 1980
Calcium, dissolved	00915	Entire period
Magnesium, dissolved	00925	Entire period
Sodium, dissolved	00930	Entire period
Potassium, dissolved	00935	Entire period
Ammonium, dissolved	00608, 71846	1969–79,[b] after 1980
Ammonium, total	00610, 71845	1971–79,[b] 81–82, 86–92
Alkalinity, laboratory	00410,[a] 90410, 00417	Entire period
Alkalinity, field	00410,[a] 39086, 00419	After 1984
Bicarbonate, field	00440, 00450, 00453	1965–78,[b] after 1985
Sulfate, dissolved	00945	Entire period
Chloride, dissolved	00940	Entire period
Nitrite plus nitrate, dissolved	00631	1974–77,[b] after 1979
Nitrite plus nitrate, total	00630	After 1971[b]
Silica, dissolved	00955	Entire period

[a] Prior to 1981, laboratory alkalinity data stored under parameter code 00410.

[b] Not reported at all Hydrologic Benchmark Network stations over entire period indicated.

charge divided by the total charge in solution. The cation charge was calculated as the sum of the hydrogen ion (calculated from field pH measurements), calcium, magnesium, sodium, and potassium concentrations, and the anion charge was calculated as the sum of laboratory alkalinity, chloride, and sulfate concentrations. Ion balance was calculated only for samples that had complete chemical analyses. The inorganic nitrogen species—nitrite plus nitrate and ammonium—were excluded from the calculation because neither of these species was measured during the entire period of record. Omission of these constituents from the ion-balance calculation was not expected to produce a substantial bias because concentrations were usually at or near the analytical reporting limit of the analytical techniques. The water-quality records also were inspected for bias that may have been introduced by sampling or analytical techniques and were compared to the chronology of activities and analytical techniques that were used by USGS laboratories (Durum, 1978; Fishman and others, 1994) and to operational guidelines for the HBN that were documented in a series of USGS technical memoranda available at URL http://water.usgs.gov/admin/memo/. Summary statistics of physical properties and water-quality constituents were calculated from the historical water-quality records at each HBN station. Spearman rank correlation coefficients (rho values) were calculated to measure the strength of monotonic associations among discharge and the major solutes. Values of rho range between −1.0 to 1.0, and a value of zero indicates no correlation between constituents.

Temporal trends in stream discharge and water-quality constituents were calculated by using the computer program, Estimate Trend (ESTREND), which was written by Schertz and others (1991). The program ESTREND uses two trend-detection techniques—the nonparametric seasonal Kendall test and the parametric Tobit test (Schertz and others, 1991). The seasonal Kendall test for uncensored data was used when less than 5 percent of the observations were censored. The seasonal Kendall test for censored data was used when more than 5 percent of the observations were censored. In analyses where a large number of detected concentrations were between multiple reporting limits, as often occurred for the concentrations of nitrite plus nitrate, the Tobit test was used to calculate the trend. Trends were calculated by using unadjusted concentrations and flow-adjusted concentrations. Removal of flow-related variability in the water-quality data not only improved the power of the statistical test but decreased the possibility that the observed trends were an artifact of the sampling discharge record (Hirsch and others, 1982; Schertz and others, 1991). Automated procedures are provided in ESTREND to adjust concentrations for flow-related variability. Flow adjustment was not made if the model was not significant at the 0.10 probability level (Schertz and others, 1991) or if the data were highly censored. Because the minimum sampling frequency at most HBN stations was quarterly, trends were calculated by using four 3-month seasons beginning in mid-December. Trends were considered statistically significant at the 0.01 probability level. The ESTREND program also computes a trend slope, which represents the median rate of change in discharge or concentrations for the selected period of record. Interpretation of the trends was aided by the use of a locally weighted scatterplot smoothing technique (LOWESS), which graphically smooths the pattern of the data over time (Schertz and others, 1991). LOWESS curves are presented in the time-series plots only when the trend in discharge or unadjusted pH or solute concentrations was statistically significant at the 0.01 probability level.

Stream chemistry at each HBN station was compared to precipitation chemistry at the closest National Atmospheric Deposition Program (NADP) station. The NADP is a monitoring network of nearly 200 stations nationwide that provides long-term records of weekly precipitation chemistry. Sampling, analytical, and quality-assurance protocols for the NADP network are summarized in Peden (1983). Annual volume-weighted mean (VWM) concentrations for the NADP stations presented in this report were obtained from the NADP at URL http://nadp.sws.uiuc.edu.

In addition to the historical water-quality records and NADP data, stream samples were collected at the HBN stations and from several major tributary streams in each basin between January 1991 and April 1993 to evaluate the spatial variability of surface-water chemistry as a function of subbasin characteristics, particularly geology and land use. The selection criteria for each sampling site are listed in tables throughout the report. Visits to each HBN drainage basin were scheduled during low-flow periods, and samples generally were collected for 1 to 3 days. Grab samples were collected in 2-L polyethylene bottles and filtered within 12 hours of collection. When possible, field measurements of dissolved oxygen, water temperature, and stream discharge were made at the time of sample collection. Measurements of pH were made within 12 hours of collection on unfiltered sample aliquots by using an electrode designed for low ionic-strength waters. The pH electrode was calibrated with pH 4 and pH 7 buffer solutions, then checked against a dilute sulfuric acid standard (pH 4.75) and deionized water. Samples for chemical analysis were filtered through a 0.45-µm filter and preserved within 12 hours of collection. Samples were analyzed for pH, specific conductance, major cations and anions, silica, and alkalinity at the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo., by using techniques developed for low ionic-strength waters (Fishman and Friedman, 1989). Chemical data for the synoptic samples are stored in NWIS.

ENVIRONMENTAL CHARACTERISTICS AND WATER QUALITY OF HYDROLOGIC BENCHMARK NETWORK STATIONS

Wet Bottom Creek near Childs, Arizona (Station 09508300)

Site Characteristics and Land Use

The Wet Bottom Creek HBN Basin is in the Mexican Highland of the Basin and Range physiographic province in central Arizona (fig. 2).

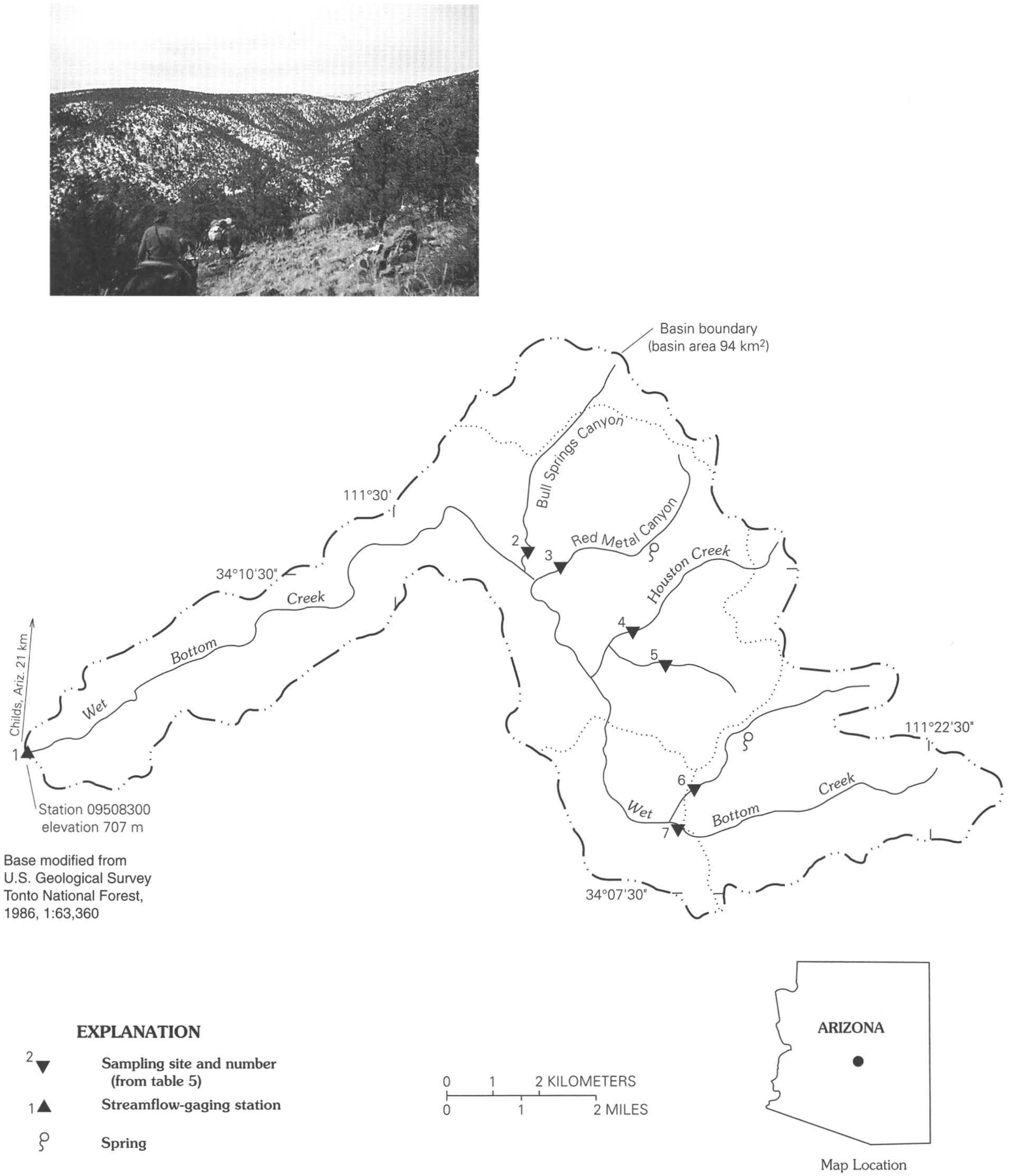


Figure 2. Map showing the study area in the Wet Bottom Creek Basin and photograph showing the basin landscape.

The 94-km^2 basin ranges in elevation from 707 m at the HBN station to 2,271 m along the eastern boundary. Topography consists of west-sloping mesas and ridges separated by steep canyons. The USGS station is located 21 km south of the town of Childs, Ariz., at latitude 34°09'39" and longitude 111°41'32". Wet Bottom Creek flows west into the Verde River, a tributary of the Colorado River, and has a channel length of 28 km upstream from the HBN station and an average stream gradient of 40 m/km. The main channel is ephemeral, often having no flow during June and July. Peak flows usually occur during February and March when spring rains combine with melting snow. Average monthly discharge ranges from 0.003 m^3/s in June to 1.4 m^3/s in March, and average annual runoff was 15.5 cm from 1968 through 1995 (Smith and others, 1996). The area has a high-elevation desert climate, with substantial diurnal temperature variations. Summers are hot and dry, and winters are cool and wet. Average daily temperatures range from 7.7°C in December to 29.4°C in July (National Weather Service at URL http://www.wrcc.dri.edu/climsum.html, accessed 1998). Snowfall is common at high elevations during the winter months; however, a seasonal snowpack seldom persists through the winter. Average annual precipitation is 63.5 cm and varies seasonally from 1 cm in June to 6.6 cm in August when thunderstorms are most common.

The basin is located in the Colorado Plateau Semidesert ecoregion (Bailey and others, 1994). Vegetation grows in zones defined by temperature and soil-moisture regimes, which are in turn dictated by elevation and aspect (Bailey and others, 1994). Low elevations are dominated by arid grasslands characterized by thin, patchy grass and xeric shrubs; cottonwoods grow along some of the streambanks. The woodland zone, which is above the grasslands, is dominated by low, open stands of pinyon pine and juniper. Ground cover includes grama grass, herbs, and shrubs, such as big sagebrush and alderleaf cercocarpus. The montane zone is on the high plateaus and mountains and is characterized by ponderosa pine and occasionally by Douglas-fir. Soils developed along flood plains of major streams are classified as Entisols, and those covering plateau tops, old stream terraces, and alluvial fans are classified as Aridisols (Bailey and others, 1994). Badlands of broken rock and steep slopewash deposits are extensive in the mountains and on the plateaus.

The geology and mineral resources of the Wet Bottom Creek Basin have been mapped by Wrucke and others (1983) and Wrucke and Conway (1987). The predominant rock type is alkali granite, which crops out in the southern two-thirds of the basin. The mineralogy of the granite includes quartz, feldspar, biotite, with minor amounts of tourmaline and hematite. Locally, the granite contains deposits of tin, although the resource potential is low (Wrucke and others, 1983). Basalt, andesite, graywacke, siltstone, and volcaniclastic rocks are the main rock types in the northeastern part of the basin. Small outcrops of dolomite and limestone also are present in this part of the basin. An area of silver and copper sulfide mineralization is mapped near the northeastern boundary of the study area, which is associated with mafic volcanic rocks.

The Wet Bottom Creek HBN Basin is in the Tonto National Forest and is mostly in the Mazatzal Wilderness Area, which was created in 1964. The HBN station is accessed by flying in a helicopter to a marked landing site near the station. Hiking trails provide access to some of the canyons and plateaus, but much of the basin is relatively inaccessible. The closest access by road is from a trailhead 5 km east of the basin boundary. The basin is protected from human effects except for a minor amount of livestock grazing (Lawrence, 1987). Prospecting has occurred intermittently in the area since the 1870's; however, only one prospect pit is mapped in the Wet Bottom Creek Basin.

Historical Water-Quality Data and Time-Series Trends

The data set for the Wet Bottom Creek HBN station analyzed for this report includes 174 water-quality samples that were collected from August 1968 through July 1995. Sampling frequency ranged from 6 to 11 times per year from 1969 to 1982, then was quarterly from 1983 to 1995. Samples from the early part of the period of record probably were analyzed at a USGS district laboratory in Yuma, Ariz. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and at the NWQL in Arvada, Colo., from 1976 through 1995. Daily discharge records for Wet Bottom Creek (station 09508300) are available beginning in June 1967.

Calculated ion balances for 173 samples that have complete major-ion analyses are shown in figure 3. Ion balances ranged from −12 to +17 percent, and 90 percent of the samples had values within the ±5-percent range, indicating that the analytical results were of high quality. The average ion balance was 1.1 percent, and 67 percent of samples had an excess of measured cations over anions, indicating that unmeasured constituents, such as organic anions, may contribute a small amount to the ionic composition of stream water at this station. Time-series plots of the major dissolved constituents were inspected for evidence of method-related effects (fig. 3). The most notable pattern was the substantial decline in the sulfate concentrations over the period of record. Although natural variations in stream-water chemistry cannot be completely ruled out, this pattern was probably caused by several changes in the analytical technique for sulfate, which included a switch from a colorimetric to a turbidimetric technique in 1983 (Office of Water Quality Technical Memorandum No. 83.07, *Analytical methods: Sulfate determinations*, issued February 25, 1983, at URL http://water.usgs.gov/admin/memo/) followed by a change to ion chromatography in 1990 (Fishman and others, 1994). The stepped pattern in the time-series plot for concentrations of nitrite plus nitrate was caused by changes in the analytical reporting limit for this constituent that occurred in 1982 and again in 1991.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Oliver Knoll NADP station are presented in table 2. Precipitation chemistry at the NADP station, which is about 200 km southeast of the HBN station, is dilute and acidic and has a VWM pH of 4.8 for 15 years of record. The predominant cations in precipitation were hydrogen and calcium, which contributed 38 and 24 percent of the total cation charge, respectively. The predominant anions were sulfate and nitrate, which accounted for 64 and 27 percent of the total anion charge, respectively. The predominance of strong acid anions in precipitation may indicate that the chemistry at the NADP station is affected by industrial emissions of sulfur and nitrogen compounds that cause acid rain.

Stream water in Wet Bottom Creek is fairly concentrated and strongly buffered; specific conductance ranged from 17 to 580 µS/cm and alkalinity ranged from 220 to 5,020 µeq/L (table 2). The major cations in stream water were calcium and sodium, and the major anion was bicarbonate. The predominance of these solutes in stream water, in addition to relatively high concentrations of silica, is attributed to the weathering of silicate minerals in the alkali granites and volcanic rocks and carbonate minerals in the sedimentary rocks. The median chloride (230 µeq/L) and sulfate (160 µeq/L) concentrations in stream water were substantially greater than the VWM concentrations of chloride (3.9 µeq/L) and sulfate (28 µeq/L) in precipitation, indicating that these solutes are derived primarily from sources in the basin. Because land-use activities in the basin are minimal, the most plausible sources of chloride other than wet deposition are wind-blown material from surrounding desert areas (Turk and Spahr, 1991) and weathering of sedimentary rocks in the northeastern part of the basin. Wind-blown material also may be a source of stream-water sulfate; however, most sulfate probably is derived from oxidation of sulfide minerals associated with mineralized areas in the basin. Concentrations of inorganic nitrogen species in stream water were less than the VWM concentrations in precipitation, indicating that most atmospheric nitrogen is retained by vegetation and soils and that livestock grazing in the basin has not substantially affected nutrient concentrations at the HBN station.

The solute composition of stream water was further evaluated by analyzing correlations among solutes and stream discharge (table 3). Most weathering-derived solutes had strong inverse correlations with stream discharge, particularly calcium (rho = −0.888) and alkalinity (rho = −0.882). These results are consistent with a hydrologic system where weathering-enriched base flow is diluted by water from shallow or surficial sources during periods

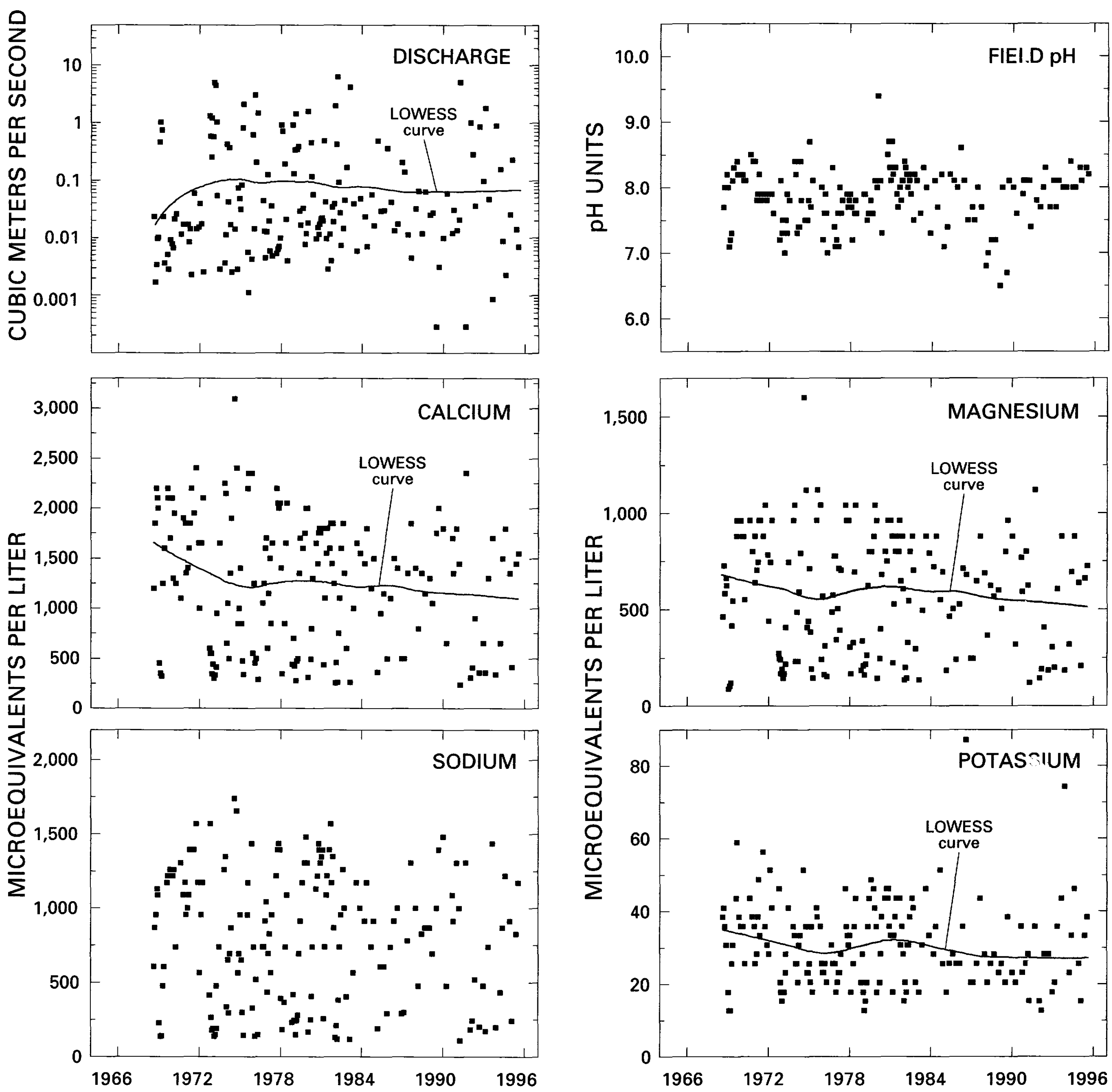


Figure 3. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Wet Bottom Creek, Arizona.

of increased discharge, such as spring snowmelt.

For the solutes, the strongest correlations were among calcium, magnesium, and alkalinity, which is consistent with the weathering stoichiometry of carbonate minerals. The combination of the strong positive correlations between chloride and the major weathering constituents and the inverse correlation between chloride and discharge may indicate that most stream-water chloride is derived from bedrock weathering rather than from wind-blown dust. The poor correlations between sulfate and other dissolved constituents was unexpected, particularly considering that most sulfate is probably derived from bedrock weathering.

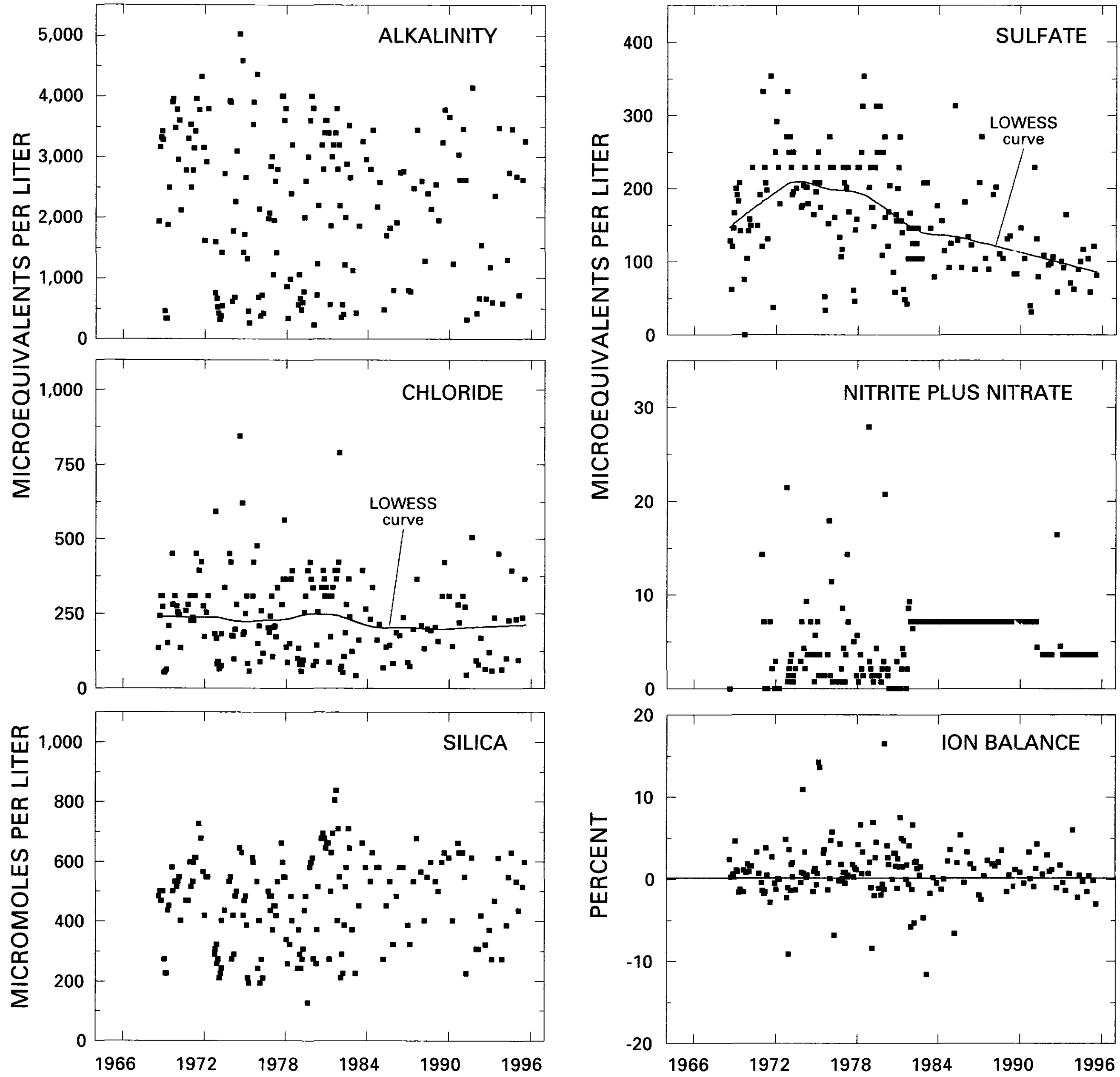


Figure 3. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Wet Bottom Creek, Arizona—Continued.

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 4. Statistically significant trends were detected in discharge and in the unadjusted calcium, magnesium, potassium, sulfate, and chloride concentrations at the 0.01 probability level. The trends in magnesium, potassium, and chloride concentrations were not significant using the flow-adjusted data; however, the trends in flow-adjusted calcium and sulfate remained significant, indicating they were not caused by the upward trend in discharge. The LOWESS curves in figure 3 show somewhat different temporal patterns in the calcium and sulfate concentrations during the period

Table 2. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Wet Bottom Creek, Arizona, August 1968 through July 1995, and volume-weighted mean concentrations in wet precipitation collected at the Oliver Knoll Station, Arizona

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation VWM[a]
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Discharge, inst.	0.00028	0.0099	0.025	0.19	6.2	173	--
Spec. cond., field	17	130	280	360	580	172	11
pH, field	6.5	7.6	7.9	8.1	9.4	166	4.8[b]
Calcium	240	610	1,350	1,790	3,100	174	9.9
Magnesium	88	300	620	880	1,600	174	2.4
Sodium	110	410	850	1,170	1,740	174	4.1
Potassium	13	23	31	38	87	174	0.5
Ammonium	<.7	.8	2.1	4.3	13	74	9.3
Alkalinity, laboratory	220	1,000	2,500	3,300	5,020	174	--
Sulfate	31	100	160	210	350	173	28
Chloride	42	140	230	310	850	174	3.9
Nitrite plus nitrate	<.7	1.4	3.6	7.1	28	151	12[c]
Silica	130	350	480	580	840	174	--

[a] Values are volume-weighted mean concentrations for 1981–95.

[b] Laboratory pH.

[c] Nitrate only.

Table 3. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Wet Bottom Creek, Arizona, 1968 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; N, nitrite plus nitrate; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	N
pH	–0.198									
Ca	–.888	0.214								
Mg	–.872	.242	0.948							
Na	–.806	.274	.904	0.943						
K	–.632	.295	.723	.751	0.744					
Alk	–.882	.262	.973	.974	.953	0.736				
SO_4	.339	–.273	–.194	–.206	–.188	–.207	–0.256			
Cl	–.800	.215	.887	.896	.923	.736	.901	–0.147		
N	.133	.000	–.111	–.153	–.079	–.115	–.109	–.083	–0.094	
Si	–.760	.267	.815	.853	.863	.672	.863	–.382	0.780	–0.038

of record. Most of the decline in calcium concentrations occurred prior to 1980, whereas most of the decline in sulfate concentrations occurred after 1980. A change in atmospheric deposition is one possible explanation for the declines in stream-water concentrations at this station. Lynch and others (1995), for example, reported significant downward trends in calcium and sulfate concentrations in precipitation at several NADP stations in the Southwestern United States from 1980 to 1992. Although this change in precipitation chemistry is consistent with the downward trend in stream-water sulfate, it cannot account for the decline in stream-water calcium concentrations, which primarily occurred prior to 1980. Alternatively, trends in stream-water chemistry at this station may be caused by method-related factors. For example, the decline in sulfate occurred during a period when there were two changes in the analytical technique for sulfate, one in 1983 and another in 1990 (Fishman and others, 1994). Method-related factors that may have introduced bias into the calcium records include a switch from a district laboratory to the central laboratory system in 1973 and a change in the analytical technique for calcium from atomic absorption (AA) spectroscopy to inductively coupled plasma (ICP) spectroscopy in 1983 (Office of Water Quality Technical Memorandum No. 82.18, *National water-quality networks*, issued September 28, 1982, at URL http://water.usgs.gov/admin/memo/).

Table 4. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Wet Bottom Creek, Arizona, August 1968 through July 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated

	Unadjusted		Flow adjusted	
Parameter	Trend	p-value	Trend	p-value
Discharge	0.001	0.001	--	--
pH, field	<.01	.744	0.01	0.169
Calcium	−21.6	.001	−7.8	.006
Magnesium	−8.0	.010	−3.2	.033
Sodium	−7.7	.060	−3.9	.073
Potassium	−.3	.002	−.2	.014
Alkalinity, laboratory	−25.1	.025	4.3	.360
Sulfate	−3.2	.000	−3.4	.000
Chloride	−3.5	.007	−1.0	.111
Nitrite plus nitrate	([a])	--	--	--
Silica	<.1	.608	1.8	.026

[a] Insufficient data to calculate trend.

Synoptic Water-Quality Data

Chemical results of the surface-water synoptic sampling of March 23 through 26, 1991, are listed in table 5, and locations of sampling sites are shown in figure 2. During the synoptic sampling, average daily discharge at the HBN station was between 3.2 and 6.3 m^3/s compared to the median daily discharge of

Table 5. Physical properties and major dissolved constituents from surface-water sampling sites in the Wet Bottom Creek Basin, Arizona, collected March 23–26, 1991

[Site locations shown in fig. 2; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate; Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]	Remarks
1	09508300	5.07	51	7.4	240	120	110	15	320	79	45	4.4	230	--	
2	341128111353300	.069	130	8.0	650	500	220	19	1,120	130	99	3.6	330	BG	Sedimentary and volcanic rocks
3	341118111350500	.067	73	7.5	340	220	150	16	480	130	85	<0.7	280	BG	Sedimentary and volcanic rocks
4	341032111340700	.19	100	7.7	550	310	160	13	820	100	73	<0.7	250	BG	Mafic volcanic rocks
5	341011111334200	.13	33	6.7	150	80	83	18	92	92	59	1.4	200	BG	Granite
6	340848111331100	--	27	6.9	130	69	65	14	100	65	37	1.4	170	BG	Granite
7	340819111333600	--	27	6.9	140	62	61	13	120	58	34	0.7	160	BG	Granite

[a] Criterion used in selection of sampling sites: BG = bedrock geology.

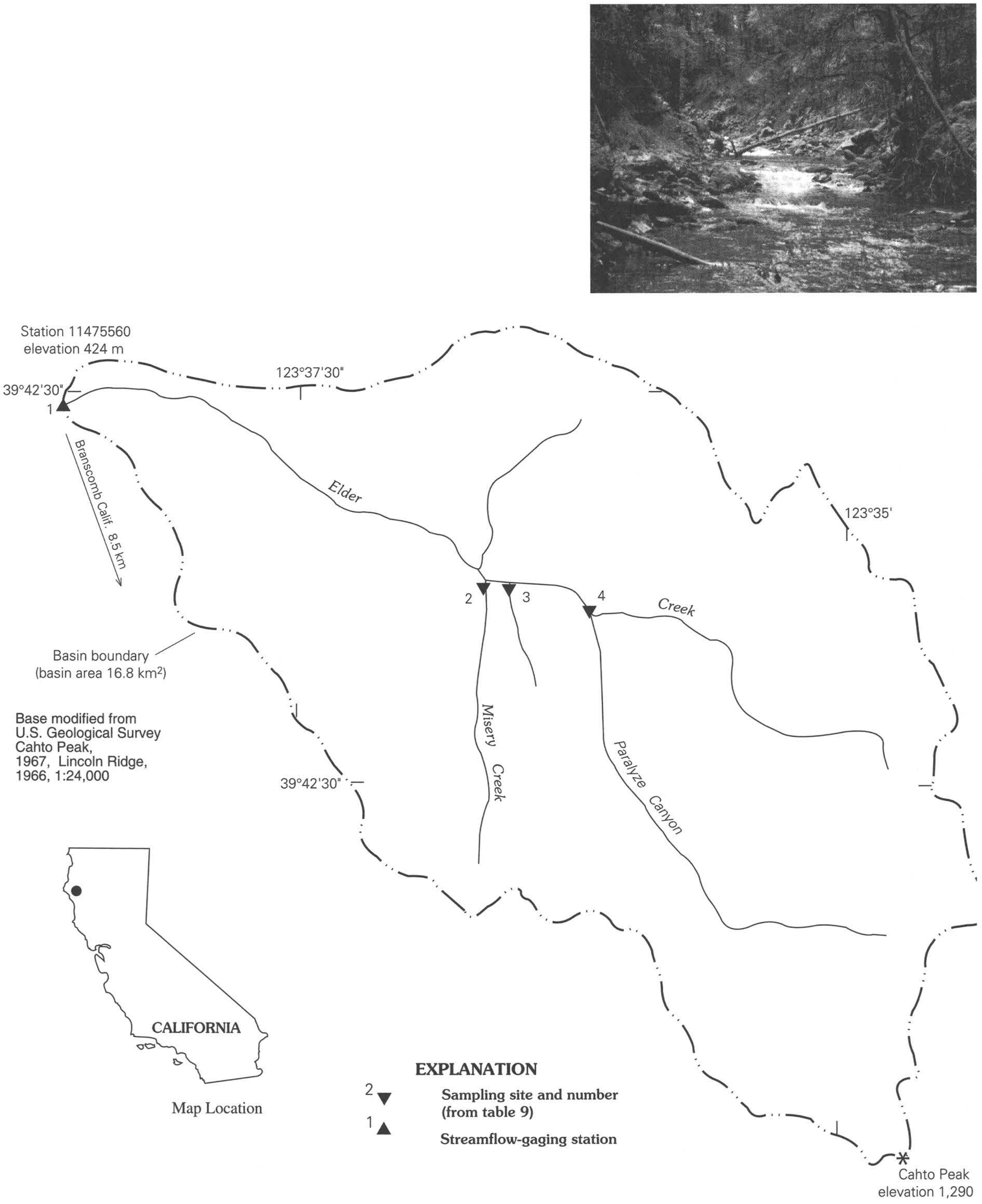
about 0.2 m^3/s for March (Lawrence, 1987), indicating that the basin was sampled during high-flow conditions for that time of year. Because of the flow conditions, most of the solute concentrations measured at the HBN station (site 1) during the sampling period were less than the first-quartile values reported for the station during the entire period of record (table 2). Samples from the upstream sites were similar in composition to the sample at site 1; calcium and bicarbonate were the predominant ions, and their concentrations bracketed the concentrations at site 1. Ion balances for all the synoptic samples were positive (range 1.3 to 15 percent), indicating that unmeasured anions, such as organic anions, may have contributed to the ionic content of stream water during the sampling period. Despite the high-flow conditions in the basin, stream-water chemistry was quite variable, particularly for the weathering-derived constituents. For example, calcium ranged from a minimum of 130 μeq/L at site 6 to 650 μeq/L at site 2, and alkalinity ranged from 92 μeq/L at site 5 to 1,120 μeq/L at site 2 (table 5). The observed variation in stream chemistry seems to reflect the distribution of mapped bedrock types in the basin. Sites that had high concentrations (sites 2–4) drain areas underlain by sedimentary and volcanic rocks, whereas sites with more dilute water (sites 5–7) drain areas underlain by granitic bedrock. This relation is demonstrated by comparing the average alkalinity of 800 μeq/L at sites 2–4 with the average alkalinity of 100 μeq/L at sites 5–7. A similar pattern occurred for calcium concentrations, which averaged 510 μeq/L at sites 2–4 compared to 140 μeq/L at sites 5–7. This pattern in stream-water concentrations seems to be consistent with the concept that the sedimentary and volcanic rocks contain more weatherable minerals, such as carbonates and mafic silicates, than the chemically resistant granites, which primarily consist of quartz and feldspar.

Elder Creek near Branscomb, California (Station 11475560)

Site Characteristics and Land Use

The Elder Creek HBN Basin is located on the west slope of the southern section of the Pacific Border physiographic province in northern California (fig. 4). The 16.8-km^2 basin ranges in elevation from 424 to 1,290 m and drains a landscape of steep hillslopes and narrow canyons. The HBN station is located 8.5 km northwest of the town of Branscomb, Calif., at latitude 39°43'47" and longitude 123°38'34". Elder Creek is a headwater tributary that flows westward into the South Fork Eel River, a tributary of the Eel River, and has a channel length of about 8.0 km upstream from the HBN station and an average stream gradient of 80 m/km. Streamflow is highly variable during storms because of surface runoff from the steep hillslopes but is well sustained by springs during periods of low rainfall. Mean monthly discharge varies from a minimum of 0.03 m^3/s in September to 1.9 m^3/s in January, and average annual runoff from the basin was 129 cm for 1968 through 1995 (Friebel and others, 1996). The area has a Mediterranean-type climate, with cool, wet winters and warm, dry summers. Average daily air temperatures range from 6°C in January to as much as 31°C in August. Cold air often drains down the valleys, creating strong temperature inversions. Average annual precipitation is about 215 cm, most of which falls as rain during intense frontal storms occurring from December through March (Herring, 1997). A solar-powered weather station was installed in 1990 just outside the Elder Creek Basin by The Nature Conservancy where data are collected on precipitation amount, air temperature, and solar radiation (Herring, 1997).

The basin is located in the Sierran Steppe-Mixed Forest-Coniferous Forest-Alpine Meadow ecoregion (Bailey and others, 1994), and vegetation grows in a mosaic of mixed forest, oak woodland, mixed chaparral, riparian, and grassland communities (Herring, 1991, 1997). The mixed forest is dominated by old-growth Douglas-fir as well as tan oak and madrone (Rundel and others, 1977; Herring, 1991). Understory plants in the mixed forest include mountain dogwood, chinquapin, and California bay. Oak woodland is present in various settings; Oregon white oak line the river terraces, black oak grows on ridges, and interior live oak and canyon live oak are dispersed throughout the basin. Chaparral communities are mostly on dry southern slopes and consist of chamise, manzanita,



Base modified from
U.S. Geological Survey
Cahto Peak,
1967, Lincoln Ridge,
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Figure 4. Map showing the study area in the Elder Creek Basin and photograph showing the forest cover in the basin.

and ceanothus (Rundel and others, 1977). The riparian community is dominated by white alder, bigleaf maple, and Oregon ash. Coastal redwoods grow along river banks and in forest swells. Grassland species include native oatgrass and rushes. Soils in the basin are classified as Inceptisols and Ultisols and primarily belong to the Hugo and Josephine soil series (Herring, 1997). These series consist of deep, well-drained soils that formed in material weathered from sedimentary rocks. Soils usually range in depth from 100 to 150 cm, have base saturations ranging from 35 to 50 percent, and contain between 15 and 35 percent rock fragments.

The basin is underlain by rocks of the Yager terrain, which consists of thinly bedded arkosic sandstone and argillite of Paleocene or Eocene age (Ogle, 1953; Blake and others, 1985; Jayko and others, 1989). The mineralogy of the sediments in the Yager terrane includes quartz, biotite, chlorite, and feldspar. Interbedded limy siltstone also is present in the Yager terrane. The Yager terrane is the easternmost of three terranes in the Coastal Franciscan Belt and may have formed as a trench-slope deposit that accumulated in its present location (Underwood, 1983; Bachmann, 1994).

Land in the Elder Creek Basin is part of the Angelo Coast Range Reserve, which was established in 1959 as The Nature Conservancy's first preserve west of the Mississippi. Since then, the reserve has been protected from development and operated by the University of California for research in freshwater ecology and old-growth forest ecosystems (Ruggiero, 1991). In 1994, the ownership of the reserve was transferred to the University of California's Natural Reserve System, which provides secure field sites for ecological study used to support university-level teaching and research. Entry to the nature reserve by the public is tightly restricted, and research is allowed to the extent that it does not damage the ecosystem or habitats. Limited logging may have occurred in the basin in the late 19th and early 20th centuries, but beginning in 1931, land in the Elder Creek Basin began to be acquired and protected by homesteaders. No grazing, mining, or logging has occurred in the basin since at least 1959, when the homesteaders sold the land to The Nature Conservancy. A small diversion upstream from the Elder Creek HBN station provides water for the dwelling used by the reserve caretakers. Access to the basin is limited to an access road that is maintained by The Nature Conservancy; the road is used by caretakers and researchers but is closed to the public. Cahto Peak can be reached through a gated gravel road from the east.

Historical Water-Quality Data and Time-Series Trends

The data set for the Elder Creek HBN station analyzed for this report includes 195 water-quality samples that were collected from February 1968 through September 1995. Sampling frequency ranged from 8 to 12 times per year from 1969 to 1982, then was decreased to quarterly from 1983 to 1995. Samples from the early part of the period of record probably were analyzed at a USGS district laboratory in Sacramento, Calif. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and at the NWQL in Arvada, Colo., from 1976 through 1995. Daily discharge records for Elder Creek (station 11475560) are available beginning in October 1967. Daily water temperature at the HBN station was measured from October 1968 through September 1979, and a precipitation gage was operated at the station from October 1968 through March 1996.

Calculated ion balances for 190 samples that have complete major-ion analyses are shown in figure 5. Ion balances ranged from −14 to +15 percent, and 85 percent of the samples had values within the ±10-percent range, indicating that the analytical results were of good quality. The average ion balance was 0.5 percent, indicating that unmeasured constituents, such as organic anions, do not seem to contribute substantially to the ionic composition of stream water at this HBN station. Time-series plots of the major dissolved constituents were inspected for evidence of method-related effects. The most notable pattern was the considerable decrease in scatter of sulfate concentrations beginning in 1983 (fig. 5). This pattern probably was caused by a change in the analytical technique for sulfate from a colorimetric to a turbidimetric technique in 1983 (Office of Water Quality Technical Memorandum No. 83.07, *Analytical methods: Sulfate determinations*, issued February 25, 1983, at URL http://water.usgs.gov/admin/memo/). A period of uniform sulfate concentrations in 1982 and 1983, which reflects a change in the analytical reporting limit for sulfate to 5 mg/L (104 μeq/L) during those 2 years, also is shown in figure 5. The temporal pattern in concentrations of nitrite plus nitrate at this station also was affected by changes in the reporting limit for this constituent that occurred in 1982 and again in 1991.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Hopland NADP station are presented in table 6. Precipitation chemistry at the NADP station, which is about 90 km south of the HBN station, is dilute and slightly acidic and had a VWM pH of 5.4 for 17 years of record. The predominant cation in precipitation was sodium, which contributed 55 percent of the total cation charge, and the predominant anion was chloride, which accounted for 64 percent of the total anion charge. The predominance of these ions in precipitation reflects the proximity of this station to the Pacific Ocean and the influence of marine aerosols on precipitation chemistry at this site. Stream water in Elder Creek is moderately concentrated and well buffered; specific conductance ranged from 49 to 190 μS/cm, and alkalinity ranged from 500 to 2,040 μeq/L (table 6). The major cation in stream water was calcium and the major anion was bicarbonate. The predominance of these solutes in stream water is attributed to the weathering of carbonate cements in the underlying arkosic sandstones, argillites, and siltstones. The median chloride (71 μeq/L) and sulfate (67 μeq/L) concentrations in stream water were substantially greater than the VWM concentrations of chloride (18 μeq/L) and sulfate (6.0 μeq/L) in precipitation, indicating that these solutes primarily are derived from sources other than wet deposition. Because land-use activities in the basin are minimal, the most plausible source of these solutes is weathering of salt and sulfate minerals in the marine sedimentary rocks and dry deposition of marine aerosols. Concentrations of inorganic nitrogen species in stream water generally were less than the VWM concentrations in precipitation, indicating that most atmospheric nitrogen is retained by vegetation and soils in the basin.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 7). Most weathering-derived solutes had strong inverse correlations with stream discharge, particularly sodium (rho = –0.940), alkalinity (rho = –0.882), magnesium (rho = –0.880), and calcium (rho = –0.874). These results are consistent with a hydrologic system where weathering-enriched base flow is diluted by water from shallow or surficial sources during periods of increased discharge. For the solutes, the strongest correlations were found among calcium, magnesium, sodium, and alkalinity. Correlations among calcium, magnesium, and alkalinity are consistent with the weathering stoichiometry of carbonate cements in the sedimentary rocks. The strong correlation between sodium and alkalinity and the lack of correlation with silica indicates that sodium perhaps is released from exchange reactions with marine clays rather than from weathering of feldspar minerals in the arkosic sandstones.

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 8. Statistically significant upward trends were detected in field pH and unadjusted magnesium and alkalinity concentrations at the 0.01 probability level. Trends were similar for the unadjusted and flow-adjusted concentrations, indicating that the trends were not caused by variations in stream discharge. Statistically significant upward trends also were detected in the flow-adjusted calcium and sodium concentrations at the 0.01 probability level. The LOWESS curves in figure 5 show that most of the increase in field pH and in magnesium and alkalinity concentrations occurred after the mid-1980's. Although not shown in figure 5, LOWESS curves through the flow-adjusted calcium and sodium concentrations show a similar pattern of

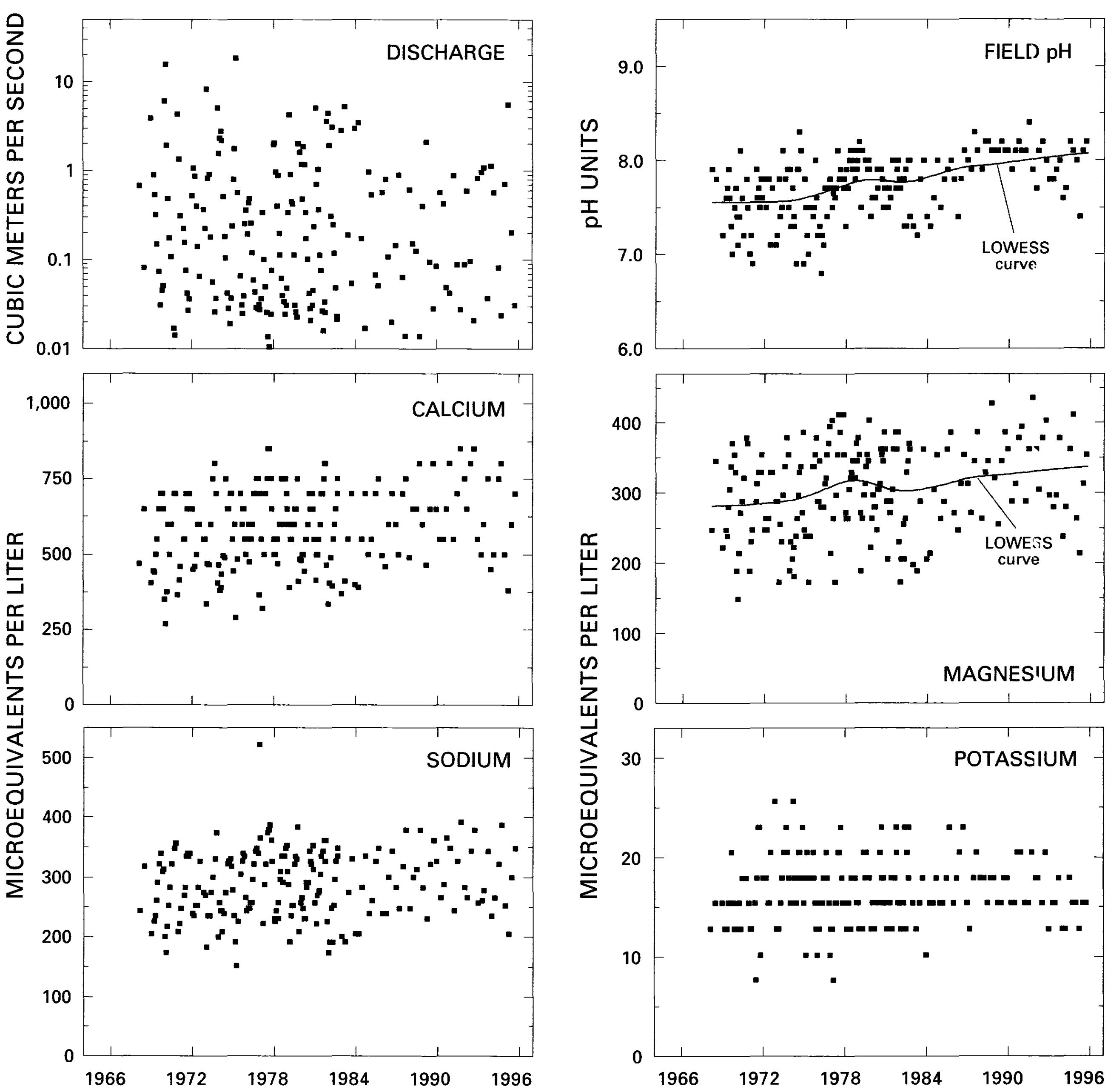


Figure 5. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Elder Creek, California.

increasing concentrations beginning about 1984. The cause of the upward trends in stream-water chemistry at this HBN station could not be identified, although the similarity in the timing of the trends indicates that they may have been caused by a similar factor. Method-related factors probably were not the cause of the trends, given that the significance of most of the trends increased after adjusting for flow. Environmental factors that may have affected stream-water chemistry include changes in atmospheric deposition, land-use activities, and climate. The stream-water trends at this station probably were not related to

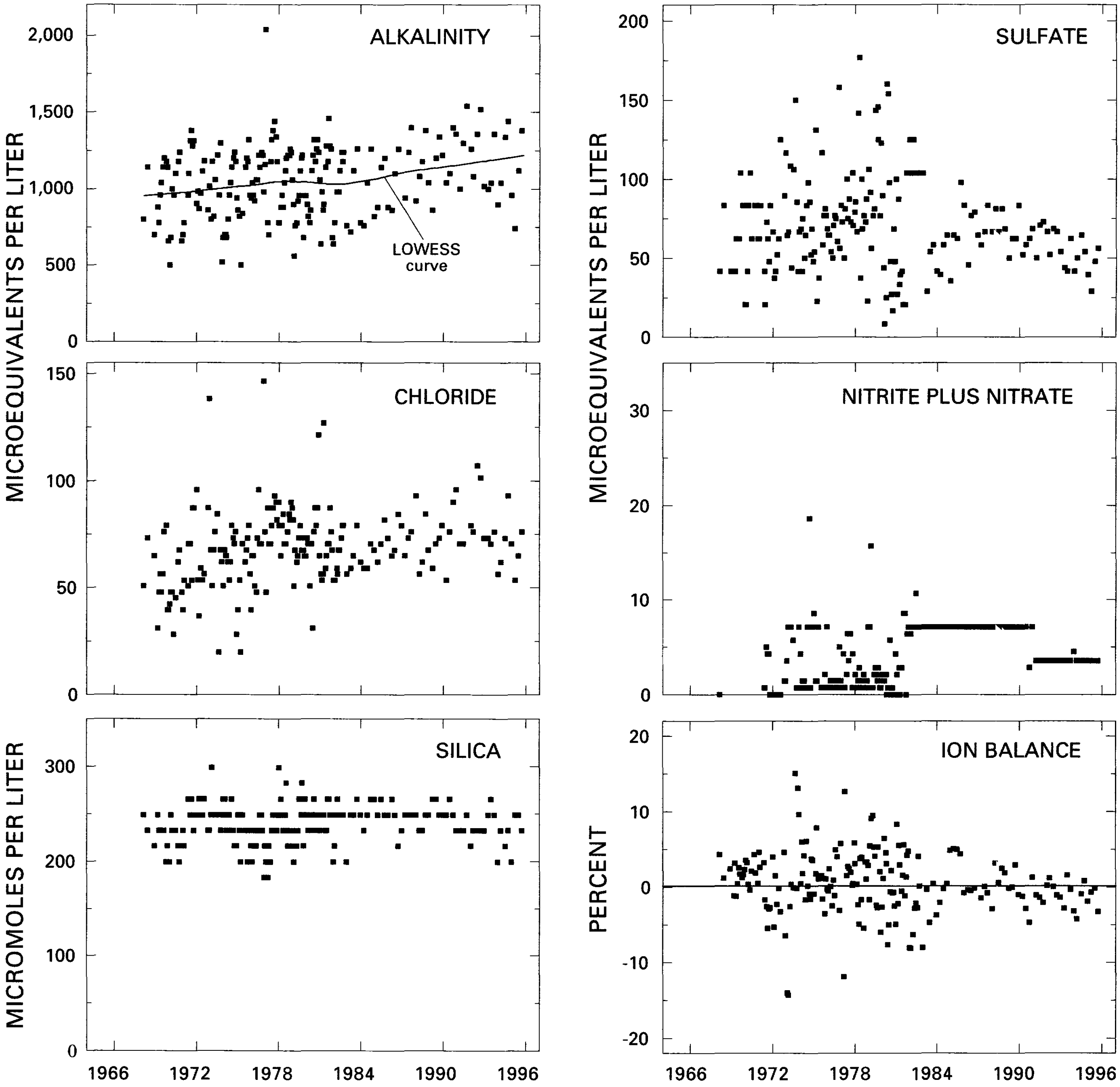


Figure 5. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Elder Creek, California—Continued.

changes in atmospheric deposition, considering the dilute chemistry of precipitation at the NADP station compared to the stream (table 6). Similarly, changes in land use probably were not an important factor because the basin has been free of human activities since it was purchased by The Nature Conservancy in 1959. Perhaps the most plausible explanation for the trends in water quality is climate variability. Although a detailed analysis of climate variability is beyond the scope of this report, long-term precipitation records indicated that there was an extended period of drought that persisted in

Table 6. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Elder Creek, California, February 1968 through September 1995, and volume-weighted mean concentrations in wet precipitation collected at the Hopland Station, California

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation
	Minimum	First quartile	Median	Third quartile	Maximum	n	VWM[a]
Discharge, inst.	0.010	0.042	0.17	0.81	18	195	--
Spec. cond., field	49	96	120	130	190	195	5.4
pH, field	6.8	7.5	7.8	8.0	8.4	190	5.4[b]
Calcium	270	500	600	700	850	195	1.8
Magnesium	150	260	300	350	440	195	3.7
Sodium	150	240	280	330	520	194	16
Potassium	7.7	15	15	18	36	194	.5
Ammonium	<.7	<.7	1.4	3.0	9.3	80	3.0
Alkalinity, laboratory	500	880	1,060	1,220	2,040	193	--
Sulfate	8.3	50	67	85	230	195	6.0
Chloride	20	57	71	78	160	194	18
Nitrite plus nitrate	<.7	.7	3.6	7.1	19	169	4.1[c]
Silica	180	230	250	250	300	195	--

[a] Values are volume-weighted mean concentrations for 1979–95.

[b] Laboratory pH.

[c] Nitrate only.

Table 7. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Elder Creek, California, 1968 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl
pH	–0.357								
Ca	–.874	0.469							
Mg	–.880	.442	0.929						
Na	–.940	.414	.874	0.897					
K	–.498	.226	.524	.476	0.480				
Alk	–.882	.428	.879	.879	.902	0.448			
SO_4	–.272	.110	.287	.273	.236	.177	0.187		
Cl	–.529	.387	.572	.582	.537	.330	.528	0.210	
Si	.042	.191	.034	.039	.041	.228	.048	–.058	0.038

the northwestern part of California from 1984 through 1994 (National Climatic Data Center at URL http://www.ncdc.noaa.gov).

Synoptic Water-Quality Data

Chemical results of the surface-water synoptic sampling of August 6, 1991, are listed in table 9, and locations of sampling sites are shown in figure 4. During the synoptic sampling, discharge at the HBN station was about 0.05 m^3/s compared to the median daily discharge of 0.03 m^3/s for August (Lawrence, 1987), indicating that the basin was sampled during normal flow conditions for that time of year. Most of the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were equal to or greater than the third-quartile values reported for the station during the entire period of record, except for the sulfate concentration, which was less than the median value (table 6). Stream water at the upstream sampling sites were similar in composition to stream water at site 1; calcium was the predominant cation and bicarbonate was the predominant anion. Ion balances for the synoptic samples ranged from −1.4 to 4.2 percent and averaged 0.5 percent, indicating that organic anions probably were not an important component of stream water during the sampling period. The results in table 9 indicate that the concentrations of the major solutes, particularly the weathering-derived solutes, did not vary markedly among the sampling sites. For example, calcium concentrations ranged from 650 to 750 μeq/L, magnesium ranged from 370 to 440 μeq/L, and alkalinity ranged from 1,130 to 1,410 μeq/L. This uniformity in stream-water composition most likely reflects the small size of the basin and the relatively homogenous composition of the underlying bedrock. Sulfate and chloride had a slightly wider range of concentrations; sulfate ranged from 50 to 140 μeq/L and chloride ranged from 51 to 93 μeq/L, perhaps due to local variations in bedrock mineralogy or differences in evapotranspiration among the sites. Nitrate concentrations at all of the sampling sites were less than the analytical reporting limit of 3.6 μeq/L, which is consistent with the minimal amount of land use in the basin.

Table 8. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Elder Creek, California, February 1968 through September 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	0.001	0.465	--	--
pH, field	.02	.000	0.02	0.000
Calcium	<.1	.083	2.3	.000
Magnesium	1.3	.006	1.3	.000
Sodium	.7	.097	.7	.000
Potassium	<.1	.875	<.1	.590
Alkalinity, laboratory	6.5	.001	6.9	.000
Sulfate	−.6	.013	−.6	.019
Chloride	.4	.024	.4	.027
Nitrite plus nitrate	(a)	--	--	--
Silica	<.1	.466	<.1	.649

[a] Insufficient data to calculate trend.

Table 9. Physical properties and major dissolved constituents from surface-water sampling sites in the Elder Creek Basin, California, collected August 6, 1991

[Site locations shown in fig. 4; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium: Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate; Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]
1	11475560	0.048	150	8.2	750	370	360	18	1,350	65	93	<3.6	250	--
2	394311123363800	--	147	7.9	700	420	360	17	1,410	50	87	<3.6	300	T
3	394311123363300	.0011	140	8.0	650	440	340	17	1,130	140	51	<3.6	320	T
4	394306123361100	--	150	8.1	750	380	350	18	1,320	83	79	<3.6	250	MC

[a] Criteria used in selection of sampling sites: MC = main channel, T = tributary.

Merced River at Happy Isles Bridge near Yosemite, California (Station 11264500)

Site Characteristics and Land Use

The Merced River HBN Basin is located on the western slope of the central Sierra Nevada, in the Sierra-Cascade Mountains physiographic province in central California (fig. 6). The basin drains an area of 469 km^2 and ranges in elevation from 1,224 to 3,997 m. The landscape in the Merced River Basin is alpine-subalpine-montane and is characterized by broad glaciated valleys with steep-sided walls. Forests and meadows mainly cover the alluvial areas along the valley floors, and the ridges have broad expanses of exposed granite and thin patches of forest. Headwater cirques are alpine in character and have numerous glacial lakes and abundant talus and till deposits. The HBN station is located 3.0 km southeast of the town of Yosemite Village, Calif., at latitude 37°43'54" and longitude 119°33'28". The Merced River is a west-flowing tributary of the San Joaquin River that has a channel length of about 31.9 km upstream from the HBN station and an average stream gradient of 27.3 m/km. The annual hydrograph is driven by melting of a seasonal snowpack that accumulates between October and early April and melts during late April to June. Mean monthly discharge varies from 1.1 m^3/s in October to 35.4 m^3/s in May, and average annual runoff from the basin was 66.5 cm from 1916 through 1995 (Hayes and others, 1996). The area has a Mediterranean-type climate with cool, wet winters and warm, dry summers. Average daily air temperatures range from 3°C in January to 22°C in July (National Weather Service at URL http://www.wrcc.dri.edu/climsum.html, 1998). Average annual precipitation at the elevation of the HBN station is about 94 cm of which about 25 percent falls as snow between October and April. Precipitation amount increases with increasing elevation up to about 2,000 m and then stabilizes (Stephenson, 1988). Precipitation averages about 140 cm at treeline (~3,200 m) of which as much as 95 percent falls in the form of snow (Stephenson, 1988; Melack and Stoddard, 1991).

The basin is located in the Sierran Steppe-Mixed Forest-Coniferous Forest-Alpine Meadow ecoregion (Bailey and others, 1994) and vegetation is dominated by old-growth pine and fir vegetation types (Rundel and others, 1977). Less than one-half of the basin area is forested and the remainder is covered by lakes, wetlands, meadows, rock outcrops, and talus slopes (Rundel and others, 1977). In the montane zone, which ranges from about 1,500 to 2,700 m, the predominant trees are ponderosa pine, Jeffrey pine, Douglas-fir, sugar pine, white fir, California red fir, and incense cedar. In the subalpine zone (about 2,700 to 3,200 m), the predominant trees include mountain hemlock, California red fir, lodgepole pine, western white pine, and whitebark pine. In the alpine zone, above about 3,200 m, vegetation consists of low-lying tundra plants and alpine meadow vegetation. Soils in the basin are Inceptisols, which mostly developed on alluvial deposits and glacial tills derived from the local bedrock. The soils are usually shallow, coarse textured, dark colored, and acidic and have variable organic-matter content. Most of the soils are highly permeable, except for meadow soils, which are poorly drained. Cryumbrepts form predominantly in granitic colluvium on ledges, on ridge slopes, and in joint systems on large rock outcrops (Huntington and Akison, 1987). These soils usually have a thick, dark-colored surface layer overlying lighter colored substrata that rest on coarse boulders or slightly weathered granite rock at depths ranging from 50 to more than 150 cm. Cryochrepts and Cryorthents are developed on hillslopes above the valley floors, where Cryoboralfs dominate. A typical forest-soil profile has a 10-cm-thick organic-rich surface layer, a 30-cm-thick brown cobbly silty loam, and a 30-cm-thick yellowish-brown cobbly sandy loam sublayer that is underlain by massive granite boulders.

The Sierra Nevada are formed by Cretaceous-age granitic rocks of the Sierra Nevada Batholith (Huber, 1987; Bateman, 1992). Most of the rocks in the upper Merced River Basin are granites and granodiorites that are part of the Tuolumne Intrusive Suite, a group of four concentrically arranged plutons (Huber, 1987). The oldest and most mafic unit forms the margin of the suite and is present in the southwest part of the basin. The rocks are progressively younger and more felsic toward the core of the suite, which underlies the basin near the northern boundary. The predominant minerals in the granodiorites are plagioclase, biotite, and hornblende; the predominant minerals in the granites are plagioclase, quartz, potassium feldspar, biotite, and hornblende. Small outcrops of

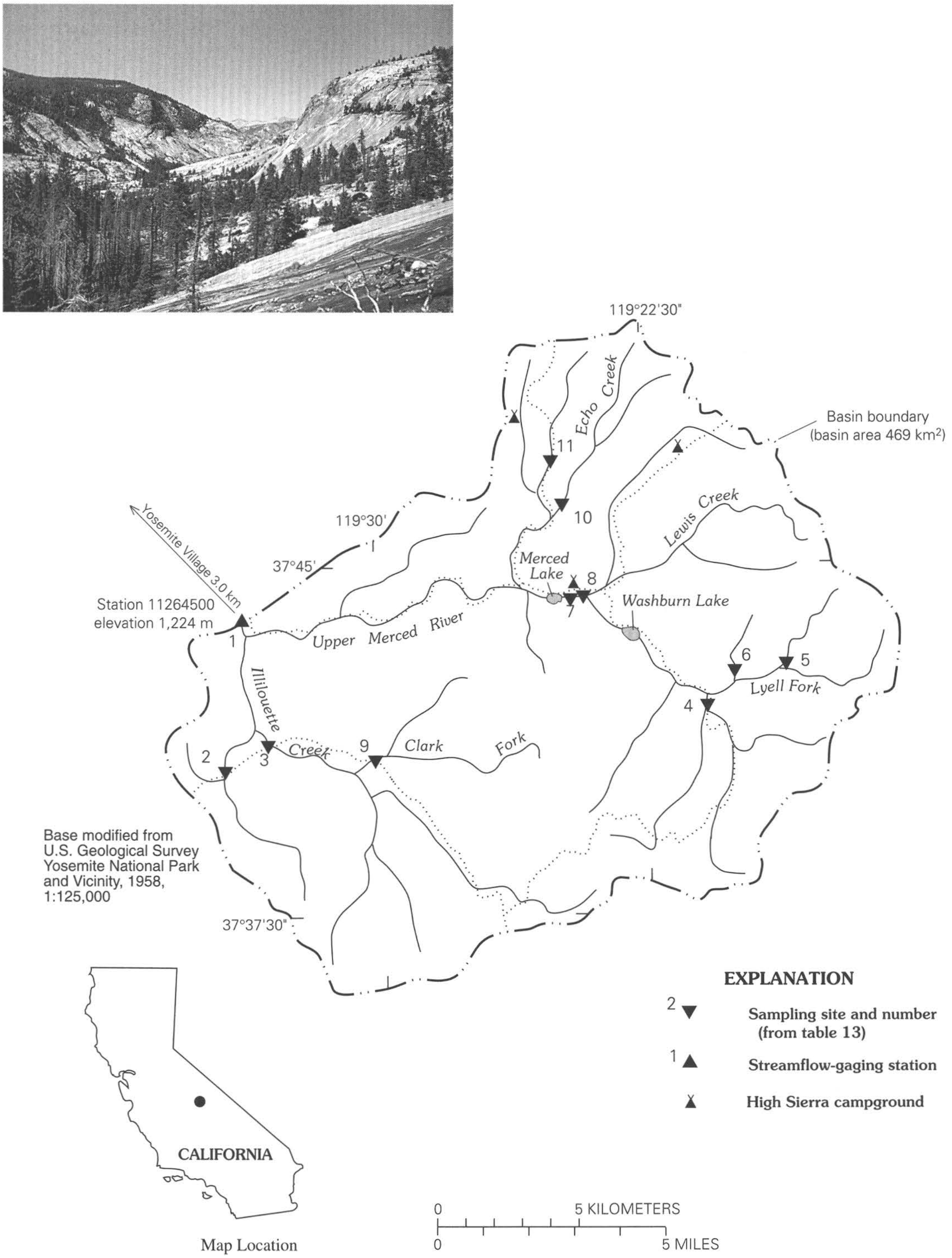


Figure 6. Map showing the study area in the Merced River Basin and photograph showing the Echo Creek subbasin.

hornfels and other metavolcanic rocks were probably derived from pyroclastic rocks (tuff and breccia) that underlie the southeastern part of the basin. Limited exposures of metasedimentary rocks and diorite crop out along the eastern margin of the basin. About 20 percent of the basin is underlain by surficial deposits, which primarily include glacial till that covers the valley bottoms as lateral and recessional moraines. Till is particularly extensive in the drainage basin of Illilouette Creek (fig. 6). Talus and colluvium form substantial deposits in high-elevation cirques, especially along the Sierran Divide, which forms the eastern boundary of the basin.

The Merced River HBN Basin drains the eastern parts of Mariposa and Madera Counties in California and is entirely within the boundaries of Yosemite National Park. The only road in the basin follows the western margin of the park, providing access to a scenic overlook. An extensive trail system provides access to much of the basin during the summer, but deep snowpacks limit accessibility during the winter. The trail system and three large campgrounds (capacity of more than 50 people per night) are heavily used during the summer. The campgrounds are operated by concessionaires as semipermanent installations that have showers and water-treatment facilities. The basin is managed solely for wilderness and recreation because of its location in a national park. Forest fires, floods, and landslides are the main natural disturbances in the basin. Possible human effects primarily are trail erosion caused by people and pack animals, which may result in siltation of surface water.

Historical Water-Quality Data and Time-Series Trends

The data set for the Merced River HBN station analyzed for this report includes 212 water-quality samples that were collected from February 1968 through September 1995. Sampling frequency ranged from bimonthly to biweekly from 1969 to 1982, then was decreased to quarterly from 1983 to 1995. Samples from the early part of the period of record probably were analyzed at a USGS district laboratory in Sacramento, Calif. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and at the NWQL in Arvada, Colo., from 1976 through 1995. Daily discharge records for the Merced River (station 11264500) are available beginning in August 1915. Daily water temperature at the station was measured from October 1965 to September 1977 and October 1978 to September 1993.

Calculated ion balances for 202 samples that have complete major-ion analyses are shown in figure 7. Ion balances ranged from –61 to +42 percent, and only 60 percent of the samples had values within the ±10-percent range. This wide range of ion balances reflects the difficulty in making precise analytical measurements at the low solute concentrations typical of this station. The average ion balance was –6.3 percent, and more than 65 percent of the samples had negative ion balances, indicating an excess of measured anions over cations in solution. Natural water commonly has an excess of cations in solution because of the presence of unmeasured organic anions. An anion excess is more difficult to explain than a cation excess and may indicate a bias in the analytical measurements. The alkalinity determination is often the largest single source of error in major-ion analyses, particularly in dilute water (Fishman and Friedman, 1989). Laboratory alkalinity in HBN samples was determined by a fixed-endpoint titration to pH 4.5. For waters that have alkalinities less than 100 μeq/L, however, the endpoint pH is closer to 5.0, and titration to pH 4.5 may overestimate alkalinity by as much as 25 μeq/L (Barnes, 1964). Because the average alkalinity and anion excess for the Merced River HBN station were 130 μeq/L and 27 μeq/L, respectively, a bias in the laboratory alkalinity seems to be a reasonable explanation for the negative bias in the ion balance. Time-series plots of the major dissolved constituents were inspected for evidence of other method-related effects (fig. 7). The most notable pattern was in sulfate concentrations, which decreased considerably in scatter beginning in 1983 and had a period of low concentrations in the 1990's. Although natural variations in stream-water chemistry cannot be completely ruled out, this pattern probably was caused by several changes in the analytical technique for sulfate, including a change to a turbidimetric technique in 1983 (Office of Water Quality Technical Memorandum No. 83.07, *Analytical methods: Sulfate determinations*, issued February 25, 1983, at URL http://water.usgs.gov/admin/memo/) and another method change to ion chromatography in 1990 (Fishman and others, 1994). The period of elevated and uniform sulfate concentrations in 1982 and 1983 is related to an increase in the analytical reporting limit for sulfate to 5 mg/L (104 µeq/L) during those 2 years. The temporal pattern in concentrations of nitrite plus nitrate at this station also was affected by changes in the analytical reporting limit for this constituent, as indicated by the stepped pattern in figure 7. High chloride concentrations were measured in several samples collected in late 1977 and early 1978; however, this pattern probably reflects natural variation in stream-water chemistry because the samples were collected during a period of extremely low streamflows.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Yosemite National Park NADP station are presented in table 10. Precipitation chemistry at the NADP station, which is about 25 km northwest of the HBN station at an elevation of 1,408 m, is very dilute and slightly acidic and has a VWM pH of 5.4 for 14 years of record. The predominant cation in precipitation was ammonium, which contributed 39 percent of the total cation charge, and the predominant anion was nitrate, which accounted for 44 percent of the total anions. The predominance of these ions in precipitation may reflect the influence of agricultural activities in the San Joaquin Valley on the western side of the Sierra Nevada.

Stream water in the Merced River is dilute and weakly buffered; specific conductance ranged from 3.0 to 65 µS/cm, and alkalinity ranged from 20 to 360 µeq/L (table 10). The major cations in stream water were calcium and sodium and the major anion was bicarbonate. The predominance of these solutes in stream water is attributed to the weathering of plagioclase and hornblende minerals in the granites and granodiorites of the Sierra Nevada Batholith (Clow and others, 1996). The median chloride concentration (68 µeq/L) in stream water was substantially greater than the VWM concentration of chloride (4.1 µeq/L) in precipitation, indicating that most stream-water chloride is derived from sources in the basin. In a detailed study of stream-water chemistry in the basin, Clow and others (1996) hypothesized that spring water that had high chloride concentrations and that was discharging from joints and fractures in the granitic bedrock was the only plausible source of chloride to surface water other than precipitation. The median concentration of sulfate in stream water was 23 µeq/L compared to the VWM concentration of 5.9 µeq/L in precipitation, indicating that some sulfate also seems to be derived from sources other than atmospheric deposition. In contrast, Clow and others (1996) reported a median sulfate concentration of 10 µeq/L for surface water in the basin, which was accounted for by atmospheric inputs and evapotranspiration. One possible explanation for this discrepancy is that the median sulfate concentration in table 10 may be overestimated because of positive bias introduced by analytical techniques used in the past. Concentrations of inorganic nitrogen species in stream water were less than the VWM concentrations in precipitation, indicating that most atmospheric nitrogen is retained by vegetation and soils in the basin.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 11). Most weathering-derived solutes had strong inverse correlations with stream discharge, particularly calcium (rho = –0.806) and sodium (rho = –0.796). These results are consistent with a hydrologic system where weathering-enriched base flow is diluted by water from shallow or surficial sources during periods of increased discharge, particularly spring snowmelt. Chloride also had a strong inverse correlation with discharge (rho = –0.842), providing additional evidence for the effect of chloride-rich ground-water springs on the chloride concentration of the stream (Clow and others, 1996). For the solutes, the strongest correlations were between calcium and sodium (rho = 0.886), calcium and chloride (rho = 0.901), and sodium and chloride (rho = 0.893). These strong correlations may indicate a common source of these solutes, such as saline springs discharging from joints and fractures in the bedrock. Calcium and sodium also had strong positive correlations with silica, which is consistent with the weathering stoichiometry of plagioclase in the granitic bedrock.

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 12. Statistically significant trends were detected in field pH and unadjusted sulfate concentrations at the 0.01 probability level. Trends were similar for the unadjusted and flow-adjusted field

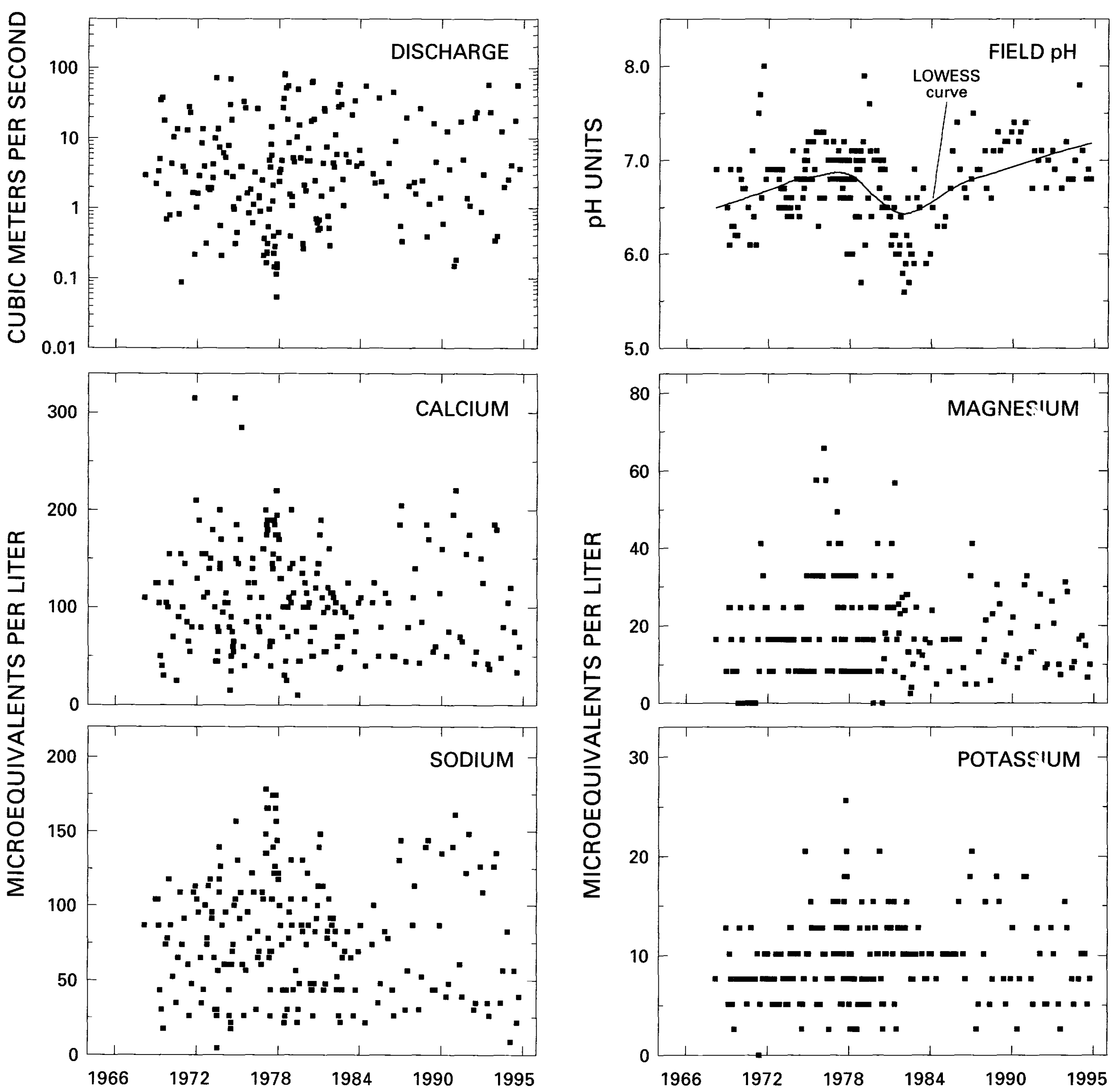


Figure 7. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in the Merced River, California.

pH, indicating that the pH trend was probably not related to variations in stream discharge. The trend in flow-adjusted sulfate concentrations was not significant at the 0.10 probability level, indicating that the trend in the unadjusted concentrations may have been caused by variations in streamflow. Interpretation of trends in sulfate concentrations at this HBN station, however, is greatly complicated by bias introduced by changes in the analytical technique for sulfate during the period of record. The LOWESS curve in figure 7 shows that the trend in pH primarily was caused by a period of low values in the early 1980's followed by high values near the end of the period of record. The trend in stream-water pH at this station probably was

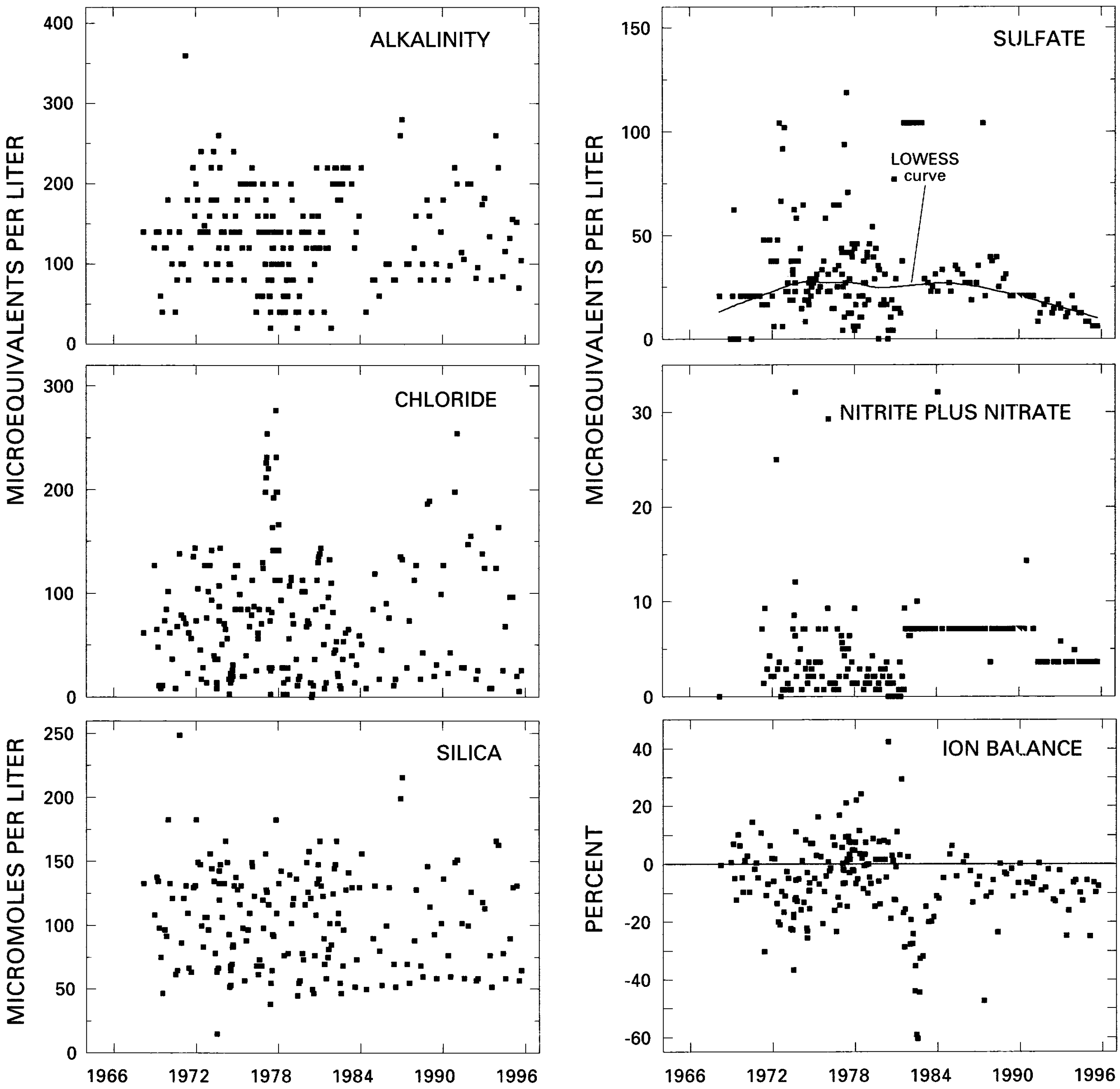


Figure 7. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in the Merced River, California—Continued.

not caused by human activities because the basin is used only for backcountry recreation. Another environmental factor that could affect stream-water chemistry is atmospheric deposition; however, no long-term records of precipitation chemistry are available at this site to confirm such a linkage. A method-related factor is perhaps the most reasonable source of the trend in stream-water pH at this station, particularly considering the rather abrupt decline in pH values in 1980. This pattern may, in part, be explained by changes in electrodes or meters used by field personnel. Some instrument-electrode systems are known to give erroneous readings, particularly when measuring pH in low-conductivity water

Table 10. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from the Merced River, California, March 1968 through September 1995, and volume-weighted mean concentrations in wet precipitation collected in Yosemite National Park, California

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation VWM[a]
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Discharge, inst.	0.054	0.96	3.3	13	82	210	--
Spec. cond., field	3.0	14	22	30	65	207	4.5
pH, field	5.6	6.5	6.8	7.0	8.0	206	5.4[b]
Calcium	10	65	110	150	320	209	2.3
Magnesium	<8.2	8.2	16	25	66	208	1.2
Sodium	4.4	44	78	110	180	211	3.8
Potassium	<2.6	5.1	10	13	26	210	.3
Ammonium	<.7	.7	2.1	4.3	16	100	7.5
Alkalinity, laboratory	20	100	140	180	360	209	--
Sulfate	<4.2	17	23	37	120	209	5.9
Chloride	2.8	25	68	110	280	212	4.1
Nitrite plus nitrate	<.7	2.1	3.6	7.1	32	163	7.7[c]
Silica	15	70	100	130	250	185	--

[a] Values are volume-weighted mean concentrations for 1982 through 1995.

[b] Laboratory pH.

[c] Nitrate only.

Table 11. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Merced River, California, 1968 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO$_4$, sulfate; Cl, chloride; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO$_4$	Cl
pH	−0.212								
Ca	−.806	0.178							
Mg	−.417	.137	0.436						
Na	−.796	.182	.886	0.479					
K	−.596	.037	.665	.435	0.694				
Alk	−.458	.087	.591	.317	.561	0.526			
SO$_4$	−.146	−.202	.166	.129	.109	.246	0.209		
Cl	−.842	.206	.901	.467	.893	.673	.474	0.137	
Si	−.480	.035	.736	.459	.730	.631	.597	.129	0.632

(Office of Water Quality Technical Memorandum No. 81.08, *Electrodes for pH measurement in low-conductivity waters*, issued February 10, 1981, at URL http://water.usgs.gov/admin/memo).

Table 12. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Merced River, California, March 1968 through September 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, aluminum, iron, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	0.011	0.751	--	--
pH, field	.01	.007	0.01	0.002
Calcium	–.2	.366	–.2	.434
Magnesium	<.1	.762	<.1	.645
Sodium	<.1	.532	.2	.299
Potassium	<.1	.287	.1	.028
Alkalinity, laboratory	<.1	.319	1.0	.091
Sulfate	–.5	.005	–.4	.020
Chloride	.2	.569	.8	.011
Nitrite plus nitrate	([a])	--	--	--
Silica	–.5	.033	.4	.051

[a] Insufficient data to calculate trend.

Synoptic Water-Quality Data

Chemical results of the surface-water synoptic sampling of August 1 through 4, 1991, are listed in table 13, and locations of sampling sites are shown in figure 6. During the synoptic sampling, discharge at the HBN station was 2.0 m^3/s compared to the median daily discharge of 2.8 m^3/s for early August (Lawrence, 1987), indicating that the basin was sampled during normal flow conditions for that time of year. Most of the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were between the first-quartile and median values reported for the station during the entire period of record, except for sulfate, which was slightly lower (table 10). Stream water at the upstream sampling sites was similar in composition to stream water at site 1; calcium and sodium were the predominant cations, and bicarbonate was the predominant anion. Ion balances for all the synoptic samples were positive (range 2.1 to 13 percent), indicating that organic anions may have contributed to the ionic content of stream water during the sampling period.

Stream-water chemistry of the synoptic samples collected in the basin varied somewhat in the concentrations of the weathering-derived solutes;

Table 13. Physical properties and major dissolved constituents from surface-water sampling sites in the Merced River Basin, California, collected August 1-4, 1991

[Site locations shown in fig. 6; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate; Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]	Remarks
1	11264500	2.0	20	7.1	90	14	65	7.2	--	11	56	2.1	70	--	
2	374041119340200	.022	32	7.1	170	38	110	15	300	3.1	3.7	<0.7	250	BG	Mafic bedrock
3	374113119323500	.22	28	7.6	140	29	91	12	230	10	25	<.7	180	BG	Mafic bedrock
4	374156119200200	--	7.0	6.5	31	4.8	13	2.6	26	10	4.8	2.9	25	BG	Mafic bedrock
5	374237119183900	.099	7.0	6.8	37	8.0	17	3.6	33	10	1.7	7.1	32	BG	Mafic bedrock
6	374239119183900	.027	6.0	7.0	23	4.8	26	3.1	38	4.2	1.4	<.7	83	BG	Felsic bedrock
7	374415119241800	--	18	6.9	80	8.8	52	4.4	59	12	62	2.1	37	MC, LU	Downstream from campground
8	374418119241100	1.6	19	6.6	80	5.6	57	7.9	65	12	68	2.1	37	MC, LU	Upstream from campground
9	374429119255300	.003	9.0	6.1	44	10	22	4.1	51	4.0	5.9	3.6	62	BG	Felsic bedrock
10	374603119245500	--	9.0	7.1	34	11	39	4.1	--	5.8	4.2	<.7	85	BG	Felsic bedrock
11	374702119250200	.014	12	6.7	55	8.0	52	4.4	77	14	4.5	<.7	90	BG	Felsic bedrock

[a] Criteria used in selection of sampling sites: BG = bedrock geology, MC = main channel, LU = land use.

for example, alkalinity ranged from 26 to 300 μeq/L, and silica ranged 25 to 250 μmol/L (table 13). The highest concentrations of alkalinity and silica were measured at sites 2 and 3 in the Illilouette Creek subbasin. Clow and others (1996) suggested that stream-water concentrations in the Illilouette subbasin were high because the subbasin is covered by a larger percentage of glacial till than other areas of the basin. Variations in the chemistry of the synoptic samples also seem to reflect the spatial distribution of the mapped bedrock geology. For example, streams draining felsic rock types (sites 6, 9, 10, and 11) had lower calcium to sodium ratios than streams draining more mafic rock types (sites 2–5), as would be expected on the basis of the calcium to sodium ratio of plagioclase minerals in these two bedrock types (Clow and others, 1996). Chloride concentrations also varied somewhat spatially; concentrations ranged from more than 50 μeq/L in samples collected from the main stem of the river compared to concentrations less than 6 μeq/L at most of the upper tributary sites. Surface-water samples collected during several previous studies also had high chloride concentrations along the main stem and low concentrations in most tributaries (Sorenson and Hoffman, 1981). The high chloride concentrations in the river were unexpected, given the low concentrations in precipitation and in common granitic minerals (Feth, 1981). Wastewater-treatment facilities at the campgrounds could be a source of chloride to surface water; however, there was little difference in chloride concentrations in samples collected upstream from (site 8) and downstream from (site 7) the campground at Merced Lake. Clow and others (1996) suggested that the most likely source of chloride was saline ground water from springs that discharge from joints or faults along the valley floor. Sulfate concentrations were low and uniform throughout the basin, which is consistent with the idea that most stream-water sulfate is derived from atmospheric sources and bedrock contributions are negligible. Nitrate concentrations at all of the sampling sites were low, which is consistent with the minimal amount of human activity in the basin and indicates that the backcountry campgrounds had a negligible effect on nutrient concentrations in the river during the synoptic sampling.

Sagehen Creek near Truckee, California (Station 10343500)

Site Characteristics and Land Use

The Sagehen Creek HBN Basin is located on the east slope of the northern Sierra Nevada section of the Sierra-Cascade Mountains physiographic province in central California (fig. 8). The basin drains an area of 27 km^2 and ranges in elevation from 1,926 to 2,663 m. The upper part of the basin is steep, with incised stream channels, and the lower part is a broad, U-shaped valley characteristic of glaciated terrain. The HBN station is located 13 km north of the town of Truckee, Calif., at latitude 39°25'54" and longitude 120°14'13". Sagehen Creek is a headwater tributary that flows eastward from the crest of the Sierra Nevada into Stampede Reservoir on the Truckee River and has a channel length of about 7.9 km upstream from the HBN station and an average stream gradient of 72 m/km. The annual hydrograph is controlled by snowmelt, and peak flows occur in late spring and minimum flows in the fall (Simpson, 1974). Mean monthly discharge varies from a minimum of 0.04 m^3/s in October to 2.2 m^3/s in May, and average annual runoff from the basin was 40 cm from 1954 through 1995 (Hayes and others, 1996). Average annual precipitation is about 94 cm; snowfall accounts for greater than 80 percent of the annual precipitation (Andrews and Erman, 1986). The area has a Mediterranean-type climate with cold, wet winters and warm, dry summers. Average daily air temperatures range from –3°C in January to 17°C in July.

The Sagehen Creek Basin is located within the Sierran Steppe-Mixed Forest-Coniferous Forest-Alpine Meadow Province (Bailey and others, 1994). Vegetation in the basin is dominated by pine and fir forest with grassy meadows along the main channel (Rundel and others, 1977; Andrews and Erman, 1986). The most common trees are Ponderosa pine, Jeffrey pine, Douglas-fir, sugar pine, white fir, red fir, and incense cedar. The basin is about 90 percent forested and 10 percent meadow. Soils are classified as Alfisols and are mapped in the Windy series (Johnson and Needham, 1966). This series consists of deep, well-drained soils developed in material weathered from volcanic rocks that contain up to 90 percent rock

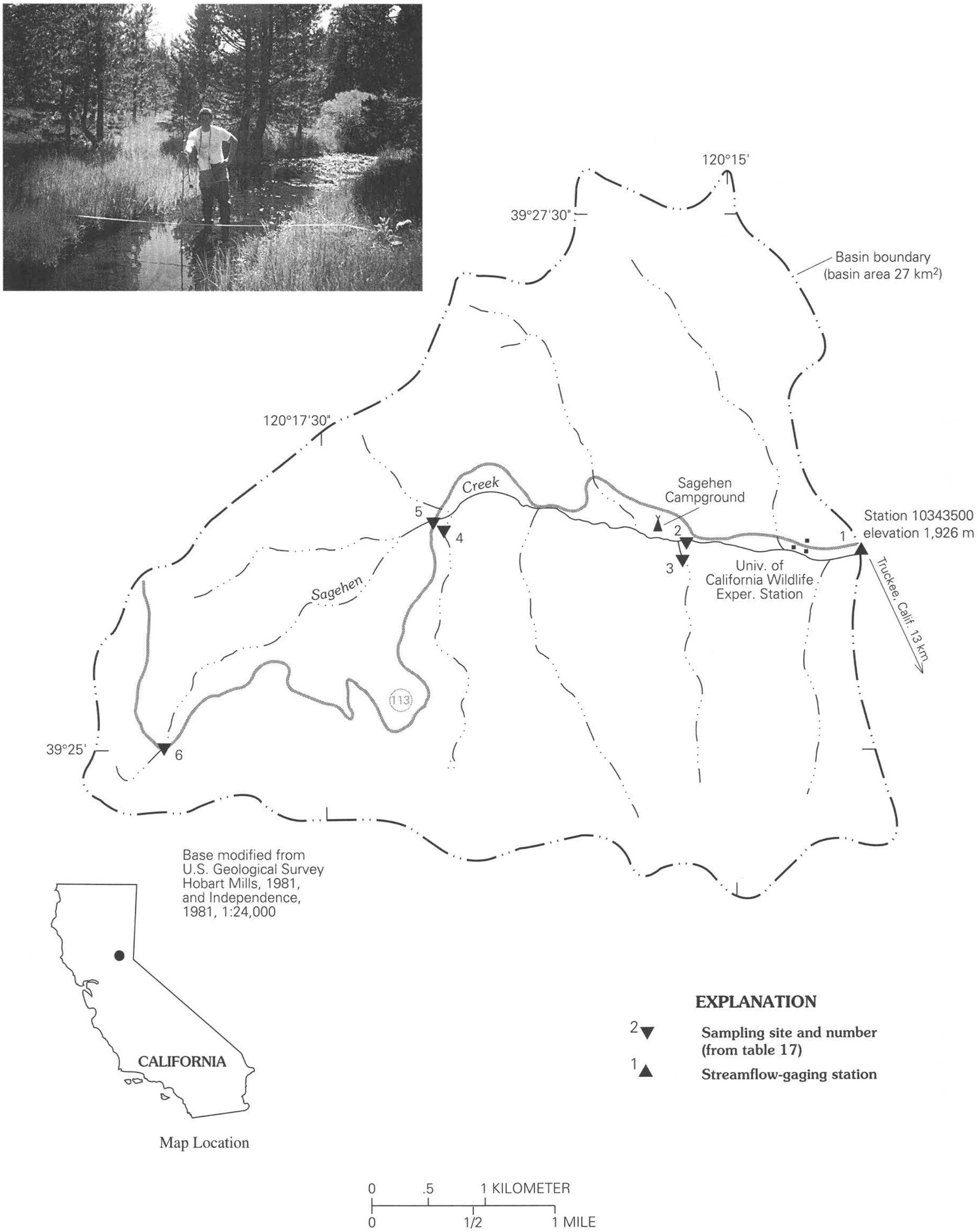


Figure 8. Map showing the study area in the Sagehen Creek Basin and photograph showing the main channel near the campground.

fragments. A typical profile has a surface layer of dark grayish brown, gravelly, sandy loam that is 60 cm thick overlying a subsoil of yellowish-brown, cobbly, sandy, loam that extends to a depth of 115 cm. Soils in this series generally are acidic and have base saturation ranges from 2 to 35 percent (Johnson and Needham, 1966).

The oldest rocks in the vicinity of the Sagehen Creek Basin are metamorphic rocks of Triassic-Jurassic age, which crop out west of the basin along the crest of the Sierra Nevada (Lindgren, 1897; Burnett and Jennings, 1962; Birkeland, 1963). The metamorphic rocks, which are mostly banded siliceous hornfels, were intruded by granitic rocks of the Sierra Nevada Batholith during the Cretaceous age (Bateman, 1992). Tertiary volcanic rocks, primarily andesitic flows and breccias, overlie the older granitic and metamorphic rocks throughout the region and are the predominant rock type in the Sagehen Creek Basin (Hudson, 1951). The Tertiary volcanic rocks contain plagioclase (andesine and labradorite), magnetite, and apatite phenocrysts, and are overlain by glacial till and alluvial deposits (Birkeland, 1964). The till is of Wisconsinan age, based on correlations made by Birkeland (1964) and Richmond and Fullerton (1986), and in the basin probably was mostly derived from the Tertiary-age volcanic rocks.

The Sagehen Creek Basin is almost entirely in the Tahoe National Forest, except for several hundred hectares that are privately owned by a lumber company. Historical records indicate that low-intensity grazing, logging, and wild fires have occurred in the basin since the late 1800's, and there has been little change in land use since the early 1950's (Erman and others, 1988). The principal human activity in the basin is hydrologic and biological research conducted by a variety of agencies, including the USGS and the University of California. A biological research station operated by the University of California is located about 0.5 km upstream from the HBN station. There are no impoundments or diversions in the basin. Two dirt roads traverse the basin, but access is limited by locked gates. There is an undeveloped campground about 2 km upstream from the HBN station. Other recreational uses include fishing, hiking, skiing, and snowmobiling. There are no mines in the basin, but extensive timber harvesting occurred between the 1880's and the early 1900's. The 10-year projected timber harvest from the basin is 9 to 10 million board feet (D.C. Erman, University of California, written commun., 1998). A sheep allotment of 1,200 units exists for the basin—animals are moved through the basin in August to higher elevations and back to lower elevations in mid-September. The sheep rest and feed 1 to 3 days in each of the large meadows in the basin on the way out (D.C. Erman, written commun., 1998).

Historical Water-Quality Data and Time-Series Trends

The data set for the Sagehen Creek HBN station analyzed for this report includes 43 water-quality samples that were collected from November 1985 through August 1995. During this period of record, samples were collected quarterly and were analyzed at the NWQL in Arvada, Colo. Eleven water-quality samples also were collected at this station between April 1968 and March 1973. Daily discharge records for Sagehen Creek (station 10343500) are available beginning in October 1953. A precipitation gage also was operated at the station from September 1990 to October 1996. Sources of other hydrologic data collected in the basin are compiled in Simpson (1974).

Calculated ion balances for 39 samples that have complete major-ion analyses are shown in figure 9. Ion balances ranged from –8.7 to +14 percent, and almost 85 percent of the samples had values within the ±5-percent range, indicating that the analytical results are of good quality. The average ion balance was 0.5 percent, indicating that unmeasured constituents, such as organic anions, did not seem to contribute substantially to the ionic composition of stream water at this HBN station. Time-series plots of the major dissolved constituents were inspected for evidence of method-related effects (fig. 9). The most notable pattern was in the sulfate concentrations, which decreased considerably in the latter part of the period of record. This pattern probably was caused by a change in the analytical technique for sulfate in 1989 from a turbidimetric technique to ion chromatography (Fishman and others, 1994). An apparent decline in concentrations of nitrite plus nitrate in the 1980's that is most likely an artifact of a decrease in the reporting-limit concentration for this constituent that occurred in 1988 is shown in figure 9.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Yosemite National Park NADP station are presented in table 14. Precipitation chemistry at the NADP station, which is about 185 km southeast of the HBN station, is very dilute and slightly acidic and has a VWM pH of 5.4 for 14 years of record. The predominant cation in precipitation was ammonium, which contributed 39 percent of the total cation charge, and the predominant anion was nitrite plus nitrate, which accounted for 44 percent of the total anions. The predominance of these ions in precipitation may reflect the influence of agricultural activities in the San Joaquin Valley along the western side of the Sierra Nevada.

Stream water in Sagehen Creek is moderately concentrated and well buffered; specific conductance ranged from 38 to 150 µS/cm, and alkalinity ranged from 440 to 1,600 µeq/L (table 14). The major cations in stream water were calcium and magnesium, and the major anion was bicarbonate. The predominance of these solutes in stream water is attributed to the weathering of plagioclase minerals in the volcanic bedrock. The median chloride concentrations in stream water was 11 µeq/L compared to the VWM concentration of 4.1 in precipitation. Based on the difference between annual precipitation and runoff, evapotranspiration can account for about a twofold increase in the chloride concentration in precipitation, indicating that most stream-water chloride is probably derived from atmospheric deposition. The median concentration of sulfate in stream water was 21 µeq/L, which was 3.6 times greater than the VWM concentrations of 5.9 µeq/L in precipitation, indicating that wet deposition alone cannot account for the sulfate concentrations in stream water. Because inputs of sulfate from dry deposition and bedrock weathering should be negligible (Melack and Stoddard, 1991), the most plausible explanation for the higher stream-water sulfate concentrations is a positive bias introduced by the analytical technique used prior to 1991 (fig. 9). Concentrations of inorganic nitrogen species in stream water generally were less than the VWM concentrations in precipitation, indicating that most atmospheric nitrogen is retained by vegetation and soils and that livestock grazing in the basin does not seem to substantially affect nutrient concentrations at the HBN station.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 15). Most weathering-derived solutes had strong inverse correlations with stream discharge, particularly sodium (rho = –0.919), potassium (rho = –0.915), and alkalinity (rho = –0.889). These results are consistent with a hydrologic system where weathering-enriched base flow is diluted by water from shallow or surficial sources during periods of increased discharge, particularly spring snowmelt. For the solutes, strong positive correlations existed among the base cations, alkalinity, and silica ($0.889 \leq \text{rho} \leq 0.969$), which is consistent with the weathering stoichiometry of silicate minerals in the volcanic rocks. Chloride and sulfate were weakly correlated with the weathering-derived solutes and with discharge, supporting the idea that these solutes primarily are derived from atmospheric sources.

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 16. Statistically significant trends were detected in unadjusted sulfate and nitrite plus nitrate concentrations at the 0.01 probability level. After the concentrations were corrected for flow, statistically significant trends also were detected in calcium, magnesium, sodium, potassium, and silica concentrations at the 0.01 probability level. The LOWESS curves in figure 9 show that the trends in sulfate and nitrite plus nitrate were probably caused by method-related factors rather than by environmental change. For example, the abrupt decline in sulfate concentrations is coincident with a change in the analytical technique for sulfate and a decrease in the analytical reporting limit beginning in 1991. Similarly, the apparent decline in nitrite plus nitrate concentrations was primarily caused by a decrease in the analytical reporting limit beginning in 1988. The cause of the downward trends in the base cation and alkalinity concentrations could not be identified;

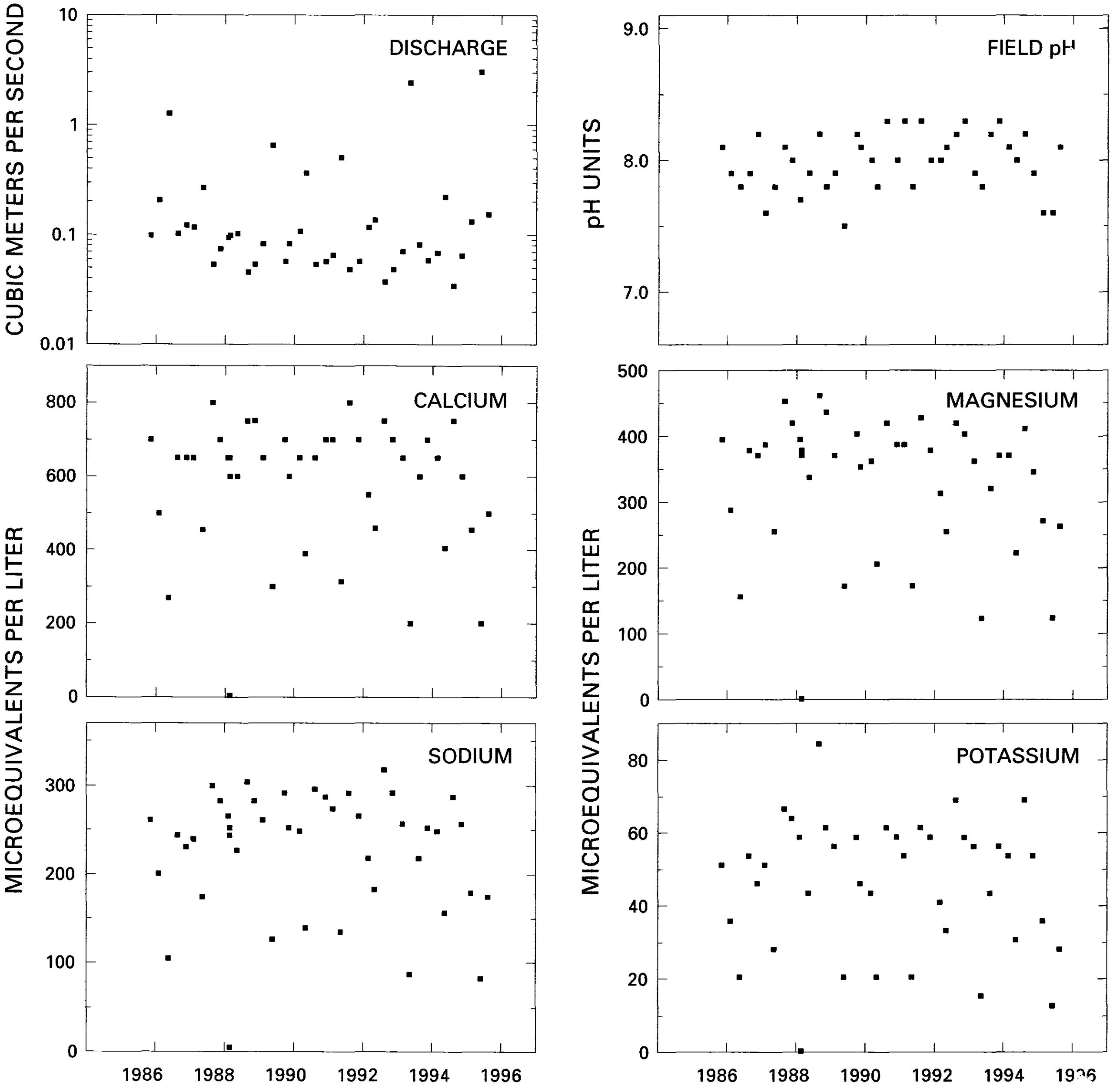


Figure 9. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Sagehen Creek, California.

however, the fact that these trends were detected only in the flow-adjusted concentrations indicates that they were probably caused by environmental change rather than by a method-related factor. Considering the dilute chemistry of precipitation at the Yosemite NADP station compared to the stream (table 14), changes in atmospheric deposition probably could not account for the trends in stream-water chemistry. Similarly, changes in land use probably were not an important factor because the basin is used only for scientific research and a limited amount of grazing. Perhaps the most plausible explanation for the trends in water quality is climate variability. Although a detailed analysis of climate effects is

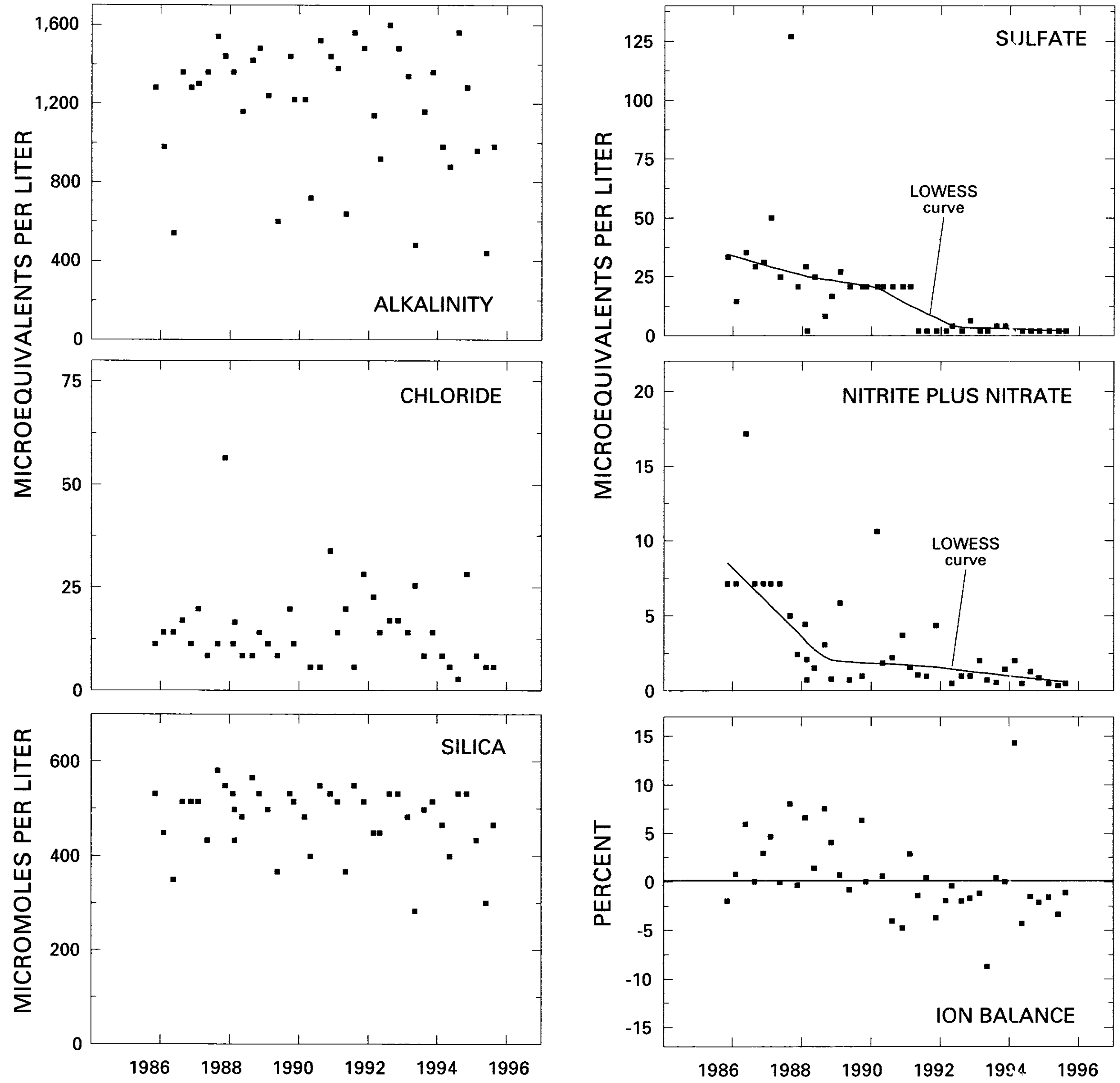


Figure 9. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Sagehen Creek, California—Continued.

beyond the scope of this report, long-term precipitation records in the area (National Climatic Data Center at http://www.ncdc.noaa.gov), as well as daily discharge records for Sagehen Creek (Hayes and others, 1996), indicated that there was an extended period of drought that persisted in the region from 1987 through 1994.

Synoptic Water-Quality Data

Chemical results of the surface-water synoptic sampling on July 27, 1991, are listed in table 17, and locations of sampling sites are shown in figure 8. During the synoptic sampling, discharge at the HBN station was 0.06 m^3/s compared to the mean daily

Table 14. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Sagehen Creek, California, November 1985 through August 1995, and volume-weighted mean concentrations in wet precipitation collected in Yosemite National Park, California

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation VWM[a]
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Discharge, inst.	0.034	0.065	0.10	0.21	3.0	53	--
Spec. cond., field	38	79	120	130	150	51	4.5
pH, field	6.5	7.7	7.9	8.1	8.3	51	5.4[b]
Calcium	4.0	460	600	690	800	54	2.3
Magnesium	.8	240	360	390	650	54	1.2
Sodium	5.2	160	240	260	320	54	3.8
Potassium	.3	28	47	59	84	52	.3
Ammonium	<.1	.4	.6	1.1	28	45	7.5
Alkalinity, laboratory	440	900	1,220	1,370	1,600	51	--
Sulfate	<2.1	2.1	21	22	130	52	5.9
Chloride	<2.8	8.5	11	17	56	51	4.1
Nitrite plus nitrate	.4	.9	2.0	4.4	21	45	7.7[c]
Silica	140	430	480	530	580	53	--

[a] Values are volume-weighted mean concentrations for 1982–95.

[b] Laboratory pH.

[c] Nitrate only.

Table 15. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Sagehen Creek, California, 1985 through 1995

[Q, discharge; Ca, calcium, Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; N, nitrite plus nitrate; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	N
pH	-0.671									
Ca	–.873	0.618								
Mg	–.847	.549	0.947							
Na	–.919	.616	.934	0.946						
K	–.915	.544	.938	.957	0.969					
Alk	–.889	.554	.909	.912	.920	0.920				
SO_4	.070	–.114	.171	.261	.159	.120	0.131			
Cl	–.098	–.088	.108	.076	.125	.114	.150	0.022		
N	–.062	–.034	.235	.237	.193	.168	.215	.683	0.223	
Si	–.867	.576	.893	.923	.928	.923	.889	.231	.133	0.266

discharge of 0.21 m^3/s and 0.09 m^3/s for July and August, indicating that the basin was sampled during low flow conditions for that time of year. Most of the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were above the third-quartile values reported for the station during the entire period of record, except for the sulfate and chloride concentrations, which were lower than the first-quartile concentrations (table 14). Stream water at the upstream sampling sites was similar in composition to stream water at site 1, with calcium the predominant cation and bicarbonate the predominant anion. Ion balances for the synoptic samples ranged from –0.3 to 3.6 percent and averaged 2.0 percent, indicating that unmeasured constituents, such as organic anions, may have contributed slightly to the ionic content of stream water during the sampling period. The results presented in table 17 had relatively little variation among the sampling sites in the concentrations of the weathering-derived solutes. For example, calcium ranged from 300 to 800 µeq/L, alkalinity ranged from 540 to 1,620 µeq/L, and silica ranged from 350 to 620 µmol/L. This similarity in stream chemistry reflects the relatively small size of the basin and the uniform composition of the underlying geology. The one spatial pattern that is apparent is a progressive increase in concentrations in samples collected along the main channel of Sagehen Creek between the headwaters (site 6) and the HBN station (site 1), which probably reflects increasing inputs of ground water with decreasing elevation along the channel. Chloride and sulfate concentrations were low and uniform among the sampling sites, supporting the idea that these solutes primarily are derived from atmospheric sources, and that basin sources are minor. Nitrate concentrations at all of the sampling sites were less than the analytical reporting limit of 3.6 µeq/L, which is consistent with the minimal amount of land use in the basin.

Table 16. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Sagehen Creek, California, November 1985 through August 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	–0.005	0.042	--	--
pH, field	<.01	.439	0.01	0.405
Calcium	<.1	.213	–12.5	.000
Magnesium	–5.4	.015	–8.6	.000
Sodium	–2.2	.378	–4.4	.000
Potassium	–.9	.278	–1.2	.000
Alkalinity, laboratory	–11.2	.426	–22.0	.000
Sulfate	–3.3[a]	.000	--	--
Chloride	–.4	.255	([b])	--
Nitrite plus nitrate	<–.1[a]	.001	--	--
Silica	–5.4	.014	–5.8	.000

[a] Trend calculated using a trend test for censored data.

[b] Flow model not significant at $\alpha = 0.10$.

Table 17. Physical properties and major dissolved constituents from surface-water sampling sites in the Sagehen Creek Basin, California, collected July 27, 1991

[Site locations shown in fig. 8; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate: Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]	Remarks
1	10343500	0.056	140	8.0	750	440	280	62	1,420	2.1	<2.8	<3.6	530	MC	
2	392558120152100	.017	120	8.0	650	380	240	44	1,320	2.1	<2.8	<3.6	470	MC	Downstream from campground
3	392558120152000	--	170	7.5	800	400	404	87	1,620	4.2	11	<3.6	550	T, BG	Pyroclastic rocks
4	392602120164500	--	140	8.1	650	420	240	67	1,280	2.1	11	<3.6	620	T, BG	Pyroclastic rocks
5	392604120164900	.0062	80	7.9	460	220	140	20	800	.8	4.5	1.4	430	MC, BG	Morainal cover
6	392501120182800	.00003	55	7.4	300	150	100	13	540	2.7	4.2	<0.7	350	MC, BG	Pyroclastic rocks, headwaters

[a] Criteria used in selection of sampling sites: BG = bedrock geology, MC = main channel, T = tributary.

Big Jacks Creek near Bruneau, Idaho (Station 13169500)

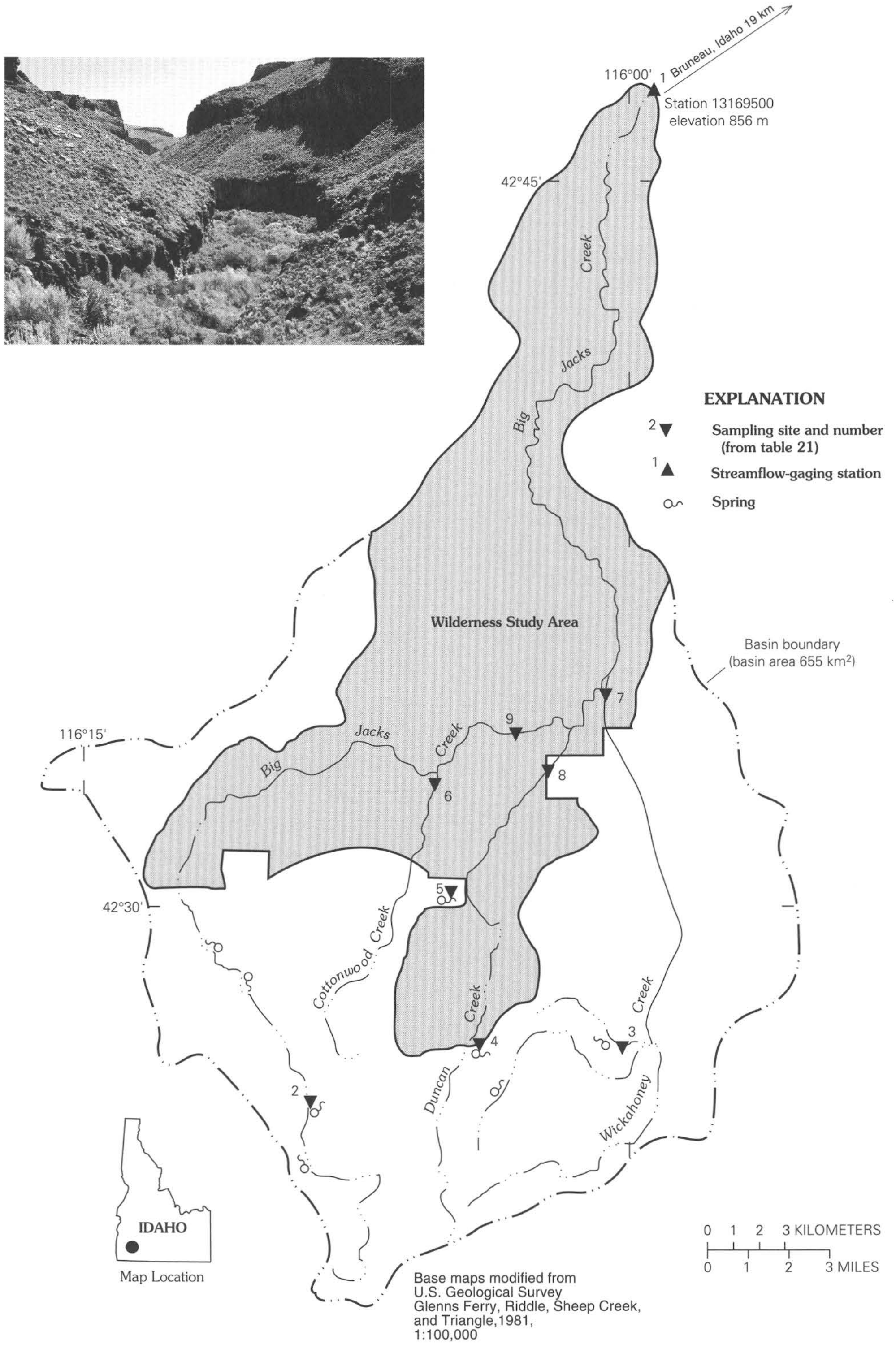
Site Characteristics and Land Use

The Big Jacks Creek HBN Basin is located in the Columbia Plateaus physiographic province in southwestern Idaho (fig. 10). The 655-km^2 basin ranges in elevation from 856 to 1,790 m and drains a sagebrush-covered plateau dissected by rugged, sheer-walled canyons that are as much as 200 m deep. The HBN station is located 19 km southwest of Bruneau, Idaho, at latitude 42°47'06" and longitude 115°59'00". Big Jacks Creek flows north into the Bruneau River, a tributary of the Snake River, and has a channel length of about 71 km upstream from the HBN station and an average stream gradient of 14.6 m/km (Slack and others, 1993). Mean monthly discharge varies from 0.016 m^3/s in December to 0.53 m^3/s in March, and average annual runoff from the basin was 0.7 cm from 1965 through 1995 (Brennan and others, 1996). There is no flow at the HBN station for long periods in most years from July to February; however, the stream is perennial at a point about 6.5 km upstream from the HBN station, where it emerges from the canyon mouth. Discharge in the perennial reach is maintained by springs located at the head of the canyon system. Once the creek leaves the confined reaches of the canyon, streamflow rapidly diminishes because of high rates of evapotranspiration and infiltration into the valley alluvium. Climate of the area is semiarid and cool (Bailey and others, 1994). Average monthly air temperatures range from –0.5°C in January to 22.9°C in July (National Climatic Data Center, 1997). Precipitation averages 19.6 cm annually and is greatest in November (2.6 cm) and least in July (0.5 cm). Average annual snowfall is 14 cm, most of which falls from November through February.

The basin is in the Intermountain Sagebrush ecoregion (Bailey and others, 1994) and is covered by big sagebrush, low sagebrush, salt desert shrub, and riparian vegetation communities (U.S. Department of the Interior, 1989). The sagebrush communities are most common; low sagebrush types are found primarily on shallow, poorly drained soil, and big sagebrush types are associated with deep, well-drained soils. The big sagebrush community is dominated by Wyoming big sagebrush and bluebunch wheatgrass, and the low sagebrush community is dominated by black sagebrush, low sagebrush, Thurber needlegrass, Idaho fescue, and bluebunch wheatgrass. The salt desert shrub type grows on poorly developed soils in northern part of the basin and consists of shadescale, bud sagebrush, and Indian ricegrass. Lush riparian vegetation grows along perennial reaches of the creek and generally includes shrubs of willow, rose, and currant as well as sedge and bluegrass in meadow areas. Most soils in the basin are classified as Aridisols and are mapped in the Cottle-Willhill complex (Noe, 1991). These are well-drained, shallow soils developed in alluvium and residuum derived from volcanic rocks. Soil textures are predominantly gravelly clay loam, and most soils contain 35 to 70 percent rock fragments. The soils are alkaline (soil pH 7.4 to 8.4), contain less than 2 percent organic matter, and range in depth from 25 to 80 cm (Noe, 1991).

The basin is in the Owyhee Uplands subprovince of the Columbia Intermontane geologic province, informally known as the Owyhee volcanic field (Winters and Leszcykowski, 1986). Bedrock underlying the basin consists of several ledge-forming rhyolite units of Miocene age capped by younger basalt flows (Kauffman and Bonnichsen, 1990). Most of the rhyolite units are lava flows, but some have characteristics that indicate they are pyroclastic flows. The rhyolite flows have a fairly uniform chemical composition and are composed of phenocrysts of plagioclase, augite, pigeonite, and opaque oxides. The basalt flows are fine to medium grained and consist predominantly of plagioclase and olivine. The rhyolite and the basalt units are cut by many northwest-trending, steeply dipping normal faults (Berenbrock, 1993).

The Big Jacks Creek HBN Basin drains the southwestern part of Owyhee County, Idaho, and land ownership is about 92 percent Federal, 7 percent State, and 1 percent private. Federally owned lands are managed by the Bureau of Land Management (BLM), of which about 40 percent (260 km^2) in the northern one-half of the basin is in the Big Jacks Creek and



Base maps modified from
U.S. Geological Survey
Glenns Ferry, Riddle, Sheep Creek,
and Triangle, 1981,
1:100,000

Figure 10. Map showing the study area in the Big Jacks Creek Basin and photograph showing the main canyon.

Duncan Creek Wilderness Study Areas (WSA), which were established in 1976 (fig. 10). Access to the basin is by way of a network of dirt roads in the southern part of the basin and mostly hiking trails in the WSA. Lands in the WSA have been identified as meeting the requirements of wilderness under the Wilderness Act (Public Law 88–577, Sept. 3, 1964) and, although designation has not yet been granted, the BLM is required to manage the lands to protect their wilderness characteristics (U.S. Department of the Interior, 1989). The major land-use activities in the WSA are recreation and livestock grazing. Visitor use of the WSA is about 1,125 annual visitor days, and hunting accounts for about 80 percent of this use (U.S.Departmet of the Interior, 1989). The WSA contains parts of four grazing allotments that are used primarily for cattle. The grazing season begins during the spring in the northern part of the WSA and moves to the southern parts during summer and fall. Although the amount of cattle grazing has not changed substantially since the establishment of the WSA, improved management practices have decreased grazing pressures on the ecosystem, particularly in riparian areas. Some prescribed burning is permitted in the WSA to improve range conditions and control juniper invasion (U.S. Department of the Interior, 1989). The primary land use in nonwilderness areas of the basin is cattle grazing, and effects from grazing are most pronounced in the vicinity of springs and several small reservoirs in the northern part of the basin.

Historical Water-Quality Data and Time-Series Trends

The data set for the Big Jacks Creek HBN station analyzed for this report includes 111 water-quality samples that were collected from January 1967 through November 1995. Sampling was scheduled as monthly from 1967 to 1982 and quarterly from 1983 to 1995; however, the actual number of samples collected was considerably lower because of the intermittent nature of the stream. Samples from the early part of the period of record were analyzed at a USGS district laboratory in Portland, Oreg. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and at the NWQL in Arvada, Colo., from 1976 through 1995. Daily discharge records for Big Jacks Creek (station 13169500) are available from December 1938 to October 1949 and July 1965 to the current year. Prior to October 1968, data were published as Wickahoney Creek near Bruneau.

Calculated ion balances for 109 samples that have complete major-ion analyses are shown in figure 11. Ion balances ranged from –28 to +20 percent, and 80 percent of the samples had values within the ±5-percent range, indicating that the analytical results are of high quality. The average ion balance was –0.2 percent, indicating that unmeasured constituents, such as organic anions, generally are not an important component of stream water at this HBN station. Time-series plots of the major dissolved constituents were inspected for evidence of method-related effects (fig. 11). The most notable pattern was observed in sulfate, which had a period of high concentrations during the late 1980's, coinciding with the use of a turbidimetric titration for sulfate analyses at the NWQL (Fishman and others, 1994). In 1990, the NWQL determined that sulfate concentrations can be overestimated by this technique and changed the technique to ion chromatography (Office of Water Quality Technical Memorandum No. 90.04, *Turbidimetric sulfate method*, issued December 21, 1989, at URL http://water.usgs.gov/admin/memo/). The stepped pattern in concentrations of nitrite plus nitrate was caused by changes in the analytical reporting limit for this constituent that occurred in 1982 and again in 1991.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Reynolds Creek NADP station are presented in table 18. Precipitation chemistry at the NADP station, which is about 80 km northwest of the HBN station, is very dilute and slightly acidic and had a VWM pH of 5.6 for 13 years of record. The predominant cations in precipitation were calcium and ammonium, which contributed 27 and 32 percent of the total cation charge, respectively. The predominant anions were sulfate and nitrate, which each accounted for 42 percent of the total anion charge, respectively.

Stream water in Big Jacks Creek is moderately concentrated and well buffered; specific conductance ranged from 66 to 190 μS/cm, and alkalinity ranged from 420 to 1,760 μeq/L (table 18). The major cations in stream water were calcium and sodium, and the major anion was bicarbonate. The predominance of these solutes in stream water, in addition to the high concentrations of potassium and silica, are attributed to the weathering of plagioclase, pyroxene, and olivine minerals in the basaltic and rhyolitic lava flows. The median chloride (130 μeq/L) and sulfate (150 μeq/L) concentrations in stream water were substantially greater than the VWM concentrations of chloride (3.4 μeq/L) and sulfate (8.6 μeq/L) in precipitation, indicating that these solutes are derived primarily from sources in the basin. Although land-use activities in the basin are minimal, some chloride may be derived from cattle activity in the riparian zone and around springs and water developments. Additional sources of chloride and sulfate may include weathering of the volcanic bedrock or thermal ground water discharging from springs (Young and Lewis, 1982; Berenbrock, 1993). Concentrations of inorganic nitrogen species in stream water generally were less than the VWM concentrations in precipitation, indicating that most atmospheric nitrogen is retained by vegetation and soils and that livestock grazing in the basin does not have a substantial effect on nutrient concentrations at the HBN station.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 19). Most weathering-derived solutes had strong inverse correlations with stream discharge, particularly sodium (rho = −0.759) and alkalinity (rho = −0.673). These results are consistent with a hydrologic system where weathering-enriched base flow is diluted by water from shallow or surficial sources during periods of increased discharge, particularly spring snowmelt. For the solutes, the strongest correlations were among calcium, magnesium, sodium, alkalinity, and silica, which is consistent with the weathering stoichiometry of silicate minerals in the volcanic bedrock. Chloride was positively correlated with the major cations, and with sulfate ($0.561 \leq \text{rho} \leq 0.599$) but was only weakly correlated with alkalinity (rho = 0.334) and silica (rho = 0.279). The moderately strong correlation between sulfate and chloride (rho = 0.599) indicates a common source of these solutes, such as thermal ground water that is discharged from springs along the canyon floor (Berenbrock, 1993).

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 20. Statistically significant upward trends were detected in unadjusted sodium and chloride concentrations and in field pH at the 0.01 probability level. Trends were similar for the unadjusted and flow-adjusted sodium and chloride concentrations; however, the trend in flow-adjusted pH was not statistically significant, indicating that the pH trend probably is related to variations in stream discharge. The LOWESS curves in figure 11 show somewhat different temporal patterns in the sodium and chloride concentrations during the period of record. For example, the increase in sodium concentrations was nearly constant during the period of record, whereas chloride concentrations increased until the late 1980's then declined slightly through the 1990's. A possible explanation for the decrease in chloride concentrations in the 1990's was a change in the analytical technique from colorimetry to ion chromatography in 1990 (Fishman and others, 1994). The cause of the upward trends in sodium and chloride concentrations prior to 1990 could not be identified but they probably are not related to changes in atmospheric deposition, considering the dilute chemistry of precipitation at the NADP station compared to the stream (table 18). Other environmental factors that may have caused changes in stream-water chemistry include changes in land use and possibly discharge from geothermal springs. Grazing is the major land use in the basin; however, livestock use has not changed substantially during the period of record, particularly since the establishment of the WSA in 1976. Discharge from geothermal springs in a nearby drainage has declined during the past 25 years in response to removal of water from the regional geothermal aquifer for irrigation (Berenbrock, 1993). Assuming geothermal springs are present in the basin and are enriched in chloride and sodium compared to stream water (Young and Lewis, 1982), similar declines in spring discharge in Big Jacks Creek would not provide a reasonable explanation for the upward trends in chloride and sodium at this HBN station.

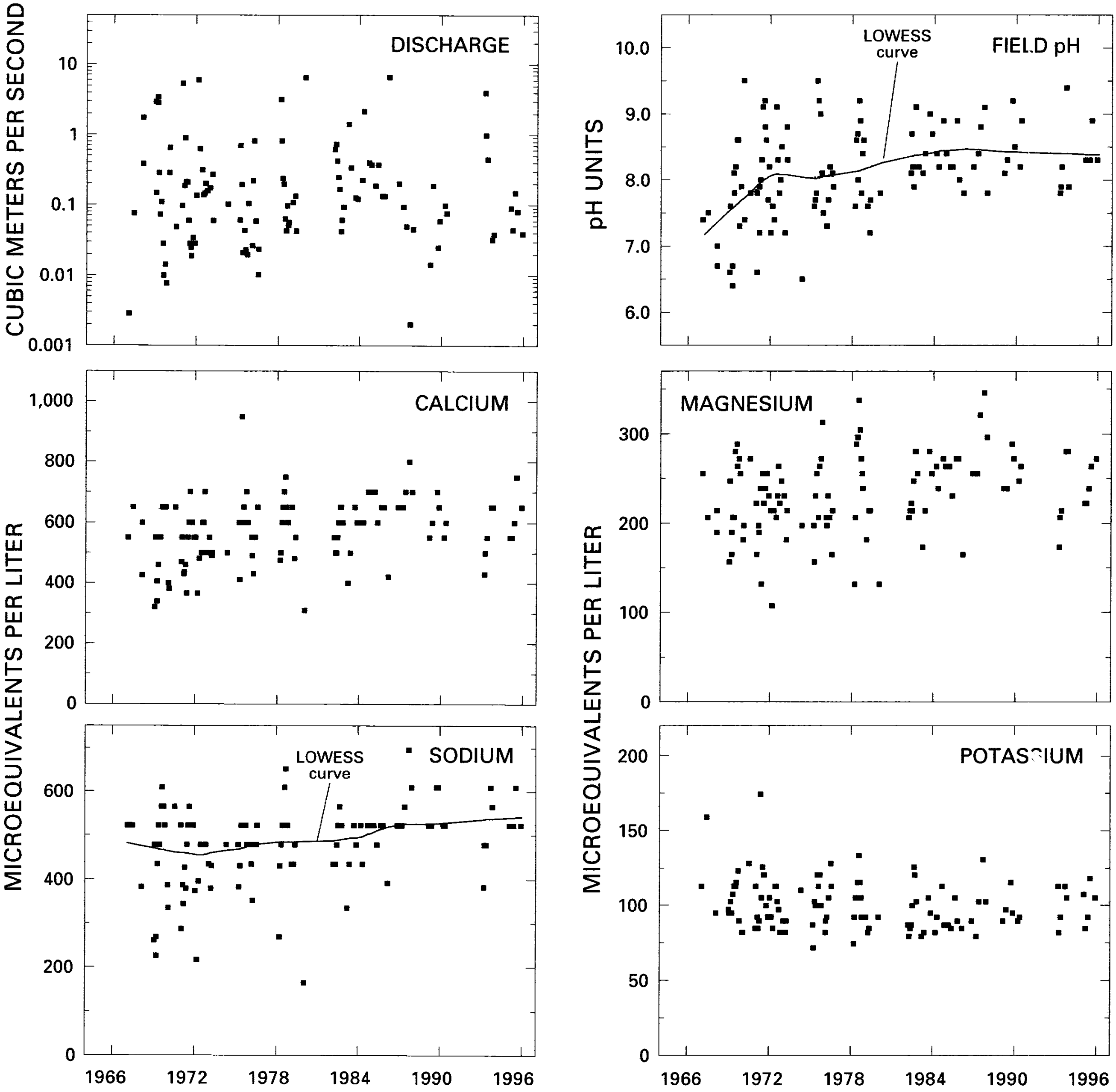


Figure 11. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Big Jacks Creek, Idaho.

Synoptic Water-Quality Data

Chemical results of the surface-water synoptic sampling of July 9–11, 1993, are listed in table 21, and locations of sampling sites are shown in figure 10. During the synoptic sampling, discharge at the HBN station was 0.12 m^3/s compared to the monthly mean discharge of 0.04 m^3/s for July (Brennan and others, 1996), indicating that the basin was sampled at nearly normal flow conditions for that time of year. Most of the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were close or equal to

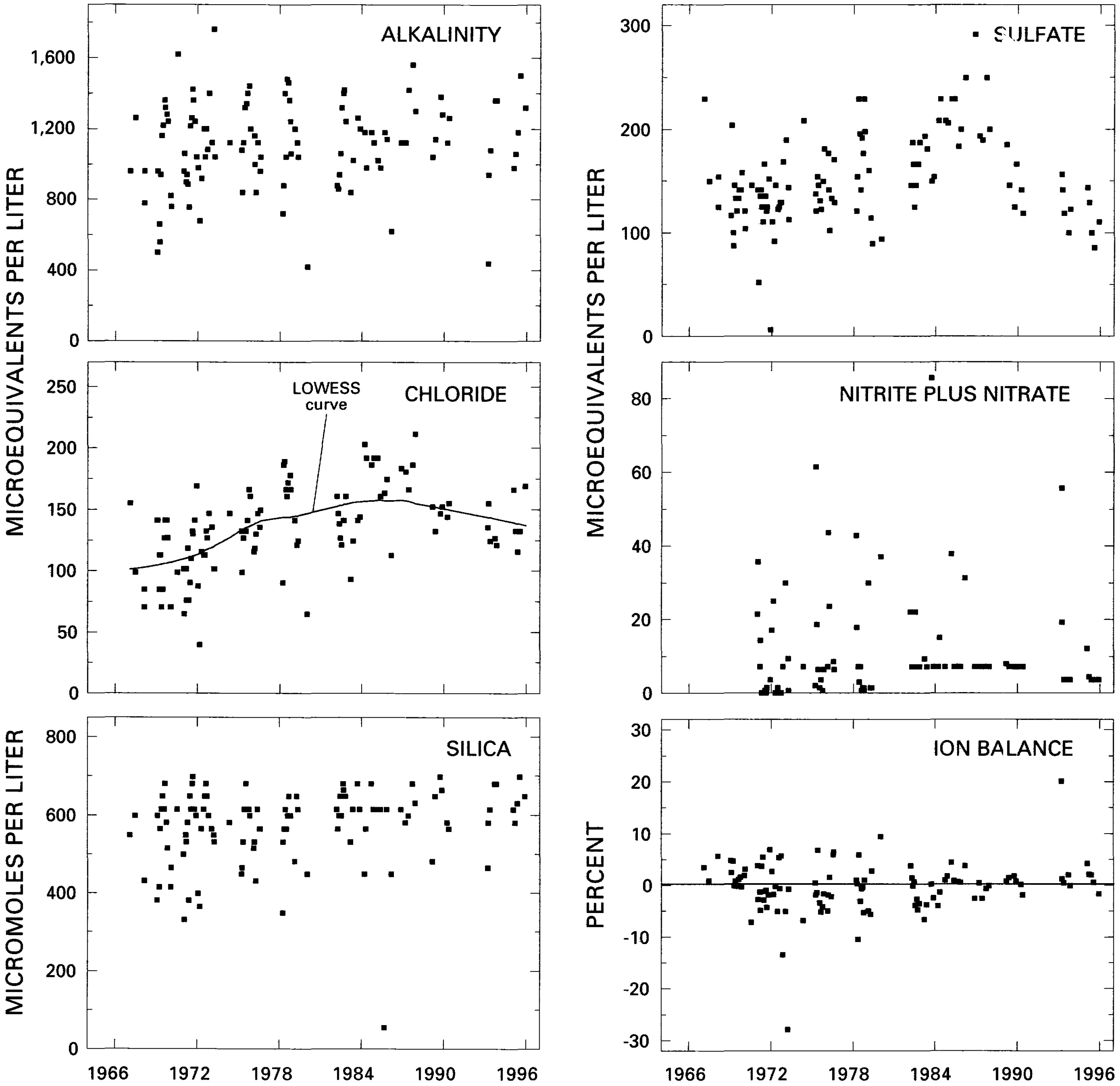


Figure 11. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Big Jacks Creek, Idaho—Continued.

the third-quartile values reported for the station during the entire period of record, except for sulfate and chloride concentrations, which were substantially lower (table 18). The concentrations of the base cations and alkalinity in the tributary streams were lower than the concentrations measured at site 1, except for site 4. Ion balances for all the synoptic samples were positive (ranging from 0.1 to 5.5 percent), indicating that unmeasured constituents. such as organic anions, may have contributed slightly to the ionic content of stream water during the synoptic sampling.

Table 18. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Big Jacks Creek, Idaho, January 1967 through November 1995, and volume-weighted mean concentrations in wet precipitation collected at the Reynolds Creek Station, Idaho

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation VWM[a]
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Discharge, inst.	0.0020	0.047	0.13	0.33	6.5	111	--
Spec. cond., field	66	120	140	150	190	110	5.2
pH, field	6.4	7.7	8.2	8.6	9.5	110	5.6[b]
Calcium	310	500	600	650	950	111	8.0
Magnesium	110	210	230	260	350	111	1.9
Sodium	170	440	480	520	700	110	0.7
Potassium	72	90	97	110	170	109	6.9
Ammonium	<.7	<1.1	2.9	5.0	12	41	9.3
Alkalinity, laboratory	420	960	1,120	1,270	1,760	111	--
Sulfate	6	120	150	180	290	111	8.6
Chloride	39	110	130	160	210	111	3.4
Nitrite plus nitrate	<.7	3.6	7.1	11	86	90	8.7[c]
Silica	55	530	600	610	700	109	2.5

[a] Values are volume-weighted mean concentrations for 1983 through 1995.

[b] Laboratory pH.

[c] Nitrate only.

Table 19. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Big Jacks Creek, Idaho, 1967 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl
pH	-0.339								
Ca	-.616	0.449							
Mg	-.545	.477	0.759						
Na	-.759	.488	.823	0.790					
K	-.504	.268	.508	.396	0.490				
Alk	-.673	.529	.754	.733	.762	0.524			
SO_4	-.067	.119	.332	.347	.270	-.065	0.154		
Cl	-.287	.341	.561	.592	.527	.097	.334	0.599	
Si	-.447	.484	.604	.594	.657	.410	.623	.061	0.279

In general, concentrations of the major solutes did not vary markedly among the sampling sites, probably because of the nearly uniform composition of the volcanic bedrock. For example, calcium ranged from 310 to 700 μeq/L, alkalinity ranged from 620 to 1,360 μeq/L, and silica ranged from 530 to 800 μmol/L (table 21). Of the weathering-derived constituents, potassium had the widest range of concentrations, varying from 24 μeq/L at site 2 to 190 μeq/L at site 4, perhaps reflecting different ground-water residence times. There was no substantial difference between the chemistry of several headwater springs (sites 2–5) and the chemistry of downstream sampling sites (sites 6–9), supporting the idea that ground-water discharge from upland springs is the primary source of streamflow in the canyon. Sulfate and chloride concentrations were slightly higher at two springs (sites 3 and 4) compared to the other sampling sites, probably reflecting variations in ground-water chemistry. Nitrate concentrations were low (<1.5 μeq/L) at all the sampling sites, except for Wickahoney Spring (site 3) and Hicks Spring (site 5), which had concentrations of 79 and 43 μeq/L, respectively. Because the springs are used as a water source by cattle, the high nitrate concentrations at these two sites are probably derived from livestock wastes. Nitrate concentrations at sampling sites downstream from the springs (sites 7 and 8) were less than the analytical reporting limit, indicating that the stream biota were capable of utilizing upstream inputs of nitrate.

Table 20. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Big Jacks Creek, Idaho, January 1967 through November 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	-0.002	0.420	--	--
pH, field	.03	.005	0.02	0.184
Calcium	3.3	.016	4.1	.015
Magnesium	1.2	.102	1.1	.036
Sodium	3.6	.001	3.8	.000
Potassium	-.1	.475	-.3	.132
Alkalinity, laboratory	1.3	.819	-.5	.819
Sulfate	1.7	.070	1.7	.068
Chloride	2.6	.000	2.7	.000
Nitrite plus nitrate	([a])	--	--	--
Silica	1.8	.033	2.1	.055

[a]Insufficient data to calculate trend.

Table 21. Physical properties and major dissolved constituents from surface-water sampling sites in the Big Jacks Creek Basin, Idaho, collected July 9–11, 1993

[Site locations shown in fig. 10; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate; Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]	Remarks
1	13169500	0.12	160	9.2	650	260	570	100	1,320	83	110	<0.4	670	--	
2	422612116081200	--	78	7.6	310	100	280	24	620	40	51	0.6	530	SP, LU	Livestock water source
3	422715115591400	--	110	7.4	480	150	370	59	740	150	140	79	570	SP, LU	Livestock water source
4	422724116032100	--	180	7.6	700	280	610	190	1,360	160	170	1.4	580	SP, LU	Livestock water source
5	423019116040100	--	99	7.7	410	140	340	67	720	90	87	43	720	SP	Livestock water source
6	423104116050400	--	98	7.7	410	140	350	72	700	90	87	<.4	750	MT	Canyon site
7	423231115583700	.023	140	9.4	600	210	520	77	1,120	100	120	<.4	580	MT, LU	Livestock grazing
8	423259116012800	.050	120	8.0	500	180	430	79	940	98	99	<.4	730	MT	Canyon site
9	423346116022900	.28	140	8.6	550	210	480	92	1,100	98	99	<0.4	800	MT	Canyon site

[a]Criteria used in selection of sampling sites: LU = land use, SP = spring, MT = major tributary.

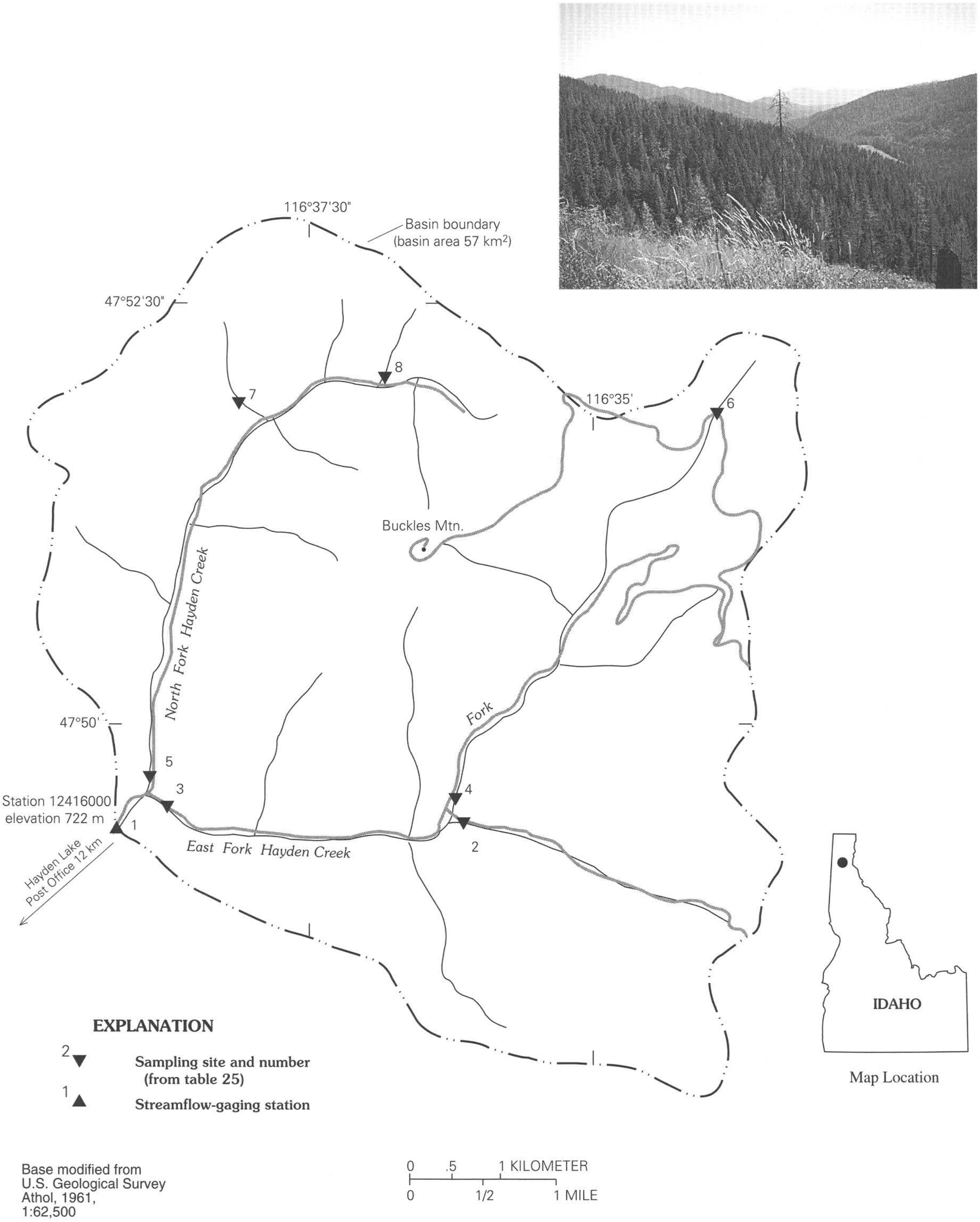
Hayden Creek below North Fork near Hayden Lake (Station 12416000)

Site Characteristics and Land Use

The Hayden Creek HBN Basin is in the northern Idaho panhandle and is part of the Northern Rocky Mountains physiographic province of the Rocky Mountain System (fig. 12). The basin drains 57 km^2 of steep, mountainous terrain that ranges in elevation from 722 m at the HBN station to 1,707 m at the summit of South Chilco Mountain. The HBN station is 12 km northeast of the Hayden Lake Post Office, at latitude 47°49'22" and longitude 116°39'10". Hayden Creek flows west into the northern inlet of Hayden Lake, which drains towards the Spokane River, and has a channel length of 11 km and an average stream gradient of 61 m/km. The main channel is perennial, and mean monthly discharge ranges from 0.14 m^3/s during low-flow conditions in September to 2.25 m^3/s in April, during spring snowmelt. Average annual runoff from the basin was 44 cm from 1965 to 1995 (Brennan and others, 1996). Climate is mainly affected by maritime air masses brought by prevailing westerly winds from the Pacific Ocean, although occasionally cold arctic air moves through the region (U.S. Department of Agriculture, 1987a). Because of the mountainous terrain and northerly latitude, the area, in general, is cool and moist, and there are pronounced elevational gradients in temperature and precipitation. Average daily temperatures at Coeur d'Alene, in the valley below the Hayden Creek Basin, range from –2°C in January to 21°C in July and August. Precipitation in Coeur d'Alene ranges from 2 cm in July to 9.7 cm in December. Temperatures probably are 5° to 10°C cooler in the Hayden Creek Basin than in Coeur d'Alene. Annual precipitation in Coeur d'Alene averages 65 cm, and at the HBN station, the average is 89 cm. Precipitation probably is substantially greater at high elevations in the basin. A deep seasonal snowpack develops each winter and melts in the spring. Snowfall amounts range from 100 cm at low elevations to 550 cm at the highest elevations (U.S. Department of Agriculture, 1987a).

The Hayden Creek HBN Basin is in the montane zone of the Northern Rocky Mountain Forest-Steppe-Coniferous Forest-Alpine Meadow ecoregion (Bailey and others, 1994). Aspect and elevation control species distribution of trees. Ponderosa pine, Douglas-fir, and grand fir tend to grow in relatively hot, dry sites, and western hemlock, western red cedar, and spruce prefer cool, wet areas. Mature forests historically were primarily Ponderosa pine, western larch, and western white pine. During the early part of the 20th century, most of the mature forests were logged, and Douglas-fir and grand fir are the predominant trees in the second-growth forests. These trees are affected by root rot and bark beetle infestations, resulting in extensive patches of diseased and dying trees in the second-growth forest. Application of pesticides by air helped control pest infestations until the 1980's, when spraying was discontinued because of environmental concerns. Understory vegetation includes pachistema, clintonia, galium, and ceanothus (U.S. Department of Agriculture, 1987a).

Soils in the basin are Inceptisols developed on alluvium and colluvium derived from the local metasedimentary bedrock. Loess, derived mostly from volcanic dust blown east from the volcanoes in the Cascade Range in Washington and Oregon, is an important component of the upper soil horizons. Soils are part of the Huckleberry-McCrosket-Ardenvoir series, which is described as sloping to very steep, moderately deep to deep soils that formed in volcanic ash and loess over metasedimentary rock (Weisel, 1981). A typical soil profile includes a gravelly silt loam surface layer and a gravelly loam subsoil and substratum. Depths to fractured bedrock are usually 50 to 150 cm. Soils below 1,500-m elevation are classified as Andic Dystrochrepts, and soils above 1,500 m are classified as Andic Cryochrepts (Kuennen and Nielsen-Gerhardt, 1995). Bedrock in the basin primarily consists of the lower Wallace Formation of Precambrian age, which includes quartzite, argillite, siltstone, dolomite, and dolomitic limestone (Gribbs, 1973). The quartzite is usually carbonate bearing. Small parts of the basin are underlain by the Striped Peak Formation, which contains siltstone, argillite, quartzite, and dolomite. The St. Regis Formation crops out in a small area in the northeastern part of the basin; it consists of argillite and has some quartzite and carbonate-bearing beds near the top.



Base modified from
U.S. Geological Survey
Athol, 1961,
1:62,500

Figure 12. Map showing the study area in the Hayden Creek Basin and photograph showing the basin landscape.

The Hayden Creek HBN Basin is in Kootenai County in Idaho and is entirely within the boundaries of the Coeur d'Alene National Forest. The basin is accessible by a network of unpaved roads that parallel most of the main drainages. Roads are not plowed or salted in winter, but they are treated with magnesium chloride during summer to control dust (Jeffery Johnson, U.S. Department of Agriculture Forest Service, oral commun., 1998). The lower part of the basin is in a management category designated for timber production and recreation (U.S. Department of Agriculture, 1987b). Timber production and recreation must be conducted so that they maintain or enhance big game habitat. In the upper part of the basin, timber harvesting and production are the primary management priorities. During the past 10 years, timber harvesting has averaged about 0.5 to 1 million board feet per year. Much of the timber harvesting involves removal of dead or damaged trees. A small grazing allotment of 18 cows and calves is allowed in the basin, but no sheep allotment exists for the basin. Two small mining prospects exist in the northern part of the basin, but there has been no recent mining activity (Jeffery Johnson, oral commun., 1998). Tailings piles at the two prospects are small, although one extends into a stream channel. Surface-water drainage from the prospect pits is insignificant, except perhaps during snowmelt. Recreational use in the basin includes dispersed (unimproved) campsites. In the early 1990's, the Forest Service instituted a policy of a 14-day limit on camping at a given site. This discouraged squatters who had been using areas in the basin as homesteads.

Historical Water-Quality Data and Time-Series Trends

The data set for the Hayden Creek HBN station analyzed for this report includes 164 water-quality samples that were collected from November 1966 through September 1995. Sampling frequency ranged from 6 to 11 times per year from 1967 to 1982, then was decreased to quarterly from 1983 to 1995. Samples from the early part of the period of record were analyzed at a USGS district laboratory in Portland, Oreg. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and at the NWQL in Arvada, Colo., from 1976 through 1995. Daily discharge records for Hayden Creek (station 12416000) are available from April 1948 to December 1953, October 1958 to September 1959, September 1961 to September 1965, and October 1965 to May 1997. A precipitation gage also was operated at the HBN station from November 1989 to March 1996.

Calculated ion balances for 150 samples that have complete major-ion analyses are shown in figure 13. Ion balances ranged from –33 to +31 percent, and 85 percent of the samples had values within the ±10-percent range, indicating that the analytical results are of good quality. The average ion balance was –0.5 percent, indicating that unmeasured constituents, such as organic anions, generally do not contribute significantly to the ionic composition of stream water at this HBN station. Time-series plots of the major dissolved constituents were inspected for evidence of method-related effects (fig. 13). The most notable patterns are a downward shift in field pH in 1970 and a decline in sulfate concentrations near the end of the period of record. The abrupt nature of the shift in pH values indicates that the measurements may have been biased by changes in field procedures or instrumentation (Schertz and others, 1994). Although natural variations in sulfate concentrations cannot be completely ruled out, the low sulfate concentrations in the 1990's were probably caused by a change in the analytical technique for sulfate from a turbidimetric technique to ion chromatography in 1990 (Fishman and others, 1994). A period of elevated and uniform sulfate concentrations in 1982 and 1983 that is shown in figure 13 was caused by an increase in the analytical reporting limit for sulfate to 5 mg/L (104 µeq/L) during those 2 years. The stepped pattern in concentrations of nitrite plus nitrate and chloride at this station also was caused by changes in the analytical reporting limits for these constituents.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Headwaters NADP station are presented in table 22. Precipitation chemistry at the NADP station, which is about 150 km southeast of the HBN station, is dilute and slightly acidic and has a VWM pH of 5.4 for 10 years of record. The predominant cations in precipitation were hydrogen, calcium, and ammonium, which contributed 26, 24, and 23 percent of the total cation charge, respectively. The predominant anions were sulfate and nitrate, which accounted for 43 and 38 percent of the total anion charge, respectively. The predominance of strong acid anions may indicate that precipitation at the NADP station is affected by industrial emissions of sulfur and nitrogen compounds that cause acid rain.

Stream water in Hayden Creek is moderately concentrated and well buffered; specific conductance ranged from 35 to 90 μS/cm and alkalinity ranged from 240 to 1,160 μeq/L (table 22). The major cations in stream water were calcium and magnesium, and the major anion was bicarbonate. The predominance of these solutes in stream water is attributed to the weathering of limestone and dolomite units in the underlying metasedimentary bedrock. The median chloride concentration of stream water was 14 μeq/L compared to the VWM concentrations of 2.4 μeq/L in precipitation. Based on the difference between runoff and precipitation, evapotranspiration can account for about a twofold increase in the concentration of precipitation, indicating that some stream-water chloride is derived from sources other than atmospheric deposition. The most likely sources of additional chloride include weathering of sedimentary rocks or, perhaps, washoff of magnesium chloride from roads, which is applied to control dust. The median sulfate concentration of 58 μeq/L was substantially greater than the VWM concentrations of 5.8 μeq/L in precipitation, indicating that most sulfate is derived from sources other than wet deposition. Possible sources include weathering of sulfate minerals in the sedimentary bedrock or dry deposition from the atmosphere derived from two ore-smelting facilities located within 50 km of the basin (Mark Hardy, U.S. Geological Survey, written commun., 1999). The concentrations of inorganic nitrogen species in stream water generally were less than the VWM concentrations in precipitation, indicating that most atmospheric nitrogen is retained by vegetation and soils and that livestock grazing and logging in the basin have not substantially affected the nutrient concentrations at this HBN station.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 23). Most weathering-derived solutes had strong inverse correlations with stream discharge, particularly calcium (rho = –0.851), magnesium (rho = –0.893) and alkalinity (rho = –0.841). These results are consistent with a hydrologic system where weathering-enriched base flow is diluted by water from shallow or surficial sources during periods of increased discharge, particularly spring snowmelt. For the solutes, the strongest correlations were found among calcium, magnesium, and alkalinity, which is consistent with the weathering of carbonate minerals. Chloride was weakly correlated with the weathering-derived constituents, which is consistent with the idea that chloride is derived from sources other than weathering. The poor correlations between sulfate and the weathering-derived solutes was unexpected because most sulfate is probably derived from the bedrock.

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 24. An increase in field pH was the only statistically significant trend detected at the 0.01 probability level. The trend in pH was similar for the unadjusted and flow-adjusted values, indicating that the trend was not related to variations in stream discharge. The LOWESS curve in figure 13 shows that field pH dropped abruptly in 1970 then increased gradually until leveling off in the late 1980's. The trend in stream-water pH at this HBN station probably was not related to a change in atmospheric deposition, considering the dilute chemistry of precipitation at the NADP station compared to the chemistry of the stream (table 22). Other environmental factors that may have caused changes in stream-water chemistry include changes in logging and grazing activities. However, a change in land use probably would not have affected stream-water pH without affecting the concentrations of other solutes as well. A method-related factor is perhaps the most reasonable cause of the trend in stream-water pH, particularly considering the rather abrupt decrease in pH values in 1970. This pattern may have been caused by a change in electrodes or

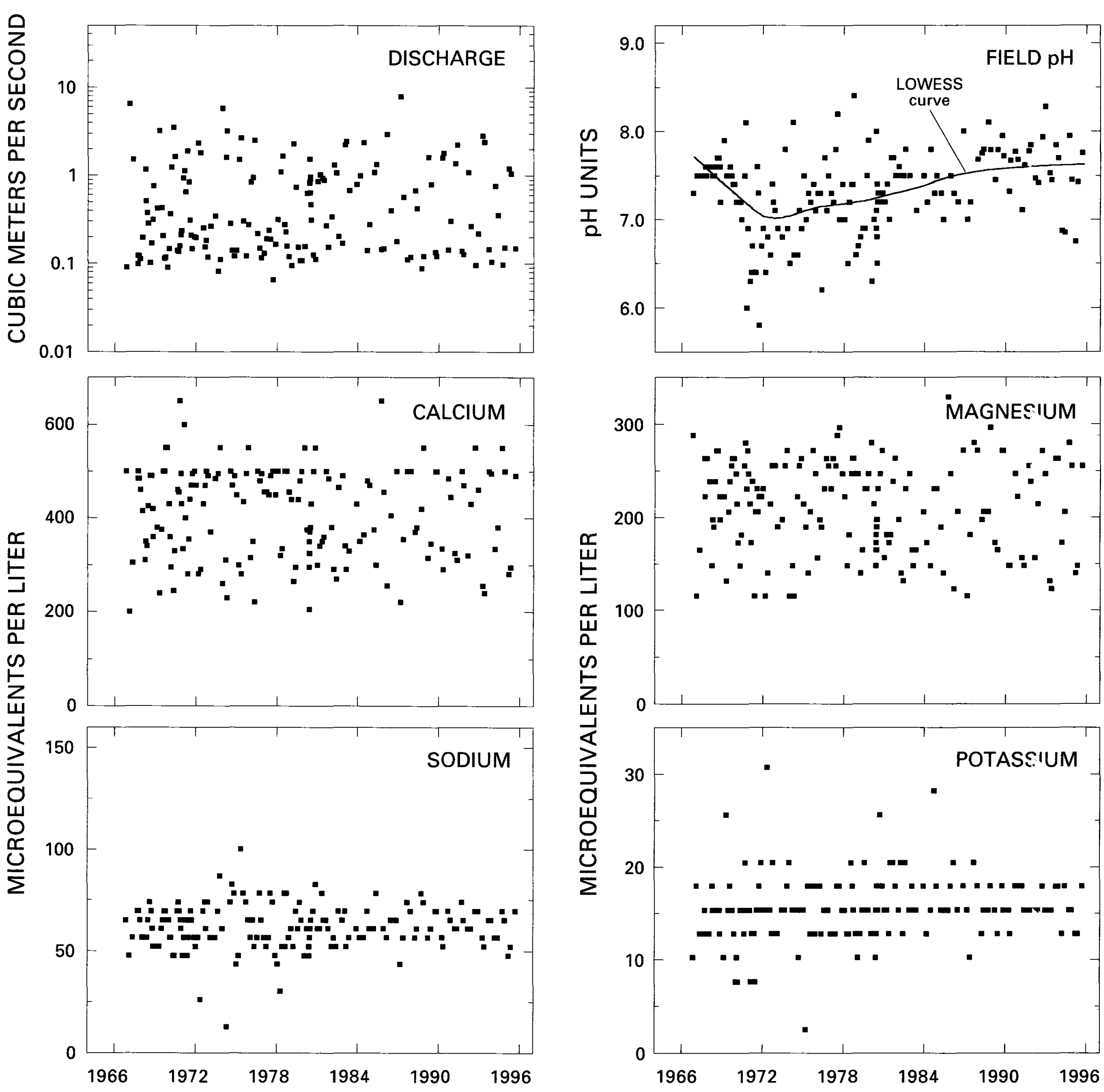


Figure 13. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Hayden Creek, Idaho.

meters used by field personnel. Some instrument-electrode systems are known to produce erroneous readings, particularly when measuring pH in low-conductivity water (Office of Water Quality Technical Memorandum No. 81.08, *Electrodes for pH measurement in low-conductivity waters*, issued February 10, 1981, at URL http://water.usgs.gov/admin/memo).

Synoptic Water-Quality Data

Results of the surface-water synoptic sampling of August 4 and 5, 1992, are presented in table 25, and locations of sampling sites are shown in figure 12. During the synoptic sampling, discharge at the HBN station was 0.10 m^3/s compared to the median daily

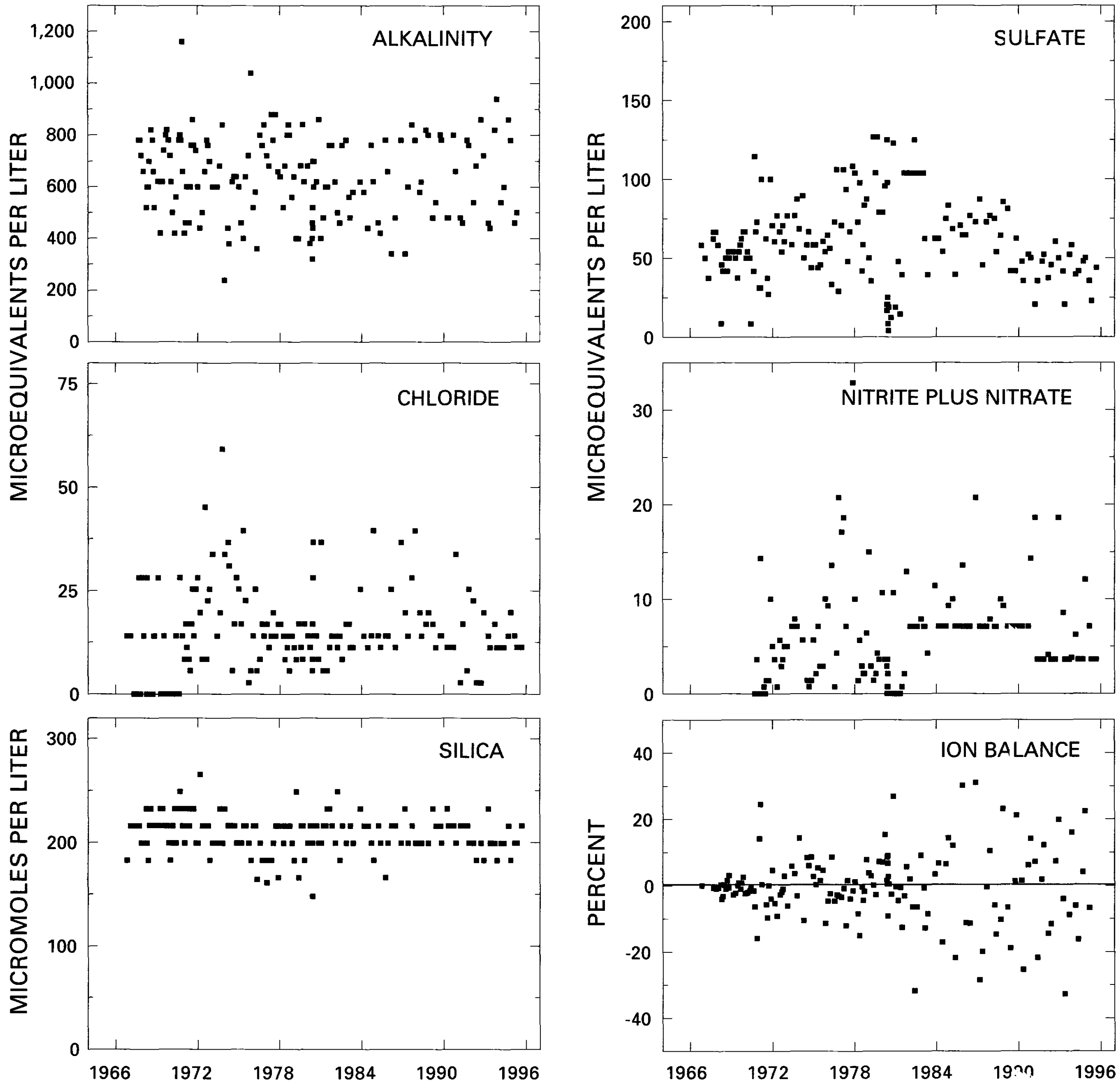


Figure 13. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Hayden Creek, Idaho—Continued.

discharge of 0.25 for July and 0.15 m^3/s for August (Lawrence, 1987), indicating that the basin was sampled under slightly lower than normal flow conditions for that time of year. Most of the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were close to the third-quartile values reported for the station during the entire period of record, except for sulfate and chloride concentrations, which were close to the first-quartile values (table 22). Stream water collected at the tributary streams was similar in composition to stream water at site 1, with calcium the major cation and bicarbonate the major anion. Ion balances for all the synoptic samples were negative (ranging from

Table 22. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Hayden Creek, Idaho, November 1966 through September 1995, and volume-weighted mean concentrations in wet precipitation collected at the Headquarters Station, Idaho

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation VWM[a]
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Discharge, inst.	0.065	0.15	0.29	1.00	7.9	164	--
Spec. cond., field	35	53	68	78	90	161	3.7
pH, field	5.8	7.0	7.4	7.6	8.4	159	5.4[b]
Calcium	200	330	430	500	650	164	3.6
Magnesium	120	170	220	260	330	164	1.1
Sodium	13	57	61	70	100	162	2.6
Potassium	2.6	13	15	18	74	163	.5
Ammonium	<.7	.7	1.4	4.3	18	70	3.5
Alkalinity, laboratory	240	500	620	780	1,160	159	--
Sulfate	4.2	42	58	75	130	160	5.8
Chloride	<2.8	8.5	14	19	59	162	2.4
Nitrite plus nitrate	<.7	2.1	5.4	7.1	33	128	5.1[c]
Silica	20	200	220	220	420	161	--

[a] Values are volume-weighted mean concentrations for 1982–91.

[b] Laboratory pH.

[c] Nitrate only.

Table 23. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Hayden Creek, Idaho, 1967 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl
pH	−0.283								
Ca	−.851	0.231							
Mg	−.893	.300	0.883						
Na	−.619	.288	.590	0.595					
K	−.099	.235	.210	.140	0.282				
Alk	−.841	.392	.852	.865	.600	0.236			
SO_4	−.270	.039	.267	.288	.092	.150	0.220		
Cl	−.053	−.006	.065	.020	.042	.158	−.034	0.217	
Si	.249	.021	−.142	−.238	.060	.201	−.100	−.111	−0.113

–2.7 to –7.5 percent), perhaps indicating a bias in the analytical measurements. Concentrations of the weathering-derived solutes in the synoptic samples varied somewhat in the basin. For example, calcium ranged from 95 to 1,400 μeq/L, magnesium ranged from 30 to 340 μeq/L, and alkalinity ranged from 240 to 1,760 μeq/L (table 25). Variations in base-cation and alkalinity concentrations do not seem to be related to differences in elevation or subbasin size. For example, the lowest concentrations were measured at site 6, which is similar in size and elevation to site 8, which had the highest concentrations. Differences in solute concentrations may reflect the distribution of different rock types in the basin; however, a detailed geologic map is not available to confirm such a relation. Sulfate concentrations ranged from 18 to 54 μeq/L and followed a pattern similar to the other weathering-derived solutes, indicating that sulfate concentrations also may reflect local variations in geology. Chloride concentrations varied somewhat, ranging from <0.3 μeq/L at site 2 to 42 μeq/L at site 4. The two highest chloride concentrations were measured in streams (sites 3 and 4) draining areas that had recent logging activity. The slightly higher chloride concentrations may be due to application of magnesium chloride to roads in this subbasin to control dust from logging traffic. Nitrite plus nitrate concentrations were low at all sampling sites, indicating that land use in the basin did not have a substantial effect on nitrate concentrations in the streams during the sampling period.

Table 24. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Hayden Creek, Idaho, November 1966 through September 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	–0.001	0.707	--	--
pH, field	.02	.000	0.02	0.000
Calcium	<.1	.640	.2	.658
Magnesium	<.1	.874	.1	.643
Sodium	<.1	.111	.1	.096
Potassium	<.1	.023	([a])	--
Alkalinity, laboratory	<.1	.468	.7	.265
Sulfate	–.3	.073	–.4	.038
Chloride	<.1	.356	([a])	--
Nitrite plus nitrate	([b])	--	--	--
Silica	<.1	.104	([a])	--

[a] Flow model not significant at $\alpha = 0.10$.

[b] Insufficient data to calculate trend.

Table 25. Physical properties and major dissolved constituents from surface-water sampling sites in the Hayden Creek Basin, Idaho, collected August 4–5, 1992

[Site locations shown in fig. 12; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate; Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]	Remarks
1	12416000	0.10	86	7.9	500	250	74	17	860	48	7.9	1.1	220		
2	474924116360600	.010	110	8.1	650	340	78	17	1,100	46	<.3	3.1	220	MT, LU	Few roads
3	474930116384600	.067	86	7.8	500	240	70	16	900	33	25	1.6	220	MT, LU	Recent logging
4	474933116361200	.033	73	7.8	420	200	65	11	720	23	42	2.2	200	MT, LU	Recent logging
5	474942116385700	.036	82	7.8	500	250	74	19	900	48	15	1.2	220	MT, LU	Downstream from Bradbury Mine
6	475150116335500	.014	21	7.3	95	30	48	7.9	240	18	11	5.7	170	HT, LU	Few roads
7	475153116380900	--	98	7.8	700	150	78	31	960	50	9.0	10	270	HT, LU	Few roads
8	475204116365000	.00028	180	8.0	1,400	240	74	44	1,760	54	11	1.5	250	HT, LU	Few roads

[a] Criteria used in selection of sampling sites: HT = headwater tributary, MT = major tributary, LU = land use.

South Twin River near Round Mountain, Nevada (Station 10249300)

Site Characteristics and Land Use

The South Twin River HBN Basin is in the Basin and Range physiographic province in the central part of Nevada (fig. 14). The topography of the area is characterized by north- to northeast-trending mountain ranges separated by long alluviated valleys. The South Twin River Basin is on the eastern side of the Toiyabe Range, which is cut by deeply incised drainages having spectacular cliffs and perennial streams (Brem and others, 1991). The basin drains 52 km^2 of rugged mountainous terrain and ranges in elevation from 1,951 m at the base of the Toiyabe Range to 3,588 m at the summit of Arc Dome. The HBN station is 24 km northwest of Round Mountain, Nev., at latitude 38°53'15" and longitude 117°14'40". The South Twin River is northeast flowing and has a channel length of 9.8 km upstream from the HBN station and an average stream gradient of 66 m/km. Downstream from the station, the river enters the Big Smoky Valley to the east where all but the highest flows are diverted into a concrete irrigation ditch. The channel upstream from the station is perennial, and mean monthly discharge varies from 0.064 m^3/s in September to 0.70 m^3/s in May during snowmelt. Average annual runoff from the basin was 11.4 cm during 1965 through 1995 (Bauer and others, 1996). Climate varies considerably with elevation but, in general, winters are long and summers are dry (Bailey and others, 1994). Average monthly air temperatures range from −1.4°C to 22.2°C at elevations below 2,750 m and from −9.4° to 12.8°C at elevations above 2,750 m (Western Regional Climate Center, at URL http://www.wrcc.sage.dri.edu, accessed 1998). Average annual precipitation ranges from 20 cm in the valleys to as much as 75 cm at high elevations in the basin. More than 90 percent of precipitation falls as snow between October and May, accumulating in a seasonal snowpack that usually reaches 50 cm in depth. Intense thunderstorms are common in summer, especially in August, and can cause flash flooding.

The basin is in the Nevada Mountains Semi-desert ecoregion (Bailey and others, 1994). Slopes in the lower part of the basin are covered by a dense juniper-pinyon forest and have an understory of sagebrush that grades upward into mountain big sagebrush and curlleaf mountain mahogany communities above 2,650 m (U.S. Department of Agriculture, 1986b). Small stands of whitebark pine grow near the crest of the range on north-facing canyon walls. Vegetation along streams and around springs is dominated by cottonwood, quaking aspen, water birch, and willow. The mountain big sagebrush and the riparian communities have been degraded by past livestock grazing. The basin also contains large areas of rock outcrops that contain virtually no vegetation (U.S. Department of Agriculture, 1986b). Soils in the basin are classified as Cryoborolls and are in the Foxvire-Packer-Scuffe soil association (John Fisher, Natural Resources Conservation Service, written commun., 1998). This association consists of deep, well-drained loamy soils that formed in residuum and colluvium derived from volcanic rocks. A typical profile has a surface layer of brown gravelly loam that is 50 cm thick overlying a sublayer of light brown, stony to gravelly loam that extends to a depth of 150 cm. Soils in this association have pH values ranging from 6.4 to 7.2 and consist of 45 to 80 percent rock fragments.

Most of the basin is underlain by rocks of the Darrough Felsite of Cretaceous age and several tuff units of Tertiary age (Brem and others, 1991) These units are similar in composition and consist of silicified and variably metamorphosed silicic ash-flow tuffs and volcaniclastic sedimentary rocks. The tuffs are rhyolitic in composition and contain phenocrysts of quartz, orthoclase, oligoclase, albite, and chlorite in a fine-grained, porcelain-like matrix. A small area near the HBN station is underlain by older sedimentary rocks, which contain argillite, siltstone, quartzite, limestone, and dolostone. The northern part of the basin is in the Twin River historic mining district, which has a resource potential for gold, silver, and base metals (Brem and others, 1991). Metallic mineral deposits in the basin are associated with polymetallic veins in the felsite and tuff. These veins range in width from a few centimeters to 3 m and generally consist of a matrix of quartz and carbonate minerals that include narrower ore zones of pyrite, gold, sphalerite, and galena. One mine site, referred to as the K claims, is located in the basin near the mouth of the South Fork

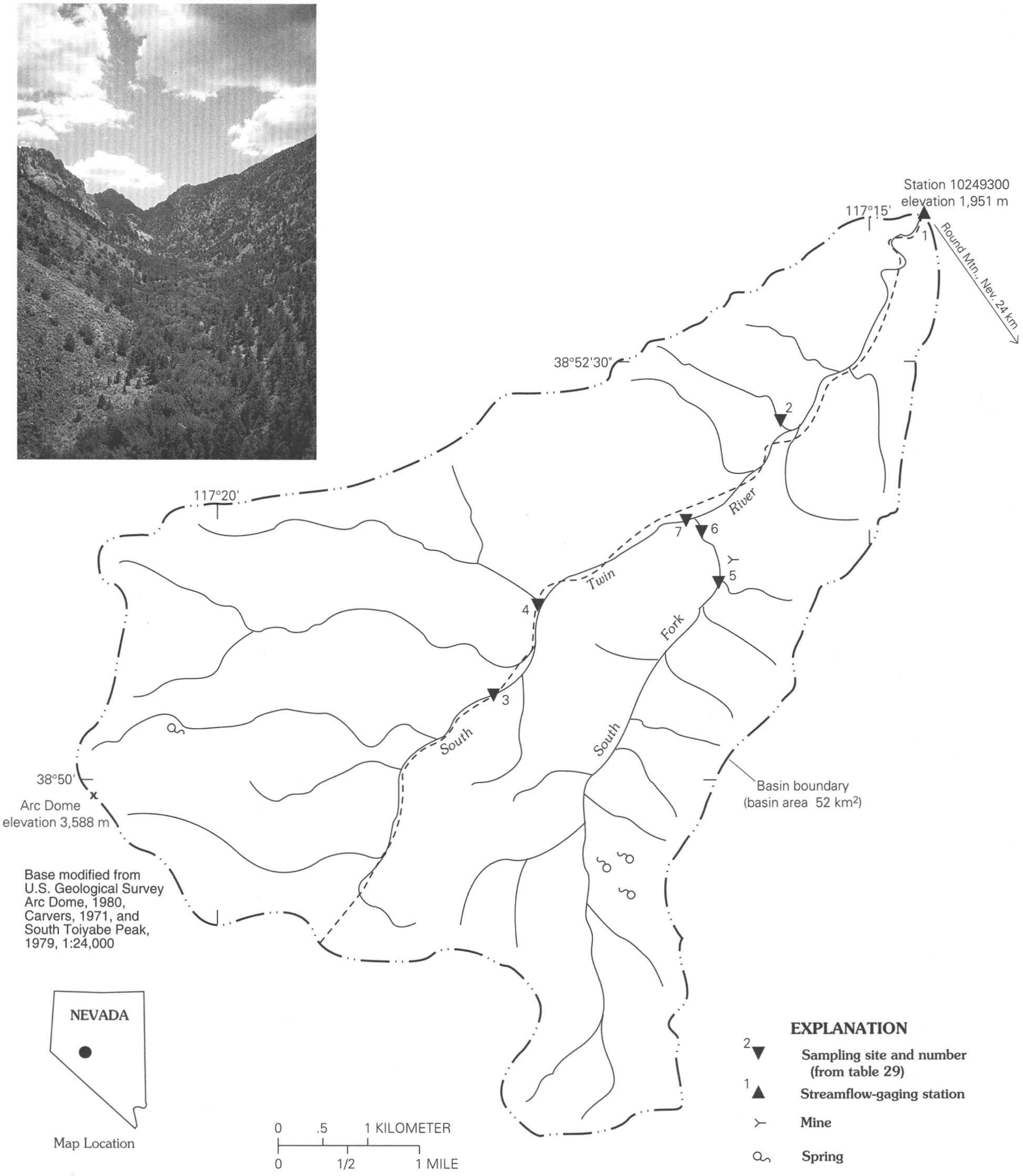


Figure 14. Map showing the study area in the South Twin River Basin and photograph showing the basin landscape.

of South Twin River. The mine site is in an area of high mineral potential, based on the study of Brem and others (1991), although it never produced more than small amounts of ore.

The South Twin River drains the northwest part of Nye County and is in the Tonopah Ranger District of the Toiyabe National Forest. Most of the basin also is in the boundaries of the Arc Dome Wilderness, which was classified as a proposed Wilderness Area in 1979 and received Federal designation on December 12, 1989 (U.S. Department of Agriculture, 1990a). The wilderness is closed to all motorized vehicles and access in the basin is limited to a few foot trails that start from a gated road at the HBN station. Human activities in the basin are limited to dispersed recreational use, including hiking, horseback riding, and hunting. There are no developed recreational sites in the basin, although the trail paralleling the main stream channel is part of the Toiyabe Crest National Recreation Trail system that was constructed by the Civilian Conservation Corps in the 1930's. Until 1991, cattle grazing was allowed in the basin from June through October, which caused considerable damage to riparian areas, particularly along the upper reaches of South Twin River (Tonopah Ranger District, Toiyabe National Forest, oral commun., 1998). Although permitted grazing is no longer allowed, about 30 head of wild cattle occasionally graze in the headwater areas of the basin (Tonopah Ranger District, Toiyabe National Forest, oral commun., 1998). The abandoned mine site (K claims) near the mouth of the South Fork South Twin River contains three underground workings and their associated waste-rock piles. Water produced in the adit does not exit the mine as surface flow and probably is not a substantial source of metals and acidity to stream water because much of the mineralized rock in the mine contains carbonate-filled voids and veinlets (U.S. Department of Agriculture, 1990a). A plan of operation to resume mining at the K claims and to restore an access road was submitted to the Forest Service in 1988 (U.S. Department of Agriculture, 1990a); however, the mine did not prove to be viable and the request was never approved (Tonopah Ranger District, Toiyabe National Forest, oral commun., 1998). A record high runoff in 1983 caused minor damage at the mine site and the access road and scoured much of the main channel of the South Twin River (U.S. Department of Agriculture, 1990a).

Historical Water-Quality Data and Time-Series Trends

The data set for the South Twin River HBN station analyzed for this report includes 192 water-quality samples that were collected from October 1967 through August 1995. Sampling frequency ranged from 7 to 12 times per year from 1968 through 1982 (except 1976 and 1977, which were quarterly) and was quarterly from 1983 to 1995. Samples from the early part of the period of record probably were analyzed at a USGS district laboratory in Sacramento, Calif. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and at the NWQL in Arvada, Colo., from 1976 to 1994. Daily discharge records for South Twin River (station 10249300) are available beginning in August 1965, and daily water temperature was measured at the station from April 1966 through September 1982.

Calculated ion balances for 176 samples that have complete major-ion analyses are shown in figure 15. Ion balances ranged from −12 to +10 percent, and 95 percent of the samples had values within the ±5-percent range, indicating that the analytical results are of high quality. The average ion balance was –0.4 percent, indicating that unmeasured constituents, such as organic anions, are not an important component of stream water at this station. Time-series plots of the major dissolved constituents were inspected for evidence of method-related effects (fig. 15). Field pH values decreased somewhat abruptly at the beginning of 1973, which may have been caused by a change in measurement method or instrumentation used by field personnel. A similar shift in field pH also was observed at Steptoe Creek, another HBN station in Nevada, providing additional evidence that the pattern is probably an analytical artifact. The stepped pattern in the concentrations of nitrite plus nitrate was caused by changes in the analytical reporting limit for this constituent that occurred in 1982 and again in 1991.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Smith Valley NADP station are presented in table 26. Precipitation chemistry at the NADP station, which is about 180 km southwest of the HBN station, is very dilute and slightly acidic and has VWM pH of 5.6 for 11 years of record. The predominant cations in precipitation were calcium and ammonium, which contributed 20 and 50 percent of the total cation charge, respectively. The predominant anions were sulfate and nitrate, which accounted for 37 and 50 percent of the total anion charge, respectively. Stream water in the South Twin River is moderately concentrated and well buffered; specific conductance ranged from 72 to 160 µS/cm, and alkalinity ranged from 580 to 1,500 µeq/L (table 26). The major cation in stream water was calcium, and the major anion was bicarbonate. The high calcium to sodium ratio in stream water and the high concentrations of alkalinity indicate that most of the solute load in the stream is probably derived from weathering of carbonate minerals associated with mineralization rather than from dissolution of sodium-rich feldspars in the unaltered volcanic rocks. The median chloride concentration in stream water was 51 µeq/L and was substantially greater than the VWM concentration of 2.8 µeq/L in precipitation, indicating that most chloride is derived from sources other than precipitation. Because land use in the basin is minimal and the bedrock probably does not contain appreciable amounts of chloride, the most likely source of additional stream-water chloride may be wind-blown material derived from arid valleys to the west and east of the Toiyabe Range. The median concentration of sulfate in stream water (120 µeq/L) also was substantially greater than the VWM concentration of 8.2 µeq/L in precipitation. Although some stream-water sulfate may be derived from wind-blown dust, most is probably contributed by oxidation of pyrite in mineralized bedrock. Concentrations of inorganic nitrogen species in stream water were less than the average concentration in precipitation, indicating that most atmospheric nitrogen is retained by vegetation and soils in the basin. Low stream-water concentrations of nitrogen species also indicate that cattle grazing in the basin has not substantially affected nutrient concentrations at the HBN station.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 27). Most weathering-derived constituents were negatively correlated with stream discharge, which is consistent with a hydrologic system where weathering-enriched base flow is diluted by water from shallow or surficial sources during periods of increased discharge, particularly spring snowmelt. For the solutes, the strongest correlations were found among calcium, magnesium, and alkalinity ($0.773 \leq \text{rho} \leq 0.874$), which is consistent with the weathering stoichiometry of carbonate minerals. The poor correlation between sodium and silica (rho = 0.043) was unexpected because feldspar minerals in the volcanic rocks should be the major source of sodium and silica. Sulfate was positively correlated with calcium (rho = 0.625) and magnesium (rho = 0.633), perhaps reflecting the presence of pyrite and carbonate minerals in mineralized veins.

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 28. A statistically significant trend was detected only in potassium concentrations at the 0.01 probability level. The magnitude and probability of the trend were similar for the unadjusted and flow-adjusted concentrations, indicating that the potassium trend was not caused by variations in stream discharge. The absence of trends in the major solutes was not unexpected because the basin is in a wilderness area and has had little land use, except grazing. The cause of the downward trend in potassium concentrations could not be identified. The LOWESS curve in figure 15 shows that potassium concentrations were fairly constant during the early part of the period of record and then declined gradually after 1984. The decrease in potassium probably was not an analytical artifact because the samples were analyzed at the NWQL since 1976 using a single technique. Environmental factors that may have affected stream-water potassium concentrations included livestock grazing and atmospheric deposition. The effect of cattle grazing on stream-water potassium concentrations is not known; however, grazing pressure in riparian areas has been substantially decreased since the establishment of the wilderness in 1979. Lynch and others (1995) reported declines in base-cation concentrations, including potassium, at several NADP stations in the southwestern part of the United States between 1980

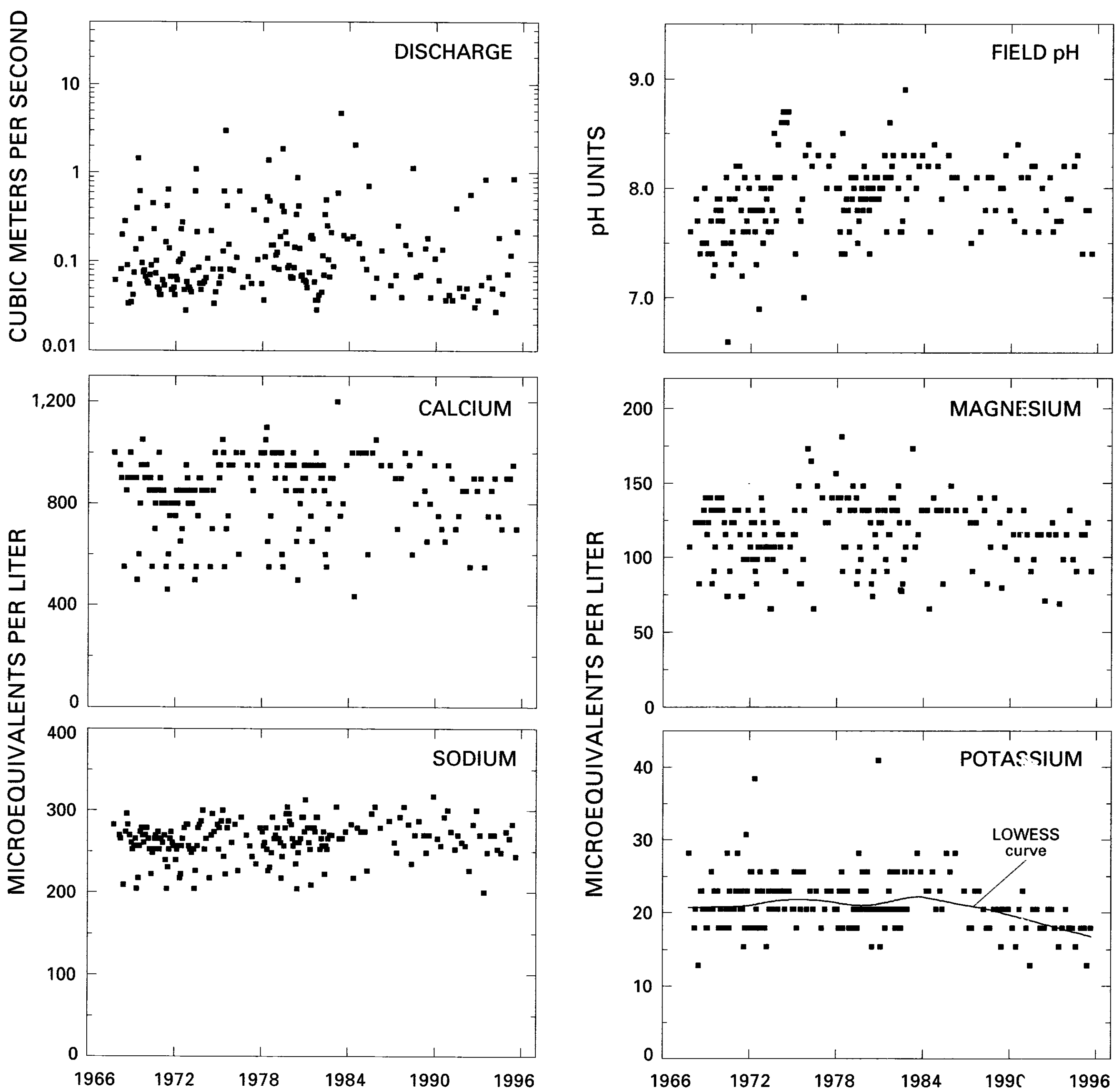


Figure 15. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in the South Twin River, Nevada.

and 1992. Although the trend in precipitation chemistry is consistent with the decline in stream-water potassium, confirmation of the linkage between precipitation and stream chemistry is difficult because no precipitation stations are located in or near the South Twin River Basin.

Synoptic Water-Quality Data

Results of the surface-water synoptic sampling of July 23–24, 1991, are presented in table 29, and locations of sampling sites are shown in figure 14. During the synoptic sampling, discharge at the HBN station was 0.082 m^3/s compared to the median daily

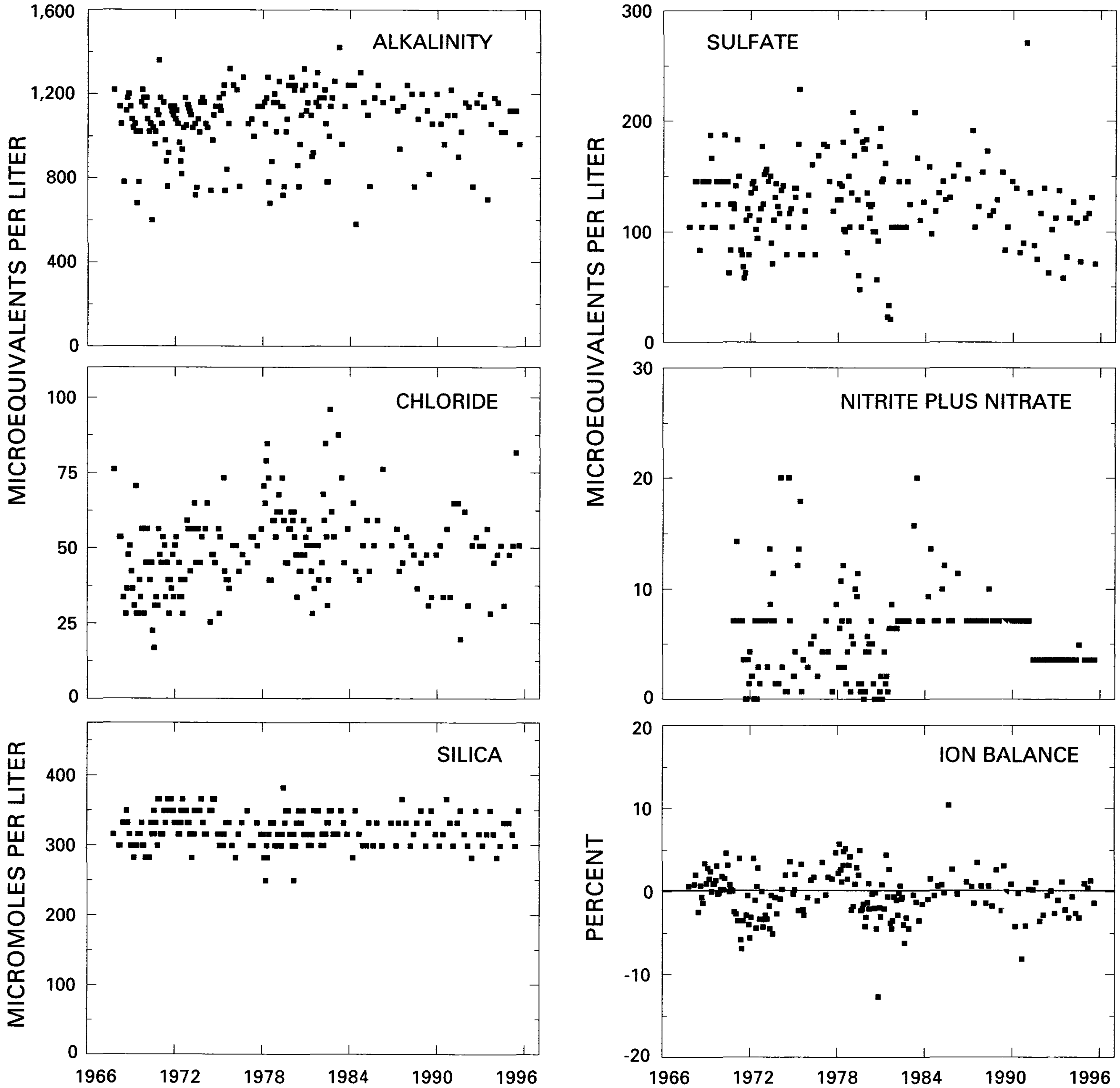


Figure 15. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in the South Twin River, Nevada—Continued.

discharge of 0.12 m^3/s for July and 0.07 m^3/s for August (Lawrence, 1987), indicating that the basin was sampled under normal flow conditions for that time of year. Most of the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were less than the first-quartile values reported for the station during the entire period of record, except for sodium and silica concentrations, which were higher (table 26). Water in the tributary streams were similar in composition to stream water at site 1, with calcium and bicarbonate the predominant solutes. Ion balances for the synoptic samples

Table 26. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from South Twin River, Nevada, October 1967 through August 1995, and volume-weighted mean concentrations in wet precipitation collected at the Smith Valley Station, Nevada

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation VWM[a]
	Minimum	First quartile	Median	Second quartile	Maximum	n	
Discharge, inst.	0.027	0.057	0.084	0.19	4.7	192	--
Spec. cond., field	72	110	130	130	160	190	5.3
pH, field	6.6	7.7	7.9	8.1	8.9	179	5.6[b]
Calcium	440	750	850	950	1,200	192	5.6
Magnesium	66	99	120	130	180	189	1.3
Sodium	200	250	270	280	320	191	3.7
Potassium	13	18	20	23	41	189	.7
Ammonium	<.7	<.7	1.4	4.3	9.3	114	14
Alkalinity, laboratory	580	1,020	1,120	1,180	1,500	190	--
Sulfate	20.8	100	120	150	270	190	8.2
Chloride	17	39	51	56	96	185	2.8
Nitrite plus nitrate	<.7	2.9	6.4	7.1	20	161	11[c]
Silica	250	300	320	350	380	192	--

[a] Values are VWM concentrations for 1985–95.

[b] Laboratory pH.

[c] Nitrate only.

Table 27. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, South Twin River, Nevada, 1968 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; N, nitrite plus nitrate; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl
pH	–0.152								
Ca	–.348	0.168							
Mg	–.354	.176	0.874						
Na	–.515	.224	.695	0.645					
K	–.027	.163	.307	.287	0.311				
Alk	–.492	.273	.820	.773	.768	0.327			
SO_4	–.182	.040	.625	.633	.479	.143	0.488		
Cl	.062	.166	.471	.415	.326	.126	.372	0.408	
Si	–.213	.117	–.297	–.288	.043	.130	–.085	–.370	–0.276

averaged 0.1 percent (ranging from −2.7 to 4.9 percent), indicating that unmeasured ions, such as organic anions, probably were not an important component of stream water during the synoptic sampling. Concentrations of the weathering-derived solutes did not vary markedly among the sampling sites, probably because of the small basin size and the relatively uniform composition of the bedrock. For example, calcium ranged from 360 to 900 μeq/L, and alkalinity ranged from 620 to 1,180 μeq/L (table 29). Silica was remarkably constant, varying only from 330 to 350 μmol/L. Sulfate concentrations also were fairly uniform and relatively low (average about 70 μeq/L), particularly considering the presence of several mineralized zones in the basin. Site 4, which drains a weakly mineralized area on a southeast-facing slope, had the highest sulfate concentration. The high chloride concentration and southerly aspect of this site, however, may indicate that the high sulfate concentration is due to evapotranspiration rather than weathering of sulfides. The abandoned mine site did not seem to affect stream chemistry during the synoptic sampling, as evidenced by the similar stream chemistry upstream (site 5) and downstream from the mine (site 6). However, because the waste-rock piles at the mine site are located near the stream, they may have a disproportionate effect on stream-water chemistry during spring snowmelt or summer thundershowers when direct runoff is more likely to enter the stream. Nitrate concentrations were extremely low at all sampling sites (<3.6 μeq/L), which is consistent with the minimal amount of land use in the basin.

Table 28. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, South Twin River, Nevada, October 1967 through August 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	<0.001	0.999	--	--
pH, field	<.01	.491	<0.01	0.430
Calcium	<.1	.400	−1.0	.527
Magnesium	<.1	.044	−.4	.050
Sodium	.3	.166	.3	.168
Potassium	−.1	.000	−.1	.000
Alkalinity, laboratory	<.1	.503	.5	.652
Sulfate	−.7	.029	−.6	.031
Chloride	<.1	.964	<.1	.955
Nitrite plus nitrate	.1[a]	.200	--	--
Silica	<.1	.284	−.3	.128

[a] Trend calculated for 1971–95 using a trend test for censored data.

Table 29. Physical properties and major dissolved constituents from surface-water sampling sites in the South Twin River Basin, Nevada, collected July 23–24, 1991

[Site locations shown in fig. 14; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate; Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]	Remarks
1	10249300	0.082	100	8.0	700	88	270	21	930	77	39	<3.6	350	--	
2	384500117145900	--	110	7.4	700	96	260	20	1,040	69	23	<3.6	350	BG	Felsite bedrock
3	384901117175500	.016	65	8.0	360	47	240	17	620	46	21	1.4	350	BG	Tuffaceous bedrock
4	384926117173100	.006	120	8.0	800	88	320	25	1,120	110	56	<3.6	330	BG	Tuff and felsite, weakly mineralized
5	384931117161000	.014	120	8.0	850	110	280	21	1,180	60	17	<3.6	330	LU	Upstream from mine site
6	384946117161800	.012	130	8.0	900	110	300	22	1,180	73	28	<3.6	330	LU, MT	Downstream from mine site and mineralized area
7	384947117162000	.053	79	7.9	490	55	250	19	650	63	28	.7	350	LU, MT	Downstream from pasture area

[a] Criteria used in selection of sampling sites: BG = bedrock geology, MT = major tributary, LU = land use.

Steptoe Creek near Ely, Nevada (Station 10244950)

Site Characteristics and Land Use

The Steptoe Creek HBN Basin is located in the Basin and Range physiographic province in east-central Nevada (fig. 16). The topography of the area is characterized by north- to northeast-trending mountain ranges separated by long alluviated valleys. The Steptoe Creek Basin is on the west side of the Schell Creek Range and drains an area of 29 km^2 that ranges in elevation from 2,268 to 3,335 m. The HBN station is located 18 km southeast of the town of Ely, Nev., at latitude 39°12'05" and longitude 114°41'15". Steptoe Creek flows south into the Duck River, a tributary of the Humboldt River, and has a channel length of 9.5 km upstream from the HBN station and an average stream gradient of 70 m/km. Mean monthly discharge ranges from 0.10 m^3/s in February to 0.45 m^3/s in June during snowmelt. Between August and April, streamflow is nearly constant because of discharge from numerous springs in the basin. Average annual runoff from the basin was 22 cm from 1966 through 1995 (Bauer and others, 1996). Climate varies considerably with elevation, but in general, winters are long and summers are dry (Bailey and others, 1994). Average monthly air temperatures range from –4.3°C in January to 19.6°C in July (Western Regional Climate Center, at URL http://www.wrcc.sage.dri.edu). Average annual precipitation ranges from 24 cm in the Steptoe Valley east of the basin to as much as 89 cm at the highest elevations in the Schell Creek Range. Most precipitation in the basin falls as snow between October and May.

The basin is in the Nevada Mountains Semidesert ecoregion (Bailey and others, 1994), and vegetation is dominated by pinyon-juniper woodlands, mountain scrub communities, and aspen forests (U.S. Department of the Interior, 1992). The pinyon-juniper woodlands are most prevalent on warm, dry sites between 2,070 and 3,050 m and consist of single-needle pinyon pine and Utah juniper that grow in scattered clumps; the ground cover consists of small shrubs, herbs, and grasses. Mountain scrub communities grow between 2,042 and 3,140 m and consist of tall shrubs that often intermix with forest stands. The predominant species in the mountain scrub communities are Wyoming big sagebrush, mountain big sagebrush, and curlleaf mountain mahogany; the understory consists of black sagebrush, serviceberry, snowberry, and bitterbrush. Aspen generally grows in riparian areas where it intergrades with Douglas-fir and Engelmann spruce at higher elevations and white fir and lodgepole pine at lower elevations. Soils in the basin are classified as Xerolls and are formed in residuum and colluvium derived from sedimentary rocks (Timothy Stack, U.S. Department of Agriculture, Natural Resources Conservation Service, written commun., 1998). Along the flood plain of Steptoe Creek, soils are fairly deep, poorly drained, and have silty to gravelly textures. The mountain slopes are covered by shallow, well-drained soils that are interspersed with outcrops of limestone and shale. These soils are alkaline, have low water-holding capacities, and range in texture from very stony over limestone bedrock to gravelly over shale bedrock.

The geology of the basin is complex and consists of highly faulted and folded marine sedimentary rocks of Paleozoic age. The areally most extensive units are the Pogonip Limestone, Chainman Shale, and Ely Limestone (Drewes, 1967). The Pogonip Limestone consists of a thick-bedded, cliff-forming limestone that primarily underlies the east side of the basin. The Chainman Shale, which underlies a broad bench along the west side of the basin, is a dark-gray shale that is highly carbonaceous, noncalcareous, and locally contains veins of selenite and carbonaceous nodules with pyrite cores. The Ely Limestone forms the ridge on the west side of the basin and consists of a light gray, cherty limestone that is the source of water for many springs in the basin. Less extensive units of dolomite, quartzite, shale, phyllite, and conglomerate crop out along the valley floor and in the southern one-half of the basin. A small exploratory mine shaft is located on the bench west of Steptoe Creek, although the waste rock on the mine dump was not mineralized (Drewes, 1967).

The Steptoe Creek HBN Basin drains the central part of White Pine County in Nevada and is in the Ely Ranger District of the Humboldt National Forest. About 85 percent of land in the basin is managed by the U.S. Forest Service, and the remainder, primarily along the main channel of Steptoe Creek, is privately

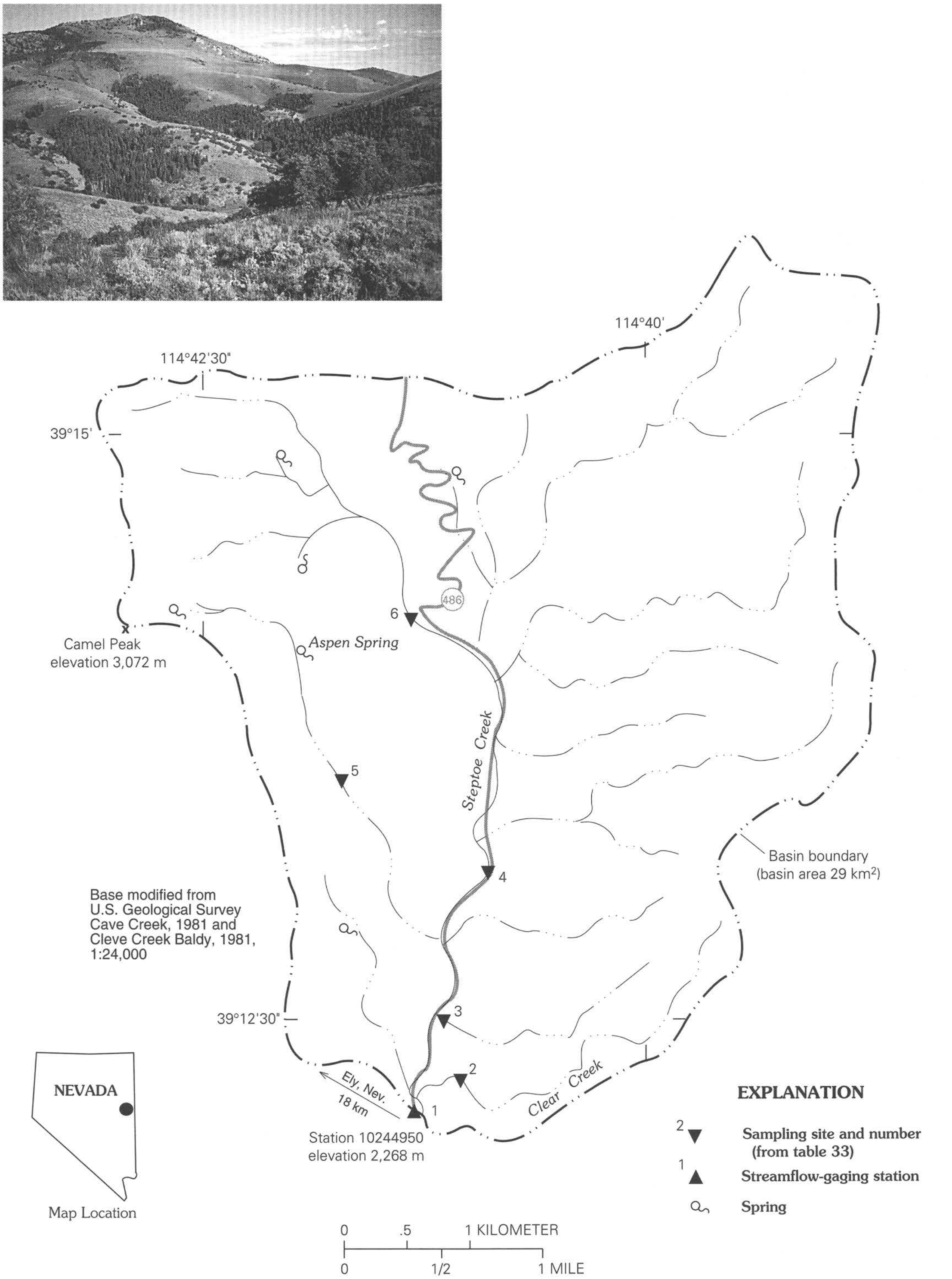


Figure 16. Map showing the study area in the Steptoe Creek Basin and photograph showing the basin landscape.

owned. The basin can be accessed from the Steptoe Creek Road, which is a dirt road that bisects the basin from south to north. Because the road provides access to National Forest lands north of the basin, it is used heavily by tourists during the summer months. In addition to motorized travel, other land-use activities in the basin include camping, hunting, and livestock grazing. The basin is heavily used for car camping from June through October, with as many as 200 campsites on weekends and holidays. All camping is dispersed (no developed campsites), and most campsites are established on private land along the main stream channel and major tributaries (Gerald Green, U.S. Department of Agriculture, Forest Service, oral commun., 1998). Cattle and sheep grazing is permitted on National Forest land throughout the Schell Creek Range. Standards and guidelines for grazing on National Forest land, which were not enforced until 1993, are outlined in the forest-management plan (U.S. Department of Agriculture, 1986a). Two flocks of about 800 sheep each and a herd of about 20 cattle rotate in and out of the basin during the grazing season from June 15 through September 15 (Gerald Green, oral commun., 1998). Many of the springs in the basin have been developed to provide water for livestock. Plant communities in some areas have changed because of the pressures of grazing; there particularly has been a decline in scrub communities because of the invasion of Utah juniper and single-leaf pinyon pine (U.S. Department of Agriculture, 1986a). In addition to livestock, the Steptoe Creek Basin provides summer range for the Schell Creek elk herd, the largest herd in Nevada. The most substantial changes in land use in the basin during the period of record have been a decrease in grazing pressure and an increase in summer recreational use.

Historical Water-Quality Data and Time-Series Trends

The data set for the Steptoe Creek HBN station analyzed for this report includes 192 water-quality samples that were collected from March 1968 through August 1995. Sampling frequency ranged from 8 to 12 samples per year from 1969 through 1982 (except for quarterly during 1976 and 1977) and was quarterly from 1983 to 1995. Samples from the early part of the period of record were probably analyzed at a USGS district laboratory in Sacramento, Calif. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and the NWQL in Arvada, Colo., from 1976 to 1995. Daily discharge records for Steptoe Creek (station 10244950) are available beginning in June 1966. Daily water temperature was measured at the HBN station from October 1966 through November 1983, and the daily precipitation amount was measured at the station from July 1991 to March 1996.

Calculated ion balances for 176 samples that have complete major-ion analyses are shown in figure 17. Ion balances ranged from –7.7 to +22 percent, and 95 percent of the samples had values within the ±10-percent range, indicating that the analytical results are of good quality. The average ion balance for all samples was 1.2 percent, and 67 percent of samples had a slight excess of measured cations compared to measured anions in solution, indicating that unmeasured constituents, such as organic anions, may be a small component of stream water at this HBN station. Time-series plots of the major dissolved constituents were inspected for evidence of method-related effects (fig. 17). Field pH measurements increased abruptly around the beginning of 1973, which may have been caused by a change in measurement method or instrumentation used by field personnel. A similar pattern was observed at South Twin River (fig. 15), another HBN station in Nevada, providing additional evidence that the shift in pH values was an analytical artifact. Some distinct patterns also are evident in the plot of ion balance, particularly the positive values in 1978, which were followed by a period of negative values in the early 1980's. Although the cause of this pattern could not be identified, it probably indicates bias in one or more of the analytical determinations during this period of record.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Lehman Caves NADP station are presented in table 30. Precipitation chemistry at the NADP station, which is about 45 km southeast of the HBN station, is dilute and slightly acidic and had a VWM pH of 5.3 for 11 years of record. The predominant cations in precipitation were calcium and ammonium, which contributed 41 and 24 percent of the total cation charge, respectively. The predominant anions were sulfate and nitrate, which accounted for 41 and 44 percent of the total anions, respectively. Stream water in Steptoe Creek is moderately concentrated and well buffered; specific conductance ranged from 220 to 400 µS/cm and alkalinity ranged from 2,120 to 4,060 µeq/L (table 30). The predominant cations in stream water were calcium and magnesium, and the major anion was bicarbonate. The predominance of these solutes in stream water is consistent with the weathering stoichiometry of carbonate minerals in the underlying sedimentary rocks. The median chloride concentration in stream water was 31 µeq/L compared to the VWM concentration of 5.4 µeq/L in precipitation. Based on the difference between average annual runoff and precipitation, evapotranspiration can account for as much as a fourfold increase in the chloride concentration of precipitation, indicating that precipitation accounts for most of the chloride in stream water. Some chloride also might be derived from weathering of the sedimentary rocks or perhaps from land-use activities, such as dispersed camping and livestock grazing. The median sulfate concentration of 170 µeq/L in stream water was substantially greater than the VWM concentration of 15 µeq/L in precipitation. This large difference in concentration indicates that most sulfate in stream water probably is derived from weathering of sulfate minerals, such as gypsum and anhydrite, in the marine sedimentary rocks. Although concentrations of inorganic nitrogen were generally lower in stream water than in precipitation, most stream-water samples had detectable concentrations of nitrite plus nitrate, indicating that grazing and camping activities may have a small but measurable effect on nutrient concentrations at the HBN station.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 31). Discharge was poorly correlated with the major solutes, except for a negative correlation with magnesium (rho = –0.648) and a positive correlation with sulfate (rho = 0.497). The lack of correlations between discharge and major solutes probably reflects the importance of springs in maintaining stream discharge during most months of the year. The positive correlation between sulfate and discharge indicates that runoff during periods of increased discharge, such as spring snowmelt, is enriched in sulfate compared to spring-fed base flow, perhaps because of compositional differences among the bedrock units. Among the solutes, the strongest correlations were between calcium and alkalinity (rho = 0.511) and sulfate and sodium (rho = 0.514), which is consistent with the weathering stoichiometry of marine limestones and shales. The cause of the weak correlations with magnesium, particularly magnesium and calcium (rho = –0.046) and magnesium and alkalinity (rho = 0.170), was unclear, particularly considering the abundance of carbonate-bearing formations in the bedrock.

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 32. Statistically significant downward trends were detected in discharge and unadjusted sulfate concentrations and upward trends were detected in unadjusted pH and calcium concentrations at the 0.01 probability level. The downward trend in sulfate was not statistically significant after flow adjustment, indicating that the trend was probably caused by the trend in stream discharge. By contrast, the calcium trend was similar for the unadjusted and flow-adjusted concentrations, indicating that it was not caused by variations in stream discharge. The trend in flow-adjusted pH was not calculated because the flow model was not significant at the 0.10 probability level (Schertz and others, 1991). The LOWESS curves in figure 17 show that most of the increase in field pH occurred in the early 1970's, whereas the increase in calcium concentrations was more gradual during the period of record. The shift in pH in the early part of the record was most likely caused by a change in measurement method or instrumentation, indicating that the trend in pH is probably an analytical artifact. The cause of the upward trend in stream-water calcium could not be identified. Environmental factors that may have affected calcium concentrations include livestock grazing, recreational use, or atmospheric deposition. Changes in atmospheric deposition probably would not affect stream-water calcium at this HBN station because of the dilute chemistry of precipitation at the nearby NADP station in comparison to the chemistry of the stream. Landscape disturbance associated with grazing and camping has the potential

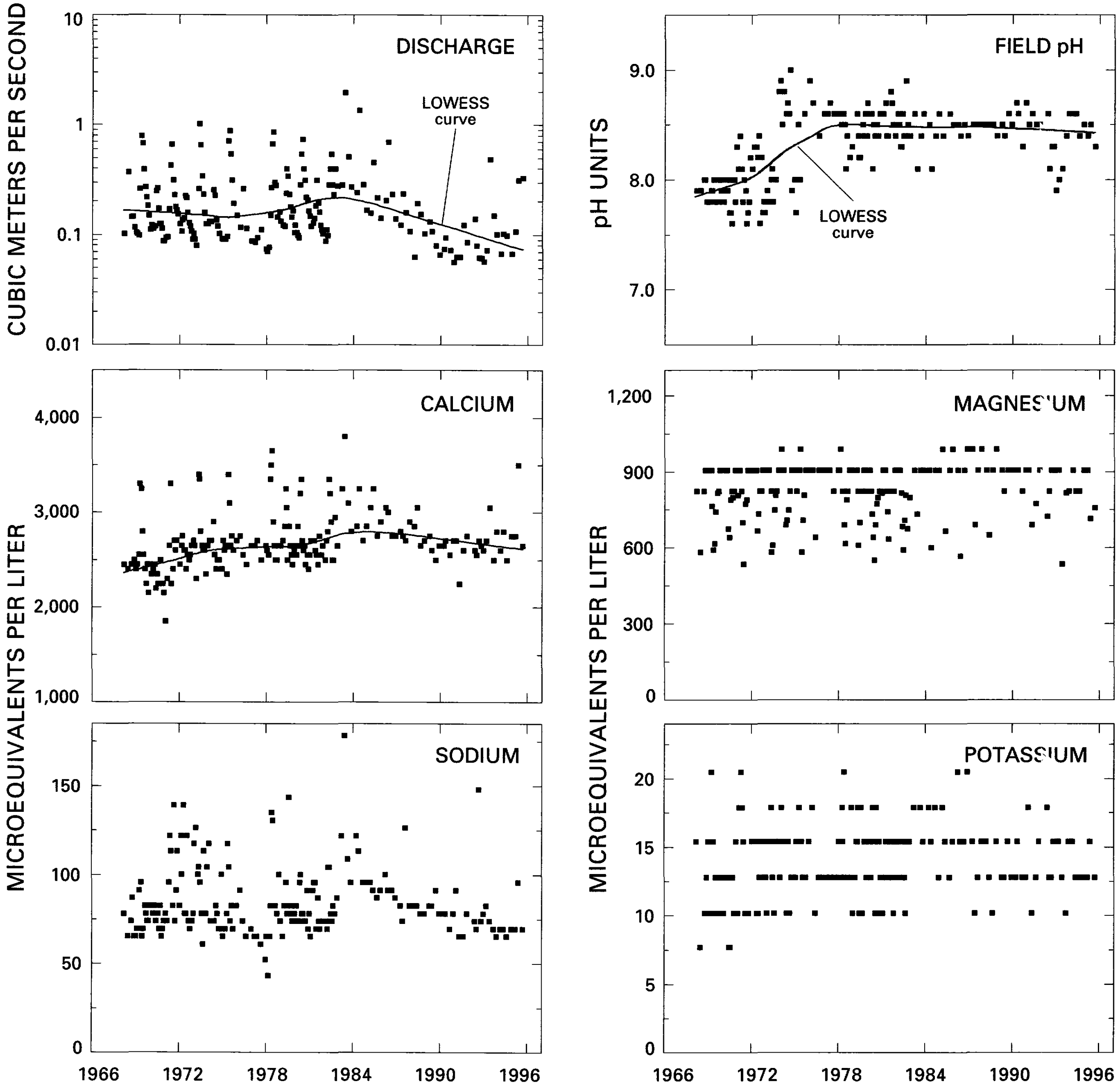


Figure 17. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Steptoe Creek, Nevada.

to increase rates of base-cation leaching from soils and bedrock (Stoddard and Murdoch, 1991). Although landscape disturbance is a plausible cause of the upward trend in stream-water calcium, increases were not observed in alkalinity, as might be expected on the basis of predominance of carbonate bedrock in the basin. Laboratory bias also may have affected the concentration pattern of calcium, particularly the change in the analytical technique for major dissolved cations and trace inorganic constituents that occurred in 1983 (Office of Water Quality Technical Memorandum No. 82.18, *National water-quality networks*, issued September 28, 1982, at URL http://water.usgs.gov/admin/memo/).

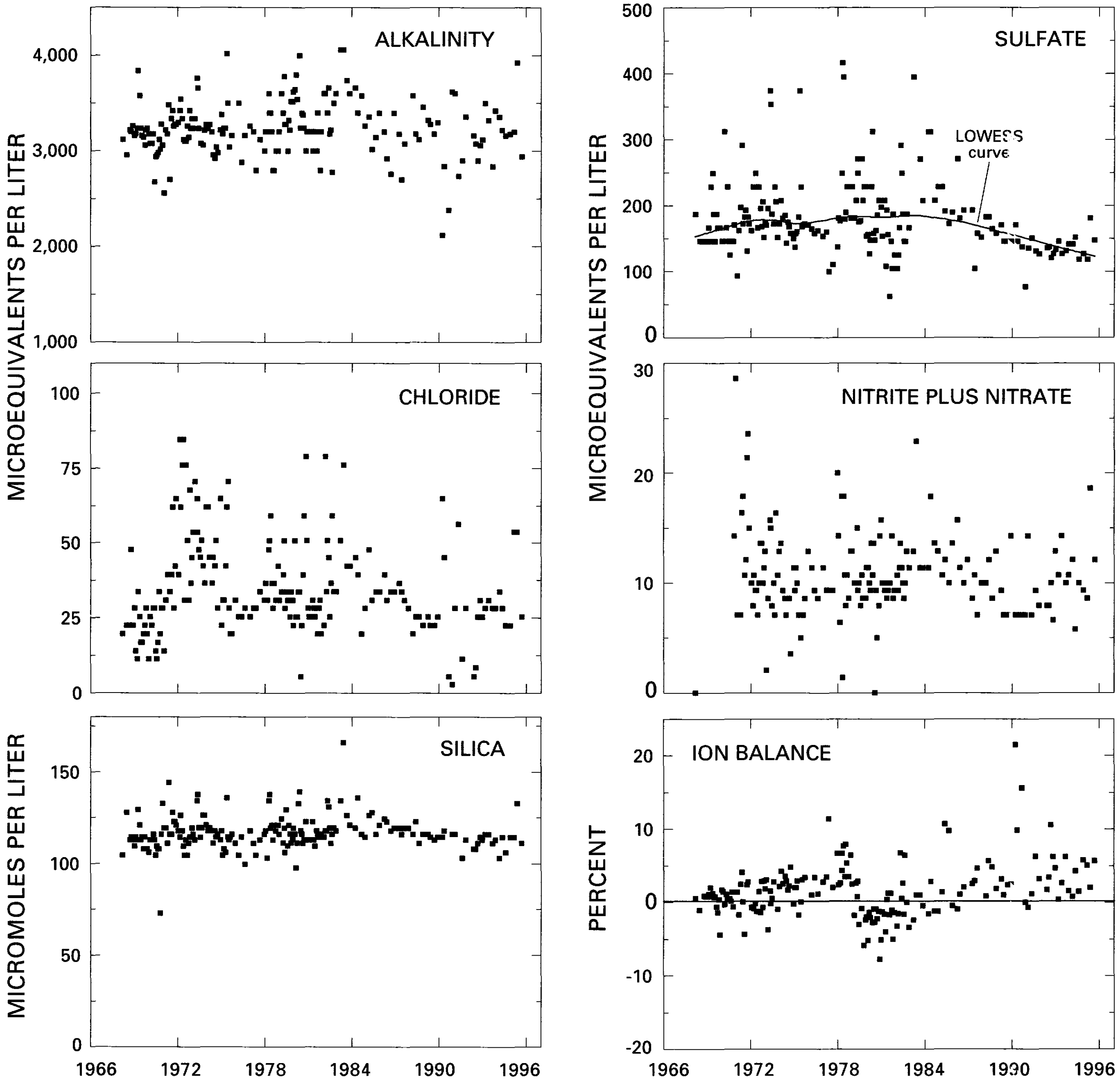


Figure 17. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Steptoe Creek, Nevada—Continued.

Synoptic Water-Quality Data

Results of the surface-water synoptic sampling of July 23, 1991, are listed in table 33, and locations of sampling sites are shown in figure 16. During the synoptic sampling, discharge at the HBN station was 0.13 m^3/s compared to the median daily discharge of 0.25 m^3/s for July (Lawrence, 1987), indicating that the basin was sampled under low-flow conditions for that time of year. Most of the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were generally less than the first-quartile concentrations reported for the station during the entire period of record (table 30). The tributary

Table 30. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Steptoe Creek, Nevada, March 1968 through August 1995, and volume-weighted mean concentrations in wet precipitation collected at the Lehman Caves Station, Nevada

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation
	Minimum	First quartile	Median	Third quartile	Maximum	n	VWM[a]
Discharge, inst.	0.057	0.10	0.14	0.26	2.0	187	--
Spec. cond., field	220	310	320	330	400	189	8.5
pH, field	7.6	8.0	8.4	8.6	9.0	179	5.3[b]
Calcium	1,850	2,500	2,650	2,750	3,800	191	21
Magnesium	530	780	820	910	990	191	4.0
Sodium	44	74	78	91	180	191	7.9
Potassium	7.7	13	13	15	20	184	.8
Ammonium	<.7	<.7	1.2	2.9	9.3	96	12
Alkalinity, laboratory	2,120	3,080	3,220	3,400	4,060	186	--
Sulfate	62	150	170	200	420	189	15
Chloride	2.8	25	31	42	85	192	5.4
Nitrite plus nitrate	<.7	8.6	10	13	29	164	16[c]
Silica	73	110	120	120	170	190	8.5

[a] Values are VWM concentrations for 1985–95.

[b] Laboratory pH.

[c] Nitrate only.

Table 31. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Steptoe Creek, Nevada, 1968 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; N, nitrite plus nitrate Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	N
pH	–0.116									
Ca	.326	0.265								
Mg	–.648	.113	–0.046							
Na	.397	–.051	.397	–0.039						
K	.056	.175	.486	.146	0.380					
Alk	.095	.090	.511	.170	.284	0.440				
SO_4	.497	–.063	.363	–.103	.514	.361	0.337			
Cl	.214	.087	.255	.000	.426	.289	.248	0.490		
N	.215	–.107	.315	.030	.227	.252	.337	.226	0.170	
Si	.363	.046	.497	–.048	.449	.293	.348	.413	.405	0.433

streams were similar in composition to stream water at site 1 with calcium and bicarbonate the predominant ions. Ion balances for all but one of the synoptic samples were positive, with an average value of +3.4 percent. The positive ion balances were somewhat unexpected because of the relatively high solute concentrations of the synoptic samples and may indicate a bias in one of the analytical measurements.

In general, concentrations of the major solutes did not vary markedly among the sampling sites, probably because of the presence of limestone bedrock throughout the basin. For example, calcium concentrations ranged from 2,400 to 3,800 µeq/L, and alkalinity ranged from 2,580 to 3,640 µeq/L (table 33). Of the weathering-derived constituents, magnesium had the widest range of concentrations, ranging from 250 to 880 µeq/L, which may reflect the distribution of different rock types in the basin. For example, the lowest magnesium concentrations (sites 5 and 6) were in areas of the basin that are underlain by the Ely Limestone, whereas the highest concentrations (sites 3 and 4) were in streams draining dolomite and shale units, as well as limestone. Silica concentrations were low and uniform (93 to 170 µmol/L) across the basin, which is reasonable, based on the lack of weatherable silicate minerals in the sedimentary rocks. Chloride and nitrate concentrations were higher at site 5 compared to the other sampling sites, probably because of livestock activity near the spring. Chloride concentrations also were slightly higher at site 4 compared to the other sites, perhaps because the site is located downstream from the highest density of campgrounds in the basin.

Table 32. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Steptoe Creek, Nevada, March 1968 through August 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	−0.002	0.003	--	--
pH, field	.01	.002	([a])	--
Calcium	8.3	.000	11.5	0.000
Magnesium	<.1	.462	−1.4	.147
Sodium	−.1	.176	−.1	.574
Potassium	<.1	.134	<.1	.035
Alkalinity, laboratory	2.3	.461	2.6	.382
Sulfate	−1.5	.001	−.5	.291
Chloride	−.3	.096	−.2	.247
Nitrite plus nitrate	<.1[b]	.808	<.1	.517
Silica	<.1	.404	<.1	.981

[a] Flow model not significant at $\alpha = 0.10$.

[b] Trend calculated for 1971–95.

Table 33. Physical properties and major dissolved constituents from surface-water sampling sites in the Steptoe Creek Basin, Nevada, collected July 23, 1991

[Site locations shown in fig. 16; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate; Si, silica; concentrations in microequivalents, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]	Remarks
1	10244950	0.13	310	8.4	2,550	770	65	12	3,040	110	5.6	7.9	110	--	
2	391216114410400	.061	300	8.4	2,400	610	52	11	2,580	83	5.6	8.6	93	BG	Mixed lithology
3	391231114410300	--	340	7.9	2,400	880	65	13	3,120	120	5.6	13	110	BG	Mixed lithology
4	391313114405300	.022	360	8.3	2,950	880	91	13	3,520	210	20	4.4	130	BG, LU	Mixed lithology, downstream from campground
5	391335114414400	.0003	380	8.2	3,350	260	160	16	3,640	250	76	21	150	BG, LU	Ely Limestone, livestock use
6	391416114411900	.0003	390	8.4	3,800	250	110	10	3,280	210	8.5	12	170	BG, LU	Ely Limestone, livestock use

[a] Criteria used in selection of sampling sites: BG = bedrock geology, LU = land use.

Crater Lake near Crater Lake, Oregon (Station 11492200)

Site Characteristics and Land Use

Crater Lake is located in the Sierra-Cascade Mountains physiographic province along the crest of the Cascade Range in southwestern Oregon (fig. 18). Crater Lake occupies the collapsed caldera of Mount Mazama and has an average surface elevation of 1,882 m, a surface area of 53.2 km^2, and a maximum depth of 589 m (Larson and others, 1993). The 67.8-km^2 drainage basin consists of the lake (53.2 km^2) and the steep walls of the caldera (14.6 km^2), which reach a maximum elevation of 2,484 m (Larson and others, 1996). The HBN station is located along the northeast shore of the lake in Cleetwood Cove at latitude 42°58'45" and longitude 122°04'45". The lake receives 85 percent of its inflow by direct precipitation, and the remainder comes from about 40 springs and streams that emanate from the caldera walls (Redmond, 1990). There is no surface flow out of the lake, and the lake level is maintained by a balance between evaporation (28 percent) and seepage from the lake bottom (72 percent) (Redmond, 1990). The lake elevation varies annually by about 60 cm in response to seasonal variations in precipitation and evaporation. The minimum and maximum lake elevations on record were 1,878.5 m on September 10, 1942, and 1,883.5 m on March 25, 1975 (Hubbard and others, 1996). The climate of Crater Lake is discussed in detail by Redmond (1990). Average monthly air temperatures range from –3.5°C in January to 12.8°C in August (URL http://www.wrcc.sage.dri.edu, accessed 1998). Precipitation averages 172 cm annually and is strongly seasonal; December (28.9 cm) and January (10.6 cm) are the wettest months and July (2.1 cm) and August (2.4 cm) are the driest. Winter snowfall averages 1,350 cm/yr and accumulates in a seasonal snowpack between November and March that usually reaches 300 cm in depth. Despite the large amount of snow, the lake almost always remains free of ice and snow during winter.

The basin is in the subalpine zone of the Sierran Steppe ecoregion (Bailey and others, 1994). Vegetation on the crater rim is dominated by mature conifer forests of mountain hemlock, red fir, and whitebark pine (Gregory and others, 1990). Small shrubs, herbaceous plants, and Sitka alder grow in thickets along springs and seeps that emanate from the crater walls. A description of the ecology of the lake itself is beyond the scope of this report but can be found in Drake and others (1990) and Larson and others (1993).

The geologic setting and history of Crater Lake are summarized by Bacon and Lanphere (1990). Crater Lake partly fills an 8- by 10-km-diameter caldera that collapsed during the eruption of Mount Mazama about 6,850 years ago (Bacon and Lanphere, 1990). The walls of the caldera consist of andesitic and dacitic lavas that primarily consist of plagioclase (An_{50}), pyroxene, and sodium-rich volcanic glass (Nathenson and Thompson, 1990). The floor of the caldera is filled by intercaldera tuffs and interbedded landslide deposits that are covered by a thin layer of lake sediment. The lake sediment represents a mixture of material from three sources—volcanic debris from the caldera walls, biogenic particulates that settle out from the lake water, and iron oxide precipitates that form where hydrothermal fluids vent from the lake floor (Dymond and Collier, 1990). Soil development on the crater walls is hindered by steep slopes and frequent avalanches, and most of the slopes are covered by loose accumulations of gravel, cobbles, and boulders (Gregory and others, 1990).

The Crater Lake HBN Basin is located in Klamath County in Oregon and is entirely in the boundaries of Crater Lake National Park. The park was established in 1902, and more than 90 percent of the park is managed as wilderness (U.S. Department of the Interior, 1995). A 53-km paved road, referred to as Rim Drive, follows the crater rim around the perimeter of the lake. The road is closed each year in mid-October because of winter snows and is plowed each spring, beginning in mid-April, to reach the north entrance of the park by mid-June. During the snow-free months, the only access to the shore of the lake is from a steep 1.8-km hiking trail between Rim Drive and the boat ramp at Cleetwood Cove. More than 500,000 people visit the park annually; the heaviest use is in July and August. The only park facilities in the basin boundary are a visitor center, a lodge and cafeteria, a sewage-disposal facility at Rim Village on the south side of the lake, several picnic areas along Rim Drive, and a research station on

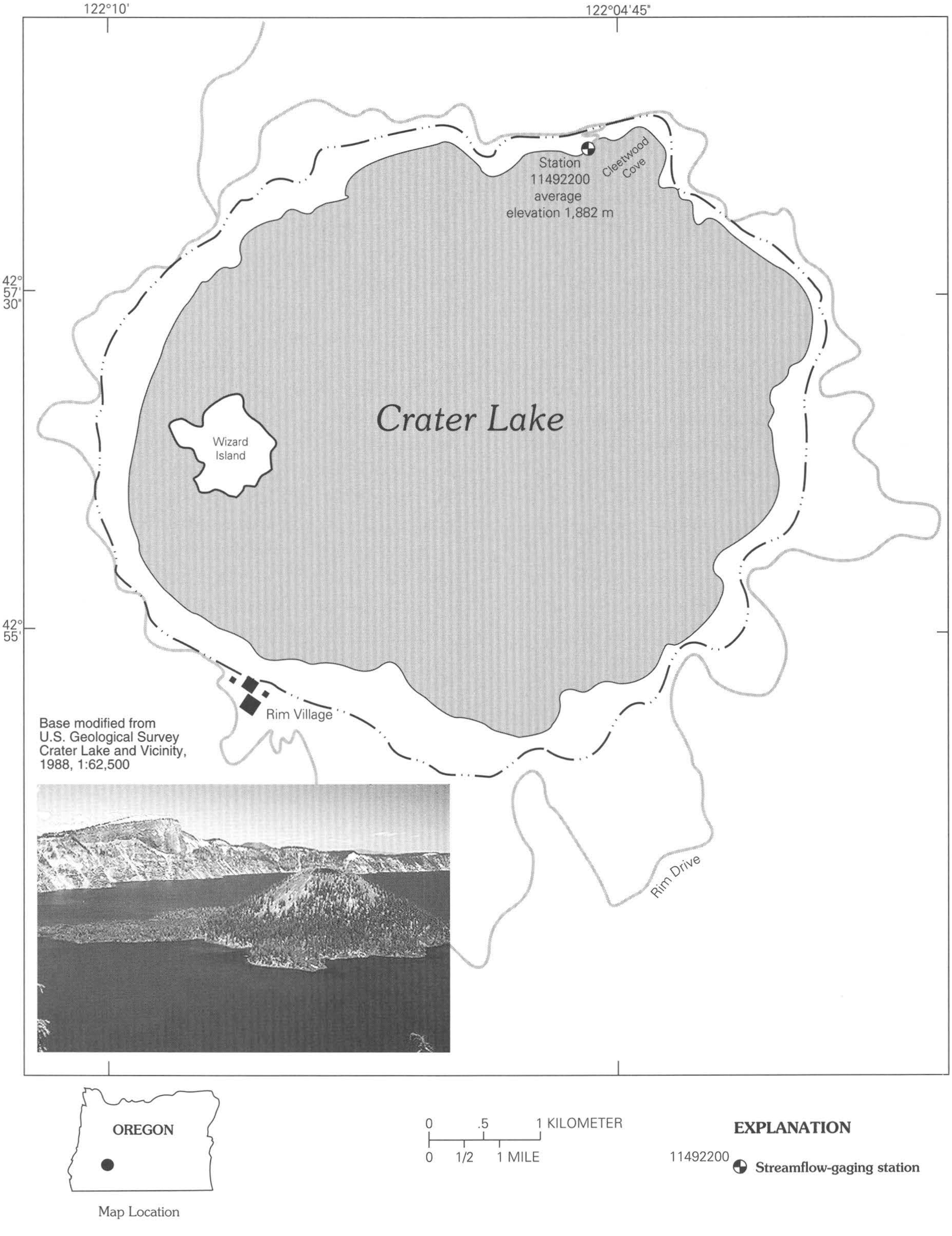


Figure 18. Map showing the Crater Lake Basin and photograph showing Wizard Island and the crater rim.

Wizard Island. The sewage-disposal facility at Rim Village consists of a septic tank that discharges as much as 62,000 m^3 of domestic wastewater each year into a drainfield that is situated 200 m above the surface of the lake (Larson and others, 1990). Recent studies of the chemistry of springs emanating from the crater walls indicate that the drainfield has increased nitrate concentrations in springs below the Rim Village that discharge directly into the lake (Larson and others, 1990).

In response to indications that the clarity of the lake might be declining, the U.S. Congress mandated a 10-year limnological study of Crater Lake (Public Law 97–250) in the fall of 1982 (Larson, 1990). The goals of the study were to develop a reliable data base for the lake, improve understanding of lake components and processes, establish a long-term program to monitor changes in the lake, and determine if the lake had changed in response to environmental stressors (Larson and others, 1993). The study concluded that long-term changes in lake clarity could not be verified because of the lack of historical data but identified climate change, air pollution, onsite automobile and boat use, and nonnative fish as the greatest human-related threats to the ecosystem. The results of scientific investigations conducted as part of this limnological program are compiled in a technical report published by the National Park Service in 1993 (Larson and others, 1993).

Historical Water-Quality Data and Time-Series Trends

The data set for the Crater Lake HBN station analyzed for this report includes 91 water-quality samples that were collected from June 1967 through September 1995. Sampling frequency averaged only three samples per year because of closure of the access road in winter. Samples from the early part of the period of record probably were analyzed at a USGS district laboratory in Portland, Oreg. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and the NWQL in Arvada, Colo., from 1976 to 1995. Lake stage for Crater Lake (station 11492200) is available beginning in October 1961, and daily water temperature at the station has been measured since October 1963.

Calculated ion balances for 86 samples that have complete major-ion analyses are shown in figure 19. Ion balances ranged from −10 to +9.6 percent, and 85 percent of the samples had values within the ±5-percent range, indicating that the analytical results are of high quality. The average ion balance for all samples was −1.0 percent, and 65 percent of samples had a slight excess of measured cations compared to measured anions, indicating that unmeasured constituents, such as organic anions, may have contributed a small amount to the ionic content of lake water at this HBN station. Time-series plots of the major dissolved constituents were inspected for evidence of method-related effects (fig. 19). The most notable pattern is in field pH, which increased rather abruptly in 1988. Several uncharacteristically high calcium and sodium concentrations were measured during the 1970's. In addition, the scatter in calcium, alkalinity, and chloride concentrations decreased noticeably during the period of record. Because the surface-water chemistry at this station should be relatively stable due to the long residence time of water in the lake, these patterns probably are caused by sampling or analytical artifacts rather than by natural variability in lake chemistry.

The median concentrations and ranges of major dissolved constituents in lake water collected at the HBN station and VWM concentrations in bulk precipitation collected in Crater Lake National Park are presented in table 34, and correlations between lake stage and the major solutes are presented in table 35. Precipitation chemistry in the park is very dilute and slightly acidic and has a VWM pH of 5.3. The predominant cations in precipitation were hydrogen ion, calcium, and sodium, which contributed 27, 25, and 17 percent of the total cation charge, respectively. The predominant anions were sulfate and chloride, which accounted for 36 and 51 percent of the total anions, respectively. Lake-water samples from Crater Lake are moderately concentrated and well buffered; specific conductance ranged from 110 to 130 μS/cm, and alkalinity ranged from 400 to 800 μeq/L (table 34). The predominant solutes in lake water were sodium, calcium, bicarbonate, silica, and concentrations of most solutes in lake water were much higher than concentrations in precipitation despite the fact that the lake receives 85 percent of its inflow from direct precipitation (Nelson and others, 1993). Sources of solutes other than atmospheric deposition include dissolution of geologic materials on the lakebed, springs and small streams that emanate from the caldera walls, and hydrothermal sources under the lake. The predominance of sodium compared to calcium and the high concentrations of dissolved silica in lake water are consistent with the weathering stoichiometry of sodium-rich volcanic glass and plagioclase minerals in the volcanic bedrock (Nathenson and Thompson, 1990). The elevated chloride and sulfate concentrations in lake water cannot be accounted for by either atmospheric deposition or bedrock weathering and may be derived from thermal springs that discharge from the floor of the lake (Van Denburgh, 1968). Biological activity also functions as a control on the solute budget of the lake. For example, diatom activity in the lake removes as much as 30 percent of the dissolved silica introduced from weathering and thermal sources (Nelson and others, 1996). More than 90 percent of the nitrate and ammonium that enters the system in atmospheric deposition is assimilated by algae and subsequently buried in sediments on the bottom of the lake (Dymond and others, 1990). All solute concentrations were poorly correlated with lake stage and with each other because of the extremely constant chemical composition of the lake (table 35). More detailed information on the processes controlling the chemistry of Crater Lake is presented in Nathenson and Thompson (1990), Larson and others (1996), and Nelson and others (1996).

The results of the seasonal Kendall test for trends in lake stage and unadjusted dissolved constituents are listed in table 36. Trends were not calculated for the stage-adjusted concentrations because correlations between solute concentrations and lake stage were not significant at the 0.10 probability level. Statistically significant trends were detected in lake stage and unadjusted magnesium, potassium, and silica concentrations at the 0.01 probability level. The LOWESS curve for lake stage in figure 19 shows that the trend in lake stage was primarily caused by declining lake levels at the end of the period of record. Given that climate variability can account for lake-level changes during the last century (Redmond, 1990), this decline was probably caused by a period of dry and warm weather in the south-central part of Oregon that persisted from about 1985 to 1995 (Oregon Climate Service, at URL http://www.ocs.orst.edu, accessed 1998). Trends in water-quality constituents at this HBN station were not expected because the water column is well mixed and the residence time of water in the lake is around 225 years (Collier and others, 1990). In addition, the trends are inconsistent with the results of Larson and others (1996) who reported no long-term changes in lake chemistry during a 10-year limnological study of the lake nor with a comparison of recent and historical data. Closer inspection of the trend results in table 36 reveals that the change in magnesium and silica concentrations was less than 0.1 percent during the entire period of record. Because the analytical precision of these analyses is no better than 5 percent (Fishman and Friedman, 1989), the statistical test probably did not detect measurable changes in the concentrations of these two constituents. The trend in potassium was considerably larger in magnitude than the trends in magnesium and silica and amounted to a total decrease in concentration of about 17 percent, most of which occurred in the latter part of the period of record (fig. 19). The cause of the downward trend in potassium could not be identified. One possibility is a method-related artifact, although there were no documented changes in the analytical technique for potassium since 1965 (Fishman and others, 1994). Alternatively, potassium concentrations may have been affected by the decline in lake level that occurred from 1985 to 1995.

Synoptic Water-Quality Data

Synoptic samples were not collected in the Crater Lake HBN Basin as part of this study because the lake receives only 15 percent of its annual water input from surface runoff. Several studies, however, have investigated the chemistry of springs and streams emanating from the caldera walls and along the flanks of Mount Mazama (Thompson and others, 1987; Greogory and others, 1990; Nathenson and Thompson, 1990). These studies have used spring chemistry to investigate hydrologic losses from the lake and to evaluate the predominant solute sources to the lake.

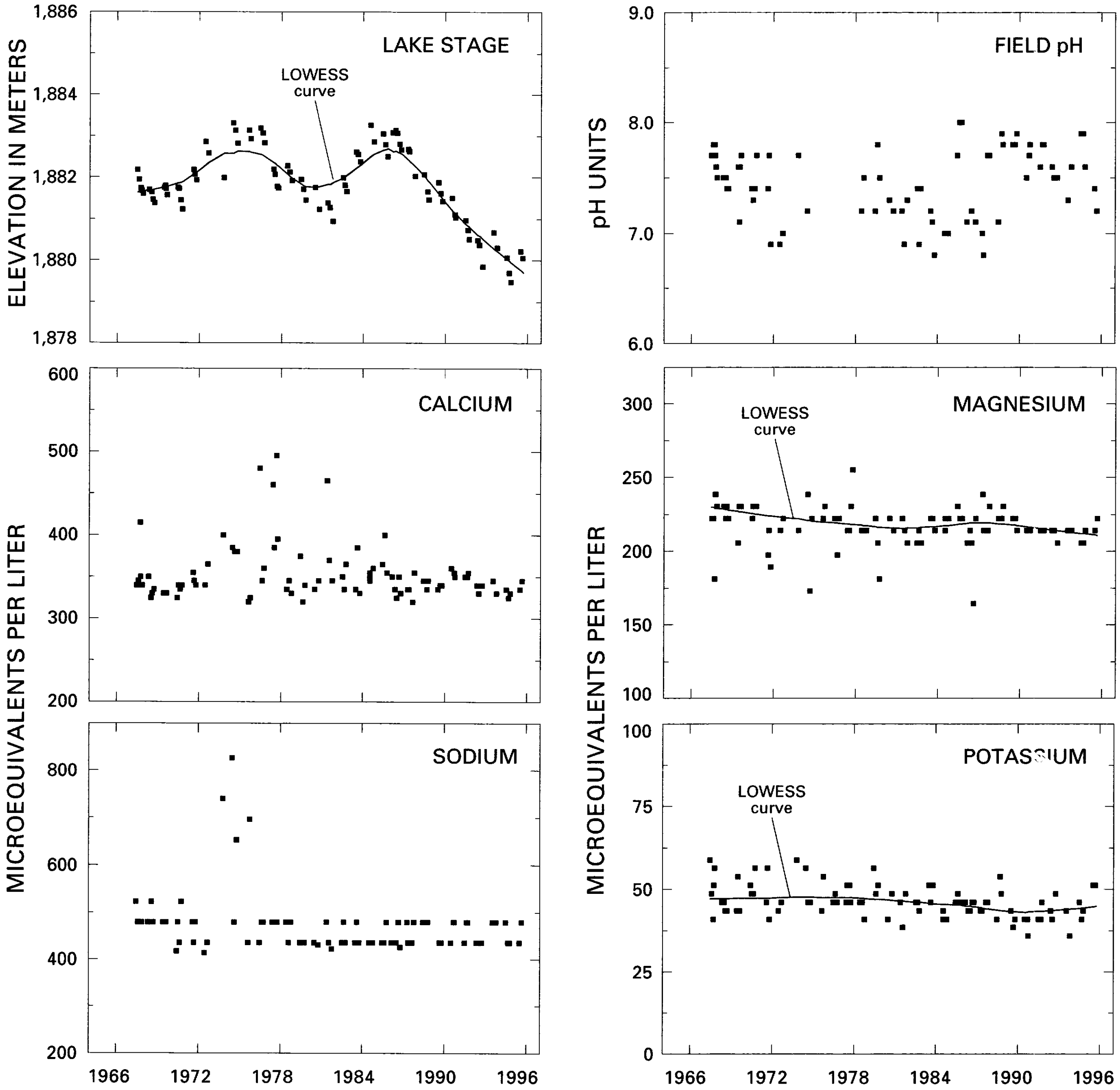


Figure 19. Temporal variation of lake stage, field pH, major-ion concentrations, and ion balance in Crater Lake, Oregon.

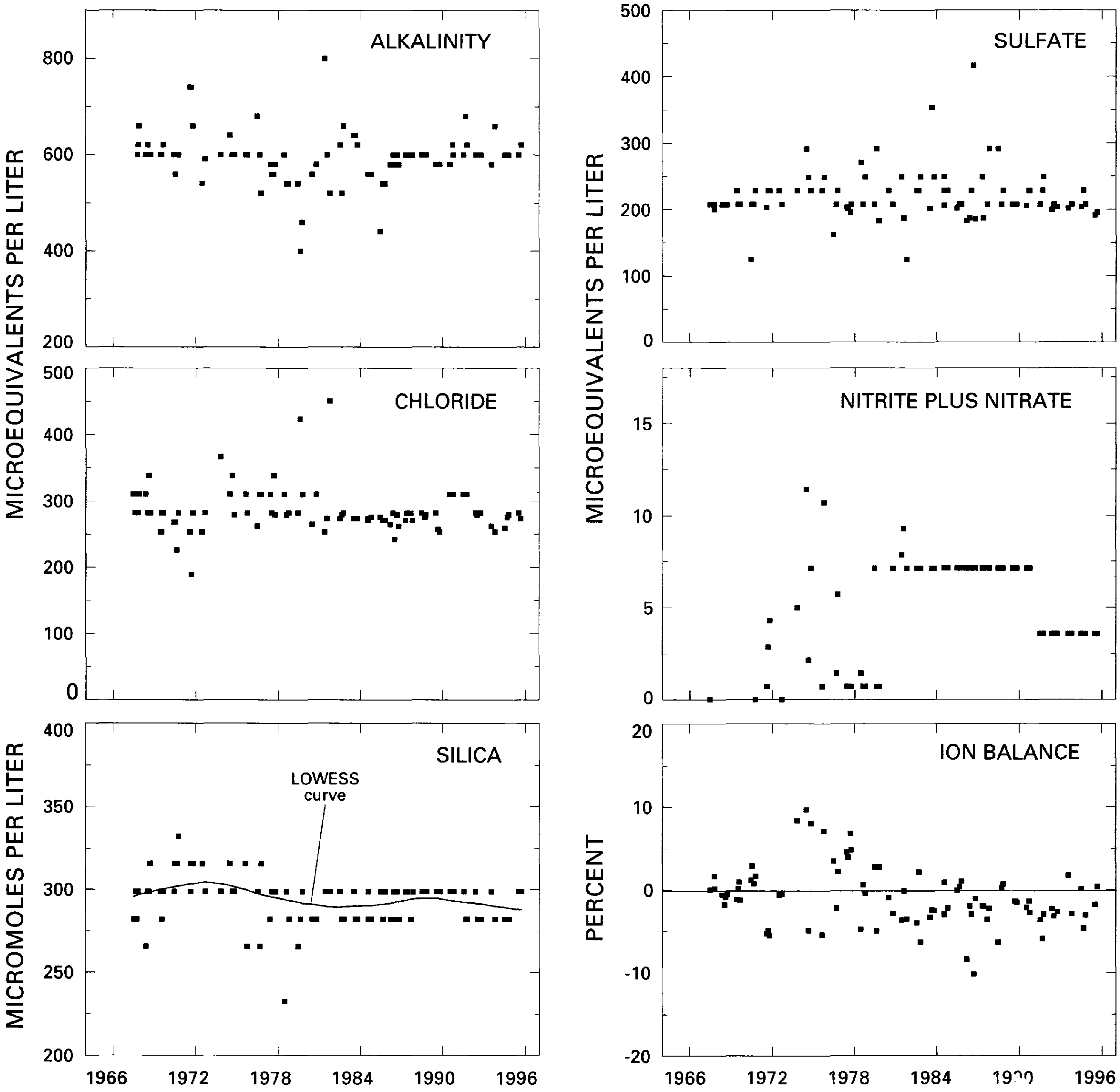


Figure 19. Temporal variation of lake stage, field pH, major-ion concentrations, and ion balance in Crater Lake, Oregon—Continued.

Table 34. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Crater Lake, Oregon, June 1967 through September 1995, and volume-weighted mean concentrations in bulk precipitation collected at Crater Lake National Park, Oregon

[Concentrations in units of microequivalents per liter, lake stage in feet, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of lake samples; VMW, volume-weighted mean; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Lake water						Precipitation VWM[a]
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Lake stage	1,879.47	1,881.44	1,881.77	1,882.56	1,883.32	88	--
Spec. cond., field	110	110	120	120	130	81	--
pH, field	6.8	7.2	7.5	7.7	8.0	77	5.3
Calcium	320	340	350	360	500	91	4.6
Magnesium	160	210	210	220	260	91	2.0
Sodium	410	440	480	480	830	90	3.1
Potassium	36	44	46	49	59	90	1.7
Ammonium	<.7	<.7	1.4	2.9	11	44	1.8
Alkalinity, laboratory	400	580	600	600	800	88	--
Sulfate	120	210	210	230	420	90	7.5
Chloride	190	270	280	310	450	91	11
Nitrite plus nitrate	<.7	3.6	7.1	7.1	11	65	2.6
Silica	230	280	300	300	330	90	--

[a]Values are VWM concentrations for 1987–88 (Nelson and others, 1993).

Table 35. Spearman rank correlation coefficients (rho values) showing the relation among lake stage, pH, and major dissolved constituents, Crater Lake, Oregon, 1967 through 1995

[Ca, calcium, Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; N, nitrite plus nitrate; Si, silica]

	Stage	pH	Ca	Mg	Na	K	Alk	SO_4	Cl
pH	−0.377								
Ca	−.176	−0.017							
Mg	.207	.011	0.017						
Na	−.069	.253	.160	0.304					
K	.189	.038	.082	.266	0.179				
Alk	−.230	.061	−.049	.030	.312	0.024			
SO_4	.225	−.019	−.001	−.015	.333	−.142	0.169		
Cl	−.223	.149	.143	−.068	.266	.141	−.034	0.062	
Si	−.006	−.007	.110	.262	.097	.093	.107	−.105	−0.056

Table 36. Results of the seasonal Kendall test for trends in lake stage and unadjusted pH and major dissolved constituents, Crater Lake, Oregon, June 1967 through September 1995

[Trends in units of microequivalents per liter per year, except for stage in meters per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted	
	Trend	p-value
Lake stage	−0.04	0.000
pH, field	.01	.035
Calcium	<.1	.301
Magnesium	<.1	.008
Sodium	<.1	.041
Potassium	-.3	.001
Alkalinity, laboratory	<.1	.778
Sulfate	<.1	.423
Chloride	−.2	.044
Nitrite plus nitrate	<.1[a]	.039
Silica	<.1	.007

[a] Trend calculated for 1971–95 using a test for censored data.

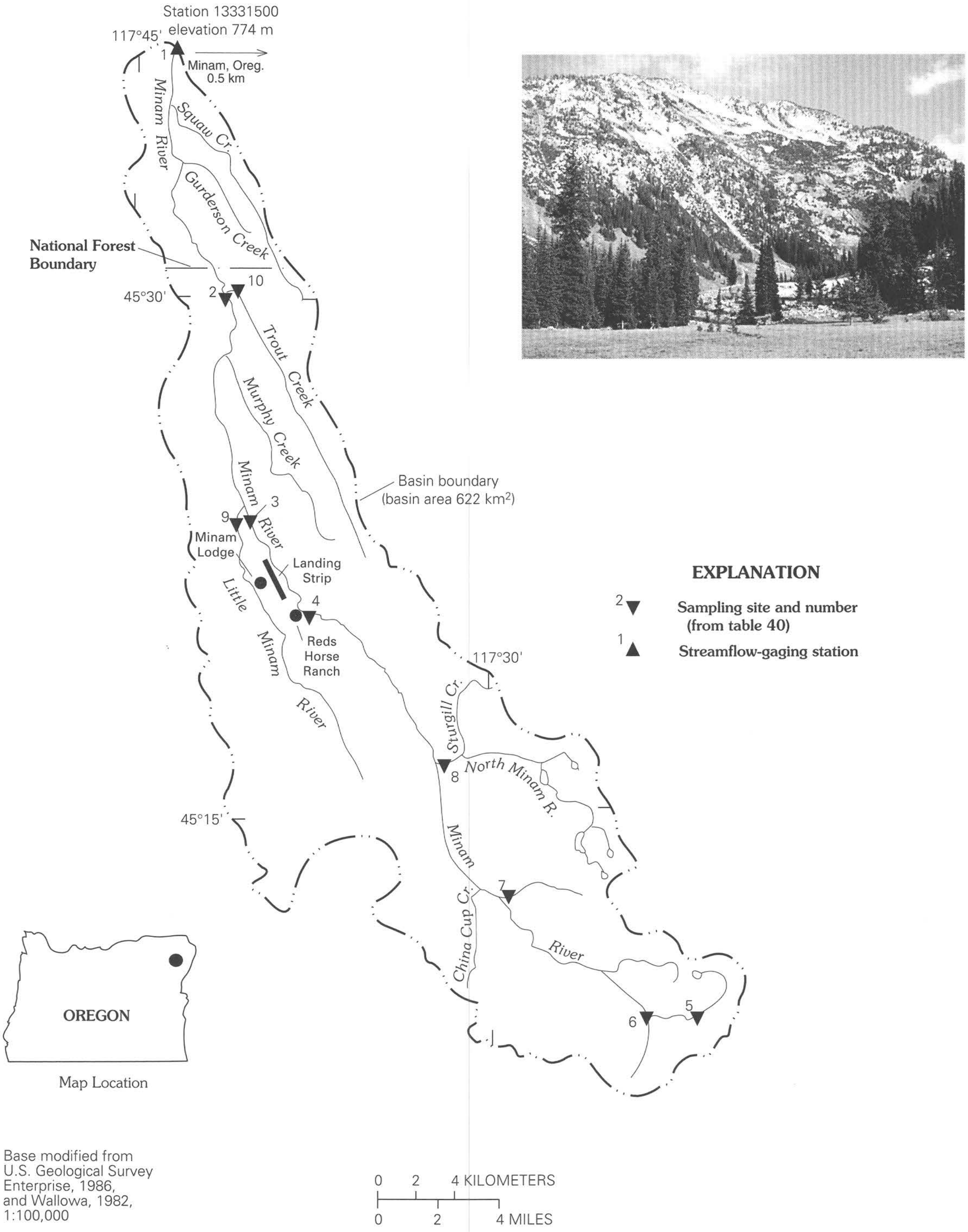
Minam River at Minam, Oregon (Station 13331500)

Site Characteristics and Land Use

The Minam River HBN Basin is located in the Columbia Plateaus physiographic province in the Wallowa Mountains in northeastern Oregon (fig. 20). The 622-km^2 basin ranges in elevation from 774 to 2,780 m and is characterized by a long, U-shaped valley bounded by jagged ridges and alpine cirques. The HBN station is located 0.5 km west of the town of Minam, Oreg., at latitude 45°37'12" and longitude 117°43'32". The Minam River flows northwest into the Wallowa River, a tributary of the Snake River, and has a channel length of 73 km upstream from the HBN station and an average stream gradient of 13.0 m/km. The main channel is perennial, and mean monthly discharge varies from a minimum of 2.7 m^3/s in October to a maximum of 44.6 m^3/s in June during peak snowmelt. Average annual runoff from the basin was 65 cm from 1912 through 1995 (Hubbard and others, 1996). The climate is characterized by short, mild summers and long, cold winters (Cole, 1982). Average monthly air temperatures range from −7.2°C in January to 14.6°C in August (National Climatic Data Center, 1997). Precipitation varies strongly with elevation, ranging from about 100 to 150 cm annually, and is evenly distributed throughout the year, except for a short summer dry season (Cole, 1982). The average annual snowfall is 680 cm, most of which falls between October and April (National Climatic Data Center, 1997).

The basin is in the Southern Rocky Mountains ecoregion and has a high diversity of plant communities that vary with landform, elevation, and aspect (Bailey and others, 1994). Below 2,000 m, forests are dominated by Douglas-fir, although ponderosa pine, western larch, lodgepole pine, and grand fir may be locally abundant (Cole, 1982). Common understory species in this forest community are Grouse huckleberry, big huckleberry, pinegrass, Idaho fescue, bluegrass, and bluebunch wheatgrass. The subalpine fir community dominates most forested sites between 2,000 and 2,300 m (Cole, 1982). The predominant species are subalpine fir and Englemann spruce; the understory is grouse whortleberry. The highest elevations in the basin are dominated by stands of whitebark pine and subalpine fir interspersed with subalpine grasslands and meadows. Other predominant species in this zone include alpine sagebrush, sandwort, fleeceflower, needlegrass, lupine, elk sedge, paintbrush, yarrow, and mosses (Wallowa-Whitman National Forest, written commun., 1998). Little information is available on soil conditions and characteristics in the Eagle Cap Wilderness (U.S. Department of Agriculture, 1995). Most soils in the Wallowa Mountains contain volcanic ash from the eruption of Mount Mazama 6,850 years ago, that has been redeposited and mixed with colluvium and alluvium from local bedrock sources.

Bedrock in the basin consists of intrusive rocks of Cretaceous age that are overlain by basalts of the Columbia River Basalt Group of Tertiary age (Weis and others, 1976). Intrusive rocks include granites of the Wallowa Batholith that are extensively exposed in the upper part of the basin roughly south of Reds Horse Ranch. The granite is generally light gray and medium grained and consists of quartz, plagioclase, hornblende, and biotite. The granite is intruded by aplite, pegmatite, and basalt dikes that range from 8 to 90 cm in width and is cut by several widely spaced joint sets. The basalts of the Columbia River Basalt Group cover the flanks of the Wallowa Range and are exposed along the lower reaches of the river canyon.



Base modified from
U.S. Geological Survey
Enterprise, 1986,
and Wallowa, 1982,
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Figure 20. Map showing the study area in the Minam River Basin and photograph showing the landscape in the headwaters.

The Columbia River Basalt Group consists of dark-colored lava flows that range in thickness from 9 to 30 m. The Wallowa Mountains were extensively glaciated during the late Pleistocene, and glacial deposits are present on the walls and floors of the river valleys and on ridges in high-elevation cirques. Some pyrite-bearing veins are present in sheared and fractured granitic rock in the Eagle Cap Wilderness, although the potential for mineral deposits is low. No active mines exist in the basin, although several abandoned prospects and adits are mapped in the southwestern part of the basin (Weis and others, 1976).

The Minam River HBN Basin drains parts of Union and Wallowa Counties in Oregon. More than 90 percent of the basin is in the Eagle Cap Wilderness in the Wallowa-Whitman National Forest, and the remainder is privately owned. Almost all of the basin is roadless, except for the area north of the national forest boundary and a few areas along the western basin divide. The national forest maintains a 165-km trail system that parallels the entire length of the main channel of the Minam River, as well as several of the major tributaries. The Eagle Cap Wilderness was created in 1964 and is managed under a nondegradation principle, which seeks to maintain the wilderness in at least as wild a condition as it was at the time of classification (U.S. Department of Agriculture, 1990b). The upper 65 km of the Minam River was added to the National Wild and Scenic Rivers System in 1988 and has the distinction of being the only component of the system to be entirely within a wilderness area (U.S. Department of Agriculture, 1995). Recreation is the major human-related activity in the basin, including backpacking, horsepacking, hunting, and fishing.

The well-maintained trail system and ease of access make the Eagle Cap Wilderness one of the most heavily used wilderness areas in Oregon. About 800 people visit the Minam River corridor each year, of which about 30 percent are with commercial outfitters and guides (U.S. Department of Agriculture, 1995). The basin contains two backcountry lodges (Minam Lodge and Reds Horse Ranch), a landing strip located along the river in the center of the basin, and a homestead on the Little Minam River used as an administrative site by the Forest Service. The Minam Lodge is still privately owned and operated; however, Reds Horse Ranch was purchased by the Forest Service in 1994 and since then has been used as an administrative facility. Although recreation is currently the only land use, timber harvesting and grazing have been important in the past. Logging occurred from 1918 to 1924, and a splash dam was constructed 9.7 km upstream from Reds Horse Ranch. The dam was removed in 1947 (U.S. Department of Agriculture, 1995). A small amount of timber harvesting has occurred in the basin in upper Squaw Creek and along the western margin of the basin since the establishment of the HBN station. Until 1940, the river corridor was heavily grazed by sheep and cattle, which resulted in some plant community alterations in the basin. However, grazing allotments in the basin have not been stocked since 1985, and range conditions have improved steadily (U.S. Department of Agriculture, 1995).

Historical Water-Quality Data and Time-Series Trends

The data set for the Minam River HBN station that was analyzed for this report includes 204 water-quality samples that were collected from January 1966 through August 1995. Samples were collected 2 to 14 times per year from 1966 to 1982 and quarterly from 1983 to 1995. Water-quality samples from the early part of the period of record probably were analyzed at a USGS district laboratory in Portland, Oreg. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and at the NWQL in Arvada, Colo., from 1976 to 1995. Daily discharge records for the Minam River (station 13331500) are available beginning in September 1965, and daily water temperature was measured from 1966 to 1985. Daily precipitation totals were measured at the station from 1990 through 1995.

Calculated ion balances for 204 samples that have complete major-ion analyses are shown in figure 21. Ion balances ranged from −31 to +16 percent, and 85 percent of samples had values in the ±10-percent range, indicating that the analytical measurements were of good quality. The average charge balance for all samples was −1.4 percent, and 60 percent of samples had slightly negative ion balances, indicating an excess of measured anions compared to cations. Natural water more commonly has an excess of cations because of the presence of unmeasured organic anions. An anion excess is more difficult to explain than a cation excess and may indicate a bias in one of the analytical measurements.

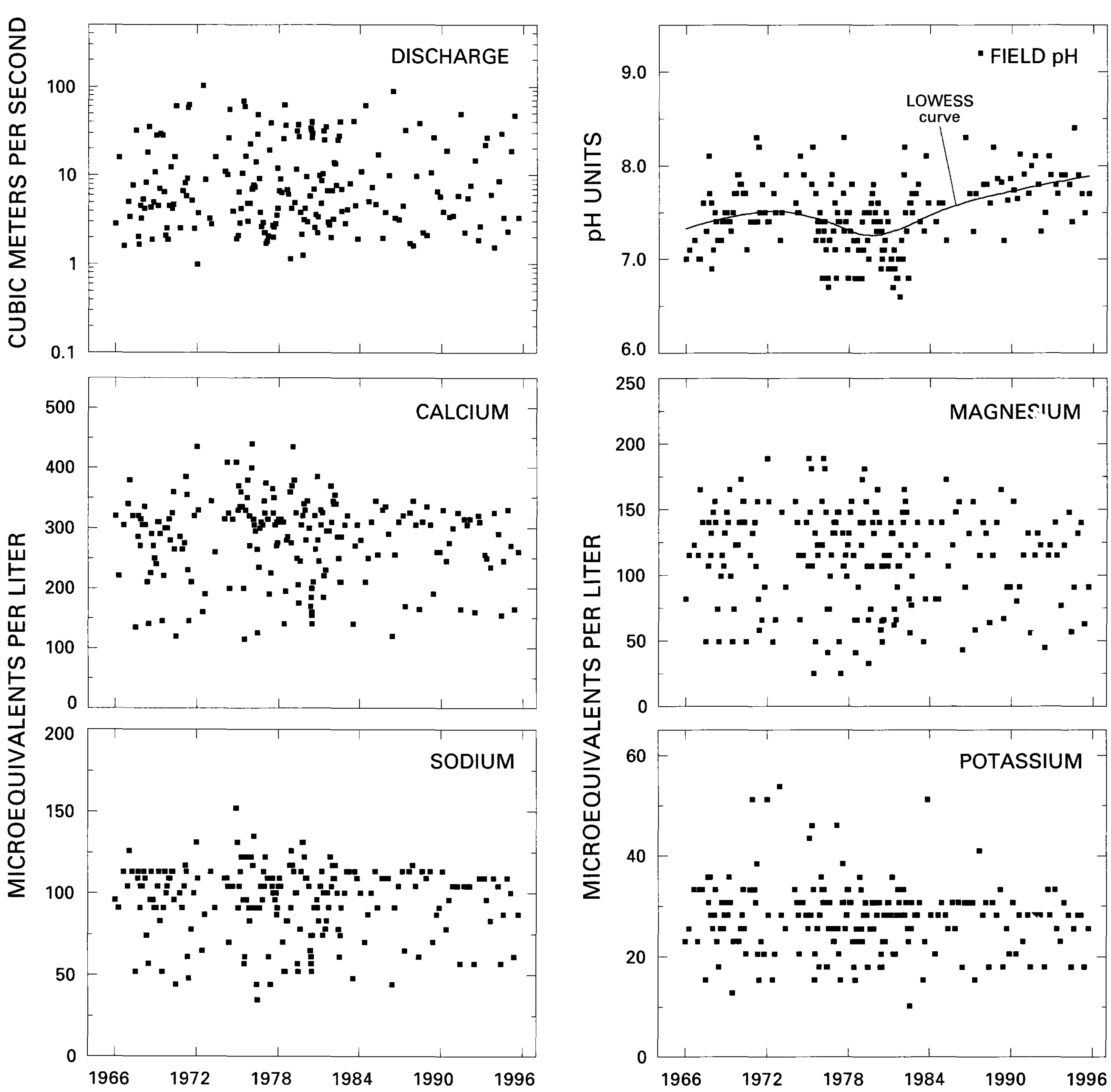


Figure 21. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in the Minam River, Oregon.

Time-series plots of the major dissolved constituents were inspected for evidence of other method-related effects (fig. 21). The most notable pattern was observed in sulfate concentrations, which were higher during the middle of the period of record, particularly during the 1980's. The high concentrations in the 1980's coincided with the period when sulfate was analyzed by the turbidimetric titration technique. In 1989, the NWQL determined that sulfate concentrations can be overestimated by this technique and changed the technique to ion chromatography in 1990 (Office of Water Quality Technical Memorandum No. 90.04, *Turbidimetric sulfate method*, issued December 21, 1989, at URL http://water.usgs.gov/admin/memo/). The bias was most pronounced in dilute waters, although it was not consistent among samples and seemed to be affected by other factors, such as color and turbidity (Schertz

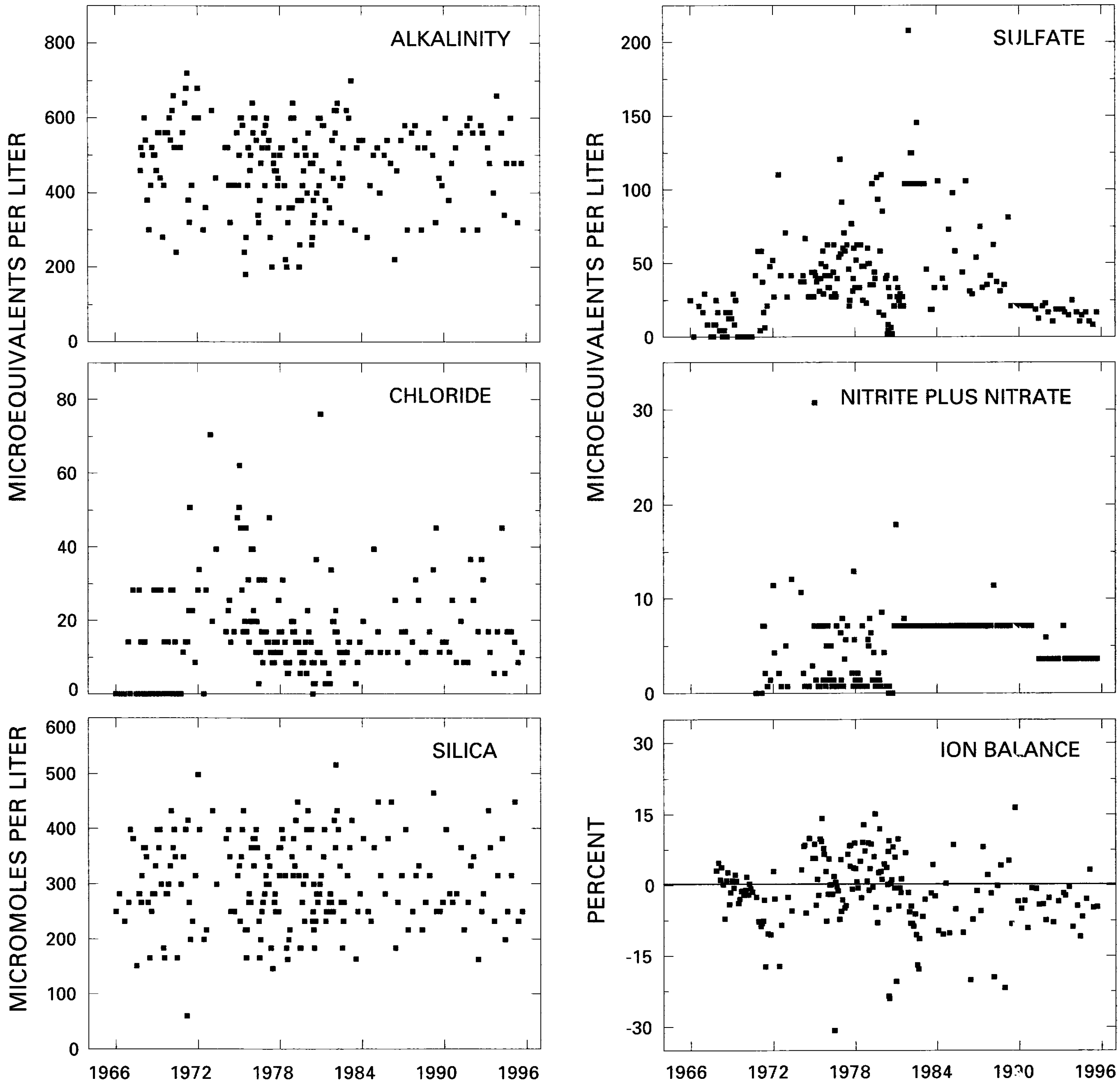


Figure 21. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in the Minam River, Oregon—Continued.

and others, 1994). In addition to the analytical bias, some of the elevated sulfate concentrations in 1982 and 1983 reflect an increase in the analytical reporting limit for sulfate from 21 µeq/L (1.0 mg/L) to 104 µeq/L (5.0 mg/L) during those 2 years of record.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Starky Experimental Station NADP site are presented in table 37. Precipitation chemistry at the NADP station, which is about 80 km southwest of the HBN station, is very dilute and slightly acidic and has a VWM pH of 5.3 for 12 years of record. The predominant cations in precipitation were hydrogen ion, ammonium, and sodium, which contributed 34, 20, and 19 percent of the total cation charge, respectively. The predominant anions were sulfate and nitrate, which accounted for

41 and 43 percent of the total anions, respectively. These results indicate that precipitation is a dilute mixture of strong acid anions derived from industrial emissions of sulfur and nitrogen compounds and from salt derived from marine aerosols.

Stream water in the Minam River is fairly dilute and moderately buffered; specific conductance ranged from 19 to 137 µS/cm and alkalinity ranged from 180 to 720 µeq/L (table 37). The major cations in stream water were calcium, magnesium, and sodium, and the major anion was bicarbonate. The predominance of these solutes in stream water, in addition to the relatively high concentrations of silica, is consistent with the weathering stoichiometry of plagioclase, hornblende, and biotite in the granitic rocks and more mafic minerals in rocks of the Columbia River Basalt Group. The median concentration of chloride in stream water was 14 µeq/L, which is about 8 times greater than the VWM concentration of 1.8 µeq/L in precipitation. Based on the difference between precipitation and runoff, evapotranspiration can account for no more than a threefold increase in the chloride concentration of precipitation, indicating that some stream-water chloride is derived from sources other than wet precipitation. Because land-use activities in the basin are minimal, the only plausible sources of additional stream-water chloride are dust from arid valleys surrounding the Wallowa Mountains (Turk and Spahr, 1991) and weathering of amphibole minerals in the granitic and basaltic bedrock (Peters, 1991). The median concentration of sulfate in stream water was 33 µeq/L compared to the VWM concentration of 4.6 µeq/L and was slightly higher than was expected based solely on the effects of evapotranspiration. As with chloride, these results may indicate that there are additional sources of stream-water sulfate, such as bedrock weathering or eolian dust. Alternatively, stream-water sulfate may be high relative to concentrations in precipitation because of analytical bias in the historical records rather than because of natural sources. Most concentrations of inorganic nitrogen species in stream water were similar to VWM concentrations in precipitation, indicating that not all atmospheric nitrogen is retained by vegetation and soil in the basin.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 38). Most weathering-derived solutes were negatively correlated with stream discharge, particularly calcium (rho = –0.649), sodium (rho = –0.643), and alkalinity (rho = –0.579). These results are consistent with a hydrologic system where weathering-enriched base flow is diluted by water from shallow or surficial sources during periods of increased discharge, particularly spring snowmelt. For the solutes, the strongest correlations were found among base cations, alkalinity and silica, which is consistent with the weathering stoichiometry of silicate minerals in the granitic and basaltic bedrock. A strong correlation between silica and magnesium (rho = 0.866) is somewhat unusual and may reflect the weathering of magnesium silicate minerals, such as biotite and hornblende, in the granitic rocks or mafic minerals in the basalt. Sulfate and chloride were weakly correlated with discharge and with the major solutes, supporting the assumption that most sulfate and chloride are derived from atmospheric deposition.

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 39. A statistically significant upward trend was detected in unadjusted field pH at the 0.01 probability level. The trend was similar for the unadjusted and flow-adjusted pH values, indicating that it was not caused by variations in stream discharge. The LOWESS curve in figure 21 shows that field pH was at a minimum in the late 1970's and that most of the trend was caused by an increase in pH during the 1980's. One possible explanation for the trend in stream-water pH was a change in atmospheric deposition. Lynch and others (1995) reported statistically significant downward trends in hydrogen ion and sulfate and chloride concentrations at several NADP stations in the Northwestern United States from 1980 to 1992. Although the upward trend in stream-water pH is consistent with the downward trend in precipitation acidity, trends were not detected in stream-water sulfate or chloride concentrations as might be expected if changes in atmospheric deposition were affecting stream-water chemistry. Alternatively, the trend in field pH may have been caused by a method-related factor, such as a change in field pH meters or electrodes. Some instrument-electrode systems produce erroneous readings, particularly when measuring pH in low-conductivity water (Office of Water Quality Technical Memorandum No. 81.08, *Electrodes for pH measurement in low-conductivity waters*, issued February 10, 1981, at URL

Table 37. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Minam River, Oregon, January 1966 through August 1995, and volume-weighted mean concentrations in precipitation collected at the Starky Experimental Station

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation VWM[a]
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Discharge, inst.	0.99	3.2	6.2	16	100	204	--
Spec. cond., field	19	42	52	56	137	204	3.6
pH, field	6.6	7.2	7.5	7.7	9.2	192	5.3[b]
Calcium	120	250	300	330	440	201	2.6
Magnesium	25	82	120	140	190	201	.9
Sodium	35	83	100	110	150	201	2.8
Potassium	10	23	28	31	54	203	.4
Ammonium	<.7	<.7	1.4	4.3	14	81	2.9
Alkalinity, laboratory	180	390	500	560	720	191	--
Sulfate	<2.1	17	33	53	210	203	4.6
Chloride	<2.8	8.5	14	20	76	201	1.8
Nitrite plus nitrate	<.7	1.4	5.7	7.1	31	162	4.8[c]
Silica	60	250	280	370	510	202	--

[a] Values are VWM concentrations for 1984–95.

[b] Laboratory pH.

[c] Nitrate only.

Table 38. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Minam River, Oregon, 1966 through 1995

[Q, discharge; Ca, calcium, Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl
pH	–0.241								
Ca	–.649	0.093							
Mg	–.414	.101	0.731						
Na	–.643	.214	.811	0.776					
K	–.468	.108	.571	.636	0.637				
Alk	–.579	.218	.754	.753	.784	0.600			
SO_4	–.026	–.139	.238	.165	.127	.146	0.038		
Cl	–.130	.171	.342	.411	.264	.296	.310	0.222	
Si	–.231	.056	.607	.866	.687	.623	.688	.170	0.362

http://water.usgs.gov/admin/memo/, accessed 1998). The absence of trends in the other stream-water solutes was not unexpected because of the pristine condition of the basin and the minimal amount of human activity during the past 30 years.

Table 39. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Minam River, Oregon, January 1966 through August 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, aluminum, iron, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	−0.02	0.662	--	--
pH, field	.02	.001	0.02	0.001
Calcium	−.5	.395	−.3	.369
Magnesium	<.1	.952	−.1	.653
Sodium	<.1	.702	−.1	.467
Potassium	<.1	.582	<.1	.554
Alkalinity, laboratory	<.1	.266	.2	.757
Sulfate	.4	.203	([a])	--
Chloride	<.1	.902	([a])	--
Nitrite plus nitrate	([b])	--	--	--
Silica	<.1	.289	.1	.658

[a] Flow model not significant at $\alpha = 0.10$.

[b] Insufficient data to calculate trend.

Synoptic Water-Quality Data

Chemical results of the surface-water synoptic sampling of August 13–18, 1993, are listed in table 40, and locations of sampling sites are shown in figure 20. During the synoptic sampling, discharge at the HBN station was 2.9 m^3/s compared to the median daily discharge of 3.2 m^3/s for August (Lawrence, 1987), indicating that the basin was sampled during near normal flow conditions for that time of year. Most of the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were between the first-quartile and median concentrations reported for the station during the entire period of record, except for the chloride concentration, which was lower (table 37). The predominant solutes at the upstream sampling sites were calcium and bicarbonate, and the concentrations bracketed the concentrations measured at site 1. The average ion balance for all the synoptic samples was 1.0 percent (ranging from −1.7 to 4.1 percent), indicating that unmeasured ions, such as organic anions, did not contribute greatly to the ionic content of stream water during the synoptic sampling.

Variations in the concentrations of the major solutes indicate that bedrock type seems to be the predominant factor controlling spatial variability in surface-water chemistry. This can be seen by comparing the chemistry of tributaries draining granitic rocks (sites 4–8) with tributaries that drain only basaltic rocks (sites 9 and 10). For example,

Table 40. Physical properties and major dissolved constituents from surface-water sampling sites in the Minam River Basin, Oregon, collected August 13–18, 1993

[Site locations shown in fig. 20; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate; Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]	Remarks
1	13331500	2.9	54	7.0	300	100	91	26	500	17	7.9	<0.4	270		Downstream from wilderness boundary
2	453007117411000	--	54	8.0	300	100	91	28	510	17	8.2	<.4	270	BG, MC	Mixed lithology
3	452356117401300	2.5	51	7.8	300	79	83	28	470	20	8.2	<.4	230	BG, MC	Mixed lithology
4	452049117372600	1.9	50	7.5	320	70	110	28	450	19	8.2	<.4	230	BG, MC	Granite
5	450852117213500	.043	34	6.8	200	18	65	13	200	96	2.8	<.4	140	BG, MC	Granite
6	450853117233000	--	32	6.9	200	28	52	20	290	15	3.1	1.1	130	BG, T	Granite
7	451230117293500	.11	41	7.0	270	37	57	22	350	9.2	3.1	<.4	150	BG, T	Granite
8	451621117320000	.33	38	7.0	250	49	83	25	350	10	6.2	<.4	180	BG, T	Granite
9	452358117402200	.76	58	7.9	290	160	140	26	570	10	6.5	<.4	430	BG, T	Basalt
10	453013117410000	.051	61	7.8	280	180	140	38	580	12	6.8	<.4	520	BG, T	Basalt

[a] Criteria used in selection of sampling sites: BG = bedrock geology, MC = main channel, T = tributary.

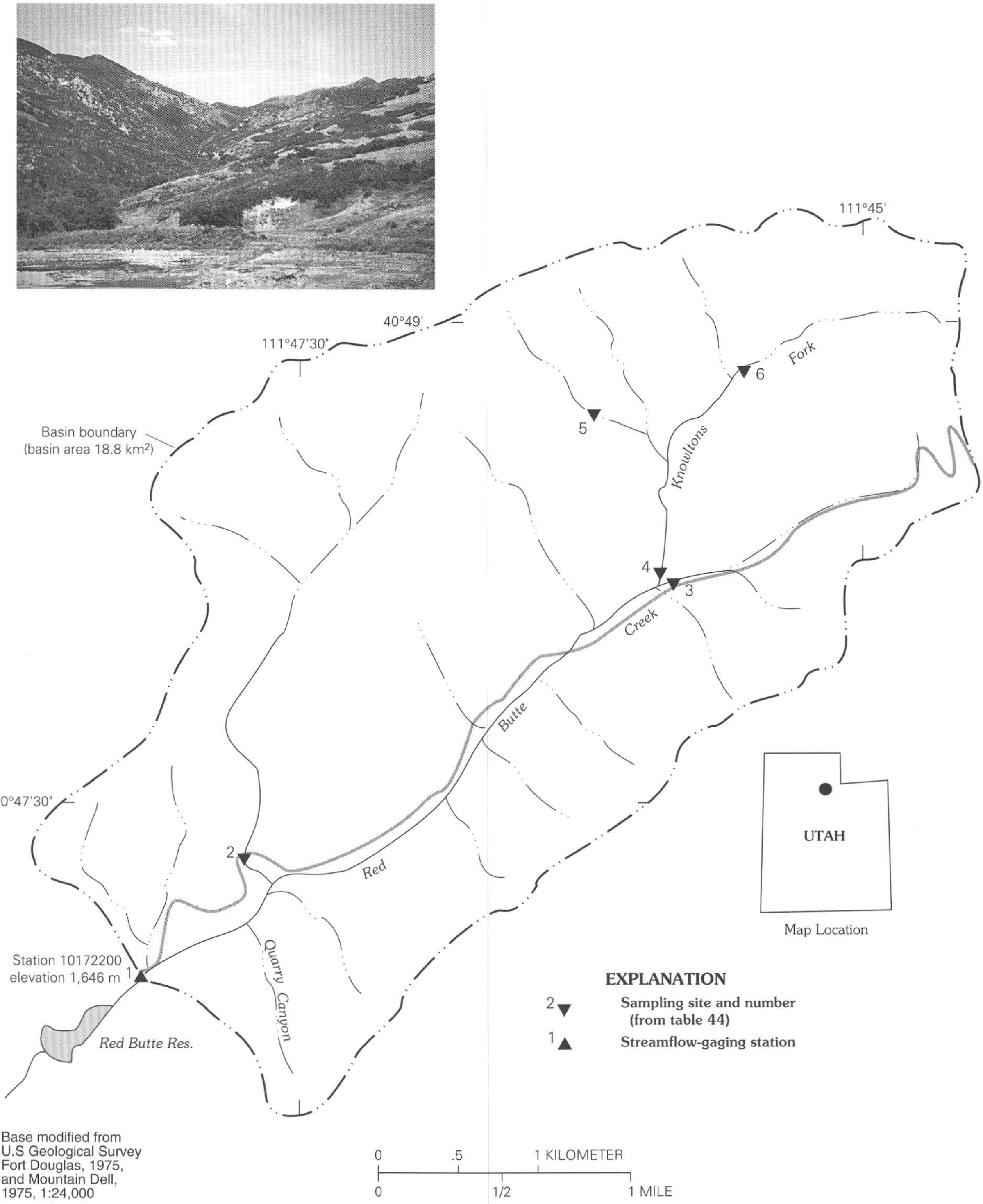
magnesium concentrations were, on average, 4 times higher in streams draining basalt than in streams draining granite and sodium concentrations were about 2 times higher. Alkalinity and silica averaged 575 µeq/L and 475 µmol/L, respectively, for the basaltic streams compared to 328 µeq/L and 166 µmol/L, respectively, for the granitic streams. Although data are available for only two tributaries draining basalt, this pattern seems to reflect the higher weathering rates and more mafic composition of silicate minerals in the basalt compared to plagioclase and hornblende in the granite. Concentrations of the weathering-derived constituents in the five samples collected along the main channel of the Minam River (sites 1–5) generally decreased with increasing distance upstream from the HBN station. This pattern is consistent with the concept that granitic bedrock in the upper part of the basin contains slower weathering minerals than the basaltic rocks in the lower part of the basin. Another contributing factor is that stream water in the upper part of the basin should have a shorter contact time with soils and bedrock than stream water in lower reaches of the basin. The one exception to the pattern in stream chemistry was sulfate, which was 5 times higher at the headwaters site (site 5) than at the HBN station (site 1). Because sulfate concentrations were not elevated at any of the other main channel or tributary sites, there is probably a local source of sulfate in the headwaters of the basin, the most likely being several mineralized veins that are mapped on the ridgeline just above the sampling site (Weis and others, 1976). Chloride and nitrate concentrations were uniformly low at all the sampling sites; chloride ranged from 2.8 to 8.2 µeq/L, and nitrate concentrations were less than 1.2 µeq/L at all the sampling sites (table 40). These results are consistent with the low concentrations of chloride and nitrate in precipitation and provide no evidence that human-related activities affected stream-water concentrations of these solutes during the sampling period.

Red Butte Creek at Fort Douglas near Salt Lake City, Utah (Station 10172200)

Site Characteristics and Land Use

The Red Butte Creek HBN Basin is located in the Middle Rocky Mountains physiographic province in the western foothills of the Wasatch Range in northern Utah (fig. 22). The 18.8-km^2 basin ranges in elevation from 1,646 to 2,524 m and drains a narrow-based canyon that has steep valley walls (Ehleringer and others, 1992). The HBN station is located just upstream from Red Butte Reservoir and on the east edge of Salt Lake City, Utah, at latitude 40°46'48" and longitude 111°48'19". Red Butte Creek flows southwest into the Jordan River, which drains into the Great Salt Lake, and has a channel length of about 7.6 km upstream from the HBN station and an average stream gradient of 74.3 m/km. Mean monthly discharge varies from a minimum of 0.052 m^3/s in September, when most flow is derived from ground water, to 0.37 m^3/s in May during the peak of spring snowmelt. Average annual runoff from the basin was 20 cm from 1964 through 1995 (ReMillard and others, 1996). The climate is characterized by hot, dry summers and long, cold winters. Average monthly air temperatures range from –0.7°C in January to 25.4°C in July (National Climatic Data Center, 1997). Variation in annual precipitation in the basin is strongly related to elevation and ranges from about 50 cm at the lower elevations to about 90 cm at the higher elevations (Ehleringer and others, 1992). Most precipitation occurs as snow in winter and spring; March (5.7 cm) is generally the wettest month and July (1.8 cm) the driest (National Climatic Data Center, 1997).

The basin is in the Southern Rocky Mountains ecoregion (Bailey and others, 1994) and is dominated by four distinct plant communities—riparian, grass-forb, oak-maple, and coniferous (Ehleringer and others, 1992). Riparian communities consist chiefly of western water birch, mountain alder, and occasional dense stands of red osier dogwood and willow. The grass-forb communities dominate large open areas on south-facing slopes below 1,800 m. The principal grass species is bluebunch wheatgrass; there also are occasional big sagebrush, squawbush, and bitterbrush. Slopes above 1,800 m are dominated by communities of Gambel oak and bigtooth maple that grow in dense thickets along the canyon walls. The coniferous communities grow chiefly on north-facing slopes above 2,000 m and are dominated by pure or mixed stands of Douglas-fir and white fir with some aspen. Soils in the basin are classified as Mollisols and consist of well-drained soils that are formed in colluvium and alluvium derived from mixed sedimentary rocks (Woodward, 1974). There is little profile



Base modified from
U.S Geological Survey
Fort Douglas, 1975,
and Mountain Dell,
1975, 1:24,000

Figure 22. Map showing the study area in the Red Butte Creek Basin and photograph showing the basin landscape.

development, and most soils consist of a layer of dark- to reddish-brown, cobbly silt loam or cobbly loamy sand overlying bedrock. Depth of soils is irregular, varying from 50 cm on south-facing slopes to as much as 150 cm on north-facing slopes. Soils are neutral to moderately alkaline (pH 6.1 to 8.4), and the deeper horizons have 55 to 80 percent coarse fragments that, in the more alkaline soils, are coated with lime (Woodward, 1974).

Bedrock underlying the basin includes southeast-dipping beds of Weber Quartzite of Pennsylvanian age, Park City Formation of Permian age, Thaynes and Ankareh Formations of Triassic age, and Nugget Sandstone and Twin Creek Limestone of Jurassic age that form the north limb of a syncline whose axis trends roughly parallel to Red Butte Canyon (Van Horn and Crittenden, 1987). The Weber Quartzite and Park City Formation crop out in the northern part of the basin and consist of sandy limestone, calcareous sandstone, phosphatic shale, and cross-bedded quartzite. The Thaynes Formation, which crops out northwest of the stream, consists of nodular limestone, limy siltstone, and sandstone. The valley bottom is primarily underlain by several members of the Ankareh Formation, which include layers of reddish-brown to reddish-purple shale, siltstone, and sandstone. Massive exposures of buff-colored Nugget Sandstone crop out on the southeast side of the creek, and silty limestone of the Twin Creek Limestone forms the ridge on the southeast side of the basin.

The basin drains the northwest part of Salt Lake County in Utah immediately adjacent to Salt Lake City and is within the boundaries of the Red Butte Canyon Research Natural Area, which is administered by the Wasatch National Forest. The goal of the Research Natural Area Program is to protect and preserve a representative array of all important natural ecosystems and to conduct research on ecological processes in these areas (Ehleringer and others, 1992). The history of Red Butte Canyon, which is discussed in detail by Ehleringer and others (1992), is unusual in that it has been protected by the Federal Government for almost a century. Land in the canyon was acquired by the Federal Government between 1888 and 1909 and was used as a water source by the U.S. Army at Fort Douglas until 1991. To protect the watershed and its water quality, the Army closed the basin to logging and grazing in the early 1900's, after which time the only land-use activity was a small sandstone quarry that was operated intermittently by the Army until 1940. In 1969, the U.S. Forest Service acquired the land in the basin and designated it as a research natural area primarily because it is one of the last remaining undisturbed basins in the Great Basin. The canyon also is unique in that it is a relatively pristine watershed adjacent to a major metropolitan area (Ehleringer and others, 1992). Since being acquired by the Forest Service, the basin has remained closed to the public and has been used primarily as a research site for biologists at the University of Utah (URL at http://ecophys.biology.utah.edu/red_butte.html). The only substantial change that has occurred in the basin since the establishment of the HBN station was related to a high discharge in May 1983 that was caused by heavy snows in May followed by unusually warm temperatures (Ehleringer and others, 1992). The high flows severely eroded streambanks, destroyed beaver dams, knocked down riparian vegetation, and caused landslides in the canyon. Sediment flow in the creek increased almost 300 times, which resulted in the formation of a delta at the mouth of Red Butte Reservoir immediately downstream from the HBN station.

Historical Water-Quality Data and Time-Series Trends

The data set for the Red Butte Creek HBN station analyzed for this report includes 262 water-quality samples that were collected from October 1964 through September 1995. Samples were collected about monthly from 1965 to 1982 and quarterly from 1983 to 1995. Water-quality samples from the early part of the period of record were analyzed at a USGS district laboratory in Salt Lake City, Utah, that operated until 1973 (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City facility from 1973 to 1975 and at the NWQL in Arvada, Colo., from 1976 to 1995. Daily discharge records for Red Butte Creek (station 10172200) are available beginning in October 1963.

Calculated ion balances for 236 samples that have complete major-ion analyses are shown in figure 23. Ion balances ranged from −13 to +17 percent, and 95 percent of samples had values in the ±5-percent range, indicating that the analytical measurements were of high quality. The average charge balance for all samples was 0.3 percent, indicating that unmeasured constituents, such as organic anions, did not contribute substantially to the ion balance of stream water at this HBN station. Time-series plots of the major constituents were inspected for evidence of method-related effects (fig. 23). The only notable patterns were a few high potassium concentrations in the 1970's and a slight increase in the calculated ion balance in the latter part of the record. The high sulfate concentrations near the end of the period of record probably are related to an extended drought in the region that occurred from 1987 to 1992 (National Climatic Data Center at URL

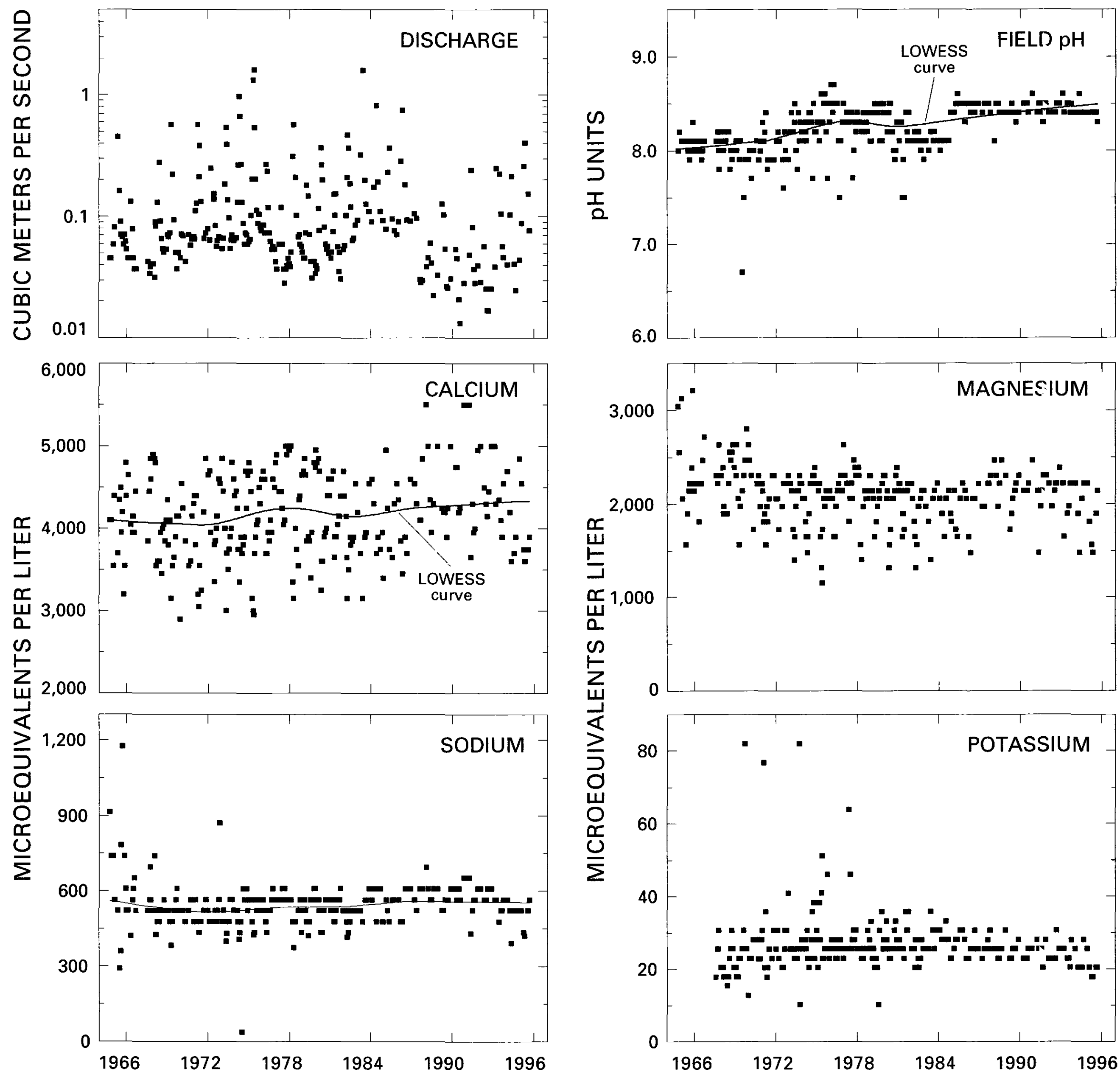


Figure 23. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Red Butte Creek, Utah.

http://www.ncdc.noaa.gov, accessed 1998) rather than to analytical bias introduced by the turbidimetric technique (Schertz and others, 1994). The stepped pattern in the concentrations of nitrite plus nitrate was caused by changes in the analytical reporting limit for this constituent that occurred in 1982 and again in 1991.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Murphy Ridge NADP station are presented in table 41. Precipitation chemistry at the NADP station, which is about 92 km northeast of the HBN station, is dilute and slightly acidic

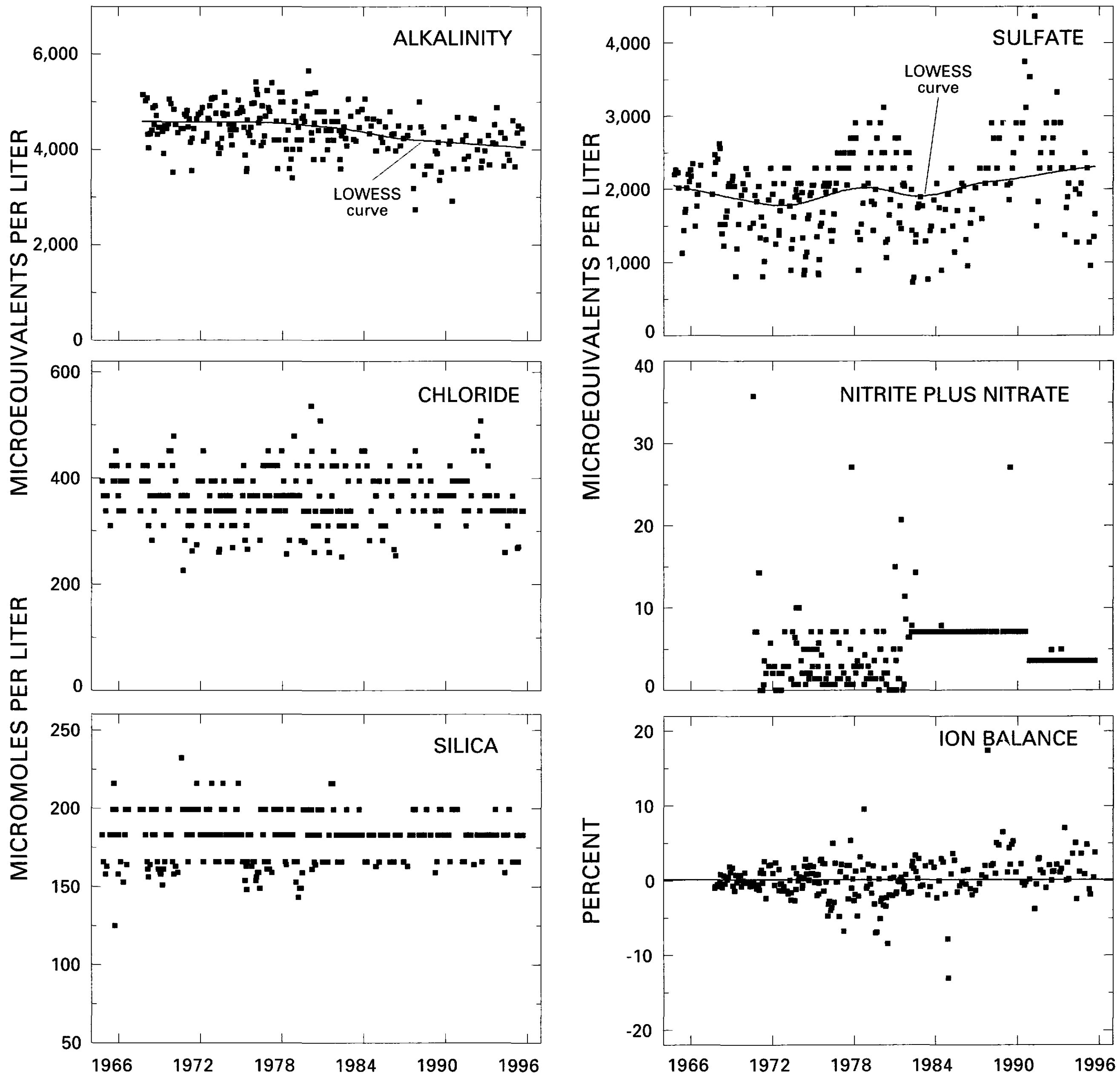


Figure 23. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Red Butte Creek, Utah—Continued.

and has a VWM pH of 5.1 for 10 years of record. The predominant cations in precipitation were calcium and sodium, which contributed 36 and 24 percent of the total cation charge, respectively. The predominant anions were sulfate and nitrate, which accounted for 50 and 34 percent of the total anions, respectively. The predominance of strong acid anions in precipitation indicates that precipitation at the NADP station may be affected by industrial emissions of sulfur and nitrogen compounds that cause acid rain.

Stream water in Red Butte Creek is moderately concentrated and strongly buffered; specific conductance ranged from 390 to 750 µS/cm, and alkalinity ranged from 2,740 to 5,660 µeq/L (table 41). The major solutes in stream water were calcium and bicarbonate, which accounted for more than 60 percent of the total ionic charge. The predominance of these solutes in stream water is attributed to the weathering of carbonate minerals in the underlying sedimentary rocks. The median chloride and sulfate concentrations in stream water were 370 and 2,000 µeq/L, respectively, and were considerably greater than the VWM concentrations of chloride (8.7 µeq/L) and sulfate (28 µeq/L) in precipitation, indicating that these solutes probably are primarily derived from sources in the basin. Because land-use activities are minimal upstream from the station, the only source of these solutes other than atmospheric deposition is weathering of salts and sulfate minerals in the marine sedimentary rocks, the most likely source being evaporite beds that locally are present in the Ankareh Formation (Van Horn and Crittenden, 1987). Concentrations of inorganic nitrogen species in stream water were lower than the VWM concentrations in precipitation, which is consistent with the pristine condition of the basin and indicates that most atmospheric nitrogen is retained by vegetation and soils in the basin.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 42). Most weathering-derived solutes had strong inverse correlations with stream discharge, particularly magnesium (rho = –0.777) and sulfate (rho = –0.816). These results are consistent with a hydrologic system where weathering-enriched base flow is diluted by water from shallow or surficial sources during periods of

Table 41. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Red Butte Creek, Utah, October 1964 through September 1995, and volume-weighted mean concentrations in wet precipitation collected at the Murphy Ridge Station, Utah

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation VWM[a]
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Discharge, inst.	0.013	0.049	0.071	0.13	1.6	261	--
Spec. cond., field	390	560	610	640	750	261	12
pH, field	6.7	8.1	8.3	8.4	8.7	260	5.1[b]
Calcium	2,900	3,850	4,150	4,550	5,500	262	26
Magnesium	1,150	1,980	2,140	2,220	3,210	262	5.2
Sodium	39	480	520	570	1,170	260	17
Potassium	10	23	26	28	82	242	.9
Ammonium	<.7	1.1	2.1	3.6	31	101	15
Alkalinity, laboratory	2,740	4,160	4,440	4,740	5,660	239	--
Sulfate	730	1,520	2,000	2,290	4,370	262	28
Chloride	230	340	370	390	540	260	8.7
Nitrite plus nitrate	<.7	2.1	3.6	7.1	36	207	19[c]
Silica	120	170	180	180	230	262	--

[a] Values are VWM concentrations for 1986–95.

[b] Laboratory pH.

[c] Nitrate only.

Table 42. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Red Butte Creek, Utah, 1965 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl
pH	0.018								
Ca	–.563	0.132							
Mg	–.777	–.213	0.494						
Na	–.639	.040	.512	0.619					
K	–.147	–.050	.233	.144	0.323				
Alk	–.163	–.193	.424	.391	.171	0.163			
SO_4	–.816	.100	.788	.659	.657	.162	0.171		
Cl	–.474	–.098	.551	.559	.514	.251	.266	0.573	
Si	–.272	–.139	.010	.307	.274	.242	.046	.051	0.062

increased discharge, particularly spring snowmelt. For the solutes, the strongest correlations were between the base cations and sulfate, and the weakest correlations were with silica concentrations. The strong correlation between sulfate and calcium is consistent with the weathering stoichiometry of gypsum or anhydrite in evaporite beds within the shale. Chloride also was positively correlated with base cations and sulfate, supporting the assumption that most chloride is derived from weathering. Alkalinity was weakly correlated with the major cations, which was somewhat unexpected because of the abundance of carbonate bedrock in the basin.

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 43. Statistically significant trends were detected in field pH and unadjusted calcium, sodium, alkalinity, and sulfate concentrations at the 0.01 probability level. The trend in flow-adjusted pH was not calculated because the flow model was not statistically significant at the 0.10 probability level. Trends were similar for the unadjusted and flow-adjusted calcium, alkalinity, and sulfate concentrations, indicating that they probably were not caused by variations in stream discharge. The trend in sodium was not statistically significant using the flow-adjusted concentrations; however, the flow-adjusted magnesium concentrations showed a significant downward trend that was not detected in the unadjusted concentrations. The similarity in the timing and magnitude of the trends as shown by the LOWESS curves in figure 23 indicates that stream-water trends at this HBN station may have been related to a similar environmental factor. The trends probably were not caused by changes in atmospheric deposition based on the dilute chemistry of precipitation at the nearby NADP station compared to stream-water chemistry at the HBN station. Similarly, changes in land use probably were not an important factor because the basin has remained largely undisturbed since the early 1900's (Ehleringer and others, 1992). Assuming that analytical bias also is negligible, perhaps the most plausible explanation for the trends in water quality is climate variability. Although a detailed analysis of climate variability is beyond the scope of this report, climatic records for the Wasatch Mountain region indicate that there was record precipitation from 1982 through 1986 that was followed by an extended period of drought that lasted from about 1987 through 1992 (National Climatic Data Center at URL http://www.ncdc.noaa.gov, accessed 1998).

Synoptic Water-Quality Data

Chemical results of the surface-water synoptic sampling of August 9, 1991, are listed in table 44, and locations of sampling sites are shown in figure 22. During the synoptic sampling, discharge at the HBN station was 0.03 m^3/s compared to the median daily discharge of 0.09 m^3/s for July (Lawrence, 1987), indicating that the basin was sampled during low-flow conditions for that time of year. Most of the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were between the first-quartile and median values that were reported for the station during the entire period of record, except for sulfate and chloride concentrations, which were lower (table 41). The upstream sampling sites were similar in composition to stream water at site 1, with calcium and magnesium the predominant cations and bicarbonate and sulfate the predominant anions. Ion balances for all but one synoptic samples were positive, ranging from −1.1 to 6.1 percent. This result was somewhat unexpected on the basis of high solute concentrations of the samples and may indicate a bias in one of the analytical measurements. The results in table 44 indicate that concentrations of the major solutes did not vary markedly among the sampling sites, probably because of the abundance of limestone bedrock. For example, calcium concentrations ranged from 3,800 to 4,350 µeq/L, magnesium ranged from 1,520 to 2,480 µeq/L, and alkalinity ranged from 3,560 to 4,960 µeq/L. Sulfate and sodium had a slightly wider range of concentrations than the divalent cations and alkalinity, which may reflect the distribution of different rock types in the basin. For example, the lowest sulfate concentration was measured at site 5, which chiefly drains quartzite and limestone of the Weber Quartzite, whereas the highest concentration was measured in the lowest part of the canyon (site 1), which is underlain by shales, siltstones, sandstones, and some evaporites belonging to the Ankareh Formation. Sodium also seemed to be slightly higher at sites draining shales (sites 1–3) compared to sites primarily draining quartzite and limestone (sites 4–6). In contrast to sulfate, calcium and alkalinity concentrations were lower at the HBN station (site 1) compared to most of the upstream sampling sites, perhaps also reflecting variations in geology. Nitrate concentrations at all of the sampling sites were less than the analytical reporting limit of 3.6 µeq/L, which is consistent with the minimal amount of land use in the basin.

Table 43. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Red Butte Creek, Utah, October 1964 through September 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, aluminum, iron, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	−0.001	0.045	--	--
pH, field	.02	.001	([a])	--
Calcium	19.2	.001	15.0	0.001
Magnesium	<.1	.084	−6.6	.001
Sodium	<.1	.001	1.2	.021
Potassium	<.1	.269	([a])	--
Alkalinity, laboratory	-12.8	.004	−13.7	.002
Sulfate	16.1	.001	11.8	.001
Chloride	<.1	.659	−.4	.539
Nitrite plus nitrate	([b])	--	--	--
Silica	<.1	.543	−.2	.073

[a] Flow model not significant at α = 0.10.

[b] Insufficient data to calculate trend.

Table 44. Physical properties and major dissolved constituents from surface-water sampling sites in the Red Butte Creek Basin, Utah, collected August 9, 1991

[Site locations shown in fig. 22; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; NO_3, nitrate; Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; Fm, Formation; <, less than]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Si	Criteria[a]	Remarks
1	10172200	0.031	580	8.4	3,800	2,160	520	24	3,560	2,060	310	<3.6	180	BG	Ankareh Fm, Nugget Sandstone
2	404716111474500	.0076	640	8.2	4,250	2,480	700	23	4,760	1,420	420	<3.6	200	MT, BG	Thaynes Fm, Ankareh Fm
3	404811111455000	.0059	540	8.2	3,950	1,520	570	23	4,500	1,000	340	<3.6	220	MT, BG	Ankareh Fm
4	404812111455400	.021	570	8.3	4,250	2,160	320	17	4,560	1,560	280	<3.6	150	MT, BG	Weber Quartzite, Park City Fm
5	404846111461400	.0011	500	8.4	3,150	1,760	260	19	4,520	500	280	<3.6	130	BG	Weber Quartzite
6	404855111453200	.0014	590	8.3	4,350	2,000	260	17	4,960	1,190	220	<3.6	160	BG	Park City Fm

[a] Criteria used in selection of sampling sites: BG = bedrock geology, MT = major tributary.

Andrews Creek near Mazama, Washington (Station 12447390)

Site Characteristics and Land Use

The Andrews Creek HBN Basin is located in the Northern Rocky Mountains physiographic province in the Cascade Mountains in northern Washington (fig. 24). The 57-km^2 basin drains a V-shaped valley and rugged mountainous terrain that ranges in elevation from 1,311 m at the HBN station to 2,647 m at the summit of Remmel Mountain. The HBN station is located 32 km northeast of Mazama, Wash., at latitude 48°49'23" and longitude 120°08'41". Andrews Creek flows southeast into the Chewuch River, a tributary of the Columbia River, and has a channel length of 13.5 km upstream from the HBN station and an average stream gradient of 55.2 m/km. The main channel is perennial, and mean monthly discharge varies from a minimum of 0.10 m^3/s in February to 4.22 m^3/s in June during peak snowmelt. Average annual runoff from the basin was 48 cm from 1968 through 1995 (Wiggins and others, 1996). The climate is characterized by cold, wet winters and dry, moderate summers. Mean annual temperatures for the Cascade Mountains range from 4 to 10°C (Nelson, 1991). Precipitation varies strongly with season and elevation. Average annual precipitation ranges from about 51 cm at low elevations to as much as 165 cm at the highest elevations in the mountains (U.S. Department of Agriculture, 1989). About 80 percent of precipitation in the mountains falls during the winter months (October to April) as snow (Nelson, 1991).

The basin is in the subalpine forest zone of the Cascade ecoregion (Bailey and others, 1994). Most forests in the basin are dominated by subalpine fir and Engelmann spruce and have variable amounts of lodgepole pine, ponderosa pine, Douglas-fir, and Pacific silver fir. Common understory species are beargrass, huckleberry, and serviceberry, and a ground cover of pinegrass, whortleberry, and lupine. Closer to timberline, forest communities are dominated by whitebark pine on southerly aspects and subalpine larch on northerly aspects; the understory consists of heathers, dwarf willows, and sedges. Timberline extends to about 2,200 m, above which vegetation is mostly lichens, forbs, and alpine shrubs. Soils in the basin are predominantly Cryoborolls and Cryochrepts that formed in glacial deposits and residuum from the granitic bedrock (Okanogan National Forest, written commun., 1998). In general, the soils are moderately deep (70 to 130 cm), are slightly acidic (pH 5.6 to 6.4), and consist of as much as 50 percent rock fragments. A typical profile has a surface layer of dark-brown silt loam usually 25 to 30 cm thick overlying a subsoil of yellowish-brown, fine sandy loam to gravelly loamy sand.

Bedrock underlying the basin is intrusive igneous rocks of Cretaceous age (Staatz, 1971). The predominant rock types are quartz monzonite and quartz diorite, which are generally light gray or light pinkish gray, medium to coarse grained, and locally porphyritic. The principal minerals are plagioclase, quartz, and perthite, and the accessory minerals are biotite, muscovite, garnet, apatite, magnetite, and chlorite. Several types of dikes that are andesitic, basaltic, and pegmatitic in composition are widely scattered in the quartz monzonite. Mineral deposits are widespread throughout the Pasayten Wilderness Area; however, no mineralized areas are mapped in the Andrews Creek Basin (Staatz, 1971). Most of the Pasayten Wilderness was intensely glaciated during the Pleistocene.

The basin drains the northwestern part of Okanogan County in Washington and is entirely in the boundaries of the Pasayten Wilderness Area, which is administered by the Methow Ranger District of the Okanogan National Forest. No motorized vehicles are allowed in the wilderness, and the HBN station can be reached by a 5.6-km pack trail that starts near the mouth of Andrews Creek. Access upstream from the station is limited to a pack trail that parallels the main channel of Andrews Creek up to Andrews Pass along the northern basin divide. The trail generally is free of snow from July through October, and winter access is limited to skis and snowshoes. Land use in the basin is limited to dispersed recreational activities and some livestock grazing (Okanogan National Forest, written commun., 1998). The trail along Andrews Creek is heavily used by hikers, horseback riders, pack animals, and livestock from July through September because it is one of the main access trails into the interior of the Pasayten Wilderness. Cattle grazing has been allowed in the basin since the establishment of the wilderness in 1968, although prior to this time, the area was heavily grazed by sheep. In even years, about

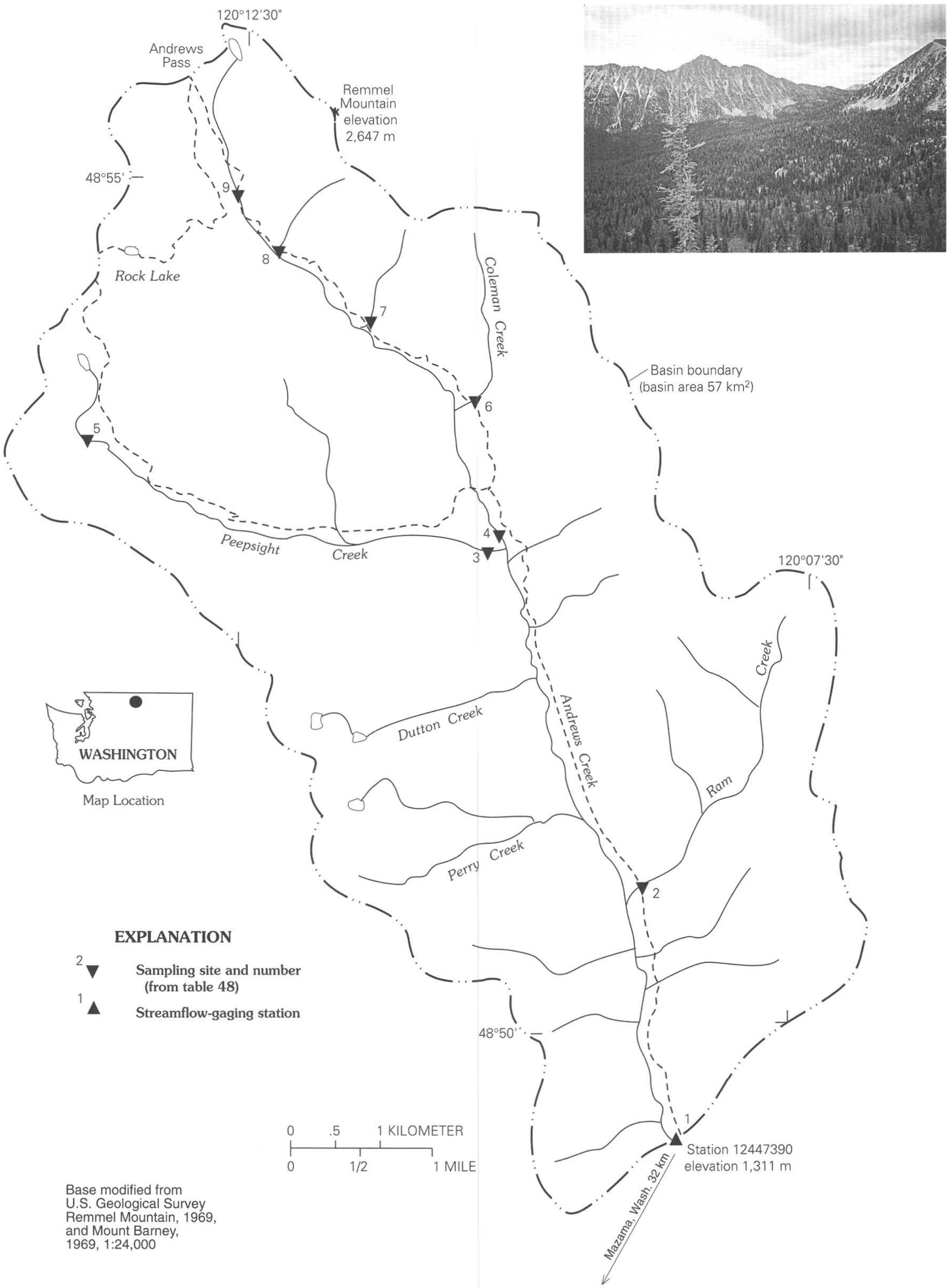


Figure 24. Map showing the study area in the Andrews Creek Basin and photograph showing the basin landscape.

320 cattle are permitted to graze in the northeastern part of the basin from mid-July to mid-September (Okanogan National Forest, written commun., 1998). In odd years, cattle are allowed to pass through the basin enroute to grazing allotments in other parts of the wilderness. No grazing occurred in the basin from 1995 through 1997.

Historical Water-Quality Data and Time-Series Trends

The data set for the Andrews Creek HBN station that was analyzed for this report includes 165 water-quality samples that were collected from December 1971 through August 1995. Samples were collected monthly from 1974 to 1982 and quarterly from 1983 to 1995. Water-quality samples collected prior to 1973 probably were analyzed at a USGS district laboratory in Portland, Oreg. (Durum, 1978). After establishment of the central laboratory system, samples were analyzed at the Salt Lake City, Utah, laboratory from 1973 to 1975 and at the NWQL in Arvada, Colo., from 1976 to 1995. Daily discharge records for Andrews Creek (station 12447390) are available beginning in June 1968.

The North Fork Quinault River (12039300) was another HBN station in Washington that operated until 1986 when the gaging station was destroyed by a flood. Over 160 water-quality samples were collected at the North Fork Quinault River from September 1965 through August 1986, and discharge records are available from November 1964 though August 1986.

Calculated ion balances for 156 samples that have complete major-ion analyses are shown in figure 25. Ion balances ranged from –22 to 16 percent, and 85 percent of samples had values in the 10-percent range, indicating that the analytical measurements were of good quality. The average charge balance for all samples was –3.7 percent, and almost 75 percent of samples had a slight excess of measured cations compared to measured anions, indicating that unmeasured constituents, such as organic anions, are an important component of stream water at this HBN station. Time-series plots of the major constituents were inspected for evidence of method-related effects (fig. 25). Some notable patterns are evident in field pH values and in sulfate and chloride concentrations. The scatter in field pH values decreased distinctly beginning in 1984, probably because of improvements in field pH meters and electrodes (Office of Water Quality Technical Memorandum No. 81.08, *Electrodes for pH measurement in low-conductivity waters*, issued February 10, 1981, at URL http://water.usgs.gov/admin/memo/, accessed 1998). Sulfate concentrations were low and had considerably less data scatter at the end of the record, perhaps because of the change in analytical technique to ion chromatography in 1990. Prior to 1990, a number of different analytical techniques were used for sulfate, including titrimetry before 1976, colorimetry from 1976 to 1982, and turbidimetric titration from 1983 to 1989 (Fishman and others, 1994). Assuming that sulfate concentrations determined by ion chromatography were historically the most accurate, the temporal pattern in sulfate indicates that most of the earlier analytical techniques probably caused a positive bias in the measured sulfate concentrations. The high chloride concentrations evident in the early part of the record are coincident with the period when samples were analyzed at the Salt Lake City, Utah, laboratory, indicating the possibility of analytical bias.

The median concentrations and ranges of major dissolved constituents in stream water collected at the HBN station and VWM concentrations in wet-only precipitation measured at the Cascades National Park NADP station are presented in table 45. Precipitation chemistry at the NADP station, which is about 100 km southwest of the HBN station, is very dilute and slightly acidic and had a VWM pH of 5.1 for 12 years of record. The predominant cations in precipitation were hydrogen and sodium, which contributed 42 and 30 percent of the total cation charge, respectively. The predominant anions were sulfate and chloride, which each accounted for 37 percent of the total anions. These results indicate that precipitation is a dilute mixture of acids derived from industrial emissions of sulfur and from salt derived from marine aerosols.

Stream water in Andrews Creek is dilute and weakly buffered; specific conductance ranged from 18 to 79 µS/cm, and alkalinity ranged from 160 to 700 µeq/L (table 45). The major cation in stream water was calcium, and the major anion was bicarbonate. The predominance of calcium compared to sodium in stream water is inconsistent with simple stoichiometric weathering of the predominant silicate minerals in the granitic bedrock. This inconsistency between bedrock mineralogy and stream chemistry has been noted at a

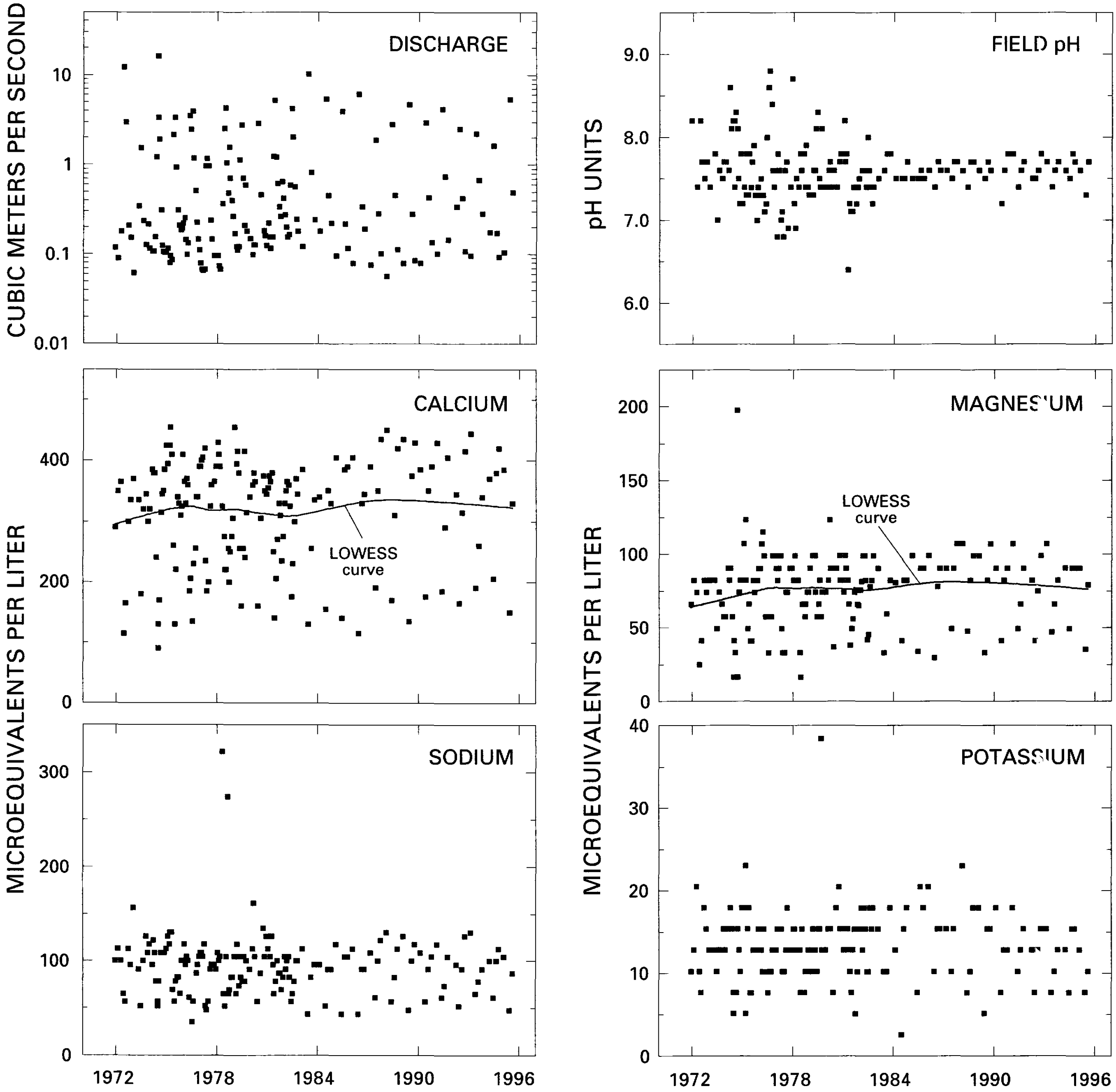


Figure 25. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Andrews Creek, Washington.

number of high-elevation granitic basins and is generally attributed to dissolution of trace amounts of calcite in the bedrock (Turk and Spahr, 1991; Clow and others, 1996). The median chloride concentration in stream water was 8.5 μeq/L compared to the VWM concentrations of 7.0 μeq/L in precipitation. Because evapotranspiration accounts for only about 15 percent of the annual precipitation (Nelson, 1991), stream-water chloride seems to be derived almost entirely from atmospheric sources. The median concentration of sulfate in stream water was 38 μeq/L compared to the VWM concentration of 7.1 μeq/L and was slightly higher than expected solely from the effects of evapotranspiration. Because sulfate inputs from dry

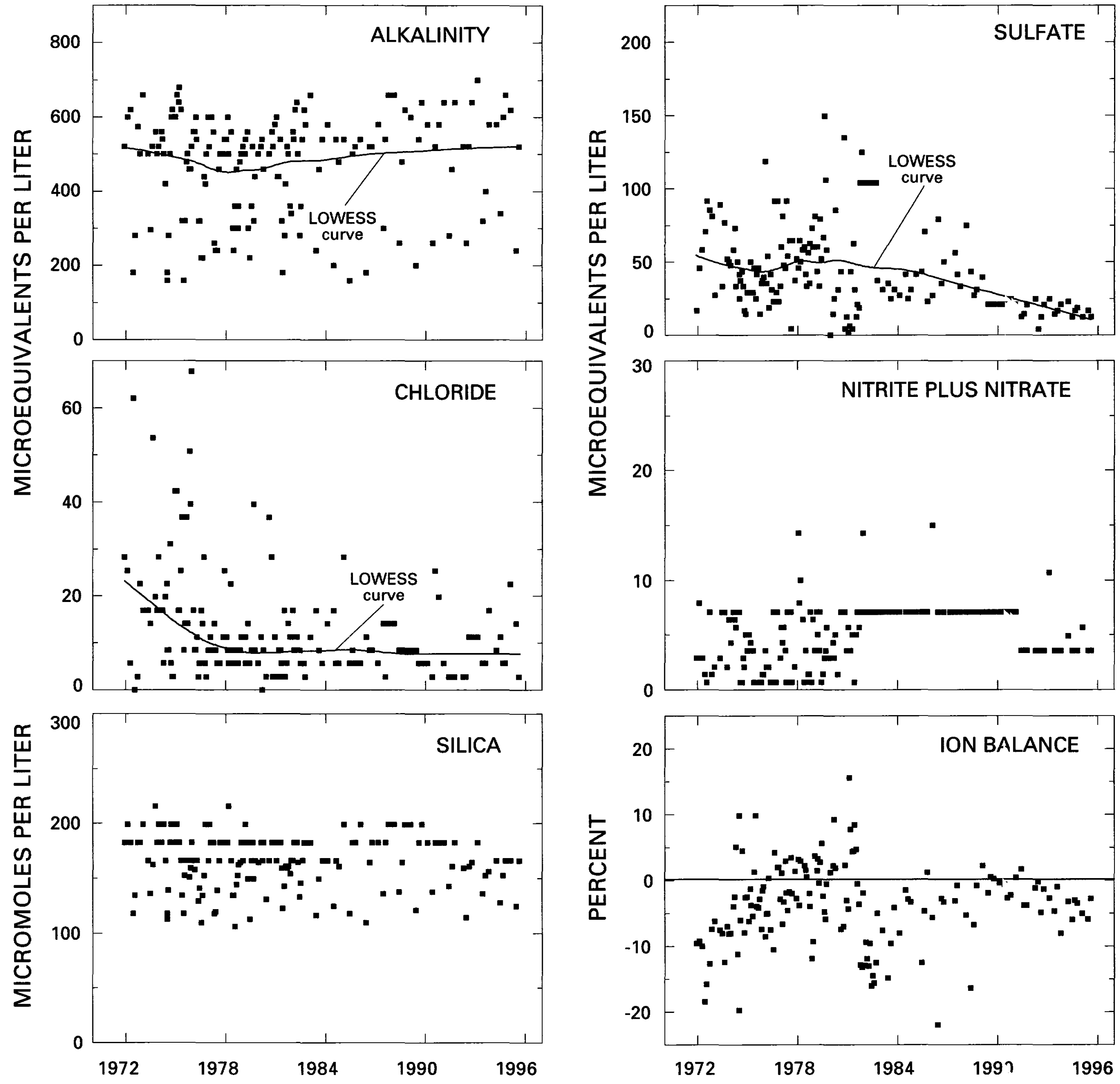


Figure 25. Temporal variation of discharge, field pH, major-ion concentrations, and ion balance in Andrews Creek, Washington—Continued.

deposition in the Cascade Mountains are small compared to wet deposition (Nelson, 1991), these results indicate that either there is an internal source of sulfate in the basin or the median sulfate concentration at this HBN station is overestimated because of analytical bias in the historical records. Most concentrations of inorganic nitrogen species in stream water were similar to the VWM concentrations in precipitation, indicating that atmospheric nitrogen is retained by vegetation and soils within the basin.

The solute composition of stream water was further evaluated by analyzing correlations between solutes and stream discharge (table 46). The weathering-derived solutes had strong inverse correlations with stream discharge, particularly calcium (rho = –0.905) and silica (rho = –0.842). These results are consistent with a hydrologic system where weathering-enriched base flow is diluted by waters from shallow or surficial sources during periods of increased discharge, particularly spring snowmelt. For the solutes, the strongest correlations were found among the base cations, alkalinity, and silica, which is consistent with the weathering stoichiometry of silicate minerals in the granitic bedrock. The weak correlations between chloride and sulfate provide additional evidence for the assumption that these solutes are primarily derived from atmospheric sources.

Table 45. Minimum, first quartile, median, third quartile, and maximum values of physical properties and major dissolved constituents measured in water-quality samples from Andrews Creek, Washington, December 1971 through August 1995, and volume-weighted mean concentrations in wet precipitation collected at Cascade National Park, Washington

[Concentrations in units of microequivalents per liter, discharge in cubic meters per second, specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, and silica in micromoles per liter; n, number of stream samples; VMW, volume-weighted mean; inst., instantaneous; spec. cond., specific conductance; <, less than; --, not reported]

Parameter	Stream water						Precipitation VWM[a]
	Minimum	First quartile	Median	Third quartile	Maximum	n	
Discharge, inst.	0.057	0.12	0.22	0.93	16	165	--
Spec. cond., field	18	38	51	58	79	164	5.6
pH, field	6.4	7.4	7.6	7.7	8.8	162	5.1[b]
Calcium	90	250	340	380	460	165	1.5
Magnesium	16	58	82	91	200	165	1.9
Sodium	35	78	96	110	320	162	6.0
Potassium	2.6	10	13	15	38	161	.3
Ammonium	<.7	<.7	1.4	4.3	13	75	1.8
Alkalinity, laboratory	160	360	520	580	700	164	--
Sulfate	<2.1	23	38	60	150	164	7.1
Chloride	<2.8	5.6	8.5	17	68	165	7.0
Nitrite plus nitrate	.7	2.9	5.0	7.1	15	156	4.8[c]
Silica	110	150	170	180	220	165	--

[a] Values are VWM concentrations for 1984–95.

[b] Laboratory pH.

[c] Nitrate only.

Table 46. Spearman rank correlation coefficients (rho values) showing the relation among discharge, pH, and major dissolved constituents, Andrews Creek, Washington, 1972 through 1995

[Q, discharge; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Alk, alkalinity; SO_4, sulfate; Cl, chloride; Si, silica]

	Q	pH	Ca	Mg	Na	K	Alk	SO_4	Cl
pH	0.050								
Ca	–.905	–0.024							
Mg	–.772	–.008	0.841						
Na	–.823	.096	.812	0.718					
K	–.568	.010	.633	.583	0.598				
Alk	–.829	.003	.856	.744	.811	0.587			
SO_4	.072	–.040	–.058	–.015	–.072	.139	–0.108		
Cl	–.080	.066	.035	.017	.076	–.005	.036	0.252	
Si	–.842	–.021	.811	.716	.761	.596	.736	.044	0.037

The results of the seasonal Kendall test for trends in discharge and major dissolved constituents are listed in table 47. Statistically significant trends were detected in unadjusted calcium, magnesium, alkalinity, sulfate, and chloride concentrations at the 0.01 probability level. Trends were not calculated for the flow-adjusted sulfate and chloride concentrations because the flow models were not statistically significant at the 0.10 probability level. Trends were similar for the unadjusted and flow-adjusted calcium, magnesium, and alkalinity concentrations, indicating that they probably were not caused by variations in stream discharge. The LOWESS curves in figure 25 showed somewhat different temporal patterns for sulfate and chloride. Most of the decrease in chloride concentrations result from a period of high concentrations near the beginning of the period of record, whereas the decline in sulfate was driven by lower than average concentrations near the end of the record. The LOWESS curves for the unadjusted calcium, magnesium, and alkalinity concentrations are difficult to interpret because of strong seasonal variations in the concentrations of these solutes. Although not shown in figure 25, LOWESS curves for the flow-adjusted concentrations showed that most of the increase in calcium and magnesium concentrations occurred prior to 1982, whereas most of the increase in alkalinity occurred after 1982. Possible causes of stream-water trends at this HBN station include environmental factors, such as changes in land use or atmospheric deposition, and method-related factors, particularly changes in analytical techniques. Changes in land-use probably did not affect stream-water chemistry because the basin is entirely within a wilderness area, and there have been few changes in land use other than a slight decrease in grazing and increase in recreational use. Changes in atmospheric deposition are difficult to confirm because no long-term records of precipitation chemistry are available for this station. However, a recent study reported statistically significant downward trends in sulfate, chloride, calcium, and magnesium at several NADP stations in the northwestern United States from 1980 to 1992 (Lynch and others, 1995). Although the trends in precipitation chemistry seem to be consistent with the trend in stream-water sulfate, they do not account for increases in stream-water calcium and magnesium or the decline in chloride prior to 1980 (fig. 25). Stream-water trends at this station are more likely to be artifacts of analytical bias rather than environmental change. For example, the decrease in chloride concentrations was concurrent with a change in analytical laboratory, whereas the decline in sulfate concentrations, particularly after 1990, seems to be caused by several changes in analytical techniques. The timing of the calcium and magnesium trends also indicates that they may have been affected by a change in analytical technique for major dissolved cations and trace inorganic constituents that occurred in 1983 (Office of Water Quality Technical Memorandum No. 82.18, *National water-quality networks*, issued September 28, 1982, at URL http://water.usgs.gov/admin/memo/, accessed 1998).

Table 47. Results of the seasonal Kendall test for trends in discharge and unadjusted and flow-adjusted pH and major dissolved constituents, Andrews Creek, Washington, December 1971 through August 1995

[Trends in units of microequivalents per liter per year, except for discharge in cubic meters per second per year, pH in standard units per year, and silica in micromoles per liter per year; <, less than; --, not calculated]

Parameter	Unadjusted		Flow adjusted	
	Trend	p-value	Trend	p-value
Discharge	–0.001	0.607	--	--
pH, field	<.01	.056	<0.01	0.070
Calcium	3.0	.002	2.4	.000
Magnesium	0.6	.005	0.5	.000
Sodium	<.1	.395	<.1	.414
Potassium	<.1	.703	<.1	.849
Alkalinity, laboratory	3.5	.009	3.8	.000
Sulfate	–1.3	.000	(a)	--
Chloride	–.3	.008	(a)	--
Nitrite plus nitrate	(b)	--	--	--
Silica	<.1	.460	<.1	.702

[a] Flow model not significant at $\alpha = 0.10$.

[b] Insufficient data to calculate trend.

Synoptic Water-Quality Data

Chemical results of the surface-water synoptic sampling of September 1–2, 1993, are listed in table 48, and locations of sampling sites are shown in figure 24. During the synoptic sampling, discharge at the HBN station was 0.40 m^3/s compared to the median daily discharge of 0.31 m^3/s for August and 0.20 m^3/s for September (Lawrence, 1987), indicating that the basin was sampled under slightly higher than normal flow conditions for that time of year. Most of

Table 48. Physical properties and major dissolved constituents from surface-water sampling sites in the Andrews Creek Basin, Washington, collected September 1–2, 1993

[Site locations shown in fig. 24; Q, discharge in cubic meters per second; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium: Alk, alkalinity; SO$_4$, sulfate; Cl, chloride; NO$_3$, nitrate; Si, silica; concentrations in microequivalents per liter, except silica in micromoles per liter; <, less than; --, not reported]

Site	Station number	Q	SC	pH	Ca	Mg	Na	K	Alk	SO$_4$	Cl	NO$_3$	Si	Criteria[a]	Remarks
1	12447390	0.40	47	7.7	310	74	87	12	450	16	3.4	<3.6	150	--	
2	485052120085800	.0045	30	7.6	170	46	78	12	280	10	2.8	<3.6	180	T	Perennial tributary
3	485244120101000	.057	29	7.4	180	37	74	5.1	250	9.0	2.3	<3.6	160	T	Perennial tributary
4	485245120100700	--	39	7.5	250	50	70	10	340	19	2.8	<3.6	150	MC	Andrews Creek upstream from Peepsight Creek
5	485354120134900	--	6.3	7.3	25	1.6	30	1.5	50	5.4	1.1	<3.6	120	T	Downstream from small cirque pond
6	485353120103700	--	66	7.5	480	100	74	23	640	25	4.2	<3.6	160	LU	Downstream from grazing area
7	485412120113600	--	19	7.5	130	18	52	2.8	170	6.9	2.8	<3.6	120	T	Intermittent tributary
8	485435120121100	--	33	7.5	210	26	65	11	230	67	2.3	<3.6	150	T	Intermittent tributary
9	485455120123300	.011	29	7.6	200	38	57	4.6	260	14	2.5	<3.6	120	MC	Andrews Creek near headwaters

[a] Criteria used in selection of sampling sites: MC = main channel, LU = land use, T = tributary.

the solute concentrations measured at the HBN station (site 1) during the synoptic sampling were between the first-quartile and median values that were reported for the station during the entire period of record, except for sulfate and chloride concentrations, which were lower (table 45). The major solutes in the tributary streams were calcium and bicarbonate, and the concentrations bracketed the concentrations measured at site 1. Ion balances for all the synoptic samples were positive (ranging from 0.2 to 5.5 percent), indicating that unmeasured ions, such as organic anions, may have contributed to the ionic content of stream water during the synoptic sampling.

In general, stream chemistry was dilute and did not vary markedly among the sampling sites, which primarily reflects the uniform composition and slow-weathering rate of minerals in the granitic bedrock. Except for site 5, specific conductance ranged from 19 to 66 µS/cm, calcium ranged from 130 to 480 µeq/L, and alkalinity ranged from 170 to 640 µeq/L (table 48). Stream water collected a site 5 was considerably more dilute than stream water at the other synoptic sampling sites because it was collected just downstream from a small cirque pond that primarily is fed by direct snowmelt and rainfall. The weathering-derived solutes, particularly calcium, magnesium, and alkalinity, were strongly correlated with chloride concentrations ($0.70 \leq r \leq 0.94$). Assuming stream-water chloride is primarily derived from atmospheric deposition, these results indicate that most of the intra-basin variability in concentrations can be accounted for by evapotranspiration. One notable exception was silica, which not only had a weaker correlation with chloride (r=0.52) but had a high concentration at site 5 compared to the other solute concentrations. Sulfate concentrations ranged from 5.4 to 67 µeq/L and, except for site 8, also were correlated with chloride (r = 0.80), indicating that most of the variability was related to differences in deposition or evapotranspiration. Assuming that sulfate deposition rates were not substantially different among the sampling sites, the most plausible explanation for the high sulfate concentration at site 8 is weathering of an unmapped mineralized zone upstream from the sampling site. Chloride and nitrate concentrations were uniformly low in the basin; chloride ranged from 1.1 to 4.2 µeq/L, and nitrate concentrations were less than the analytical reporting limit of 3.6 µeq/L. These results are consistent with the low concentrations of chloride and nitrate in precipitation and also provide no evidence that human-related activities affected stream-water concentrations of these solutes during the sampling period.

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APPENDIXES

APPENDIX A. LIST OF MAP REFERENCES

1. Wet Bottom Creek near Childs, Arizona (Station 09508300)

a. U.S. Geological Survey Topographic Maps:

Cypress Butte, Arizona (1:24,000), 1967

Table Mountain, Arizona (1:24,000), 1967

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Payson, Arizona (1:100,000), 1981

b. Geologic Maps:

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2. Elder Creek near Branscomb, California (Station 11475560)

a. U.S. Geological Survey Topographic Maps:

Cahto Peak, California (1:24,000), 1967

Lincoln Ridge, California (1:24,000), 1966, HBN gaging station on this quadrangle

Covelo, California (1:100,000), 1981

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3. Merced River at Happy Isles Bridge near Yosemite, California (Station 11264500)

a. U.S. Geological Survey Topographic Maps:

Hetch Hetchy Reservoir, California (1:62,500), 1956

Merced Peak, California (1:62,500), 1953

Tuolumne Meadows, California (1:62,500), 1956

Yosemite, California (1:62,500), 1956, HBN gaging station on this quadrangle

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4. Sagehen Creek near Truckee, California (Station 10343500)

a. U.S. Geological Survey Topographic Maps:

Hobart Mills, California (1:24,000), 1981, HBN gaging station on this quadrangle

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5. Big Jacks Creek near Bruneau, Idaho (Station 13169500)

a. U.S. Geological Survey Topographic Maps:

Little Valley, Idaho (1:24,000), 1979, HBN gaging station on this quadrangle
Glenns Ferry, Idaho (1:100,000), 1989
Riddle, Idaho (1:100,000), 1989
Sheep Creek, Idaho (1:100,000), 1989
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b. Geologic Maps:

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6. Hayden Creek below North Fork, near Hayden Lake, Idaho (Station 12416000)

a. U.S. Geological Survey Topographic Maps:

Athol, Idaho (1:24,000), 1961
Bayview, Idaho (1:24,000), 1967
Hayden Lake, Idaho (1:24,000), 1976, HBN gaging station on this quadrangle
Spades Mountain, Idaho (1:24,000), 1990
Coeur D'Alene, Idaho (1:100,000), 1987

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7. South Twin River near Round Mountain, Nevada (Station 10249300)

a. U.S. Geological Survey Topographic Maps:

Arc Dome, Nevada (1:24,000), 1980
Carvers NW, Nevada (1:24,000), 1971, HBN gaging station on this quadrangle
South Toiyabe Peak, Nevada (1:24,000), 1979
Ione Valley, Nevada (1:100,000), 1985

b. Geologic Maps

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8. Steptoe Creek near Ely, Nevada (Station 10244950)

a. U.S. Geological Survey Topographic Maps:

Cave Creek, Nevada (1:24,000), 1981, HBN gaging station on this quadrangle
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b. Geologic Maps

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c. Miscellaneous Maps

U.S. Department of Agriculture, 1984, Humboldt National Forest, White Pine Ranger District, Ely Ranger District: Ogden, Utah, U.S. Department of Agriculture Forest Service, Intermountain Region, scale 1:202,752.

9. Crater Lake near Crater Lake, Oregon (Station 11492200)

a. U.S. Geological Survey Topographic Maps:

Crater Lake East, Oregon (1:24,000), 1985, HBN gaging station on this quadrangle
Crater Lake West, Oregon (1:24,000), 1985
Crater Lake National Park and vicinity (1:62,500), 1988

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c. Miscellaneous Maps

U.S. Department of the Interior, 1982, Crater Lake National Park, Oregon: Washington, D.C., U.S. Department of the Interior National Park Service, scale 1:85,000.

10. Minam River at Minam, Oregon (Station 13331500)

a. U.S. Geological Survey Topographic Maps:

China Cap, Oregon (1:24,000), 1984
Jim White Ridge, Oregon (1:24,000), 1993
Minam, Oregon (1:24,000), 1984, HBN station on this quadrangle
Mount Moriah, Oregon (1:24,000), 1984
Mt. Fanny, Oregon (1:24,000), 1984
Eagle Cap, Oregon (1:48,000), 1954
Enterprise, Oregon (1:100,000), 1986
Wallowa, Oregon (1:100,000), 1982

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11. Red Butte Creek at Fort Douglas near Salt Lake City, Utah (Station 10172200)

a. U.S. Geological Survey Topographic Maps:

Fort Douglas, Utah (1:24,000), 1975, HBN station on this map

Mountain Dell, Utah (1:24,000), 1975

Salt Lake City, Utah (1:100,000), 1981

b. Geologic Maps

Van Horn, Richard, and Crittenden, M.D., Jr., 1987, Map showing surficial units and bedrock geology of the Fort Douglas Quadrangle and parts of the Mountain Dell and Salt Lake City North quadrangles, Davis, Salt Lake, and Morgan Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–1762, scale 1:24,000.

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c. Soil Surveys

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d. Miscellaneous Maps

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12. Andrews Creek near Mazama, Washington (Station 12447390)

a. U.S. Geological Survey Topographic Maps:

Bauerman Ridge, Washington-British Columbia (1:24,000), 1969

Coleman Peak, Washington (1:24,000), 1969

Mt. Barney, Washington (1:24,000), 1969. HBN station on this quadrangle

Remmel Mountain, Washington (1:24,000), 1969

Robinson Mountain, Washington (1:100,000), 1995

b. Geologic Maps

Staatz, M.H., 1971, Mineral resources of the Pasayten Wilderness Area, Washington: U.S. Geological Survey Bulletin 1325, 255 p., scale 1:200,000.

c. Miscellaneous Map

U.S. Department of Agriculture, 1981, Okanogan National Forest, Washington: Portland, Oreg., U.S. Department of Agriculture Forest Service, Pacific Northwest Region, scale 1:220,000.

U.S. Department of Agriculture, 1991, Pasayten Wilderness, Okanogan National Forest: Portland, Oreg., U.S. Department of Agriculture Forest Service, Pacific Northwest Region, scale 1:88,000.

APPENDIX B. NATIONAL WATER INFORMATION SYSTEM SITE-IDENTIFICATION NUMBERS

Table B–1. National Water Information System site-identification numbers and site names for water-quality sites in selected HBN basins

Site[a]	Identification number[b]	Site name
		WET BOTTOM CREEK, ARIZONA
1	09508300	WET BOTTOM CR NR CHILDS, AZ
2	341128111353300	BULL SPRING TRIB NR CYPRESS BUTTE, AZ
3	341118111350500	RED METAL CR NR CYPRESS BUTTE, AZ
4	341032111340700	HOUSTON CR NR CYPRESS BUTTE, AZ
5	341011111334200	CHALK SPRING CR NR CYPRESS BUTTE, AZ
6	340848111331100	FULLER SEEP CR NR CYPRESS BUTTE, AZ
7	340819111333600	WET BOTTOM CR NR MIDNIGHT MESA, AZ
		ELDER CREEK BASIN, CALIFORNIA
1	11475560	ELDER CR NR BRANSCOMB, CA
2	394311123363800	MISERY CR NR BRANSCOMB, CA
3	394311123363300	MERCY CR NR BRANSCOMB, CA
4	394306123361100	UPPER ELDER CR NR BRANSCOMB, CA
		MERCED RIVER BASIN, CALIFORNIA
1	11264500	MERCED R AT HAPPY ISLES BRIDGE NR YOSEMITE, CA
2	374041119340200	MONO MEADOW TRIB NR YOSEMITE, CA
3	374113119323500	ILLILOUETTE CR NR YOSEMITE, CA
4	374156119200200	UPPER MERCED R NR YOSEMITE, CA
5	374237119183900	HUTCHING CR NR YOSEMITE, CA
6	374239119183900	NORTH FORK LYELL CR NR YOSEMITE, CA
7	374415119241800	MERCED R BELOW HIGH SIERRA CAMP NR YOSEMITE, CA
8	374418119241100	MERCED R ABOVE HIGH SIERRA CAMP NR YOSEMITE, CA
9	374429119255300	CLARK FORK NR YOSEMITE, CA
10	374603119245500	ECHO CR NR YOSEMITE, CA
11	374702119250200	CATHEDRAL FORK NR YOSEMITE, CA
		SAGEHEN CREEK BASIN, CALIFORNIA
1	10343500	SAGEHEN CR NR TRUCKEE, CA
2	392558120152100	SAGEHEN CR AB CAMPGROUND NR HOBART MILLS, CA
3	392558120152000	PRE-CAMPGROUND TRIB NR HOBART MILLS, CA
4	392602120164500	SAGEHEN HILLS TRIB NR HOBART MILLS, CA
5	392604120164900	SAGEHEN CR BLW LOGGED AREA NR HOBART MILLS, CA
6	392501120182800	SAGEHEN CR NR CARPENTER RIDGE, CA
		BIG JACKS CREEK BASIN, IDAHO
1	13169500	BIG JACKS CREEK NEAR BRUNEAU, ID
2	422612116081200	BIG JACKS CR SPRING AB RESERVOIR NR BRUNEAU, ID
3	422715115591400	WICKAHONEY SPRING NR BRUNEAU, ID
4	422724116032100	DUNCAN SPRING NR BRUNEAU, ID
5	423019116040100	HICKS SPRING NR BRUNEAU, ID
6	423104116050400	COTTONWOOD CR NR HARVEY PLACE NR BRUNEAU, ID
7	423231115583700	WICKAHONEY CR NR BRUNEAU, ID
8	423259116012800	DUNCAN CR AT BUNCEL PLACE NR BRUNEAU, ID
9	423346116022900	BIG JACKS CR AT HOLMAN CABIN NR BRUNEAU, ID
		HAYDEN CREEK BASIN, IDAHO
1	12416000	HAYDEN CR BLW N FORK NR HAYDEN LAKE, ID
2	474924116360600	HELLS CANYON NR HAYDEN LK, ID
3	474930116384600	E FORK HAYDEN CR NR HAYDEN LK, ID
4	474933116361200	E FORK HAYDEN CR AB HELLS CNYN NR HAYDEN LK, ID

Table B–1. National Water Information System site-identification numbers and site names for water-quality sites in selected HBN basins—Continued

Site[a]	Identification number[b]	Site name
HAYDEN CREEK BASIN, IDAHO—Continued		
5	474942116385700	N FORK HAYDEN CR NR HAYDEN LK, ID
6	475150116335500	UPPER CHILCO CR NR HAYDEN LK, ID
7	475153116380900	BRADBURY GULCH NR HAYDEN LK, ID
8	475204116365000	UPPER BRADBURY TRIB NR HAYDEN LK, ID
SOUTH TWIN RIVER BASIN, NEVADA		
1	10249300	SOUTH TWIN R NR ROUND MOUNTAIN, NV
2	384500117145900	FIRST NORTH TRIB TO SOUTH TWIN R NR CARVERS, NV
3	384901117175500	SOUTH TWIN R AB PASTURE NR CARVERS, NV
4	384926117173100	NORTH TWIN R TRAIL TRIB NR CARVERS, NV
5	384931117161000	SOUTH FORK ABOVE MINE NR CARVERS, NV
6	384946117161800	SOUTH FORK OF SOUTH TWIN R NR CARVERS, NV
7	384947117162000	SOUTH TWIN R AB SOUTH FORK NR CARVERS, NV
STEPTOE CREEK, NEVADA		
1	10244950	STEPTOE CR NR ELY, NV
2	391216114410400	CLEAR SPRING CR NR ELY, NV
3	391231114410300	SECOND EAST TRIB TO STEPTOE CR NR ELY, NV
4	391313114405300	STEPTOE CR AT CAMPSITE NR ELY, NV
5	391335114414400	ASPEN SPRING CR NR ELY, NV
6	391416114411900	UPPER STEPTOE CR NR ELY, NV
MINAM RIVER BASIN, OREGON		
1	13331500	MINAM R AT MINAM, OR
2	453007117411000	MINAM R AB TROUT CR NR MINAM, OR
3	452356117401300	MINAM R AB LITTLE MINAM NR MINAM, OR
4	452049117372600	MINAM R AB REDS HORSE RANCH NR MINAM, OR
5	450852117213500	MINAM R AT FRASIER MEADOW NR MINAM, OR
6	450853117233000	TRAIL CR NR MINAM, OR
7	451230117293500	LAST CHANCE CR NR MINAM, OR
8	451621117320000	N MINAM R NR MINAM, OR
9	452358117402200	LITTLE MINAM R NR MINAM, OR
10	453013117410000	TROUT CR NR MINAM, OR
REB BUTTE CREEK BASIN, UTAH		
1	10172200	RED BUTTE CR NR SALT LAKE CITY, UT
2	404716111474500	BLACK MTN CR AT HAIRPIN NR SALT LAKE CITY, UT
3	404811111455000	RED BUTTE CR AB KNOWLTONS FK NR SALT LAKE CITY, UT
4	404812111455400	KNOWLTONS FORK NR SALT LAKE CITY, UT
5	404846111461400	WEST FORK KNOWLTONS FORK NR SALT LAKE CITY, UT
6	404855111453200	UPPER KNOWLTONS FORK NR SALT LAKE CITY, UT
ANDREWS CREEK BASIN, WASHINGTON		
1	12447390	ANDREWS CR NR MAZAMA, WA
2	485052120085800	RAM CR NR MAZAMA, WA
3	485244120101000	PEEPSIGHT CR NR MAZAMA, WA
4	485245120100700	ANDREWS CR AB PEEPSIGHT NR MAZAMA, WA
5	485354120134900	PEEPSIGHT CR BLW DRY LAKE NR MAZAMA, WA
6	485353120103700	COLEMAN TRIB NR MAZAMA, WA
7	485412120113600	SWAMP GAS TRIB NR MAZAMA, WA
8	485435120121100	REMMEL MTN TRIB NR MAZAMA, WA
9	485455120123300	UPPER ANDREWS CR NR MAZAMA, WA

[a] Site numbers correspond to sampling sites shown in figures 2, 4, 6, 8, 10, 12, 14, 16, 20, 22, and 24.

[b] Used for identification in the National Water Information System (NWIS).

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ISBN 0-607-95104-4

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