Gore Creek Watershed, Colorado—Assessment of Historical and Current Water Quantity, Water Quality, and Aquatic Ecology, 1968–98

By Kirby H. Wynn, Nancy J. Bauch, and Nancy E. Driver

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.028	cubic meter per second
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06308	liter per second
inch	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
picocuries per liter (pCi/L)	0.3125	tritium units
pound (lb)	0.4536	kilogram
square mile (mi^2)	2.59	square kilometer
ton	0.9072	metric ton

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

$$°C = 5/9\ (°F - 32)$$

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

$$°F = 9/5\ (°C) + 32$$

Additional Abbreviations or Terms

cols/100 mL	colonies per 100 milliliters
DOC	dissolved organic carbon
DWA	drinking water advisory
gpd/ft	gallons per day per foot
HA	health advisory
µg/g	microgram per gram
µg/kg	microgram per kilogram
µg/L	microgram per liter
$\mu m^3/cm^2$	cubic micrometers per square centimeter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
mg/L	milligram per liter
mg/m^2	milligrams per square meter
mL	milliliter
MBAS	methylene blue active substances
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
NTU	nephelometric turbidity units
pfu	plaque-forming unit
PMCL	proposed maximum contaminant level
SMCL	secondary maximum contaminant level
SOC	suspended organic carbon
units/yr	units per year
as N	as quantified, as measured nitrogen
as P	as quantified, as measured phosphorus
VOC	volatile organic compound

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Abstract

The historical and current (1998) water-quantity, water-quality, and aquatic-ecology conditions in the Gore Creek watershed are described as part of a study by the U.S. Geological Survey, done in cooperation with the Town of Vail, the Eagle River Water and Sanitation District, and the Upper Eagle Regional Water Authority. Interpretation of the available water-quantity, water-quality, and aquatic-ecology data collected by various agencies since 1968 showed that background geology and land use in the watershed influence the water quality and stream biota.

Surface-water nutrient concentrations generally increased as water moved downstream through the Town of Vail, but concentrations at the mouth of Gore Creek were typical when compared with national data for urban/undeveloped sites. Nitrate concentrations in Gore Creek were highest just downstream from a wastewater-treatment plant discharge, but concentrations decreased at sites farther downstream because of dilution and nitrogen uptake by algae. Recent total phosphorus concentrations were somewhat elevated when compared to the U.S. Environmental Protection Agency recommended level of 0.10 milligram per liter for control of eutrophication in flowing water. However, total phosphorus concentrations at the mouth of Gore Creek were relatively low when compared to a national study of phosphorus in urban land-use areas.

Historically, suspended sediment associated with construction of Interstate 70 in the early 1970's has been of primary concern; however, recent data indicate that streambed aggradation of sediment originating from Interstate 70 traction sanding currently is a greater concern. About 4,000 tons of coarse sand and fine gravel is washed into Black Gore Creek each year following application of traction materials to Interstate 70 during adverse winter driving conditions. Suspended-sediment concentrations were low in Black Gore Creek; however, bedload-transport rates of as much as 4 tons per day have been measured.

Water samples were collected during spring and fall of 1997 from five alluvial monitoring wells located throughout the Town of Vail. Nutrient concentrations generally were low in the alluvial monitoring wells. Specific-conductance values ranged from 265 to 557 microsiemens per centimeter at 25 degrees Celsius. Concentrations of radon in monitoring-well samples exceeded the 300-picocuries-per-liter U.S. Environmental Protection Agency proposed maximum contaminant level (which has been suspended pending further review). Low levels of bacteria and methylene blue active substances indicate there is little or no wastewater contamination of shallow ground water in the vicinity of the monitoring wells and one of the municipal water-supply wells. Ground-water ages in the alluvial aquifer ranged from about 2 to about 50 years old. These ages indicate that changes in land-management practices may not have an effect on ground-water quality for many years.

Differences in macroinvertebrate-community structure were found among sites in Gore Creek by evaluating changes in relative abundance, total abundance, and dominant functional feeding groups of the major macroinvertebrate groups. Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), and Coleoptera (beetles) exhibited relatively low tolerance to water-quality degradation when compared with Diptera (midges) and non-insects (sludge worms). More than 80 percent of the macroinvertebrate community at sites located farthest upstream was composed of mayflies, stoneflies, and caddisflies, indicating favorable water-quality and habitat conditions. The relative percentages of midges and sludge worms greatly increased in the downstream reaches of Gore Creek, which drain relatively larger areas of urban and recreation land uses, indicating the occurrence of nutrient and organic enrichment in Gore Creek.

The macroinvertebrate community in Black Gore Creek indicated adverse effects from sediment deposition. Macroinvertebrate abundance was considerably reduced at the two sites where streambed sediment was more prevalent; however, differences in abundance also may have been related to differences in habitat and availability of food resources.

The lower 4 miles of Gore Creek, downstream from Red Sandstone Creek, have been designated a Gold Medal fishery in recognition of the high recreational value of the abundant brown trout community. Gore Creek contained twice as many trout as a reference site with similar habitat characteristics in Rocky Mountain National Park.

Moderate increases in nutrient concentrations above background conditions have increased the growth and abundance potential for aquatic life in Gore Creek, while at the same time, esthetic and water-quality conditions have remained favorable. The spatial distribution of nitrate concentrations was consistent with the observed spatial distribution of algal biomass and macroinvertebrate-community characteristics. Algal biomass was limited by available resources (sunlight and nutrients) in the upstream reaches of Gore Creek and limited by macroinvertebrate grazing and water-quality conditions in the downstream reaches. The fish community has benefited from enhanced biological production in the downstream reach of Gore Creek. Increases in algal biomass and macroinvertebrate abundance, in response to higher nutrient concentrations, provide ample food resources necessary to support the abundant fish community.

Trace-element data for surface water, ground water, streambed sediment, fish tissue, and macroinvertebrate tissue indicate that concentrations are generally low in the Gore Creek watershed. In streambed-sediment samples, cadmium, copper, and zinc concentrations were below background levels reported for the Upper Colorado River Basin in Colorado. Concentrations of cadmium, copper, iron, and silver in surface water have occasionally exceeded stream standards in the past, but recent surface-water data indicate these trace elements currently are not of concern. Manganese concentrations commonly exceeded the 50-microgram-per-liter stream standard in Black Gore Creek. Elevated manganese concentrations were primarily attributable to the sedimentary geology of the area.

Concentrations of organic constituents are low in the Gore Creek watershed. Pesticides were detected infrequently and at low concentrations in surface-water, ground-water, bed-sediment, and whole-body fish-tissue samples. Volatile organic compounds also were detected at low concentrations in surface- and ground-water samples.

INTRODUCTION

Gore Creek, which drains an area of about 102 mi^2, flows about 19 miles, from an area along the Gore Range through the Town of Vail, joining the Eagle River near Vail in Eagle County, Colorado (fig. 1). Development in the Gore Creek watershed has the potential to detrimentally affect the water quality in Gore Creek and its tributaries. To manage water resources, local entities are interested in better understanding water quality and its relation to land uses and natural factors in the Gore Creek watershed. In response to these concerns, the Town of Vail,

Figure 1. Location of the Gore Creek watershed.

the Eagle River Water and Sanitation District, Vail Associates, and the Upper Eagle Regional Water Authority created the Gore Creek Watershed Management Program in 1996. The goal of this program is to provide information for the management and protection of water quality and aquatic life in the watershed.

The U.S. Geological Survey (USGS), in cooperation with the Town of Vail, the Eagle River Water and Sanitation District, and the Upper Eagle Regional Water Authority, compiled and analyzed the available information on the historical and current (1998) water quantity, water quality, and aquatic ecology in the Gore Creek watershed. These data were analyzed to assess the effects of human and natural factors on the surface- and ground-water resources in the watershed.

Purpose and Scope

This report presents the available historical and current (1998) water-quantity, water-quality, and aquatic-ecology information for the Gore Creek watershed. Surface-water data are available for locations throughout the watershed but are limited for long-term analysis. Ground-water data are available only for the alluvial aquifer that underlies the Town of Vail. Based on available data in the Gore Creek watershed, specific objectives of this report are to: (1) characterize existing water-resources data; (2) analyze historical data and assess the broad-scale spatial and seasonal variability in water quantity, water quality, and stream biota; and (3) summarize the environmental setting and identify, describe, and explain, where possible, the major natural and human factors that affect observed water-quantity, water-quality, and aquatic-ecology conditions in the Gore Creek watershed.

Available physical, chemical, and biological data useful for characterizing factors affecting water-quantity, water-quality, and aquatic-ecology conditions were compiled for 66 surface-water sites within the Gore Creek watershed. These data were collected from 1968 to 1997. Some of the categories of data include major ions, nutrients, trace elements, pesticides, volatile organic compounds (VOCs), and algae, macroinvertebrate, and fish communities. In addition, results from regional and national studies were compiled for comparison of surface-water nutrient concentrations in the Gore Creek watershed with other urban areas.

Ground-water-quality data were available from six sites in the alluvial aquifer. These ground-water data were limited to periodic trace-element samples collected from the Town of Vail water-supply well field during 1988–89, a sample collected from a single well from the well field in 1997, and two samples collected from each of five alluvial monitoring wells within the Town of Vail during 1997. The 1997 well-field and monitoring-well data, though limited, provided valuable new information about the age of ground water and a variety of inorganic and organic constituents such as nutrients, trace elements, pesticides, VOCs, bacteria, and radon.

Acknowledgments

The authors thank the many individuals and agencies that provided data for the Gore Creek watershed. Special thanks to Russell Forrest, Town of Vail; Caroline Byus, Eagle River Water and Sanitation District; Joe Macy, Vail Associates; Bill Andree, Colorado Division of Wildlife; Robert Ray, Northwest Colorado Council of Governments; and Dennis Anderson, Colorado Department of Public Health and Environment. The authors thank Ken Neubecker for providing most of the photographs for this report. We also thank Cory Stephens, USGS, and David K. Mueller, USGS, for their assistance in generating some of the figures for this report, Janet S. Heiny, USGS, for reviewing the manuscript, and Stephen D. Porter, USGS, for his assistance with the interpretation of the ecological data and for reviewing the manuscript. The authors also thank Mary Kidd for editorial review of this report, Joy Monson for manuscript preparation, and Sharon P. Clendening for producing the illustrations.

DESCRIPTION OF STUDY AREA

The Gore Creek watershed, located in the Southern Rocky Mountains physiographic province (Apodaca and others, 1996), lies in a narrow valley surrounded by high mountains and drains an area of about 102 mi^2. Gore Creek originates in pristine alpine headwaters of the Gore Range and flows through the Town of Vail before joining the Eagle River. Land-surface elevation in the watershed ranges from about 7,700 ft in the valley to about 13,200 ft in the Gore Range. Monthly average temperatures in Vail range from a low of –8°C in January to a high of 15°C in July (National Oceanic and Atmospheric Administration, http://ulysses.atmos.colostate.edu/mly_form.html, accessed September 24, 1998). Precipitation in the watershed ranges from between 20 and 30 inches per year (in/yr) in the lower valleys to between 40 and 50 in/yr in the higher peaks (Colorado Climate Center, 1984) (fig. 2). The average precipitation is 34 in/yr, of which two-thirds falls as snow. In the Town of Vail, at an elevation of 8,225 ft, annual snowfall ranges from 79 inches to 313 inches (National Oceanic and Atmospheric Administration, accessed September 24, 1998).

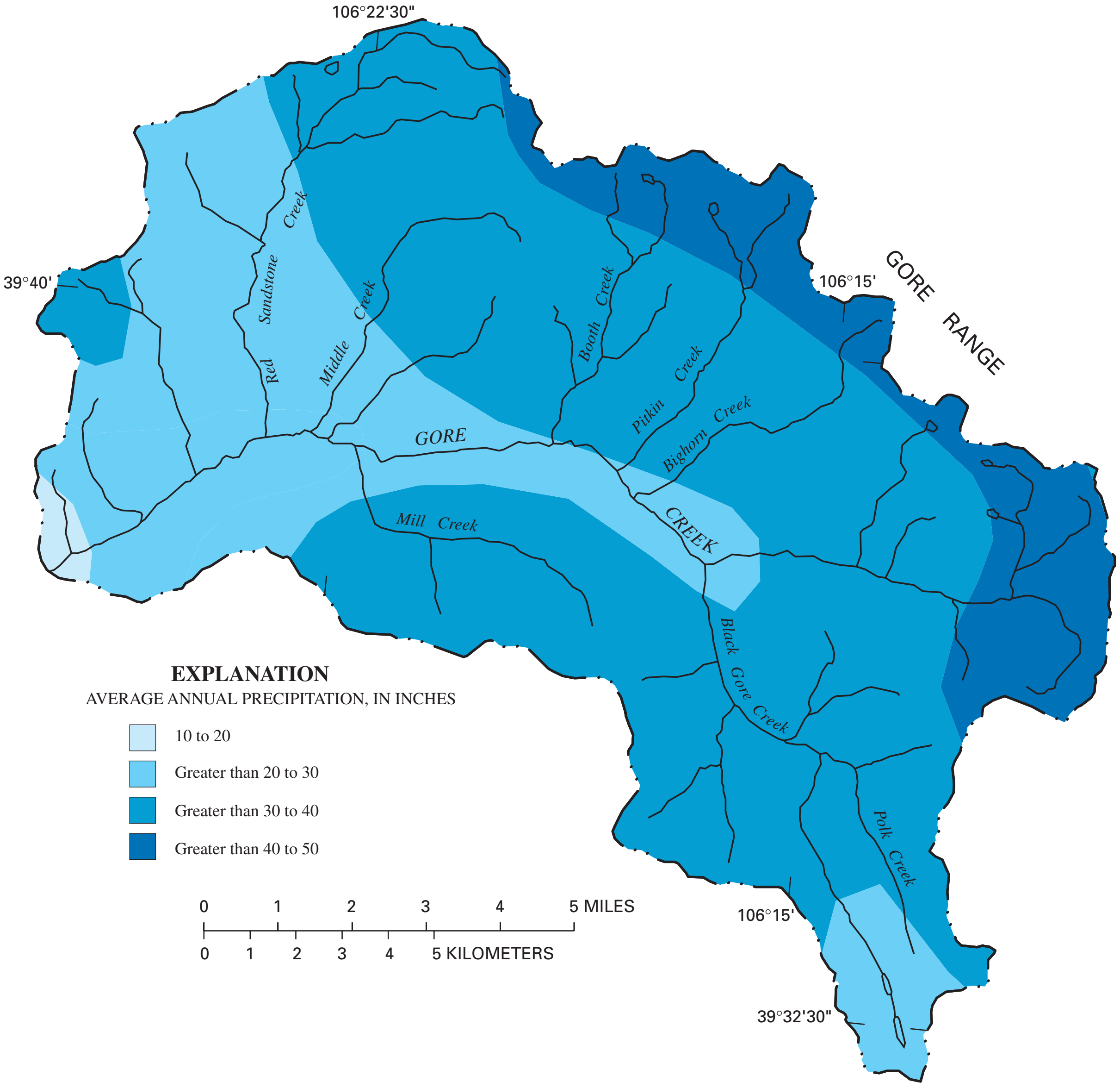


Figure 2. Average annual precipitation (1951–80) in the Gore Creek watershed.

The geology of the Gore Creek watershed varies from older Precambrian-age basement rocks to Quaternary-age alluvial deposits (fig. 3). The Precambrian rocks, which are predominantly igneous with some metamorphics, form the mountains in the northern and eastern parts of the watershed. The headwaters area of Gore Creek consists of predominantly igneous rocks. Fractured Precambrian rocks generally yield small quantities of water that are adequate only for domestic supplies. Where the Precambrian rocks are fractured, water may discharge from springs. Water from these rocks is suitable for all uses (Voegeli, 1965). Sedimentary rocks of pre-Pennsylvanian Paleozoic, Pennsylvanian, and Permian age crop out in the southern and western parts of the watershed. Rocks in the Black Gore Creek watershed are predominantly sedimentary.

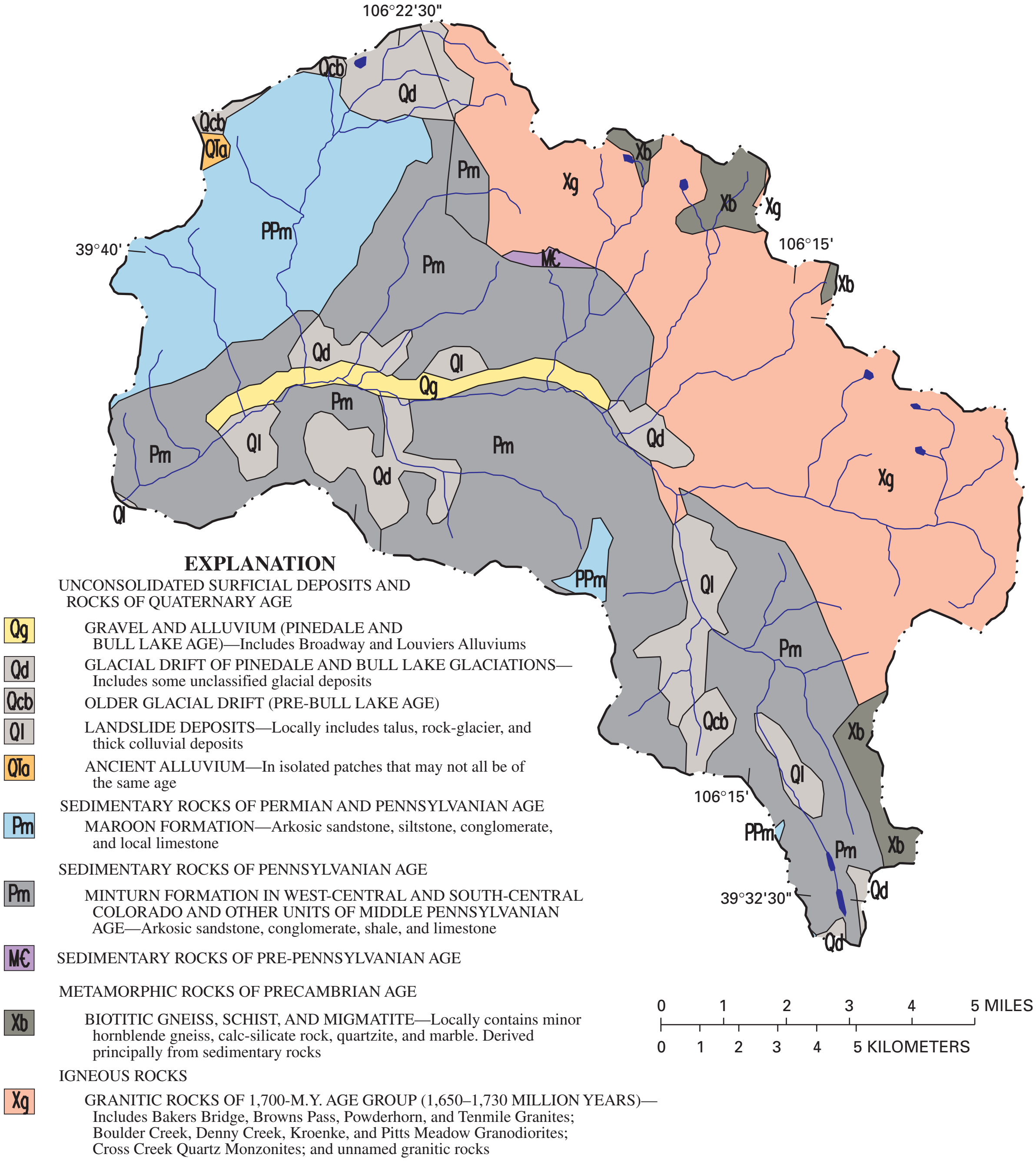


Figure 3. Geology of the Gore Creek watershed.

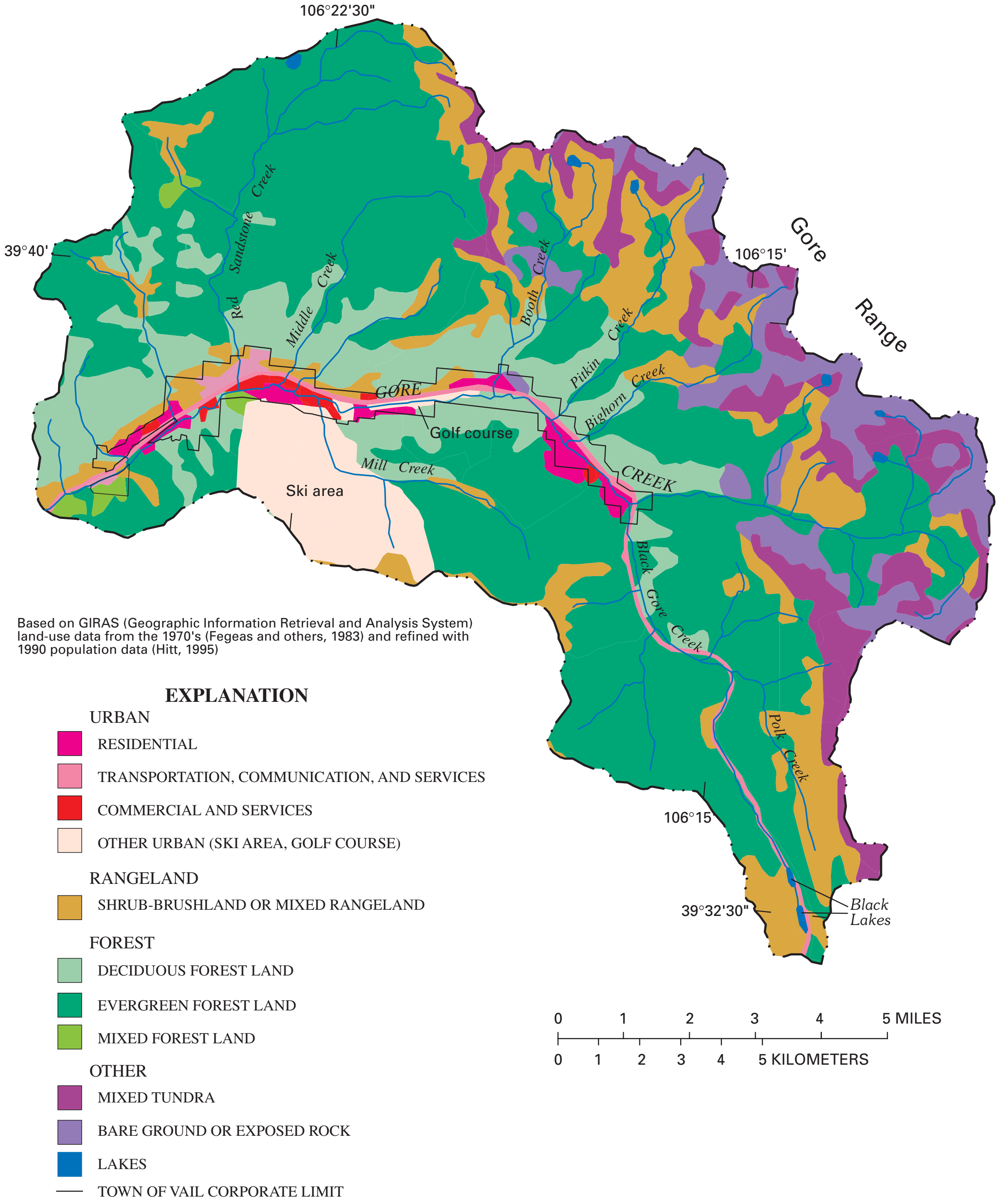
The Gore Creek watershed has undergone rapid land-use changes since the 1960's as the Vail area shifted from traditional mountain ranchlands to a four-season resort community. Land use/land cover in the Gore Creek watershed is 63 percent forested land, 14 percent shrub-brushland or mixed rangeland, 14 percent tundra and exposed rock areas, 8 percent urban, and 1 percent other land-use/land-cover classifications (fig. 4). Forested lands, which include deciduous, evergreen, and mixed forests, dominate the area below timberline (about 12,000 ft) and above the valley floor. The north-facing slopes contain a greater percentage of aspen and evergreen forests than the south-facing slopes, which contain sparser vegetation dominated more by shrubs and grasses. The U.S. Forest Service manages approximately 96 mi^2 of Federal land in the Gore Creek watershed, including about 6 mi^2 of the Vail Mountain ski area. The urban classification includes residential, transportation, commercial, and other urban categories. Residential, recreational, commercial, and transportation development occurs near Gore Creek and its tributaries to support the increasing permanent and tourist population of the area. The Town of Vail (which is about 6 mi^2 along a narrow corridor adjacent to Gore Creek), the Vail Mountain ski area, and Interstate 70 comprise the major land developments in the watershed. Interstate 70 extends 18 miles from Vail Pass along Black Gore and Gore Creeks through the Town of Vail. About one-half of the urban classification is the Vail Mountain ski area. Nearly all development is confined by terrain to the narrow Gore Creek valley floor, which is about 3,000 ft wide. All land-use/land-cover classifications were determined during the late 1970's (Fegeas and others, 1983) and redefined with 1990 population data (Hitt, 1995).

The population of Eagle County has increased about 192 percent between 1970 (7,498 people) and 1990 (21,928 people) (U.S. Bureau of the Census, 1970, 1990). An increase of about 158 percent from the 1990 population is projected for Eagle County by the year 2020 (56,668 people). The population of the Town of Vail, about 17 percent of the Eagle County population, has increased about 20 percent from 1990 (3,716 people) to 1997 (4,454 people) (Russell Forrest, Director of Community Development, Town of Vail, oral commun., 1998). Vail is about 85 percent developed; therefore, population growth is limited by availability of land for development (Russell Forrest, Director of Community Development, Town of Vail, oral commun., 1998). However, these population numbers only represent the permanent population, and unincorporated towns are not included in the census. Also, many tourists add significantly to the population of the watershed primarily during the winter and summer months. Therefore, the population census does not reflect the full demand on the water resources in the area.

Town of Vail. Photograph by Ken Neubecker.

DATA SOURCES AND COMPILATION

Data describing water, sediment, and tissue chemistry; water quantity; and macroinvertebrate, algal, and fish communities were obtained from many local, State, and Federal agencies and individuals. Electronically available data were merged into a relational database to facilitate analysis of the historical and current (1998) water-quantity, water-quality, and ecological conditions for the Gore Creek watershed. The type of data and its sources are summarized in table 1. Data for many of the sampling sites listed in table 1 were collected by more than one agency, and each agency had its own site-numbering and naming conventions. If a sampling site had several identification numbers, the USGS site name and site identification number, if available, were used and are listed in table 1.



Based on GIRAS (Geographic Information Retrieval and Analysis System) land-use data from the 1970's (Fegeas and others, 1983) and refined with 1990 population data (Hitt, 1995)

Figure 4. Land use for the Gore Creek watershed.

Table 1. Surface-water, ground-water, and aquatic-ecology sampling sites, and data sources and types in the Gore Creek watershed

[**Data source:** ASI, Advanced Sciences Incorporated, for Eagle River Water and Sanitation District; CDPHE, Colorado Department of Public Health and Environment, Water Quality Control Division; ERWSD, Eagle River Water and Sanitation District; USFS, U.S. Forest Service; USGS, U.S. Geological Survey National Water Information System; **Type of data:** A, algal community and biomass; B, bacteria; C, chlorofluorocarbons; F, fish community; FP, field properties; MB, methylene blue active substances; MC, macroinvertebrate community; MI, major ions; N, nutrients; OR, organics in water; P, pesticides in water; P2, pesticides in sediment; P3, pesticides in fish tissue; Q, continuous streamflow; R, radon; S, suspended sediment; TE, trace element in water; TE2, trace element in sediment; TE3, trace element in fish tissue; TE4, trace element in macroinvertebrate tissue; V, volatile organic compounds; **Site type:** GW, ground water; SW, surface water; **Latitude and Longitude:** degrees, minutes, and seconds]

Site number (figs. 5–9)	Site name	Identification number	Data source	Type of data	Period of discharge record	Period of water-quality record	Site type	Latitude	Longitude
1	Gore Creek at Upper Station, near Minturn	09065500	ASI, USGS	A, B, FP, MC, MI, N, Q, TE, TE2	1947–56, 1963–98	1976–96	SW	39°37'33"	106°16'39"
2	Gore Creek below Black Gore Creek, near Vail	393737106165900	USGS	FP, MI, N, TE		1996	SW	39°37'37"	106°16'59"
3	Gore Creek above Bighorn Creek, near Vail	393807106174600	USGS	FP, MI, N, TE		1996	SW	39°38'07"	106°17'46"
4	Gore Creek at Bighorn Subdivision, below Pitkin Creek	393831106181900	ASI, CDPHE, USGS	B, FP, MI, N, TE		1968–97	SW	39°38'31"	106°18'19"
5	Gore Creek above Katsos	393836106182500	USGS	A, FP, MC		1997	SW	39°38'36"	106°18'25"
6	Gore Creek below Katsos	393848106185900	USGS	A, FP, MC		1997	SW	39°38'48"	106°18'59"
7	Gore Creek above Wellfield near Vail	393844106192100	ASI, USGS	FP, MI, N, TE		1988–96	SW	39°38'44"	106°19'21"
8	Gore Creek at Booth Creek Road	393851106193100	USGS	A, FP, MC		1997	SW	39°38'51"	106°19'31"
9	Gore Creek at Golf Course at Vail	393844106195300	USGS	FP, MI, N, TE		1995	SW	39°38'44"	106°19'53"
10	Gore Creek at Vail	09066250	ASI, USGS	FP, MI, N, Q, S, TE	1974–79	1973–96	SW	39°38'35"	106°20'44"
11	Gore Creek at Vail WWTP Intake	393826106212900	USGS	B, FP, MI, TE		1976–77	SW	39°38'26"	106°21'29"
12	Gore Creek downstream of Pulis Bridge	393825106213400	USGS	A, FP, MC		1997	SW	39°38'25"	106°21'34"
13	Gore Creek below Golf Course at Vail	393825106220000	USGS	FP, MI, N, TE		1996	SW	39°38'25"	106°22'00"
14	Gore Creek near Middle Creek	393826106223800	USGS	A, FP, MC		1997	SW	39°38'26"	106°22'38"
15	Gore Creek above STP near Vail	393901106231400	USGS	B, FP, MI, N, TE		1976–77	SW	39°39'01"	106°23'14"
16	Gore Creek at Lower Station at Vail	09066310	ASI, ERWSD, USGS	A, B, FP, MC, MI, N, Q, TE	1988–98	1997	SW	39°38'28"	106°23'37"
17	Gore Creek 50 ft below WWTP	GC50FBLWSTP	ERWSD	B, FP, MI, N, TE		1990–96	SW	38°38'29"	106°23'38"

Table 1. Surface-water, ground-water, and aquatic-ecology sampling sites, and data sources and types in the Gore Creek watershed—Continued

[**Data source:** ASI, Advanced Sciences Incorporated, for Eagle River Water and Sanitation District; CDPHE, Colorado Department of Public Health and Environment, Water Quality Control Division; ERWSD, Eagle River Water and Sanitation District; USFS, U.S. Forest Service; USGS, U.S. Geological Survey National Water Information System; **Type of data:** A, algal community and biomass; B, bacteria; C, chlorofluorocarbons; F, fish community; FP, field properties; MB, methylene blue active substances; MC, macroinvertebrate community; MI, major ions; N, nutrients; OR, organics in water; P, pesticides in water; P2, pesticides in sediment; P3, pesticides in fish tissue; Q, continuous streamflow; R, radon; S, suspended sediment; TE, trace element in water; TE2, trace element in sediment; TE3, trace element in fish tissue; TE4, trace element in macroinvertebrate tissue; V, volatile organic compounds; **Site type:** GW, ground water; SW, surface water; **Latitude and Longitude:** degrees, minutes, and seconds]

Site number (figs. 5–9)	Site name	Identification number	Data source	Type of data	Period of discharge record	Period of water-quality record	Site type	Latitude	Longitude
18	Gore Creek below WWTP	393826106235300	USGS	A, FP, MC		1997	SW	39°38'26"	106°23'53"
19	Gore Creek below Red Sandstone Creek at Vail	393823106240000	ASI, USGS	FP, MI, N, TE		1988–96	SW	39°38'23"	106°24'00"
20	Gore Creek 0.5 mile downstream of WWTP	GC1/2MDNSTP	ERWSD	FP		1994–95	SW	39°38'17"	106°24'05"
21	Gore Creek 1 mile downstream of WWTP	GC1MDNSTP	ERWSD	FP		1994–96	SW	39°38'01"	106°24'33"
22	Gore Creek below Buffehr Creek near West Vail	393756106244300	USGS	FP, MI, N, TE		1996	SW	39°37'56"	106°24'43"
23	Gore Creek 1.5 miles downstream of WWTP	GC15MDNSTP	ERWSD	FP		1994–96	SW	39°37'46"	106°24'53"
24	Gore Creek at West Vail Exit	393738106251000	USGS	FP, MI, N, TE		1996	SW	39°37'38"	106°25'10"
25	Gore Creek 2 miles downstream of WWTP	GC2MDNSTP	ERWSD	FP,		1994–96	SW	39°37'32"	106°25'19"
26	Gore Creek at Stephens Park	393715106253600	USGS	A, FP, MC		1997	SW	39°37'15"	106°25'36"
27	Gore Creek at West Vail	393713106253900	USGS	FP, MI, N, TE		1995–96	SW	39°37'13"	106°25'39"
28	Gore Creek near Dowds Junction	393649106263201	USGS	FP, MI, TE		1983–84	SW	39°36'49"	106°26'32"
29	Gore Creek at Mouth, near Minturn	09066510	ASI, CDPHE, USGS	A, F, FP, MC, MI, N, OR, P, P2, P3, Q, TE, TE2, TE3, TE4,V	1944–56,[1] 1995–98	1968–98	SW	39°36'34"	106°26'50"
30	Black Gore Creek above Black Lake	393212106125800	ASI, USGS	FP, MI, N, TE		1988–96	SW	39°32'12"	106°12'58"
31	Black Lake	393253106132000	USEPA	FP, MI, TE		1985	SW	39°32'53"	106°13'20"
32	Black Gore Creek below Black Lake #2	393307106133200	ASI, USGS	FP, MI, N, TE		1988–96	SW	39°33'07"	106°13'32"
33	Black Gore Creek below Black Lake #2	393303106133100	USGS	FP, MC		1997	SW	39°33'03"	106°13'31"
34	Black Gore Creek above Polk Creek	393535106144300	USGS	FP, MC		1997	SW	39° 35'35"	106°14'43"

Table 1. Surface-water, ground-water, and aquatic-ecology sampling sites, and data sources and types in the Gore Creek watershed—Continued

[**Data source:** ASI, Advanced Sciences Incorporated, for Eagle River Water and Sanitation District; CDPHE, Colorado Department of Public Health and Environment, Water Quality Control Division; ERWSD, Eagle River Water and Sanitation District; USFS, U.S. Forest Service; USGS, U.S. Geological Survey National Water Information System; **Type of data:** A, algal community and biomass; B, bacteria; C, chlorofluorocarbons; F, fish community; FP, field properties; MB, methylene blue active substances; MC, macroinvertebrate community; MI, major ions; N, nutrients; OR, organics in water; P, pesticides in water; P2, pesticides in sediment; P3, pesticides in fish tissue; Q, continuous streamflow; R, radon; S, suspended sediment; TE, trace element in water; TE2, trace element in sediment; TE3, trace element in fish tissue; TE4, trace element in macroinvertebrate tissue; V, volatile organic compounds; **Site type:** GW, ground water; SW, surface water; **Latitude and Longitude:** degrees, minutes, and seconds]

Site number (figs. 5–9)	Site name	Identification number	Data source	Type of data	Period of discharge record	Period of water-quality record	Site type	Latitude	Longitude
35	Polk Creek at Interstate 70	393527106143500	USGS	FP, MI, N, TE, TE2		1996	SW	39°35'27"	106°14'35"
36	Polk Creek at I–70	393530106143800	USGS	FP, MC		1997	SW	39°35'30"	106°14'38"
37	Black Gore Creek near Minturn	09066000	USGS	FP, MC, MI, N, Q, TE	1947–56, 1963–98	1996	SW	39°35'47"	106°15'52"
38	Black Gore Creek near Vail	09066050	ASI, USGS	A, FP, MC, MI, N, Q, S, TE	1974–79	1973–96	SW	39°37'24"	106°16'47"
39	Ditch near Juniper Lane	393737106170500	USGS	FP, MC		1997	SW	39°37'37"	106°17'05"
40	Bighorn Creek near Minturn	09066100	USGS	FP, MI, N, Q, TE	1963–98	1996	SW	39°38'24"	106°17'34"
41	Bighorn Creek near Vail	393813106174500	USGS	A, FP, MC		1997	SW	39°38'13"	106°17'45"
42	Bighorn Creek near Vail	393813106174501	USGS	A, FP, MC		1997	SW	39°38'13"	106°17'45"
43	Columbine Pond Outflow near East Vail	393816106180100	USGS	FP, MC		1997	SW	39°38'16"	106°18'01"
44	Pitkin Creek near Minturn	09066150	USGS	FP, MC, MI, N, Q, TE	1966–98	1996	SW	39°38'37"	106°18'07"
45	Booth Creek near Minturn	09066200	USGS	A, FP, MC, MI, N, Q, TE	1964–98	1992–96	SW	39°38'54"	106°19'21"
46	Booth Creek Near Vail	393849106192000	USGS	A, FP, MC		1997	SW	39°38'49"	106°19'20"
47	Booth Creek near Vail	393849106192001	USGS	A, FP, MC		1997	SW	39°38'49"	106°19'18"
48	Mill Creek on Vail Mountain	393726106212000	USGS	A, FP, MC		1997	SW	39°37'26"	106°21'20"
49	Mill Creek near Mouth at Vail	393814106221500	ASI, USGS	FP, MI, N, TE		1988–96	SW	39°38'14"	106°22'15"
50	Mill Creek near Vail	393824106221700	USGS	A, FP, MC		1997	SW	39°38'24"	106°22'17"
51	Mill Creek near Vail	393824106221701	USGS	A, FP, MC		1997	SW	39°38'24"	106°22'17"
52	Mill Creek near Mouth at Vail	393827106222100	USGS	B, FP, N, TE		1976–77	SW	39°38'27"	106°22'21"
53	Ditch at end of Rockledge Road	393829106225400	USGS	FP, MC		1997	SW	39°38'29"	106°22'54"
54	Ditch at 123 Beaver Dam Road	393828106224800	USGS	FP, MC		1997	SW	39°38'28"	106°22'48"
55	Middle Creek near Minturn	09066300	USGS	FP, MI, N, Q, TE	1964–98	1996	SW	39°38'45"	106°22'54"

Table 1. Surface-water, ground-water, and aquatic-ecology sampling sites, and data sources and types in the Gore Creek watershed—Continued

[**Data source:** ASI, Advanced Sciences Incorporated, for Eagle River Water and Sanitation District; CDPHE, Colorado Department of Public Health and Environment, Water Quality Control Division; ERWSD, Eagle River Water and Sanitation District; USFS, U.S. Forest Service; USGS, U.S. Geological Survey National Water Information System; **Type of data:** A, algal community and biomass; B, bacteria; C, chlorofluorocarbons; F, fish community; FP, field properties; MB, methylene blue active substances; MC, macroinvertebrate community; MI, major ions; N, nutrients; OR, organics in water; P, pesticides in water; P2, pesticides in sediment; P3, pesticides in fish tissue; Q, continuous streamflow; R, radon; S, suspended sediment; TE, trace element in water; TE2, trace element in sediment; TE3, trace element in fish tissue; TE4, trace element in macroinvertebrate tissue; V, volatile organic compounds; **Site type:** GW, ground water; SW, surface water; **Latitude and Longitude:** degrees, minutes, and seconds]

Site number (figs. 5–9)	Site name	Identification number	Data source	Type of data	Period of discharge record	Period of water-quality record	Site type	Latitude	Longitude
56	Middle Creek near Vail	393836106230101	USGS	A, FP, MC		1997	SW	39°38'36"	106°23'01"
57	Middle Creek near Vail	393836106230100	USGS	A, FP, MC		1997	SW	39°38'36"	106°23'01"
58	Culvert near Lionshead	393836106230400	USGS	FP, MC		1997	SW	39°38'36"	106°23'04"
59	Red Sandstone Creek, near Minturn	09066400	USGS, USFS	B, FP, MI, N, Q	1963–98	1978–90	SW	39°40'58"	106°24'03"
60	Lower Red Sandstone Creek above first switchback	393755106234500	USFS	B, FP, N,		1978–82	SW	39°37'55"	106°23'45"
61	Red Sandstone Creek near Vail	393852106234300	USGS	A, FP, MC		1997	SW	39°38'52"	106°23'43"
62	Red Sandstone Creek near Vail	393841106234200	USGS	A, FP, MC		1997	SW	39°38'41"	106°23'42"
63	Red Sandstone Creek near Vail	393841106234201	USGS	A, FP, MC		1997	SW	39°38'41"	106°23'42"
64	Red Sandstone Creek at Mouth at Vail	393829106234400	USGS	FP, MI, N, TE		1996	SW	39°38'29"	106°23'44"
65	Buffehr Creek near Vail	393801106244800	USGS	A, FP, MC		1997	SW	39°38'01"	106°24'48"
66	Buffehr Creek near Vail	393801106244801	USGS	A, FP, MC		1997	SW	39°38'01"	106°24'48"
67	Bighorn Park	393743106171000	USGS	B, C, FP, MB, MI, N, P, R, TE, V		1997	GW	39°37'43"	106°17'10"
68	SC00508003DDB00—VAIL, Well Field Composite, wells R–1, R–6, and R–7	393844106193300	ASI, USGS	B, C, FP, MB, MI, N, P, R, TE, V		1988–89, 1997	GW	39°38'45"	106°19'54"
69	Vail Golf Course	393830106210600	USGS	B, C, FP, MB, MI, N, P, R, TE, V		1997	GW	39°38'30"	106°21'06"
70	Gerald R. Ford Park	393823106215900	USGS	B, C, FP, MB, MI, N, P, R, TE, V		1997	GW	39°38'23"	106°21'59"
71	Pedestrian Bridge	393844106232300	USGS	B, C, FP, MB, MI, N, P, R, TE, V		1997	GW	39°38'44"	106°23'23"
72	Stephens Park Well	393718106253000	USGS	B, C, FP, MB, MI, N, P, R, TE, V		1997	GW	39°37'18"	106°25'30"

[1] Discharge record from discontinued station 09066500, 0.4 mile upstream from current station.

Most of the data used in assessing the water-quantity, water-quality, and aquatic-ecology conditions in the Gore Creek watershed were obtained from three sources: (1) the USGS, (2) the Colorado Department of Public Health and Environment, Water Quality Control Division, and (3) the Eagle River Water and Sanitation District. A large part of the available data from the USGS was collected since 1995, as part of the USGS Upper Colorado River Basin (UCOL) National Water-Quality Assessment (NAWQA) Program, and through a cooperative agreement between the USGS, the Town of Vail, the Eagle River Water and Sanitation District, and the Upper Eagle Regional Water Authority. Additional information from numerous published reports pertaining to various aspects of water-quantity, water-quality, and aquatic-ecology conditions in the Gore Creek watershed are discussed in this report to aid in the interpretation and understanding of historical and present conditions in the watershed.

Water-quantity, water-quality, or aquatic-ecology data were collected at surface-water sites. The sites are listed as site numbers 1–66 in table 1 and are shown in figures 5 and 6. Sites, such as site 29, where surface-water quality and aquatic-ecology samples were

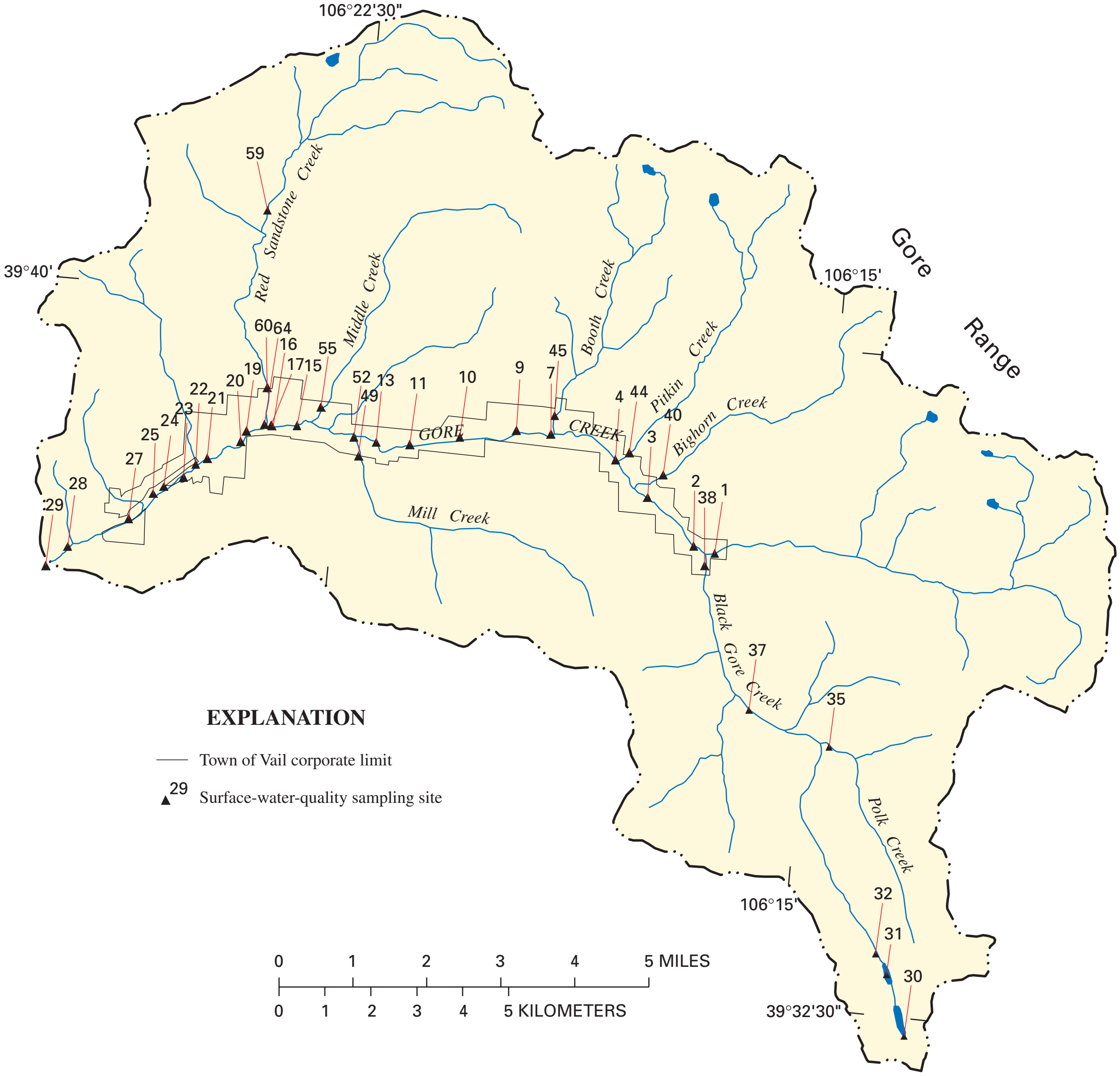


Figure 5. Surface-water-quality sampling sites in the Gore Creek watershed.

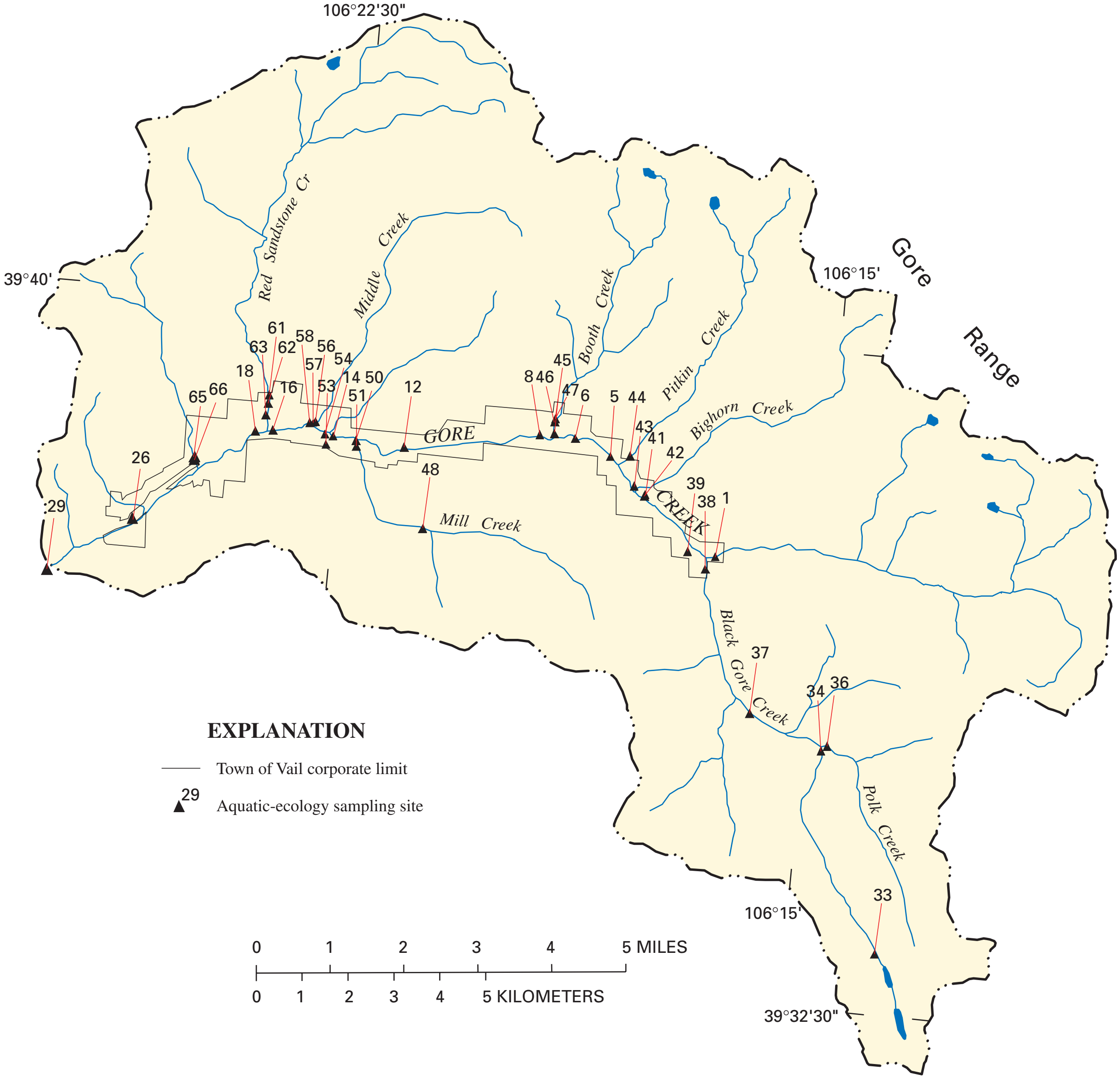


Figure 6. Aquatic-ecology sampling sites, 1995–97.

collected, are shown in both figures. Data available for surface-water-quality sites include continuous streamflow; field properties (water temperature, specific conductance, dissolved oxygen, pH, and alkalinity); major ions; nutrients; pesticides; dissolved and suspended organic carbon (DOC and SOC); suspended sediment; VOCs; trace elements; and algae, macroinvertebrate, and fish communities. Sampling media for the various chemical constituents are water, bed sediment, fish tissues, and macroinvertebrate tissues. Figure 7 shows the distribution and period of record for surface-water nutrient samples. Nutrient data were collected at 30 sites in the Gore Creek watershed, but only 9 sites had more than 5 nutrient samples. Figure 8 shows the distribution and period of record for surface-water trace-element samples. Trace-element data were collected at 30 sites, and only 12 sites had more than 5 trace-element samples.

Ground-water sampling sites are listed in table 1 (sites 67–72) and are shown in figure 9. Five ground-water-monitoring wells (sites 67 and 69–72) were completed in the unconsolidated alluvium and were sampled as part of an urban land-use study conducted by the USGS. Ground-water site 68 is a three-well

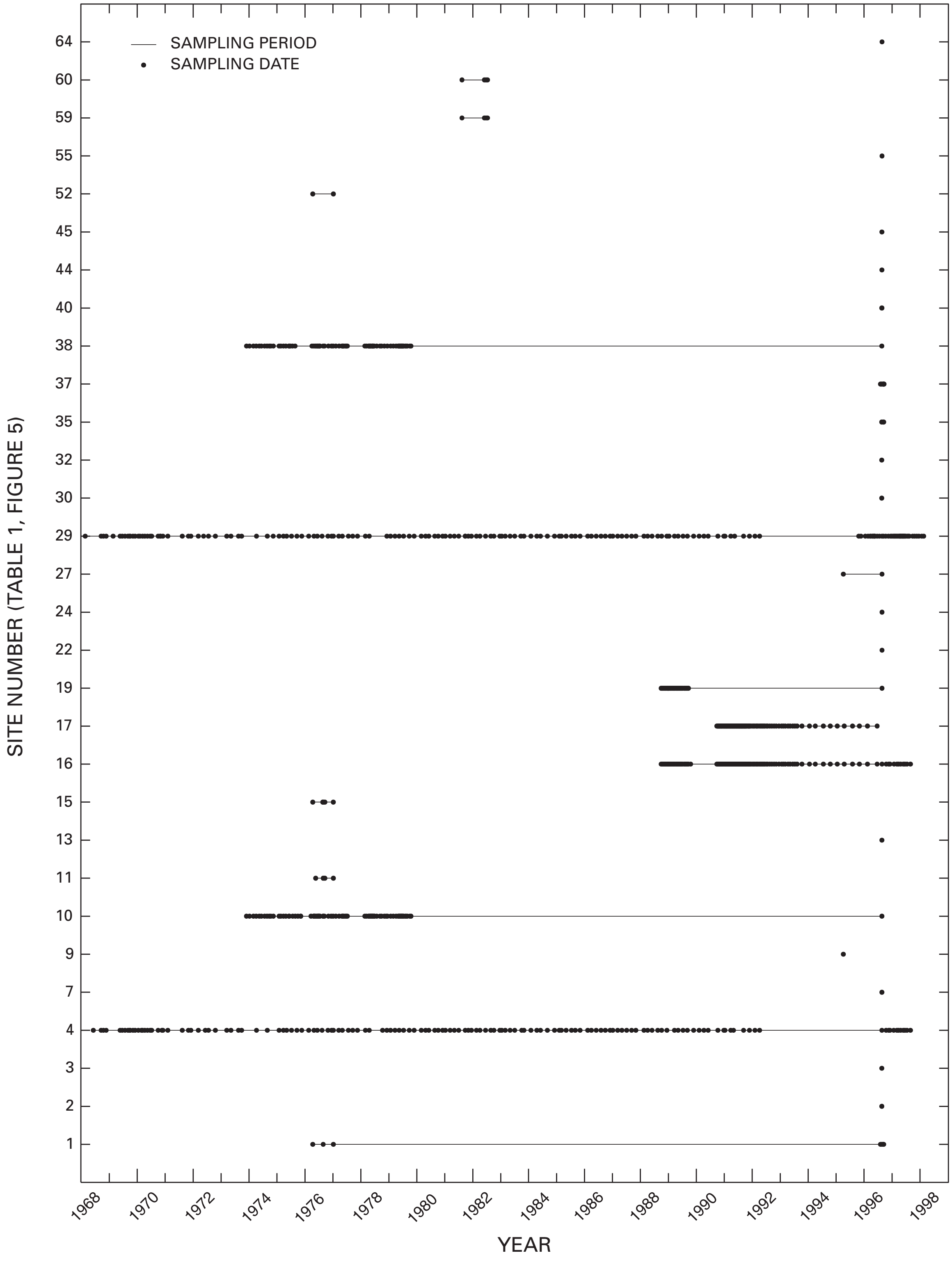


Figure 7. Distribution of sampling dates and period of record for nutrient samples at surface-water sampling sites.

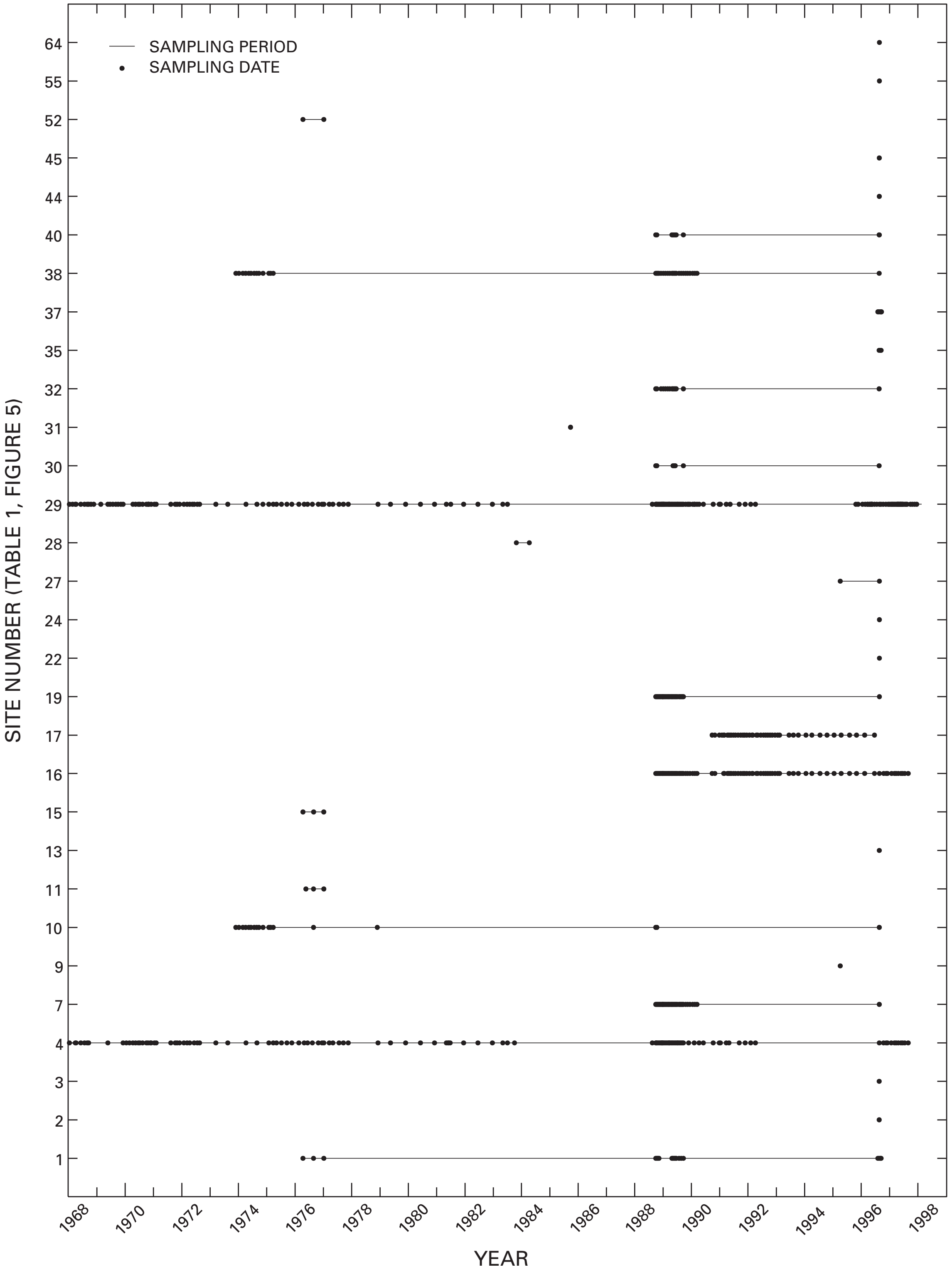


Figure 8. Distribution of sampling dates and period of record for trace-element samples at surface-water sampling sites.

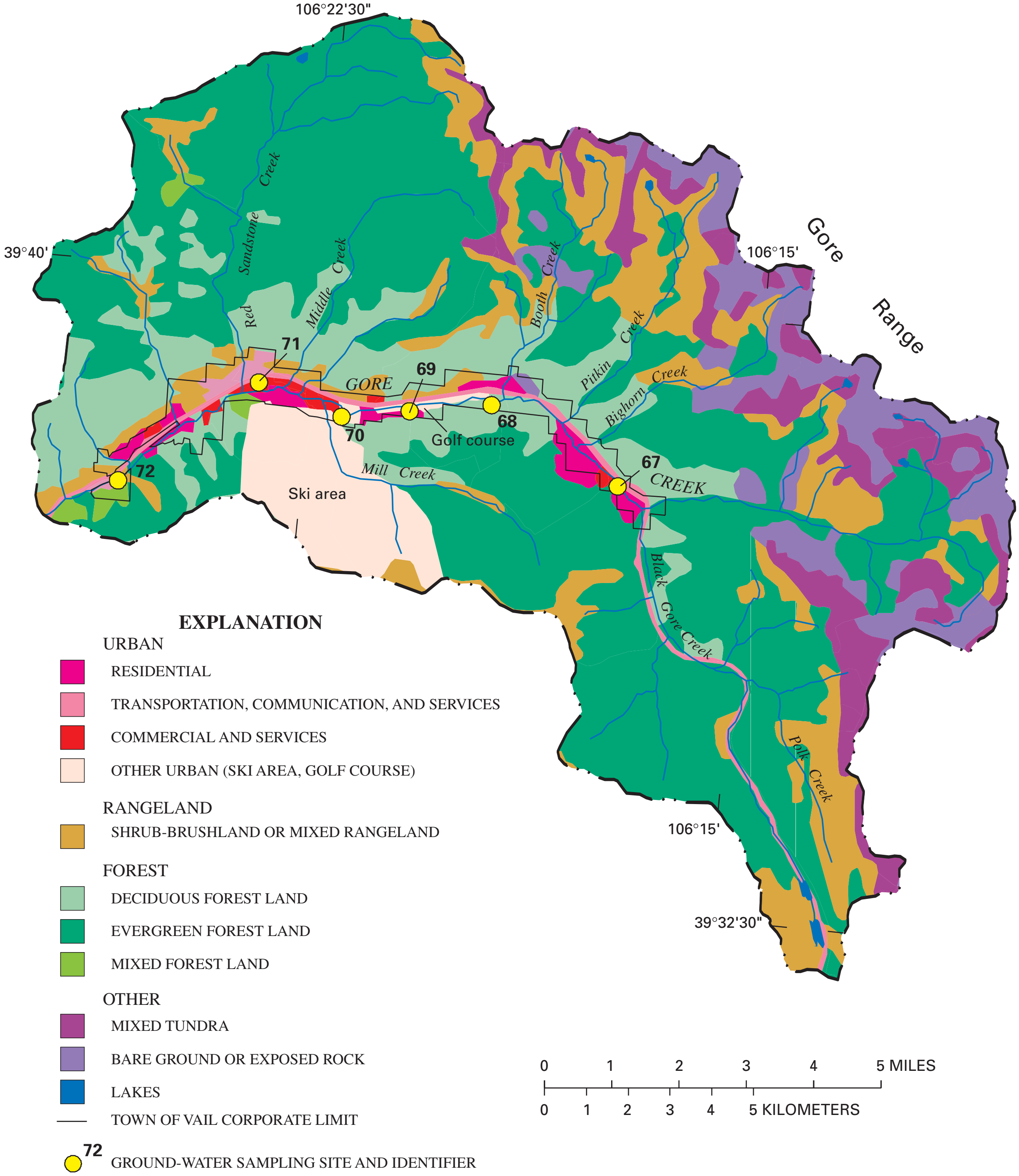


Figure 9. Ground-water sampling sites, 1988–97.

municipal well field that is operated by the Eagle River Water and Sanitation District. Ground-water data were available for field properties, major ions, nutrients, trace elements, pesticides, DOC, VOCs, bacteria (total coliforms and *Escherichia coli* [*E. coli*]), methylene blue active substances (MBAS), and chlorofluorocarbons at the USGS sites.

Aquatic-ecology data (stream and riparian habitat, and algae, macroinvertebrate, or fish community) were available for 36 sites in the Gore Creek watershed (fig. 6, table 1). Fish-community data at one site were available for 1995–98. Algae, macroinvertebrate, and habitat data were available from a synoptic study done in September 1997. Discussion of historical and current aquatic ecology in this report focuses on sites in the main stem of Gore Creek as it flows from its headwaters through the Town of Vail and sites in Black Gore Creek as it flows from Vail Pass to its confluence with Gore Creek along Interstate 70. Most of the data from this synoptic study were collected by the USGS for the Town of Vail, as part of a national study by the U.S. Environmental Protection Agency (USEPA) to assess the ecological benefits of stormwater controls such as natural vegetation buffer strips or swales (Watershed Management Institute, unpub. data, 1996). Interpretation of the tributary-stream data is beyond the scope of this report.

METHODS OF DATA REVIEW AND ANALYSIS

Water-quality properties and constituents are presented graphically and statistically in this report. The surface- and ground-water-quality data were quality assured by examining the total cation and total anion concentrations and the total nitrogen and total phosphorus concentrations in all samples with available data. For data used in this report, differences in total cation and total anion concentrations were less than 10 percent. Fewer than 5 percent of the available nutrient samples were discarded for use in this report because total nitrogen or total phosphorus concentrations were less than the sum of the constituents that make up the total concentration.

Water-quality data were analyzed using nonparametric statistical methods. Nonparametric statistical analyses of rank-transformed data are not unduly affected by outliers and are not dependent on a normal distribution of the data. During assessment of the spatial distribution of individual nutrient species, greater than one-half of the data for some sites were censored (reported below a laboratory reporting limit). If more than one-half the data for a particular nutrient constituent were censored at a site, estimates of the 10th, 25th, 50th (median), 75th, and 90th percentiles were calculated using the maximum likelihood estimation (MLE) method (Helsel, 1990; Helsel and Cohn, 1988). These estimated percentiles were used to construct the boxplots and provide median concentrations plotted on the maps. Statistical comparison of streamflow relations to nitrate and total phosphorus concentrations was performed using the Mann-Whitney U test, which is a nonparametric version of the two-group unpaired t-test (Helsel and Hirsch, 1992). For this test, censored values were treated as equal to the reporting limit for that sample. Long-term temporal differences in the concentrations of ammonia, nitrate, orthophosphate, total phosphorus, and specific-conductance values were compared statistically for the 1968–97 period by using Tukey's Significant Difference Test (Tukey test) on the rank-transformed data (Helsel and Hirsch, 1992). Because of a high percentage of censored data values during the spring and summer seasons, and because higher nutrient concentrations occur typically during low flow, only the winter season (November–April) was tested statistically for trends for each constituent. For the Tukey test, censored values were treated as equal to the reporting limit. Flow-adjusted concentrations were not used to evaluate temporal changes in nutrient concentrations because much of the available data lacked concurrent streamflow information and also because a high percentage of the data was censored.

Boxplots were used to display the central tendency and variability in specific-conductance values and nutrient concentrations. Boxplots (for example, fig. 13) graphically show the central tendency of the data (the median, or 50th percentile line of the box, marked with a diamond for clarity), the variation of the data (interquartile range, or the box height between the 25th and 75th percentiles), the 10th and 90th percentiles (shown by whiskers below and above the box), and the skewness (quartile skew, or the relative size of the box halves divided by the median line) (Helsel and Hirsch, 1992). Data points plotted below and above the boxplot whiskers represent data values that are less than the 10th and greater than the 90th percentile, respectively.

The water-quality data were compared with drinking-water and stream-quality standards where applicable. Drinking-water standards are set by the USEPA and include the primary (MCL), secondary

(SMCL), and proposed (PMCL) maximum contaminant levels set for drinking water, and maximum contaminant level goals (MCLG), drinking-water advisory (DWA), and health advisory (HA) standards (U.S. Environmental Protection Agency, 1996). The USEPA standards are defined as the permissible level of a contaminant in treated water delivered to users of a public water-supply system, and as such, do not relate specifically to the untreated water samples discussed in this report, except as a point of reference. The lowest applicable stream-quality standards are discussed, where applicable, in this report; values were calculated for Gore Creek by Wynn and Spahr (1998) using the methods of the Colorado Department of Health (1996). These standards are generally the chronic or acute aquatic-life standards for the protection of aquatic life.

Data collection in the Gore Creek watershed by the USGS since October 1995 has followed published protocols for the USGS NAWQA Program. The following information summarizes the sample-collection protocols followed by the USGS for water, sediment, and stream-biota data collection. Surface- and ground-water samples were collected following the protocols described by Shelton (1994) and Koterba and others (1995), respectively. As part of the UCOL NAWQA assessment of surface- and ground-water quality, quality-assurance samples constituted no less than 10 percent of the total number of environmental samples. An interim report of surface-water quality-control sample results is presented by Spahr and Boulger (1997). Fish-community data for the mouth of Gore Creek were collected by electroshocking in a 450-ft stream reach near the mouth of Gore Creek, using protocols described by Meador and others (1993). Fish- and macroinvertebrate-tissue samples were collected using the protocols described by Crawford and Luoma (1994). Algae samples were collected from rock surfaces in riffle areas using the protocols described by Porter and others (1993). Streambed-sediment samples were collected using the protocols described by Shelton and Capel (1994). Macroinvertebrate-community samples were collected from riffle areas by using a 1-m^2 hand screen equipped with 425-μm^2 mesh material. Generally, 1 to 2 m^2 of substrate was sampled upstream from the hand screen to collect a macroinvertebrate sample. Macroinvertebrate-community abundance results were normalized to the number of organisms per square meter. Qualitative riparian and aquatic habitat was scored using USEPA rapid bioassessment protocols (RBP) described by Plafkin and others (1989).

Triplicate samples were collected at selected sites for quality control of the algal-biomass and algae- and macroinvertebrate-community sampling in September 1997. Where triplicate samples were collected, the values discussed and shown on graphs represent the average value for that site. The standard error of the mean (standard deviation divided by the square root of the number of samples) was calculated and included on graphs to show the variability of the sample results. For example, in figure 25B, the error bars overlain on the graphs represent the standard error of the mean biovolume for nitrogen-autotroph diatom for the two sites where triplicate algae samples were taken for quality-control purposes. Short error bars indicate less variability in sampling and processing methods. For example, the biovolume at site 26 is about $5.25\times10^7\ \mu\text{m}^3/\text{cm}^2$ plus or minus the standard error of $0.75\times10^7\ \mu\text{m}^3/\text{cm}^2$. Because the standard error at site 26 overlaps the measured algal biovolume at site 18, one cannot say with confidence that algal biovolume at site 26 is significantly lower than algal biovolume at site 18.

Nutrient data for surface-water sites in the Gore Creek watershed were identified and compiled from several sources (table 1). Because the data were collected by various groups for different purposes and a variety of laboratory methods were used, nutrient constituents were reported in numerous ways. The available nutrient data included 24 nitrogen and phosphorus constituents that were collected at 30 sites between February 21, 1968, and December 16, 1997 (fig. 7).

For the evaluation of nutrient conditions in the Gore Creek watershed, nutrient constituents were aggregated to reduce the number of constituents from 15 to 5. The procedures used to aggregate nutrient constituents follow the method of Mueller and others (1995) and are summarized in table 2. The data aggregation resulted in the creation of a nutrient-analysis data set that included the following constituents:

- ammonia nitrogen, as nitrogen (hereinafter referred to as “ammonia”);
- nitrate nitrogen, as nitrogen (hereinafter referred to as “nitrate”);
- total nitrogen, as nitrogen (hereinafter referred to as “total nitrogen”);
- orthophosphate, as phosphorus (hereinafter referred to as “orthophosphate”); and
- total phosphorus, as phosphorus (hereinafter referred to as “total phosphorus”).

Table 2. Summary of procedure used to aggregate nutrient data in the Gore Creek watershed into selected nutrient constituents (from Mueller and others, 1995)

[mg/L, milligrams per liter; N, nitrogen; NO_3, nitrate; P, phosphorus; PO_4, orthophosphate; *, parameter determined by using the procedure listed for nitrite, as N; **, parameter determined by using the procedure listed for nitrate, as N]

Constituent	Nutrient data parameter name	Nutrient data parameter code[1]
Ammonia, as N	Nitrogen, ammonia, dissolved (mg/L as N)	00608
	Nitrogen, ammonia, total (mg/L as N)	00610
Nitrate, as N	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	00631
	minus nitrite,[2] as N	*
	Nitrogen, nitrite plus nitrate, total (mg/L as N)	00630
	minus nitrite,[2] as N	*
	Nitrogen, nitrate, dissolved (mg/L as N)	00618
	Nitrogen, nitrate, total (mg/L as N)	00620
	Nitrogen, nitrate, total (mg/L as NO_3)	71850 (multiplied by 0.2259)
Total nitrogen	Nitrogen, total (mg/L as N)	00600
	Nitrogen, total (mg/L as NO_3)	71887 (multiplied by 0.2259)
	Nitrogen,[3] ammonia plus organic, total (mg/L as N)	00625
	plus nitrate,[2] as N, plus nitrite,[2] as N	**, *
Orthophosphate, as P	Phosphorus, orthophosphate, dissolved (mg/L as P)	00671
	Phosphate, ortho, dissolved (mg/L as PO_4)	00660 (multiplied by 0.3261)
	Phosphorus, orthophosphate, total (mg/L as P)	70507
	Phosphate, total (mg/L as PO_4)	00650 (multiplied by 0.3261)
Total phosphorus	Phosphorus, total (mg/L as P)	00665

[1] From the USGS National Water Information System (NWIS) and the USEPA Data Storage and Retrieval system (STORET).

[2] Missing values or values less than detection are not included in this calculation.

[3] Also called total Kjeldahl nitrogen. If value is missing or less than detection, total nitrogen is not computed.

SURFACE WATER

Water-quantity, water-quality, streambed-sediment chemistry, and tissue-chemistry data were available for 37 sites in the Gore Creek watershed. These data and information were used to evaluate the historical and current water-quality conditions. Predominant natural and human factors affecting surface-water conditions were identified to the extent possible.

Water Quantity

The major tributaries of Gore Creek are Black Gore, Bighorn, Pitkin, Booth, Mill, Middle, and Red Sandstone Creeks (fig. 1). The hydrologic characteristics of the Gore Creek watershed can be represented in a generalized water budget (table 3). This generalized budget provides an understanding of water storage and flux through the watershed. Average annual water input for the watershed is 185,000 acre-ft, based on an average annual precipitation of 34 inches distributed over the drainage area (Colorado Climate Center, 1984). Because the Gore Creek watershed is a headwater system, there are no surface-water inflows to the watershed except for an estimated maximum of 500 acre-ft/yr of water from the Eagle River for snowmaking (assuming snowmaking for all of November and December) (Jim Roberts, Vail Associates, oral commun., August 1998). This diversion into Gore Creek is highly variable, depending upon the needs for snowmaking, air temperature, and availability of other sources for snowmaking. The remaining water inputs by interbasin-water transfers and ground-water inflow are negligible. Water outputs from the watershed are more diverse; the predominant output is by surface-water outflow, which accounts for about 55 percent of the total water output. Evapotranspiration, which is calculated as the residual in the water balance, accounts for about 40 percent of the total water output. Consumptive water use, estimated to be 9,300 acre-ft/yr based on 1995 water-use data, accounts for 5 percent of the total water output (R.G. Dash, U.S. Geological Survey, written commun., 1998).

Streamflow has been measured at 11 gaging stations in the watershed, and in 1998, 9 of these stations were active (table 4). The first streamflow-gaging station in the area was established in 1944 on Gore Creek at the mouth; however, the longest records of operation in the watershed are for two upstream stations, Gore Creek at Upper Station near Minturn and Black Gore Creek near Minturn. About 80 percent of the annual streamflow is derived from snowmelt, which occurs in May, June, and July. During most of the year, the daily flow is less than one-third of the mean annual streamflow, which ranges from 5.95 to 140 ft^3/s among selected stations in the watershed (table 4). Mean annual runoff ranges from 4,310 to 101,340 acre-ft/yr and reflects the large amounts of precipitation in the watershed. Coefficient of variation, which is a measure of the variability of streamflow from year to year, is low for all 11 gaging stations, ranging from 0.26 to 0.37. Water-quality conditions can be affected by variation in the timing and magnitude of streamflow from year to year.

Annual streamflow patterns are similar at five selected stations (fig. 10). Streamflow at Gore Creek at Upper Station near Minturn has no upstream diversions, and the variability in the streamflow is low (coefficient of variation, 0.26). Streamflow in Black Gore Creek near Minturn is affected by the operations of the Black Lakes, which are used to mitigate the impacts of diversions of instream flows for snowmaking during the winter months (Weaver and Jones, 1995). However, the annual streamflow pattern is similar to the other four stations and the variability in the streamflow is low (0.30). The streamflow pattern at Red Sandstone Creek near Minturn, a major tributary to Gore Creek, is similar to the other gaging stations. The two downstream main-stem stations, Gore Creek at Lower Station at Vail and Gore Creek at Mouth near Minturn, have a streamflow pattern similar to the other three gaging stations including low variability in streamflow; however, these two stations lack long-term streamflow data.

Monthly streamflows for the five gaging stations (fig. 11) are similar and indicate streamflow in the Gore Creek watershed is dominated by snowmelt during May, June, and July. Although the magnitude of peak flows in this watershed can be quite large, exceptionally large snowmelt flows that cause severe flooding are uncommon. Because of the annual nature of snowmelt flows, most stream channels are capable of carrying these flows without extensive overbank flooding (Apodaca and others, 1996). Reservoir storage and local diversions also diminish the magnitude of the annual snowmelt peak flows. The 10-year flood (table 4), which indicates that a given peak flow has a 10-percent chance of occurring in any given year, ranges from 106 to 1,715 ft^3/s at the streamflow-gaging stations in the Gore Creek watershed.

Table 3. Generalized water budget for the Gore Creek watershed

[acre-ft/yr, acre-feet per year; <, less than]

Source	Inputs (acre-ft/yr)	Percentage	Source	Outputs (acre-ft/yr)	Percentage
Precipitation	185,000	100	Evapotranspiration from nonirrigated land (residual)	74,900	40
Surface-water inflow	[a]500	<1	Surface-water outflow	[b]101,300	55
Interbasin transfers (negligible)	0		Consumptive water use	[c]9,300	5
Ground-water inflow (negligible)	0		Interbasin water transfers	0	
			Reservoir evaporation	Negligible	
			Ground-water outflow	Negligible	
			Change in ground-water storage	Negligible	
Total (rounded)	185,500	100		185,500	100

[a] Based on estimated data 1996–98 (Jim Roberts, Vail Associates, oral commun., 1998).

[b] Data from the U.S. Geological Survey National Water Information System.

[c] Based on 1995 data (R.G. Dash, U.S. Geological Survey, written commun., 1998).

Table 4. Hydrologic characteristics for surface-water sampling sites in the Gore Creek watershed

[mi^2, square miles; ft^3/s, cubic feet per second; acre-ft/yr, acre-feet per year]

Site no. (table 1, fig. 5)	Site name	Station identification number	Period of record, in calendar years	Drainage area (mi^2)	Mean annual streamflow (ft^3/s)	Coefficient of variation of annual streamflow	Mean annual runoff (acre-ft/yr)	2-year, 7-day low-flow value (ft^3/s)	10-year, 7-day low-flow value (ft^3/s)	10-year flood (ft^3/s)
1	Gore Creek at Upper Station, near Minturn, CO	09065500	1947–56, 1963–98	14.4	30.3	0.26	21,990	2.30	1.5	550
37	Black Gore Creek, near Minturn, CO	09066000	1947–56, 1963–98	12.6	17.4	.30	12,600	1.70	1.1	315
38	Black Gore Creek, near Vail, CO	09066050	1974–79	19.6	27.3	.34	19,790	2.7	2.1	420
40	Bighorn Creek, near Minturn, CO	09066100	1963–98	4.54	10.1	.31	7,295	.63	.28	180
44	Pitkin Creek, near Minturn, CO	09066150	1966–98	5.32	11.8	.32	8,586	1.0	.4	194
45	Booth Creek, near Minturn, CO	09066200	1964–98	6.02	12.2	.28	8,864	.72	.35	249
10	Gore Creek at Vail, CO	09066250	1974–79	57.3	90.4	.31	65,490	4.6	3.9	1,484
55	Middle Creek, near Minturn, CO	09066300	1964–98	5.94	5.95	.37	4,310	.19	No flow	106
16	Gore Creek at Lower Station, at Vail, CO	09066310	1988–98	77.1	122	.32	88,690	8.70	6.0	1,664
59	Red Sandstone Creek, near Minturn, CO	09066400	1963–98	7.32	9.23	.29	6,688	.75	.44	191
29	Gore Creek at Mouth, near Minturn, CO	09066510	[1]1944–56, 1995–98	102	140	.28	101,340	16.0	11.26	1,715

[1] Streamflow data for the period 1944–56 are from discontinued station 09066500 located 0.4 mile upstream from station 09066510.

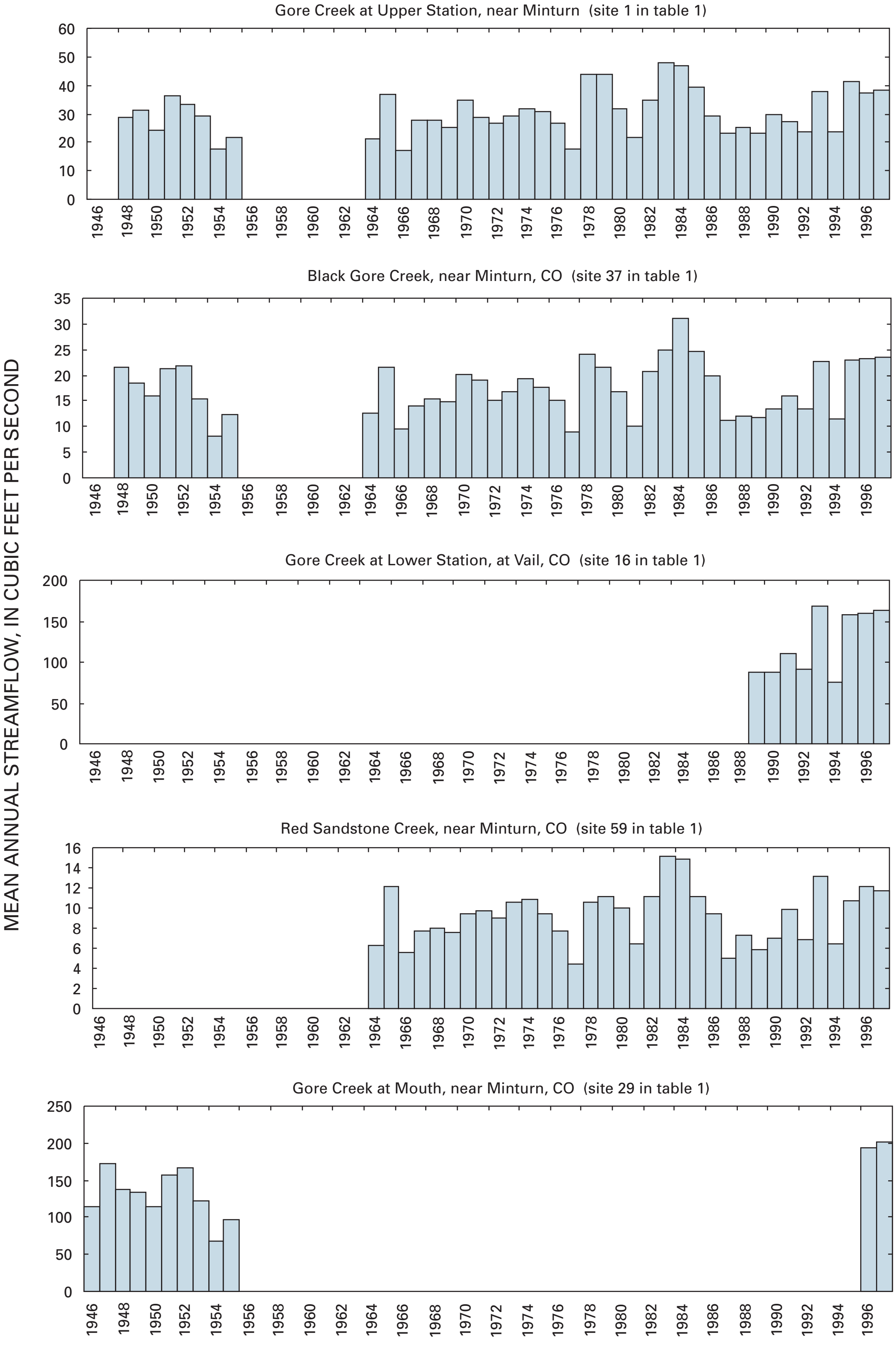


Figure 10. Mean annual streamflow at selected gaging stations in the Gore Creek watershed.

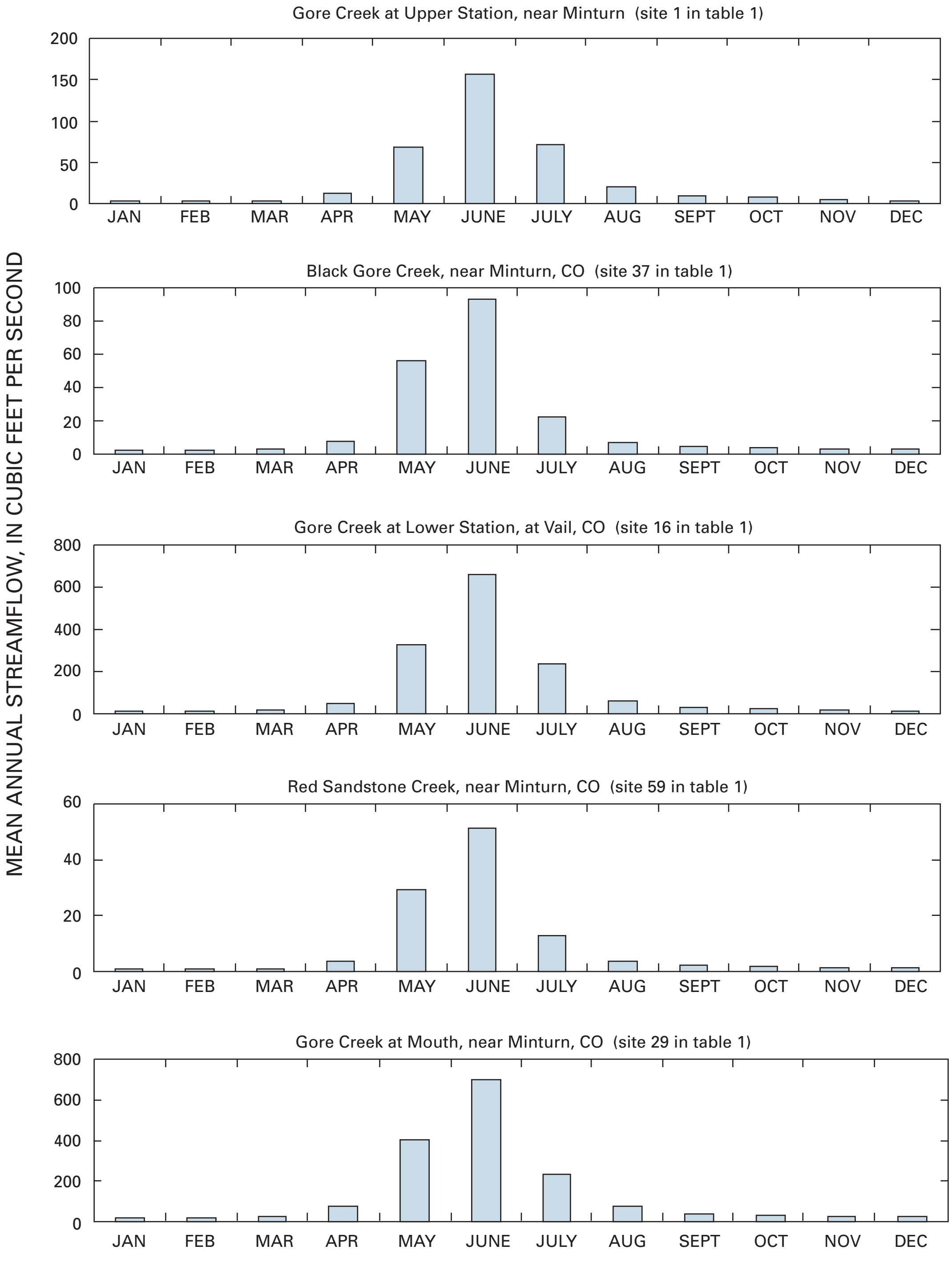
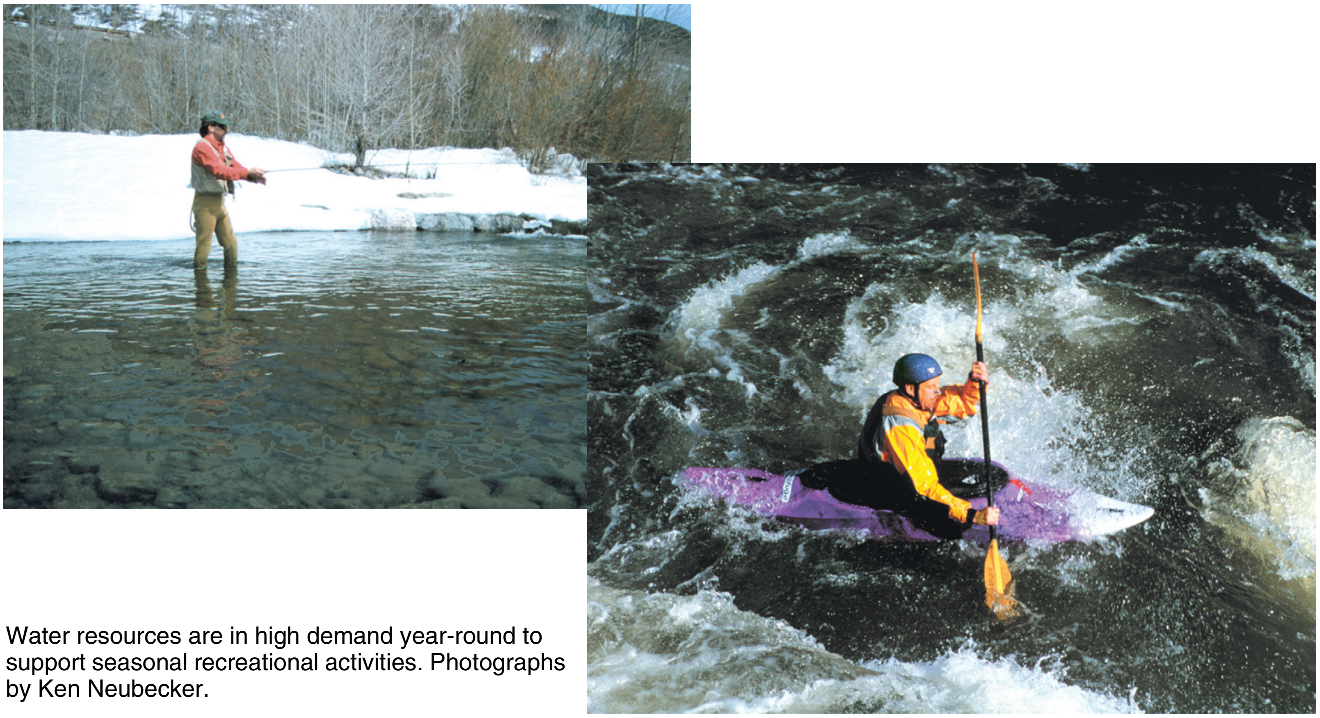


Figure 11. Mean monthly streamflow at selected gaging stations in the Gore Creek watershed.



Water resources are in high demand year-round to support seasonal recreational activities. Photographs by Ken Neubecker.

Low flows in Gore Creek are sustained primarily by ground-water discharge and the gradual melting of perennial snowfields. Knowledge about the expected frequency of certain low flows is important because of potential detrimental effects to stream biota resulting from depletion of dissolved oxygen and higher concentrations of dissolved contaminants in low flows. The 2-year and 10-year 7-day low flows (table 4) indicate the lowest mean streamflow for a period of 7 consecutive days that have a 50-percent or 10-percent chance, respectively, of not being exceeded in any given year the values range from no flow to 16 ft^3/s (table 4).

Water Quality

Water-quality property and constituent data available for surface-water sites consist of field properties (specific conductance, dissolved oxygen, pH, and water temperature), inorganic constituents (major ions, trace elements, and nutrients), sediment (suspended sediment and bedload), and organic constituents (DOC, SOC, pesticides, and VOCs). Data were collected at 37 sites throughout the Gore Creek watershed (fig. 5).

Field Properties

Field properties such as specific conductance, dissolved oxygen, pH, and water temperature are indicators of water-quality conditions. Specific conductance provides a good measure of the amount of dissolved constituents in water. Adequate concentrations of dissolved oxygen are critical to aquatic life. Even infrequent periods of dissolved-oxygen depletion can have adverse effects on stream biota such as fish and macroinvertebrates. pH is a controlling factor for partitioning of trace elements in sediment and water. Low pH tends to increase solubility of trace elements in water. Streams with very low pH, such as found in streams affected by mining, can have much reduced or even nonexistent macroinvertebrate and fish communities. Temperature influences metabolic rates in stream organisms. Aquatic organisms are adapted to specific temperature regimes; for example, trout are considered a cold-water fish.

Specific conductance. Specific conductance is proportional to the dissolved-solids concentration in a given water sample. The major ions that compose dissolved solids for water samples from the Gore Creek watershed are calcium, magnesium, sodium, potassium, silica, chloride, sulfate, and bicarbonate.

Because of the direct relation between specific conductance and dissolved-solids concentrations in water, and because specific-conductance data are more widely available for surface-water sites in the Gore Creek watershed, specific conductance will be discussed in this report.

Because of dilution, specific conductance increases as streamflow decreases at site 29, at the mouth of Gore Creek (fig. 12). Specific-conductance values were highest during December–March 1996–97. These specific-conductance values coincided with low-flow conditions, when ground water accounts for a larger portion of streamflow, and discharges from tributary streams to dilute point and nonpoint sources that enter Gore Creek are reduced. The peak-flow months of May–July 1997 coincided with the lowest values for specific conductance (fig. 12), which can be attributed to large volumes of relatively dilute snowmelt waters entering Gore Creek. From October 1996 to September 1997, mean daily specific conductance at site 29 ranged from 94 µS/cm to 452 µS/cm, with a median value of 306 µS/cm.

The spatial distribution of stream specific-conductance values can be related to natural and human sources of dissolved constituents in the watershed. The highest specific-conductance values in tributary streams to Gore Creek occurred at sites 38 and 49 on Black Gore Creek and Mill Creek, respectively (fig. 13A and 13B). The higher values in these drainages can be partly attributed to natural sources, such as the Pennsylvanian-age sedimentary rocks, in these drainages. Human activities in the Vail Mountain ski area also may contribute to the higher specific-conductance values in Mill Creek (fig. 13A). Application of traction sand to the Interstate 70 roadway is also a contributing factor for elevated specific conductance in Black Gore Creek. Lorch (1998) estimated that the Colorado Department of Transportation annually applies about 13,000 tons of traction sanding material, including about 650 tons of rock salt by weight, to the Interstate 70 roadway between Vail Pass and the mouth of Black Gore Creek. Lorch estimated that about 30 percent of the applied traction sand is transported to Black Gore Creek annually; therefore, an estimated 195 tons of rock salt enters Black Gore Creek, providing soluble material that can

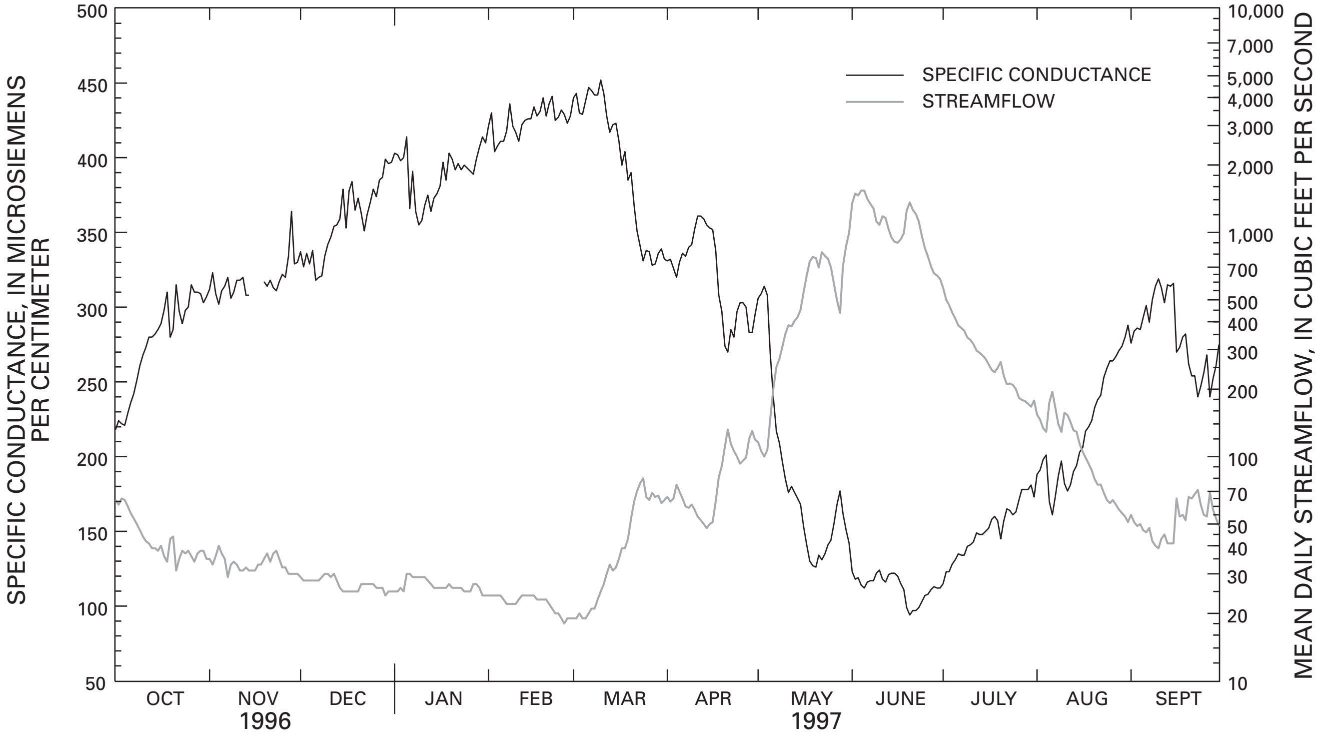


Figure 12. Mean daily streamflow and specific conductance at the mouth of Gore Creek.

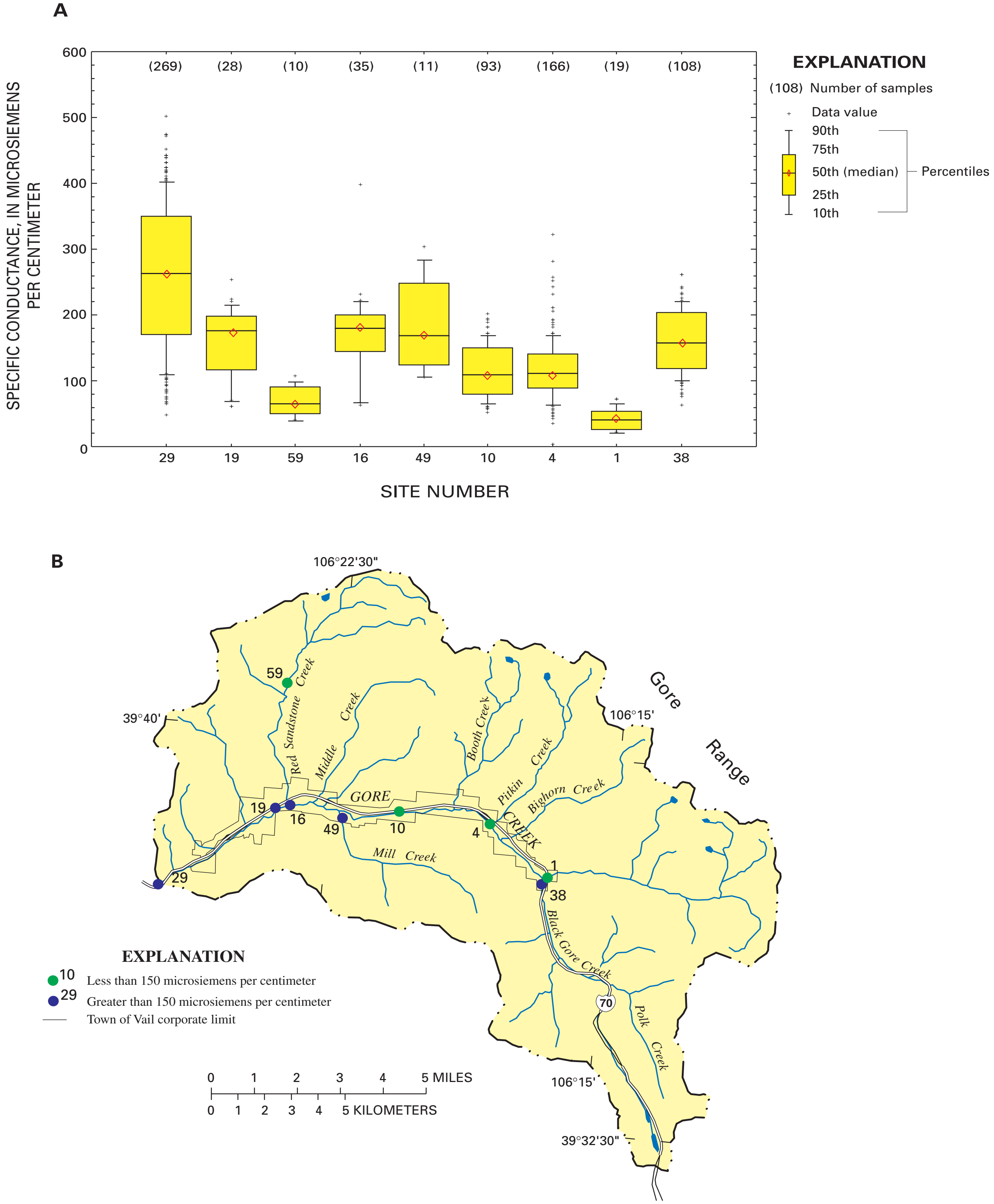


Figure 13. Distribution (A) and spatial distribution (B) of specific conductance.

increase stream specific conductance. Although information regarding rock-salt application was quantified only for the Black Gore Creek area, Interstate 70 is adjacent to Gore Creek through the Town of Vail and is subject to traction sanding; therefore, some quantity of salt probably enters Gore Creek from the Interstate 70 roadway downstream from the confluence with Black Gore Creek. An additional source of salt that may affect specific-conductance values in Black Gore Creek is liquid magnesium chloride (MgCl), which has been used since 1995 in conjunction with traction sand to keep Interstate 70 open during snowstorms. The annual number of MgCl applications to Interstate 70 is unknown; however, a single application from Vail Pass to Gore Creek requires approximately 1 ton of material. The use of MgCl is eventually expected to reduce the amount of traction sand required on Interstate 70, but there was no reduction during the winter of 1995–96 (Lorch, 1998).

Specific-conductance values in the Gore Creek watershed are relatively low (median value of 145 µS/cm for 32 sites) when compared to other sites sampled in the Southern Rocky Mountains physiographic province (median value of 254 µS/cm for seven sites, Jeffrey R. Deacon, U.S. Geological Survey, written commun., 1998) as part of the UCOL NAWQA Program. Specific conductance increased in a downstream direction in the main stem of Gore Creek (fig. 13). The lowest and least variable specific-conductance values (median value of 40 µS/cm) occurred at site 1, which represents background conditions with the crystalline bedrock. Specific conductance increased slightly at sites 4 and 10, where lower specific-conductance water from Gore, Bighorn, Pitkin, and Booth Creeks dilutes the higher specific-conductance water from Black Gore Creek. Site 16, which is downstream from site 10, Mill Creek, Middle Creek, and urban and recreational land uses, had higher specific-conductance values than site 10. The highest specific-conductance values were at site 29, at the mouth of Gore Creek. This site integrates all the natural and land-use-related sources of dissolved constituents that can increase specific conductance in the watershed. During the stable low-flow conditions in August 1996, Wynn and Spahr (1998) determined that increasing values of specific conductance and dissolved solids in Gore Creek were partially caused by inflows from tributaries such as Mill Creek and Black Gore Creek that drain areas where sedimentary rock is predominant.

The Northwest Colorado Council of Governments (NWCCOG) (1993) reported that specific conductance was significantly higher at site 29 at the mouth of Gore Creek than at upstream site 10 from 1978 to 1992. The NWCCOG study concluded that periods of low flow coincide with the highest specific-conductance values when Gore Creek is more strongly influenced by discharges from the wastewater-treatment plant. These results are consistent with the data discussed in this report (figs. 12 and 13). The NWCCOG study also determined that specific-conductance values showed significant upward temporal trends at sites 10 and 29 between 1978 and 1992. These increases were at least partially caused by stormwater runoff from the increasing amounts of urban land-use areas within the watershed (Northwest Colorado Council of Governments, 1995).

Values of specific conductance for site 29 were compared statistically by using Tukey’s Significant Difference Test on the rank-transformed data (Helsel and Hirsch, 1992). The 1968–97 period of record was divided into three time periods—1968–79, 1980–92, and 1995–97—and further divided into a lower flow season (November–April) and a higher flow season (May–October). The Tukey test indicated no difference in specific-conductance values among the three time periods when data for all months were compared; however, the months of November–April did contain significantly higher specific-conductance values (alpha level = 0.05) during the 1995–97 period when compared to the 1968–79 and 1980–82 time periods.

Dissolved oxygen. Surface water in the Gore Creek watershed is well oxygenated and typical of high-gradient streams in the Southern Rocky Mountains physiographic province. Concentrations below the 6.0-mg/L aquatic-life stream standard were measured twice in Gore Creek. A concentration of 5.9 mg/L was measured just downstream from the wastewater-treatment plant in July 1994, and a concentration of 5.6 mg/L was measured at site 29, the mouth of Gore Creek, in December 1978. Seventy-five percent of the 783 dissolved-oxygen measurements taken at 37 sites in the watershed exceeded 8.8 mg/L. The median dissolved-oxygen concentration was 9.5 mg/L. Well-oxygenated stream conditions like those in the Gore Creek watershed support aquatic organisms such as macroinvertebrates and fish.

pH. Values of pH ranged from 5.9 to 10.0 standard units. Only 23 of more than 1,000 pH values were outside the range of the recommended stream standard for pH (6.5–9.0). Of those values, 18 were measured at site 29 between 1969 and 1997. There was no discernible long-term or seasonal pattern to the measurements that were outside the recommended range for pH. Eighty percent of the pH values were between 7.5 and 8.6 within the Gore Creek watershed. The toxicity of dissolved ammonia increases with increasing pH, but ammonia concentrations were low at site 29, precluding any possible concern for ammonia toxicity.

Water temperature. Water temperatures within the Gore Creek watershed typically were low. More than 90 percent of the temperature measurements were less than 11°C. During an August 1996 sampling of 13 sites on the main stem of Gore Creek, Wynn and Spahr (1998) found little variability in water temperatures (8°–16°C). Temperature can influence the composition of fish communities. Relatively low water temperatures such as those in the Gore Creek watershed provide favorable habitat for trout and sculpin (Deacon and Mize, 1997).

Inorganic Constituents

Inorganic constituent data for major ions, trace elements, and nutrients are useful for describing water-quality conditions. Major-ion data are needed to determine the relative significance of various sources of dissolved constituents in the water column such as ground-water discharge or precipitation runoff. Trace-element data provide information about the natural and human sources of contaminants such as zinc or cadmium, which can be harmful to aquatic life. Nutrient concentrations can have a large effect on stream biota. Seasonal differences and changes in nutrient concentrations can be a primary factor for changes observed in the algal and macroinvertebrate communities.

Major ions. Concentrations of major ions (calcium, magnesium, sodium, potassium, silica, chloride, sulfate, and bicarbonate) in Gore Creek vary with streamflow and season. Data collected periodically from 1995 to 1997 (46 samples) at site 29, at the mouth of Gore Creek, are plotted on a trilinear diagram in figure 14. Trilinear diagrams are useful for examining the relative percentages of major ions for multiple samples so that trends or patterns in relative major-ion chemistry may be determined (Freeze and Cherry, 1979).

The data were grouped in 3-month time periods in which the samples were collected (October–December, January–March, April–June, July–September) so that seasonal (and associated streamflow) patterns could be examined. Percentages of major cations indicated little variation. Calcium was the dominant cation, accounting for more than 60 percent of cations in all samples (fig. 14). The relative percentages of anions indicated seasonal variability. Bicarbonate accounted for 50–60 percent of anions during January–March but as much as 90 percent during high flow (April–June) when most streamflow originates from snowmelt. Sulfate and chloride ions were prevalent, accounting for as much as 50 percent of all major ions, during the annual recession of the hydrograph (October–December) and during winter low-flow (January–March) conditions when a large part of the streamflow consists of base flow rather than snowmelt (fig. 14).

Trace elements. Historically, concentrations of several trace elements have occasionally (cadmium, copper, iron, and silver) or frequently (manganese, in Black Gore Creek) exceeded aquatic-life stream standards in the Gore Creek watershed (Northwest Colorado Council of Governments, 1995). Presence of all of these trace elements except silver is at least partially attributable to bedrock geology (Northwest Colorado Council of Governments, 1995; Steele and others, 1991; Wynn and Spahr, 1998). However, studies in other locations have linked increased copper and manganese concentrations to highway runoff and traction sand (Kobringer, 1984; Novotny and Olem, 1994). Silver concentrations have been associated with treated wastewater effluent (Northwest Colorado Council of Governments, 1993).

Land disturbance near Black Gore Creek during construction of the Interstate 70 roadway in the 1970's probably caused some of the documented increases in trace-element concentrations. A study of temporal trends of trace-element concentrations in the watershed indicated that cadmium, copper, manganese, and zinc concentrations have decreased over time (Northwest Colorado Council of Governments, 1995). Part of the decrease in trace-element concentrations may be related to the restabilization of the hill slopes that were disturbed during highway construction. The stream standard for manganese, 50 μg/L, was exceeded only one time among 11 samples collected at 4 sites in Black Gore Creek in 1996 (Crowfoot and others, 1996; Lorch, 1998). That sample, collected near Vail Pass where the creek flows into Black Lake (site 30), contained a manganese concentration of 530 μg/L. The range in manganese concentrations for the 10 samples collected downstream from the Black Lakes in 1996 was 2–36 μg/L.

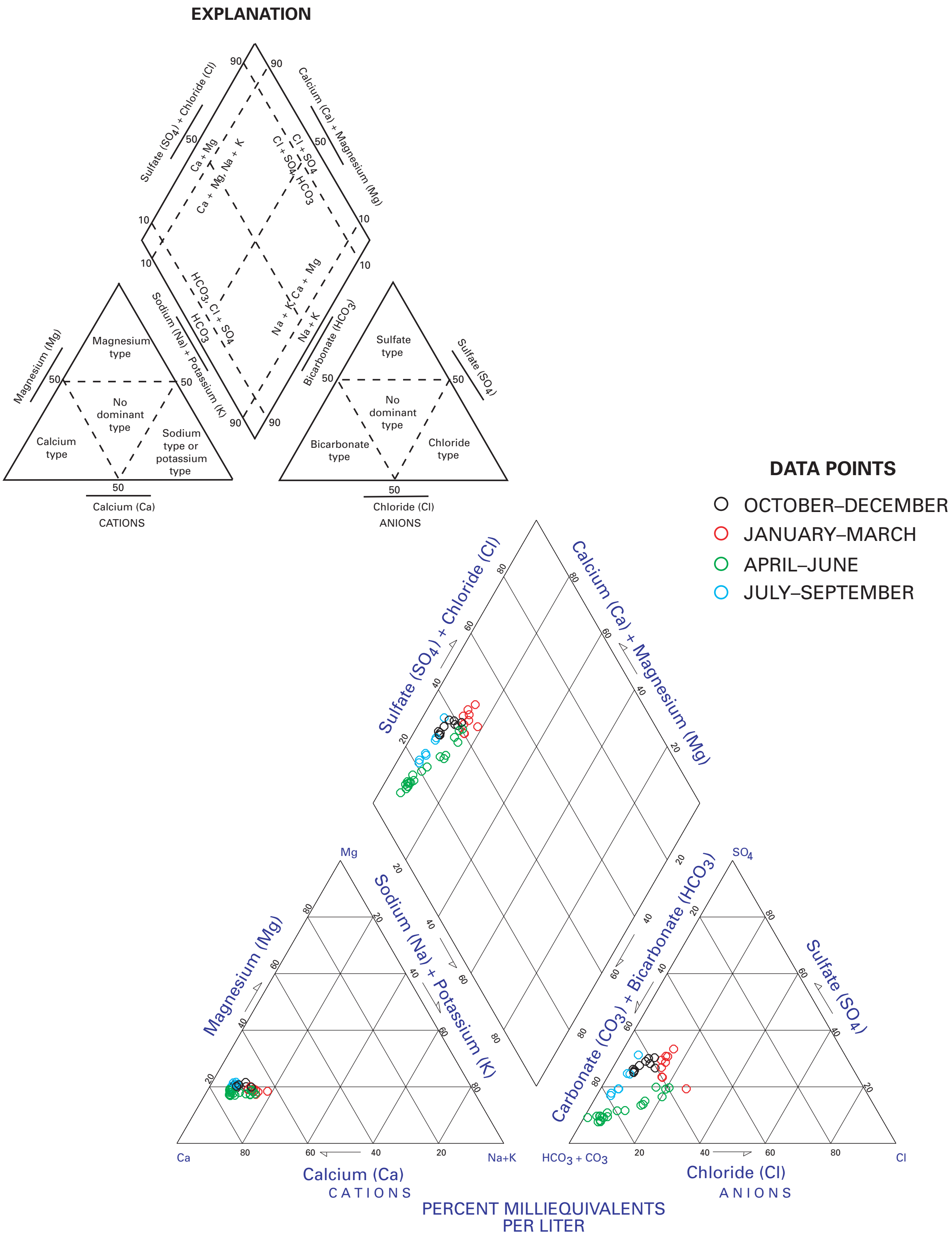


Figure 14. Trilinear diagram of major-ion data for site 29, at the mouth of Gore Creek.

Lorch (1998) found a significant correlation ($p<0.0001$) between chloride and manganese concentrations in 22 stream and runoff samples in and near Black Gore Creek. Lorch attributed this correlation to impurities in the salt material applied to Interstate 70 during snowstorms. Cadmium, chromium, nickel, and zinc concentrations also were highly correlated with chloride concentrations ($p<0.0001$), whereas copper and lead concentrations were not as highly correlated with chloride (p-values were equal to 0.0003 and 0.0004, respectively).

Silver concentrations exceeded the 0.08-µg/L aquatic-life stream standard at two sites in Gore Creek downstream from Red Sandstone Creek in December 1988 (Advanced Sciences, Inc., 1990). The concentrations were 0.2 and 0.3 µg/L. Silver was detected at a concentration of 0.1 µg/L in four samples in 1989. Silver has not been detected in Gore Creek downstream from Red Sandstone Creek in the 22 samples collected since 1989; however, the reporting limit (0.5 and 1.0 µg/L) for most of those samples was higher than all of the previous silver detections. Trace-element sampling programs that may be conducted for sites in Gore Creek in the future should use analytical methods for silver analyses with a reporting limit no higher than 0.05–0.1 µg/L to determine whether silver concentrations are still a concern in Gore Creek.

Nutrients. Distributions of concentrations for ammonia, nitrate, total nitrogen, orthophosphate, and total phosphorus for 30 surface-water sites are represented by boxplots in figure 15. Ammonia concentrations for all sites were low, with 75 percent of the concentrations equal to or less than 0.10 mg/L (fig. 15). The ammonia data contained a variety of minimum reporting limits, and no discrete median concentration could be determined because more than one-half the data was below one of the reporting limits. The range of nitrate concentrations was the largest (three orders of magnitude) of the five nutrient constituents, and the median concentration was 0.40 mg/L. Four nitrate concentrations in samples collected during winter 1976–77 exceeded the USEPA drinking-water maximum contaminant level (MCL) of 10 mg/L. Only 53 analyses were available for total nitrogen, which had the highest median concentration of 0.6 mg/L. The median orthophosphate concentration was 0.01 mg/L, and 90 percent of the data were 0.10 mg/L or less. Total phosphorus concentrations were somewhat elevated. The median concentration was 0.05 mg/L, and 25 percent of the total phosphorus concentrations were greater than 0.12 mg/L, which exceeds the USEPA recommended level of 0.10 mg/L for control of eutrophication in flowing water (U.S. Environmental Protection Agency, 1986).

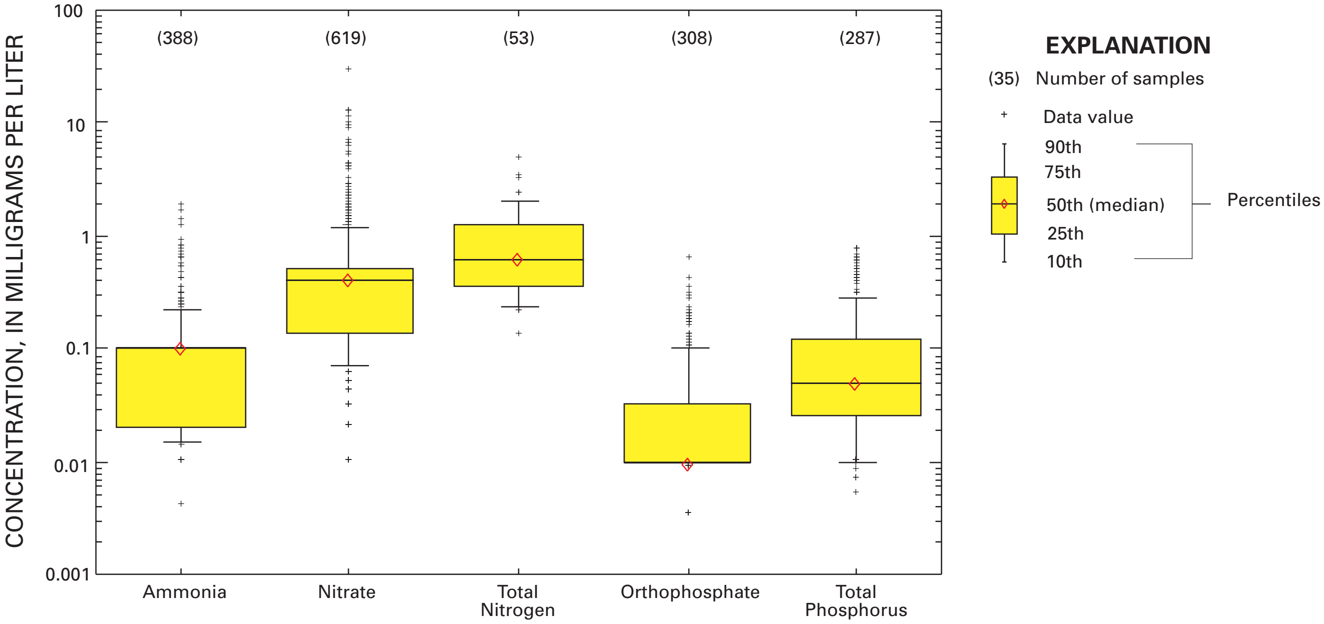


Figure 15. Distribution of nutrient concentrations for all surface-water sampling sites in the Gore Creek watershed.

Distribution of concentrations of ammonia, nitrate, orthophosphate, and total phosphorus for sites with 10 or more analyses are shown in figures 16A–19A, and median concentrations for sites with five or more analyses are shown in map figures 16B–19B. When more than one-half the data for a particular nutrient constituent at a site were censored, estimates of the concentration percentiles were calculated using the maximum likelihood estimation (MLE) method (Helsel, 1990; Helsel and Cohn, 1988). These estimated percentiles were used to construct the boxplots and provide the median concentrations plotted on the maps for sites and constituents where data were censored at the 50th percentile.

Sites 1, 37, and 38 are located in forested areas with minimal land-use effects on nutrient concentrations and are assumed to represent background conditions. Sites 4, 10, 16, 17, 19, and 29 are located within or downstream from the Town of Vail and represent urban and recreational land use. The Vail wastewater-treatment-plant outfall is located between sites 16 and 17, upstream from the confluence of Red Sandstone and Gore Creeks. The concentration ranges in figures 16B, 18B, and 19B (shown as different colored dots) represent the 50th and greater than 50th percentiles of the median concentrations for all sites shown on the map; whereas nitrate concentration ranges in figure 17B represent the less than 25th, 25th to 50th, 51st to 75th, and greater than 75th percentiles for all the sites shown of the respective map figures.

In general, nutrient concentrations were higher in the downstream reaches than in the upstream reaches (figs. 16–19). Median concentrations of ammonia, nitrate, orthophosphate, and total phosphorus were lowest at background sites 1, 37, and 38 (forested areas with minimal developed land use). Concentrations of nutrients were relatively higher at urban and recreational land-use sites 4, 10, 16, 17, 19, and 29. This downstream increase in nutrients in the Gore Creek watershed also has been reported by the Northwest Colorado Council of Governments (1993, 1995) and, for low-flow conditions in August 1996, by Wynn and Spahr (1998).

Ammonia concentrations were low throughout the watershed (fig. 16). Median concentrations for background sites were less than 0.02 mg/L and between 0.023 and 0.038 mg/L for urban sites. The median ammonia concentrations at urban sites did not change substantially in a downstream direction. Individual ammonia concentrations greater than 0.50 mg/L occurred only at site 29, the mouth of Gore Creek.

Median nitrate concentrations gradually increased in a downstream direction from sites 1 and 38 to site 16, reflecting background conditions and minor urban influences (fig. 17). At site 10, several measurements of nitrate concentrations greater than 9 mg/L occurred in the 1970's; however, more recent data contained only low concentrations. The sharp rise in median nitrate concentration (to about 2 mg/L) at site 17 was likely caused by nutrient inputs from the Town of Vail wastewater-treatment plant. This effect was localized, as the median concentration decreased to about 0.5 and 0.4 mg/L at downstream sites 19 and 29. Two likely factors for decreased nutrient concentrations downstream from site 17 are dilution by additional streamflow inputs and nitrogen uptake by algae.

Median orthophosphate concentrations for sites located upstream from site 29 were below or near the detection limit of 0.01 mg/L but the median was 0.06 mg/L at site 29, the mouth of Gore Creek (fig. 18). Median total phosphorus concentrations for sites upstream from site 29 also were 0.01 mg/L or less (fig. 19). The median total phosphorus concentration at site 29 was 0.12 mg/L, reflecting urban point and nonpoint sources. For site 29, more than one-half of the analyses exceeded 0.10 mg/L, the recommended USEPA level for control of eutrophication in flowing water (U.S. Environmental Protection Agency, 1986). Total phosphorus concentrations at sites that represent background conditions did not exceed 0.1 mg/L.

Historical nutrient concentrations for sites representing background conditions and urban land uses in the Gore Creek watershed can be compared with concentrations at similarly classified sites within the Upper Colorado River Basin (UCOL) (Spahr and Wynn, 1997) in Colorado and throughout the United States (Mueller and others, 1995) (table 5). The time periods of the available data used in this comparison are: Gore Creek watershed, 1968–97; UCOL, 1980–94; and United States, 1970–92. Sites in the Gore Creek watershed that are classified as representing background conditions and urban land use equate with the background and urbanization sites of Spahr and Wynn (1997) and background and urban/undeveloped sites (combination of urban land with forest land or rangeland) of Mueller and others (1995). For the Gore Creek watershed, nutrient data for 10 headwaters sites were combined for the background classification, and data for site 29, at the mouth of Gore Creek, were chosen to represent urban land use.

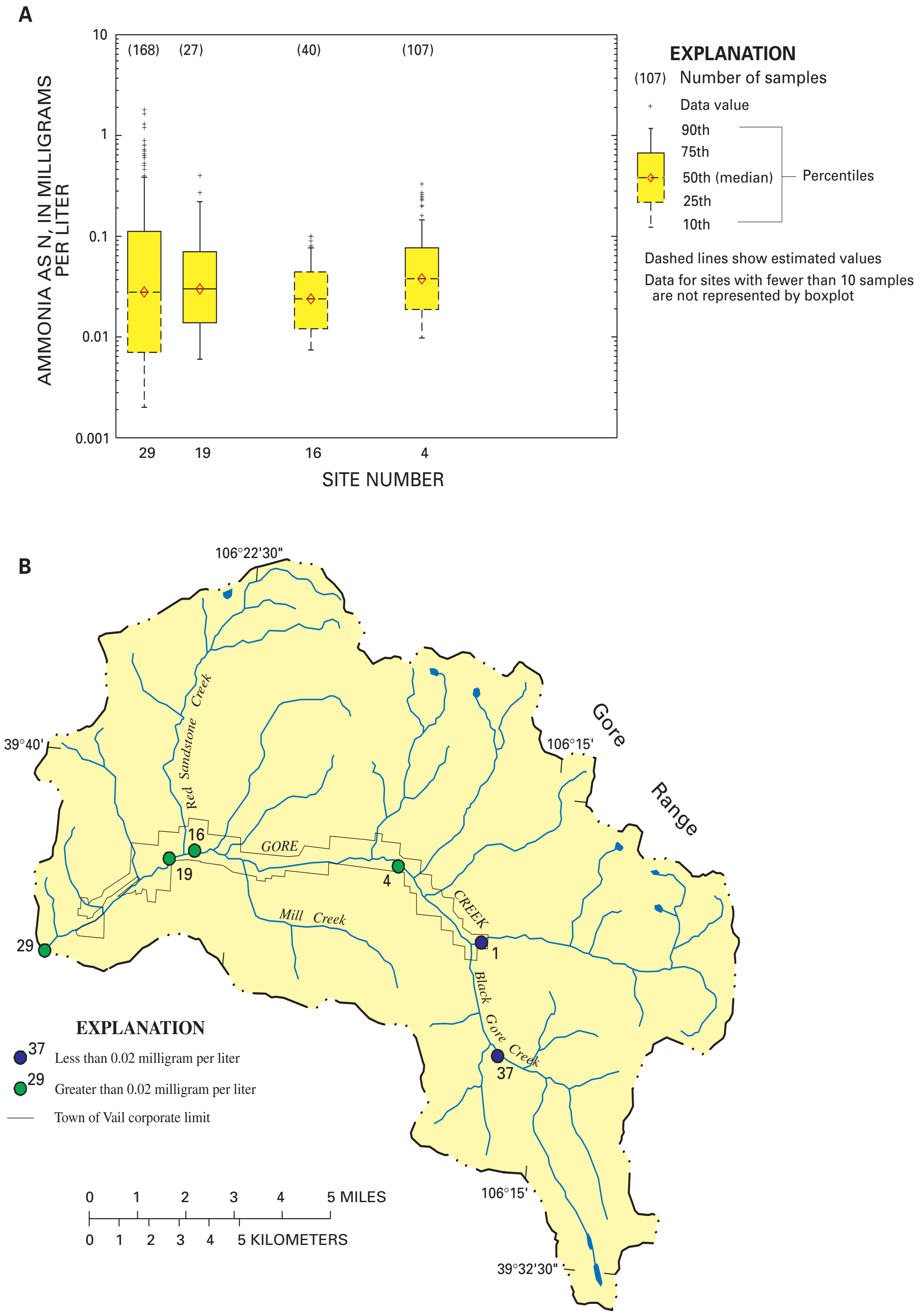


Figure 16. (A) Distribution of ammonia and (B) spatial distribution of median concentrations of ammonia for surface-water sampling sites in the Gore Creek watershed.

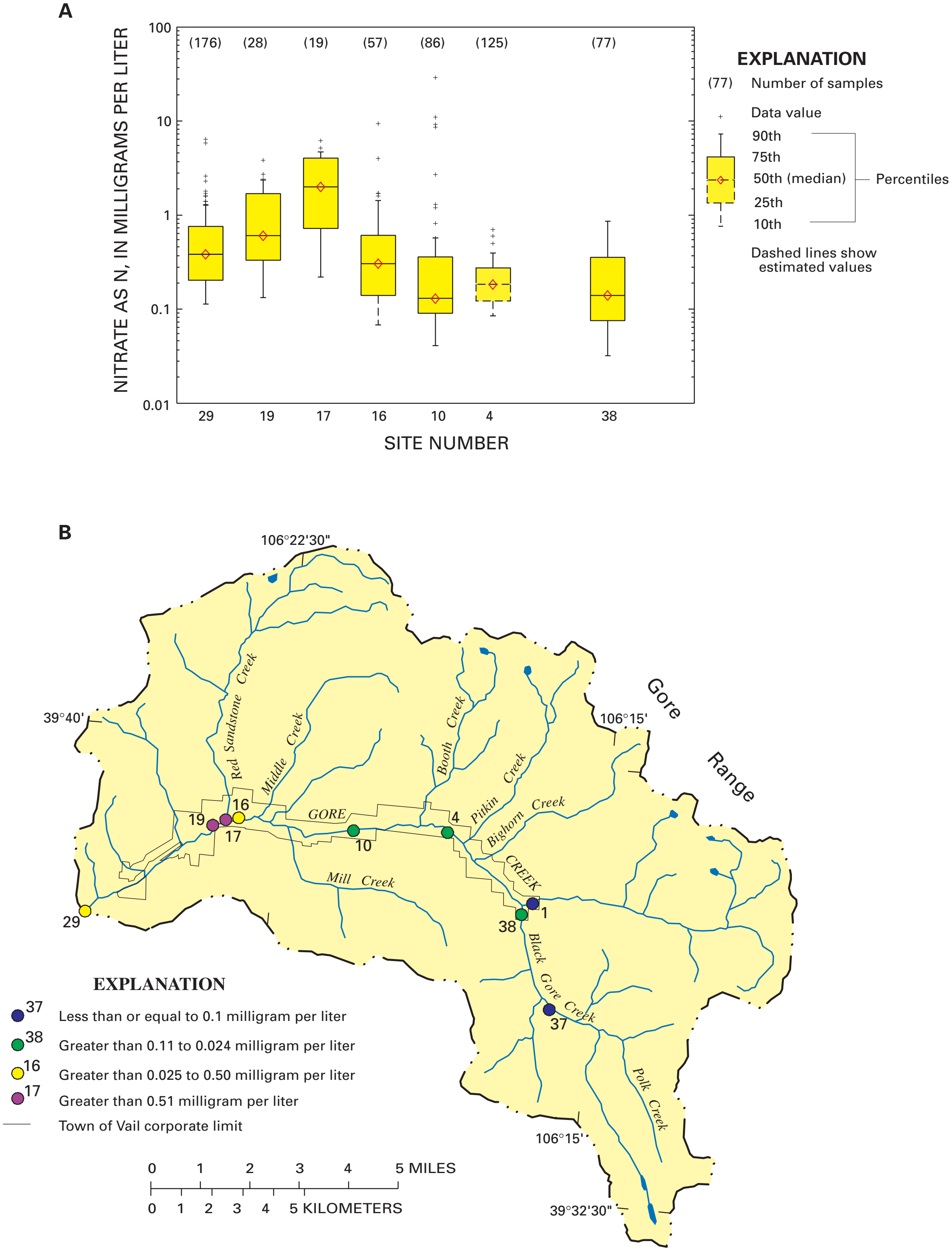


Figure 17. (A) Distribution of nitrate and (B) spatial distribution of median concentrations of nitrate for surface-water sampling sites in the Gore Creek watershed.

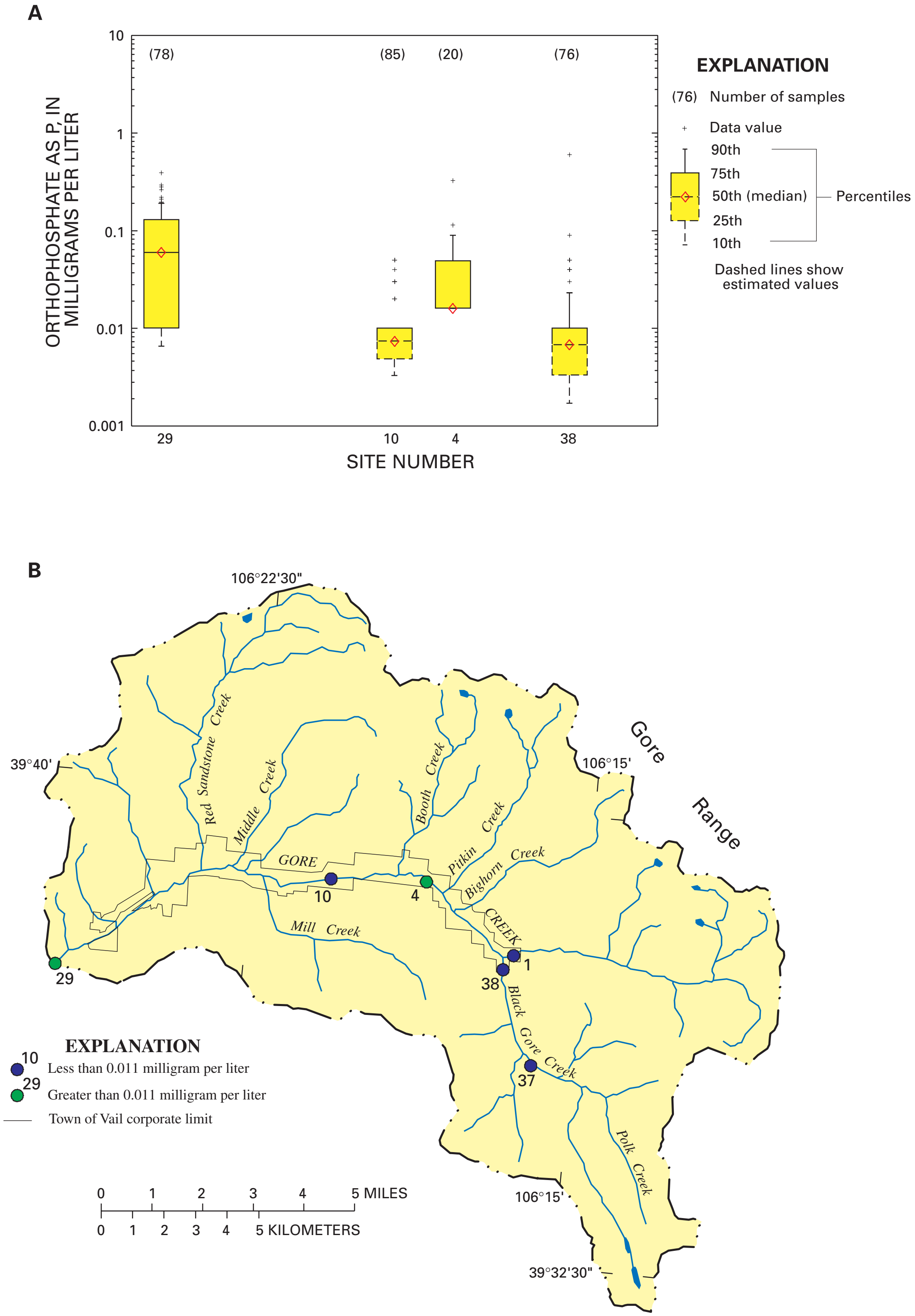


Figure 18. (A) Distribution of orthophosphate and (B) spatial distribution of median concentrations of orthophosphate for surface-water sampling sites in the Gore Creek watershed.

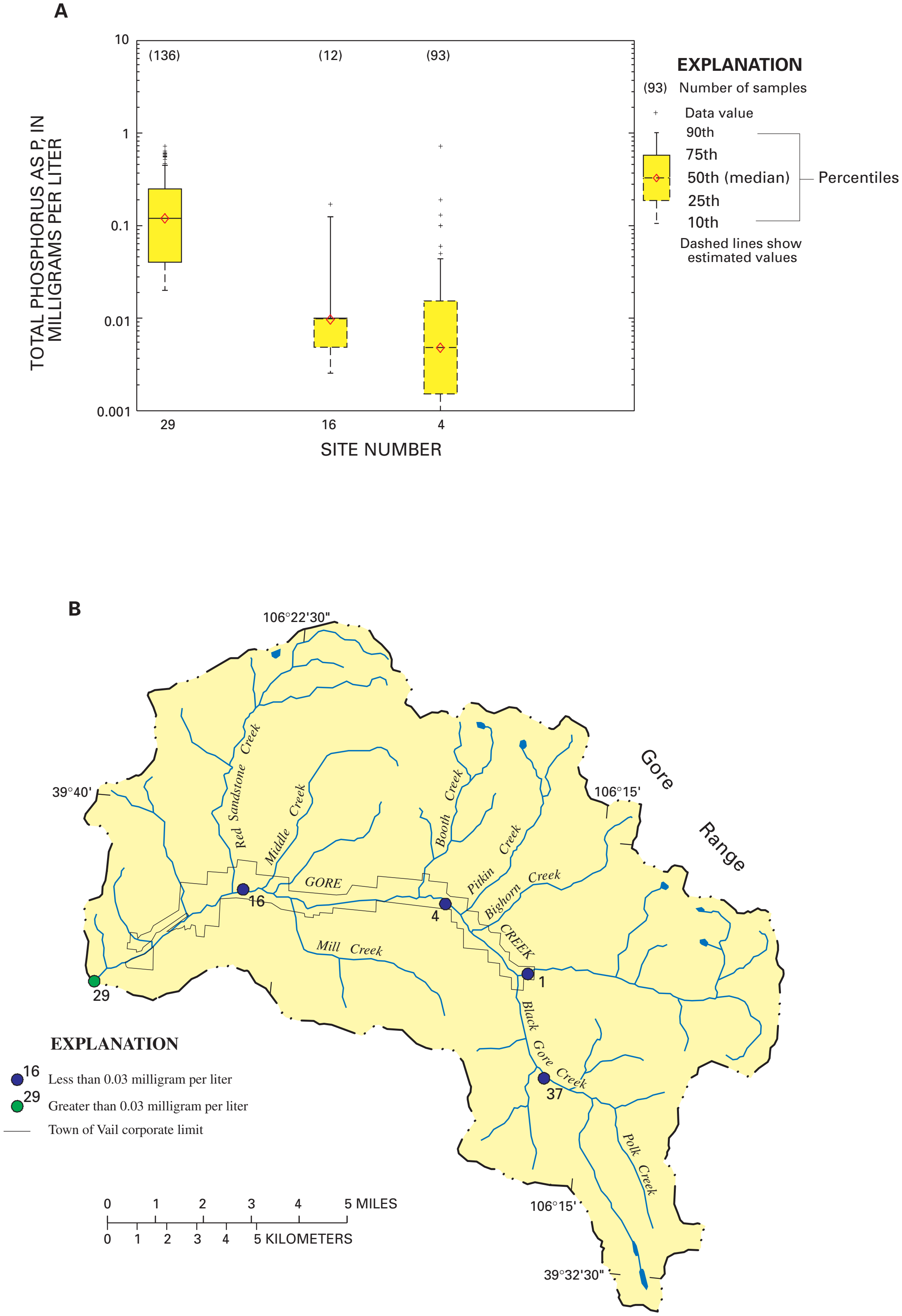


Figure 19. (A) Distribution of total phosphorus and (B) spatial distribution of median concentrations of total phosphorus for surface-water sampling sites in the Gore Creek watershed.

Table 5. Median nutrient concentrations for background and urban land-use categories for the Gore Creek watershed, Upper Colorado River Basin, and the United States

[<, less than; mg/L, milligrams per liter]

Constituent and location	Background	Urban land use
Ammonia		
Gore Creek watershed	<0.02 mg/L	<0.10 mg/L[1]
Upper Colorado River Basin[2]	.02	.04
United States[3]	.02	.1
Nitrate		
Gore Creek watershed	0.11 mg/L	0.38 mg/L[1]
Upper Colorado River Basin[2]	.09	.3
United States[3]	.14	.4
Total Phosphorus		
Gore Creek watershed	<0.01 mg/L	0.12 mg/L[1]
Upper Colorado River Basin[2]	.03	.04
United States[3]	.03	.16

[1] Data for Gore Creek at mouth, site 29, urban integrator site for the Gore Creek watershed.

[2] From Spahr and Wynn (1997).

[3] From Mueller and others (1995). Data listed for urban land use are Mueller and others (1995) urban/undeveloped sites.

Median nutrient concentrations for the Gore Creek watershed were generally less than for the national study but greater than those reported in the UCOL study. The median ammonia concentration for background conditions in the Gore Creek watershed was less than the median ammonia concentration for the UCOL and national studies (table 5). The median ammonia concentration for urban land use in the Gore Creek watershed was lower than the national study, and, because the Gore Creek median is censored at 0.1 mg/L, no comparison can be made between median ammonia concentrations in the Gore Creek watershed and the UCOL study. The median nitrate concentrations for background and urban sites in the Gore Creek watershed were greater than the median for the UCOL study but less than the national study. For total phosphorus, median concentrations for background sites in the Gore Creek watershed were lower than the median concentrations for background sites in the UCOL study unit and the national study. The median total phosphorus concentration for urban sites was higher in the Gore Creek watershed than the UCOL study unit but lower than the median total phosphorus concentration for the national study.

Nutrient concentrations and streamflow. The relation between nutrient concentrations and streamflow can be examined by evaluating the most recent data for Gore Creek at the mouth, site 29. For other sites in the Gore Creek watershed, nutrient and(or) streamflow data are limited temporally, and no comparison between the two can be made. Concentrations of most nutrients in Gore Creek at the mouth varied with streamflow from 1995 through 1997. Because most analyses were below the 0.015-mg/L reporting limit, ammonia concentrations did not appear to vary with streamflow. Nitrate and total phosphorus data were plotted with streamflow and also were grouped into higher flow (May–September) and lower flow (October–April) (fig. 20). A Mann-Whitney U test was used to test for significant differences in nitrate and total phosphorus concentrations between the groups (Helsel and Hirsch, 1992). Nitrate concentrations and orthophosphate concentrations (not shown) increased as streamflow decreased (fig. 20A). Streamflow is highest during the higher runoff months of May through September. During these months, nitrate concentrations were lower due to dilution. The peak flow months of May and June coincided with the lowest concentrations for nitrate. Nitrate concentrations were significantly higher ($p<0.0001$) in fall, winter, and early spring (October–April), when low streamflow conditions predominate, than during the May–September period (fig. 20A). Total phosphorus concentrations also were significantly ($p<0.0001$) higher during the October–April months than in the higher flow months of May–September. Concentrations of total phosphorus increased as streamflow decreased, except during the first large runoff event of the year (fig. 20B). Total phosphorus concentrations decreased as streamflow gradually increased during March and April; however, when the initial large pulse of snowmelt runoff reached Gore Creek in May or early June, total phosphorus concentrations increased for a period of time because the total phosphorus concentration includes any phosphorus adsorbed to suspended sediment. When streamflow and suspended-sediment concentrations are highest, as in May and June, bottom sediments are resuspended, possibly accounting for the sharp rise in total phosphorus concentrations on the rising limb of the annual hydrograph.

Temporal trends in nutrient concentrations. To partially address the question of whether water quality is changing over time in the Gore Creek watershed, temporal trends in nutrient concentrations were investigated. Some trends in data may be significant statistically but not environmentally; for example,

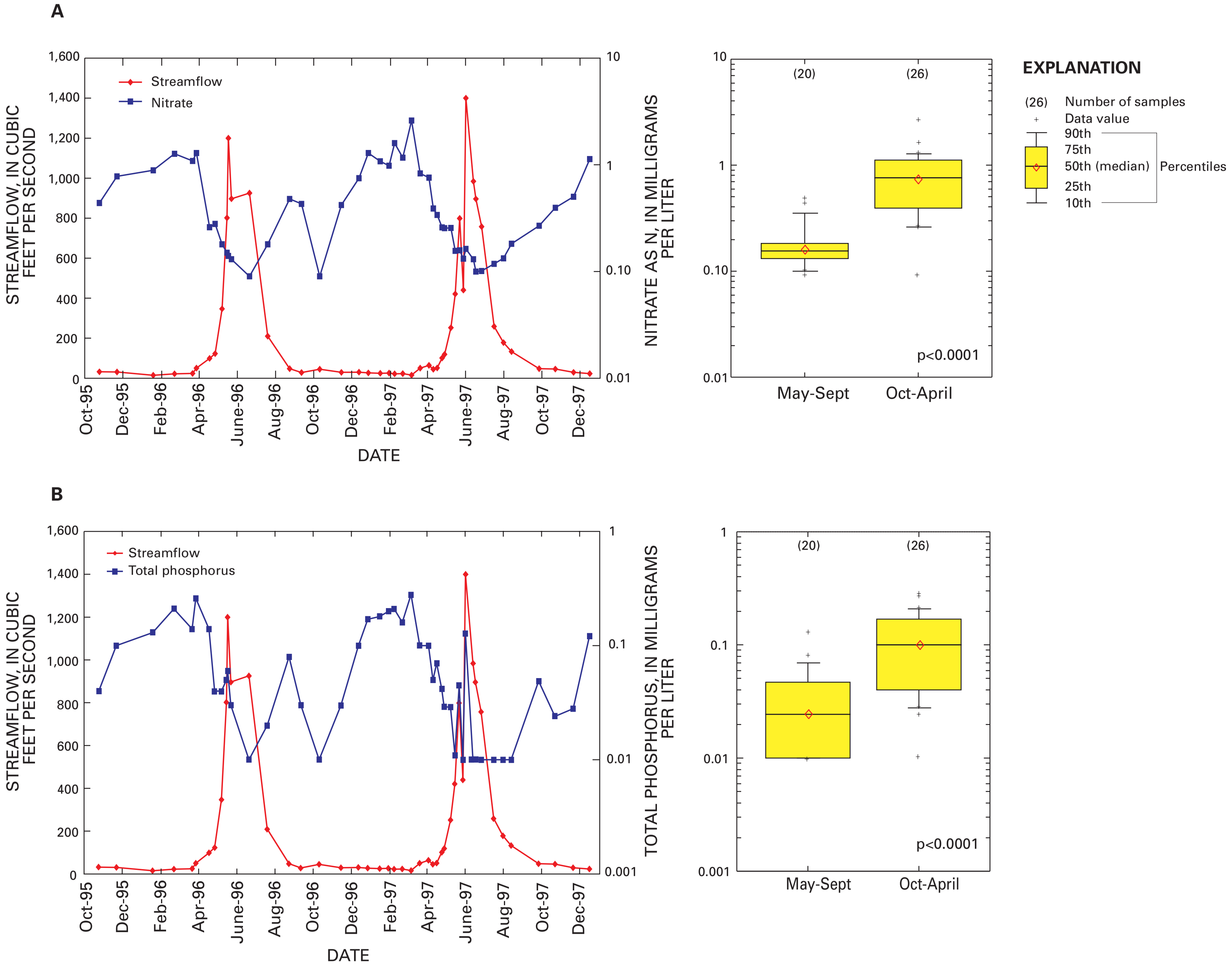


Figure 20. Streamflow and (A) nitrate and (B) total phosphorus concentrations, Gore Creek at mouth (site 29), October 1995–December 1997.

when concentrations are very low or when the rate of change is small. Also, trend results can differ depending on the period of record.

The period of record for trends analysis, 1968–97, was separated into three time periods: 1968–79, 1980–92, and 1995–97, and further divided into two seasons (May–October and November–April) within each time period. This latter division accounts for the seasonal variation that occurs in nutrient concentrations in Gore Creek. Nutrient data for most or all of the 1968–97 analysis period were available only for site 29, the mouth of Gore Creek, and site 4, Gore Creek at Bighorn Subdivision below Pitkin Creek. Comparison of nutrients between time periods at site 4 was not possible, however, because high reporting limits resulted in a large percentage of censored data. Hence, only data for site 29, which represents an integration of all upstream land-use effects on water quality, were analyzed for temporal changes. Because of a high percentage of censored data values during the spring and summer seasons, and because higher nutrient concentrations typically occur during low flow, only the winter season (November–April) was tested statistically for trends at site 29. Although boxplots for the May–October months also are included in figures 21 and 22 for comparative purposes, the following discussion will be focused on data collected during the winter seasons only.

Concentrations of ammonia, nitrate, orthophosphate, and total phosphorus were compared statistically using Tukey's Significant Difference Test on the rank-transformed data (Helsel and Hirsch, 1992). Results of the Tukey test are represented as letters (*a*, *b*, or *c*) adjacent to the median on the November–April boxplots in figures 21 and 22. Nutrient concentrations for boxplots with different letters adjacent to the median line are significantly different at an alpha level of 0.05, which translates to a 95-percent confidence level for the test results. For example, the November–April boxplots for ammonia each have a different letter (*a*, *b*, or *c*) adjacent to the median; therefore, ammonia concentrations are significantly different for each consecutive time period (fig. 21A).

Median ammonia concentrations were significantly different for each of the three time periods (fig. 21A). Concentrations were highest during 1968–79 and lowest during 1995–97. Ammonia concentrations were highly variable during 1968–83, with concentrations frequently exceeding 0.60 mg/L. After 1984, only two detections of ammonia were above 0.10 mg/L, and there was very little variability in the 1995–97 data. Nitrate concentrations were significantly higher during 1980–92 as compared to 1968–79, and there was no difference between concentrations during the 1980–92 and 1995–95 time periods (fig. 21B). Prior to 1984, it was uncommon for nitrate concentrations to be higher than 1.0 mg/L. After 1983, detections above this level were common. In the early 1980's, the Vail wastewater-treatment plant was upgraded to convert ammonia into nitrate through the process of nitrification (Caroline Byus, Eagle River Water and Sanitation District, oral commun., 1998). The upgrade reduced discharges of ammonia while increasing discharges of nitrate. This wastewater-processing change was made to reduce the exposure of stream biota to un-ionized ammonia, which can be toxic at relatively low concentration levels (Thurston and others, 1974). The shift in nitrogen speciation from ammonia to nitrate is evident in figure 21, with ammonia concentrations lower and nitrate concentrations generally higher after 1983. However, the total amount of nitrogen potentially available to algae has not necessarily decreased with the change in wastewater-treatment methods. Few historical total nitrogen data are available for the Gore Creek watershed, and comparison of total nitrogen concentrations cannot be made between time periods.

The difference in orthophosphate concentrations at the mouth of Gore Creek, site 29, between 1968–73 and 1995–97 was not significant (fig. 22A). Total phosphorus concentrations were significantly lower in 1995–97 as compared to 1974–79 and 1980–92 (fig. 22B). Total phosphorus concentrations above 0.30 mg/L were common through 1992 but were not detected above this level during 1995–97.

The Northwest Colorado Council of Governments (1993) reported that total phosphorus concentrations were increasing downstream from the Town of Vail. Results of monthly and quarterly seasonal Kendall trend tests indicated increasing total phosphorus concentrations at site 29, the mouth of Gore Creek, during the 1978–91 time period at a 95-percent confidence level. As stated previously, the analysis of the most recent phosphorus data indicated a significant decrease in total phosphorus concentrations for site 29 between the 1980–92 and the 1995–97 time periods. Therefore, it would appear that total phosphorus concentrations have now decreased downstream from the Town of Vail. However, in the Upper Colorado River Basin, higher than average streamflow

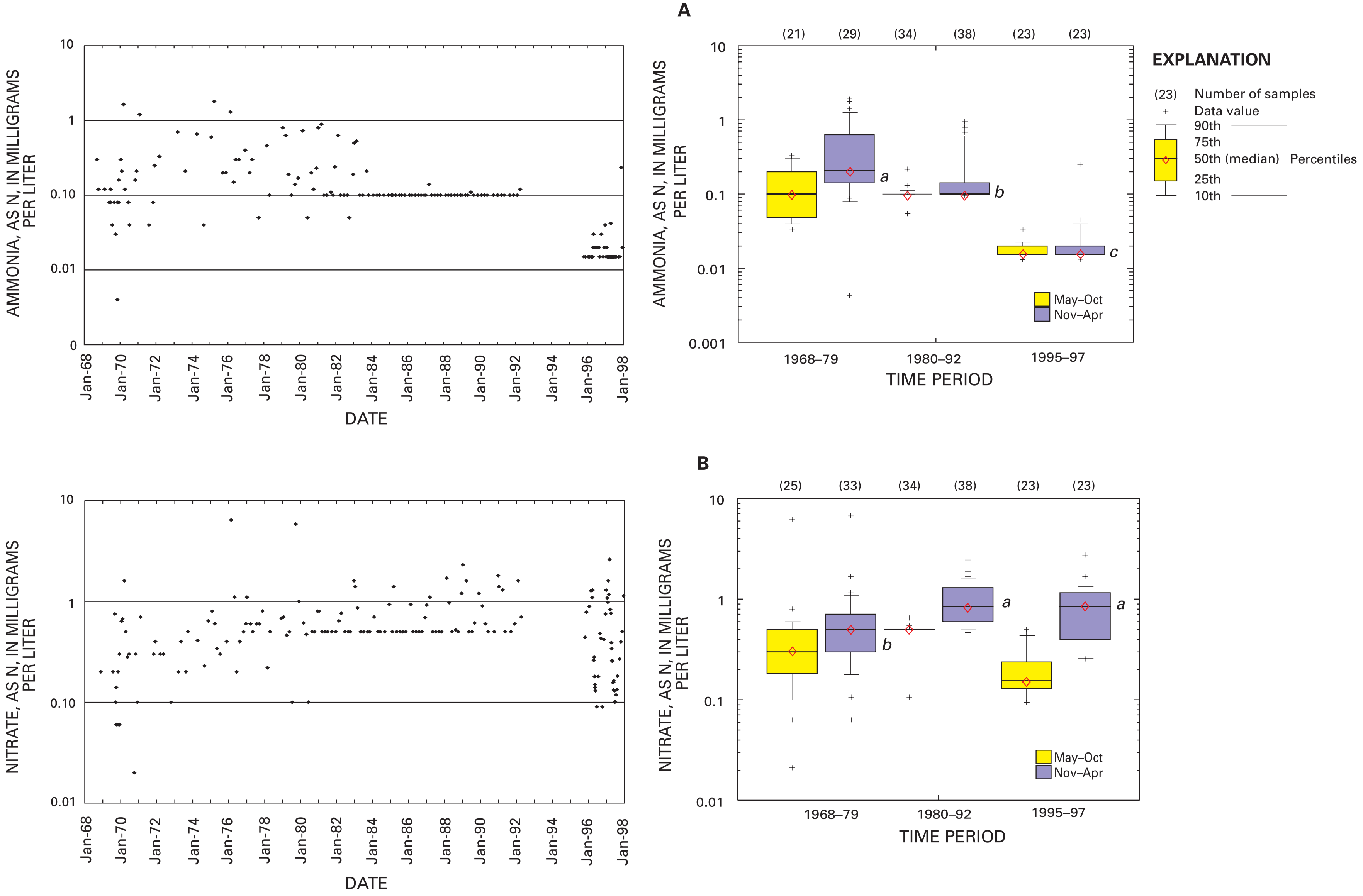


Figure 21. Temporal distribution of ammonia (**A**) and nitrate (**B**) at Gore Creek at mouth, site 29.

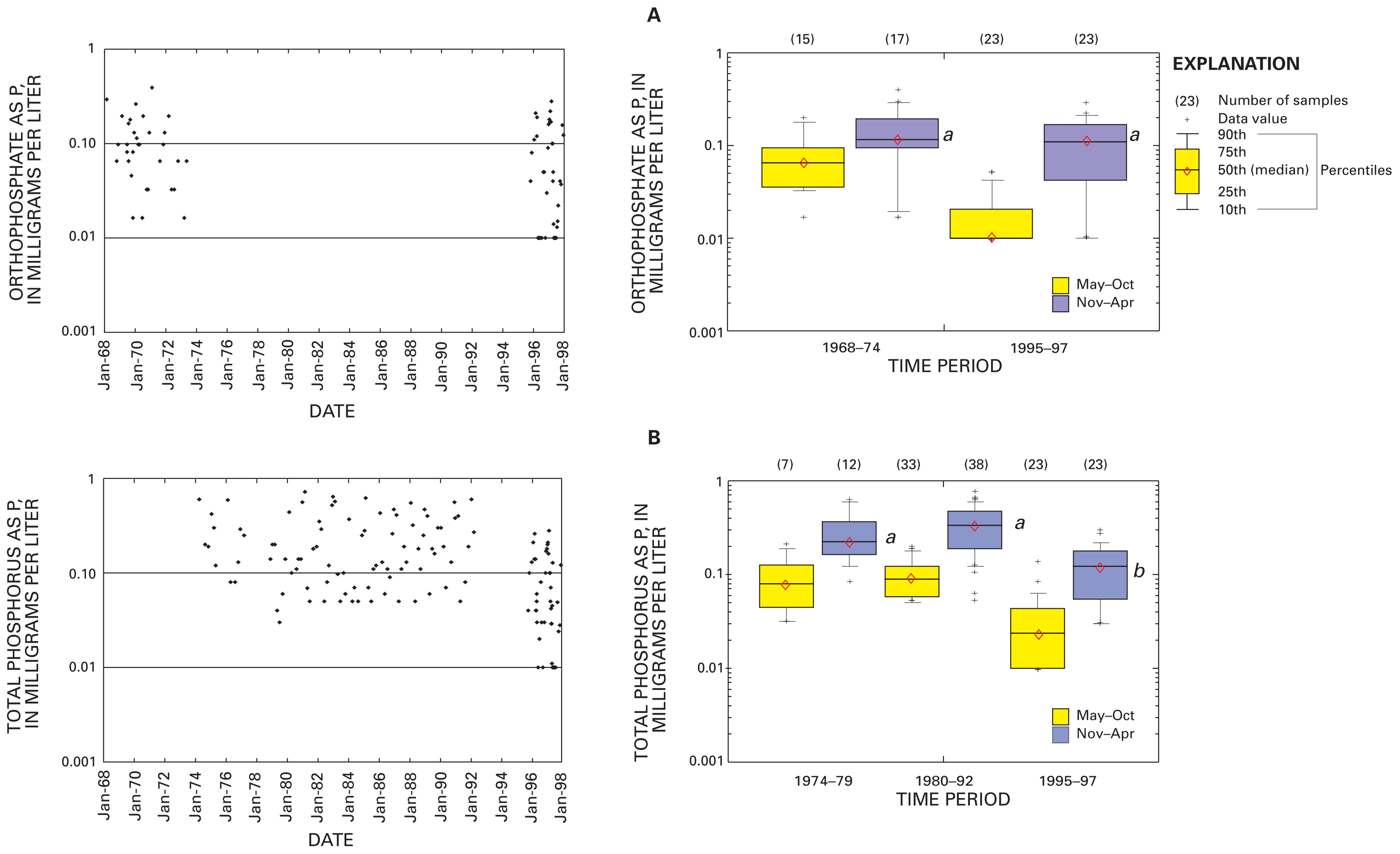


Figure 22. Temporal distribution of orthophosphate (**A**) and total phosphorus (**B**) at Gore Creek at mouth, site 29.

occurred during 1995–97. A difference in streamflow between the time periods partially accounts for the difference in total phosphorus concentrations, as concentrations tend to be higher during low flow than during high flow. Streamflow data were not collected concurrently with the total phosphorus data for much of the 1980–92 time period; therefore, direct comparison of flow-adjusted concentrations is not possible.

Censored data and the lack of concurrent streamflow data limited evaluation of nutrient conditions for the Gore Creek watershed. For some sites, the reporting limit was so high that no data were reported above that level, thereby limiting the usefulness of the data. Should additional nutrient data be collected in the future, analytical methods with reporting limits low enough to provide uncensored data over the range of ambient water-quality conditions would be needed. Along with the censored data, the lack of concurrent streamflow information prevented a thorough analysis of temporal trends in nutrient concentrations. Because nutrient concentrations vary with streamflow, concurrent discharge measurements are highly desirable to normalize nutrient concentrations that occur at different times of the year.

Organic Constituents

Organic carbon. Organic constituent data such as organic carbon, pesticides, and VOCs have been collected at site 29 since 1995. Dissolved and suspended organic carbon (DOC or SOC) can have an important role in the transport of trace elements because many trace elements are readily bound to the surface of organic carbon material and also can provide food for bacteria and macroinvertebrates. Pesticides and VOCs can, at elevated concentrations, be harmful or toxic to stream biota and human health.

Major sources of organic carbon include natural decay of plant or animal matter, runoff from urban land-use areas, or discharge from point sources. DOC and SOC concentrations were low throughout the watershed; however, limited data (72 samples collected at 25 sites since October 1995) were available for interpretation. The DOC concentrations generally were greater than SOC concentrations. Ten of the 12 highest concentrations of DOC (2.8–4.6 mg/L) were detected at site 29, the mouth of Gore Creek. Each of these 10 DOC samples was collected during peak runoff in May or June, indicating the source of DOC probably was from nonpoint rather than point sources. The median DOC concentration was 1.3 mg/L. Presence of organic carbon could have a major influence on macroinvertebrate-community structure.

Pesticides. Historically, pesticides have not been identified as a water-quality concern in the watershed. Coincident with its application to the golf course, sampling for the fungicide “Banner” (propiconazole) was conducted in Gore Creek during 1992. The fungicide was not detected during this sampling effort (Northwest Colorado Council of Governments, 1995). The USGS collected 10 samples for pesticide analysis during various streamflow conditions during 1996 and 1997 at the mouth of Gore Creek. These samples were analyzed for a suite of 87 pesticides and pesticide-degradation products (Timme, 1995). Of the 12 pesticide compounds detected at low concentrations, 11 were herbicides and 1 was an insecticide degradate (DDE, a degradation product of DDT). The concentrations for the 12 pesticides that were detected did not exceed USEPA drinking-water standards. Only samples collected between May and September 1997 contained detectable concentrations of pesticides. Atrazine was detected in the highest concentration, 0.014 μg/L, in a June 1997 sample. This sample also contained low levels (less than 0.008 μg/L) of alachlor, benfluralin, bentazon, cyanazine, dacthal (DCPA), metolachlor, DDE, and trifluralin. The only pesticide detected more than once was DCPA, with three detections. Three other pesticides were detected one time at low concentrations: deethylatrazine, prometon, and simazine.

Volatile organic compounds. Seven VOC samples were collected during February–September 1997 at site 29. The samples were analyzed for 87 different VOCs (Timme, 1995). Of the 10 compounds that were detected, 9 are classified as solvents and 1, methyl *tert*-butyl ether (MTBE), is a fuel oxygenate. The USEPA MCLs for drinking water were not exceeded in any of the samples. Acetone was the most commonly detected VOC, with four detections at 1–2 μg/L. Carbon disulfide was detected three times at concentrations ranging from 0.006 to 0.01 μg/L. Methyl *tert*-butyl ether was detected one time at a concentration of 0.02 μg/L.

Sediment

Previous reports have identified sediment as one of the primary water-quality concerns in the Gore Creek watershed. The earlier reports identified suspended sediment flushing into Black Gore Creek, caused by land disturbance during construction of Interstate 70 during the early 1970's, as the major concern (Wuerthele, 1976; Britton, 1979; Engineering Science Inc., 1980; Resource Consultants Inc., 1986). More recently, traction sanding material, washed into Black Gore Creek from the Interstate 70 road surface, has been identified as the sediment of concern (Weaver and Jones, 1995; Lorch, 1998).

Seventy-one samples collected at the mouth of Gore Creek since 1995 indicate that suspended sediment is not a major water-quality concern. Suspended-sediment concentrations ranged from 0 to 172 mg/L, with a median of 4 mg/L. Only 14 samples contained sediment concentrations higher than 25 mg/L, and each of those samples was collected during the high-flow months of May and June, when increased stream velocities are better able to transport sediment in suspension.

Using automatic samplers that were activated following a predefined increase in streamflow, Lorch (1998) measured order-of-magnitude higher concentrations of suspended sediment, as much as 112 mg/L in Black Gore Creek, when compared to background sites in Polk and Gore Creeks. Although Lorch found relatively low concentrations of suspended sediment in Black Gore Creek, high bedload transport rates of about 0.1 to 4 tons per day were measured during June and July 1996. These measurements were made after the annual peak flow and probably do not reflect maximum bedload transport rates for Black Gore Creek. The source of most of the bedload was identified as traction-sand material from Interstate 70. Lorch determined that nearly 20 percent of the total traction sand washed into Black Gore Creek originated from just two locations, and more than one-half of the total sediment input originated from 20 percent of the locations. Therefore, significant reductions in sediment transport into Black Gore Creek may be possible by capturing sediment at relatively few locations before it reaches the stream.

Streambed Sediment and Tissue Chemistry

Many hydrophobic constituents such as organochlorine pesticides and trace elements may be present in water but commonly are at concentrations that are below laboratory reporting limits. However, these constituents are more likely to be detectable or even elevated in other sample media such as streambed sediment or the tissues of aquatic organisms such as fish or macroinvertebrates. Organochlorine pesticides and many trace elements, because of their hydrophobic chemical properties, have a higher affinity for sediment, organic matter, and(or) tissues than for water (Stephens and Deacon, 1998; Coles, 1998). For this reason, streambed-sediment and tissue samples provide better information than water samples about the occurrence and distribution of organochlorine pesticides and trace elements.

Organochlorine Compounds

Streambed-sediment and whole-body fish-tissue samples were collected at the mouth of Gore Creek in 1995 and the samples were analyzed for organochlorine-pesticide and polychlorinated biphenyl (PCB) compounds. Sediment samples were tested for 32 compounds and fish-tissue samples were tested for 28 compounds (Timme, 1995). PCBs were not detected in sediment or fish tissue. Pesticides were not detected in streambed sediment, and only one organochlorine pesticide degradate, DDE, was detected in fish tissue at a concentration of 8.2 μg/kg. This detection was well below the 1,000-μg/kg National Academy of Sciences and National Academy of Engineering guideline for the protection of wildlife that consume fish (National Academy of Sciences and National Academy of Engineering, 1973). DDE was detected in 12 of 14 whole-body fish-tissue samples collected throughout the Upper Colorado River Basin during 1995 (Stephens and Deacon, 1998). The low concentration of DDE in fish tissue from Gore Creek (8.2 μg/kg) is similar to concentrations that ranged from 6 to 15 μg/kg at five other sampling locations in the Southern Rocky Mountains physiographic province, and is about one to two orders of magnitude less than concentrations at sites associated with agricultural land use (Stephens and Deacon, 1998). The detection of DDE at the more remote sites in the Upper Colorado River Basin probably indicates that widespread distribution is caused by atmospheric transport from areas of application. In 1993, DDE was detected in a sample of sediment collected from the water hazard at hole number eight on the Vail golf course (Northwest Colorado Council of Governments, 1995). A repeat sampling in 1994 failed to detect DDE in sediment from the same location.

Trace Elements

Previous studies have concluded that both streambed-sediment and fish-tissue samples are needed for a complete assessment of the occurrence and distribution of trace elements (Deacon and Stephens, 1998; Heiny and Tate, 1997; Carter, 1997). Streambed-sediment and fish-liver samples were analyzed for trace-element content from sites representing urban, mining, and background conditions in the UCOL in fall 1995 and 1996. Currently (1998) there are no State or Federal guidelines or standards for concentrations of trace elements in streambed sediment; however, the Ontario (Canada) Ministry of Environment and Energy (Persaud and others, 1993) has developed guidelines for trace elements considered most toxic to aquatic life. Examples of trace elements that can be toxic to aquatic life under certain duration and exposure levels are cadmium, copper, silver, and zinc. Samples of streambed sediment collected at the mouth of Gore Creek did not exceed these guidelines. Cadmium, copper, and zinc concentrations in streambed sediments collected from site 29 and background sites 1 and 36 (Gore and Polk Creeks) were less than background concentrations calculated for the UCOL (Deacon and Stephens, 1998).

Silver concentrations in streambed sediment also were low (less than 2.5 μg/g) at three sites in the Gore Creek watershed. However, the concentration of silver was elevated (19.7 μg/g) in a brown-trout liver sample at site 29 when compared to other sites in the UCOL (Deacon and Stephens, 1998). The silver concentration in liver tissue from this site was more than three times greater than the next highest concentration from a sample of liver tissue collected from the Blue River in Summit County, Colorado, a stream that is known to be affected by mining land uses. In 159 fish-liver samples collected during 1992–95 from 20 river basins throughout the United States, representing all land-use categories, the maximum silver concentration was only 3.6 μg/g (L. Rod DeWeese, U.S. Geological Survey, oral commun., 1998). The silver concentration in fish livers from site 29 was five times higher than the maximum silver concentration observed nationally. Fish-liver samples were not collected at the background sites on Gore and Polk Creeks, so comparisons cannot be made within the Gore Creek watershed.

Because dissolved silver can be toxic at low levels to trout under certain conditions and because Gore Creek is classified as a “Gold Medal fishery” by the Colorado Division of Wildlife, additional samples were collected at site 29 in April 1998 to verify the elevated silver concentration found in a brown-trout liver sample. Migration and mobility of fish complicate direct comparisons of land use and geology with trace-element concentrations in fish tissue. Therefore, spring was chosen as the best time to collect additional fish samples to avoid the fall brown-trout spawning season. Spring samples have a higher probability of being from resident brown trout instead of those that have recently migrated into Gore Creek from the Eagle River to spawn. Concentration of silver in brown-trout liver was determined to be 16.7 μg/g, similar to the elevated silver concentration in brown trout from Gore Creek in 1995.

To determine specifically whether silver in aquatic biota originated from natural or human sources in the Gore Creek watershed and(or) in the Eagle River, macroinvertebrate (caddisfly) samples also were collected for silver analyses during the fish sampling in April 1998. Although some macroinvertebrates drift downstream, the majority of the macroinvertebrate community is somewhat sessile. Therefore, sampling the macroinvertebrate community may provide a better indication of upstream contaminant sources than sampling only fish. Samples were collected at the mouth of Gore Creek, in the Eagle River just upstream from the mouth of Gore Creek, and in Brush Creek, a tributary to the Eagle River near the town of Eagle. The three macroinvertebrate sampling sites were chosen to estimate the bioavailability of silver in Gore Creek, the Eagle River, and a background site on Brush Creek. To minimize variability associated with rates of silver uptake by different taxa, the same genus of caddisfly (*Hydropsyche* sp.) was collected at all three sites. Replicate samples were collected for quality-assurance purposes at each site and analyzed to determine variability within the sampling technique. Quality-assurance results indicated sample variability was less than 5 percent between replicate samples for each site.

Caddisflies at the Brush Creek background site contained silver concentrations of 0.04 μg/g, and caddisflies in the Eagle River and Gore Creek contained concentrations of 0.13 and 0.67 μg/g, respectively. These results indicate that more bioavailable silver was present in Gore Creek than in the Eagle River or Brush Creek during winter/spring 1998. In comparison, there were only 4 silver detections in 49 caddisfly-tissue samples collected nationally by the NAWQA Program during 1992–95, and the maximum silver concentration was 0.60 μg/g (L. Rod Deweese, U.S. Geological Survey, written commun., 1998). Although most of the 49 samples collected nationally did not yield detectable silver, the laboratory reporting limits were relatively high and ranged from 0.20 to 0.40 μg/g. Water-sample and streambed-sediment results discussed earlier indicate that background geology is an unlikely source of silver, but point or nonpoint sources may be the source of silver in the Gore Creek watershed. Although silver concentrations were elevated in two brown-trout liver samples collected at site 29 during 1995 and 1998, a study of silver toxicity determined that internal buildup of silver does not necessarily imply an impairment of biological function (Hogstrand and Wood, 1998).

GROUND WATER

Ground-water-quality data were available for only five shallow alluvial-aquifer monitoring wells and the Eagle River Water and Sanitation District's (ERWSD) alluvial municipal well field in the Town of Vail (fig. 23). The temporal scale of the data was limited; composite samples were collected from the municipal well field in 1988–89, one discrete sample was collected from a single well from the well field in 1997, and two discrete samples were collected from each of the five monitoring wells in 1997. The data from the 1997 samples included a variety of inorganic and organic constituents, as well as bacteria and age-dating information.

Water Quantity

Municipal wells completed in the alluvial aquifer in the Vail area provide most of the developed ground-water supplies for the Gore Creek watershed. Well yields from alluvial aquifers in the Upper Colorado River Basin commonly range from 5 to 100 gal/min but can exceed 500 gal/min (U.S. Geological Survey, 1985). The combined yield for the three wells in the ERWSD municipal ground-water supply system is 4,200 gal/min. Water-level data were not available for these municipal wells, but water levels for five alluvial monitoring wells in the Town of Vail ranged from about 4 to 25 ft below land surface in 1997 (Lori Apodaca, U.S. Geological Survey, written commun., 1998), indicating a shallow water table. Water levels were 1 to 5 ft higher in the spring than in the fall.

Data were not available for bedrock wells in the Gore Creek watershed. Precambrian-age basement rocks are exposed in the eastern and northern mountains of the Gore Creek watershed. Precambrian rocks generally yield small quantities of water, suitable only for domestic supplies, but water can discharge from springs where the rocks are fractured (Voegeli, 1965).

The ERWSD well field consisting of three wells provides most of the municipal water supplies for the Town of Vail (Tipton and Kalmbach Incorporated, 1990). The three wells, shown as site 68 in figure 23, are located near the confluence of Gore and Booth Creeks. The wells are hydraulically connected to Gore Creek. Tipton and Kalmbach (1990) estimated that operation of the well field for municipal water supplies diverted 2,626 acre-ft from Gore Creek from October 1988 to September 1989. No estimate of return flows was made for the 1988–89 period; however, 1985–86 return-flow estimates indicated that about 88 percent of well-field diversions from Gore Creek were returned to Gore Creek as treated wastewater. Generally, there was a higher percentage of return flow to Gore Creek during the months of October through May, when more consumptive water uses such as lawn irrigation are negligible.

Water Quality

To assess the shallow ground-water-quality conditions in the aquifer used for drinking-water supply in the Gore Creek watershed, five monitoring wells were installed in the alluvium along Gore Creek as part of the UCOL NAWQA Program. These five wells were each sampled twice for water quality in April/May and October of 1997 (sites 67, 69–72, table 1, fig. 23). The wells were installed according to NAWQA Program protocols (Lapham and others, 1995) to minimize subsurface contamination and effects on ground-water chemistry due to well

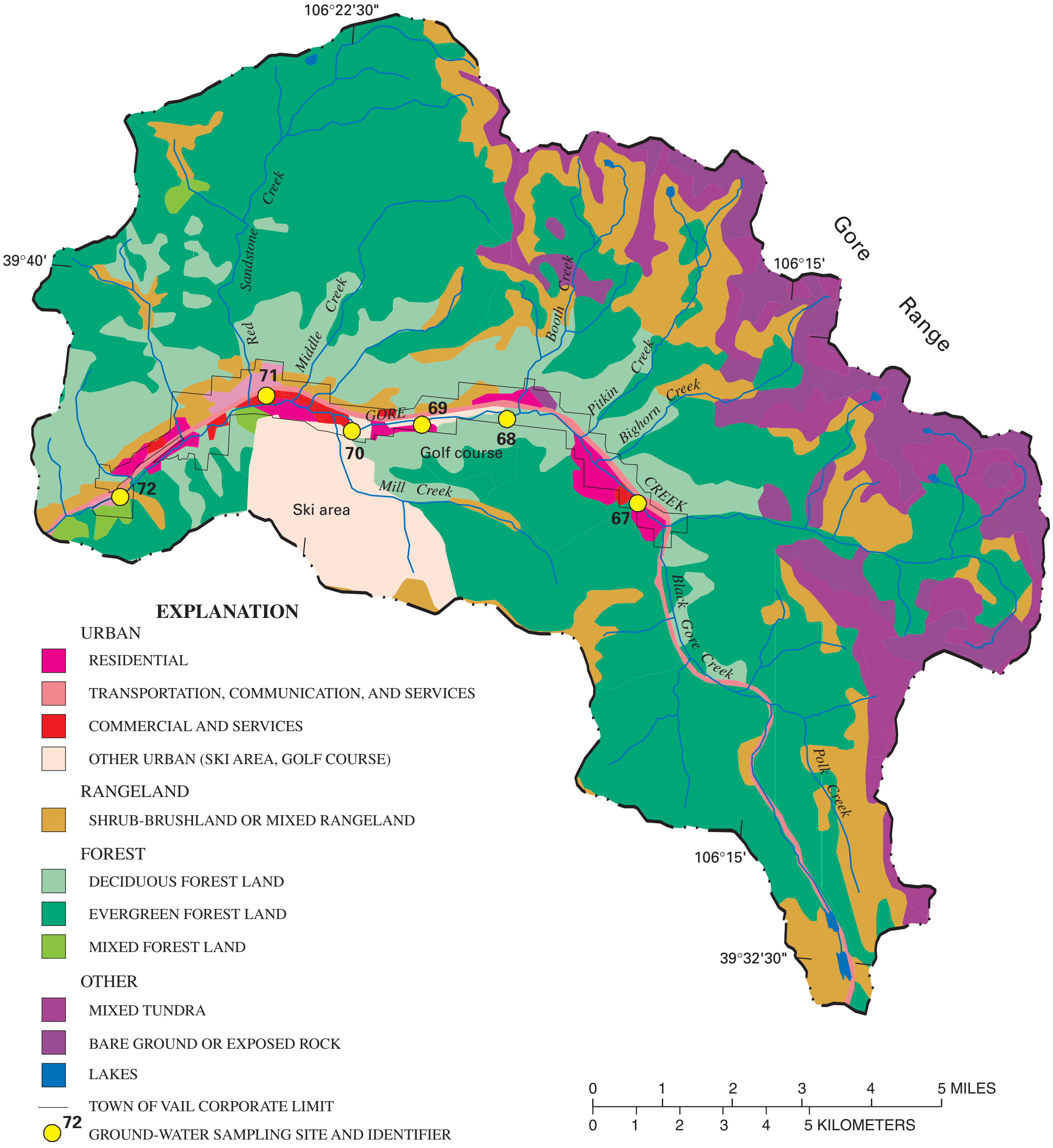


Figure 23. Ground-water sampling sites in the Gore Creek watershed, 1988–97.

construction and installation. Information from these shallow alluvial wells can be used to assess the effects of land use on ground-water quality in the Town of Vail. Additional water-quality data were available for 27 periodic composite samples collected from the ERWSD municipal well field during 1988 and 1989 and also a single sample collected from well R–1 of the well field in August 1997 by the UCOL NAWQA Program (site 68, table 1 and fig. 23).

Field properties measured by the USGS included temperature, pH, dissolved oxygen, turbidity, specific conductance, and alkalinity. Samples from each well were analyzed for major ions, nutrients, trace elements, radon-222, DOC, 87 pesticides, and 87 VOCs (Apodaca and Bails, 1999; Timme, 1995). Samples also were analyzed for total coliforms and *Escherichia coli* (*E. coli*) using the mENDO and NA-MUG methods (American Public Health Association and others, 1992; Britton and Greeson, 1989; U.S. Environmental Protection Agency, 1991). Samples that tested positive for total coliform colonies on an mENDO plate were transferred to an NA-MUG plate and tested for *E. coli*. The April and May 1997 ground-water samples were analyzed for chlorofluorocarbons (CFCs) to determine the age of the ground water (Plummer and others, 1993). Water-quality samples were analyzed at the USGS National Water Quality Laboratory in Arvada, Colo. The CFC samples were analyzed at the USGS CFC Laboratory in Reston, Va.

Inorganic Constituents

A summary of the water-quality properties and constituents for the five monitoring wells in the Gore Creek watershed sampled by the UCOL NAWQA Program in 1997 (10 samples total) is provided in table 6. Also included are USEPA drinking-water standards and health advisories. Data for the five monitoring wells are summarized in table 6 and discussed as a group because the well construction, sampling, and laboratory analyses were all performed in a consistent manner among wells. Water-quality data collected from wells in the ERWSD municipal well field will be discussed separately. In the monitoring wells, pH values ranged from 6.5 to 7.8, with a median value of 7.4. Dissolved-oxygen concentration ranged from 0.8 to 4.7 mg/L; only one concentration was less than 1.0 mg/L. Specific-conductance values ranged from 265 to 557 µS/cm, and the median was 325 µS/cm. The dominant major ions were calcium and bicarbonate.

Nutrients. Nutrient concentrations for all five monitoring-well sites were low and less than USEPA drinking-water standards. Nitrate was detected in 90 percent of the samples. The other dissolved nutrient species (ammonia, ammonia plus organic nitrogen, nitrite, orthophosphate, and total phosphorus) were detected at most in 3 of 10 samples (table 6). Nitrate concentrations ranged from less than detection to 2.82 mg/L, with a median concentration of about 0.49 mg/L. For sites 67, 70, and 72 (fig. 23), nitrate concentrations were higher in the spring than fall of 1997. For example, at site 70, Gerald R. Ford Park, spring and fall nitrate concentrations were 2.47 and 0.12 mg/L, respectively. All sites with higher concentrations in the spring were associated with recreational land use, either public parks or the golf course. The maximum nitrate concentration of 2.82 mg/L was at site 72 in May 1997 and was well below the USEPA MCL for nitrate of 10 mg/L (U.S. Environmental Protection Agency, 1996).

Trace elements. Trace elements were detected at all five sites, generally at low concentrations, except for dissolved iron and manganese (table 6). Ground-water samples for sites 67 and 71 contained 10 trace elements each, while site 69 contained the fewest number of trace elements at 6. Dissolved aluminum, barium, boron, chromium, and uranium were detected at all sites. Concentrations of aluminum and chromium for the spring samples were nearly twice the concentrations for fall samples at four sites. The USEPA SMCL (U.S. Environmental Protection Agency, 1996) for dissolved iron (300 µg/L) and dissolved manganese (50 µg/L) were exceeded in both spring and fall samples at site 67, Bighorn Park. Iron concentrations were 8,500 µg/L and 2,900 µg/L, and manganese concentrations were 1,020 µg/L and 394 µg/L in the spring and fall samples, respectively, at Bighorn Park. High iron concentrations in drinking water form red precipitates that stain plumbing fixtures and laundry, and high manganese concentrations can affect the taste and color of the water and deposit black-oxide stains (Hem, 1992). These elevated iron and manganese concentrations are probably a result of local geology and reducing conditions that may exist at the site. Dissolved-oxygen concentrations were lowest (1.2 and 0.8 mg/L) at Bighorn Park when compared to the other sites during spring and fall. Also, high manganese concentrations attributable to minerals in bedrock of the upper Black Gore Creek drainage have been detected in Gore and Black Gore Creeks (Advanced Sciences, Inc., 1990). Similar minerals may be present in the alluvium at Bighorn Park, site of the well nearest to Black Gore Creek.

Radon-222. Radon-222, a noble gas, is a natural decay product of uranium and radium-226. Large quantities of radon occur naturally as gases below the land surface and are mostly derived from uranium and radium-226 in the solids in an aquifer (Hem, 1992). In the Gore Creek watershed, radon-222 was detected in all five wells sampled

Table 6. Summary of the minimum, median, and maximum values for the water-quality properties and constituents of monitoring wells sampled in the Gore Creek watershed, 1997

[----, no data; <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; cols/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; USEPA, U.S. Environmental Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; PMCL, proposed maximum contaminant level; MCLG, maximum contaminant level goal; HA, health advisory level]

Properties and constituents and reporting unit	Number of analyses/ number of detections	Minimum	Median	Maximum	USEPA drinking-water standards or health advisories
Field properties					
Water temperature (degrees Celsius)	10/10	3.5	9.3	11.5	----
Specific conductance, field (µS/cm)	10/10	265	325	557	----
Dissolved solids (mg/L)	10/10	146	186	329	500 (SMCL)
Hardness total (mg/L as $CaCO_3$)	10/10	130	155	300	----
Oxygen, dissolved (mg/L)	10/10	0.8	2.9	4.7	----
pH, field (standard units)	10/10	6.5	7.4	7.8	6.5–8.5 (SMCL)
Alkalinity (mg/L as $CaCO_3$)	10/10	114	136	273	----
Turbidity (NTU)	8/8	0.72	29	120	----
Major ions					
Bicarbonate, dissolved (mg/L)	4/4	159	244	329	----
Calcium, dissolved (mg/L)	10/10	42	51	95	----
Chloride, dissolved (mg/L)	10/10	1.4	4.7	19	250 (SMCL)
Fluoride, dissolved (mg/L)	10/2	<0.1	<0.1	0.11	2.0 (SMCL)
Magnesium, dissolved (mg/L)	10/10	3.3	6.2	15	----
Potassium, dissolved (mg/L)	10/10	0.87	1.3	2.0	----
Silica, dissolved (mg/L as SiO_2)	10/10	5.2	6.6	10	----
Sodium, dissolved (mg/L)	10/10	3.3	4.4	12	----
Sulfate, dissolved (mg/L)	10/10	3.2	12	28	250 (SMCL)
Nutrients					
Ammonia, dissolved (mg/L as N)	10/2	<0.015	<0.015	0.047	30 (HA)
Nitrite, dissolved (mg/L as N)	10/1	<0.01	<0.01	0.044	1 (MCL)
Nitrate, dissolved (mg/L as N)	10/9	<0.05	0.489	2.82	10 (MCL)
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	10/1	<0.20	<0.20	0.21	----
Orthophosphate, dissolved (mg/L as P)	10/3	<0.01	<0.01	0.035	----
Total phosphorus, dissolved (mg/L as P)	10/1	<0.01	<0.01	0.032	----
Trace elements					
Aluminum, dissolved (µg/L)	10/10	4.0	9.1	14	50–200 (SMCL)
Antimony, dissolved (µg/L)	10/0	<1.0	<1.0	<1.0	6.0 (MCL)
Arsenic, dissolved (µg/L)	10/0	<1.0	<1.0	<1.0	50 (MCL)
Barium, dissolved (µg/L)	10/10	99	173	233	2,000 (MCL)
Beryllium, dissolved (µg/L)	10/0	<1.0	<1.0	<1.0	4.0 (MCL)
Boron, dissolved ((µg/L)	5/5	22	24	30	----
Cadmium, dissolved (µg/L)	10/0	<1.0	<1.0	<1.0	5.0 (MCL)
Chromium, dissolved (µg/L)	10/10	1.5	3.1	7.7	100 (MCL)
Cobalt, dissolved (µg/L)	10/3	<1.0	<1.0	3.0	----
Copper, dissolved (µg/L)	10/4	<1.0	<1.0	1.4	1,300 (action level)
Iron, dissolved (µg/L)	10/6	<3.0	13.8	8,500	300 (SMCL)
Lead, dissolved (µg/L)	10/0	<1.0	<1.0	<1.0	15 (action level)
Manganese, dissolved (µg/L)	10/6	<1.0	2.1	1,020	50 (SMCL)
Molybdenum, dissolved (µg/L)	10/4	<1.0	<1.0	3.5	----

Table 6. Summary of the minimum, median, and maximum values for the water-quality properties and constituents of monitoring wells sampled in the Gore Creek watershed, 1997—Continued

[----, no data; <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; cols/100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; USEPA, U.S. Environmental Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; PMCL, proposed maximum contaminant level; MCLG, maximum contaminant level goal; HA, health advisory level]

Properties and constituents and reporting unit	Number of analyses/ number of detections	Minimum	Median	Maximum	USEPA drinking-water standards or health advisories
Trace elements—Continued					
Nickel, dissolved (µg/L)	10/7	<1.0	1.2	14	100 (MCL)
Selenium, dissolved (µg/L)	10/0	<1.0	<1.0	<1.0	50 (MCL)
Silver, dissolved (µg/L)	10/0	<1.0	<1.0	<1.0	100 (SMCL)
Uranium, dissolved (µg/L)	10/10	1.6	2.0	3.5	20 (PMCL)
Zinc, dissolved (µg/L)	10/0	<1.0	<1.0	<1.0	5,000 (SCML)
Pesticides					
Atrazine, dissolved (µg/L)	10/2	0.002	0.002	0.002	3 (MCL)
Prometon, dissolved (µg/L)	10/1	----	0.006	----	----
Volatile organic compounds					
1,2,4-Trimethylbenzene (µg/L)	10/5	0.01	0.02	0.05	----
4-methyl-2-pentanone (µg/L)	10/1	----	0.09	----	----
Acetone (tot) (µg/L)	10/1	----	52.4	----	----
Bromodichloromethane (µg/L)	10/1	----	0.006	----	100 (MCL)
Carbon disulfide (tot) (µg/L)	10/2	0.01	0.05	0.1	----
Chloroform (µg/L)	10/8	0.007	0.035	0.05	100 (MCL)
Chloromethane (µg/L)	10/1	----	1	----	----
Diethyl ether (tot) (µg/L)	10/1	----	0.04	----	----
Ethyl chloride (µg/L)	10/1	----	1.23	----	----
Iodomethane (tot) (µg/L)	10/1	----	0.02	----	----
Methylene chloride (µg/L)	10/1	----	0.182	----	----
Methyl ethyl ketone (tot) (µg/L)	10/1	----	1.22	----	----
Tetrachloroethylene (µg/L)	10/1	----	0.004	----	5 (MCL)
Other constituents					
Carbon, organic, dissolved (mg/L as C)	9/9	0.6	1.0	1.9	----
Total coliform bacteria (cols/100 mL)	10/1	<1	<1	5	0 (MCLG)
E. coli bacteria (cols/100 mL)	1/0	<1	<1	<1	0 (MCLG)
Methylene blue active substances (MBAS) (mg/L)	5/2	<0.02	<0.02	0.05	----
Radon-222, total (pCi/L)	10/10	978	1,174	1,517	300 (PMCL)

(table 6). The radon-222 concentrations ranged from 978 to 1,517 pCi/L, and the median was 1,174 pCi/L. The highest radon-222 concentrations were at sites 71 and 72. Every sample exceeded the USEPA-proposed maximum contaminant level (PMCL) for radon, 300 pCi/L, which has been withdrawn pending additional review. Throughout the Southern Rocky Mountains physiographic province, radon concentrations typically are above 300 pCi/L due to the presence of uranium-bearing minerals in association with bedrock (Lori Apodaca, U.S. Geological Survey, oral commun., 1998). Radon gas is important environmentally because it can cause lung cancer. It is soluble in water and can enter the home through water use (U.S. Environmental Protection Agency and others, 1992). After a new standard for radon is established, ground water in the Gore Creek watershed may need to be treated prior to human use.

Organic Constituents

Dissolved organic carbon. Ground-water DOC concentrations in the Gore Creek watershed were low relative to alluvial wells sampled during 1997 in the Fraser River watershed. The DOC concentrations ranged from 0.6 to 1.9 mg/L, with a median concentration of 1.0 mg/L, in the Gore Creek watershed (table 6). In comparison, DOC concentrations ranged from 0.6 to 7.3 mg/L, with a median concentration of 3.4 mg/L, in the Fraser River watershed (Apodaca and Bails, 1999).

Pesticides. Only two pesticides, both in very low concentrations, were detected in three of the five wells sampled in the watershed (table 6). Even at low concentrations, the presence of pesticides indicates that there are some land-use effects on shallow ground-water resources. Atrazine was detected twice at a concentration of 0.002 μg/L at sites 69 and 72, and prometon was detected once, at site 67, at a concentration of 0.006 μg/L. Atrazine was detected in the spring and fall, but prometon was detected only in the fall. Atrazine has been applied statewide to corn and sorghum and fallow land, and prometon has been applied to National Forest lands (Bohmont, 1993).

Volatile organic compounds. Thirteen VOCs were detected in the five wells sampled in the Gore Creek watershed. Most detections (21 of 25) occurred during spring. Chloroform, with eight detections, was the most frequently detected VOC, followed by 1,2,4-trimethylbenzene with five detections, all in spring. Chloroform is used in various manufacturing processes and as a solvent. 1,2,4-Trimethylbenzene is also used in manufacturing. Ten VOCs were detected only once, with 80 percent of these detections occurring during the spring sampling at site 67, Bighorn Park (fig. 23). Eleven different VOCs were detected at site 67, four at site 71, and three at site 69. Drinking-water standards for VOCs were not exceeded at any sites. Acetone, detected at site 67 at a concentration of 52.4 μg/L, was the only VOC with a concentration greater than 1.23 μg/L (table 6). Additional investigation is needed to determine the source of this VOC and the others detected in the Gore Creek watershed. The presence of VOCs in the five wells indicates that shallow alluvial ground-water quality is susceptible to land-use effects.

Other Constituents

Bacteria. Water samples from the five monitoring wells in the Gore Creek watershed were analyzed for bacteria (total coliforms and *E. coli*). The presence or absence of bacteria reflects the sanitary quality of water and the potential health risk from waterborne diseases (Meyers and Sylvester, 1997). Total coliforms are correlated with the existence of several waterborne disease-causing organisms but usually do not cause disease themselves. *E. coli* is more closely related to fecal contamination. Total coliforms were detected only once in the watershed, at the Pedestrian Bridge, site 71 (fig. 23), in the fall. This sample also was tested for *E. coli*, and none were found. The concentration of total coliforms for site 71, 5 colonies/100 mL, exceeded the maximum contaminant level goals (MCLGs) of zero total coliforms in drinking water (U.S. Environmental Protection Agency, 1996). According to Meyers and Sylvester (1997), the detection of as few as 4 colonies of total coliform bacteria per 100 mL is a public health concern.

Methylene blue active substances. The fall 1997 sample from each well was analyzed for methylene blue active substances (MBAS), which can be indicators of nonpoint-source contamination by wastewater. The analytical procedure used can detect the presence of anionic sulfate- and sulfonate-based surfactants (Burkhardt and others, 1995) that are found in soaps and detergents. The MBAS concentrations for the five wells were very low, with a range from less than 0.02 to 0.05 mg/L (table 6). Sites 67 and 72, where MBAS concentrations were 0.05 mg/L, were the only locations with MBAS concentrations above the detection limit of 0.02 mg/L. Data from the five wells indicate that there is little to no nonpoint-source contamination of ground water in the vicinity of the wells by wastewater.

Other Ground-Water Data

In addition to the ground-water-quality data collected at five monitoring wells, data are available from 27 composite samples from the ERWSD alluvial water-supply well field (site 68, fig. 23), collected by In-Situ, Inc., and Advanced Sciences, Inc., between September 1988 and September 1989 (Advanced Sciences, Inc., 1990) plus a single sample collected by the USGS in August 1997 at well R–1, which is part of the well field. Composite water samples from the well field were measured for field properties (dissolved oxygen and specific conductance) and were analyzed for hardness, dissolved copper, lead, mercury, silver, and zinc, and dissolved and total iron and manganese. No USEPA drinking-water standards were exceeded in these samples. Dissolved-oxygen concentrations were relatively high for ground water, ranging from 6.4 to 9.6 mg/L, indicating a possible hydraulic connection to Gore Creek. However, unless careful sampling methods are followed, it is relatively easy to inadvertently introduce dissolved oxygen while compositing ground-water samples. Specific-conductance values ranged from 133 to 158 μS/cm. Copper was detected three times at 2–3 μg/L. Total iron was detected in 10 of 27 samples, with concentrations ranging from 20 to 490 μg/L. Dissolved iron and dissolved manganese, which are subject to USEPA SMCLs, were not detected. Silver was detected in one sample at 0.1 μg/L, and lead was detected twice at 1 and 2 μg/L. Mercury was detected once at a concentration of 0.1 μg/L. Copper, total iron, lead, mercury, and silver were all detected in a sample collected on September 20, 1989.

In August 1997, the USGS collected a ground-water-quality sample from well R–1 of the municipal well field and analyzed that sample for the same properties and constituents as the five monitoring-well samples. No USEPA drinking-water standards were exceeded in this sample; however, the radon concentration (1,239 pCi/L) exceeded the former USEPA PMCL. Dissolved oxygen was 2.85 mg/L, which is much lower than the 6.4 to 9.6 mg/L range in dissolved oxygen for the composite ground-water samples from 1988 and 1989. Specific conductance was 267 μS/cm, higher than the 133 to 158 μS/cm range of values measured in the composite samples. The dominant major ions were calcium and bicarbonate. Ammonia, nitrite, and orthophosphate were not detected. Dissolved phosphorus and nitrate concentrations were 0.01 and 0.29 mg/L, respectively. Dissolved copper, lead, manganese, and silver were not detected above the 1.0-μg/L reporting limit. Dissolved iron and zinc concentrations were 11.77 and 1.88 μg/L, respectively. DOC concentration was 0.3 mg/L. Pesticides, VOCs, total coliforms, and MBAS were not detected, indicating that ground water was not severely affected by land use during this time period.

In the Gore Creek watershed, ground-water data are lacking because of the small number of monitoring wells (five, excluding municipal supply wells) and infrequent sampling. A comprehensive water-quality analysis and characterization of ground water in the watershed cannot be accomplished with the ground-water data that are currently available.

Dating Analysis

The concentrations of chlorofluorocarbons (CFCs), which are manmade and used as aerosol propellants, blowing and cleaning agents, refrigerants, and solvents, can be used to date young ground water (Plummer and others, 1993). As a result of their initial use in the 1940’s, CFCs were introduced into the atmosphere, and atmospheric concentrations of CFCs continued to rise until the early 1990’s. Because ground water acquires CFCs through recharge, the time of ground-water recharge can be determined using knowledge of the temporal variations in atmospheric CFC concentrations. The CFC data were obtained from the five ground-water monitoring wells installed in the Gore Creek watershed in 1997. Data for site 67 (fig. 23) indicated that the ground water recharged from about 1940 to 1950. However, low dissolved-oxygen concentrations (0.8 mg/L), such as that measured at site 67, may have resulted in an incorrectly old age determination. The CFC data for sites 69 and 71 indicated similar ages in the ground water, with recharge occurring during the early to mid-1990’s. Ground water at site 70 was slightly older, from the late 1980’s. The youngest ground water, at site 72, was dated as “modern” (only about 2 years old). Based on the CFC data for the five wells, recharge to the aquifer would have occurred from about 2 to about 50 years ago. These dates indicate that changes in land-use activities may not affect ground-water quality for 2 to 50 years.

Supplementing water-quality data with the age of ground water can provide a better understanding of the link between land use and the water quality in the underlying aquifer (Apodaca and Bails, 1999). The implementation of land-management practices prior to land development may help to reduce the potential contamination from land-use practices. Ground-water dating can be used in conjunction with information about ground-water flow paths so that managers can select strategies for maintaining or improving ground-water quality.

AQUATIC ECOLOGY

Since 1995, the USGS has collected algal-, macroinvertebrate-, and fish-community data at sites in the Gore Creek watershed to assess the effects of urban development on aquatic life. Fish-community data were collected annually at site 29, the mouth of Gore Creek, during August 1995, 1996, and 1997. In cooperation with the Town of Vail, Eagle River Water and Sanitation District, and Upper Eagle Regional Water Authority, algal- and macroinvertebrate-community data plus ancillary data and information, such as physical habitat and field properties, were collected at 15 sites in the Gore Creek watershed during September 1997 (fig. 24). These 15 sites were chosen to evaluate differences in the aquatic communities as Black Gore Creek flows from Vail Pass along Interstate 70, and as Gore Creek flows from its headwaters through urban land uses in the Town of Vail.

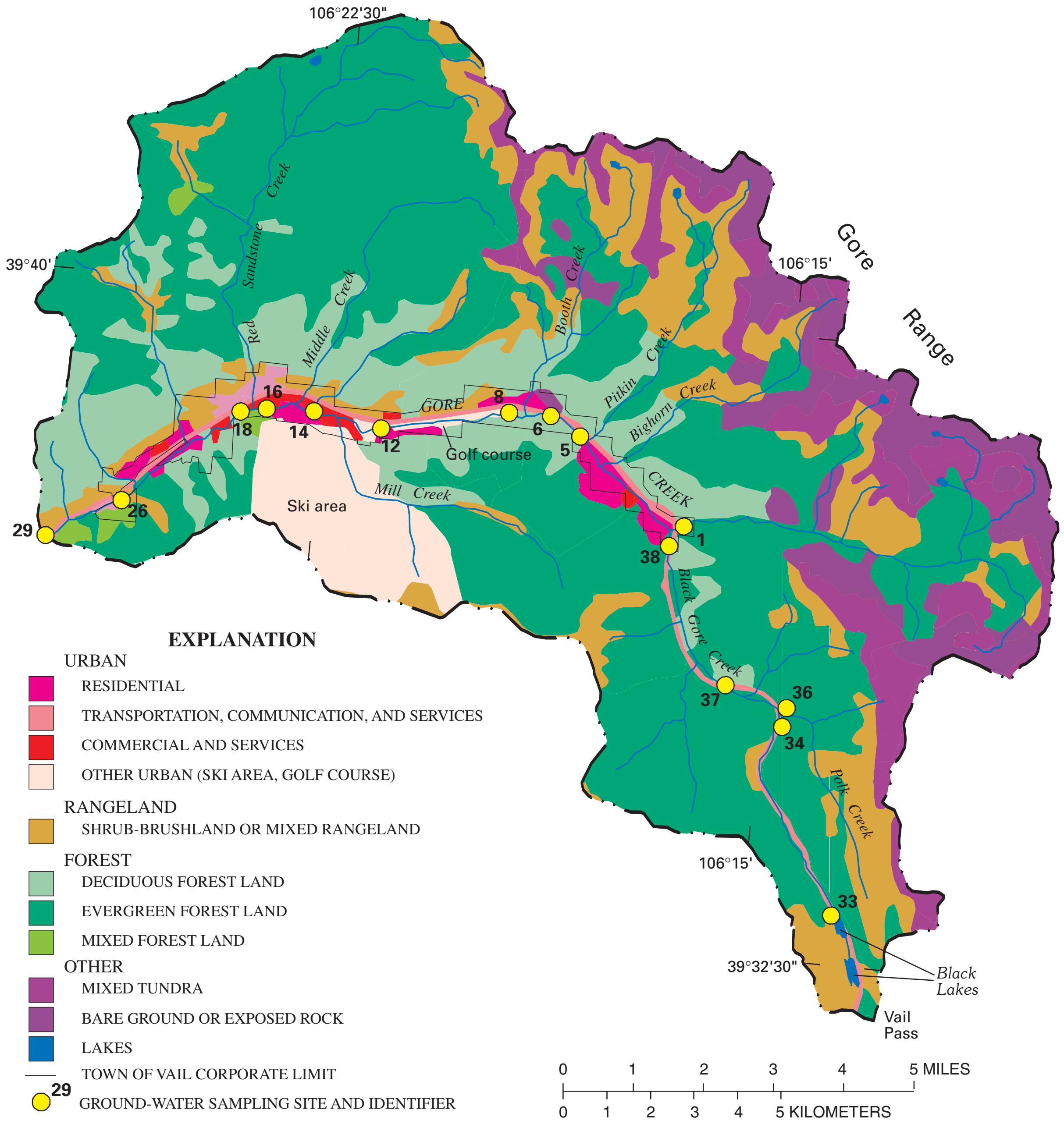


Figure 24. Aquatic-ecology sites on Gore, Black Gore, and Polk Creeks.

In any biological assessment of a stream, water-quality, water-quantity, and habitat data are needed to understand the status and potential of the aquatic community. Water quality is commonly regarded as a major limiting factor for aquatic communities; however, the quality and quantity of physical habitat also has a major influence. Aquatic and riparian habitat influences the structure and function of the aquatic community in a stream (Barbour and others, 1997).

Macroinvertebrate-community, habitat, discharge, and field-property data were collected at 10 sites on Gore Creek, 4 sites on Black Gore Creek, and 1 site on Polk Creek during September 1997 (fig. 24). Algal-community data also were collected at the same 10 sites on Gore Creek and site 38 at the mouth of Black Gore Creek. The Gore Creek sites (sites 1 through 29, fig. 24) represent background conditions as well as various land uses, including the more densely developed sections in the Town of Vail. Site 1, which is located upstream from Interstate 70 and any land development, represents “pristine” background conditions (fig. 24). Sites 5 and 6 are downstream from the confluence of Gore and Black Gore Creeks and bracket an open-space park. Sites 8 and 12 bracket a golf course. Site 14 is downstream from the golf course and the Vail Mountain ski area, which is drained by Mill Creek, and also is adjacent to residential and commercial land uses. Sites 16 and 18 bracket the wastewater-treatment plant and relatively dense urban development. Sites 26 and 29 were selected to evaluate the cumulative effects of upstream urban, transportation, and recreational land uses. Sites 33, 34, 37, and 38 were selected to assess the macroinvertebrate-community structure in Black Gore Creek. Site 36 on Polk Creek was selected to represent background conditions for Black Gore Creek, which receives runoff from Interstate 70 for much of the length of the creek.

Specific conductance, dissolved oxygen, pH, and temperature were measured at each site in addition to discharge and velocity (table 7). Rapid bioassessment protocols (RBP) (Plafkin and others, 1989) were used to qualitatively document habitat conditions at all the sites; selected habitat properties are listed in table 7. Field-properties data did not indicate any water-quality concerns at the sampling sites. Dissolved-oxygen concentration was high; sites were well oxygenated and percent saturation ranged from 85.2 to 119.5. Specific-conductance values ranged from 62 to 293 µS/cm at the sampling sites. Within Gore Creek, specific-conductance values were higher in the downstream reaches than in the upstream reaches. Values for pH ranged from neutral to somewhat alkaline (7.05 to 8.78 standard units).

Efforts were made to select sites with similar habitat characteristics to minimize the effect of habitat conditions on biological community structure. However, the sites on Black Gore Creek generally received lower habitat rankings because of higher sedimentation and embeddedness of rocks in the stream channel when compared with sites on Gore Creek (table 7). The increased sedimentation and embeddedness reduces available living space for stream biota. In Black Gore Creek, this effect is attributable to the large inputs of sediment from traction sanding on Vail Pass (Lorch, 1998).

Algae

Benthic algae are important primary producers in streams, can be an indicator of water-quality conditions, and are a source of food for higher trophic levels such as macroinvertebrates and fish (Stevenson and others, 1996). Sites with sufficient, but not excessive, algal production generally support greater abundances of macroinvertebrates and fish. Algal communities respond rapidly to changes in stream conditions such as available nutrients or sunlight. Because of this quick response to stream conditions, algal-community structure can reflect prevailing water-quality conditions for time periods ranging from several days to weeks (Porter and others, 1993).

Algae samples are processed by scraping algal material from stream cobbles. Photograph by Kirby Wynn, U.S. Geological Survey.

Table 7. Summary of selected water-quality and habitat data for aquatic-ecology sampling sites in Gore, Black Gore, and Polk Creeks

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ft^3/s, cubic feet per second; °C, degrees Celsius; ft/s, feet per second]

Property	Gore Creek		Black Gore Creek	
	Reference (site 1)	Sites 5–29	Reference (site 36)	Sites 33, 34, 37, and 38
Specific conductance, µS/cm	62.0	96–257	124.0	192–293
Dissolved oxygen, mg/L	8.3	8.39–10.1	11.2	8.4–11
Percent saturation	85.2	86.4–101.1	108.3	108.4–119.5
pH, standard units	8.1	7.05–8.78	7.1	7.02–7.7
Discharge, ft^3/s	2.4	31–72	2.1	0.65–7.6
Temperature, °C	6.0	4.3–10.5	7.5	6.6–10.6
Velocity, ft/s	1.66	1.71	1.63	1.402
Embeddedness score[1]	optimal	optimal	suboptimal	marginal to suboptimal
Sediment deposition score[1]	optimal	suboptimal to optimal	suboptimal	marginal to suboptimal
Habitat assessment total[1]	optimal	suboptimal to optimal	optimal	suboptimal

[1] Based on qualitative habitat scoring method in Plafkin and others (1989).

The relative biomass (biovolume/cm^2) for the major algal divisions is shown in figure 25A for the 10 sites on Gore Creek. Diatoms account for more than 70 percent of the algal community at all sites except site 5, where green algae is the dominant group. Dense assemblages of green algae also were observed at site 38 (at the mouth of Black Gore Creek and not shown in figure 25A), which is upstream from site 5, indicating that water-quality factors favoring green algae over diatoms had a similar influence at both sites. The occurrence and biovolume of diatom taxa have been used as indicators of environmental factors such as nitrogen availability, pH, and dissolved-oxygen concentration (Van Dam and others, 1994). Because diatoms accounted for most of the community biovolume at all but one site, the biovolumes of individual diatom taxa classified as nitrogen-autotrophs were summed to determine if nitrogen availability is affecting the algal-community structure. Increases in biovolume for these taxa can be related to increased availability of inorganic nitrogen (Van Dam and others, 1994).

An example of undisturbed (optimal) habitat conditions including stream meanders and dense native vegetation. Photograph by Ken Neubecker.

Figure 25B shows the biovolume of all diatom taxa that are classified as nitrogen autotrophs by Van Dam and others (1994). The error bars overlain on the graphs represent the standard error of the mean of the nitrogen-autotroph diatom biovolume for the two sites where triplicate samples were taken for quality-assurance purposes. The biovolume of nitrogen autotrophs observed at sites 1–12 was considerably lower than at sites 14–29, indicating increased availability of nitrogen downstream. Increases in biovolume at sites 14 and 16 indicate an increase in available inorganic nitrogen upstream from the wastewater-treatment plant that is consistent with the moderate increases in nitrate concentrations that were discussed previously in this report (fig. 17A). Biovolumes were greatest at sites 18 and 26 and apparently were affected by increased inorganic nitrogen discharged by the wastewater-treatment plant. A large decrease in nitrogen-autotroph biovolume occurred at site 29, the mouth of Gore Creek, when compared to upstream sites 18 and 26. This decrease may be caused by two related factors: decreasing amounts of available inorganic nitrogen and grazing on algae by algivores (macroinvertebrates that feed on algae). The decreasing nitrate in the downstream reaches of Gore

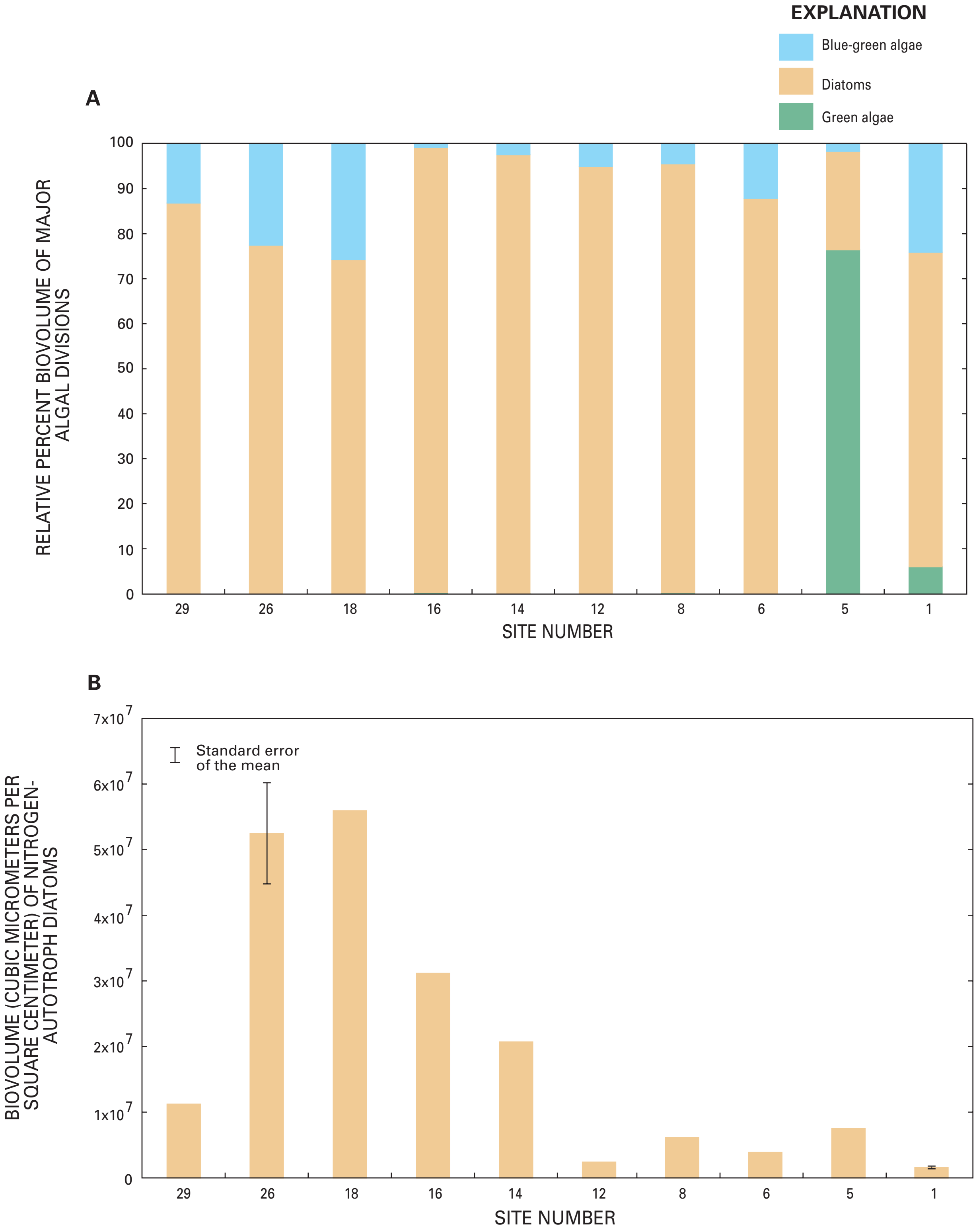


Figure 25. (A) Relative percent biovolume of the major algal divisions and (B) total biovolume for nitrogen-autotroph diatoms at sampling sites on the main stem of Gore Creek.

Creek was discussed previously in this report, and a direct comparison of algivores and algal biomass in Gore Creek is presented in the "Relations Among Water Quality, Aquatic Ecology, and Bed-Sediment and Tissue Chemistry" section of this report.

Similar to benthic algal-community structure, benthic algal biomass (the mass of organic matter attributable to algae that has accumulated on an area of substratum over time) can be an indication of water-quality conditions, especially nutrients. Chlorophyll-*a* (photosynthetic pigment concentration of algae in milligrams per square meter) was used to estimate and compare algal biomass among sites. According to Biggs (1996), median chlorophyll-*a* values in unenriched and moderately enriched streams are reported to be 1.7 and 21 mg/m^2, respectively. Chlorophyll-*a* biomass at sites 1–12 was less than 2 mg/m^2, and it generally exceeded 2 mg/m^2 at sites 14–29 (fig. 26), which corresponds with nutrient availability (fig. 26). Sites 8 and 12 bracket the golf course (fig. 24); however, the algal biomass did not increase at site 12. During similar, stable low-flow conditions in August 1996, Wynn and Spahr (1998) reported gradual increases in nitrate concentrations of 0.07 to 0.17 mg/L from site 1 to site 16. Figures 17A and 17B in this report also show some increase in nitrate concentrations at site 16, relative to sites upstream. Sites 14 and 16 both show a response (increased biomass) to nutrient enrichment that is consistent with the moderate increases in the available nitrogen determined by Wynn and Spahr (1998) and in this report.

Macroinvertebrates

Because stream macroinvertebrates spend most of their life in the water column, they are strongly affected by prevailing water-quality, streamflow, and habitat conditions. Organisms living in a body of water are, in effect, sampling the water continuously; therefore, the community reflects the average water quality over time (Davis and George, 1987). The Gore Creek watershed contains abundant and diverse macroinvertebrate fauna that are indicative of the favorable water-quality and habitat conditions.

Gore Creek

Abundance. Differences in the macroinvertebrate-community structure were observed among the Gore Creek sites. Relative abundance of the five most common macroinvertebrate groups—Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Diptera—and non-insects can be useful for determining water-quality conditions (fig. 27A). The Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), and Coleoptera (beetles) exhibit relatively low tolerance to water-quality degradation when compared to Diptera (midges) and non-insects (sludge worms) that generally are more tolerant (Barbour and others, 1997; Cairns and Dickson, 1971; Johnson and others, 1993). Mayflies, stoneflies, and caddisflies dominated more than 80 percent of the community at sites 1, 5, 6, 8, 12, and 14, which is an indication of favorable water-quality and habitat conditions. There was a much-reduced relative abundance of

Macroinvertebrate sample collection. Photograph by Kirby Wynn, U.S. Geological Survey.

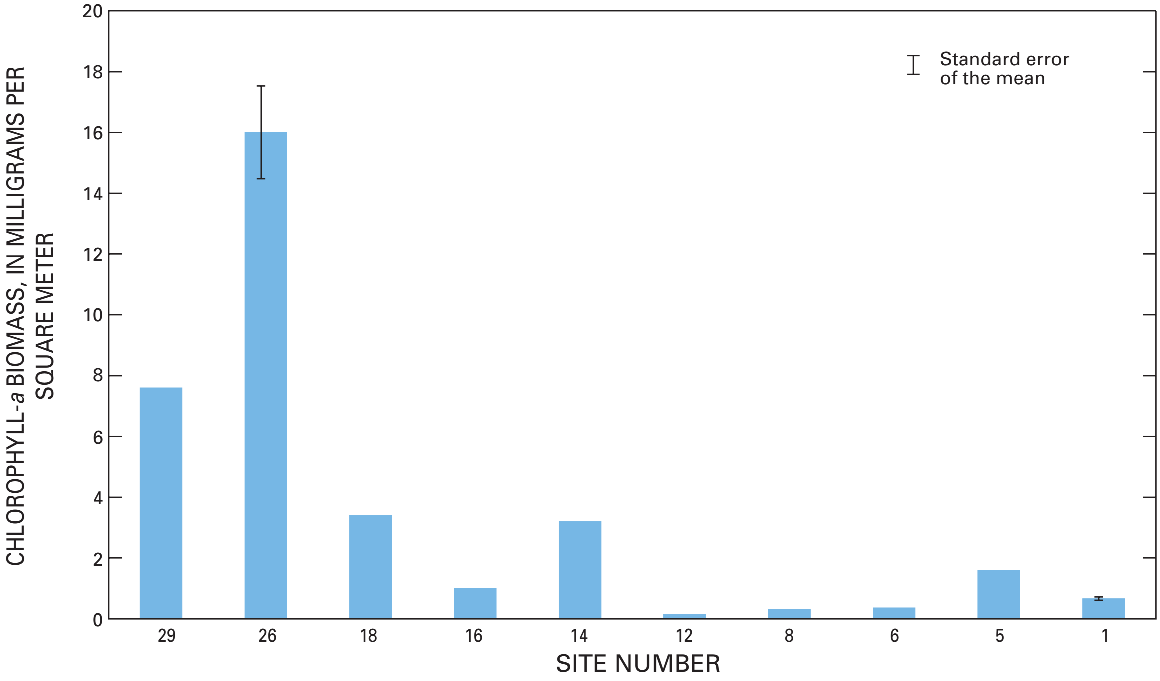


Figure 26. Chlorophyll-*a* biomass at sampling sites on the main stem of Gore Creek.

mayflies, stoneflies, and caddisflies at sites 16, 18, 26, and 29, which are downstream from larger areas of urban and recreational land uses. The increased dominance of tolerant midges and sludge worms at these sites is an indication of point- and nonpoint-source contaminants in Gore Creek.

In addition to relative abundance, analysis of total abundance within the macroinvertebrate groups can be useful for evaluating stream conditions and estimating secondary production (macroinvertebrates are the primary food source for fish). Figure 27B shows the total abundance (organisms per square meter) of macroinvertebrate groups at the Gore Creek sites. The error bars overlain on the graphs represent the standard error of the mean of the total abundance for the six sites where triplicate samples were collected for quality-assurance purposes. The abundance of macroinvertebrates at sites 1, 5, 6, 8, 12, 14, and 16 is variable, ranging from 117 to 1,415 organisms per square meter. Abundance at site 5 was less than 10 percent of the abundance at adjacent sites 1 and 6. Habitat scores, field properties, and streamflow were similar for the three sites. The lower abundance at site 5 may be related more to physical factors (sediment deposition) than to chemical factors. Site 5 is downstream from Black Gore Creek, which receives large volumes of sediment from Interstate 70 and where similarly low abundance levels were measured at site 38. Embeddedness at site 5 was rated as optimal; however, more sand was observed in the interstitial spaces of the cobble stream bottom than at sites 1 and 6. Large increases in abundance were recorded at sites 18, 26, and 29, which are downstream from the wastewater-treatment plant outfall and most of the urban areas in the watershed. Most of this increase is attributable to large numbers of pollution-tolerant midges. Wuerthele (1976) also reported increased abundances of midges downstream from the wastewater-treatment plant and categorized the quality of the macroinvertebrate community as reduced because of organic enrichment. Wuerthele made this determination by comparing equitability, a calculated metric related to Shannon-Weaver diversity that is more sensitive to slight to moderate levels of water-quality degradation (Weber, 1973; Wuerthele, 1976). Equitability values above 0.6 indicate unpolluted streams, and values below 0.5 indicate some water-quality degradation effects on the macroinvertebrate community. In 1975, equitability values at three sites upstream from the wastewater-treatment plant were 0.79–0.87, while values at three sites downstream from the wastewater-treatment plant were 0.33–0.45. The data collected in 1997 show similar results with equitability values

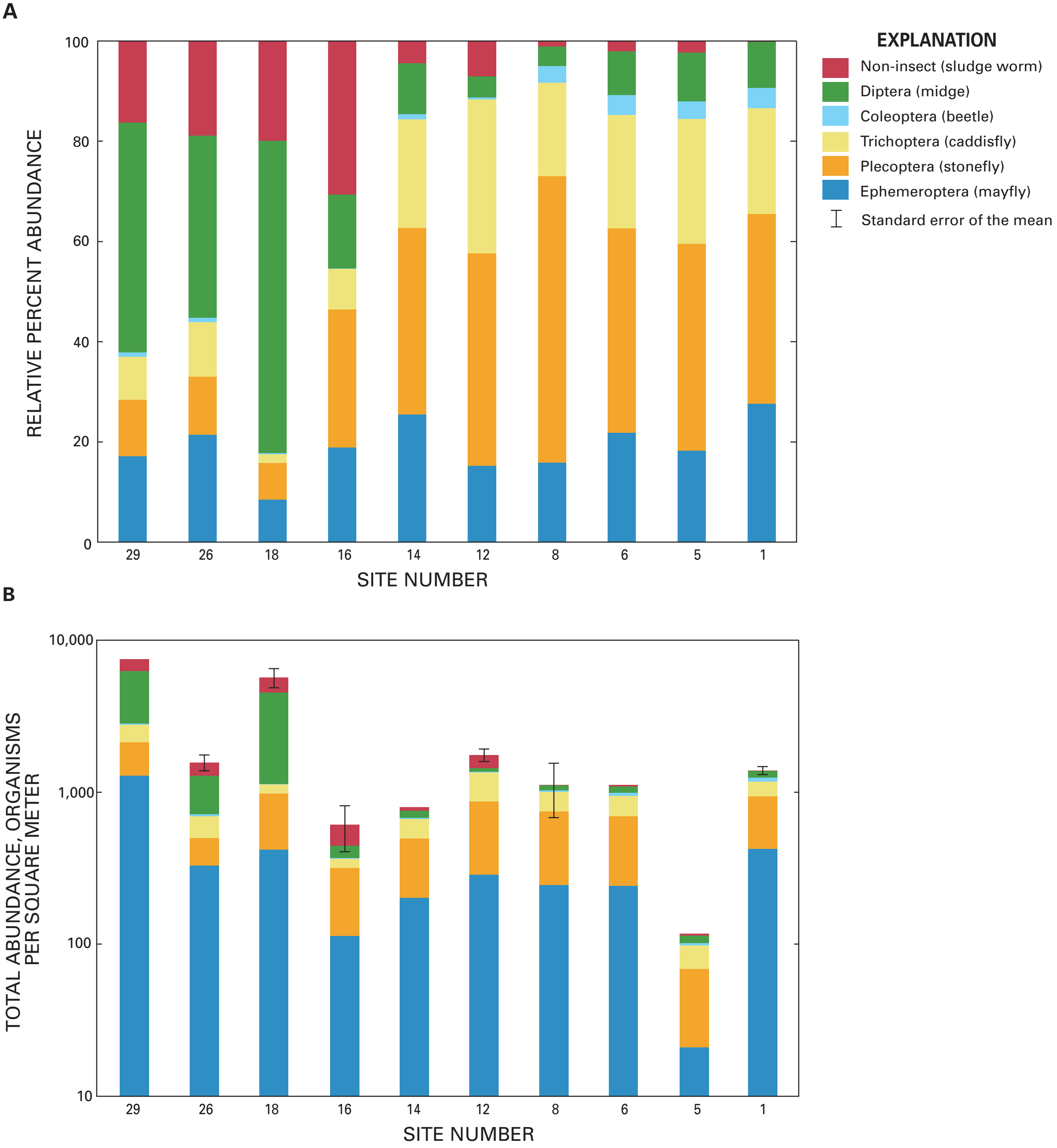


Figure 27. Relative (A) and total (B) abundance of the major macroinvertebrate groups at sampling sites on the main stem of Gore Creek.

Gore Creek near the golf course (site 12). Photograph by Ken Neubecker.

ranging from 0.68 to 0.93 at sites 1–16 and 0.29 to 0.60 at sites 18–29, indicating that, based on equitability, water-quality conditions may not have changed much since 1975.

Functional feeding groups. The dominant feeding mechanisms for macroinvertebrates at a site can be an indication of the water quality as it relates to available food resources such as coarse (CPOM) or fine (FPOM) particulate organic matter or algae (Cummins and Klug, 1979). Analysis of the relative abundance of the different functional feeding groups at sites can be an indirect measure of underlying water-quality factors such as organic or nutrient enrichment. For example, a site dominated by predator organisms that survive by consuming other macroinvertebrates can indicate water quality that supports an abundance of prey organisms. At these sites, the predators may outcompete the filter-feeding groups, which must acquire food by filtering FPOM from the water column. The dominant functional-feeding mechanism for caddisflies clearly changes from predators at upstream sites 1–12 to collector-filterers at downstream sites 16–29 (fig. 28). This change from predators to collector-filterers could reflect an increase in suspended organic material from point and nonpoint sources as Gore Creek flows through urban areas. Stream velocity alone can cause changes in caddisfly community structure (Gallep, 1977). However, stream velocities at the sampling sites ranged from about 1 to 2.5 ft/s, well within the upper and lower velocity limits cited by Gallep (1977). The observed upstream to downstream changes in the caddisfly community from predators to collector-filterers probably are caused by increases in organic food sources suspended in the water column.

Non-insects such as sludge worms are abundant in streams affected by industrial contamination or organic enrichment (Goodnight, 1973; Brinkhurst and Gelder, 1991; Johnson and others, 1993). The relative abundance of sludge worms increases from less than 10 percent at sites 1–14 to about 30 percent of the macroinvertebrate community at site 16 and remains elevated at sites 18–29 (fig. 27A). In reference to the level of organic enrichment, the water-quality conditions, with sludge worms ranging from 20 to 25 percent, are still considered favorable at sites 18–29 according to Goodnight (1973). However, the increase in abundance of sludge worms at site 16 is unexpected because the suspected source of organic enrichment (the wastewater-treatment plant outfall) is located about 600 ft downstream from the site. There is clearly a response in the aquatic community to organic enrichment upstream from the wastewater-treatment plant, suggesting a point or nonpoint source of organic material upstream from site 16. Potential sources could include leaking sewer lines, abandoned septic systems, or runoff from urban land-use areas. A study in 1966 (Federal Water Pollution Control Administration, 1968) determined that sludge worms composed less than 1 percent of the macroinvertebrate community near site 26; however, a 1977 study indicated that

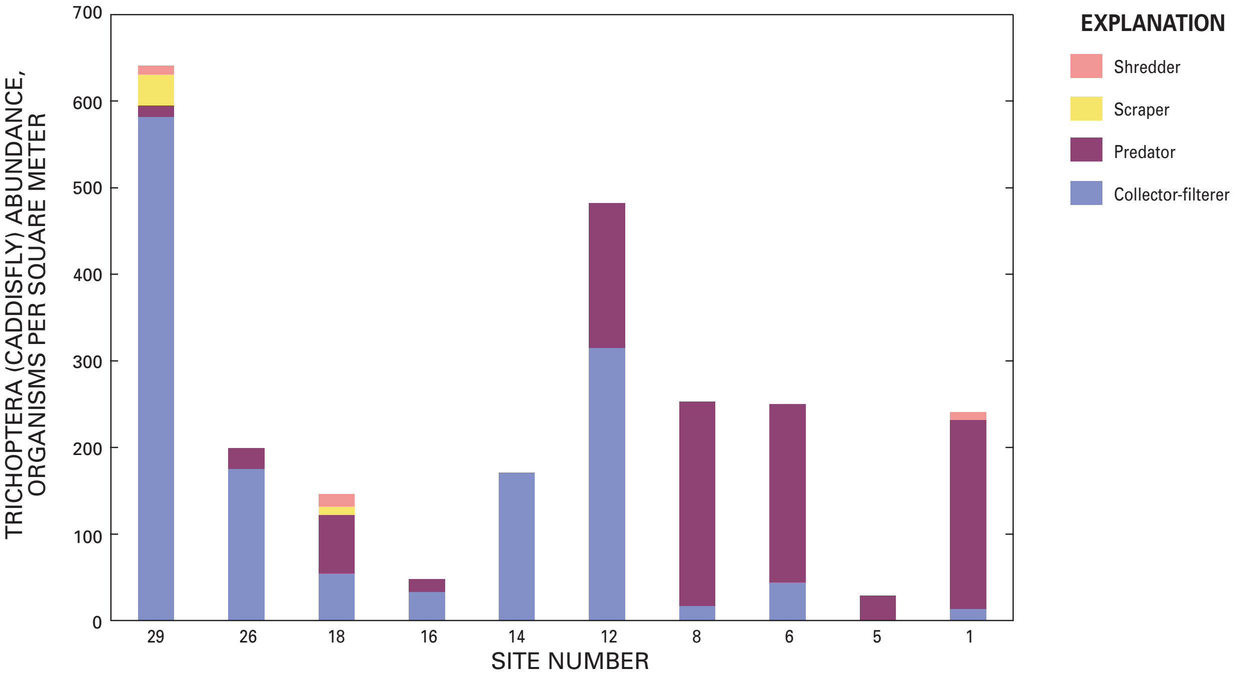


Figure 28. Abundance of Trichoptera individuals, by functional feeding mechanism.

the abundance of the sludge worms had increased to about 11 percent (Four Corners Environmental Research Institute, 1976).

Collector-filterers and collector-gatherers such as pollution-tolerant midges commonly are abundant at sites affected by moderate levels of organic enrichment (Cairns and Dickson, 1971; Johnson and others, 1993). The percentage of collector-gatherers such as midges (and other Diptera) ranged from 37 to 62 percent at sites 18–29 and was largest at site 18 downstream from the wastewater-treatment plant outfall (fig. 27A). Midges accounted for about 85 percent of the dipterans at sites 18 and 29 and about 60 percent at site 26, indicating a response by the macroinvertebrate community to organic material discharged to Gore Creek from the wastewater-treatment plant. The shift to midge dominance also may be related to changes in physical habitat associated with increases in algal biomass (Hynes, 1964; Cairns and Dickson, 1971). This relation between midge dominance and algal biomass also is supported by figure 26. As compared with site 18, the macroinvertebrate community at sites 26 and 29 contained decreased relative percentages of midges with similar increases in mayflies, stoneflies, and caddisflies (individuals less tolerant to organic enrichment), indicating some improvement in stream conditions from site 18 to site 29.

Black Gore Creek

The transport of sediment from the Interstate 70 roadway to Black Gore Creek has long been considered a primary water-quality and ecological concern for Black Gore Creek and, to a lesser extent, Gore Creek (Wuerthele, 1976; Resource Consultants Inc., 1986; Britton, 1979; Weaver and Jones, 1995). Lorch (1998) estimated that approximately 4,000 tons of coarse sand to fine-gravel-sized sediment is transported annually into Black Gore Creek. Lorch indicated that the aquatic habitat is persistently degraded in Black Gore Creek when compared to reference sites in Gore and Polk Creeks. Finer grained substrate, one-third fewer pools, and much shallower pools were caused by infilling of the stream channel by sand in Black Gore Creek (Lorch, 1998). Peak runoff during spring snowmelt delivers much of the sediment to Black Gore Creek. However, greater adverse effects to habitat may occur during early fall (September–October) when snowstorms that require traction sanding of Interstate 70 are followed by periods of warmer weather. During these periods, snowmelt generates sufficient runoff to deliver sediment to the stream but not enough velocity to flush the sediment from the pools. This results in accumulation of sediment in pools that could serve as brown trout spawning habitat and adversely affects the available over-wintering habitat for fish and macroinvertebrates (Lorch, 1998).

Abundance. The 1997 macroinvertebrate study partially supports Lorch's findings. The relative abundance of the major macroinvertebrate groups at site 36 on Polk Creek and sites 33, 34, 37, and 38 on Black Gore Creek are shown in figure 29A, and the total abundance (organisms per square meter) is shown in figure 29B. Site 36, the reference site on Polk Creek, is diverse and abundant with more than 90 percent of the community composed of relatively less tolerant mayfly, stonefly, caddisfly, and beetle taxa. Site 33 also contains abundant organisms but includes about 20 percent of the more tolerant midges. Site 33 is downstream from Black Lake and several beaver ponds (a potential nutrient source) and contained abundant growths of filamentous algae (a preferred midge habitat) (Hynes, 1964). Therefore, a relative increase in midge abundance was not unexpected. The abundance of macroinvertebrates at sites 34 and 38 was much less than the abundance at site 37 (fig. 29B). The difference in abundance may be related to habitat and available food sources. Greater amounts of sediment were observed at sites 34 and 38 than at site 37. Also, site 37 had accumulated leaf packs (a food source), which can have a large positive effect on the abundance of macroinvertebrate shredders and collector-gatherers (Ward, 1992).

Recent algae and macroinvertebrate data were limited to a single set of samples collected at sites in September 1997. Patterns attributable to specific water-quality and land-use factors were observed in the community structures for these data. However, the available data represent only a relatively short period of time and do not reveal temporal variations that may exist between seasons or from one year to the next. A more comprehensive assessment of macroinvertebrate and algal communities may have been possible if additional data were available for more than a single year and season. Future macroinvertebrate and algae sampling programs in the Gore Creek watershed should incorporate spring and fall data collection into the sampling strategy. In particular, collection of additional data immediately before spring snowmelt, in April, may provide valuable information on the condition of the aquatic community at a time when streamflows are at annual lows and the winter recreational season is just past its peak.

Fish

A fish community is an assemblage of fish that share the same area of a stream and interact with each other. The structure of a fish community is determined by the species present, their relative abundances, their life stages and size distributions, and their distributions in space and time (Meador and others, 1993). Natural variability in fish communities can be attributed to differences in elevation, water temperature, water chemistry, and physical habitat. The abundance and species composition of fish communities can be influenced by water quality and habitat modified by surrounding land use (Deacon and Mize, 1997).

Each fish is measured and weighed during an assessment of the fish community at the mouth of Gore Creek. Photograph by David Manzella.

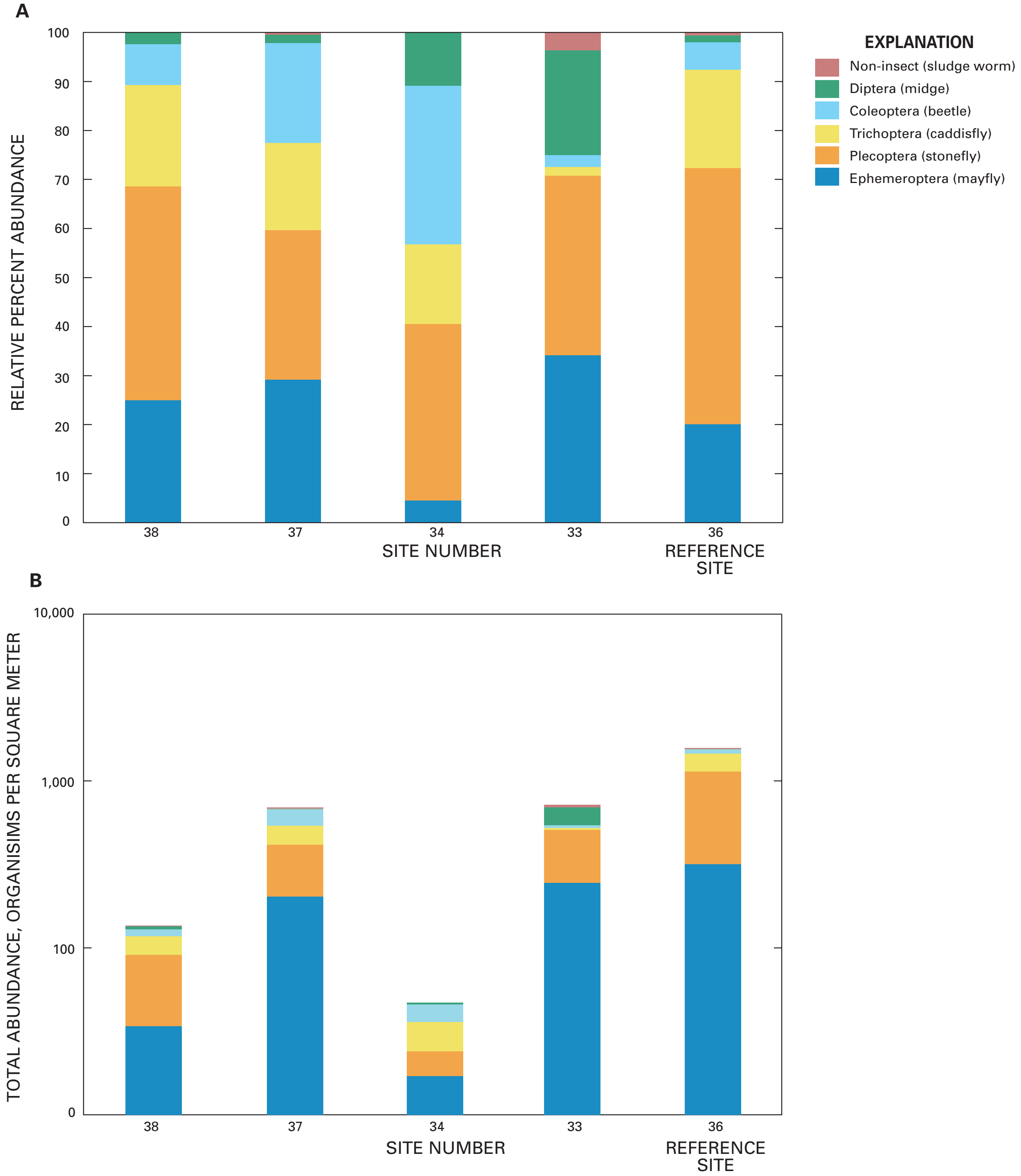


Figure 29. Relative (A) and total (B) abundance of the major macroinvertebrate groups in Black Gore and Polk Creeks.

The lower 4 miles of Gore Creek, downstream from Red Sandstone Creek, have been designated a Gold Medal trout fishery by the Colorado Division of Wildlife, in recognition of the high recreational value of the brown-trout community in that stream reach (Weaver and Jones, 1995). As part of an ongoing water-quality and aquatic-ecology study by the USGS, the fish community was assessed at site 29, at the mouth of Gore Creek, during August for three consecutive years (1996–98). Results of these assessments are compared to fish-community data collected in August 1996 and 1997 at a reference site in the Colorado River at Rocky Mountain National Park (RMNP) (fig. 30). Both sites have optimal habitat when assessed using the RBP qualitative habitat protocol (Plafkin and others, 1989); however, the habitat in Gore Creek received a slightly lower rating than the RMNP reference site because of ongoing sedimentation and lower quality riparian-zone vegetation. Neither site has been part of a fish-stocking program in recent years. The area upstream from the RMNP site does not have urban, transportation, or recreational land uses that affect water quality, and the water is somewhat more dilute, with lower dissolved-solids and suspended-sediment concentrations (Deacon and Mize, 1997). The trout portion of the fish community at Gore Creek was twice as abundant in 1996 and 1997 as the RMNP reference site. Large numbers of brown trout and mottled sculpin that are indicative of high-quality fisheries in the Southern Rocky Mountains ecoregion were present at both sites. In Gore Creek, mottled sculpin abundance for 1998 was nearly double the abundance for 1996 and 1997. This increase may be more a factor of sampling efficiency than an indication of a change in community structure. Water clarity was noticeably better in 1998 as compared to 1996 and 1997, and mottled sculpin capture rates improved (J.R. Deacon, U.S. Geological Survey, oral commun., 1998).

RELATIONS AMONG WATER QUALITY, AQUATIC ECOLOGY, AND BED-SEDIMENT AND TISSUE CHEMISTRY

Analysis of water quality and aquatic ecology in the Gore Creek watershed is enhanced by integrating interpretive results for various indicators of stream quality such as water, sediment, and tissue chemistry, algal-, macroinvertebrate-, and fish-community structure, and stream-habitat conditions to develop a more holistic understanding of environmental conditions and responses. Because these indicators are interdependent, an integrated approach can use multiple

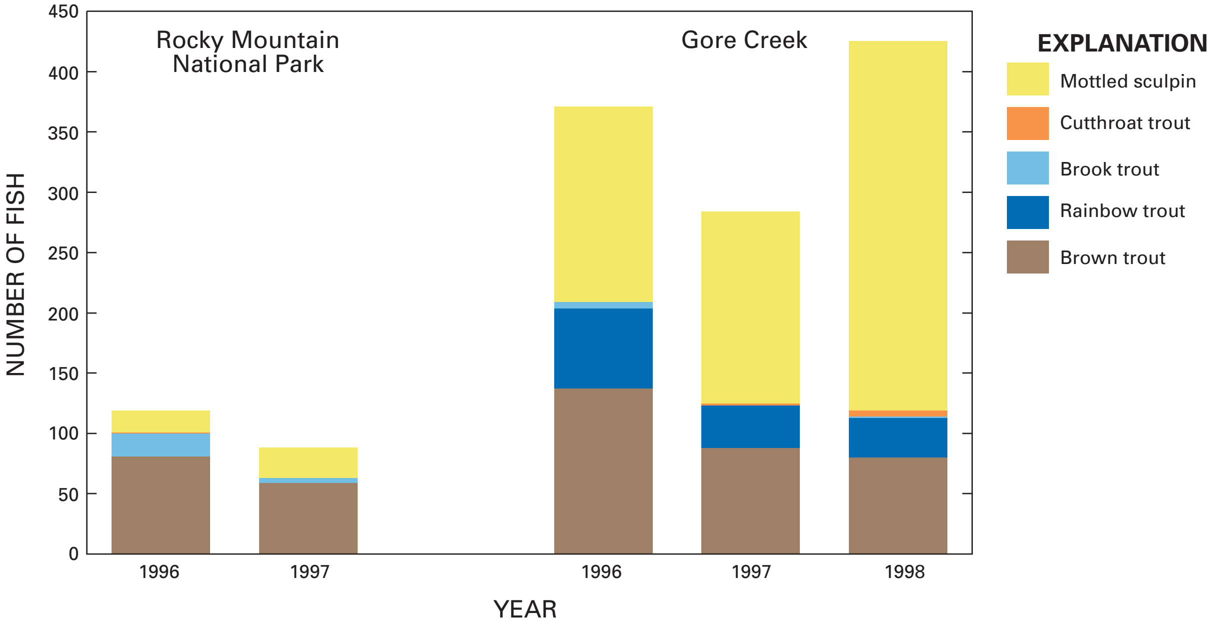


Figure 30. Comparison of fish-community structure at the mouth of Gore Creek with a reference site in Rocky Mountain National Park.

lines of evidence to develop hypotheses and support conclusions about effects of land use on the quality of aquatic resources. For example, algae are the primary producers in Gore Creek, providing the primary food sources to support higher trophic levels such as macroinvertebrates and fish. Algae are dependent on adequate available resources (nutrients and sunlight) to reproduce and grow. Many types of macroinvertebrates depend on benthic algae as a microhabitat, food source, or both. The abundance of algae-dependent macroinvertebrates (algivores) may increase or decrease, depending on the abundance of their microhabitat and food resources. In other cases, macroinvertebrates feeding on algae can control the amount of algae at a site (Deacon and Spahr, 1998; Gallep, 1977). Because the fish in Gore Creek are insectivores, their abundance and growth rates are tied to the abundance and composition of the macroinvertebrate community.

Water, sediment, and tissue-chemistry and biological-community data each represent stream conditions at differing time scales. Water samples represent water quality at the time of sample collection, whereas algae integrate water-quality conditions over several days to weeks depending on hydrologic conditions (Porter and others, 1993). Macroinvertebrate data integrate chemical and habitat conditions over a span of many weeks to a year, while fish data can indicate stream conditions over several years (Cuffney and others, 1993). Because of these varying time scales, it is important to consider interpretive results for these water-quality indicators within the context of spatial and temporal scales of condition and response.

The spatial distribution of nitrate concentrations is consistent with the observed spatial patterns in algal biomass and macroinvertebrate-community structure. Nitrate concentrations gradually increased from the headwaters through the Town of Vail to the wastewater-treatment plant, with a large increase immediately downstream from the wastewater-treatment plant, followed by a large decrease at sites farther downstream to the mouth of Gore Creek (fig. 17A). Algal biomass followed a similar pattern of moderate increases from the headwaters to the middle reaches of Gore Creek, then larger increases below the wastewater-treatment plant, followed by subsequent decreases in the downstream reaches (fig. 26). The increased abundance in the macroinvertebrate community in the downstream reaches of Gore Creek (fig. 27B) is most likely attributable to similar increases in nutrients, algal biomass, and organic enrichment. Figure 31 shows the somewhat parallel changes in relative abundance of algivores and algal biomass (chlorophyll-*a*). Under certain conditions, algivores may be reducing the amount of algae at a

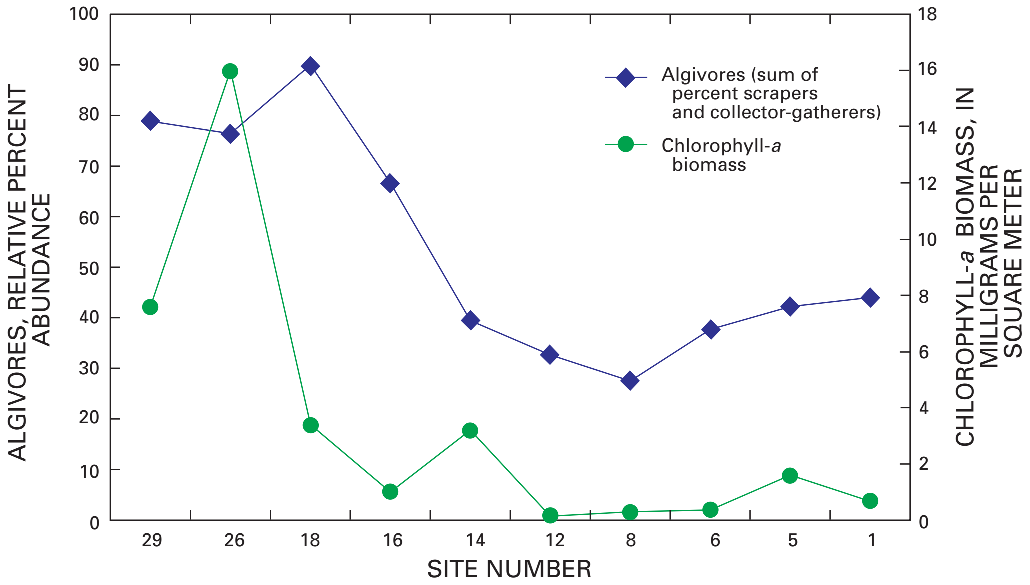


Figure 31. Comparison of chlorophyll-*a* biomass with relative percent algivores at sampling sites on the main stem of Gore Creek.

site. For example, both chlorophyll-*a* and percentage of algivores increased from site 8 to site 14 as Gore Creek flows through the golf course and urban land-use areas. In this segment of Gore Creek, algal biomass was probably resource controlled (controlled more by growth factors such as available sunlight and nutrients than by algivores). Algal biomass at sites 16–29 was more likely controlled by algivore grazing than by the availability of resources. There was a large increase in the percentage of algivores at sites 16 and 18 but little increase in algal biomass, despite relative increases in nutrient concentrations. At site 26, the percentage of algivores decreased and the algal biomass increased, suggesting reduced grazing pressure on benthic-algal biomass. At site 29, the percentage of algivores was about the same as at site 26, but algal biomass was reduced by one-half. The decrease in algal biomass may be related to two competing factors: (1) decreased availability of nutrients as indicated by water chemistry (fig. 17A) and increased nitrogen-autotroph biovolume (fig. 25B) and (2) increases in the total numbers of macroinvertebrates (fig. 27B), including algivores (fig. 31).

The fish community, in terms of abundance, probably benefits from the current (1998) level of available nutrients. The fish community at the mouth of Gore Creek is very productive, particularly when compared to a reference site with similar habitat characteristics but much lower levels of available resources. The amount of algae increased downstream in Gore Creek in response to increased nutrient availability. This increase in algae provides considerable food resources to support large increases in the macroinvertebrate community, thereby providing ample food resources (aquatic insects) that are necessary to support a productive trout fishery.

Recent data indicate concentrations of many trace elements are low in the Gore Creek watershed. Cadmium, copper, zinc, and silver concentrations were detected at low concentrations in streambed-sediment and surface- and ground-water samples. However, elevated levels of silver in brown-trout fish-liver and caddisfly samples require further investigation to understand sources and fate of silver in the Gore Creek watershed. Further comprehensive assessment of silver or other trace elements in the watershed should consider including analyses of biological tissue. Iron and manganese concentrations were one to two orders of magnitude higher in ground-water samples than in stream samples, which supports the hypothesis that the history of elevated manganese concentrations in the Gore Creek watershed is attributable mostly to sedimentary bedrock mineralogy in the southern and western parts of the watershed (Steele and others, 1991).

Surface-water, ground-water, bed-sediment, and fish-tissue analytical results indicate few detections and low concentrations of pesticides in the Gore Creek watershed. DDE, an environmentally persistent organochlorine insecticide, was detected at low levels in a bed-sediment sample from the Vail golf course, in fish tissue, and in a water sample from Gore Creek. Since 1996, several other pesticides and VOCs have been detected at low concentrations in water samples from Gore Creek and alluvial monitoring wells.

SUMMARY

Data were compiled from local, State, and Federal sources to assess the historical and current (1998) water-quantity, water-quality, and aquatic-ecology conditions in the Gore Creek watershed. Most of the data and information were available from: (1) the U.S. Geological Survey, (2) the Colorado Department of Public Health and Environment, Water Quality Control Division, and (3) the Eagle River Water and Sanitation District. Streamflow data have been collected at surface-water sites since 1946. Surface-water-quality and aquatic-ecology data have been collected at 66 sites from 1968 to present. Ground-water-quality data were more limited, with data available for six sites. Ground-water samples were collected at one site in 1988–89 and six sites in 1997.

Located in the Southern Rocky Mountains physiographic province, the Gore Creek watershed is a narrow valley surrounded by high mountains and drains an area of about 102 square miles. Land-surface elevation in the watershed ranges from about 7,700 ft in the valley to about 13,200 ft near the Gore Range. Precipitation within watershed ranges between 20 and 30 in/yr in the lower valleys to between 40 and 50 in/yr in the higher peaks of the watershed. Geology in the headwaters of Gore Creek predominantly consists of Precambrian-age igneous rocks, whereas the southern and western parts of the watershed are primarily sedimentary rocks of pre-Pennsylvanian Paleozoic, Pennsylvanian, and Permian age. Most of the low-lying areas along Gore Creek are overlain with Quaternary-age alluvial deposits. Land cover in the watershed is primarily forested, with about 8 percent of the land area classified as urban or recreation. Most urban development is confined to a narrow corridor along Gore Creek. Population increased about 20 percent, to 4,454 people between 1990 and 1997. This population density does not account for the substantial numbers tourists that add significantly to the population, primarily during summer and winter.

Surface-water-quality property and constituent data were available for field properties, major ions, trace elements, nutrients, suspended sediment, bedload, organic carbon, pesticides, and volatile organic compounds (VOCs). Sample media for surface-water chemical constituents were water, sediment, fish tissue, and macroinvertebrate tissue. Ground-water-quality property and constituent data were available for field properties, major ions, trace elements, nutrients, organic carbon, pesticides, VOCs, radon-222, bacteria, and chlorofluorocarbons (for age dating). Aquatic-ecology data were available for aquatic and riparian habitat, and algae, macroinvertebrate, and fish community.

Average annual precipitation of 34 inches in the Gore Creek watershed provides a water input of about 185,000 acre-ft/yr. Surface-water outflow averages about 55 percent of water inputs, and evapotranspiration accounts for the loss of about 40 percent of inputs. Consumptive water uses average about 9,300 acre-ft/yr, or 5 percent of water inputs. About 80 percent of annual streamflow is derived from snowmelt and occurs during May, June, and July. Annual variability of streamflow is low, with coefficient of variance ranging from 0.26 to 0.37 at Gore Creek and tributary gaging stations.

Trace-element concentrations in surface water generally were low in samples collected during 1995–97. Past exceedances of aquatic-life stream standards for trace elements such as cadmium, copper, iron, and manganese were attributed to soil disturbance and natural, geochemical properties of the Gore Creek watershed. Historically, manganese concentrations commonly were elevated, or in exceedance of stream standards in Black Gore Creek. Manganese concentrations in Black Gore Creek primarily were attributable to the sedimentary geology of the area and likely were exacerbated by land disturbance during construction of Interstate 70 during the early 1970's. Manganese concentrations were one to two orders of magnitude higher in samples from a ground-water monitoring well near Black Gore Creek than in stream samples, suggesting the source of manganese is natural and regulated more by physical conditions in the aquifer. Manganese concentrations in surface water appear to have declined from historical levels.

Concentrations of trace elements generally were low in streambed-sediment and tissue samples. In streambed-sediment samples, cadmium, copper, and zinc concentrations were below background levels reported for Upper Colorado River Basin in Colorado. Silver concentrations also were low in streambed-sediment samples. However, the concentration of silver was elevated in brown-trout fish-liver and caddisfly samples collected at the mouth of Gore Creek when compared to samples collected from sites representing mining and other land uses in Colorado and the Nation.

Nutrient concentrations generally increased as water moved downstream through the Town of Vail; however, the concentrations at the mouth of Gore Creek were typical when compared to national data for urban/undeveloped sites. Nitrate concentrations in Gore Creek were highest just downstream from the wastewater-treatment plant, but concentrations decreased at sites farther downstream, probably because of dilution from tributary streams and nutrient uptake by benthic algae. Since the 1970's, ammonia concentrations have decreased and nitrate concentrations have increased in Gore Creek because of changes in wastewater-treatment methods. Recent ammonia concentrations at the mouth of Gore Creek were mostly below the 0.015-mg/L reporting limit. Orthophosphate concentrations were low at the mouth of Gore Creek and have remained relatively stable over time. Total phosphorus concentrations were significantly lower at the mouth of Gore Creek during 1995–97 when compared to concentrations from the 1974–79 and 1980–92 time periods. Part of the difference was probably caused by dilution from above-average streamflow observed during 1995–97. Recent total phosphorus concentrations are still somewhat elevated when compared with the U.S. Environmental Protection Agency (USEPA) recommended level of 0.10 mg/L for control of eutrophication in flowing water. However, total phosphorus concentrations at the mouth of Gore Creek were relatively low when compared to a national study of phosphorus in urban land-use areas. Analysis of nutrient conditions in the watershed was limited by high percentages of data that were censored at multiple reporting levels and by the lack of concurrent streamflow data. For some sites and nutrients, the reporting limit was so high that no data were reported above that level, thereby limiting the usefulness of the data for interpreting water-quality conditions and trends.

Surface-water quality in the Gore Creek watershed was good in relation to field properties. Dissolved-oxygen concentrations were high and water temperatures were low throughout the watershed. Specific-conductance values generally were higher in the downstream reaches of Gore Creek and in tributaries to Gore Creek that drain sedimentary rock formations. Rock salt and magnesium chloride applied to Interstate 70 are primary sources for some of the dissolved constituents affecting specific conductance in Black Gore and Gore Creeks. Specific-conductance values were relatively low in the watershed when compared to other sites in the Upper Colorado River Basin in Colorado, although values have increased over the 1978 to 1992 time period in areas affected by urban runoff.

Aggradation of sediment in stream channels, rather than suspended sediment currently is the primary sediment concern in the upstream reaches of the watershed. The median suspended-sediment concentration at the mouth of Gore Creek was only 4 mg/L for 71 samples collected since 1995. About 4,000 tons of coarse sand and fine gravel is washed into Black Gore Creek each year as a result of traction sanding on Interstate 70. More than 50 percent of this material is delivered to Black Gore Creek from only 20 percent of the drainage locations. During the months of September and October, snowstorms that require traction sanding on Interstate 70 were followed by periods of warmer weather. During these periods, snowmelt generates sufficient runoff to deliver sediment to the stream but not enough velocity to flush sediment from pools. This process has resulted in accumulation of sediment in streams reducing the available habitat for brown trout spawning as well as overwintering habitat for fish and macroinvertebrates.

Sample results indicated organic constituents were not a primary concern in the Gore Creek watershed. Median dissolved-organic-carbon concentrations in surface and ground water were 1.3 mg/L and 1.0 mg/L, respectively. Pesticides were occasionally detected in low concentrations in surface-water, ground-water, bed-sediment, and whole-body fish-tissue samples. VOCs also were detected at low concentrations in surface- and ground-water samples. The presence of pesticides and VOCs in ground-water samples indicates that alluvial ground-water resources may be susceptible to human sources of pollution.

An alluvial well field provides most of the municipal water supply for the Town of Vail. These wells were sampled for field properties and trace elements. Water from the wells was well oxygenated, suggesting hydraulic connection with Gore Creek. Copper, lead, mercury, and silver were detected at low concentrations in several samples.

Two samples, collected during spring and fall of 1997, from each of five alluvial monitoring wells located throughout the Town of Vail, provided the most comprehensive information about ground-water conditions. Specific-conductance values in the samples ranged from 265 to 557 µS/cm. Nitrite and total phosphorus were detected at low concentrations in only 1 of the 10 samples. Orthophosphate was detected in three samples, also at low concentrations. Nitrate concentrations ranged from less than detection to 2.82 mg/L, with concentrations typically higher in spring than fall. Dominant major ions were calcium and bicarbonate.

Concentrations of radon exceeded the 300-pCi/L USEPA proposed maximum contaminant level (which has been suspended pending further review) in all five monitoring wells and one of the municipal water-supply wells. Radon concentrations above 300 pCi/L are typical for the Southern Rocky Mountains physiographic province because of the presence of uranium-bearing minerals in Precambrian-age rocks.

Total coliforms were detected in one monitoring-well sample. The presence or absence of bacteria reflects the sanitary quality of water and the potential health risk from waterborne disease. The sample that contained total coliforms was tested for *E. coli* and none were found. Methylene blue active substances (MBAS) were detected at low levels at two sites. Low levels of bacteria and MBAS indicate that there is little or no wastewater contamination of alluvial ground water in the vicinity of the monitoring wells.

Chlorofluorocarbon sample results indicated that the age of the alluvial ground water in the Gore Creek watershed ranged from about 2 to about 50 years old. These dates indicate that changes in land-use activities may not affect ground-water quality for 2 to 50 years.

Since 1995, habitat, algal-, macroinvertebrate-, and fish-community data have been collected at sites in the Gore Creek watershed to assess the effects of urban development on aquatic life. Algal- and macroinvertebrate-community data, in addition to stream and riparian habitat data, were collected during September 1997 at 15 sites. These 15 sites were selected to evaluate differences in the aquatic community as Black Gore Creek flows from Vail Pass along Interstate 70, and as Gore Creek flows from its headwaters through urban and recreation land uses in the Town of Vail. Although efforts were made to select sites with similar habitat conditions, the Black Gore Creek sites generally received lower habitat scores because of higher levels of sedimentation and substrate embeddedness. Fish-community data were collected annually at the mouth of Gore Creek during August of 1995–97.

The benthic-algal community was dominated by diatoms at 9 of 10 sites in Gore Creek. The algal community was responsive to small changes in available inorganic nitrogen. Upstream sites containing relatively low nitrate concentrations contained comparatively less algae (nitrogen-autotroph diatom biovolume and chlorophyll-*a* biomass) than downstream sites where nitrate concentrations were relatively higher. Large increases in algal biovolume and biomass were measured at sites downstream from Red Sandstone Creek, where nitrate concentrations were much higher due to point and nonpoint sources. No significant differences were observed in algal biomass or community structure between sites located upstream and downstream from the Vail golf course.

Differences in macroinvertebrate-community structure were observed among sites in Gore Creek by evaluating changes in abundance and dominant functional feeding groups of the major macroinvertebrate groups among sites. Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), and Coleoptera (beetles) exhibited relatively low tolerance to water-quality degradation when compared with Diptera (midges) and non-insects (sludge worms). More than 80 percent of the macroinvertebrate community at six upstream sites was composed of mayflies, stoneflies, and caddisflies, indicating favorable water-quality and habitat conditions. There was a large increase in relative percentages of midges and sludge worms at four downstream sites on Gore Creek that represent relatively larger areas of urban and recreation land uses. The increased dominance of tolerant midges and sludge worms at those sites indicates the occurrence of nutrient and organic enrichment in Gore Creek. Part of the increase in midges was probably related to changes in physical habitat associated with increased algal biomass because benthic algae provide excellent habitat for midges. Large increases in macroinvertebrate abundance were observed at the three sites downstream from the wastewater-treatment plant outfall and a majority of the urban areas in the watershed. Most of this increase was attributable to large numbers of pollution-tolerant midges. The macroinvertebrate community at the two sites farthest downstream had reduced percentages of midges with similar increases in mayflies, stoneflies, and caddisflies, indicating some improvement in stream conditions near the mouth of Gore Creek. Sludge worms are abundant in streams affected by organic enrichment. Sludge worms accounted for less than 10 percent of the macroinvertebrate community at the six upstream sites and 20–25 percent of macroinvertebrates at four downstream sites. One of the downstream sites with a large abundance of sludge worms was located upstream from the wastewater-treatment plant outfall. Sources of organic enrichment at this site are unknown.

The macroinvertebrate community in Black Gore Creek showed signs of impairment by sediment. Macroinvertebrate abundance was reduced considerably at the two sites where streambed sediment was more evident; however, differences in abundance may have been related partially to differences in habitat and food resources.

Patterns attributable to specific water-quality and land-use factors were observed in algal- and macroinvertebrate-community structures. However, the available data collected in September 1997 only represent a relatively short period of time and do not indicate temporal variations that may exist between seasons or from one year to the next. A more comprehensive assessment of macroinvertebrate and algal communities would be possible if data were available for more than a single year and season.

The lower 4 miles of Gore Creek, downstream from Red Sandstone Creek, have been designated a Gold Medal fishery in recognition of the high recreational value of the productive brown trout community. In comparison to a reference site in Rocky Mountain National Park, Gore Creek contained twice as many fish, primarily brown trout, rainbow trout, and mottled sculpin. The enhanced productivity of the fishery in Gore Creek is attributable to the responses of the algal and macroinvertebrate communities to increased nutrient availability. Large increases in algal biomass in turn caused order-of-magnitude increases in the macroinvertebrate community, thereby providing ample food resources (macroinvertebrates) needed to support a productive trout fishery.

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