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EVALUATION OF WATER QUALITY AND BULK ATMOSPHERIC DEPOSITION IN THE GUANELLA PASS AREA, CLEAR CREEK AND PARK COUNTIES, COLORADO, WATER YEAR 1995

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 98–4193

Prepared in cooperation with the
FEDERAL HIGHWAY ADMINISTRATION and
CLEAR CREEK COUNTY

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Denver, Colorado
1999

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per square mile (acre-ft/mi^2)	0.000476	cubic hectometer per square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	centimeter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	megagram
ton per day (ton/d)	0.9072	megagram per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

ADDITIONAL ABBREVIATIONS

kg/d	kilogram per day
L/ft^3	liter per cubic foot
MCL	maximum contaminant level
mg	milligram
$(mg/d)/ft^2$	milligrams per day per square foot
mg/L	milligram per liter
mm	millimeter
NTU	nephelometric turbidity units
$organisms/m^2$	organisms per square meter
ROE	residue on evaporation
µg/L	microgram per liter
µm	micrometer
$\mu m^3/cm^2$	cubic micrometer per square centimeter
µS/cm	microsiemens per centimeter at 25 degrees Celsius

Evaluation of Water Quality and Bulk Atmospheric Deposition in the Guanella Pass Area, Clear Creek and Park Counties, Colorado, Water Year 1995

By Michael R. Stevens

Abstract

A study of water quality and bulk atmospheric deposition in the Guanella Pass area during water year 1995 (October 1994 to September 1995) has provided information to characterize conditions in the South Clear Creek and Geneva Creek Basins about 40 miles west of Denver, Colorado, prior to a possible road-reconstruction project.

Analytical results of water samples collected from streams, ground water, and lakes and reservoirs indicate that water in the study area generally contained small concentrations of dissolved solids (low-flow stream sample median, 43 milligrams per liter; ground-water median, 104 milligrams per liter) and suspended sediment (high-flow stream sample median, 115 milligrams per liter). Nutrient, trace-element, and organic-carbon concentrations also were small. Acidic pH and large trace-element concentrations were associated with areas affected by natural acid-sulfate weathering or mining. Increases in particulate nutrients, total recoverable trace elements, and suspended sediment were related to seasonal snowmelt and thunderstorms. Benthic macroinvertebrate and periphyton (algae) samples collected from selected sites in August 1995 indicated large variability in characteristics among sites. Macroinvertebrate density ranged from 6.5 to 1,300 organisms per square meter, and periphyton biovolume ranged from 0.023 to 4,700 × 10^6 cubic microns per square centimeter.

The discharge of road runoff from any single drainage feature (ditch or culvert) was small compared to streamflows. Analytical results from samples of road runoff indicated a large range in specific conductance, pH in a neutral range, large values of turbidity, and calcium bicarbonate type water. Sodium or magnesium and chloride, however, were predominant in some samples and were probably related to applications of sodium and magnesium chloride to the roads. Although dissolved nutrients and trace elements were detected in samples of road runoff, particulate forms had the largest concentrations. Suspended-sediment concentrations in road runoff were large, and the sediment was primarily fine grained.

Large concentrations of dissolved and total recoverable nutrients, total recoverable trace elements, total organic carbon, and suspended sediment in road runoff could cause increased concentrations in streams, lakes, and reservoirs. Ground-water concentrations of chloride, nitrite plus nitrate, and dissolved iron and manganese could increase if the large concentrations present in road runoff infiltrate shallow aquifers.

Bulk atmospheric deposition was collected at three sites with a paved road surface, five sites with a gravel or dirt surface, and five sites with collectors at least 500 feet away from a road. The median bulk-atmospheric-deposition rate for gravel (or dirt) roads was 106 times the median rate at a reference site (located at least 500 feet away from a road) and 39 times the median rate at

a typical paved road site. If a stream, lake, or reservoir is located near the road, bulk-atmospheric-deposition products may settle directly onto open water or be washed in by surface runoff.

Because the predominant road-runoff trace-element phase is particulate, potential toxic effects on receiving water may be minimal when compared to aquatic-life standards and regulations in the State of Colorado, which are primarily based on dissolved concentrations. U.S. Environmental Protection Agency primary maximum contaminant levels for drinking water were exceeded for dissolved uranium (proposed) in one ground-water sample.

INTRODUCTION

The Guanella Pass road between Georgetown and Grant, Colo. (fig. 1), which has been designated a scenic byway, is being considered for reconstruction. The mountainous area along the road is drained by South Clear Creek north of the pass and by Geneva Creek south of the pass (fig. 1). The areas drained by these two streams and their tributaries are an important natural area that is used for water supplies, recreation, and wildlife habitat.

The existing road is a result of construction during the 1950's and 1960's. The road consists of a series of paved and unpaved (dirt and gravel) sections, with road cuts and fills that were left to revegetate naturally. Alternatives considered for road reconstruction range from complete reconstruction and paving to leaving the road in the present form. The proposed road reconstruction could include new asphalt paving, retaining walls, changes in drainage features, and revegetated slopes. The reconstruction could affect the chemical quality and sediment loading of the adjacent streams. However, an erosion-resistant road surface, engineered drainage system, and revegetation efforts might reduce the long-term amount of eroded sediment in the streams.

The U.S. Geological Survey (USGS), in cooperation with the Federal Highway Administration (FHWA) and Clear Creek County, began a study in 1994 to characterize the water resources along the Guanella Pass road. Characterization of the existing hydrologic conditions was necessary to properly evaluate any effects of the road reconstruction, both during and after the reconstruction.

Purpose and Scope

The purpose of this report is to present an evaluation of water quality and bulk atmospheric deposition in the Guanella Pass area based on the data collected during the first year of a 3-year data-collection effort. The data used in this analysis were collected during water year (WY) 1995 (October 1994 through September 1995). Fifty-seven sites were established in the study area to obtain a variety of data to enable characterization of streams, lakes and reservoirs, ground water, and runoff and bulk atmospheric deposition related to the current road. Data were collected in the South Clear Creek and Geneva Creek Basins; a site in the West Chicago Creek Basin was added as an additional reference site. The location of the sites are shown in figures 1–3, and the site names and identification numbers are listed in table 1.

Continuous records of discharge, water temperature, and specific conductance were collected at 5 sites on perennial streams; seasonal samples for surface-water chemical quality were collected at 21 sites at high flow in June, and 23 sites at low flow in September; samples for road-runoff quality were collected at 11 sites during the snowmelt and rainstorm seasons; samples for ground-water quality were collected at 8 sites at springs and wells; late-summer samples that included chemical samples, field profiles of physical properties, and a bottom-sediment sample were collected at 4 lakes and reservoirs; samples of benthic macroinvertebrates and periphyton were collected at 11 sites; and bulk-atmospheric-deposition samples were collected at 10 sites.

The types of data collected in WY 1995 include field measurements (streamflow, water temperature, specific conductance, pH, turbidity, and dissolved oxygen); concentrations of major ions and dissolved solids (calcium, magnesium, sodium, potassium, hardness, sulfate, chloride, fluoride, silica, dissolved-solids residue, and alkalinity); nutrients (nitrogen and phosphorus compounds); trace elements (such as cadmium, copper, iron, lead, manganese, mercury, and zinc); organic carbon; and suspended sediment. These data and the methods of data collection are listed and described by Stevens and others (1997).

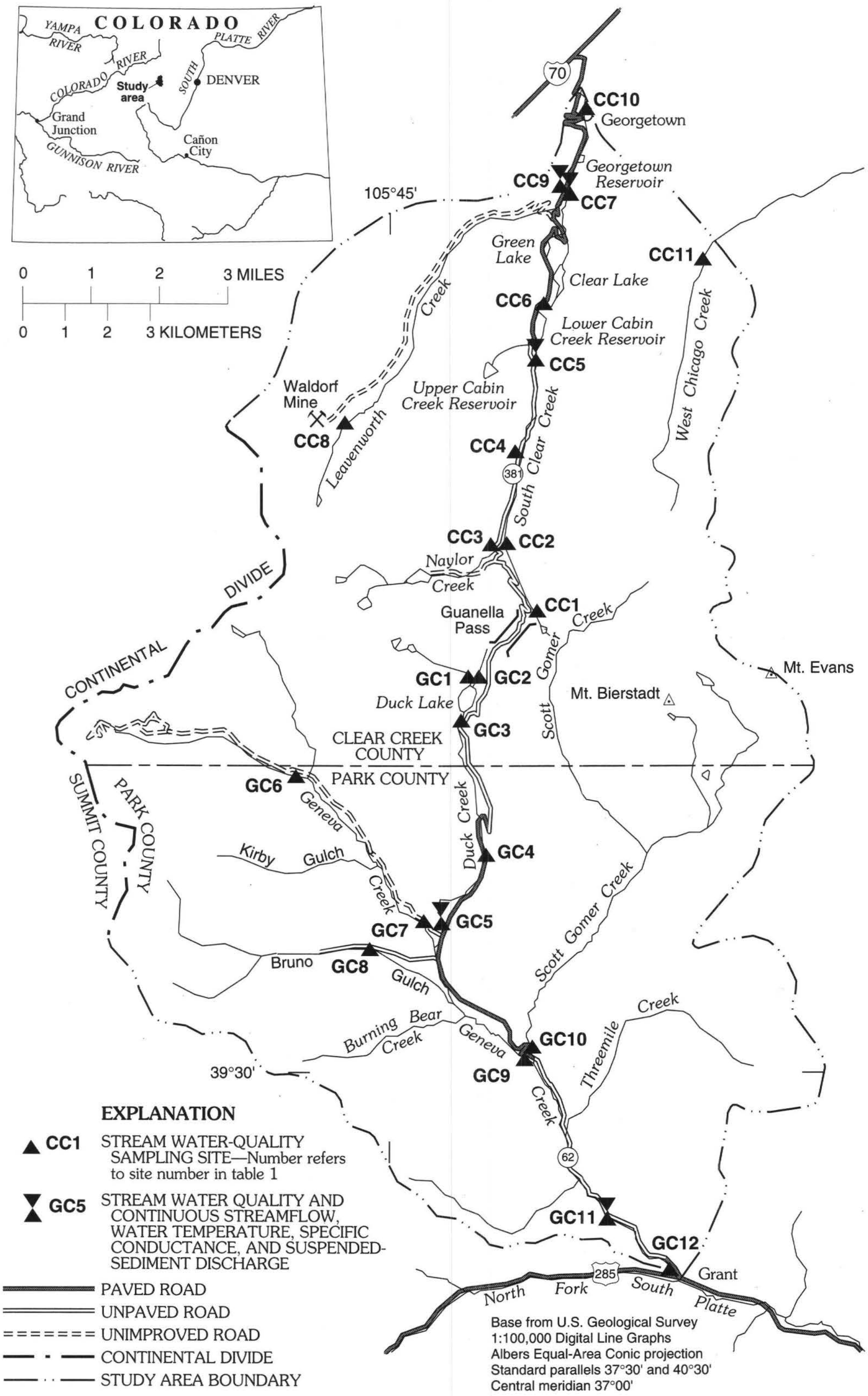
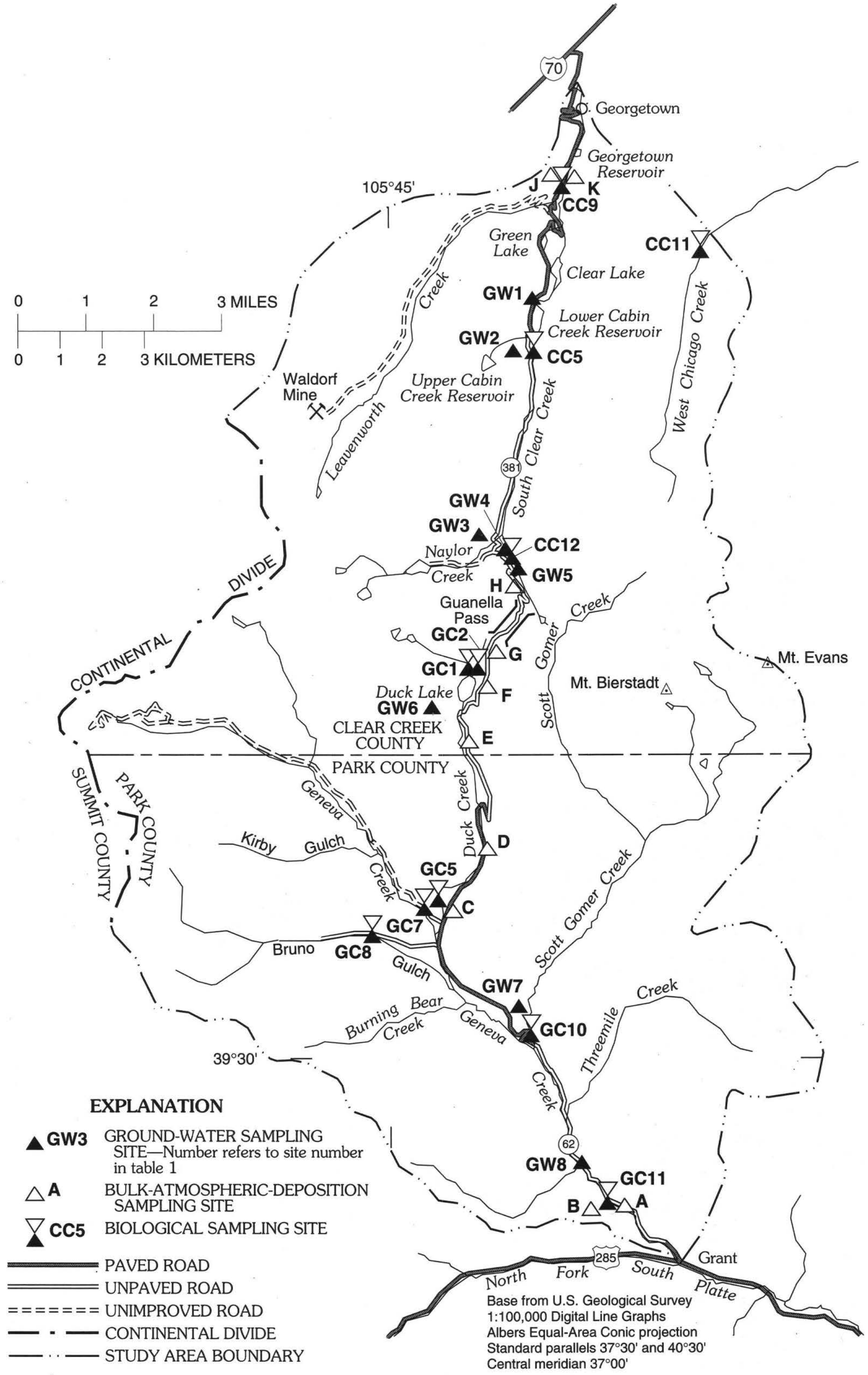


Figure 1. Location of study area, stream sampling sites, and continuous monitoring sites.



Base from U.S. Geological Survey
1:100,000 Digital Line Graphs
Albers Equal-Area Conic projection
Standard parallels 37°30' and 40°30'
Central meridian 37°00'

Figure 2. Location of ground-water, bulk-atmospheric-deposition, and biological sampling sites.

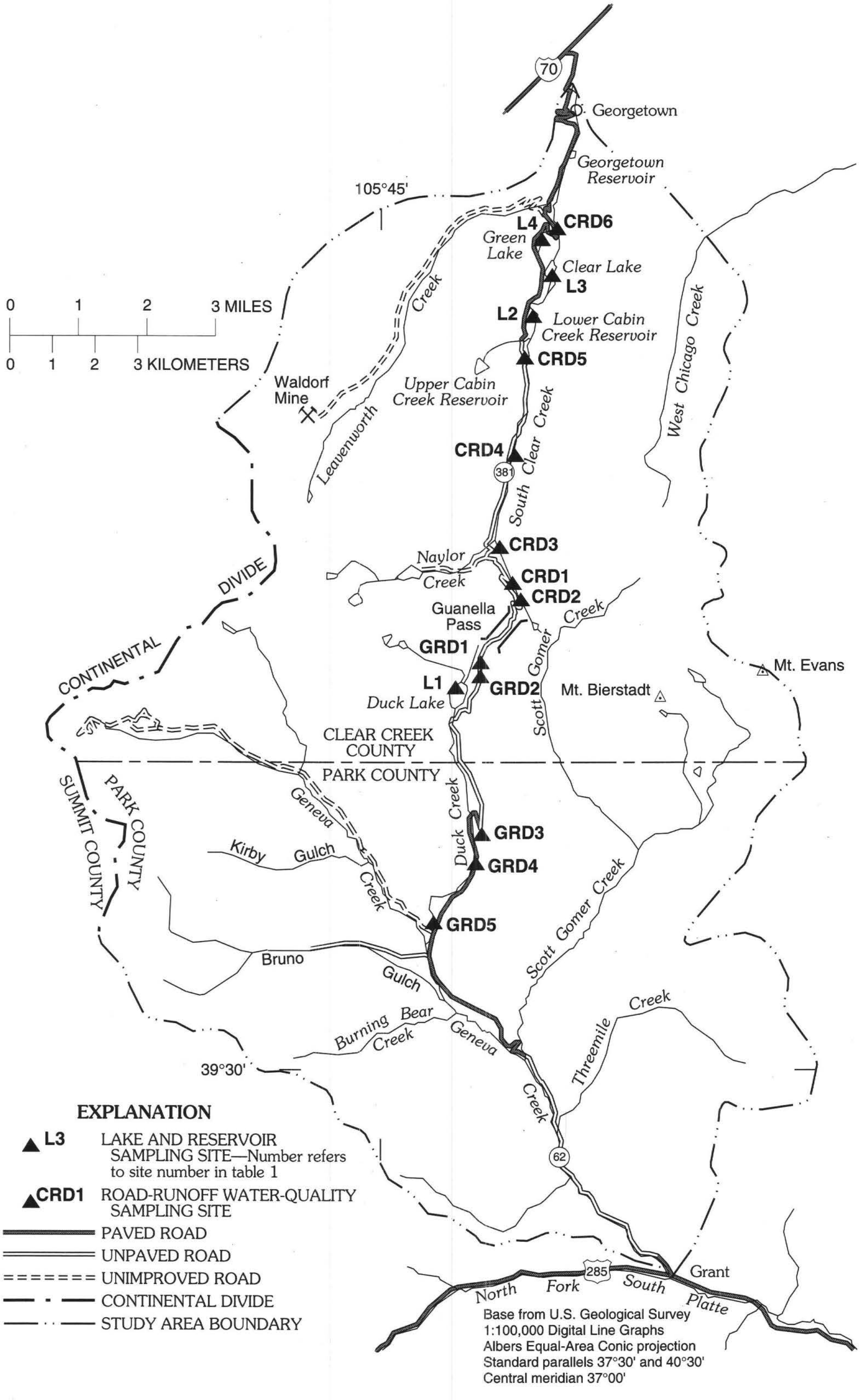


Figure 3. Location of lake, reservoir, and road-runoff sampling sites.

Table 1. Data-collection sites

Site number (figs. 1, 2, 3)	U.S. Geological Survey identification number	Site name
CC1	393606105422118	South Clear Creek near Guanella Pass
CC2	393647105425317	South Clear Creek above Naylor Creek near Georgetown
CC3	393642105430416	Naylor Creek at mouth near Georgetown
CC4	393804105423413	South Clear Creek below Naylor Creek near Georgetown
CC5	06714400	South Clear Creek above Lower Cabin Creek Reservoir near Georgetown
CC6	393946105422203	South Clear Creek above Clear Lake near Georgetown
CC7	06714600	South Clear Creek above Leavenworth Creek near Georgetown
CC8	393819105452801	Leavenworth Creek above Waldorf Mine near Georgetown
CC9	06714800	Leavenworth Creek at mouth near Georgetown
CC10	394211105414100	South Clear Creek at Georgetown
CC11	394027105393900	West Chicago Creek near Idaho Springs
CC12	393619105423700	South Clear Creek above Naylor Creek at upper station near Georgetown
GC1	393504105432312	Duck Creek above Duck Lake West Branch near Grant
GC2	393458105431511	Duck Creek above Duck Lake East Branch near Grant
GC3	393433105433210	Duck Creek below Duck Lake near Grant
GC4	393243105430814	Duck Creek above Mill Gulch near Grant
GC5	06704500	Duck Creek near Grant
GC6	393348105460415	Geneva Creek above Smelter Gulch near Grant
GC7	393153105440109	Geneva Creek above Duck Creek near Grant
GC8	393141105445808	Bruno Gulch above Geneva Park near Grant
GC9	393018105421707	Geneva Creek above Scott Gomer Creek near Grant
GC10	393028105421706	Scott Gomer Creek at mouth near Grant
GC11	06705500	Geneva Creek at Grant
GC12	392735105394705	Geneva Creek near Grant
GW1	393944105422500	Lower Cabin Creek Reservoir dam spring
GW2	393904105422800	Clear Lake Campground well
GW3	393644105430400	Guanella Pass Campground west well
GW4	393638105425900	Guanella Pass Campground east well
GW5	393620105423900	Guanella Pass spring #1
GW6	393439105434200	Duck Lake spring
GW7	393052105423300	Burning Bear Campground well
GW8	392853105405800	Whiteside Campground well
L1	393454105432900	Duck Lake near Grant
L2	393937105423900	Lower Cabin Creek Reservoir near Georgetown
L3	394011105425700	Clear Lake near Georgetown
L4	394032105421700	Green Lake near Georgetown
CRD1	393612105423800	Road ditch below Guanella Pass
CRD2	393602105423000	Road ditch near Guanella Pass
CRD3	393643105430200	Road ditch at Naylor Creek near Georgetown
CRD4	393643105425200	Road ditch above Lower Cabin Creek Reservoir near Georgetown
CRD5	393859105422700	Road ditch above Clear Lake Campground near Georgetown
CRD6	394036105415900	Road ditch below Green Lake near Georgetown
GRD1	393516105430700	Road ditch near Duck Lake near Grant
GRD2	393506105430600	Road ditch above Duck Lake near Grant

Table 1. Data-collection sites—Continued

Site number (figs. 1, 2, 3)	U.S. Geological Survey identification number	Site name
GRD3	393309105430200	Road ditch near Geneva Mountain near Grant
GRD4	393244105430800	Road ditch below Duck Lake
GRD5	393152105434700	Road ditch below Mill Gulch near Grant
A	392813105403200	Grant road site near Grant
B	392822105410600	Grant reference site near Grant
C	393152105434701	Road site below Mill Gulch near Grant
D	393300105431100	Road site above Mill Gulch near Grant
E	393413105432700	Geneva Basin Ski Area road site near Grant
F	393506105430601	Road site above Duck Lake near Grant
G	393516105430701	Road site near Duck Lake near Grant
H	393612105423801	Road site below Guanella Pass near Georgetown
J	394113105420000	Road site above Georgetown Reservoir near Georgetown
K	394116105414900	Clear Creek reference site near Georgetown

Description of Study Area

The Guanella Pass road, which is located approximately 40 mi west of Denver (fig. 1), connects Interstate 70 (I–70) at Georgetown with U.S. Highway 285 (U.S. 285) at Grant. The northern 13.1 mi is known as Clear Creek County Road 381 and the southern 10.4 mi is known as Park County Road 62 (Federal Highway Administration, 1993). The road ranges in altitude from about 8,600 ft at Georgetown and Grant to 11,699 ft at the top of the pass and consists of several paved and unpaved sections; the paved sections total 11.4 mi and the unpaved sections total 12.1 mi (Federal Highway Administration, 1993). The section of the road in Clear Creek County is maintained year-round, whereas the section in Park County is not maintained in winter, but seldom is impassable. During winter, salt (sodium chloride) and sand are applied to sections of the road in Clear Creek County; the county also has applied a magnesium chloride dust inhibitor to control seasonal dust on the road (Jim Cannedy, Clear Creek County, oral commun., 1997).

The study area (fig. 1) includes the watersheds of South Clear Creek, Geneva Creek, and part of West Chicago Creek. The Guanella Pass road parallels South Clear Creek from the northern terminus at Georgetown to the top of Guanella Pass; south of the pass, the road parallels Duck Creek to the confluence with Geneva Creek and then parallels Geneva Creek to the southern terminus at Grant. The Continental Divide forms the western boundary of the study area, and the eastern part of the study area includes the Mt. Evans and Mt. Bierstadt area, two peaks exceeding 14,000 ft in altitude.

Annual precipitation in the study area ranges from about 12 to 16 in. near Georgetown and Grant to about 40 to 50 in. in the higher mountains (Colorado Climate Center, 1984). Winter precipitation primarily is in the form of snow, which accumulates to form deep snowpacks. Most streamflow is derived from melting of the snowpacks during late spring and early summer. Short, locally intense, thunderstorms are common during summer, but produce little increase in streamflow. Distribution of vegetation is related to altitude and the precipitation pattern. Vegetation includes conifer and aspen forest at low altitudes and alpine tundra above timberline, which is about 11,500 ft.

Land use in the sparsely populated area is limited because of minimal private ownership and a harsh climate. The primary land use is recreation; most of the area is managed by the U.S. Department of Agriculture Forest Service. The Forest Service maintains five campgrounds in the area, two on the South Clear Creek side and three on the Geneva Creek side of Guanella Pass. Dispersed camping on the roadside is popular throughout the area. The eastern one-half of the study area includes part of the Mt. Evans Wilderness Area, which is closed to motor vehicles. Some livestock grazing occurs in the Geneva, Scott Gomer, and Duck Creek drainages. Although there was substantial logging in the area in the past (Nichols, 1992), there are no current (1995) logging operations. A few residences, some seasonal, are located at Duck and Naylor Lakes and along Duck, Geneva, and lower South Clear Creeks.

Ore deposits were mined near the headwaters of Geneva and Leavenworth Creeks. These areas were known as the Geneva Creek and Argentine Districts (Davis and Streufert, 1990). Naturally occurring pyritic components of the intrusive rocks and mineral deposits become oxidized and produce acidic ground water and surface water in the upper basin of Geneva Creek (Bassett and others, 1992) and Leavenworth Creek. Precambrian granite, gneiss, and schist compose the bedrock in the study area. Glaciers deposited drift in the valleys of Duck, Geneva, and South Clear Creeks (Tweto, 1979) and created many of the natural lakes in the area.

The Vidler Tunnel diverts water from upper Peru Creek, west of the Continental Divide, into the Leavenworth Creek Basin for downstream use. The Roberts Tunnel diverts water from Dillon Reservoir, also west of the divide, to the North Fork of the South Platte River near Grant. An aqueduct diverts water from Leavenworth Creek on a seasonal basis for maintaining the water level in Green Lake. Some of the natural lakes, such as Duck Lake, have been modified for storage by the construction of small dams. The Public Service Company of Colorado operates two reservoirs in the South Clear Creek Basin for a pumped-storage hydroelectric facility. Water is diverted from South Clear Creek at Georgetown Reservoir for drinking-water supplies and hydroelectric power generation in Georgetown.

Discharge and basin characteristics at the five streamflow-monitoring sites are listed in table 2. Annual runoff for WY 1995 ranged from 59,510 acre-ft at Geneva Creek at Grant (GC11) to 5,310 acre-ft at Duck Creek near Grant (GC5). Runoff generally is proportional to drainage area, although the runoff per square mile differs because of variations in precipitation with altitude. An example of a typical snowmelt-dominated streamflow hydrograph (Geneva Creek at Grant, GC11) is plotted in figure 4. The WY 1995 snowpack in the South Platte River Basin, which includes the study area, was larger than normal (Crowfoot and others, 1996), but because no long-term streamflow records are available in the study area, an evaluation of WY 1995 peak flow and water yield in a historical context is not possible. However, annual runoff at Clear Creek near Lawson, Colo., a streamflow-gaging station 6 mi downstream from Georgetown, was 51 percent above the 41-year average (1946–86) (Crowfoot and others, 1996).

Acknowledgments

The assistance of others in the completion of this study was invaluable. The author is grateful to Historic Georgetown, Inc.; Public Service Company of Colorado; William and Julia Holmes; Clear Creek and Park Counties; and the U.S. Department of Agriculture Forest Service for access to property. Many of the data-collection tasks were performed by Jennifer Cox, John Dick, David Johncox, Cristin Dyster, and other members of the USGS in Lakewood, Colo.

Table 2. Discharge and basin characteristics for gaging stations in the Guanella Pass study area, water year 1995

[--, not determined; ft, feet; mi^2, square miles; ft^3/s, cubic feet per second; acre-ft, acre-feet; acre-ft/mi^2, acre-feet per square mile]

Site number (fig. 1)	Altitude of station (ft)	Drainage area (mi^2)	Daily mean extreme flow (ft^3/s)		Instantaneous peak flow (ft^3/s)	Annual runoff (acre-ft)	Annual runoff (acre-ft/mi^2)
			Maximum	Minimum			
CC5	10,100	11.8	107	1.6	--	11,110	942
CC7	9,280	16.0	147	3.6	215	15,350	959
CC9	9,320	12.0	125	1.2	168	12,830	1,070
GC5	10,000	7.78	78	.46	97	5,310	683
GC11	8,760	74.6	746	7.4	1,070	59,510	798

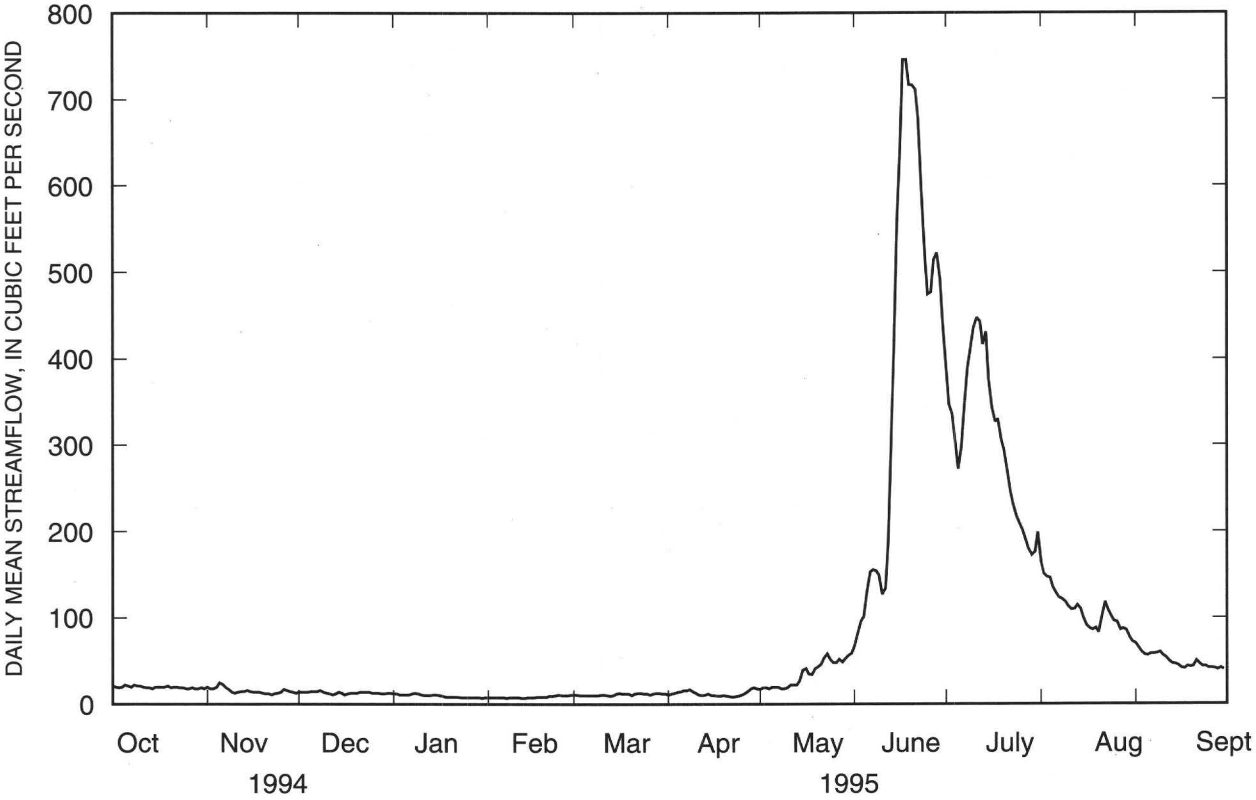


Figure 4. Streamflow hydrograph for Geneva Creek near Grant, Colorado, water year 1995.

WATER QUALITY

Statistical summaries for data collected at streams during high flow and low flow and at ground-water sites, lake/reservoir sites, and road-runoff sites for WY 1995 are the basis for the water-quality evaluation. Comparisons of chemical concentrations between possible receiving waters (such as streams, ground water, and lakes/reservoirs) and road runoff can indicate potential for alteration of receiving-water quality.

Streams

A high-flow sample was collected at 21 sites and a low-flow sample was collected at 23 sites to determine the variability and seasonal differences in water chemistry across the study area (fig. 1, table 1). Analytical results of these samples are presented by Stevens and others (1997). Statistical summaries for the high-flow samples and low-flow samples are listed in tables 3 and 4.

Field Parameters

Specific conductance ranged from 26 to 98 µS/cm at the high-flow sampling (table 3) and 35 to 210 µS/cm during the low-flow sampling (table 4). Specific conductance is directly proportional to the concentration of dissolved ionic substances in water. The distribution of specific-conductance values during the low-flow sampling, when flows are generally stable, is shown in figure 5. The smallest specific-conductance values (indicating small dissolved-solids concentrations), generally less than 60 µS/cm, were in Duck Creek and the most upstream site on South Clear Creek (CC1). The largest specific-conductance values, generally more than 100 µS/cm, were at sites in the upper Geneva Creek area and at South Clear Creek at Georgetown and are related to water affected by acidic weathering processes.

One trend indicated by the data in figure 5 is increasing specific conductance in a downstream direction along South Clear Creek. In the uppermost section of South Clear Creek, upstream from Naylor Creek, the stream specific conductance increases by

Table 3. Statistical summaries of water-quality properties and constituents for high-flow samples, June 1995

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephalometric turbidity units; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter; mm, millimeter]

Property or constituent	Sample size	Maximum	Minimum	Twenty-fifth percentile	Median	Seventy-fifth percentile
Discharge (ft^3/s)	21	542	0.9	19	51	69
Specific conductance (µS/cm)	21	98	26	37	55	64
pH (standard units)	19	8.0	5.0	7.1	7.4	7.8
Water temperature (°C)	21	11.5	.0	3.0	5.0	7.0
Turbidity (NTU)	20	94	2	8.8	22	67
Dissolved oxygen (mg/L)	18	11.3	6.7	8.4	8.8	9.4
Hardness (mg/L as $CaCO_3$)	21	42	9	15	21	25
Calcium, dissolved (mg/L as Ca)	21	11	2.6	3.9	5.5	6.5
Magnesium, dissolved (mg/L as Mg)	21	3.6	.65	1.2	1.8	2.3
Sodium, dissolved (mg/L as Na)	21	1.9	.7	1.0	1.1	1.5
Potassium, dissolved (mg/L as K)	21	1.4	.6	.9	1.0	1.1
Alkalinity, total laboratory (mg/L as $CaCO_3$)	20	40	4.6	9.9	16	22
Sulfate (mg/L as SO_4)	21	34	1.3	2.5	4.9	8.2
Chloride (mg/L as Cl)	21	2.5	.2	.6	.7	1.5
Fluoride, dissolved (mg/L as F)	21	.2	<.1	<.1	<.1	.1
Silica, dissolved (mg/L as SiO_2)	21	7.9	4.1	5.0	5.8	6.3
Dissolved solids, ROE at 180°C (mg/L)	21	60	25	34	42	48
Nitrogen, nitrite, dissolved (mg/L as N)	21	.01	<.01	<.01	<.01	<.01
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	21	.12	<.05	.05	.06	.08
Nitrogen, ammonia, dissolved (mg/L as N)	21	.03	.02	.02	.02	.03
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	21	.3	<.2	<.2	<.2	.2
Nitrogen, ammonia plus organic, total (mg/L as N)	21	1.2	<.2	<.2	<.2	.6
Phosphorus, total (mg/L as P)	21	.17	<.01	<.01	.02	.09
Phosphorus, dissolved (mg/L as P)	21	.04	<.01	<.01	<.01	<.01
Phosphorus, orthophosphate, dissolved (mg/L as P)	21	.02	<.01	<.01	<.01	<.01
Aluminum, total as Al (µg/L)	21	11,000	90	270	1,100	2,800
Aluminum, dissolved (µg/L as Al)	21	580	10	30	40	100
Antimony, dissolved (µg/L as Sb)	21	<1	<1	<1	<1	<1
Arsenic, total recoverable (µg/L as As)	21	<1	<1	<1	<1	<1
Barium, total recoverable (µg/L as Ba)	21	100	<100	<100	<100	<100
Barium, dissolved (µg/L as Ba)	21	33	16	18	27	29
Beryllium, total recoverable (µg/L as Be)	21	<10	<10	<10	<10	<10
Beryllium, dissolved (µg/L as Be)	21	<1	<1	<1	<1	<1
Cadmium, total recoverable (µg/L as Cd)	21	2	<1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	21	<1	<1	<1	<1	<1
Chromium, total recoverable (µg/L as Cr)	21	20	<1	1	3	6
Chromium, dissolved (µg/L as Cr)	21	2	<1	<1	<1	<1
Cobalt, total recoverable (µg/L as Co)	21	10	<1	<1	<1	2
Cobalt, dissolved (µg/L as Co)	21	<1	<1	<1	<1	<1
Copper, total recoverable (µg/L as Cu)	21	53	<1	1	2	14
Copper, dissolved (µg/L as Cu)	21	7	<1	<1	1	2
Iron, total recoverable (µg/L as Fe)	21	47,000	210	740	2,700	7,700
Iron, dissolved (µg/L as Fe)	21	480	40	83	180	230
Lead, total recoverable (µg/L as Pb)	21	55	<1	<1	2	7
Lead, dissolved (µg/L as Pb)	21	2	<1	<1	<1	<1
Manganese, total recoverable (µg/L as Mn)	21	900	<10	40	140	220

Table 3. Statistical summaries of water-quality properties and constituents for high-flow samples, June 1995—Continued

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephalometric turbidity units; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter; mm, millimeter]

Property or constituent	Sample size	Maximum	Minimum	Twenty-fifth percentile	Median	Seventy-fifth percentile
Manganese, dissolved as Mn (µg/L as Mn)	21	190	2	7	18	30
Mercury, total recoverable (µg/L as Hg)	21	.1	<.1	<.1	<.1	<.1
Molybdenum, total recoverable (µg/L as Mo)	21	2	<1	<1	<1	1
Molybdenum, dissolved (µg/L as Mo)	21	<1	<1	<1	<1	<1
Nickel, total recoverable (µg/L as Ni)	21	17	<1	<1	2	5
Nickel, dissolved (µg/L as Ni)	21	4	<1	<1	1	2
Selenium, total recoverable (µg/L) as Se)	21	<1	<1	<1	<1	<1
Silver, total recoverable (µg/L as Ag)	21	<1	<1	<1	<1	<1
Silver, dissolved (µg/L as Ag)	21	<1	<1	<1	<1	<1
Uranium, dissolved as U (µg/L)	21	<1	<1	<1	<1	<1
Zinc, total recoverable (µg/L as Zn)	21	430	<10	<10	<10	60
Zinc, dissolved (µg/L as Zn)	21	200	2	5	6	11
Carbon, organic, total (µg/L as C)	21	33	<.1	4.7	6.4	9.2
Carbon, organic, dissolved (µg/L as C)	0	--	--	--	--	--
Sediment, suspended (mg/L)	21	939	6	20	115	146
Sediment, percent finer than 0.062 mm	21	93	34	48	62	66

Table 4. Statistical summaries of water-quality properties and constituents for low-flow samples, September 1995

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephalometric turbidity units; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter; mm, millimeters]

Property or constituent	Sample size	Maximum	Minimum	Twenty-fifth percentile	Median	Seventy-fifth percentile
Discharge (ft^3/s)	23	66	0.44	3.6	10	17.5
Specific conductance (µS/cm)	23	210	35	45	63	82
pH (standard units)	22	7.9	3.8	7.4	7.6	7.7
Water temperature (°C)	23	12.5	7.0	8.5	10.0	11.5
Turbidity (NTU)	22	4.8	.3	1.0	1.7	2.6
Dissolved oxygen (mg/L)	23	10.5	7.0	7.6	8.2	8.6
Hardness (mg/L as $CaCO_3$)	23	47	12	18	25	32
Calcium, dissolved (mg/L as Ca)	23	12	3.4	4.9	6.5	8.2
Magnesium, dissolved (mg/L as Mg)	23	4.6	.9	1.3	2.1	2.6
Sodium, dissolved (mg/L as Na)	23	2	.9	1.3	1.4	1.7
Potassium, dissolved (mg/L as K)	23	1.2	.2	.6	.8	.9
Alkalinity, total laboratory (mg/L as $CaCO_3$)	23	43	<.1	14	19	26
Sulfate (mg/L as SO_4)	23	90	1.5	3.0	4.2	18
Chloride (mg/L as Cl)	23	1.6	.1	.3	.5	.7
Fluoride, dissolved (mg/L as F)	23	.4	<.1	.1	.2	.2
Silica, dissolved (mg/L as SiO_2)	23	13	4.1	6.0	7.7	9.0
Dissolved solids, ROE at 180°C (mg/L)	23	127	25	36	43	53
Nitrogen, nitrite, dissolved (mg/L as N)	23	.01	<.01	<.01	<.01	<.01
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	23	.13	<.05	<.05	.06	.08
Nitrogen, ammonia, dissolved (mg/L as N)	23	.02	<.015	<.015	<.015	<.015

Table 4. Statistical summaries of water-quality properties and constituents for low-flow samples, September 1995—Continued

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephalometric turbidity units; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter; mm, millimeters]

Property or constituent	Sample size	Maximum	Minimum	Twenty-fifth percentile	Median	Seventy-fifth percentile
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	23	0.2	<0.2	<0.2	<0.2	<0.2
Nitrogen, ammonia plus organic, total (mg/L as N)	23	<.2	<.2	<.2	<.2	<.2
Phosphorus, total (mg/L as P)	23	.04	<.01	<.01	.01	.01
Phosphorus, dissolved (mg/L as P)	23	.02	<.01	<.01	<.01	<.01
Phosphorus, orthophosphate, dissolved (mg/L as P)	23	<.01	<.01	<.01	<.01	<.01
Aluminum, total as Al (µg/L)	23	5,100	10	30	40	100
Aluminum, dissolved (µg/L as Al)	23	4,700	3	6	10	30
Antimony, dissolved (µg/L as Sb)	23	<1	<1	<1	<1	<1
Arsenic, total recoverable (µg/L as As)	23	<1	<1	<1	<1	<1
Barium, total recoverable (µg/L as Ba)	23	<100	<100	<100	<100	<100
Barium, dissolved (µg/L as Ba)	23	38	16	22	28	31
Beryllium, total recoverable (µg/L as Be)	23	<10	<10	<10	<10	<10
Beryllium, dissolved (µg/L as Be)	23	<1	<1	<1	<1	<1
Cadmium, total recoverable (µg/L as Cd)	23	2	<1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	23	2	<1	<1	<1	<1
Chromium, total recoverable (µg/L as Cr)	23	3	<1	<1	<1	<1
Chromium, dissolved (µg/L as Cr)	23	<1	<1	<1	<1	<1
Cobalt, total recoverable (µg/L as Co)	23	9	<1	<1	<1	<1
Cobalt, dissolved (µg/L as Co)	23	8	<1	<1	<1	<1
Copper, total recoverable (µg/L as Cu)	23	39	<1	<1	<1	5
Copper, dissolved (µg/L as Cu)	23	37	1	<1	1	2
Iron, total recoverable (µg/L as Fe)	23	2,100	40	140	270	510
Iron, dissolved (µg/L as Fe)	23	1,800	9	56	130	250
Lead, total recoverable (µg/L as Pb)	23	2	<1	<1	<1	<1
Lead, dissolved (µg/L as Pb)	23	1	<1	<1	<1	<1
Manganese, total recoverable (µg/L as Mn)	23	730	<10	10	20	40
Manganese, dissolved as Mn (µg/L as Mn)	23	760	<1	5	11	28
Mercury, total recoverable (µg/L as Hg)	23	<.1	<.1	<.1	<.1	<.1
Molybdenum, total recoverable (µg/L as Mo)	23	2	1	<1	1	2
Molybdenum, dissolved (µg/L as Mo)	23	<1	<1	<1	<1	<1
Nickel, total recoverable (µg/L as Ni)	23	16	<1	<1	<1	2
Nickel, dissolved (µg/L as Ni)	23	17	<1	<1	<1	1
Selenium, total recoverable (µg/L) as Se)	23	<2	<1	<1	<1	<1
Silver, total recoverable (µg/L as Ag)	23	<1	<1	<1	<1	<1
Silver, dissolved (µg/L as Ag)	23	2	<1	<1	<1	1
Uranium, dissolved as U (µg/L)	23	2	<1	<1	<1	<1
Zinc, total recoverable (µg/L as Zn)	23	330	<10	<10	<10	55
Zinc, dissolved (µg/L as Zn)	23	320	<1	2	3	46
Carbon, organic, total (µg/L as C)	22	6.7	.6	1.9	2.0	2.3
Carbon, organic, dissolved (µg/L as C)	22	3.3	.5	1.1	1.2	1.4
Sediment, suspended (mg/L)	23	9	1	2	2	4
Sediment, percent finer than 0.062 mm	20	100	100	100	100	100

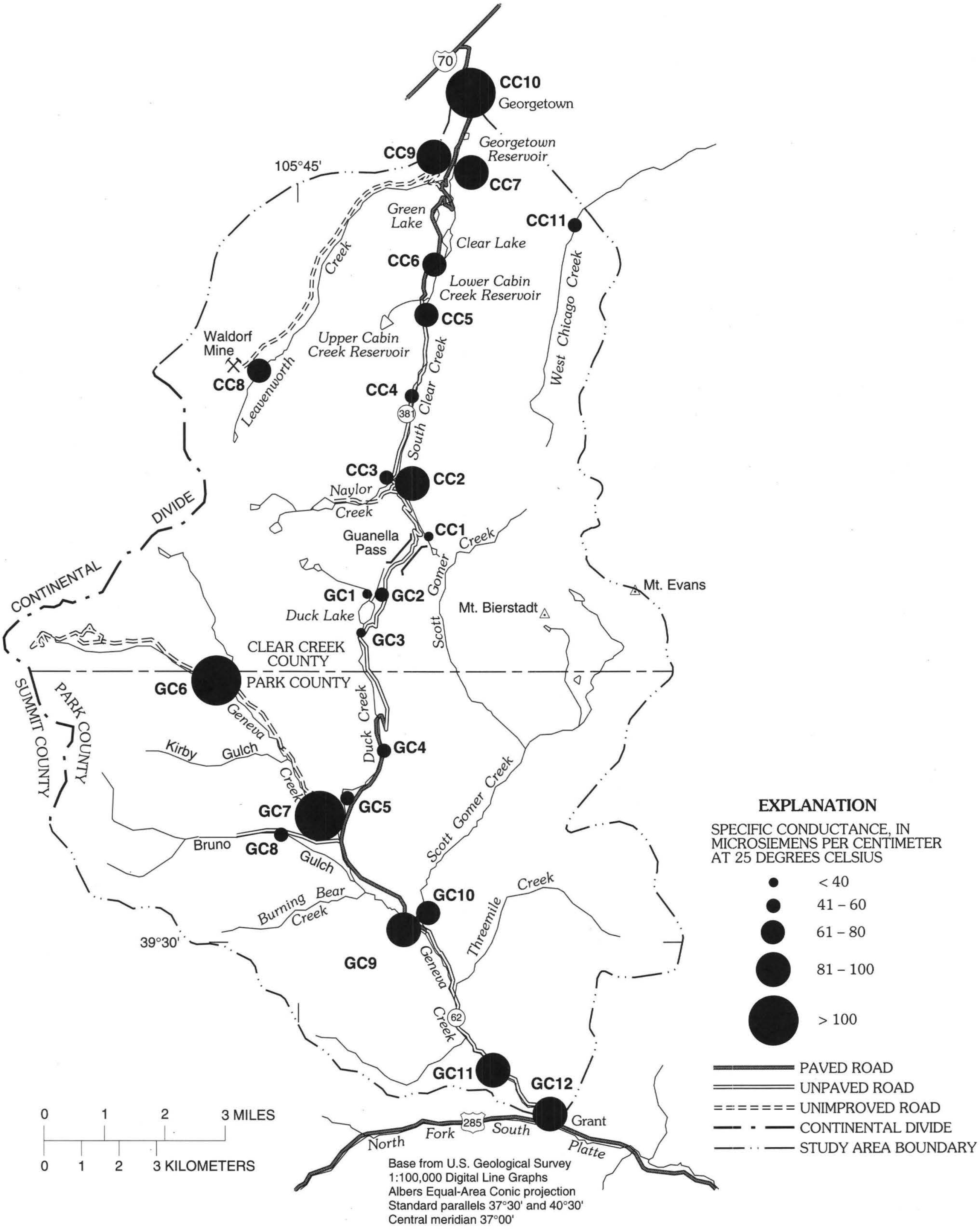


Figure 5. Distribution of specific-conductance values during the low-streamflow synoptic sampling, September 1995.

145 percent between sites CC1 and CC2. Springs with high specific conductance (such as GW5, Stevens and others, 1997) that discharge in the reach between the two sites probably contribute to increasing specific conductance in South Clear Creek. Downstream from Naylor Creek, South Clear Creek is diluted by water having relatively small specific conductance. Even so, at the low-flow sampling, specific conductance in South Clear Creek increased steadily about 100 percent from CC4 below Naylor Creek to CC10 downstream at Georgetown. The downstream increase in specific conductance does not seem to be related to any particular constituent because all of the major ions tend to increase in a downstream direction. Possible causes of the increase are the influx of ground water of large specific conductance and the release of higher conductivity water from Lower Cabin Creek Reservoir and Clear Lake during the seasonal lag between upstream and downstream sites caused by residence time in the reservoir and lake.

A second trend in figure 5 is the decrease in specific conductance in the downstream direction on Geneva Creek. Large specific-conductance values in the headwaters are most likely the result of acidic weathering processes. Downstream tributaries such as Duck Creek, Bruno Gulch, and Scott Gomer Creek dilute Geneva Creek with relatively small specific-conductance water. Concentrations of dissolved aluminum and iron decrease in a downstream direction at rates greater than expected by dilution. Precipitation of these trace elements also might contribute to the decrease in specific conductance.

Values of pH were generally in the neutral range (7.0 to 8.0), except at sites in the upper part of Geneva Creek (upstream from Scott Gomer Creek) where acidic pH values as low as 3.8 were measured (tables 3 and 4). Dissolved-oxygen concentrations ranged from 6.7 to 11.3 mg/L during the high-flow synoptic sampling (table 3) and 7.0 to 10.5 mg/L during the low-flow synoptic sampling (table 4). No dissolved-oxygen deficiencies were detected.

Turbidity was collected as a measurement of the clarity of water that can indicate impairment of light penetration crucial to sustaining periphyton (algae). Decreases in light penetration can reduce primary productivity and affect the feeding habits of fish (MacDonald and others, 1991). The highest turbidities during high flow occurred predominately along Geneva Creek. The orange hue of Geneva Creek at high flow indicates that resuspended iron hydroxide precipitates from the streambed could be a source of fine particles. Lower Cabin Creek Reservoir and Clear Lake on South Clear Creek seem to effectively decrease downstream turbidity by settling and dilution.

Major Ions

Stream major-ion chemistry is characterized by the predominance of calcium for cations and generally bicarbonate (as indicated by alkalinity and the range in pH) for anions at most sites. Chloride concentration (median 0.7 mg/L, high flow, and median 0.5 mg/L, low flow) is small because of the absence of chloride-rich rock in the area (tables 3 and 4). One source of the chloride is precipitation. Two snow samples from WY 1995 contained 0.22 and 0.11 mg/L chloride (Stevens and others, 1997). Other probable sources of chloride are dry deposition and anthropogenic sources (human waste and pollution, road salt, and road-dust inhibitor). Water samples collected at high flow from upper South Clear Creek (upstream from Lower Cabin Creek Reservoir) indicate generally increasing concentrations of chloride in a downstream direction. This trend was not evident at low flow on upper South Clear Creek or at high or low flow on the main stem of Geneva Creek. Concentrations of chloride greater than 1 mg/L were only measured at sites along South Clear Creek and Duck Creek (Stevens and others, 1997).

Dissolved-solids [residue-on-evaporation (ROE)] concentration ranged from 25 to 60 mg/L at high flow and from 25 to 127 mg/L at low flow (tables 3 and 4). The median dissolved-solids concentration was only slightly larger at low flow, 43 mg/L, than at high flow, 42 mg/L. Small concentrations of dissolved solids are typical of headwater streams with similar geology (Hofstra and Hall, 1975).

Nutrients

Dissolved-nutrient concentrations in stream water were generally small or less than the laboratory reporting limit. Nitrite was rarely detected. Median concentrations of dissolved ammonia were larger at the high-flow sampling (median 0.02 mg/L) than at the low-flow sampling (median <0.015 mg/L) (tables 3 and 4). Concentrations of nitrite plus nitrate had the same median value at high and low flows (0.06 mg/L). Concentrations of dissolved ammonia plus organic nitrogen were rarely greater than the reporting limit. Dissolved phosphorus was detected more frequently at high flow than at low flow, but few samples contained concentrations greater than the reporting limit. Comparison of total and dissolved-nutrient concentrations (Stevens and others, 1997) indicates that, at the high-flow sampling during the period of large suspended-sediment concentrations, particulate organic nitrogen and particulate phosphorus predominate. On the basis of samples collected during the low-flow sampling, nutrients are transported mostly in the dissolved phase. Nutrient concentrations are typical of mountain streams that have similar geology (Hofstra and Hall, 1975).

Trace Elements

The trace-element concentrations (excluding aluminum, barium, iron, zinc, and manganese) were generally less than 10 µg/L, except in areas of ore deposits and acid-sulfate weathering. Dissolved trace-element concentrations were above a few micrograms per liter only in streams with source waters of acidic pH (Stevens and others, 1997). In a downstream direction along Geneva Creek, the trace-element particulate fraction (as indicated by the difference between total and dissolved concentrations, Stevens and others, 1997) increases along with pH and alkalinity, a result of inflow from nonacidic tributaries. Along Geneva Creek, orange and white precipitates, probably of iron and aluminum, form at confluences with tributaries and along the streambed as in other acidic/neutral-stream mixing zones in the region (Bassett and others, 1992; McKnight and others, 1992). During the low-flow sampling, the acidic pH in the flow of upper Geneva Creek was neutralized before reaching Grant. The only trace elements remaining in substantial concentration in the dissolved phase are zinc (80 percent) and manganese (100 percent). Precipitates are observed to accumulate on the streambed during low flow. During high flow, the precipitates on the streambed are scoured. The scoured precipitates could be a substantial annual source of trace elements that are adsorbed to amorphous phases of iron and aluminum and to organic particles. The precipitates also could be a source of trace elements for desorption reactions farther downstream.

Except for Leavenworth Creek, water from sampling sites in the South Clear Creek Basin has small concentrations of dissolved trace elements that are typical for neutral-pH streams of similar geology (Hall and others, 1980). Only trace concentrations of zinc and copper and moderate concentrations of iron and manganese are in the dissolved phase (Stevens and others, 1997). Most trace elements in South Clear Creek are transported in the particulate phase at high flow, but concentrations are small compared to streams associated with acid-sulfate weathering. The relatively large suspended-sediment concentration in stormflows in South Clear Creek were associated with particulate trace elements, mostly zinc, lead, and copper.

Because South Clear Creek downstream from the confluence with Leavenworth Creek is used by Georgetown for a drinking-water supply, it is important to compare the two major tributaries, Leavenworth Creek (CC9, fig. 1) and South Clear Creek (CC7, fig. 1), as sources of trace elements. In table 5, the loads for total recoverable copper, lead, and zinc at the high-flow sampling are listed. The sample data indicate that Leavenworth Creek is the primary contributor of these trace elements. For example, the load of total recoverable lead was more than 80 times greater at Leavenworth Creek than at South Clear Creek upstream from Leavenworth Creek. Despite a neutral pH near the mouth, Leavenworth Creek still has a substantial concentration of dissolved zinc (200 µg/L at high flow, 130 µg/L at low flow) (Stevens and others, 1997).

Table 5. Selected trace-element loads for high-flow synoptic sampling at South Clear Creek above Leavenworth Creek (CC7) and Leavenworth Creek (CC9), June 13, 1995

[µg/L, micrograms per liter; ft^3/s, cubic feet per second; kg/d, kilograms per day; $kg/10^9 µg$, kilograms per 10^9 micrograms; L/ft^3, liters per cubic foot; s/d, seconds per day]

Trace element	South Clear Creek (CC7)			Leavenworth Creek at mouth (CC9)		
	Concentration (µg/L)	Discharge (ft^3/s)	Load (kg/d)[1]	Concentration (µg/L)	Discharge (ft^3/s)	Load (kg/d)[1]
Copper, total recoverable (µg/L as Cu)	<1	35	<0.09	14	56	1.9
Lead, total recoverable (µg/L as Pb)	1	35	.09	55	56	7.5
Zinc, total recoverable (µg/L as Zn)	<10	35	<.9	430	56	59

[1] Load (kg/d) calculated from: concentration (µg/L) × 1 $kg/10^9 µg$ × 28.3 L/ft^3 × streamflow (ft^3/s) × 86,400 s/d.

Suspended Sediment

Suspended-sediment concentrations were small in low-flow samples and were larger, with considerable site-to-site variation, in high-flow samples. Instantaneous sediment concentrations ranged from 6 mg/L at site GC1 to 939 mg/L at site GC11 in water samples collected during the high-flow sampling (table 3). Instantaneous sediment discharge for high-flow samples ranged from 0.1 ton/d at headwater site GC1 to 1,400 ton/d at Geneva Creek (GC11) (Stevens and others, 1997). The sediment finer than 0.062 mm ranged from 34 to 93 percent at high flow (table 3) and was 100 percent for all samples collected during the low-flow sampling (table 4). Distribution of suspended-sediment concentrations in samples collected during the high-flow sampling is shown in figure 6. The plot shows that headwater sampling sites generally have smaller suspended-sediment concentrations than sites farther downstream. Lakes and reservoirs can reduce suspended-sediment concentrations by allowing particles to settle. At low flow, suspended-sediment concentrations are small at all sites, ranging from 1 to 9 mg/L (table 4).

Acid-Sulfate Weathering Effects

Streams that are affected by acid-sulfate weathering processes (either naturally occurring or as a result of mining) can have different water chemistry than nearby unaffected streams. The acidic parts of upper Geneva Creek have alkalinity concentrations that were very small or less than the reporting limit. Sulfate was the predominate anion in the headwaters of Geneva Creek and Leavenworth Creek due to acid-sulfate weathering in those basins. When water and oxygen oxidize the mineral pyrite, the process produces acid, sulfate, and iron hydroxide. A summary of the reactions can be represented as follows (Moran and Wentz, 1974):

$$FeS_2 + 3.75O_2 + 3.5H_2O \Leftrightarrow Fe(OH)_3 + 2SO_4^{-2} + 4H^+$$

This acid-sulfate weathering process can result in lowering of pH, large sulfate and dissolved-solids concentrations, production of iron hydroxide (also known as yellow boy), and the release of trace elements associated with the pyrite or other minerals attacked by the acids (Moran and Wentz, 1974).

Scott Gomer Creek (site GC10, fig. 1), with a pH in the neutral range and relatively small sulfate concentrations, originates in the Mt. Evans Wilderness Area and is not affected by acid weathering. The upper Geneva Creek Basin, represented in this comparison by site GC7, is affected by naturally occurring acid-sulfate weathering (Bassett and others, 1992). A water sample from site GC7, the acidic stream, had a lower pH and a larger sulfate concentration than the more alkaline stream (GC10) (table 6) due to the products of the weathering of pyrite. Additionally, the alkalinity concentration at site GC7 was smaller, whereas the concentration of dissolved solids was larger than at site GC10. Streamflow and chloride, nutrient (nitrogen and phosphorus compounds), and suspended-sediment concentrations were similar at the two sites (table 6). Large concentrations of total recoverable trace elements and a large proportion of dissolved-phase trace elements are present in the acidic stream, resulting from the occurrence of mineralization in the basin, accelerated weathering from acidic reactions, and low stream pH. Among the abundant trace elements in the samples of acidic stream water (site GC7) are relatively large concentrations of aluminum, iron, and manganese, which contribute to stream-bottom precipitates (Basset and others, 1992), and of copper, lead, and zinc, which are toxic to aquatic life when in sufficient concentrations.

Storm-Runoff Effects

Storm runoff can have an effect on stream-water chemistry and sediment transport in the study area. The analytical results of a water sample taken at South Clear Creek above Lower Cabin Creek Reservoir (CC5, fig. 1) at base flow just before a thunderstorm and a sample taken during stormflow are listed in table 7. The storm caused a small increase in streamflow. The pH was unchanged, whereas turbidity increased more than 20 times, indicating a higher concentration of suspended particles. The major cations calcium, sodium, and potassium had the same concentrations before and during the stormflow, whereas there was a small increase in magnesium. Among major anions, alkalinity and sulfate concentrations decreased slightly, whereas the concentration of chloride more than doubled. Minor differences in specific conductance and concentration of dissolved solids between the two samples indicate that overall changes in major-ion concentration were small.

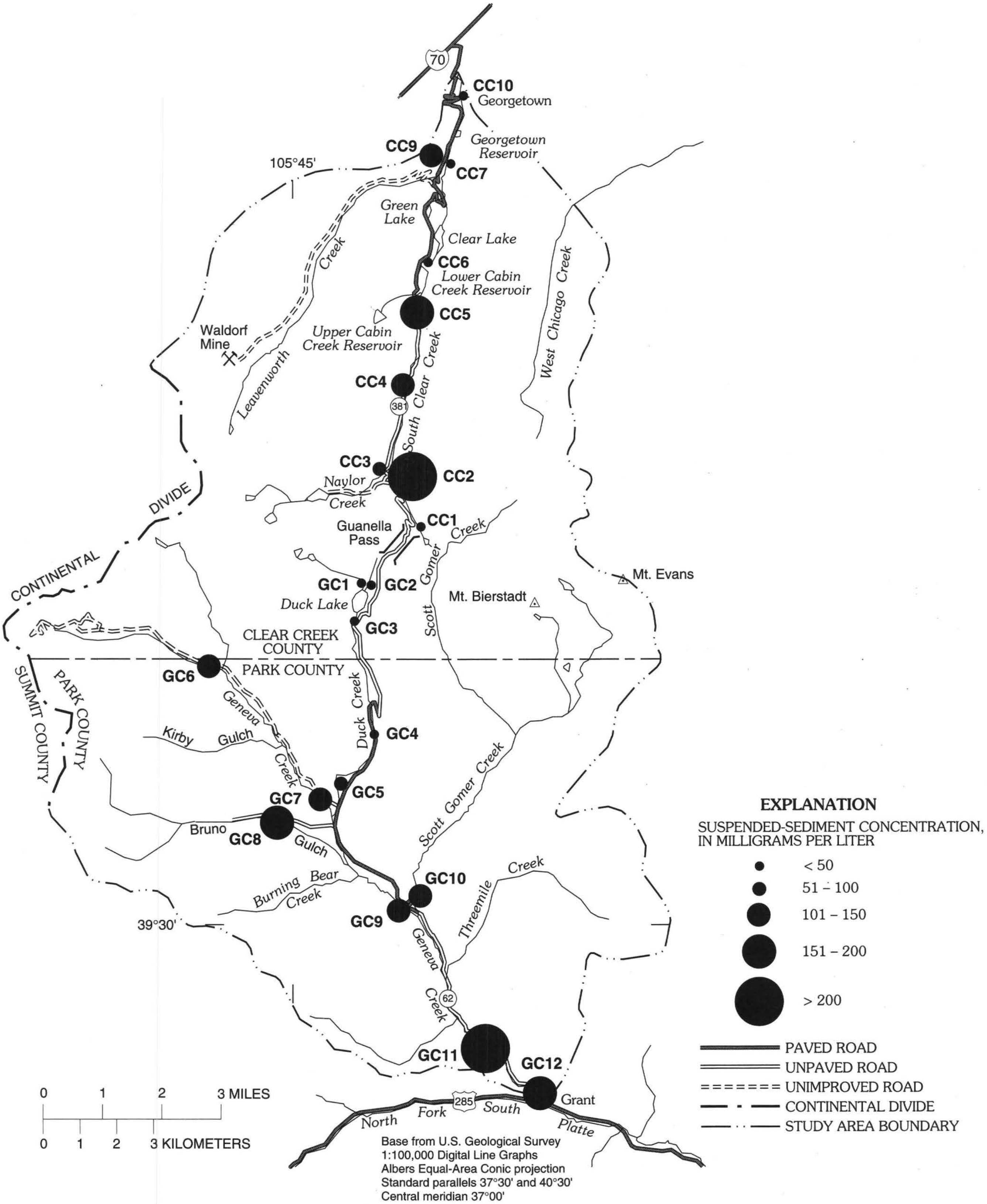


Figure 6. Distribution of suspended-sediment concentrations during high-streamflow synoptic sampling, June 1995.

Table 6. Selected water-quality properties and constituents for a stream with neutral pH (GC10) and small concentrations of trace elements for a stream with acidic pH (GC7) and larger concentrations of trace elements in the Guanella Pass study area on June 14, 1995 (high flow), and September 7, 1995 (low flow)

[ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter]

Property or constituent	Scott Gomer Creek (GC10)		Geneva Creek above Duck Creek (GC7)	
	High flow	Low flow	High flow	Low flow
Discharge (ft^3/s)	160	18	153	20
pH (standard units)	7.3	7.7	6.8	4.9
Alkalinity, total laboratory (mg/L as $CaCO_3$)	11	18	4.6	<1
Sulfate (mg/L as SO_4)	1.3	2.4	18	50
Chloride (mg/L as Cl)	.6	.1	.6	.7
Dissolved solids, ROE at 180°C (mg/L)	29	34	41	79
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	.06	.07	.07	.07
Nitrogen, ammonia plus organic, total (mg/L as N)	.7	<.2	.7	<.2
Phosphorus, total (mg/L as P)	.17	.02	.17	<.01
Aluminum, total recoverable (µg/L as Al)	1,900	40	3,600	2,500
Aluminum, dissolved (µg/L as Al)	40	10	120	1,800
Copper, total recoverable (µg/L as Cu)	2	<1	18	18
Copper, dissolved (µg/L as Cu)	<1	<1	2	18
Iron, total recoverable (µg/L as Fe)	7,700	510	21,000	1,100
Iron, dissolved (µg/L as Fe)	210	320	260	480
Lead, total recoverable (µg/L as Pb)	2	<1	7	<1
Lead, dissolved (µg/L as Pb)	<1	<1	<1	<1
Manganese, total recoverable (µg/L as Mn)	210	10	190	530
Manganese, dissolved (µg/L as Mn)	10	6	120	520
Zinc, total recoverable (µg/L as Zn)	<10	<10	40	180
Zinc, dissolved (µg/L as Zn)	2	2	24	190
Carbon, organic, total (mg/L as C)	11	2.9	6.2	1
Sediment, suspended (mg/L)	139	2	119	7

The fact that magnesium and chloride concentrations increased while other ionic-constituent concentrations were either unchanged or decreased indicate that road applications of magnesium chloride could be affecting stormwater or ground water reaching the stream.

A comparison of the analytical results of the pre-storm and storm-runoff samples in table 7 indicates that concentrations of nutrients, such as dissolved nitrite plus nitrate, ammonia plus organic nitrogen (total as N), and total phosphorus, increased during the storm. The additional nitrite plus nitrate could be the result of an influx of nutrient-bearing surface runoff or ground water. The increases in ammonia plus organic nitrogen and total phosphorus are related to the increases in suspended particles from erosion associated with the storm.

Pre-storm and storm-runoff analytical results for trace-element analyses greater than the reporting limit indicate that total recoverable and dissolved concentrations were higher for the selected trace elements during storm-runoff conditions. The concentration increases in the storm runoff are on the order of three to eight times the pre-storm concentrations. Most of the increase in total recoverable concentrations is the result of increases in suspended particles from erosion associated with the storm, and part is related to the increase in dissolved proportion that is a part of the total recoverable analysis. The dissolved trace-element increases could be the result of an influx of trace-element-bearing surface runoff or ground water.

During storm runoff, the streamflow was only 17 percent greater than at pre-storm conditions, whereas the suspended-sediment concentration increased 450 percent. Total organic-carbon concentration also increased. Sources of suspended sediment are bank and streambed erosion, surface runoff, and stormflow from the road. The small increase in streamflow seems insufficient to cause dramatic increases in instream sediment-erosion processes. Although surface runoff is rare in forested basins (Luce, 1995), some sparsely vegetated areas exist in small areas near South Clear Creek and could contribute to suspended sediment if overland flow occurred. During the field reconnaissance, evidence of discharge to upper South Clear Creek from culverts and shoulder ditches on the road was found. The length of roads in a basin has been positively correlated with sediment yield (Reid and Dunne, 1984).

Ground Water

Eight ground-water samples were collected in late summer of WY 1995 during a limited reconnaissance of ground-water quality (table 1, fig. 2). Five samples were from U.S. Department of Agriculture Forest Service campground handpumps, and three samples were from springs in the area. Statistics for properties and constituents determined from the analytical results of the ground-water samples are listed in table 8.

Field Parameters and Major Ions

The specific conductance of ground-water samples ranged from 24 to 584 µS/cm, with a median value of 167 µS/cm (table 8). The pH ranged from 6.9 to 7.7, a generally neutral range. Turbidity was generally low, ranging from 0.5 to 15.5 NTU. Hardness concentration ranged from 7 to 250 mg/L (as $CaCO_3$), which is soft to very hard according to the classification of Hem (1985). The predominant cation in all of the ground-water samples was calcium, and the predominant anion was bicarbonate (as indicated by alkalinity and pH). The median concentration of chloride was 1.2 mg/L, and concentrations ranged from 0.2 to 18 mg/L. Natural background concentrations of chloride are generally low in this type of hydrologic environment.

Table 7. Analytical results of selected water-quality properties or constituents for water samples collected during pre-storm (base-flow) and storm-runoff conditions from South Clear Creek above Lower Cabin Creek Reservoir (CC5) on August 22, 1995

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephalometric turbidity units; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter; mm, millimeters]

Property or constituent	Pre-storm (1433 hours)	Storm runoff (1625 hours)
Discharge (ft^3/s)	23	27
pH (standard units)	7.7	7.7
Specific conductance (µS/cm)	61	60
Turbidity (NTU)	5	112
Calcium, dissolved (mg/L as Ca)	6.3	6.3
Magnesium, dissolved (mg/L as Mg)	2.2	2.3
Sodium, dissolved (mg/L as Na)	1.2	1.2
Potassium, dissolved (mg/L as K)	.7	.7
Alkalinity, total laboratory (mg/L as $CaCO_3$)	26	25
Sulfate (mg/L as SO_4)	3.2	3.0
Chloride, dissolved (mg/L as Cl)	.4	1.0
Dissolved solids, ROE at 180°C (mg/L)	33	35
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	.11	.12
Nitrogen, ammonia plus organic, total (mg/L as N)	<.2	.2
Phosphorus, total (mg/L as P)	.02	.11
Phosphorus, orthophosphate, dissolved (mg/L as P)	<.01	<.01
Aluminum, total recoverable (µg/L as Al)	230	1,900
Aluminum, dissolved (µg/L as Al)	20	120
Copper, total recoverable (µg/L as Cu)	1	3
Copper, dissolved (µg/L as Cu)	<1	<1
Iron, total recoverable (µg/L as Fe)	500	4,000
Iron, dissolved (µg/L as Fe)	140	320
Lead, total recoverable (µg/L as Pb)	<1	2
Lead, dissolved (µg/L as Pb)	<1	<1
Manganese, total recoverable (µg/L as Mn)	30	100
Manganese, dissolved (µg/L as Mn)	8	14
Zinc, total recoverable (µg/L as Zn)	<10	10
Zinc, dissolved (µg/L as Zn)	<1	3
Carbon, organic, total (mg/L as C)	2.8	3.5
Sediment, suspended (mg/L)	16	88
Sediment, percent finer than 0.062 mm	100	96

of total phosphorus were present, ranging from less than 0.01 to 0.03 mg/L. Orthophosphate was not detected above the reporting limit of 0.01 mg/L.

Trace Elements

Particulate-phase concentrations of trace elements were relatively small, as indicated by differences between total recoverable and dissolved concentrations (table 8) (Stevens and others, 1997). Large dissolved-zinc (4,600 µg/L) and -copper (9 µg/L) concentrations possibly indicate trace elements leached into well water from handpump or well materials. Concentrations of zinc and copper in samples collected from campground sites (GW2, GW3, GW4, GW7, and GW8) were consistently larger than in samples collected from springs (GW1, GW5, and GW6). Concentrations of dissolved uranium were present in a few samples. In one campground well (GW3), a relatively large concentration of 67 µg/L was determined. However, the next largest concentration in the sample set was 5 µg/L (GW1), so the large concentration is not representative of general uranium concentrations in the area. A potential source of uranium is from ground-water contact with uranium-bearing rocks that are sometimes present in crystalline rocks of the Front Range (Hills and others, 1982).

Lakes and Reservoirs

Selected lakes and reservoirs in the study area were sampled to describe water-quality conditions. Green Lake, Clear Lake, Lower Cabin Creek Reservoir, and Duck Lake were sampled for water-quality properties and constituents at the surface and near the bottom on August 15–16, 1995 (table 1, fig. 3). These water bodies are receiving waters from streams potentially carrying road runoff.

Lake Profiles and Major Ions

Lake and reservoir profiles of water temperature, specific conductance, pH, and dissolved oxygen can aid in the evaluation of water-quality characteristics. In the water columns of the three deeper water bodies, Duck Lake (101 ft), Clear Lake (105 ft), and Green Lake (52 ft), water temperature, specific conductance, pH, and dissolved oxygen were moderately to strongly stratified with depth in August 1995 (Stevens and others, 1997). Lower Cabin Creek Reservoir (depth 18 ft) was not stratified, probably because of shallow depth and daily pumping of the reservoir contents for hydroelectric power generation. Of all the stratified water bodies, Duck Lake was the most hypoxic near the bottom where dissolved-oxygen concentrations were less than 1 mg/L about 20 ft above the bottom of the lake. As in stream water, major-ion chemistry was dominated by calcium and bicarbonate. Chloride concentrations were small (median 0.6 mg/L) (table 9). Hardness (median 28 mg/L) and alkalinity (median 28 mg/L) concentrations also were small.

Nutrients and Trace Elements

Nutrient concentrations were small, with only nitrite plus nitrate having a median concentration (0.07 mg/L) greater than the laboratory reporting limit. Dissolved ammonia and dissolved ammonia plus organic nitrogen were detected in the bottom sample of Duck Lake (Stevens and others, 1997). All analyses of dissolved or total phosphorus were less than the laboratory reporting limit of 0.01 mg/L. Concentrations of dissolved and total recoverable trace elements were small, with only iron, manganese, and zinc having median concentrations greater than laboratory reporting limits. Green Lake contained the maximum dissolved-zinc concentration of 29 µg/L (table 9) (Stevens and others, 1997). Leavenworth Creek, which drains a mineralized area, contributes water to Green Lake and, as indicated in table 5, carries a large zinc load that is a possible source of zinc concentrations in Green Lake larger than in any of the other lakes sampled. Concentrations of organic carbon were similar to concentrations determined for streams during the low-flow sampling (tables 4 and 9).

Hypoxic Conditions

The minimum dissolved-oxygen concentration (0.6 mg/L) and the maximum total recoverable iron (2,500 µg/L), total recoverable manganese (540 µg/L), and dissolved-ammonia (0.15 mg/L) concentrations (table 9) (Stevens and others, 1997) were from a sample collected just above the bottom of Duck Lake and indicate that hypoxic (low-oxygen) conditions develop at the bottom of this lake. The resulting reducing conditions caused the release of iron, manganese, and ammonia from bottom sediments.

Table 9. Statistical summary of analyses of water samples collected from lake and reservoir sampling sites, August 15–16, 1995

[in., inches; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephalometric turbidity units; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter]

Property or constituent	Sample size	Maximum	Minimum	Twenty-fifth percentile	Median	Seventy-fifth percentile
Transparency, surface (in.)	4	353	114	118	148	221
Specific conductance (µS/cm)	8	212	29	62	66	124
pH (standard units)	8	8.2	6.7	7.6	7.7	7.8
Water temperature (°C)	8	14.5	4	8.0	11.5	14.0
Turbidity (NTU)	7	1	.4	.8	.8	.9
Dissolved oxygen (mg/L)	8	7.3	.6	5.6	7.0	7.2
Hardness (mg/L as $CaCO_3$)	8	88	12	25	28	53
Calcium, dissolved (mg/L as Ca)	8	24	3.4	6.6	7.4	14
Magnesium, dissolved (mg/L as Mg)	8	6.8	.9	2.0	2.4	4.3
Sodium, dissolved (mg/L as Na)	8	1.7	1.1	1.3	1.4	1.5
Potassium, dissolved (mg/L as K)	8	1.6	.5	.8	.9	1.2
Alkalinity, total laboratory (mg/L as $CaCO_3$)	8	70	14	22	28	49
Sulfate (mg/L as SO_4)	8	18	2.1	3.2	3.4	7.4
Chloride (mg/L as Cl)	8	1.2	.3	.6	.6	.8
Fluoride, dissolved (mg/L as F)	8	.2	<.1	<.1	<.1	.2
Silica, dissolved (mg/L as SiO_2)	8	7.7	5.5	6.0	6.3	7.1
Dissolved solids, ROE at 180°C (mg/L)	8	107	24	38	42	67
Nitrogen, nitrite, dissolved (mg/L as N)	8	<.01	<.01	<.01	<.01	<.01
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	8	.15	<.05	<.05	.07	.11
Nitrogen, ammonia, dissolved (mg/L as N)	8	.15	<.015	<.015	<.015	.02
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	8	.2	<.2	<.2	<.2	<.2
Nitrogen, ammonia plus organic, total (mg/L as N)	8	.3	<.2	<.2	<.2	<.2
Phosphorus, total (mg/L as P)	8	<.01	<.01	<.01	<.01	<.01
Phosphorus, dissolved (mg/L as P)	8	<.01	<.01	<.01	<.01	<.01
Phosphorus, orthophosphate, dissolved (mg/L as P)	8	<.01	<.01	<.01	<.01	<.01
Aluminum, total as Al (µg/L)	8	70	<10	10	30	32
Aluminum, dissolved (µg/L as Al)	8	10	2	4	8	8
Antimony, dissolved (µg/L as Sb)	8	<1	<1	<1	<1	<1
Arsenic, total recoverable (µg/L as As)	8	<1	<1	<1	<1	<1
Barium, total recoverable (µg/L as Ba)	8	<100	<100	<100	<100	<100
Barium, dissolved (µg/L as Ba)	8	40	17	26	28	36
Beryllium, total recoverable (µg/L as Be)	8	<10	<10	<10	<10	<10
Beryllium, dissolved (µg/L as Be)	8	<1	<1	<1	<1	<1
Cadmium, total recoverable (µg/L as Cd)	8	<1	<1	<1	<1	<1
Cadmium, dissolved (µg/L as Cd)	8	<1	<1	<1	<1	<1
Chromium, total recoverable (µg/L as Cr)	8	<1	<1	<1	<1	<1
Chromium, dissolved (µg/L as Cr)	8	<1	<1	<1	<1	<1
Cobalt, total recoverable (µg/L as Co)	8	<1	<1	<1	<1	<1
Cobalt, dissolved (µg/L as Co)	8	<1	<1	<1	<1	<1
Copper, total recoverable (µg/L as Cu)	8	1	<1	<1	<1	<1

Table 9. Statistical summary of analyses of water samples collected from lake and reservoir sampling sites, August 15–16, 1995—Continued

[in., inches; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephalometric turbidity units; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter]

Property or constituent	Sample size	Maximum	Minimum	Twenty-fifth percentile	Median	Seventy-fifth percentile
Copper, dissolved (µg/L as Cu)	8	2	<1	<1	1	1
Iron, total recoverable (µg/L as Fe)	8	2,500	<10	55	130	150
Iron, dissolved (µg/L as Fe)	8	440	8	19	52	69
Lead, total recoverable (µg/L as Pb)	8	<1	<1	<1	<1	<1
Lead, dissolved (µg/L as Pb)	8	<1	<1	<1	<1	<1
Manganese, total recoverable (µg/L as Mn)	8	540	<10	<10	<10	30
Manganese, dissolved as Mn (µg/L as Mn)	8	510	<1	3	4	28
Mercury, total recoverable (µg/L as Hg)	8	<.1	<.1	<.1	<.1	<.1
Molybdenum, total recoverable (µg/L as Mo)	8	1	<1	<1	<1	<1
Molybdenum, dissolved (µg/L as Mo)	8	1	<1	<1	<1	1
Nickel, total recoverable (µg/L as Ni)	8	<1	<1	<1	<1	<1
Nickel, dissolved (µg/L as Ni)	8	1	<1	<1	<1	1
Selenium, total recoverable (µg/L) as Se)	8	<1	<1	<1	<1	<1
Silver, total recoverable (µg/L as Ag)	8	<1	<1	<1	<1	<1
Silver, dissolved (µg/L as Ag)	8	<1	<1	<1	<1	<1
Uranium, dissolved as U (µg/L)	8	7	<1	<1	<1	2
Zinc, total recoverable (µg/L as Zn)	8	30	<10	<10	<10	12
Zinc, dissolved (µg/L as Zn)	8	29	<1	1	1	5
Carbon, organic, total (µg/L as C)	8	3.7	1.3	2.0	2.5	3.2
Carbon, organic, dissolved (µg/L as C)	8	2.4	1.3	1.4	1.8	1.9

Lower Cabin Creek Reservoir may release hypoxic waters periodically. Orange-red, flocculated material accumulates on the streambed downstream from the reservoir. The material probably consists of iron and manganese hydroxides precipitated as the water from the reservoir is reoxygenated. The reservoir is shallow, and water levels fluctuate rapidly and frequently as a result of pumping for hydroelectric power generation. No stratification was detected in the August 1995 profile of the reservoir (Stevens and others, 1997). Reducing conditions resulting from winter stratification or ground-water seepage under the dam are possible sources of remobilized iron. The Upper Cabin Creek Reservoir, into which water from the Lower Cabin Creek Reservoir is pumped, is much deeper than the lower reservoir and, therefore, more susceptible to hypoxia, making it a possible source of iron and manganese. Hypoxic conditions in the Upper Cabin Creek Reservoir may cause a release of iron and manganese from bottom sediments, periodically supplying water that is rich in these elements to the lower reservoir for release downstream. Because large concentrations of iron and manganese were not detected in water samples downstream from any of the reservoirs (Stevens and others, 1997) and because iron staining on the streambed is common downstream from almost all of the lakes, reservoirs, and beaver dams in the study area, iron may precipitate in the reoxygenated waters downstream from many area impoundments on a periodic basis.

Bottom Sediment

Bottom-sediment samples (<62 µm) were collected from Green Lake, Clear Lake, Lower Cabin Creek Reservoir, and Duck Lake in 1995.

Trace-element analyses were performed on samples from all four lakes/reservoirs. Nutrient analyses were performed on samples from all but Lower Cabin Creek Reservoir. A trace-organic sample was collected only from Lower Cabin Creek Reservoir. The concentrations of ammonia, ammonia plus organic nitrogen (Kjeldahl), and phosphorus in bottom sediment generally were several times larger in Duck Lake than in Green or Clear Lakes. Zinc, lead, and copper concentrations in bottom sediment were generally several times larger in Green Lake than in the other water bodies (Stevens and others, 1997). The source of trace elements in Green Lake could be water from the Leavenworth Creek aqueduct used to maintain the lake level. Mercury concentrations were largest in Clear and Green Lakes and were substantially larger than concentrations in the bottom sediment of Duck Lake or Lower Cabin Creek Reservoir. Total organic carbon also was largest in Duck Lake. The only trace-organic chemicals detected in Lower Cabin Creek Reservoir sediment were dichlorodiphenyldichloroethylene (DDE) and polychlorinated biphenyl compounds (PCB's). The small concentrations of DDE and PCB's in Lower Cabin Creek Reservoir sediment are probably the result of bulk atmospheric deposition resulting from the wide use of these chemicals and do not necessarily indicate a source in the basin. These organic chemicals are environmentally persistent and readily partition into a sorbed phase, which, when present, is generally detected in the bottom sediment.

Road Runoff

Water quality of road runoff was characterized by collecting and analyzing 5 snowmelt-runoff and 6 rainstorm-runoff samples from 11 sampling sites in the study area (table 1, fig. 3). Statistics for road-runoff samples are listed in table 10. The volume of road runoff from any single drainage feature (ditch or culvert) is small (0.004 to 0.153 ft^3/s) compared to streamflows (Stevens and others, 1997). However, there are many of these point sources along any given reach of the road that may flow into the streams along the road.

Field Parameters and Major Ions

Specific conductance varied widely, ranging from 14 to 468 $\mu S/cm$ (table 10). The pH was generally neutral, ranging from 6.9 to 8.5. Turbidity was extremely high, generally greater than 1,000 NTU, and the flows were well oxygenated. As in stream water, ground water, and lake/reservoir water, median major-ion concentrations from road runoff were dominated by calcium and bicarbonate (as indicated by alkalinity and pH). The maximum concentrations of anions were dominated by chloride, followed by bicarbonate and sulfate (table 10). Some samples had major-ion composition characteristics that indicate effects from de-icing salt (NaCl) and dust inhibitor ($MgCl_2$) applied to sections of the road. The road-runoff sample for site CRD1 (rainstorm related) was dominated by concentrations of magnesium and chloride. The road-runoff sample for site CRD5 (rainstorm related) was dominated by concentrations of magnesium/calcium and chloride. The road-runoff sample for site CRD6 (snowmelt related) was dominated by concentrations of sodium and chloride (Stevens and others, 1997). The samples from these sites also had the three largest dissolved-solids concentrations of all of the road-runoff samples (Stevens and others, 1997). The samples with predominant magnesium were from sections of road treated with magnesium chloride (Jim Cannedy, Clear Creek County, oral commun., 1997). The sample with predominant sodium was from a section of road receiving sodium chloride in traction materials in winter (Jim Cannedy, Clear Creek County, oral commun., 1997).

Nutrients

Nutrients (nitrogen and phosphorus compounds) were commonly detected in road-runoff samples at higher concentrations than in streamflow (Stevens and others, 1997). Samples analyzed for dissolved nitrite plus nitrate had a median concentration of 0.13 mg/L, and concentrations ranged from less than 0.05 to 0.65 mg/L (table 10). Samples analyzed for dissolved ammonia had a median concentration of 0.04 mg/L, and concentrations ranged from 0.01 to 0.08 mg/L (table 10). These forms of dissolved inorganic nitrogen are common chemical components of precipitation. Concentrations of dissolved nitrite plus nitrate were substantially larger for rainfall-related samples of

Table 10. Statistical summary of water-quality properties and constituents for road-runoff samples

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephalometric turbidity units; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter; mm, millimeters]

Property or constituent	Sample size	Maximum	Minimum	Twenty-fifth percentile	Median	Seventy-fifth percentile
Discharge (ft^3/s)	9	0.153	0.004	0.008	0.016	0.066
Specific conductance (µS/cm)	11	468	14	25	51	186
pH (standard units)	11	8.5	6.9	7.2	7.3	7.4
Water temperature (°C)	6	20	.5	1.0	3.0	4.5
Turbidity (NTU)	9	>1,000	430	>1,000	>1,000	>1,000
Dissolved oxygen (mg/L)	6	10.2	6.7	9.2	9.4	9.8
Hardness (mg/L as $CaCO_3$)	11	160	5	7	17	34
Calcium, dissolved (mg/L as Ca)	11	20	1.5	2.2	3.4	8.2
Magnesium, dissolved (mg/L as Mg)	11	26	.25	.4	1.1	3.7
Sodium, dissolved (mg/L as Na)	11	54	.2	.7	1.9	3.4
Potassium, dissolved (mg/L as K)	11	5.2	.59	.8	1.0	2.0
Alkalinity, total laboratory (mg/L as $CaCO_3$)	11	43	4.8	14	19	23
Sulfate (mg/L as SO_4)	11	6.1	.35	.8	1.4	3.8
Chloride (mg/L as Cl)	11	120	.4	.5	4.3	34
Fluoride, dissolved (mg/L as F)	11	.3	.04	.1	.1	.2
Silica, dissolved (mg/L as SiO_2)	11	8.7	.62	1.3	1.9	4.0
Dissolved solids, ROE at 180°C (mg/L)	10	286	11	34	38	129
Nitrogen, nitrite, dissolved (mg/L as N)	11	.01	.002	<.01	<.01	<.01
Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	11	.65	<.05	.10	.13	.27
Nitrogen, ammonia, dissolved (mg/L as N)	11	.08	.01	.04	.04	.05
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	11	.2	<.2	<.2	<.2	<.2
Nitrogen, ammonia plus organic, total (mg/L as N)	11	6.1	<.2	.2	.6	.8
Phosphorus, total (mg/L as P)	11	6	.03	.06	.33	1.02
Phosphorus, dissolved (mg/L as P)	11	.03	<.01	<.01	.01	.02
Phosphorus, orthophosphate, dissolved (mg/L as P)	11	.03	<.01	<.01	<.01	.02
Aluminum, total as Al (µg/L)	11	130,000	550	15,000	41,000	80,000
Aluminum, dissolved (µg/L as Al)	11	330	30	50	140	225
Antimony, dissolved (µg/L as Sb)	11	<1	<1	<1	<1	<1
Arsenic, total recoverable (µg/L as As)	11	2	<1	<1	<1	1
Barium, total recoverable (µg/L as Ba)	11	2,600	<100	200	700	2,000
Barium, dissolved (µg/L as Ba)	11	48	7	12	16	30
Beryllium, total recoverable (µg/L as Be)	11	<10	<10	<10	<10	<10
Beryllium, dissolved (µg/L as Be)	11	<1	<1	<1	<1	<1
Cadmium, total recoverable (µg/L as Cd)	11	4	<1	<1	<1	2
Cadmium, dissolved (µg/L as Cd)	11	<1	<1	<1	<1	<1
Chromium, total recoverable (µg/L as Cr)	11	150	<1	22	97	130
Chromium, dissolved (µg/L as Cr)	11	1	<1	<1	<1	<1
Cobalt, total recoverable (µg/L as Co)	11	120	<1	10	20	80
Cobalt, dissolved (µg/L as Co)	11	<1	<1	<1	<1	<1
Copper, total recoverable (µg/L as Cu)	11	290	<1	34	72	88

Table 10. Statistical summary of water-quality properties and constituents for road-runoff samples—Continued

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephalometric turbidity units; mg/L, milligrams per liter; ROE, residue on evaporation; µg/L, micrograms per liter; mm, millimeters]

Property or constituent	Sample size	Maximum	Minimum	Twenty-fifth percentile	Median	Seventy-fifth percentile
Copper, dissolved (µg/L as Cu)	11	3	<1	<1	1	2
Iron, total recoverable (µg/L as Fe)	11	280,000	780	44,000	59,000	180,000
Iron, dissolved (µg/L as Fe)	11	1,100	34	48	150	320
Lead, total recoverable (µg/L as Pb)	11	460	2	16	37	160
Lead, dissolved (µg/L as Pb)	11	<1	<1	<1	<1	<1
Manganese, total recoverable (µg/L as Mn)	11	13,000	60	800	1,400	5,600
Manganese, dissolved as Mn (µg/L as Mn)	11	120	6	20	26	50
Mercury, total recoverable (µg/L as Hg)	11	.4	<.1	<0.1	<0.1	0.1
Molybdenum, total recoverable (µg/L as Mo)	11	2	<1	<1	<1	1
Molybdenum, dissolved (µg/L as Mo)	11	3	<1	<1	<1	1
Nickel, total recoverable (µg/L as Ni)	11	140	<1	16	70	110
Nickel, dissolved (µg/L as Ni)	11	2	<1	<1	<1	1
Selenium, total recoverable (µg/L) as Se)	11	5	<1	<1	<1	<1
Silver, total recoverable (µg/L as Ag)	11	<1	<1	<1	<1	<1
Silver, dissolved (µg/L as Ag)	11	<1	<1	<1	<1	<1
Uranium, dissolved as U (µg/L)	11	3	<1	<1	<1	<1
Zinc, total recoverable (µg/L as Zn)	11	900	<10	140	200	520
Zinc, dissolved (µg/L as Zn)	11	4	<1	<1	2	3
Carbon, organic, total (µg/L as C)	11	140	4.7	9.4	12	80
Carbon, organic, dissolved (µg/L as C)	7	3.8	2.3	2.4	3.2	3.6
Sediment, suspended (mg/L)	11	30,800	66	900	6,190	7,780
Sediment, percent finer than 0.062 mm	11	100	35	40	84	90

road runoff (samples collected in August 1995) than for snowmelt-related samples (April to June 1995) (Stevens and others, 1997). Dissolved ammonia plus organic nitrogen was rarely detected (Stevens and others, 1997). The concentrations of ammonia plus organic nitrogen (total as N) ranged from less than 0.2 to 6.1 mg/L, and the median value was 0.6 mg/L (table 10). The total organic nitrogen in road runoff is probably related to plant detritus from forest vegetation near the road.

Total phosphorus concentrations in road runoff were much larger than dissolved-phosphorus or dissolved-orthophosphorus concentrations. Total phosphorus concentrations ranged from 0.03 to 6.0 mg/L, and the median value was 0.33 mg/L (table 10). Dissolved phosphorus and dissolved orthophosphorus had median concentrations of 0.01 and less than 0.01 mg/L (table 10). Large total phosphorus concentrations with small dissolved-phosphorus concentrations indicate that much of the phosphorus is in mineral or organic particles and is associated with the large concentrations of suspended sediment in road-runoff samples. Dissolved phosphorus can be readily adsorbed to sediment, which may account for the small concentrations of dissolved phosphorus in these samples.

Trace Elements

The trace elements detected in highest concentrations in road-runoff samples were iron, aluminum, and manganese (table 10), which are abundant rock-forming elements. Other trace elements with median concentrations greater than the laboratory reporting limit were total recoverable and dissolved barium, total recoverable chromium, total recoverable cobalt, total recoverable copper, total recoverable lead, total recoverable nickel, and total recoverable and dissolved zinc. Total recoverable arsenic, total recoverable cadmium, dissolved chromium, total recoverable mercury, total recoverable and dissolved molybdenum, dissolved nickel, total recoverable selenium, and dissolved uranium were detected, but did not have median concentrations greater than the laboratory reporting limit.

Analytical results of water samples from runoff from the Guanella Pass road indicate that total recoverable trace-element concentrations were substantially larger (by several times) than dissolved trace-element concentrations (Stevens and others, 1997), indicating that most trace elements are in the form of particles. The particulate trace elements are probably components of the rock and soil composing the road bed, ditches, and cut slopes. Vehicles emissions and wear products also contribute to trace elements (such as cadmium, copper, lead, zinc, iron, and manganese) available on the road for erosion (Young and others, 1996).

Organic Compounds

Dissolved organic-carbon concentrations in road runoff ranged from 2.3 to 3.8 mg/L, with a median concentration of 3.2 mg/L (table 10). The median concentration for total organic carbon was 12 mg/L, with a range in concentration of 4.7 to 140 mg/L. The large total organic-carbon concentrations in a few samples are probably related to plant detrital material. Two road-runoff samples collected during snowmelt and analyzed for trace-organic substances (organic chemicals normally present in small concentrations in the environment) had no detections of volatile or semivolatile organic substances greater than the laboratory reporting limits (Stevens and others, 1997).

Sediment

The generally large suspended-sediment concentrations in road runoff ranged from 66 to 30,800 mg/L, with a median concentration of 6,190 mg/L (table 10). These sediments are primarily fine grained (median percent finer than 0.062 mm is 84 percent) (table 10), which facilitates transport of the sediment and diminishes the likelihood that settling or deposition of the sediments would occur prior to reaching a stream. Fine sediment often contains the largest proportion of trace elements, nutrients, and oxygen-consuming substances that are transported in suspended sediment (Horowitz, 1995). Sediments that subsequently settle out in streams contribute to the reduction of suitable fish spawning areas and filling of pool habitat (MacDonald and others, 1991).

Potential Effects on Receiving Water

Receiving waters are the streams, ground water, and lakes and reservoirs into which road runoff flows. If road runoff flows into receiving waters in sufficient amounts, the result could be an alteration of water quality. By comparing the chemistry of the road runoff to the chemistry of the receiving water, the potential effect that road runoff could have on the receiving water can be qualitatively estimated.

Streams

The median concentrations for many constituents in road runoff are larger than in nearby stream water indicating that, depending on the relative flow rates, road runoff may alter stream-water quality. When compared to stream chemistry (tables 3 and 4), road runoff (table 10) generally has larger median values or concentrations of turbidity, sodium, chloride, dissolved nitrite plus nitrate, dissolved ammonia, total ammonia plus organic nitrogen, total phosphorus, dissolved phosphorus, total recoverable and dissolved aluminum, total recoverable barium, total recoverable chromium, total recoverable cobalt, total recoverable copper, total recoverable iron, total recoverable lead, total recoverable and dissolved manganese, total recoverable nickel, total recoverable zinc, total organic carbon, and suspended sediment. The difference between median road-runoff values and concentrations that are larger than median stream values and concentrations ranges from 42 percent larger for sodium to more than 3,000 times larger for suspended sediment.

Road runoff occurs during early spring from melting snow, often beginning before peak flow in streams, and during summer from afternoon and evening thunderstorms. Both early snowmelt and thunderstorm situations can occur when stream-flows are low and have a correspondingly small capacity for dilution. Thus, the potential water-quality effects of road runoff could be substantial during low streamflows and inconsequential during high streamflows because of differences in degrees of dilution potential. However, because of the cumulative effects of multiple sources of road-runoff inputs, dilutional effects may diminish.

Most of the stream trace-element standards are not likely to be exceeded as a result of road-runoff constituents discharged into streams because the standards specify primarily dissolved phases (Colorado Department of Health, Water Quality Control Commission, 1996), and the predominate trace-element phase associated with road runoff in the study area seems to be particulate (will not pass through a 0.45-µm filter). Dissolved trace elements may be more bioavailable than particulate trace elements (Rainbow and Dallinger, 1993). The particle-related trace elements, however, may be transported to other geochemical environments where they could become available to biota (Sundby, 1994). Some of the trace elements associated with particles are probably adsorbed to sediment; without lowering the pH, these trace elements are not likely to be desorbed or weathered from particles (Davis and others, 1991). Stream reaches that are paralleled by the Guanella Pass road are generally of neutral pH in most areas, although Geneva Creek is slightly acidic between Duck and Scott Gomer Creeks. If desorbtion is contributing trace elements to neutral-pH streams, the effect is small because background concentrations in these streams are small. If the desorbed trace elements are capable of substantially altering water quality for a neutral-pH stream, larger dissolved trace-element concentrations than those measured would be evident, especially in streams that are probably receiving road runoff.

Increased concentrations of sediment-related trace elements, such as iron from road runoff, could cause exceedance of instream standards. Individual sample concentrations of total recoverable iron in stream samples may exceed the fixed chronic stream standard (a numeric restriction established by the Colorado Water Quality Control Commission) of 1,000 µg/L during snowmelt or stormflow because of the association of iron concentration with large suspended-sediment concentrations (Gaggiani and others, 1987) during these periods. Therefore, large suspended-sediment concentrations may indirectly cause exceedance of standards for aquatic life because of total recoverable iron content. However, because the standard is chronic, the 85th percentile of data collected over a period of time would probably be used as the iron concentration (Eric Oppelt, Colorado Department of Health, Water-Quality Control Division, oral commun., 1998). This decreases the likelihood that large seasonal or storm concentrations increased by road runoff would affect the concentration compared with the standard.

The relation of total recoverable iron concentration to suspended-sediment concentration for samples collected during the high-flow sampling (fig. 7) indicates that the total recoverable iron standard of 1,000 µg/L was commonly exceeded in the range of suspended-sediment concentrations measured. This association of particulate iron to suspended sediment and the presence of large concentrations of suspended sediment in road-runoff samples may indicate that road runoff to streams could exacerbate seasonally large concentrations of total recoverable iron.

For about the same suspended-sediment concentration, the concentrations from upper Geneva Creek sites (GC6, GC7, and GC9) were much larger than from all other sites for high-flow samples (fig. 7). Precipitating ferric iron along Geneva Creek is probably the cause of the iron-rich character of the sediment. Because some streams are currently (1995) affected by acid weathering and mine drainage, trace elements in streams as a result of road runoff may have a small effect on concentrations by comparison. However, an aquatic system stressed by acid drainage could be more vulnerable if the additional road runoff causes concentrations to exceed water-quality standards.

Ground Water

The potential effects of road runoff on ground water would result from dissolved constituents because the particle component is reduced by adsorption to soil particles and filtering by infiltration through soil. Even if particle-related constituents reached fracture systems, particulate matter would probably be reduced substantially by processes such as sedimentation, precipitation, and adsorption as the water moves through the ground-water system (Andrews and others, 1984). Of the dissolved constituents, median concentrations of hardness, alkalinity, the major ions (except chloride), and dissolved solids are lower in road runoff (table 10) than the medians

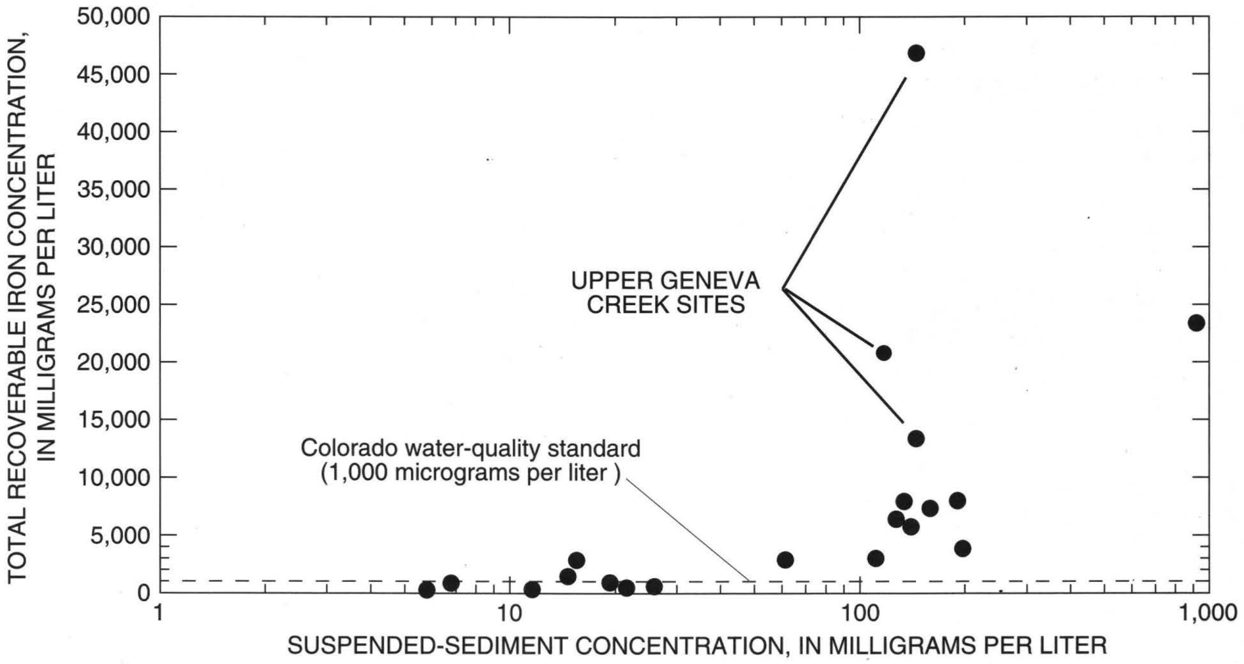


Figure 7. Relation of total recoverable iron to suspended-sediment concentration at the high-streamflow sampling.

in the ground water sampled (table 8), indicating a potential dilutional effect on ground water if simple mixing is assumed. The median concentrations of chloride, nitrite plus nitrate, ammonia, and dissolved aluminum, iron, and manganese were larger in road runoff, indicating that ground-water concentrations of these constituents might increase with road-runoff infiltration and simple mixing. Wells near areas receiving sodium or magnesium chloride treatments may be affected by large concentrations of sodium, magnesium, and chloride from road runoff.

On the basis of road-runoff chemistry and the ground-water data collected in WY 1995, road runoff would be unlikely to cause ground-water constituent concentrations at campground wells to exceed U.S. Environmental Protection Agency drinking-water regulations because the road runoff dissolved concentrations do not exceed the primary maximum contaminant limits (MCL's) (U.S. Environmental Protection Agency, 1996). The MCL's in campground wells (drinking-water sources) were exceeded in only a single sample for a single constituent. An analysis of a water sample from the well on the west loop of the Guanella Pass campground (GW3) contained 67 µg/L of uranium (Stevens and others, 1997), exceeding the proposed primary MCL of 20 µg/L (U.S. Environmental Protection Agency, 1996). The uranium is probably naturally present in the bedrock materials near the well. The bedrock in the study area is similar to other metamorphic and igneous rocks of the Colorado Front Range that are favorable for the presence of uranium (Hofstra and Hall, 1975; Hills and others, 1982). Although uranium was detected in some road-runoff samples, concentrations were much lower than the 67-µg/L concentration determined in GW3.

Lakes and Reservoirs

Lakes and reservoirs may be long-term storage sites for many of the constituents associated with road runoff (table 10). In general, the lakes and reservoirs in the area (table 9) had values and concentrations similar to low-flow stream concentrations (table 4). Road runoff has the potential to alter lake/reservoir inflows, as described for stream-water effects, and to flow directly into lakes/reservoirs near the road. Increases in dissolved ions or turbidity in inflows can exacerbate or initiate stratification in lakes/reservoirs because of density differences between inflows and lake/reservoir water (Cole, 1994). Studies of Alaskan lakes indicate an increase of a mere 5 NTU of turbidity in a clear lake can reduce the euphotic volume by as much as 80 percent (Lloyd and others, 1987). Increases in nutrients from road runoff may increase lake/reservoir algal productivity and accelerate eutrophication. Inputs of organic carbon from road runoff may increase oxygen demand and cause oxygen deficiencies in water at lake/reservoir bottoms. Low oxygen concentrations in the bottom of lakes/reservoirs may, in turn, cause reducing geochemical conditions that might release more nutrients from the bottom sediments, creating a seasonal cycle of nutrient enrichment that could increase algal productivity (Cole, 1994). Trace elements, including some of the same trace elements delivered by road runoff, may become environmentally available during turnover of oxygen-depleted bottom waters of the lake/reservoir (Sundby, 1994). Excess sediment may accumulate causing a loss of useful capacity in reservoirs (MacDonald and others, 1991).

Macroinvertebrates and Periphyton

Samples for analysis of benthic macroinvertebrates (aquatic insects) and periphyton (algae) were collected in August 1995 at 11 sites (table 1, fig. 2) (Stevens and others, 1997) to assess current (1995) conditions and develop a baseline of data prior to possible reconstruction of the road. As basic components of the food chain, benthic macroinvertebrates and periphyton are important components of the aquatic ecosystem.

Macroinvertebrates

Some descriptive characteristics and known potential land-use effects or water-quality characteristics for the macroinvertebrate samples are listed in table 11. Values for the taxa richness, density, and the Shannon-Weaver (log base 2) diversity index (Ward and Kondratieff, 1992) at each site were calculated for analysis of the samples. The values for the three characteristics were ranked for ease of comparison. Taxa richness is the number of taxa (to the lowest identified taxonomic level) at each site. Density refers to the total number of individuals per square meter of all species collected in the sample. The Shannon-Weaver (log base 2) diversity is the product of a calculation, involving the number of individuals and the number of species, that is commonly used to evaluate diversity, a desirable characteristic of macroinvertebrate community structure (Ward and Kondratieff, 1992). In general, large values of density are indicative of increasing ecosystem health if diversity is maintained. However, a site dominated by a large number of individuals of a single taxon could indicate an imbalance reflected in a low value for the diversity index (Ward and Kondratieff, 1992). The list of known potential land-use effects or water-quality characteristics were used to aid in selection of sampling sites. Road effect was listed at sites with roads in the basin. Natural conditions were listed if no developed land uses were known in the basin. Acidic and trace-element effects were listed if the high-flow sampling indicated trace-element concentrations larger than other sites in the study area (Stevens and others, 1997) or if evidence of mining was present in the basin (Davis and Streufert, 1990). Primitive camping was listed in table 11 for site GC5 because of the high density of streamside, undeveloped campgrounds.

Benthic macroinvertebrate samples collected from selected sites in August 1995 indicated large variability in characteristics between sites. The taxa richness values ranged from 3 (site GC7) to 32 (site CC9), with a median value of 24 (table 11). The density of organisms ranged from 6.5 (site GC7) to 1,300 organisms/m^2 (site GC5), with a median value of 360 organisms/m^2. The values for the Shannon-Weaver diversity index ranged from 1.58 (site GC7) to 3.84 (site GC8), with a median value of 3.49. Site GC7 consistently ranked lowest for all three characteristics. Sites GC7, CC12, and GC11 had values for all three characteristics that were smaller than the median for each characteristic. Sites GC8, GC10, and CC11 had values for all three characteristics that were larger than or equal to the median for each characteristic (table 11).

Geneva Creek above Duck Creek (site GC7) seems to be less productive (density) and less diverse than the other sites sampled in the study. Two characteristics that differentiate the stream at site GC7 from the other streams sampled in the study are acidic pH and large concentrations of dissolved trace elements (Stevens and others, 1997). Decreasing pH and increasing dissolved trace elements have been implicated in the reduction of benthic macroinvertebrates by toxicity and avoidance of affected stream habitat (Newman and Jagoe, 1994; Allen, 1995). Dissolved trace elements in urban runoff also have been implicated in the reduction of benthic macroinvertebrates by toxicity (Shutes and others, 1993). Of the three sites (GC7, GC11, and CC12) with consistent ranks below the median for the characteristics in table 11,

Table 11. Benthic macroinvertebrate descriptive characteristics and known potential land-use effects or water-quality characteristics for sites sampled in August 1995

[Rank is from smallest = 1 to largest = 11; density reported in number of organisms per square meter]

Site number	Site name	Taxa richness[1]		Density[2]		Diversity[3]		Potentially related land-use or water-quality characteristic
		Value	Rank	Value	Rank	Value	Rank	
CC5	South Clear Creek above Lower Cabin Creek Reservoir near Georgetown	18	3	120	3	3.77	9	Road
CC9	Leavenworth Creek at mouth near Georgetown	32	11	580	8	3.31	3	Trace elements, road
CC11	West Chicago Creek near Idaho Springs	24	6	610	9	3.79	10	Natural conditions
CC12	South Clear Creek above Naylor Creek at upper station near Georgetown	15	2	90	2	3.41	5	Road
GC1	Duck Creek above Duck Lake West Branch near Grant	20	4	490	7	3.53	8	Natural conditions
GC2	Duck Creek above Duck Lake East Branch near Grant	25	7	350	5	3.51	7	Road
GC5	Duck Creek near Grant	30	10	1,300	11	3.36	4	Road, primitive camping areas
GC7	Geneva Creek above Duck Creek near Grant	3	1	6.5	1	1.58	1	Trace elements, acidic, road
GC8	Bruno Gulch above Geneva Park near Grant	26	8	360	6	3.84	11	Natural conditions
GC10	Scott Gomer Creek at mouth near Grant	26	8	760	10	3.49	6	Natural conditions
GC11	Geneva Creek at Grant	20	4	260	4	3.29	2	Trace elements, road
	Median	24		360		3.49		

[1] Taxa richness: the number of taxa in the sample.

[2] Total number of individuals collected per square meter of sample area.

[3] Shannon-Weaver (log base 2) diversity index (Ward and Kondratieff, 1992).

two are Geneva Creek sites affected by upstream acid-sulfate weathering, and the Clear Creek site has road-runoff inputs from upstream and within the reach. The three sites (GC8, GC10, and CC11) with consistent ranks equal to or above the median for the characteristics in table 11 had neutral pH, small dissolved trace-element concentrations (Stevens and others, 1997), and natural conditions in the basin.

Habitat factors that can have substantial effects on benthic macroinvertebrate populations were not analyzed, and the results of analysis of the single sample period in August 1995 probably do not adequately represent long-term averages or seasonal differences. Thus, the determination of any effects of water quality or land use on benthic macroinvertebrates needs additional data and analysis.

Periphyton

Periphyton were sampled at the same 11 sites contemporaneously with the benthic macroinvertebrates (Stevens and others, 1997). Periphyton are algae growing on submerged substrates, such as rocks on the stream bottom. Sample data can be described by density (abundance), which refers to the number of cells per unit of area, and biovolume, which refers to the volume of algal material per unit of area. Total biovolume of periphyton by site is listed in table 12. Relative density and biovolume of periphyton by site and phylum are listed in table 13. Some of the data used have been recalculated from data reported in Stevens and others (1997) to include biovolumes for taxa that were not greater than 5 percent of the cell total at any site. Because the algal-size information necessary for computing biovolume for these taxa could not be accurately measured by the laboratory, the size information was obtained from regional information or standard literature sources (Frank Acker, Academy of Natural Sciences of Philadelphia, written commun., 1998) (appendix, table 15).

Periphyton samples indicated large variability in characteristics between sites. Total biovolume ranged from $0.023 \times 10^6\ \mu m^3/cm^2$ (site GC7) to $4{,}700 \times 10^6\ \mu m^3/cm^2$ (site GC5), with a median value of $0.65\ \mu m^3/cm^2$ (table 12). Total taxa detected ranged from 21 (site GC1) to 99 (site GC5), with a median of 38 taxa. Sites GC5 and CC11 had biovolumes that were about three orders of magnitude larger than the next largest total biovolume at any site (table 12). These sites had large proportions of their biovolume in green algae (table 13), which are larger in size at these sites than the other phyla. Sites GC5 and CC11 also had the largest number of total taxa detected and were the only sites at which phytoflagellate algae were detected (tables 12 and 13). The total number of taxa seem to be somewhat proportional to the total biovolume. Four sites (CC9, GC1, GC8, and GC11) had values that were equal to or less than the median for total taxa and for total biovolume (table 12). Four sites (CC5, CC11, GC5, and GC10) had values that were greater than the median for total taxa and for total biovolume (table 12).

Although three major phyla (green algae, golden algae/diatoms, and blue-green algae) were detected at many sites, each site had a single phylum with greater than 50 percent of the biovolume. Two sites (CC11 and GC5) were dominated by green algae; six sites (CC9, CC12, GC2, GC7, GC10, and GC11) by golden algae/diatoms; and three sites (CC5, GC1, and GC8) by blue-green algae (table 13).

The smallest total biovolume collected was at site GC7 on Geneva Creek upstream from Duck Creek (table 12). As with the benthic macroinvertebrates, periphyton are reduced in population at site GC7 compared to other sites sampled. This site is unique among the sites sampled because of the low pH and relatively large concentrations of trace elements (Stevens and others, 1997). Possible chemical mechanisms that could inhibit algal growth are pH sensitivity (some blue-green algae are known to be pH sensitive) (McKnight, 1988), metal toxicity (copper, a well-known algicide) (Cole, 1994), or excessive deposition of coatings of inorganic precipitates (iron and aluminum hydroxides). Dilution and added alkalinity from Duck Creek, Bruno Gulch, and Scott Gomer Creek neutralizes pH and decreases dissolved trace-element concentrations in a downstream direction. The apparent recovery of macroinvertebrate populations and periphyton biovolume between

Table 12. Periphyton taxa richness and biovolume for sites sampled in August 1995

[Total taxa at lowest taxonomic level; biovolume in units of 10^6 cubic micrometers per square centimeter; rank is from smallest = 1 to largest = 11]

Site	Total taxa detected	Rank	Total biovolume	Rank	Total biovolume, green algae	Total biovolume, golden algae/diatoms	Total biovolume, blue-green algae	Total biovolume, phytoflagellate algae
CC5	68	9	4.9	8	0	1.4	3.5	0
CC9	38	6	.60	5	.050	.55	.0041	0
CC11	86	10	1,000	10	680	300	53	4.4
CC12	27	4	.65	6	0	.59	.062	0
GC1	21	1	.40	4	0	.18	.22	0
GC2	29	5	6.8	9	1.0	4.0	1.8	0
GC5	99	11	4,700	11	4,600	54	3.2	2.6
GC7	42	7	.023	1	.00050	.022	.00099	0
GC8	23	2	.16	2	0	.066	.094	0
GC10	44	8	1.7	7	0	1.7	.048	0
GC11	25	3	.19	3	0	.12	.067	0
Median	38		.65					

Table 13. Relative density and biovolume of periphyton by phylum at biological sampling sites

[Density in percent of total cells at a site; biovolume in percent of total biovolume at a site]

Site	Green algae		Golden algae/diatoms		Blue-green algae		Phytoflagellate algae	
	Density	Biovolume	Density	Biovolume	Density	Biovolume	Density	Biovolume
CC5	0	0	5	28	95	72	0	0
CC9	1	8	68	91	31	1	0	0
CC11	6	66	42	29	52	5	<1	<1
CC12	0	0	29	90	71	10	0	0
GC1	0	0	6	44	94	56	0	0
GC2	<1	15	32	58	68	26	0	0
GC5	11	99	59	1	30	<1	<1	<1
GC7	10	2	34	94	56	4	0	0
GC8	0	0	13	41	87	59	0	0
GC10	0	0	51	97	49	3	0	0
GC11	0	0	31	64	69	36	0	0

sites GC7 and GC11 is consistent with decreasing dissolved trace-element concentrations, such as copper and zinc, and increasing stream pH between those sites. However, the reason for this recovery cannot be fully evaluated in this analysis because habitat factors were not considered for this report, and their effects should not be dismissed.

BULK ATMOSPHERIC DEPOSITION

Bulk-atmospheric-deposition samples were collected at 10 sites (A, B, C, D, E, F, G, H, J, and K) (table 1, fig. 2) near the Guanella Pass road to assess particle- (dust) deposition conditions. Bulk atmospheric deposition is being studied because the issue of dust deposition as a source of sediment to streams and lakes has been raised during initial discussions of the project. The difference in bulk-deposition rates near the road indicates which surface treatment has the greater production of particles and provides a comparison with background rates at sites located away from the road, which may indicate which treatment has the greater effect on surrounding water resources and vegetated areas.

Sites were chosen to represent the range of geographical and road-surface variation in the study area. The collected bulk-atmospheric material included precipitation, atmospheric particles, sidecast or wind-blown particles, loose particles bouncing downslope, raindrop-impact splash, throughfall from vegetation, vegetation debris, and insects. Because these data include only deposited material, dust that is transported out of the area is not sampled by this technique. Particles settling to the ground or deposited with precipitation were measured using 2 to 10 open-bucket collectors (Stevens and others, 1997) at each location, placed along paved (3 sites) and gravel (or dirt) sections (5 sites) of the Guanella Pass road and at sites located at least 500 ft away from any road (5 sites). The collectors near the road were placed 15 ft (horizontal distance) from the edge of the road. At most sites, this distance from the road was near the edge of the disturbed zone (cut or fill area) along the road. The collected particulate matter was measured for 14 days in August and 21 days in October. These periods were long enough to include some dry periods and were chosen to include full weeks because of strong weekly traffic patterns. Average loading rates for each site for both periods were computed, and then all loading rate computations, by site type, were grouped together for computation of median deposition rates (table 14, fig. 8).

The comparison of deposition rates indicates that gravel roads produce substantially more bulk deposition near the road than paved roads. The median deposition rate near gravel (or dirt) roads was 106 times the median rate at a reference site (located at least 500 ft away from a road) and 39 times the median rate near a paved road (table 14). Because the weights of solids for the 21 days were smaller than for the 14 days, other factors, such as precipitation or traffic levels, may have had a more important effect than the length of the collection period. A comparison of the deposition rates between individual sites and the deposition rates during the two sample periods at the same site indicates that deposition rates are highly variable areally and temporally (table 14).

The materials captured by the collector consisted of mostly inorganic particles (rock and soil dust) with some organic particles (leaves and insects). The chemical analyses of bulk atmospheric deposition (Stevens and others, 1997) indicate that material being deposited near the road contains trace elements, phosphorus, and chloride. Sites E, F, G, H, and J are on road segments that have been either treated with magnesium chloride or receive traction materials containing sodium chloride. The chloride deposition rates at sites E, F, G, H, and J (collectors 15 ft away from road only) average 6.85 (mg/ft^2)/d. Chloride

Table 14. Bulk-atmospheric-deposition computations and characteristics by type of site

[ft, feet; mg, milligrams; ft^2, square feet; (mg/d)/ft^2, milligrams per day per square foot]

Site	Start date	Distance from road (ft)	Average solids[1] (mg)	Number of days	Area of collector (ft^2)	Deposition rate [(mg/d)/ft^2]
			Reference sites[2]			
B	08–09–95	500	185	14	0.688	19.2
B	10–04–95	500	143	21	.688	9.9
C	08–09–95	500	235	14	.688	24.4
C	10–04–95	500	90	21	.688	6.23
F	08–09–95	500	662	14	.688	68.7
F	10–04–95	500	61	21	.688	4.22
H	08–09–95	500	1,372	14	.688	142
H	10–04–95	500	106	21	.688	7.34
K	08–09–95	1,000	98	14	.688	10.2
K	10–04–95	1,000	197	21	.688	13.6
					Median	11.9
			Paved sites[3]			
C	08–09–95	15	487	14	.688	50.6
C	10–04–95	15	262	21	.688	18.1
D	08–09–95	15	959	14	.688	99.6
D	10–04–95	15	359	21	.688	24.8
J	08–09–95	15	322	14	.688	33.4
J	10–04–95	15	442	21	.688	30.6
					Median	32.0
			Gravel or dirt sites[4]			
A	08–09–95	15	5,980	14	.688	621
A	10–04–95	15	6,900	21	.688	478
E	08–09–95	15	19,600	14	.688	2,030
E	10–04–95	15	110,000	21	.688	7,590
F	08–09–95	15	4,320	14	.688	449
F	10–04–95	15	22,300	21	.688	1,540
G	08–09–95	15	9,470	14	.688	983
G	10–04–95	15	39,300	21	.688	2,720
H	08–09–95	15	17,800	14	.688	1,850
H	10–04–95	15	1,160	21	.688	80.3
					Median	1,260

[1] Average of all collectors at the indicated distance (data from Stevens and others, 1997). Duplicate samples not included.

[2] Collectors at least 500 feet away from road.

[3] Collectors adjacent to paved sections of road.

[4] Collectors adjacent to gravel or dirt sections of road.

deposition rates for reference sites B, C, F, H, and K (at least 500 ft from the road) average 0.22 (mg/ft^2)/d (Stevens and others, 1997). The large chloride deposition rates near the road indicate that some of the chloride is moving off the road in bulk deposition.

Concentrations of trace elements (copper, iron, lead, manganese, and zinc) in bulk atmospheric deposition seem to be related to the concentration of undissolved solids (Stevens and others, 1997). Iron, manganese, and zinc are the most abundant, whereas lead and copper are the least. Phosphorus concentration also seems to increase with increasing undissolved solids (Stevens and others, 1997). Sites J and K have anomalously large phosphorus concentrations, probably because of organic phosphorus in leaf matter captured in the collector.

If a stream, lake, or reservoir is located near a road, bulk atmospheric deposition may settle directly onto open water or be washed into these water bodies by surface runoff. In sufficient quantity, these materials could increase concentrations of water-quality constituents, especially sediment, and degrade water quality.

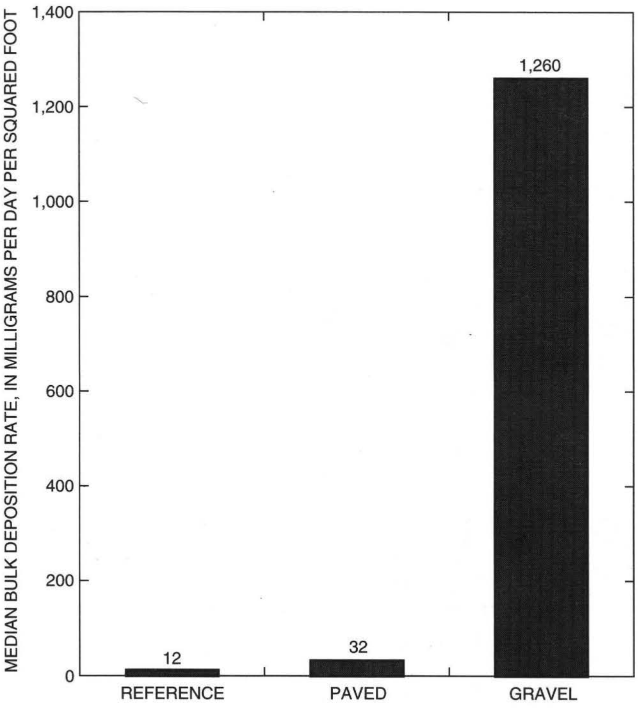


Figure 8. Comparison of median bulk-atmospheric-deposition rates by type of site. Median bulk-deposition rates indicated above the bars in the graph.

SUMMARY

A study of water quality and bulk atmospheric deposition in the Guanella Pass area during water year 1995 (October 1994 to September 1995) has provided information to characterize current conditions in the South Clear Creek and Geneva Creek Basins about 40 mi west of Denver, Colorado, prior to a possible road-reconstruction project. Water samples were collected from streams, ground water, lakes and reservoirs, and road runoff.

Streamflow in the Guanella Pass area is primarily the result of the melting of winter-accumulated snowpack. Afternoon thunderstorms contribute minimally to flow in summer. Annual runoff at five stream-monitoring sites ranged from 683 to 1,070 acre-ft/mi^2. Because no long-term streamflow records are available in the study area, an evaluation of peak flow and water yield in a historical context for the five monitoring sites was not possible. However, a long-term site 6 mi downstream from the study area on Clear Creek had a 1995 annual runoff of 150 percent of normal.

Results of a high- and low-flow water-quality sampling at 21 sites in June and 23 sites in September indicated that streams in the study area generally had small concentrations of dissolved solids, nutrients, trace elements, organic carbon, and suspended sediment. Concentrations varied seasonally, with larger concentrations of dissolved constituents at the low-flow sampling and larger concentrations of total recoverable constituents and suspended sediment at the high-flow sampling. Specific conductance generally increased in a downstream direction along South Clear Creek and generally decreased in a downstream direction on Geneva Creek. Low pH values and large trace-element concentrations were associated with areas affected by mining activity or in areas where the natural oxidation of sulfide minerals may produce acidic conditions and release trace elements. Increases in particulate nutrients, total recoverable trace elements, and suspended-sediment transport were related to snowmelt and thunderstorms. Benthic macroinvertebrate and periphyton (algae) samples collected from selected sites in August 1995 indicated large variability in characteristics among sites. An upper Geneva Creek site, which has water chemistry affected by acid-sulfate weathering, consistently ranked lowest in benthic macroinvertebrate taxa richness, density, and diversity and lowest in total biovolume of periphyton among all sites sampled.

Analytical results of ground-water samples collected from selected springs and U.S. Department of Agriculture Forest Service campground wells indicated that ground water near the road had a generally neutral pH, was a calcium bicarbonate type, and contained small concentrations of nutrients and trace elements. Large dissolved-zinc and -copper concentrations in campground well water probably reflected leaching of handpump hardware or well-casing materials. The median concentrations of chloride, nitrite plus nitrate, ammonia, and dissolved aluminum, iron and manganese were larger in road runoff, indicating that ground-water concentrations of these constituents might increase with road-runoff infiltration. Based on U.S. Environmental Protection Agency drinking-water regulations and water samples collected at campground wells, the primary maximum contaminant levels were exceeded once for dissolved uranium, but road runoff is unlikely to affect uranium concentrations.

Analytical results of samples collected at the surface and near the bottom of four lakes and reservoirs (Green Lake, Clear Lake, Lower Cabin Creek Reservoir, and Duck Lake) during August 1995 indicated that the water was a calcium bicarbonate type and was characterized by generally small concentrations of nutrients and trace elements. The three deeper water bodies, Duck Lake (101 ft), Clear Lake (105 ft), and Green Lake (52 ft), were moderately to strongly stratified on the basis of water temperature, specific conductance, pH, and dissolved oxygen in August 1995. Duck Lake was the most hypoxic near the bottom where dissolved-oxygen concentrations were less than 1 mg/L about 20 ft above the bottom of the lake. Water samples collected near the bottom of Duck Lake had relatively large concentrations of dissolved ammonia, total recoverable iron, and total recoverable manganese and low concentrations of dissolved oxygen, indicating that reducing conditions developed at the bottom of the lake. Relatively large concentrations of trace elements in bottom sediment from Green Lake indicated the contribution of mineralized water from Leavenworth Creek that is used to maintain the lake level.

Road runoff was characterized by 11 water samples collected during water year 1995 (5 snowmelt, 6 rainfall). Instantaneous flow measurements at the time of sampling indicated that the volume of road runoff from any single drainage feature (ditch or culvert) was small compared to streamflows. Analytical results of samples of road runoff indicated a large range in specific conductance, pH in a neutral range, and large values of turbidity. Median major-ion concentrations indicated a calcium bicarbonate type water. Sodium or magnesium and chloride, however, were predominant in some samples and were probably related to applications of sodium and magnesium chloride to the road.

Although dissolved nutrients and trace elements were detected in samples of road runoff, particulate forms had the largest concentrations. Many trace elements had median total recoverable concentrations that were several times larger than median dissolved concentrations. Suspended-sediment concentrations in road runoff were large, and the sediment was primarily fine grained. Large concentrations of dissolved and total recoverable nutrients, total recoverable trace elements, total organic carbon, and suspended sediment in road runoff may indicate the potential to increase concentrations in streams, lakes, and reservoirs when road runoff reaches these surface waters. Because the predominant road-runoff trace-element phase is particulate, potential toxic effects on receiving water may be minimal compared to aquatic-life standards and regulations in the State of Colorado, which are primarily based on dissolved concentrations. Ground-water concentrations of chloride, nitrite plus nitrate, and dissolved iron and manganese could increase if the larger concentrations present in road runoff infiltrate shallow aquifers.

Bulk-atmospheric-deposition samples (primarily inorganic particles with some organic material) were collected at 10 sites near the Guanella Pass road to assess deposition rates adjacent to paved and unpaved roads and reference sites located away from the road. The median bulk-atmospheric-deposition rate for gravel (or dirt) roads was 106 times the median rate at a reference site (located at least 500 ft away from a road) and 39 times the median rate at a paved road site. If a stream, lake, or reservoir is located near the road, bulk-atmospheric-deposition products may settle directly onto open water or be washed in by surface runoff.

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APPENDIX

Table 15. Periphyton taxa, biovolume per cell, sources of cell size, and reference sources for estimated biovolumes

[Source: Frank Acker, Academy of Natural Sciences of Philadelphia, written commun., 1998; biovolume in cubic millimeters; --, not applicable]

Phylum	Family	Taxon name (genus species)	Biovolume/ cell	Biovolume source[1]	Reference source[2]
Chlorophyta	Chaetophoraceae	*Stigeoclonium lubricum*	16	AVG	--
Chlorophyta	Desmidiaceae	*Closterium acerosum*	191,090	L	15
Chlorophyta	Desmidiaceae	*Closterium moniliferum*	14,078	AVG	--
Chlorophyta	Desmidiaceae	*Closterium littorale*	22,882	L	16
Chlorophyta	Desmidiaceae	*Cosmarium botrytes*	206,633	L	16
Chlorophyta	Desmidiaceae	*Staurastrum* sp.	13,742	[3]L	--
Chlorophyta	Microsporaceae	*Microspora* sp.	4,979	[3]L	--
Chlorophyta	Ulvaceae	*Schizomeris leibleinii*	6,914	L	13
Chlorophyta	Zygnemataceae	*Spirogyra* sp.	38,858	AVG	--
Chlorophyta	(undetermined)	(undetermined) sp. (filamentous)	142	AVG	--
Chlorophyta	(undetermined)	(undetermined) sp.	120	AVG	--
Chlorophyta	(undetermined)	(undetermined) (coccoid 3–5)	8	AVG	--
Chlorophyta	(undetermined)	(undetermined) (coccoid >10)	1,767	[3]L	--
Chrysophyta	Achnanthaceae	*Achnanthes clevei* var. *rostrata*	140	L	11
Chrysophyta	Achnanthaceae	*Achnanthes deflexa*	205	AVG	--
Chrysophyta	Achnanthaceae	*Achnanthes detha*	85	AVG	--
Chrysophyta	Achnanthaceae	*Achnanthes grana*	36	L	2
Chrysophyta	Achnanthaceae	*Achnanthes lapponica*	225	L	5
Chrysophyta	Achnanthaceae	*Achnanthes microcephala*	62	L	11
Chrysophyta	Achnanthaceae	*Achnanthes minutissima*	75	GP	--
Chrysophyta	Achnanthidiaceae	*Achnanthidium affine*	121	AVG	--
Chrysophyta	Achnanthidiaceae	*Achnanthidium biporomum*	334	L	2
Chrysophyta	Achnanthidiaceae	*Achnanthidium clevei rostratum*	300	L	11
Chrysophyta	Achnanthidiaceae	*Achnanthidium exiguum*	54	AVG	--
Chrysophyta	Achnanthidiaceae	*Achnanthidium lanceolatum*	118	AVG	--
Chrysophyta	Achnanthidiaceae	*Achnanthidium lanceolatum dubium*	75	AVG	--
Chrysophyta	Achnanthidiaceae	*Achnanthidium minutissimum*	204	L	10
Chrysophyta	Achnanthidiaceae	*Achnanthidium pusillum*	76	AVG	--
Chrysophyta	Amphiphleuraceae	*Frustulia rhomboides*	2,299	AVG	--
Chrysophyta	Amphiphleuraceae	*Frustulia vulgaris*	3,450	L	7
Chrysophyta	Aulacoseiraceae	*Aulacoseira alpigena*	165	GP	--
Chrysophyta	Aulacoseiraceae	*Aulacoseira ambigua*	74	AVG	--
Chrysophyta	Aulacoseiraceae	*Aulacoseira italica*	207	AVG	--
Chrysophyta	Aulacoseiraceae	*Aulacoseira italica tenuissima*	401	GP	--
Chrysophyta	Bacillariaceae	*Denticula elegans*	574	AVG	--
Chrysophyta	Bacillariaceae	*Denticula tenuis*	600	L	8

Table 15. Periphyton taxa, biovolume per cell, sources of cell size, and reference sources for estimated biovolumes—Continued

[Source: Frank Acker, Academy of Natural Sciences of Philadelphia, written commun., 1998; biovolume in cubic millimeters; --, not applicable]

Phylum	Family	Taxon name (genus species)	Biovolume/ cell	Biovolume source[1]	Reference source[2]
Chrysophyta	Bacillariaceae	*Hantzschia amphioxys*	11,285	L	8
Chrysophyta	Bacillariaceae	*Nitzschia acicularis*	113	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia amphibia*	168	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia dissipata*	244	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia dissipata media*	268	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia frustulum*	92	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia frustulum perminuta*	56	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia frustulum subsalina*	74	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia kuetzingiana*	69	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia palea*	200	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia romana*	48	AVG	--
Chrysophyta	Bacillariaceae	*Nitzschia sociabilis*	240	L	8
Chrysophyta	Bacillariaceae	*Nitzschia subtilis*	956	L	3
Chrysophyta	Biddulphiaceae	*Biddulphia laevis*	9,975	AVG	--
Chrysophyta	Brachysiraceae	*Brachysira brebissonii*	129	AVG	--
Chrysophyta	Brachysiraceae	*Brachysira vitrea*	75	AVG	--
Chrysophyta	Catenulaceae	*Amphora ovalis*	44,280	L	12
Chrysophyta	Catenulaceae	*Amphora ovalis pediculus*	692	AVG	--
Chrysophyta	Catenulaceae	*Amphora perpusilla*	75	AVG	--
Chrysophyta	Cocconeidaceae	*Cocconeis pediculus*	1,060	AVG	--
Chrysophyta	Cocconeidaceae	*Cocconeis placentula euglypta*	283	AVG	--
Chrysophyta	Cocconeidaceae	*Cocconeis placentula lineata*	427	AVG	--
Chrysophyta	Cocconeidaceae	*Cocconeis thumensis*	62	AVG	--
Chrysophyta	Cymbellaceae	*Cymbella affinis*	480	AVG	--
Chrysophyta	Cymbellaceae	*Cymbella aspera*	11,390	L	7
Chrysophyta	Cymbellaceae	*Cymbella brehmii*	61	L	12
Chrysophyta	Cymbellaceae	*Cymbella cesatii*	351	L	7
Chrysophyta	Cymbellaceae	*Cymbella cistula*	1,270	AVG	--
Chrysophyta	Cymbellaceae	*Cymbella cuspidata*	3,949	L	12
Chrysophyta	Cymbellaceae	*Cymbella lunata*	306	L	12
Chrysophyta	Cymbellaceae	*Cymbella microcephala*	36	AVG	--
Chrysophyta	Cymbellaceae	*Cymbella minuta latens*	183	L	12
Chrysophyta	Cymbellaceae	*Cymbella minuta silesiaca*	480	AVG	--
Chrysophyta	Cymbellaceae	*Cymbella naviculiformis*	1,320	L	7
Chrysophyta	Cymbellaceae	*Cymbella tumida*	2,688	AVG	--
Chrysophyta	Cymbellaceae	*Cymbella turgidula*	884	AVG	--

Table 15. Periphyton taxa, biovolume per cell, sources of cell size, and reference sources for estimated biovolumes—Continued

[Source: Frank Acker, Academy of Natural Sciences of Philadelphia, written commun., 1998; biovolume in cubic millimeters; --, not applicable]

Phylum	Family	Taxon name (genus species)	Biovolume/ cell	Biovolume source[1]	Reference source[2]
Chrysophyta	Cymbellaceae	*Encyonema minutum*	342	GP	--
Chrysophyta	Cymbellaceae	*Encyonema muelleri*	924	AVG	--
Chrysophyta	Cymbellaceae	*Placoneis placentula*	1,155	L	7
Chrysophyta	Diadesmidaceae	*Luticola cohnii*	303	AVG	--
Chrysophyta	Diploneidaceae	*Diploneis bombus*	8,370	L	11
Chrysophyta	Diploneidaceae	*Diploneis elliptica*	7,875	L	11
Chrysophyta	Diploneidaceae	*Diploneis oblongella*	3,383	L	11
Chrysophyta	Epithemiaceae	*Rhopalodia gibba*	12,525	AVG	--
Chrysophyta	Epithemiaceae	*Rhopalodia gibba* var. *ventricosa*	5,082	AVG	--
Chrysophyta	Eunotiaceae	*Eunotia exigua*	103	GP	--
Chrysophyta	Eunotiaceae	*Eunotia flexuosa*	6,799	L	9
Chrysophyta	Eunotiaceae	*Eunotia pectinalis* var. *minor*	257	AVG	--
Chrysophyta	Eunotiaceae	*Eunotia praerupta*	4,275	L	11
Chrysophyta	Eunotiaceae	*Eunotia tenella*	91	AVG	--
Chrysophyta	Fragilariaceae	*Asterionella formosa*	24	AVG	--
Chrysophyta	Fragilariaceae	*Diatoma anceps*	1,116	L	11
Chrysophyta	Fragilariaceae	*Diatoma mesodon*	793	GP	--
Chrysophyta	Fragilariaceae	*Diatomella balfouriana*	2,240	L	11
Chrysophyta	Fragilariaceae	*Fragilaria brevistriata inflata*	23	AVG	--
Chrysophyta	Fragilariaceae	*Fragilaria construens binodis*	40	AVG	--
Chrysophyta	Fragilariaceae	*Fragilaria construens pumila*	126	GP	--
Chrysophyta	Fragilariaceae	*Fragilaria construens venter*	46	AVG	--
Chrysophyta	Fragilariaceae	*Fragilaria pinnata lancettula*	9	AVG	--
Chrysophyta	Fragilariaceae	*Fragilaria vaucheriae*	192	GP	--
Chrysophyta	Fragilariaceae	*Fragilariforma virescens*	301	GP	--
Chrysophyta	Fragilariaceae	*Fragilaria virescens clavata*	3,381	L	14
Chrysophyta	Fragilariaceae	*Fragilaria virescens exigua*	4	AVG	--
Chrysophyta	Fragilariaceae	*Hannaea arcus*	780	GP	--
Chrysophyta	Fragilariaceae	*Hannaea arcus amphioxys*	1,908	L	11
Chrysophyta	Fragilariaceae	*Martyana martyi*	289	AVG	--
Chrysophyta	Fragilariaceae	*Meridion circulare*	39	AVG	--
Chrysophyta	Fragilariaceae	*Meridion circulare constrictum*	1,341	L	11
Chrysophyta	Fragilariaceae	*Pseudostaurosira brevistriata*	99	GP	--
Chrysophyta	Fragilariaceae	*Staurosira construens*	54	AVG	--
Chrysophyta	Fragilariaceae	*Staurosirella leptostauron*	36	AVG	--
Chrysophyta	Fragilariaceae	*Staurosirella pinnata*	113	GP	--

Table 15. Periphyton taxa, biovolume per cell, sources of cell size, and reference sources for estimated biovolumes—Continued

[Source: Frank Acker, Academy of Natural Sciences of Philadelphia, written commun., 1998; biovolume in cubic millimeters; --, not applicable]

Phylum	Family	Taxon name (genus species)	Biovolume/ cell	Biovolume source[1]	Reference source[2]
Chrysophyta	Fragilariaceae	*Synedra acus*	1,064	AVG	--
Chrysophyta	Fragilariaceae	*Synedra minuscula*	39	AVG	--
Chrysophyta	Fragilariaceae	*Synedra rumpens*	122	GP	--
Chrysophyta	Fragilariaceae	*Synedra rumpens familiaris*	201	AVG	--
Chrysophyta	Fragilariaceae	*Synedra rumpens fragilarioides*	230	L	11
Chrysophyta	Fragilariaceae	*Synedra rumpens meneghiniana*	134	AVG	--
Chrysophyta	Fragilariaceae	*Synedra tenera*	739	L	11
Chrysophyta	Fragilariaceae	*Synedra ulna*	8,762	AVG	--
Chrysophyta	Fragilariaceae	*Synedra ulna oxyrhynchus*	1,773	AVG	--
Chrysophyta	Gomphonemataceae	*Gomphoneis eriense*	3,877	AVG	--
Chrysophyta	Gomphonemataceae	*Gomphoneis herculeana*	5,391	AVG	--
Chrysophyta	Gomphonemataceae	*Gomphonema acuminatum*	1,172	AVG	--
Chrysophyta	Gomphonemataceae	*Gomphonema angustatum*	345	GP	--
Chrysophyta	Gomphonemataceae	*Gomphonema angustatum productum*	610	L	10
Chrysophyta	Gomphonemataceae	*Gomphonema* cf. *clevei*	129	AVG	--
Chrysophyta	Gomphonemataceae	*Gomphonema grunowii*	757	L	12
Chrysophyta	Gomphonemataceae	*Gomphonema intricatum*	1,400	L	12
Chrysophyta	Gomphonemataceae	*Gomphonema olivaceoides hutchinsoniana*	112	AVG	--
Chrysophyta	Gomphonemataceae	*Gomphonema olivaceum*	246	AVG	--
Chrysophyta	Gomphonemataceae	*Gomphonema parvulum*	148	GP	--
Chrysophyta	Gomphonemataceae	*Gomphonema subclavatum*	675	AVG	--
Chrysophyta	Gomphonemataceae	*Reimeria sinuata*	230	GP	--
Chrysophyta	Naviculaceae	*Caloneis bacillum*	413	AVG	--
Chrysophyta	Naviculaceae	*Caloneis ventricosa* var. *truncatula*	1,132	AVG	--
Chrysophyta	Naviculaceae	*Navicula abiskoensis*	1,004	L	7
Chrysophyta	Naviculaceae	*Navicula bryophila*	79	L	7
Chrysophyta	Naviculaceae	*Navicula cincta*	283	L	7
Chrysophyta	Naviculaceae	*Navicula contenta* var. *biceps*	48	AVG	--
Chrysophyta	Naviculaceae	*Navicula cryptocephala*	218	AVG	--
Chrysophyta	Naviculaceae	*Navicula lanceolata*	683	AVG	--
Chrysophyta	Naviculaceae	*Navicula luzonensis*	30	AVG	--
Chrysophyta	Naviculaceae	*Navicula minima*	36	AVG	--
Chrysophyta	Naviculaceae	*Navicula paucivisitata*	40	L	11
Chrysophyta	Naviculaceae	*Navicula pupula* var. *mutata*	91	L	11

[1] Biovolume sources: GP = measured in samples from Guanella Pass; AVG = average size from all samples analyzed from 1993–95 collections; L = calculated using size values from literature sources.

[2] Number of reference cited on following page.

[3] Biovolume size information for taxa not identified to species are estimated from an average of sizes within the lowest taxonomic classification.

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