Prepared in cooperation with the National Park Service

Water-Quality Characteristics of Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006

Scientific Investigations Report 2007–5221

U.S. Department of the Interior
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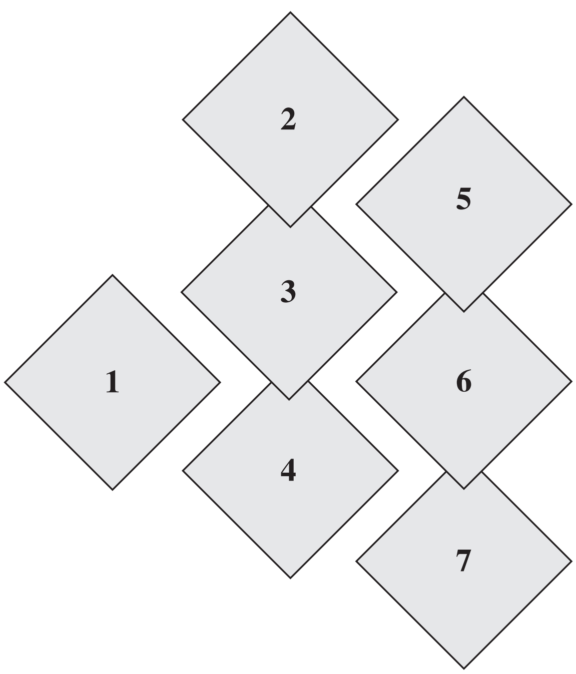

Front cover photographs:

1. Site TC1 on Taggart Creek in June 2006 (photograph by Jon Mason)
2. Site GC2 on Granite Creek in June 2006 (photograph by Jon Mason)
3. Site CC1 on Cottonwood Creek in July 2006.
4. Site CC2 on Cottonwood Creek in July 2006.
5. Site LC1 on Lake Creek in August 2006.
6. Site GC2 on Granite Creek in August 2006.
7. Site CC2 (dry) on Cottonwood Creek in October 2006.

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Conversion Factors, Datum, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton per day (ton/d)	0.9072	metric ton per day

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

$$°F=(1.8×°C)+32$$

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

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L)

Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Thus, the water year ending September 30, 2006 is called water year 2006.

Abbreviated Water-Quality Units

mg/L	milligrams per liter
µg/L	micrograms per liter
µm	micrometer
µS/cm at 25°C	microsiemens per centimeter at 25 degrees Celsius

Abbreviations

GC/MS	gas chromatography/mass spectrometry
NAWQA	National Water-Quality Assessment
NPS	National Park Service
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Water-Quality Characteristics of Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006

By Melanie L. Clark[1], Jerrod D. Wheeler[1], and Susan E. O'Ney[2]

Abstract

To address water-resource management objectives of the National Park Service in Grand Teton National Park, the U.S. Geological Survey in cooperation with the National Park Service has conducted water-quality sampling on streams in the Snake River headwaters area. A synoptic study of streams in the western part of the headwaters area was conducted during 2006. Sampling sites were located on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek. Sampling events in June, July, August, and October were selected to characterize different hydrologic conditions and different recreational-use periods. Stream samples were collected and analyzed for field measurements, major-ion chemistry, nutrients, selected trace elements, pesticides, and suspended sediment.

Water types of Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek were calcium bicarbonate. Dissolved-solids concentrations were dilute in Cottonwood Creek and Taggart Creek, which drain Precambrian-era rocks and materials derived from these rocks. Dissolved-solids concentrations ranged from 11 to 31 milligrams per liter for samples collected from Cottonwood Creek and Taggart Creek. Dissolved-solids concentrations ranged from 55 to 130 milligrams per liter for samples collected from Lake Creek and Granite Creek, which drain Precambrian-era rocks and Paleozoic-era rocks and materials derived from these rocks. Nutrient concentrations generally were small in samples collected from Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek. Dissolved-nitrate concentrations were the largest in Taggart Creek. The Taggart Creek drainage basin has the largest percentage of barren land cover of the basins, and subsurface waters of talus slopes may contribute to dissolved-nitrate concentrations in Taggart Creek. Pesticide concentrations, trace-element concentrations, and suspended-sediment concentrations generally were less than laboratory reporting levels or were small for all samples.

Water-quality characteristics of streams in the western part of the Snake River headwaters area were compared to water-quality characteristics of streams sampled in 2002 in the eastern part of the headwaters area. The median dissolved-solids concentration (55 milligrams per liter) for samples collected from western streams was smaller than the median dissolved-solids concentration (125 milligrams per liter) for samples collected from eastern streams. The small dissolved-solids concentrations in the western streams are a result of the large areas underlain by resistant Precambrian-era rocks that compose the Teton Range compared to the more erodable Mesozoic-era sedimentary rocks that compose the mountains in the eastern part of the headwaters area. The Teton Range also receives higher annual precipitation than the mountains in the east. The median total-nitrogen concentration (0.17 milligram per liter) in samples collected from streams in the western part of the Snake River headwaters area was larger than the median concentration (0.10 milligram per liter) for samples collected from streams in the eastern part of the headwaters area, in part because of larger dissolved-nitrate concentrations in samples from the western streams compared to the eastern streams. In contrast, total-phosphorus concentrations generally were larger for samples collected from eastern streams. Large total-phosphorus concentrations in the eastern streams were associated with large suspended-sediment concentrations. The source of the phosphorus and sediment probably is Mesozoic-era sedimentary rocks of marine origin that underlie parts of the eastern drainage basins.

Introduction

Nearly four million people each year visit Grand Teton National Park in northwestern Wyoming because of its stunning mountain scenery, wilderness lakes, and abundant wildlife. Surface-water resources (including Jackson Lake, high alpine lakes, and streams) cover more than 10 percent of the Park (Mott, 1998). The Snake River and its tributaries are important features of Grand Teton National Park (fig. 1), and visitors use the streams for recreation, consume fish caught from the streams, and enjoy their aesthetic qualities. The

[1] U.S. Geological Survey

[2] National Park Service

Snake River and its tributaries are designated as “outstanding waters” (Class 1) through Grand Teton National Park (Wyoming Department of Environmental Quality, 2001). The maintenance of the Park’s good quality waters is one of the primary management objectives for the National Park Service (NPS) (Mott, 1998).

To address water-resource management objectives of the NPS, the U.S. Geological Survey (USGS), in cooperation with the NPS, has conducted various surface-water investigations in Grand Teton National Park. A summary of water resources of Grand Teton National Park by Cox (1974) represents one of the early cooperative investigations. More recently, water-quality sampling on the Snake River regularly has been conducted to characterize water quality in the Snake River. Discrete water-quality samples were collected from the Snake River at Flagg Ranch in Grand Teton National Park as part of the USGS National Water-Quality Assessment (NAWQA) Program during 1992–95 (Clark, 1997; Clark and others, 1998). Additional discrete water-quality sampling on the Snake River at Flagg Ranch and at Moose, Wyo., was conducted during 1995–2004. In 2002, continuous monitoring for dissolved oxygen, specific conductance, pH, and stream temperature was established on the Snake River at Moose, Wyo. The continuous monitoring on the Snake River is ongoing (2007). A synoptic study of five tributaries (Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek) was conducted during 2002 to characterize baseline water quality in the eastern part of the Snake River headwaters area. Water-quality characteristics of the Snake River and five eastern tributaries to the Snake River are summarized in Clark and others (2004). Other USGS and NPS surface-water-quality studies include an investigation of bacteria sources in high recreational use basins (Farag and others, 2001) and a sensitivity analysis of alpine and subalpine lakes in Grand Teton National Park to acidification from atmospheric deposition (Nanus and others, 2005).

To further characterize stream-water quality in Grand Teton National Park, a synoptic study of four streams (Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek) was conducted during 2006 in the western part of the Snake River headwaters area. Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek drain much of the western part of Grand Teton National Park downstream from Jackson Lake (fig. 1, table 1). Stream samples were collected and analyzed for field measurements, major-ion chemistry, nutrients, selected trace elements, pesticides, and suspended sediment. Baseline water-quality information from these studies will be used by the NPS to assess changes that may occur in water quality in the water resources of Grand Teton National Park.

Purpose and Scope

The purpose of this report is to describe the water-quality characteristics of selected streams in the Snake River headwaters area that flow through Grand Teton National Park. Specifically, this report describes (1) land cover and baseline water-quality conditions for streamflow, major-ion chemistry, nutrients, selected trace elements, pesticides, and suspended sediment for sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek during a synoptic study in 2006; and (2) a comparison of results of the synoptic study of the western streams conducted during 2006 in the Snake River headwaters area with results of a synoptic study of eastern streams conducted during 2002. Two sampling sites were selected on each of the streams for the synoptic study. Sampling events in June, July, August, and October were selected to characterize different hydrologic conditions and different recreational-use periods by visitors to Grand Teton National Park.

Study Area

Grand Teton National Park is in Teton County in northwestern Wyoming and lies within the Middle Rocky Mountain Province (Omernik, 1987) and entirely within the Snake River Basin. The Teton Range, which bounds the Park to the west, is an upthrown, tilted fault-block. The steepness of the Teton Range along the eastern fault makes the mountains the focal point of Grand Teton National Park, rising more than 7,000 feet above the valley floor. Altitudes in the study area range from about 6,400 feet (ft) above the National Geodetic Vertical Datum of 1929 (NGVD 29) at site GC2 on Granite Creek to 13,770 ft above NGVD 29 at the summit of the Grand Teton. Most of the rest of Grand Teton National Park is within the Jackson Hole structural basin, a folded and faulted downwarp of deposits that range in thickness from 4,000 to 7,000 feet (Nolan and Miller, 1995). The central part of Jackson Hole tilted to the west as the western edge of the valley block moved downward along the Teton fault system (Love and others, 1972). Much of the park, including Jackson Hole, has been covered by glaciers that originated in the mountainous areas and generally flowed southward during several periods of glaciation.

The geology of the study area includes Precambrian-era rocks, Paleozoic-era rocks, and Quaternary-period surficial deposits (Love and Christiansen, 1985). The Teton Range consists of a core of Precambrian-era igneous and metamorphic rocks overlain by westward dipping Paleozoic-era sedimentary rocks (Cox, 1974). Precambrian-era rocks include granite gneiss, granitic rocks, metamorphosed mafic and ultramafic rocks, and metasedimentary and metavolcanic rocks (Love and others, 1992). Paleozoic-era sedimentary rocks include the Bighorn Dolomite, Gallatin Limestone, Gros Ventre Formation, Flathead Sandstone, Madison Limestone, and Darby Formation (Love and others, 1992). Quaternary-period surficial deposits are in all of the drainage basins (Love and others, 1992). Alluvium and colluvium are present in stream valleys as flood-plain deposits, with alluvial fans along the margins of Jackson Hole where streams enter the valley, and as glacial-outwash material that has been reworked by

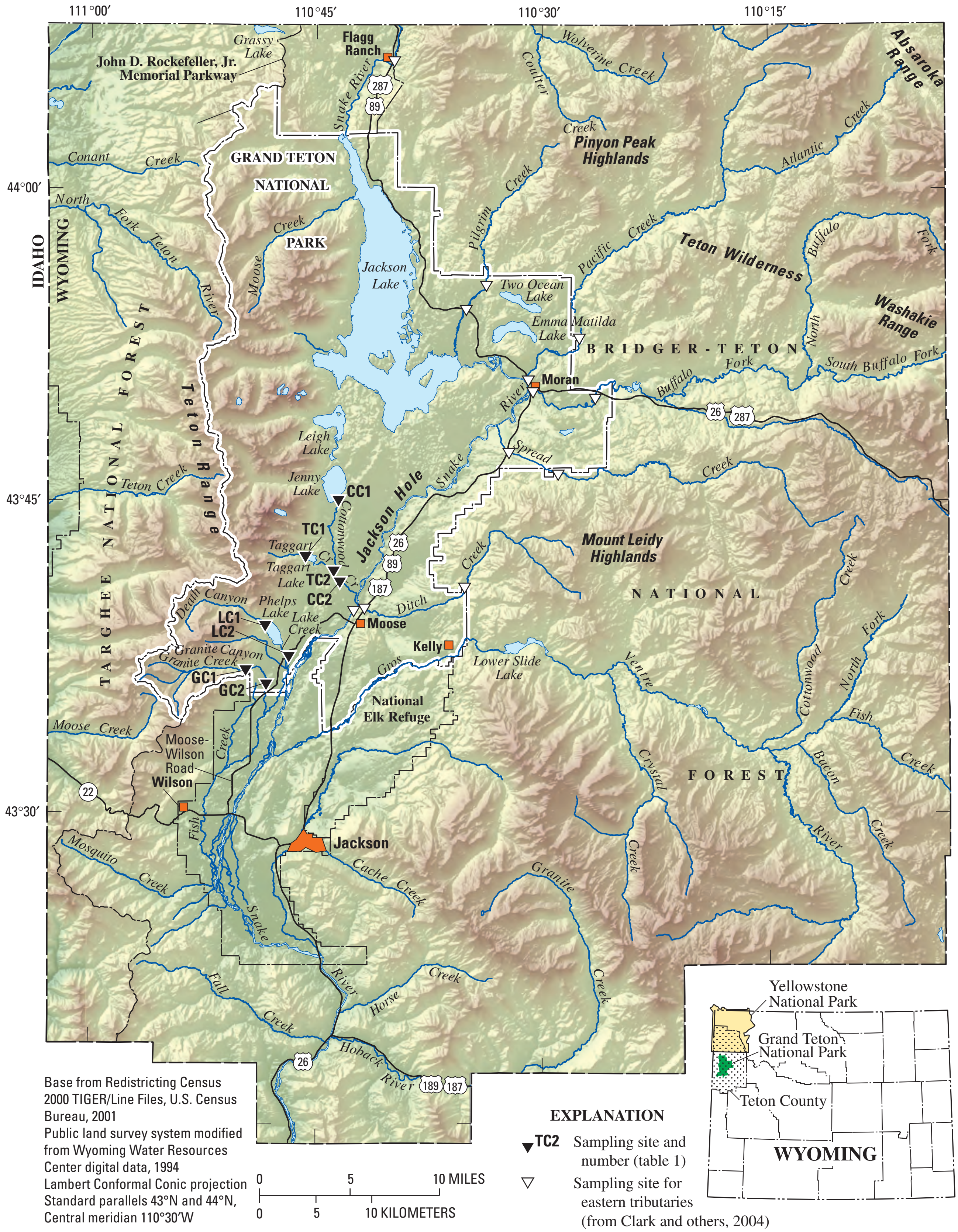

Figure 1. Location of sampling sites in the Snake River headwaters area, Grand Teton National Park, Wyoming.

Table 1. Sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming.

Site number (fig. 1)	U.S. Geological Survey station number	Site name	Drainage-basin area (square miles)
CC1	13012800	Cottonwood Creek at outlet of Jenny Lake near Moose, Grand Teton National Park, Wyo.	48.8
TC1	434222110454601	Taggart Creek near inlet to Taggart Lake near Moose, Grand Teton National Park, Wyo.	5.5
TC2	13012900	Taggart Creek near Moose, Grand Teton National Park, Wyo.	6.7
CC2	13013000	Cottonwood Creek near Moose, Grand Teton National Park, Wyo.	72.3
LC1	433908110482201	Lake Creek near inlet to Phelps Lake near Moose, Grand Teton National Park, Wyo.	13.2
LC2	433738110465301	Lake Creek at Moose-Wilson Road near Moose, Grand Teton National Park, Wyo.	15.6
GC1	433655110494101	Granite Creek near mouth of Granite Canyon near Moose, Grand Teton National Park, Wyo.	13.7
GC2	13016305	Granite Creek above Granite Creek supplemental near Moose, Grand Teton National Park, Wyo.	14.9

streams. Glacial deposits are present, including drift deposits, which are associated with morainal features (Cox, 1974). Small glaciers that flowed east from the Teton Range melted and formed glacial lakes (including Jenny Lake, Taggart Lake, and Phelps Lakes) behind the moraines. Gravel, pediment, fan deposits, and landslide deposits (including talus and related deposits) also are in the study area. Distribution of rocks types for the drainage basins (table 2) were determined using digital drainage area boundaries and a digital version of bedrock geology (Green and Drouillard, 1994) that was based on the geologic map of Wyoming by Love and Christiansen (1985).

Of the four western streams in the synoptic study, Cottonwood Creek is the only stream that is a direct tributary to the Snake River. Taggart Creek is a tributary to Cottonwood Creek. Lake Creek is a tributary to Fish Creek, a tributary to the Snake River downstream from Grand Teton National Park. Granite Creek is a tributary to Lake Creek. The general hydrology of the streams is typical of mountainous areas in Wyoming. Peak streamflows occur in late spring or early summer with the melting of the annual snowpack. Ground water generally sustains flows in the streams throughout the year, although reaches of some of the streams in the lower parts of their basins may lose water to the coarse Quaternary deposits of Jackson Hole and occasionally become dry for short periods.

The study area has cold winters and warm summers. Average monthly temperatures at the Moose, Wyo., climate station ranged from –10.3°C in January to 16.0°C in July (Western Regional Climate Center, 2007) during the period 1958–2006, based on the average of monthly mean minimum and maximum temperatures. Average temperatures decrease with increasing altitude. Annual precipitation increases with increasing altitude. Annual precipitation, which primarily falls in the form of snow, ranges from about 21 inches near Moose, Wyo., (Western Regional Climate Center, 2007) to more than 70 inches in the Teton Range (Oregon Climate Service, 2007).

Acknowledgments

The authors thank the people who assisted with the data collection and preparation of this report. Thanks are extended to John Clune, formerly with the NPS, Ty Blacklock with the USGS, and Jon Mason and Jodi Norris, formerly with the USGS, for collecting or compiling data used in this report. Thanks also are extended to Kathy Tonnessen of the NPS and to Cheryl Miller and Janet Carter of the USGS for providing reviews of the manuscript. Suzanne Roberts assisted in the preparation of the illustrations and layout of the report.

Methods

Field measurements for the synoptic study sampling were made onsite using USGS standard methods as described in Rantz and others (1982) and the National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997–2007). Stream properties measured in the field included streamflow, dissolved oxygen, pH, specific conductance, water temperature, and alkalinity (table 3). Samples generally were collected with depth-integrating samplers. A DH–81 sampler with an equal-width-increment or multiple-vertical sampling technique was used to cross-sectionally composite samples. A few samples during the synoptic study were collected using a

Table 2. Distribution of rock types for drainage basins upstream from sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming (Love and Christiansen, 1985; Green and Drouillard, 1994).

[Some rows may not sum to 100.0 due to rounding. --, not applicable]

Site number (fig. 1)	Precambrian-era rocks (percent)				Paleozoic-era rocks (percent)		Quaternary-period surficial deposits (percent)			
	Granite gneiss	Granitic rocks	Metamorphosed mafic and ultramafic rocks	Meta-sedimentary and metavolcanic rocks	Bighorn Dolomite, Gallatin Limestone, Gros Ventre Formation, and Flathead Sandstone	Madison Limestone and Darby Formation	Alluvium and colluvium	Glacial deposits	Gravel, pediment, and fan deposits	Landslide deposits
CC1	2.1	32.0	--	20.8	0.60	--	4.7	18.5	11.5	9.9
TC1	--	--	--	61.3	1.5	--	--	2.6	--	34.6
TC2	--	--	--	50.4	1.2	--	--	19.0	1.3	28.2
CC2	1.4	25.6	--	25.0	.50	--	4.9	18.3	15.0	9.3
LC1	--	3.8	--	40.2	33.7	1.1	--	5.3	--	16.0
LC2	--	3.4	--	37.7	30.0	1.0	--	13.1	--	15.0
GC1	--	--	10.5	7.8	28.4	25.2	--	14.9	--	13.2
GC2	--	--	11.7	7.0	25.4	22.5	2.6	17.6	--	13.2

hand-dip method from the centroid of flow when the streams were too shallow for a sampler. Pesticide samples were collected using a hand-dip method.

Samples were composited in a churn splitter and processed, preserved, and shipped according to USGS standard methods (U.S. Geological Survey, 1997–2007). Samples for major-ion chemistry, nutrients, and trace elements were filtered onsite using a 0.45-micrometer (µm) disposable capsule filter. Samples for pesticides were filtered at the laboratory through a 0.70-µm filter. Data for filtered constituents are reported as dissolved, and data for unfiltered constituents are reported as total in this report. Samples were analyzed for major-ion chemistry, nutrients, trace elements, and pesticides at the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo. Sediment samples were analyzed for suspended concentrations at the USGS sediment laboratory in Helena, Mont. (Lambing and Dodge, 1993).

Analyses for major-ion chemistry (table 3) were conducted using the inductively coupled plasma method with atomic emission spectrometry and ion-exchange chromatography as described in Fishman and Friedman (1989) and Fishman (1993). Major-ion analyses also included dissolved-solids concentrations, which often are used as a general indicator of stream-water quality. The analysis of dissolved solids measures the residue on evaporation at 180°C of all of the dissolved constituents, with the primary contributors being the major ions and nonionic silicon that is reported in terms of the equivalent concentration of silica.

The quality of major-ion analyses was checked using ratios of dissolved solids and specific conductance, ratios of cations and specific conductance, ratios of anions and specific conductance, and ion balances. Results were considered to be of good quality. The median percent difference for the ion balances for samples from the western streams was –0.83 percent. The interquartile range was –2.2 to 0.95 percent. The largest percent difference was –12.8 percent. These results indicate a slight negative bias in some analytical results. The source of the negative bias may be alkalinity values, which may have been slightly overtitrated because of the small concentrations present in samples. Large percent differences in ion balances were associated with samples that had small dissolved-ion concentrations. Small deviations in precision of laboratory measurements can result in relatively large percent difference in samples having small dissolved-ion concentrations.

Nutrient analyses included nitrogen and phosphorus species (table 3). Colorimetry and Kjeldahl digestion methods for dissolved and total nutrients are described in Fishman (1993) and Patton and Truitt (2000). Nitrogen species analyzed included dissolved ammonia plus organic nitrogen as nitrogen, total ammonia plus organic nitrogen as nitrogen, dissolved ammonia as nitrogen, dissolved nitrite plus nitrate as nitrogen (referred to as dissolved nitrate in this report), and dissolved nitrite as nitrogen. Nitrate, the oxidized form of nitrogen, typically is the most common form of dissolved nitrogen in streams. For data analysis, total-nitrogen concentrations were calculated as follows: (1) the sum of total ammonia plus organic nitrogen and dissolved nitrate when both values were uncensored (greater than laboratory reporting levels), (2) set equal to total ammonia plus organic nitrogen when total ammonia plus organic nitrogen values were uncensored and dissolved nitrate values were censored (less than laboratory reporting levels), or (3) the sum of dissolved ammonia plus organic nitrogen and dissolved nitrate values when total ammonia plus organic nitrogen values were censored. Phosphorus species analyzed included dissolved orthophosphate as phosphorus, dissolved phosphorus, and total phosphorus. Censored concentrations of total-phosphorus concentrations were set equal to the method reporting level, which is one-half the laboratory reporting level, for data analysis.

Trace-element analyses (table 3) included dissolved-iron and dissolved-manganese concentrations, which were analyzed for all samples collected during the synoptic study. Additionally, dissolved-arsenic, dissolved-cadmium, dissolved-chromium, dissolved-copper, dissolved-nickel, dissolved-selenium, and dissolved-zinc concentrations were analyzed during the June sampling. Analyses for dissolved-iron and dissolved-manganese concentrations were conducted using the inductively coupled plasma methods described in Fishman (1993). Analyses for dissolved-arsenic, dissolved-chromium, and dissolved-selenium concentrations were conducted using collision/reaction cell inductively coupled plasma-mass spectrometry methods described in Garbarino and others (2006). Analyses for dissolved-cadmium, dissolved-copper, dissolved-nickel, and dissolved-zinc concentrations were conducted using inductively coupled plasma-mass spectrometry methods described in Faires (1993).

Samples were analyzed for 52 pesticide compounds during the June sampling events. The pesticide compounds were 26 commonly used herbicides, 18 commonly used insecticides, and 8 breakdown products (table 4). Analyses for pesticide compounds were made using a gas chromatography/mass spectrometry (GC/MS) method (Zaugg and others, 1995; Madsen and others, 2003). The GC/MS method developed at the NWQL measures pesticide compounds at very low concentrations, often 10 to 1,000 times lower than U.S. Environmental Protection Agency (USEPA) drinking-water standards and reporting levels commonly used at other analytical laboratories. Pesticide concentrations detected below the long-term method detection level are reported as estimated concentrations (Childress and others, 1999). The laboratory reporting level generally is twice the yearly determined long-term method detection level (Childress and others, 1999).

As part of the synoptic study, the distribution of land cover for Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek drainage basins was determined using the National Land Cover Data (NLCD), which is a 30-meter resolution, raster-based data set that includes land-cover data compiled for Wyoming during 1986–93. Because most of the study area is contained within national forest or national park, land cover has not changed substantially since the data were compiled. Details of the NLCD land-cover classification process are discussed in Vogelmann, Sohl, Campbell, and Shaw (1998) and Vogelmann, Sohl, and Howard (1998). Land-cover classifications in the basins included water (open water, snow/ice); developed (residential, commercial, industrial, transportation); barren (bare rock/sand/clay, quarries/strip mines/pits, transitional); forested upland (deciduous, evergreen, and mixed forest); shrubland; herbaceous upland natural/semi-natural vegetation; and wetlands (woody wetlands, emergent herbaceous wetlands).

Water-quality data in this report are compared to State of Wyoming water-quality criteria for surface waters (Wyoming Department of Environmental Quality, 2007) or to USEPA water-quality criteria (U.S. Environmental Protection Agency, 2003) that apply to water-column constituents (table 5). Aquatic-life acute concentrations are based on a 1-hour average concentration. Aquatic-life chronic concentrations are based on a 4-day average concentration. Wyoming human-health criteria are based on USEPA National Secondary Drinking Water Regulations (or secondary standards), which are non-enforceable guidelines regulating constituents that may cause adverse cosmetic effects or aesthetic effects in drinking water (U.S. Environmental Protection Agency, 2003). Several of the criteria in table 5 are dependent upon other factors and are not a single value. The aquatic-life acute and chronic values for dissolved cadmium, dissolved copper, dissolved manganese, dissolved nickel, and dissolved zinc are dependent upon hardness values. For this report, the minimum hardness value reported for all of the stream samples (10 milligrams per liter (mg/L) as calcium carbonate) during the synoptic study was used to calculate the aquatic criteria shown in table 5. Dissolved-chromium concentrations were not speciated for oxidation states. Chromium (VI), the most toxic of the chromium species, is used for comparison and represents a conservative value because all the dissolved chromium probably is not in the form of chromium (VI). For the chronic criterion for dissolved ammonia, the maximum reported temperature (21°C) and maximum reported pH (8.8) for all samples were used to select a conservative value for comparing samples.

In addition to water-quality criteria, nutrient data are compared to median concentrations determined by Clark and others (2000) for undeveloped stream basins in the United States. Clark and others (2000) computed flow-weighted concentrations; however, nitrogen and phosphorus concentrations in this report were not flow-weighted because continuous streamflow data were not available for most sites. Total-nitrogen and total-phosphorus concentrations also are compared to ambient water-quality criteria recommendations prepared by the USEPA for forested mountain streams in the Middle Rockies ecoregion to address cultural eutrophication (U.S. Environmental Protection Agency, 2000).

Suspended-sediment loads were calculated for the streams in the synoptic study using instantaneous streamflow, the suspended-sediment concentration, and a conversion factor. Suspended-sediment concentrations of less than 1 were

Table 3. Stream properties measured in the field and inorganic constituents for which water-quality samples were analyzed on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.

[--, not applicable]

Stream property or constituent	Unit of measure	Maximum laboratory reporting level used for analyses (unit of measure)
Field measurements		
Instantaneous streamflow	Cubic feet per second	--
Dissolved oxygen	Milligrams per liter	--
pH	Standard units	--
Specific conductance	Microsiemens per centimeter at 25 degrees Celsius	--
Water temperature	Degrees Celsius	--
Alkalinity	Milligrams per liter, as calcium carbonate	--
Major-ion chemistry		
Calcium, dissolved	Milligrams per liter	0.02
Magnesium, dissolved	Milligrams per liter	.014
Sodium, dissolved	Milligrams per liter	.20
Sodium-adsorption ratio (calculated)	--	--
Potassium, dissolved	Milligrams per liter	.04
Sulfate, dissolved	Milligrams per liter	.18
Chloride, dissolved	Milligrams per liter	.20
Fluoride, dissolved	Milligrams per liter	.1
Silica, dissolved	Milligrams per liter	.04
Dissolved solids, residue on evaporation at 180 degrees Celsius	Milligrams per liter	10
Nutrients		
Ammonia plus organic nitrogen, dissolved	Milligrams per liter as nitrogen	0.1
Ammonia plus organic nitrogen, total	Milligrams per liter as nitrogen	.1
Ammonia, dissolved	Milligrams per liter as nitrogen	.02
Nitrite plus nitrate, dissolved	Milligrams per liter as nitrogen	.06
Nitrite, dissolved	Milligrams per liter as nitrogen	.002
Nitrogen, total (calculated)	Milligrams per liter	--
Orthophosphate, dissolved	Milligrams per liter as phosphorus	.006
Phosphorus, dissolved	Milligrams per liter	.004
Phosphorus, total	Milligrams per liter	.008
Trace elements		
Arsenic, dissolved	Micrograms per liter	0.12
Cadmium, dissolved	Micrograms per liter	.04
Chromium, dissolved	Micrograms per liter	.12
Copper, dissolved	Micrograms per liter	.4
Iron, dissolved	Micrograms per liter	6
Manganese, dissolved	Micrograms per liter	.6
Nickel, dissolved	Micrograms per liter	.06
Selenium, dissolved	Micrograms per liter	.08
Zinc, dissolved	Micrograms per liter	.6

Table 4. Pesticide compounds, type, and reporting levels for which water-quality samples were analyzed on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.

Pesticide	Type	Maximum laboratory reporting level used for analyses (micrograms per liter)
2,6-Diethylaniline	Breakdown product	0.006
CIAT	Breakdown product	.014
Acetochlor	Herbicide	.006
Alachlor	Herbicide	.005
alpha-HCH	Breakdown product	.005
Atrazine	Herbicide	.007
Azinphos-methyl	Insecticide	.186
Benfluralin	Herbicide	.010
Butylate	Herbicide	.004
Carbaryl	Insecticide	.041
Carbofuran	Insecticide	.020
Chlorpyrifos	Insecticide	.005
cis-Permethrin	Insecticide	.006
Cyanazine	Herbicide	.018
DCPA	Herbicide	.003
Desulfinyl fipronil	Breakdown product	.012
Diazinon	Insecticide	.005
Dieldrin	Insecticide	.009
Disulfoton	Insecticide	.02
EPTC	Herbicide	.004
Ethalfluralin	Herbicide	.009
Ethoprop	Insecticide	.012
Desulfinylfipronil amide	Breakdown product	.029
Fipronil sulfide	Breakdown product	.013
Fipronil sulfone	Breakdown product	.024
Fipronil	Insecticide	.016
Fonofos	Insecticide	.005
Lindane	Insecticide	.004
Linuron	Herbicide	.035
Malathion	Insecticide	.027
Methyl parathion	Insecticide	.015
Metolachlor	Herbicide	.006
Metribuzin	Herbicide	.028
Molinate	Herbicide	.003
Napropamide	Herbicide	.007
p,p'-DDE	Breakdown product	.003
Parathion	Insecticide	.010

Table 4. Pesticide compounds, type, and reporting levels for which water-quality samples were analyzed on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

Pesticide	Type	Maximum laboratory reporting level used for analyses (micrograms per liter)
Pebulate	Herbicide	0.004
Pendimethalin	Herbicide	.022
Phorate	Insecticide	.055
Prometon	Herbicide	.01
Propyzamide	Herbicide	.004
Propachlor	Herbicide	.010
Propanil	Herbicide	.011
Propargite	Insecticide	.02
Simazine	Herbicide	.005
Tebuthiuron	Herbicide	.02
Terbacil	Herbicide	.034
Terbufos	Insecticide	.02
Thiobencarb	Herbicide	.010
Triallate	Herbicide	.006
Trifluralin	Herbicide	.009

set equal to 1 for data analysis. The equation for the load calculation was:

$$SSL = Q \times SSC \times 0.0027 \qquad (1)$$

where:

SSL is the suspended-sediment load, in tons per day;

Q is the instantaneous streamflow, in cubic feet per second (ft^3/s); and

SSC is the suspended-sediment concentration, in mg/L.

Data distributions of water-quality constituents are summarized using boxplots. For boxplots, the lower and upper edges of the box indicate the 25th and 75th percentiles, respectively. The median is a line within the box. The whiskers extend beyond the 25th and 75th percentiles to 1.5 times the interquartile range. If the smallest or largest value in the data set is less than 1.5 times the interquartile range, the whisker extends to the smallest or largest value. Otherwise, values outside the whiskers are shown as individual points.

USGS hydrologist prepares water samples in the back country of Grand Teton National Park.

Table 5. State of Wyoming water-quality criteria for surface waters and U.S. Environmental Protection Agency water-quality criteria for selected constituents.

[All criteria are from Wyoming Department of Environmental Quality (2007) unless otherwise noted. All constituents are in micrograms per liter unless otherwise noted. mg/L, milligrams per liter; --, no data available]

Constituent	Aquatic-life acute criterion	Aquatic-life chronic criterion	Human-health criterion, fish and drinking water[1]
	Priority pollutants		
Arsenic	340	150	10
Cadmium[2]	.2	.05	[3]5
Chromium (VI)	16	11	[3]100
Copper[2]	1.6	1.3	[4]1,000
Nickel[2]	66	7.4	[3]100
Selenium	20	5	[3]50
Zinc[2]	16	16	[4]5,000
Dieldrin	.24	.056	.00052
	Non-priority pollutants		
Dissolved oxygen (mg/L)[5]	8.0, 4.0	--	--
pH (standard units)	--	6.5–9.0	--
Chloride (mg/L)	860	230	[7]250
Fluoride (mg/L)	--	--	[3]4
Ammonia (mg/L)	[6]1.23	[6].44	--
Nitrite (mg/L)	--	--	[3]1
Nitrite plus nitrate (mg/L)	--	--	[3]10
Iron	--	1,000	[7]300
Manganese[2]	530	420	[7]50
Alachlor	--	--	[3]2.0
Atrazine	--	--	[3]3.0
Carbofuran	--	--	[3]40
Chlorpyrifos	.083	.041	--
Lindane	.95	--	[3].2
Malathion	--	.1	--
Parathion	.065	.013	--
Simazine	--	--	[3]4.0

[1]Except where otherwise noted, values are based on U.S. Environmental Protection Agency Section 304(a) criteria recommendations assuming consumption of 2 liters of water and 6.5 grams of aquatic organisms per day.

[2]Based on a hardness value of 10 milligrams per liter.

[3]Criterion is based on U.S. Environmental Protection Agency drinking-water Maximum Contaminant Level (U.S. Environmental Protection Agency, 2003).

[4]Value is based on taste and odor effects and is more stringent than if based solely on toxic or carcinogenic effects.

[5]For Class 1 cold waters, 8.0 applies to early life stages, 4.0 applies to other life stages; instantaneous values.

[6]Criteria based on early life stages of fish present and conditions of maximum reported pH of 8.8 and maximum reported temperature of 21°C.

[7]Criterion is based on U.S. Environmental Protection Agency National Secondary Drinking Water Regulations, which are nonenforceable guidelines for contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water (U.S. Environmental Protection Agency, 2003).

Water-Quality Characteristics

The water-quality characteristics of four western streams (Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek) are described in this section. Sampling results from a synoptic study during 2006 are presented. Water types of sampled streams are described; see Hem (1985) for a basic discussion of water types. In addition, sampling results from the synoptic study of western streams are compared to sampling results from a synoptic study of eastern streams during 2002 to describe spatial variations in the water quality in the Snake River headwaters area.

Synoptic Study

A synoptic study to describe baseline water-quality characteristics of Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek was conducted during 2006. Two sampling sites were selected on each of the streams for the synoptic study. An upstream site was established to describe water quality in the upper part of the drainage basin, generally upstream from roads and much of the recreational use. A second site was established downstream near roads and or other areas that have high visitor use. Sampling events in June, July, August, and October were selected to characterize different hydrologic conditions and different recreational-use periods by visitors to Grand Teton National Park. The June sampling event coincided with high-flow conditions. The July and August sampling events coincided with the period of high recreational use. The October sampling event generally coincided with low-flow conditions. The lowest streamflows typically occur in the winter; however, site access is very difficult because of snow during the winter. Streamflow measured during the October sampling event was slightly higher than the streamflow measured during the August sampling event at sites LC1, LC2, and GC2 (table 6). A small rain event occurred during the October sampling that may have contributed flow to Lake Creek and Granite Creek.

Site GC2 on Granite Creek is the only study site with a USGS streamflow-gaging station (13016305) that continuously records stage measurements, which are used to produce an annual record of streamflow (fig. 2). The annual-runoff value of 27,460 acre-feet (acre-ft) at site GC2 on Granite Creek during water year 2006 (October 1, 2005 to September 30, 2006) was slightly less than the average annual-runoff value of 28,170 acre-ft for the period of record (1995–2006) for this site, indicating streamflow conditions were near average during the synoptic study (U.S. Geological Survey, 2007).

Results for stream properties measured in the field and for constituents analyzed in water-quality samples are presented in this report (table 6). In addition, results are electronically stored in the USGS's National Water Information System (NWIS) and are available to the public from NWISWeb at *http://waterdata.usgs.gov/nwis/*.

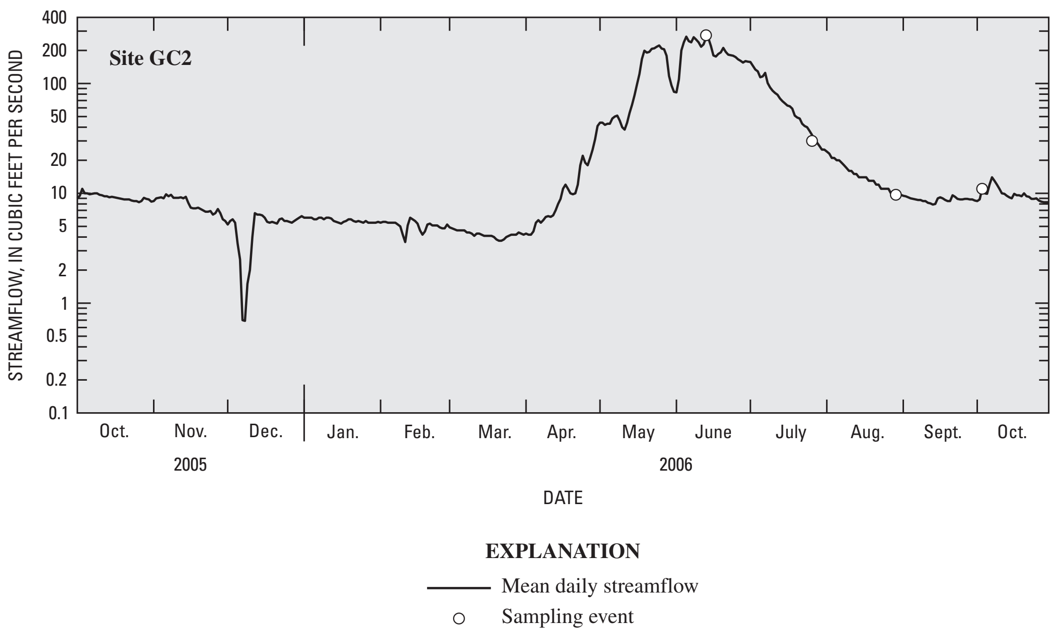

Figure 2. Streamflow and distribution of sampling events for Granite Creek, Grand Teton National Park, Wyoming, 2006.

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Site number	Date	Time	Instantaneous streamflow, in ft³/s	Barometric pressure, mm Hg	Dissolved oxygen, mg/L	Dissolved oxygen, percent of saturation	pH, unfiltered, field, standard units	Specific conductance, µS/cm
CC1	6/12/2006	1350	688	598	9.2	108	8.0	28
	7/24/2006	1500	240	592	8.0	114	8.4	24
	8/28/2006	1430	48	595	7.2	98	8.1	27
	10/4/2006	1500	29	608	8.6	100	7.8	28
TC1	6/14/2006	1700	88	597	12.3	120	8.3	32
	7/25/2006	915	50	595	9.0	100	8.2	41
	8/29/2006	1000	11	596	9.2	99	8.5	45
	10/2/2006	1330	5.1	600	10.3	105	7.8	48
TC2	6/14/2006	1230	99	597	8.8	103	7.5	32
	7/25/2006	1400	46	595	6.8	96	7.7	37
	8/29/2006	1345	8.7	596	7.0	96	7.9	39
	10/2/2006	1615	3.6	600	8.7	97	8.2	43
CC2	6/14/2006	850	610	597	8.6	102	7.2	27
	7/24/2006	1715	279	592	6.8	96	7.7	25
	8/28/2006	1700	18	595	6.1	84	7.4	28
	10/4/2006	1400	0	--	--	--	--	--
LC1	6/15/2006	1100	143	595	10.7	106	8.5	101
	7/26/2006	945	35	593	8.9	100	8.3	120
	8/30/2006	900	6.2	595	8.9	97	8.6	132
	10/3/2006	1145	14	609	10.3	104	7.5	140
LC2	6/15/2006	1700	231	595	9.2	106	8.5	106
	7/25/2006	1630	40	595	6.7	97	8.5	106
	8/29/2006	1600	6.6	596	7.0	99	8.8	105
	10/3/2006	1500	7.2	609	8.3	99	7.9	108
GC1	6/13/2006	1410	285	607	9.9	101	8.5	215
	7/26/2006	1400	37	593	8.7	101	8.4	214
	8/30/2006	1400	11	595	9.0	101	8.6	218
	10/4/2006	1030	10	608	10.9	104	8.5	222
GC2	6/13/2006	830	275	607	10.2	99	8.6	214
	7/26/2006	1745	30	593	8.5	102	8.3	215
	8/29/2006	1800	9.7	596	8.4	98	8.8	217
	10/3/2006	1645	11	609	9.9	101	8.2	223

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Temperature, air, °C	Temperature, water, °C	Hardness, mg/L as calcium carbonate	Calcium, dissolved, mg/L	Magnesium, dissolved, mg/L	Potassium, dissolved, mg/L	Sodium-adsorption ratio	Sodium, dissolved, mg/L
28.0	11.5	11	3.11	0.663	0.62	0.1	0.51
23.0	20.0	10	3.10	.632	.58	.1	.47
25.0	17.5	11	3.13	.653	.57	.1	.45
12.5	12.0	12	3.42	.725	.61	.1	.57
8.0	4.0	13	3.81	.927	.62	.1	.46
30.0	9.0	17	4.87	1.21	.63	<.1	.46
14.0	7.5	19	5.35	1.35	.79	.1	.61
7.0	6.0	17	4.90	1.16	.79	.1	.61
11.5	11.5	13	3.65	.893	.66	.1	.51
31.0	20.0	13	3.67	.885	.57	.1	.52
25.0	18.5	16	4.61	1.15	.67	.1	.48
6.0	9.5	18	5.05	1.26	.81	.1	.54
14.0	12.0	11	3.17	.677	.62	.1	.53
23.0	19.5	11	3.19	.684	.56	.1	.49
27.0	19.0	11	3.33	.758	.61	.1	.48
--	--	--	--	--	--	--	--
13.0	4.5	48	13.9	3.24	.53	<.1	.36
19.0	9.5	58	16.7	3.88	.73	<.1	.58
16.0	8.0	62	17.9	4.28	1.05	<.1	.70
9.0	6.0	66	18.9	4.52	.96	<.1	.69
17.0	10.5	53	15.3	3.49	.66	<.1	.46
29.0	21.0	50	14.6	3.27	.60	<.1	.42
27.0	20.0	53	15.3	3.63	.67	<.1	.47
17.0	13.0	52	15.3	3.44	.62	<.1	.57
27.0	6.5	110	30.3	8.09	.40	<.1	.33
29.0	10.5	110	29.5	7.92	.49	<.1	.57
24.0	9.5	110	30.2	8.52	.61	<.1	.52
2.5	4.0	120	34.8	9.13	.56	<.1	.57
16.0	4.5	110	30.4	7.89	.37	<.1	.34
28.0	12.0	110	29.4	7.69	.52	<.1	.56
25.0	11.0	110	30.8	8.34	.63	<.1	.62
14.0	6.5	110	31.8	8.44	.59	<.1	.62

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Site number	Date	Time	Alkalinity, mg/L as $CaCO_3$	Chloride, dissolved, mg/L	Fluoride, dissolved, mg/L	Silica, dissolved, mg/L	Sulfate, dissolved, mg/L	Residue on evaporation at 180°C, dissolved, mg/L
CC1	6/12/2006	1350	11	E0.19	<0.10	1.99	1.66	11
	7/24/2006	1500	10	E.11	<.10	1.86	1.57	19
	8/28/2006	1430	14	E.16	<.10	1.67	1.67	15
	10/4/2006	1500	11	E.10	<.10	1.72	1.73	18
TC1	6/14/2006	1700	11	.29	<.10	2.77	1.52	23
	7/25/2006	915	17	.28	<.10	2.32	1.81	19
	8/29/2006	1000	22	.35	<.10	2.82	2.26	29
	10/2/2006	1330	17	.84	<.10	2.78	2.51	31
TC2	6/14/2006	1230	12	E.18	<.10	2.99	1.50	24
	7/25/2006	1400	17	<.20	<.10	1.90	1.66	26
	8/29/2006	1345	19	E.16	<.10	1.96	1.87	25
	10/2/2006	1615	17	.13	<.10	1.93	1.91	30
CC2	6/14/2006	850	11	E.20	<.10	2.23	1.58	24
	7/24/2006	1715	8	<.20	<.10	2.00	1.46	20
	8/28/2006	1700	12	E.11	<.10	1.71	1.60	19
	10/4/2006	1400	--	--	--	--	--	--
LC1	6/15/2006	1100	46	.27	<.10	2.77	2.46	55
	7/26/2006	945	47	<.20	<.10	2.32	4.55	73
	8/30/2006	900	60	.20	<.10	3.29	5.63	72
	10/3/2006	1145	61	.60	E.06	2.88	7.08	87
LC2	6/15/2006	1700	50	.31	<.10	2.51	2.67	57
	7/25/2006	1630	55	.21	<.10	1.93	2.87	61
	8/29/2006	1600	52	.22	<.10	1.96	2.99	59
	10/3/2006	1500	51	E.11	<.10	1.50	2.93	58
GC1	6/13/2006	1410	109	.29	<.10	2.48	2.17	108
	7/26/2006	1400	110	.30	<.10	2.94	3.28	122
	8/30/2006	1400	113	.21	<.10	3.34	3.51	110
	10/4/2006	1030	116	.25	<.10	2.99	3.69	130
GC2	6/13/2006	830	108	E.18	<.10	2.48	2.08	105
	7/26/2006	1745	107	E.19	<.10	2.97	3.23	120
	8/29/2006	1800	114	.28	<.10	3.71	3.42	120
	10/3/2006	1645	115	.28	<.10	3.36	3.56	125

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Ammonia + organic N, dissolved, mg/L as N	Ammonia + organic N, total, mg/L as N	Ammonia, dissolved, mg/L as N	Nitrate + nitrate, dissolved, mg/L as N	Nitrite, dissolved, mg/L as N	Orthophosphate, dissolved, mg/L as P	Phosphorus, dissolved, mg/L	Phosphorus, total, mg/L
E.07	0.15	E0.008	<0.06	E0.001	<0.006	<0.004	E0.003
E.06	.10	E.006	<.06	<.002	<.006	E.003	.005
.16	E.09	.015	<.06	<.002	<.006	<.004	E.003
.14	E.08	E.012	<.06	<.002	<.006	<.006	E.004
<.10	E.08	E.007	.17	<.002	<.006	<.004	E.003
<.10	E.08	.022	.12	<.002	<.006	E.003	.005
.18	E.07	.012	.15	<.002	<.006	<.004	<.004
E.08	<.10	E.013	.17	<.002	<.006	<.006	<.008
E.07	.12	.012	.13	<.002	<.006	<.004	.004
E.08	.10	.011	.08	E.001	<.006	E.003	.007
.23	.11	.014	E.03	<.002	<.006	<.004	.005
.14	E.09	<.020	<.06	<.002	<.006	E.003	E.007
E.08	.15	E.007	E.05	<.002	<.006	<.004	.011
E.09	.17	.013	E.04	<.002	<.006	E.004	.008
.16	.10	.014	E.04	<.002	<.006	<.004	E.003
--	--	--	--	--	--	--	--
E.06	.11	E.006	.06	<.002	<.006	<.004	.009
.12	E.06	<.010	E.04	<.002	<.006	<.004	E.003
E.08	<.10	E.007	.08	<.002	E.003	<.004	E.002
.21	E.09	<.020	.10	<.002	<.006	.006	<.008
E.08	.15	.012	E.03	<.002	E.004	<.004	.005
.11	.11	E.006	<.06	<.002	<.006	.004	.007
.23	.12	E.010	<.06	<.002	E.003	<.004	.005
E.06	.25	<.020	<.06	<.002	<.006	<.006	E.005
E.06	.12	E.007	E.05	<.002	E.003	E.002	.010
.10	E.08	E.005	<.06	<.002	<.006	E.002	E.003
.15	E.09	.011	E.05	<.002	E.003	<.004	E.003
.13	<.10	<.020	.11	<.002	<.006	<.006	<.008
<.10	.13	E.007	.07	<.002	E.004	E.002	.023
E.09	.34	E.007	<.06	<.002	<.006	<.004	<.004
.16	.13	.013	E.04	<.002	<.006	<.004	.007
E.07	<.10	<.020	.06	<.002	<.006	<.006	<.008

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Site number	Date	Time	Arsenic, dissolved, µg/L	Cadmium, dissolved, µg/L	Chromium, dissolved, µg/L	Copper, dissolved, µg/L	Iron, dissolved, µg/L	Manganese, dissolved, µg/L	Nickel, dissolved, µg/L	Selenium, dissolved, µg/L	Zinc, dissolved, µg/L	2,6-Diethylaniline, dissolved, µg/L	CIAT, dissolved, µg/L	Acetochlor, dissolved, µg/L	Alachlor, dissolved, µg/L	alpha-HCH, dissolved, µg/L
CC1	6/12/2006	1350	0.12	E0.03	0.07	E0.3	<6	E0.5	0.09	<0.08	<0.6	<0.006	<0.014	<0.006	<0.005	<0.005
	7/24/2006	1500	--	--	--	--	E3	E.6	--	--	--	--	--	--	--	--
	8/28/2006	1430	--	--	--	--	6	1.5	--	--	--	--	--	--	--	--
	10/4/2006	1500	--	--	--	--	E4	E.4	--	--	--	--	--	--	--	--
TC1	6/14/2006	1700	E.08	<.04	.10	E.3	E6	<.6	E.04	<.08	E.5	<.006	<.014	<.006	<.005	<.005
	7/25/2006	915	--	--	--	--	<6	E.4	--	--	--	--	--	--	--	--
	8/29/2006	1000	--	--	--	--	E5	E.4	--	--	--	--	--	--	--	--
	10/2/2006	1330	--	--	--	--	E5	E.3	--	--	--	--	--	--	--	--
TC2	6/14/2006	1230	E.09	<.04	.08	E.3	13	.8	E.06	<.08	.7	<.006	<.014	<.006	<.005	<.005
	7/25/2006	1400	--	--	--	--	14	1.4	--	--	--	--	--	--	--	--
	8/29/2006	1345	--	--	--	--	19	2.1	--	--	--	--	--	--	--	--
	10/2/2006	1615	--	--	--	--	18	2.8	--	--	--	--	--	--	--	--
CC2	6/14/2006	850	E.11	<.04	.08	E.3	E5	E.4	.08	<.08	1.4	<.006	<.014	<.006	<.005	<.005
	7/24/2006	1715	--	--	--	--	E6	1.0	--	--	--	--	--	--	--	--
	8/28/2006	1700	--	--	--	--	10	1.3	--	--	--	--	--	--	--	--
	10/4/2006	1400	--	--	--	--	--	--	--	--	--	--	--	--	--	--
LC1	6/15/2006	1100	.16	<.04	.12	4.5	13	.9	.16	<.08	1.1	<.006	<.014	<.006	<.005	<.005
	7/26/2006	945	--	--	--	--	<6	.8	--	--	--	--	--	--	--	--
	8/30/2006	900	--	--	--	--	8	.7	--	--	--	--	--	--	--	--
	10/3/2006	1145	--	--	--	--	8	.7	--	--	--	--	--	--	--	--
LC2	6/15/2006	1700	.19	<.04	.07	E.4	9	.8	.14	<.08	6.2	<.006	<.014	<.006	<.005	<.005
	7/25/2006	1630	--	--	--	--	E4	1.0	--	--	--	--	--	--	--	--
	8/29/2006	1600	--	--	--	--	E5	1.4	--	--	--	--	--	--	--	--
	10/3/2006	1500	--	--	--	--	E3	.7	--	--	--	--	--	--	--	--
GC1	6/13/2006	1410	.21	<.04	.11	E.4	<6	E.4	.17	E.04	E.4	<.006	<.014	<.006	<.005	<.005
	7/26/2006	1400	--	--	--	--	<6	E.5	--	--	--	--	--	--	--	--
	8/30/2006	1400	--	--	--	--	E3	E.5	--	--	--	--	--	--	--	--
	10/4/2006	1030	--	--	--	--	<6	<.6	--	--	--	--	--	--	--	--
GC2	6/13/2006	830	.19	<.04	.11	E.3	<6	<.6	.16	E.04	.9	<.006	<.014	<.006	<.005	<.005
	7/26/2006	1745	--	--	--	--	<6	.6	--	--	--	--	--	--	--	--
	8/29/2006	1800	--	--	--	--	<6	E.6	--	--	--	--	--	--	--	--
	10/3/2006	1645	--	--	--	--	<6	E.4	--	--	--	--	--	--	--	--

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft^3/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Site number	Date	Time	Atrazine, dissolved, µg/L	Azinphos-methyl, dissolved, µg/L	Benfluralin, dissolved, µg/L	Butylate, dissolved, µg/L	Carbaryl, dissolved, µg/L	Carbofuran, dissolved, µg/L
CC1	6/12/2006	1350	<0.007	<0.050	<0.010	<0.004	<0.041	<0.020
	7/24/2006	1500	--	--	--	--	--	--
	8/28/2006	1430	--	--	--	--	--	--
	10/4/2006	1500	--	--	--	--	--	--
TC1	6/14/2006	1700	<.007	<.050	<.010	<.004	<.041	<.020
	7/25/2006	915	--	--	--	--	--	--
	8/29/2006	1000	--	--	--	--	--	--
	10/2/2006	1330	--	--	--	--	--	--
TC2	6/14/2006	1230	<.007	<.170	<.010	<.004	<.041	<.020
	7/25/2006	1400	--	--	--	--	--	--
	8/29/2006	1345	--	--	--	--	--	--
	10/2/2006	1615	--	--	--	--	--	--
CC2	6/14/2006	850	<.007	<.050	<.010	<.004	<.041	<.020
	7/24/2006	1715	--	--	--	--	--	--
	8/28/2006	1700	--	--	--	--	--	--
	10/4/2006	1400	--	--	--	--	--	--
LC1	6/15/2006	1100	<.007	<.186	<.010	<.004	<.041	<.020
	7/26/2006	945	--	--	--	--	--	--
	8/30/2006	900	--	--	--	--	--	--
	10/3/2006	1145	--	--	--	--	--	--
LC2	6/15/2006	1700	<.007	<.087	<.010	<.004	<.041	<.020
	7/25/2006	1630	--	--	--	--	--	--
	8/29/2006	1600	--	--	--	--	--	--
	10/3/2006	1500	--	--	--	--	--	--
GC1	6/13/2006	1410	<.007	<.050	<.010	<.004	<.041	<.020
	7/26/2006	1400	--	--	--	--	--	--
	8/30/2006	1400	--	--	--	--	--	--
	10/4/2006	1030	--	--	--	--	--	--
GC2	6/13/2006	830	<.007	<.050	<.010	<.004	<.041	<.020
	7/26/2006	1745	--	--	--	--	--	--
	8/29/2006	1800	--	--	--	--	--	--
	10/3/2006	1645	--	--	--	--	--	--

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft^3/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Chlorpyrifos, dissolved, µg/L	*cis*-Permethrin, dissolved, µg/L	Cyanazine, dissolved, µg/L	DCPA, dissolved, µg/L	Desulfinyl fipronil, dissolved, µg/L	Diazinon, dissolved, µg/L	Dieldrin, dissolved, µg/L	Disulfoton, dissolved, µg/L
<0.005	<0.006	<0.018	<0.003	<0.012	<0.005	<0.009	<0.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.005	<.006	<.018	<.003	<.012	<.005	<.009	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.005	<.006	<.018	<.003	<.012	<.005	<.009	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.005	<.006	<.018	<.003	<.012	<.005	<.009	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.005	<.006	<.018	<.003	<.012	<.005	<.009	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.005	<.006	<.018	<.003	<.012	<.005	<.009	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.005	<.006	<.018	<.003	<.012	<.005	<.009	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.005	<.006	<.018	<.003	<.012	<.005	<.009	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Site number	Date	Time	EPTC, dissolved, µg/L	Ethalfluralin, dissolved, µg/L	Ethoprop, dissolved, µg/L	Desulfinylfipronil amide, dissolved, µg/L	Fipronil sulfide, dissolved, µg/L	Fipronil sulfone, dissolved, µg/L
CC1	6/12/2006	1350	<0.004	<0.009	<0.012	<0.029	<0.013	<0.024
	7/24/2006	1500	--	--	--	--	--	--
	8/28/2006	1430	--	--	--	--	--	--
	10/4/2006	1500	--	--	--	--	--	--
TC1	6/14/2006	1700	<.004	<.009	<.012	<.029	<.013	<.024
	7/25/2006	915	--	--	--	--	--	--
	8/29/2006	1000	--	--	--	--	--	--
	10/2/2006	1330	--	--	--	--	--	--
TC2	6/14/2006	1230	<.004	<.009	<.012	<.029	<.013	<.024
	7/25/2006	1400	--	--	--	--	--	--
	8/29/2006	1345	--	--	--	--	--	--
	10/2/2006	1615	--	--	--	--	--	--
CC2	6/14/2006	850	<.004	<.009	<.012	<.029	<.013	<.024
	7/24/2006	1715	--	--	--	--	--	--
	8/28/2006	1700	--	--	--	--	--	--
	10/4/2006	1400	--	--	--	--	--	--
LC1	6/15/2006	1100	<.004	<.009	<.012	<.029	<.013	<.024
	7/26/2006	945	--	--	--	--	--	--
	8/30/2006	900	--	--	--	--	--	--
	10/3/2006	1145	--	--	--	--	--	--
LC2	6/15/2006	1700	<.004	<.009	<.012	<.029	<.013	<.024
	7/25/2006	1630	--	--	--	--	--	--
	8/29/2006	1600	--	--	--	--	--	--
	10/3/2006	1500	--	--	--	--	--	--
GC1	6/13/2006	1410	<.004	<.009	<.012	<.029	<.013	<.024
	7/26/2006	1400	--	--	--	--	--	--
	8/30/2006	1400	--	--	--	--	--	--
	10/4/2006	1030	--	--	--	--	--	--
GC2	6/13/2006	830	<.004	<.009	<.012	<.029	<.013	<.024
	7/26/2006	1745	--	--	--	--	--	--
	8/29/2006	1800	--	--	--	--	--	--
	10/3/2006	1645	--	--	--	--	--	--

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Fipronil, dissolved, µg/L	Fonofos, dissolved, µg/L	Lindane, dissolved, µg/L	Linuron, dissolved, µg/L	Malathion, dissolved, µg/L	Methyl parathion, dissolved, µg/L	Metolachlor, dissolved, µg/L	Metribuzin, dissolved, µg/L
<0.016	<0.005	<0.004	<0.035	<0.027	<0.015	E0.002	<0.028
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.016	<.005	<.004	<.035	<.027	<.015	<.006	<.028
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.016	<.005	<.004	<.035	<.027	<.015	<.006	<.028
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.016	<.005	<.004	<.035	<.027	<.015	<.006	<.028
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.016	<.005	<.004	<.035	<.027	<.015	<.006	<.028
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.016	<.005	<.004	<.035	<.027	<.015	<.006	<.028
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.016	<.005	<.004	<.035	<.027	<.015	<.006	<.028
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.016	<.005	<.004	<.035	<.027	<.015	<.006	<.028
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Site number	Date	Time	Molinate, dissolved, µg/L	Napropamide, dissolved, µg/L	*p,p'*-DDE, dissolved, µg/L	Parathion, dissolved, µg/L	Pebulate, dissolved, µg/L	Pendimethalin, dissolved, µg/L
CC1	6/12/2006	1350	<0.003	<0.007	<0.003	<0.010	<0.004	<0.022
	7/24/2006	1500	--	--	--	--	--	--
	8/28/2006	1430	--	--	--	--	--	--
	10/4/2006	1500	--	--	--	--	--	--
TC1	6/14/2006	1700	<.003	<.007	<.003	<.010	<.004	<.022
	7/25/2006	915	--	--	--	--	--	--
	8/29/2006	1000	--	--	--	--	--	--
	10/2/2006	1330	--	--	--	--	--	--
TC2	6/14/2006	1230	<.003	<.007	<.003	<.010	<.004	<.022
	7/25/2006	1400	--	--	--	--	--	--
	8/29/2006	1345	--	--	--	--	--	--
	10/2/2006	1615	--	--	--	--	--	--
CC2	6/14/2006	850	<.003	<.007	<.003	<.010	<.004	<.022
	7/24/2006	1715	--	--	--	--	--	--
	8/28/2006	1700	--	--	--	--	--	--
	10/4/2006	1400	--	--	--	--	--	--
LC1	6/15/2006	1100	<.003	<.007	<.003	<.010	<.004	<.022
	7/26/2006	945	--	--	--	--	--	--
	8/30/2006	900	--	--	--	--	--	--
	10/3/2006	1145	--	--	--	--	--	--
LC2	6/15/2006	1700	<.003	<.007	<.003	<.010	<.004	<.022
	7/25/2006	1630	--	--	--	--	--	--
	8/29/2006	1600	--	--	--	--	--	--
	10/3/2006	1500	--	--	--	--	--	--
GC1	6/13/2006	1410	<.003	<.007	<.003	<.010	<.004	<.022
	7/26/2006	1400	--	--	--	--	--	--
	8/30/2006	1400	--	--	--	--	--	--
	10/4/2006	1030	--	--	--	--	--	--
GC2	6/13/2006	830	<.003	<.007	<.003	<.010	<.004	<.022
	7/26/2006	1745	--	--	--	--	--	--
	8/29/2006	1800	--	--	--	--	--	--
	10/3/2006	1645	--	--	--	--	--	--

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft³/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Phorate, dissolved, µg/L	Prometon, dissolved, µg/L	Propyzamide, dissolved, µg/L	Propachlor, dissolved, µg/L	Propanil, dissolved, µg/L	Propargite, dissolved, µg/L	Simazine, dissolved, µg/L	Tebuthiuron, dissolved, µg/L
<0.055	<0.01	<0.004	<0.010	<0.011	<0.02	<0.005	<0.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.055	<.01	<.004	<.010	<.011	<.02	<.005	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.055	<.01	<.004	<.010	<.011	<.02	<.005	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.055	<.01	<.004	<.010	<.011	<.02	<.005	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.055	<.01	<.004	<.010	<.011	<.02	<.005	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.055	<.01	<.004	<.010	<.011	<.02	<.005	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.055	<.01	<.004	<.010	<.011	<.02	<.005	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
<.055	<.01	<.004	<.010	<.011	<.02	<.005	<.02
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--

Table 6. Results for stream properties measured in the field and constituents analyzed in water-quality samples collected at sampling sites on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek, Grand Teton National Park, Wyoming, 2006.—Continued

[ft^3/sec, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; --, not determined; E, estimated; <, less than]

Site number	Date	Time	Terbacil, dissolved, µg/L	Terbufos, dissolved, µg/L	Thiobencarb, dissolved, µg/L	Triallate, dissolved, µg/L	Trifluralin, dissolved, µg/L	Suspended-sediment concentration, mg/L
CC1	6/12/2006	1350	<0.034	<0.02	<0.010	<0.006	<0.009	<1
	7/24/2006	1500	--	--	--	--	--	1
	8/28/2006	1430	--	--	--	--	--	<1
	10/4/2006	1500	--	--	--	--	--	<1
TC1	6/14/2006	1700	<.034	<.02	<.010	<.006	<.009	1
	7/25/2006	915	--	--	--	--	--	1
	8/29/2006	1000	--	--	--	--	--	1
	10/2/2006	1330	--	--	--	--	--	1
TC2	6/14/2006	1230	<.034	<.02	<.010	<.006	<.009	2
	7/25/2006	1400	--	--	--	--	--	2
	8/29/2006	1345	--	--	--	--	--	1
	10/2/2006	1615	--	--	--	--	--	3
CC2	6/14/2006	850	<.034	<.02	<.010	<.006	<.009	10
	7/24/2006	1715	--	--	--	--	--	2
	8/28/2006	1700	--	--	--	--	--	1
	10/4/2006	1400	--	--	--	--	--	--
LC1	6/15/2006	1100	<.034	<.02	<.010	<.006	<.009	17
	7/26/2006	945	--	--	--	--	--	3
	8/30/2006	900	--	--	--	--	--	1
	10/3/2006	1145	--	--	--	--	--	2
LC2	6/15/2006	1700	<.034	<.02	<.010	<.006	<.009	3
	7/25/2006	1630	--	--	--	--	--	2
	8/29/2006	1600	--	--	--	--	--	1
	10/3/2006	1500	--	--	--	--	--	1
GC1	6/13/2006	1410	<.034	<.02	<.010	<.006	<.009	17
	7/26/2006	1400	--	--	--	--	--	2
	8/30/2006	1400	--	--	--	--	--	<1
	10/4/2006	1030	--	--	--	--	--	1
GC2	6/13/2006	830	<.034	<.02	<.010	<.006	<.009	29
	7/26/2006	1745	--	--	--	--	--	3
	8/29/2006	1800	--	--	--	--	--	1
	10/3/2006	1645	--	--	--	--	--	1

Cottonwood Creek

Cottonwood Creek flows south from the outlet of Jenny Lake and is the principal tributary on the west side of the Snake River in Grand Teton National Park. The upstream sampling site (site CC1) on Cottonwood Creek is located at the outlet of Jenny Lake (fig. 1). The downstream sampling site on Cottonwood Creek (site CC2) is downstream from Taggart Creek and near the confluence with the Snake River. Cottonwood Creek has the largest drainage basin of the four western streams (table 1); about 67 percent of the drainage area at site CC1 is upstream from Jenny Lake. The drainage area at the downstream site (site CC2) is 72.3 square miles (mi^2). The drainage basin includes most of the high peaks that are at the core of the Teton Range, including the Grand Teton. The bedrock geology of the Cottonwood Creek drainage basin upstream from Jenny Lake primarily is composed of Precambrian-era granite gneiss, granitic rocks, and metasedimentary and metavolcanic rocks (Love and others, 1992). Sedimentary rocks that overlie the Precambrian-era rocks in the northern and southern part of the Teton Range mostly have been eroded in this part of the range. Cottonwood Creek flows entirely through Quaternary-period alluvial deposits of Jackson Hole. Cottonwood Creek has a gravel, cobble, and rock streambed at site CC1 and is mostly cobble with some braided sections at the downstream site (site CC2).

Land cover in the Cottonwood Creek drainage basin is dominated by herbaceous uplands and forested uplands in the upper part of the drainage basin (fig. 3). Shrubland dominates in the alluvial valley. Water (including lakes and snow/ice fields) and barren land (mostly rock) compose about 18 percent of the drainage area at site CC2. Cottonwood Creek has the most developed area of the four drainage basins; however, developed land cover accounts for less than 1 percent of the drainage area. Unlike upstream sites on the other streams, site CC1 is in a developed area that includes Grand Teton National Park concessions for Jenny Lake, which is an area of high visitor use.

Streamflow for Cottonwood Creek varied during the sampling events (fig. 4). Streamflow ranged from 29 ft^3/s in October to 688 ft^3/s in June at site CC1 and from no flow in October to 610 ft^3/s in June at downstream site CC2. The high flows in June are a result of snowmelt runoff. Streamflow was smaller at site CC2 than at site CC1 during three of the four sampling events, despite flow contributions from Taggart Creek between the two sites. This indicates streamflow was lost to ground water through the coarse alluvial deposits of Cottonwood Creek. Cox (1974) reported Cottonwood Creek had an average loss rate of 11.7 cubic feet per mile for a 4.2-mile reach of the stream downstream from Jenny Lake, which approximately coincides with the reach in this study.

Waters of Cottonwood Creek were near neutral to alkaline (pH values ranged from 7.2 to 8.4) and were dilute calcium-bicarbonate type (table 6). Among major cations, the concentration order from largest to smallest was calcium, magnesium, potassium, and sodium. Among major anions, the concentration order from largest to smallest was bicarbonate (determined from alkalinity), sulfate, and chloride. Alkalinity concentrations in samples collected from Cottonwood Creek ranged from 8 to 14 mg/L as calcium carbonate, indicating the stream has a small buffering capacity. Nanus and others (2005) and Corbin and others (2006) reported that alpine to subalpine lakes in Grand Teton National Park are sensitive to acidification. The small alkalinity values for Cottonwood Creek are similar to some of the acid-neutralizing-capacity values reported for the alpine to subalpine lakes that are considered to be sensitive to acidification. Granitic rocks compose a large percentage of the Precambrian-era rocks in the Cottonwood Creek drainage basin. Studies by Nanus and others (2005) and Corbin and others (2006) identified granitic rocks as an important factor in determining the potential for sensitivity to acidification.

Dissolved-solids concentrations for Cottonwood Creek were the smallest of the four streams that were sampled for this study. Concentrations ranged from 11 to 19 mg/L at site CC1 and from 19 to 24 mg/L at downstream site CC2 (fig. 4). Dissolved-solids concentrations generally did not vary inversely with streamflow, likely a result of streamflow being largely controlled by Jenny Lake. The small dissolved-solids concentrations in samples from Cottonwood Creek are the result of high annual precipitation in the Teton Range and steep gradients in this basin that produce relatively fast stream velocities, which results in short contact time between stream waters and the chemically resistant Precambrian-era rocks and material derived from these rocks that compose the basin.

Concentrations of nitrogen and phosphorus species generally were small in samples collected at sites CC1 and CC2 on Cottonwood Creek (table 6, fig. 4). Dissolved-ammonia, dissolved-nitrate, and dissolved-nitrite concentrations in all samples were less than the water-quality criteria for surface waters in Wyoming (table 5). Dissolved-nitrate concentrations were less than the laboratory reporting level of 0.06 mg/L and were smaller than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States (Clark and others, 2000) in samples collected at both sites. In all samples collected at both sites, total-nitrogen concentrations were less than the median concentration of 0.26 mg/L determined for undeveloped streams in the United States (Clark and others, 2000) and the ambient total-nitrogen criterion of 0.34 mg/L for forested mountain streams in the Middle Rockies ecoregion recommended by the USEPA to address cultural eutrophication (U.S. Environmental Protection Agency, 2000). Dissolved-orthophosphate concentrations were less than the laboratory reporting level of 0.006 mg/L, and dissolved-phosphorus concentrations were less than 0.006 mg/L in all samples. Total-phosphorus concentrations were less than the median concentration of 0.022 mg/L determined for undeveloped streams in the United States (Clark and others, 2000) in samples collected at both sites.

Dissolved-iron and dissolved-manganese concentrations were small in the samples collected at sites CC1 and CC2 on Cottonwood Creek (table 6). The maximum dissolved-iron

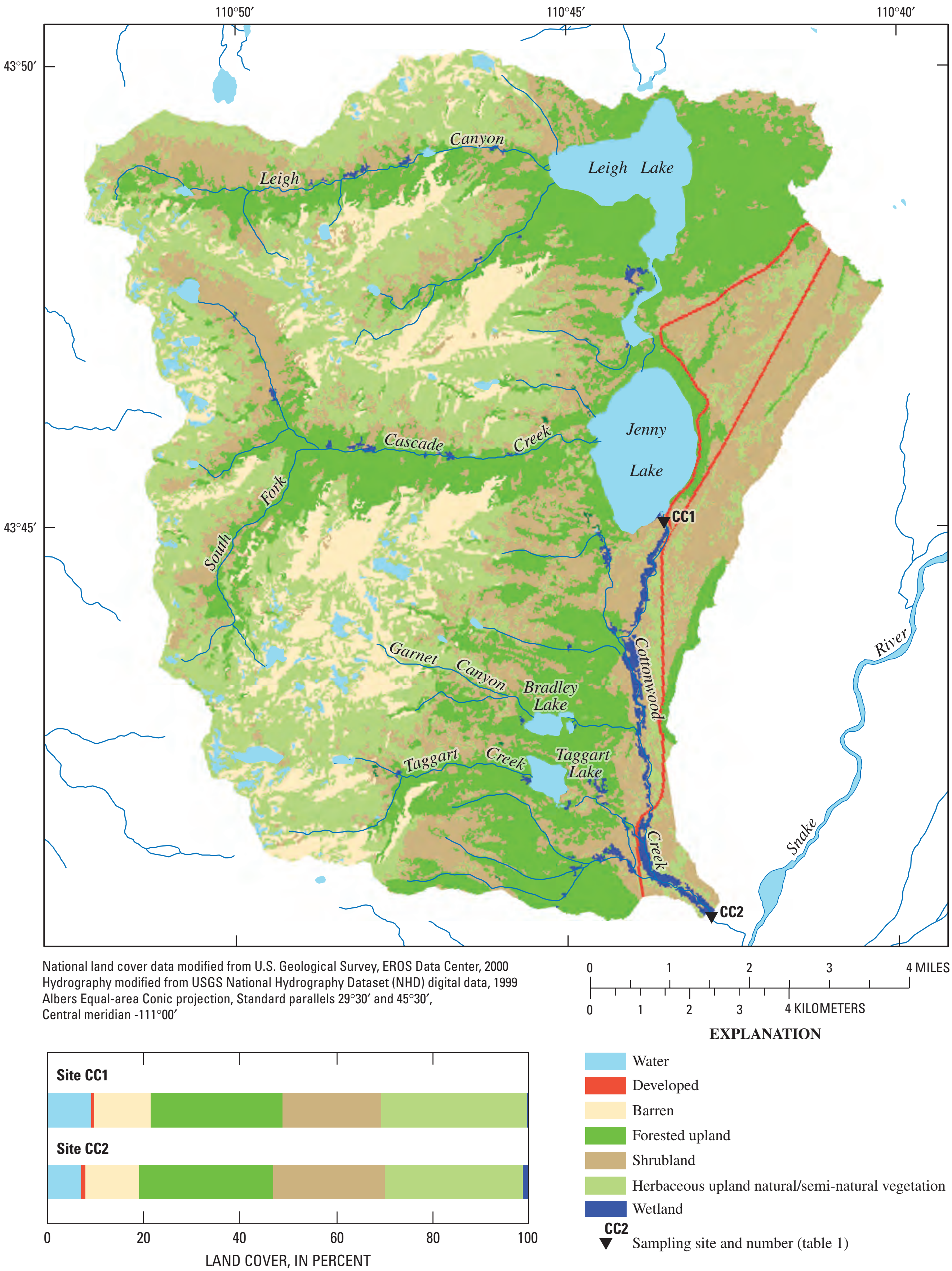

Figure 3. Distribution of land cover in the Cottonwood Creek drainage basin, Grand Teton National Park, Wyoming.

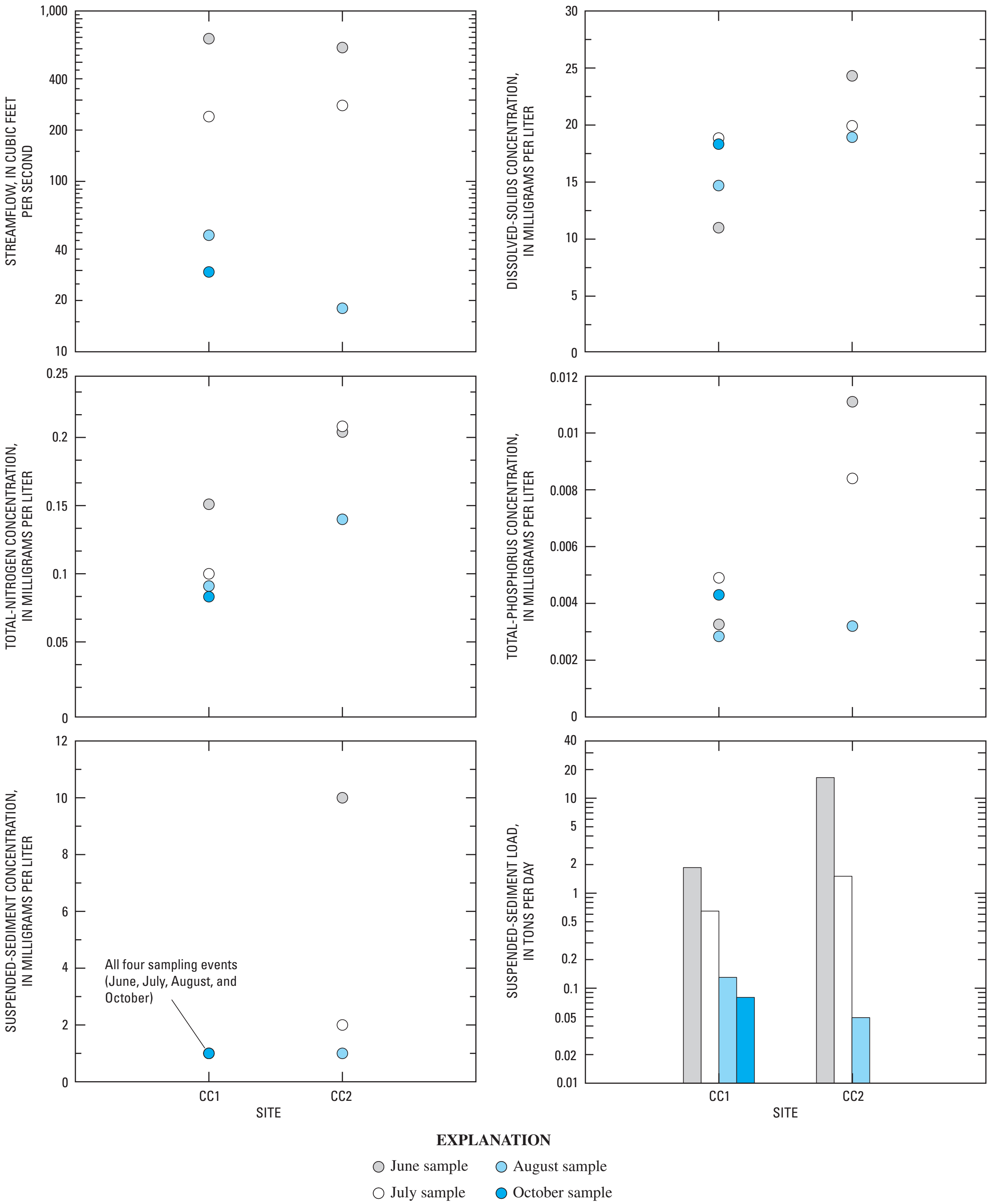

Figure 4. Streamflow; dissolved-solids, total-nitrogen, total-phosphorus, and suspended-sediment concentrations; and suspended-sediment loads for Cottonwood Creek, Grand Teton National Park, Wyoming, 2006.

concentration was 10 micrograms per liter (µg/L) (site CC2), and the maximum dissolved-manganese concentration was 1.5 µg/L (site CC1) for samples collected from Cottonwood Creek. These concentrations were substantially less than the aquatic-life criteria and human-health criteria for dissolved iron and dissolved manganese (table 5). Dissolved-arsenic, dissolved-cadmium, dissolved-chromium, dissolved-copper, dissolved-nickel, dissolved-selenium, and dissolved-zinc concentrations (table 6) were substantially less than aquatic-life acute and chronic criteria (table 5) during the June sampling of Cottonwood Creek. Sources of trace elements in the Cottonwood Creek drainage basin most likely are natural because the basin is mostly undeveloped.

During the June sampling event, one sample was collected at site CC1 and one sample was collected at site CC2 and analyzed for 52 commonly used pesticides or their breakdown products. All of the concentrations in the samples were less than the laboratory reporting levels for the compounds (table 4) and aquatic-life criteria established for surface waters in Wyoming (table 5). Metolachlor was detected in the sample from site CC1 in June. Metolachlor is a herbicide used to control broadleaf and annual grassy weeds along road right-of-ways (Meister Publishing Company, 2001). The concentration was less than the laboratory reporting level of 0.006 µg/L and was estimated to be 0.002 µg/L.

Suspended-sediment concentrations and loads for Cottonwood Creek were small for all the sampling events (fig. 4). Suspended-sediment concentrations were 1 mg/L or less than 1 mg/L in the four samples at site CC1 and ranged from 1 mg/L in August to 10 mg/L in June at site CC2. The small suspended-sediment concentrations at site CC1 reflect the influence of Jenny Lake, which likely reduces the suspended material. The suspended-sediment concentration at site CC2 was largest during snowmelt runoff in June when suspended sediment typically is carried to streams with overland flow or is resuspended from the stream bottom from turbulent flows; however, the concentration was small compared to other streams in Wyoming (Peterson, 1993). The coarse bottom material of Cottonwood Creek generally is too heavy to be resuspended.

Taggart Creek

Taggart Creek is a small tributary to Cottonwood Creek. The upstream sampling site on Taggart Creek (site TC1) is upstream from the inlet to Taggart Lake. The downstream sampling site (site TC2) is downstream from Taggart Lake near the parking lot for the Taggart Lake trailhead, just upstream from the confluence with Cottonwood Creek (fig. 1). Taggart Creek has the smallest drainage basin of the four western streams (table 1) where most of the drainage area for the basin (about 82 percent) is upstream from site TC1 near the inlet to Taggart Lake. The drainage area at the downstream site (TC2) is about 6.7 mi^2. The bedrock geology of the Taggart Creek drainage basin is predominantly Precambrian-era metasedimentary and metavolcanic rocks. As with the Cottonwood Creek drainage basin, the overlying sedimentary rocks have largely been eroded in this drainage basin. A small area of Paleozoic-area sedimentary rocks (less than 2 percent of the drainage basin) is exposed at the head of the basin. Quaternary-period deposits include glacial deposits that form the moraine at Taggart Lake, and landslide deposits (Love and Christiansen, 1985). Landslide deposits are mainly talus and related materials (Love and others, 1992). Taggart Creek has a predominantly cobble and rock streambed at the upstream site (site TC1), and a gravel and cobble streambed at the downstream site (site TC2).

Land cover in the Taggart Creek drainage basin is dominated by herbaceous uplands, forested uplands, and barren land (fig. 5). Barren land (mostly rock) composes about 22 percent of the drainage area at site TC1. Forested uplands cover the glacial moraine. A parking lot for the Taggart Lake trailhead, an area of high visitor use, is near site TC2. The lower part of the basin has more recreational use than the rugged upper part of the basin.

Streamflow for Taggart Creek varied during the sampling events (fig. 6). Streamflow ranged from 5.1 ft^3/s in October to 88 ft^3/s in June at site TC1 and from 3.6 ft^3/s in October to 99 ft^3/s in June at downstream site TC2. The high flows in June are a result of snowmelt runoff. Streamflow was smaller at site TC2 compared to site TC1 during three of the four sampling events. Taggart Lake, glacial drift deposits, and alluvial deposits along Taggart Creek may be recharged by Taggart Creek between sites TC1 and TC2.

Waters of Taggart Creek were near neutral to alkaline (pH values ranged from 7.5 to 8.5) and were calcium-bicarbonate type (table 6). Among major cations, the concentration order from largest to smallest was calcium, magnesium, potassium, and sodium. Among major anions, the concentration order from largest to smallest was bicarbonate (determined from alkalinity), sulfate, and chloride. Alkalinity concentrations in samples collected from Taggart Creek ranged from 11 to 22 mg/L as calcium carbonate, indicating the stream has a small buffering capacity. As with Cottonwood Creek, the small alkalinity values for Taggart Creek are similar to some of the acid-neutralizing-capacity values reported for the alpine and subalpine lakes that are considered to be sensitive to acidification (Nanus and others, 2005; Corbin and others, 2006).

Dissolved-solids concentrations for Taggart Creek were slightly larger than dissolved-solids concentrations for Cottonwood Creek (table 6). Concentrations ranged from 19 to 31 mg/L at site TC1 and from 24 to 30 mg/L at downstream site TC2 (fig. 6). The small range of dissolved solids at downstream site TC2 reflects the influence of Taggart Lake. Dissolved-solids concentrations generally showed an inverse relation with streamflow at site TC1. Dissolved-solids concentrations are smallest during high-flow conditions, when stream waters are diluted by snowmelt runoff, and are largest during low-flow conditions, when ground water that has larger dissolved solids contributes to streamflow. The small dissolved-solids concentrations in samples collected from Taggart Creek are the result of high annual precipitation in

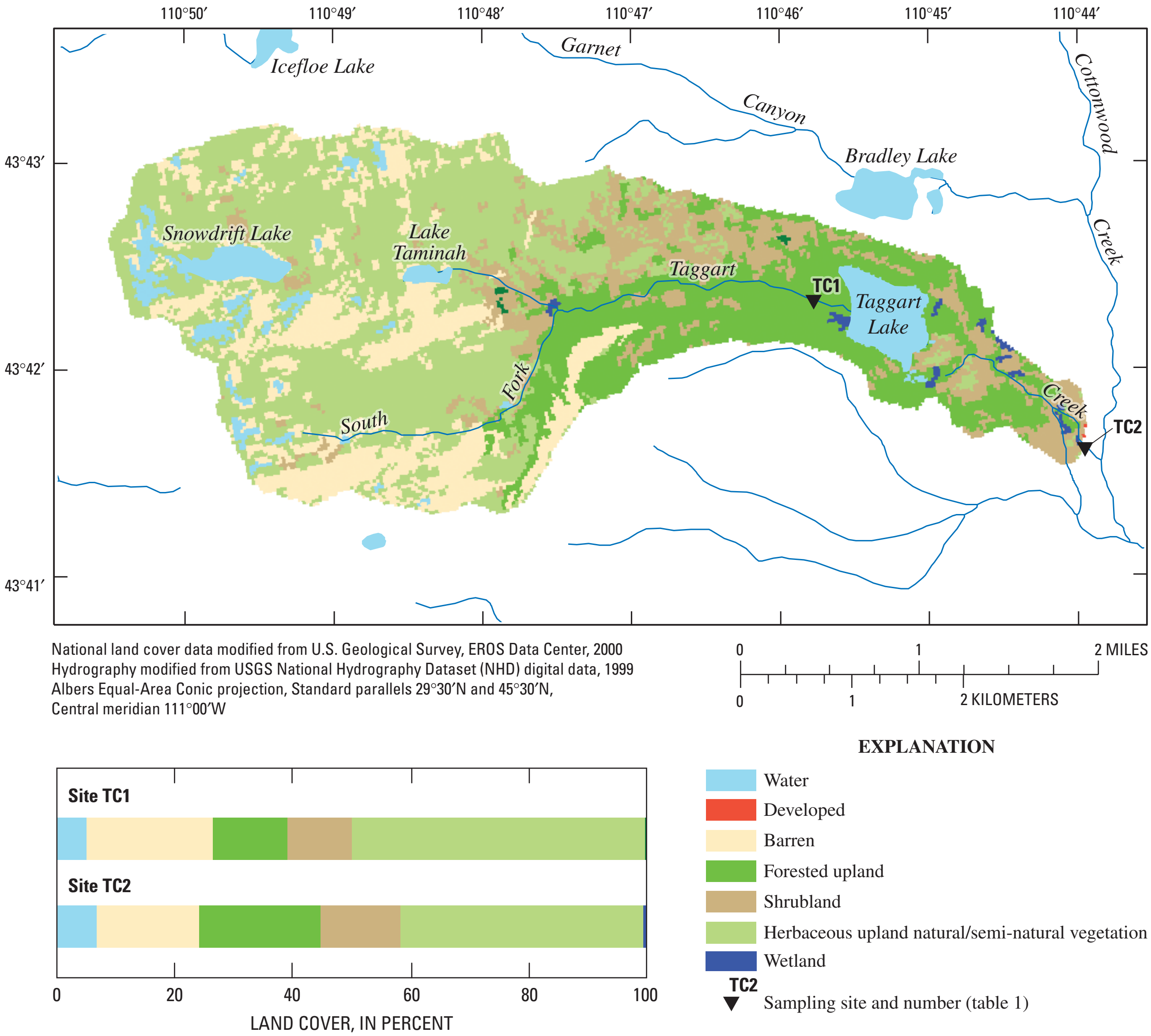

Figure 5. Distribution of land cover in the Taggart Creek drainage basin, Grand Teton National Park, Wyoming.

the Teton Range and steep gradients in this basin that produce relatively fast stream velocities, which results in short contact time between stream waters and the chemically resistant Precambrian-era rocks and material derived from these rocks that compose the basin.

Concentrations of nitrogen and phosphorus species generally were small in samples collected at sites TC1 and TC2 on Taggart Creek (table 6, fig. 6). Dissolved-ammonia, dissolved-nitrate, and dissolved-nitrite concentrations in all samples were less than the water-quality criteria for surface waters in Wyoming (table 5). All four samples collected at site TC1 and one sample collected at site TC2 had dissolved-nitrate concentrations larger than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). Monitoring of high-altitude lakes in Colorado, including lakes in Rocky Mountain National Park, has indicated water quality is being affected by inorganic nitrogen in atmospheric deposition (Campbell and others, 2000, and references therein; Williams and Tonnessen, 2000). Dissolved inorganic nitrogen concentrations were largest in subsurface waters of talus landscapes, where mineralization and nitrification augmented high rates of atmospheric deposition of nitrogen (Campbell and others, 2000). Dissolved-nitrate concentrations were relatively large in samples collected from Taggart Creek compared to the other streams, particularly at site TC1. Site TC1 has the largest percentage of barren land cover of all sites, indicating subsurface waters of talus slopes may contribute to dissolved-nitrate concentrations

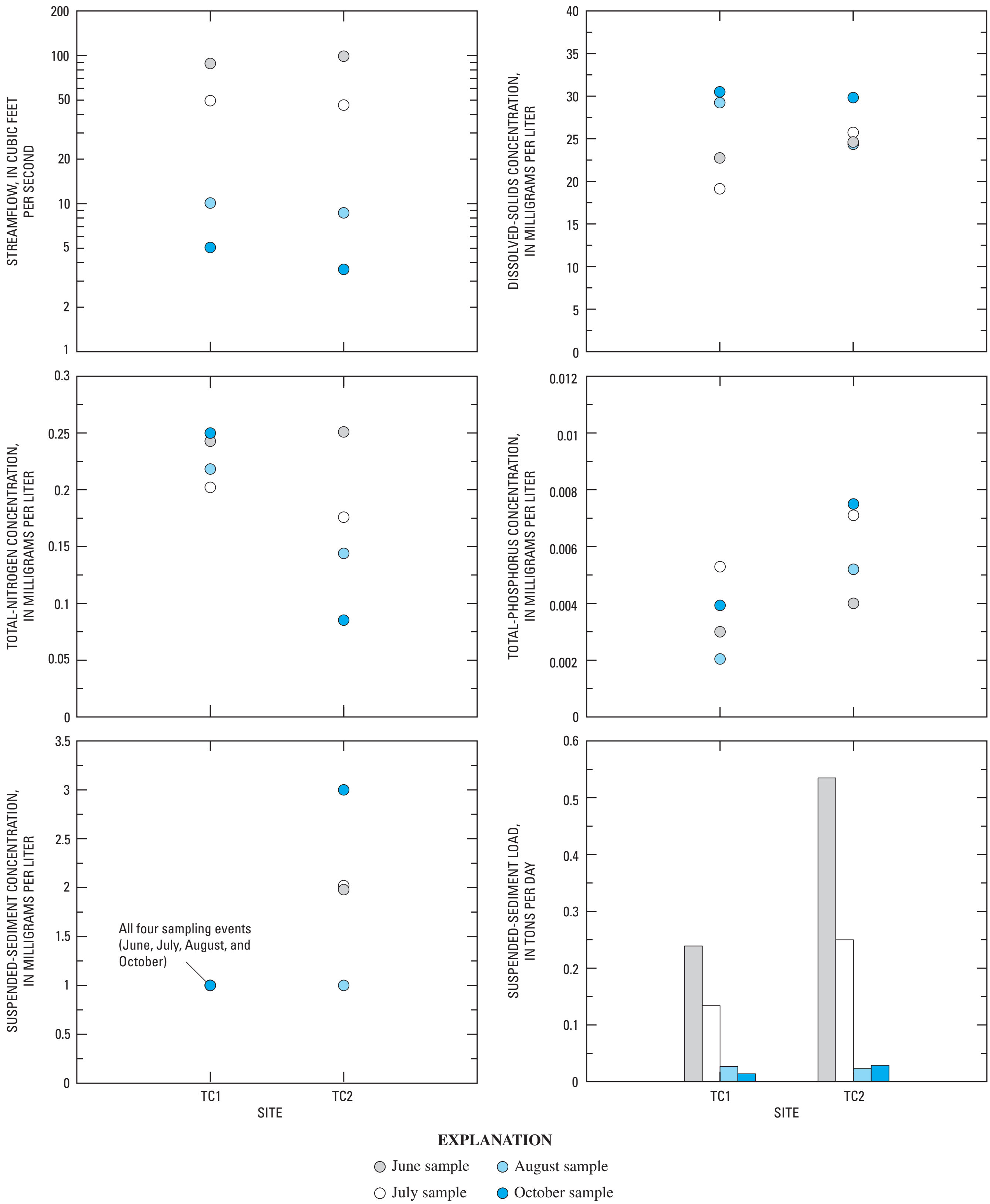

Figure 6. Streamflow; dissolved-solids, total-nitrogen, total-phosphorus, and suspended-sediment concentrations; and suspended-sediment loads for Taggart Creek, Grand Teton National Park, Wyoming, 2006.

in Taggart Creek. Because of the small buffering capacity of Taggart Creek, this drainage basin may be the most sensitive to future increases in atmospheric deposition of nitrogen and subsequent eutrophication and acidification. Total-nitrogen concentrations in samples collected at both sites were sometimes near, but were still less than the median concentration of 0.26 mg/L determined for undeveloped streams in the United States (Clark and others, 2000) and less than the ambient total-nitrogen criterion of 0.34 mg/L for forested mountain streams in the Middle Rockies ecoregion recommended by the USEPA to address cultural eutrophication (U.S. Environmental Protection Agency, 2000). In addition to atmospheric sources of nitrogen, it is possible that recreational use in the drainage basin could contribute to nitrogen concentrations. Dissolved-orthophosphate concentrations were less than the reporting level of 0.006 mg/L, and dissolved-phosphorus concentrations were less than 0.006 mg/L in all samples. Total-phosphorus concentrations were less than the total-phosphorus median concentration of 0.022 mg/L determined for undeveloped streams in the United States (Clark and others, 2000) in samples collected at both sites.

Dissolved-iron and dissolved-manganese concentrations were small in the samples collected at sites TC1 and TC2 on Taggart Creek (table 6). For all samples collected from the four western streams, the maximum dissolved-iron concentration (19 µg/L) and the maximum dissolved-manganese concentration (2.8 µg/L) were in samples collected at site TC2 on Taggart Creek. The relatively larger concentrations of these trace elements at site TC2 compared to site TC1 and sampling sites on other streams may be the result of processes associated with Taggart Lake. These concentrations were substantially less than the aquatic-life criteria and human-health criteria for dissolved iron and dissolved manganese (table 5). Dissolved-arsenic, dissolved-cadmium, dissolved-chromium, dissolved-copper, dissolved-nickel, dissolved-selenium, and dissolved-zinc concentrations (table 6) were substantially less than aquatic-life acute and chronic criteria (table 5) during the June sampling of Taggart Creek. Sources of trace elements in the Taggart Creek drainage basin most likely are natural because the basin is mostly undeveloped.

During the June sampling event, one sample was collected at site TC1 and one sample was collected at site TC2 and analyzed for 52 commonly used pesticides or their breakdown product. All of the concentrations in the samples were less than the laboratory reporting levels for the compounds (table 4) and aquatic criteria established for surface waters in Wyoming (table 5).

Suspended-sediment concentrations and loads for Taggart Creek were small for all the sampling events (fig. 6). Suspended-sediment concentrations were 1 mg/L in all four samples at site TC1 and ranged from 1 to 3 mg/L at site TC2. Typically, suspended sediment is carried to streams with overland flow or is resuspended from the stream bottom from turbulent flows. The upper basin largely contains rocky, coarse materials that are too heavy to be suspended at site TC1, and Taggart Lake probably reduces suspended material at site TC2.

Lake Creek

Lake Creek is a tributary to Fish Creek, a large tributary that flows into the Snake River downstream from Grand Teton National Park. The upstream site (site LC1) is located near the terminus of Death Canyon and is upstream from the inlet to Phelps Lake. The downstream site on Lake Creek is downstream from Phelps Lake and the Moose-Wilson Road (fig. 1). Most of the drainage area for the basin (about 85 percent) is upstream from site LC1. The drainage area at the downstream site (site LC2) is about 15.6 mi^2 (table 1). The bedrock geology of the Lake Creek drainage basin is dominated by Precambrian-era metasedimentary and metavolcanic rocks in the lower basin, with Paleozoic-era sedimentary rocks (including limestones, dolomites, and sandstones predominantly from the Ordovician period) in the upper basin. In this part of the study area, the Precambrian-era rocks at the core of the Teton Range are overlain by western dipping Paleozoic-era rocks. Quaternary-period deposits include glacial deposits that form the moraine at Phelps Lake, and landslide deposits of talus and related materials (Love and others, 1992). Lake Creek has a gravel, cobble, and rock streambed.

Land cover for both sites is similar; the predominant land covers are herbaceous uplands, forested uplands, and shrubland (fig. 7). Forested uplands, including deciduous forest, cover most of the glacial moraine. Private inholdings within Grand Teton National Park and a parking lot for the Death Canyon trailhead are accessed from a gravel road in the lower basin. Phelps Lake has high visitor use, primarily hiking and some camping. Some recreational use occurs upstream from site LC1. Site LC2 is downstream from most of the recreational uses. Lake Creek has several diversions downstream from site LC2.

Streamflow for Lake Creek varied during the sampling events (fig. 8). Streamflow ranged from 6.2 ft^3/s in August to 143 ft^3/s in June at site LC1 and from 6.6 ft^3/s in August to 231 ft^3/s in June at downstream site LC2. The high flows in June are a result of snowmelt runoff. Streamflow was higher at site LC2 than at site LC1 during three of the four sampling events. Phelps Lake contributes most of the streamflow at site LC2. Streamflow measured during the October sampling event was slightly higher than the streamflow measured during the August sampling event at sites LC1 and LC2. A small rain event occurred during the October sampling that may have contributed flow to Lake Creek.

Waters of Lake Creek were near neutral to alkaline (pH values ranged from 7.5 to 8.8) and were calcium-bicarbonate type (table 6). Among major cations, the concentration order from largest to smallest was calcium, magnesium, potassium, and sodium. Among major anions, the concentration order from largest to smallest was bicarbonate (determined from alkalinity), sulfate, and chloride. Alkalinity concentrations in samples collected from Lake Creek ranged from 46 to 61 mg/L as calcium carbonate, more than two times the concentrations measured for any sample collected from

Cottonwood Creek or Taggart Creek. Large dissolved-calcium and dissolved-magnesium concentrations are from the large area underlain by Paleozoic-era sedimentary rocks in the upper basin.

Dissolved-solids concentrations were substantially larger in Lake Creek than in Cottonwood Creek and Taggart Creek. Concentrations ranged from 55 mg/L to 87 mg/L at site LC1 and from 57 to 61 mg/L at downstream site LC2. The smaller range in concentrations at downstream site LC2 compared to site LC1 reflects the influence of Phelps Lake. Dissolved-solids concentrations generally showed an inverse relation with streamflow at site LC1. Concentrations are smallest during high-flow conditions, when stream waters are diluted by snowmelt runoff, and are largest during low-flow conditions, when ground water that has relatively larger dissolved-solids concentrations contributes to streamflow. The larger dissolved-solids concentrations in samples collected from Lake Creek compared to Cottonwood Creek and Taggart Creek are the result of the Paleozoic-era sedimentary rocks that are in the upper drainage basin, which generally are more soluble than the Precambrian-era rocks.

Concentrations of nitrogen and phosphorus species generally were small in samples collected at sites LC1 and LC2 on Lake Creek (table 6, fig. 8). Dissolved-ammonia, dissolved-nitrate, and dissolved-nitrite concentrations in all samples were less than the water-quality criteria for surface waters in Wyoming (table 5). One sample collected at site LC1 had a dissolved-nitrate concentration of 0.10 mg/L, which was larger than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). The sample was collected in October when subsurface waters of talus slopes may contribute to streamflow and dissolved-nitrate concentrations. Total-nitrogen concentrations in samples collected at sites LC1 and LC2 were less than the median concentration of 0.26 mg/L determined for undeveloped streams in the United States (Clark and others, 2000) and the ambient total-nitrogen criterion of 0.34 mg/L for forested mountain streams in the Middle Rockies ecoregion recommended by the USEPA to address cultural eutrophication (U.S. Environmental Protection Agency, 2000). All total-ammonia and organic nitrogen concentrations (0.11 to 0.25 mg/L) were larger than the laboratory reporting level for samples collected at site LC2. Dispersed back-country camping and other recreational use in the Phelps Lake area may contribute to nitrogen concentrations in Lake Creek in addition to natural sources. During all four sampling visits at site LC2, algal growth that covered 50 percent or more of the streambed was observed, which may indicate some nutrient enrichment of Lake Creek. All eight samples of dissolved orthophosphate had concentrations less than the reporting level of 0.006 mg/L. Dissolved-phosphorus concentrations were 0.006 mg/L or less in all samples. Total-phosphorus concentrations in samples were less than the total-phosphorus median concentration of 0.022 mg/L determined for undeveloped streams in the United States (Clark and others, 2000).

Dissolved-iron and dissolved-manganese concentrations generally were small in the samples collected at sites LC1 and LC2 on Lake Creek (table 6). The maximum dissolved-iron concentration was 13 µg/L (site LC1), and the maximum dissolved-manganese concentration was 1.4 µg/L (site LC2) for samples collected from Lake Creek. These concentrations were substantially less than the aquatic-life criteria and human-health criteria for dissolved iron and dissolved manganese (table 5). Dissolved-arsenic, dissolved-cadmium, dissolved-chromium, dissolved-nickel, dissolved-selenium, and dissolved-zinc concentrations (table 6) were substantially less than aquatic-life acute and chronic criteria (table 5) during the June sampling of Lake Creek. The dissolved-copper concentration of 4.5 µg/L at site LC1 was large compared to all other samples for dissolved copper. The concentration was near the aquatic-life chronic criterion of 4.7 µg/L calculated for waters with a hardness of 48 mg/L as calcium carbonate (Wyoming Department of Environmental Quality, 2007). Because only one sample was collected at this site, it is not possible to determine whether this concentration is an outlier. The large dissolved-copper concentration was associated with the largest dissolved-iron and suspended-sediment concentrations that were reported for samples collected at site LC1. Some trace elements might remain in a colloidal form after passing through the 0.45-µm filter and exhibit a flow-driven characteristic, like suspended sediment, during runoff. Sources of trace elements in the Lake Creek drainage basin most likely are natural because the basin is mostly undeveloped.

During the June sampling event, one sample was collected at site LC1 and one sample was collected at site LC2 and analyzed for 52 commonly used pesticides or their breakdown products. All of the concentrations in the samples were less than the laboratory reporting levels for the compounds (table 4) and aquatic criteria established for surface waters in Wyoming (table 5).

Suspended-sediment concentrations and loads for Lake Creek were small for all the sampling events (fig. 8), and ranged from 1 to 17 mg/L in the four samples at site LC1 and from 1 to 3 mg/L at downstream site LC2. The large suspended-sediment concentration at site LC1 was during snowmelt runoff in June when suspended sediment is carried to streams with overland flow or is resuspended from the stream bottom from turbulent flows. The smaller sediment concentrations at site LC2 compared to those at site LC1 reflect the influence of Phelps Lake, which likely reduces the suspended material.

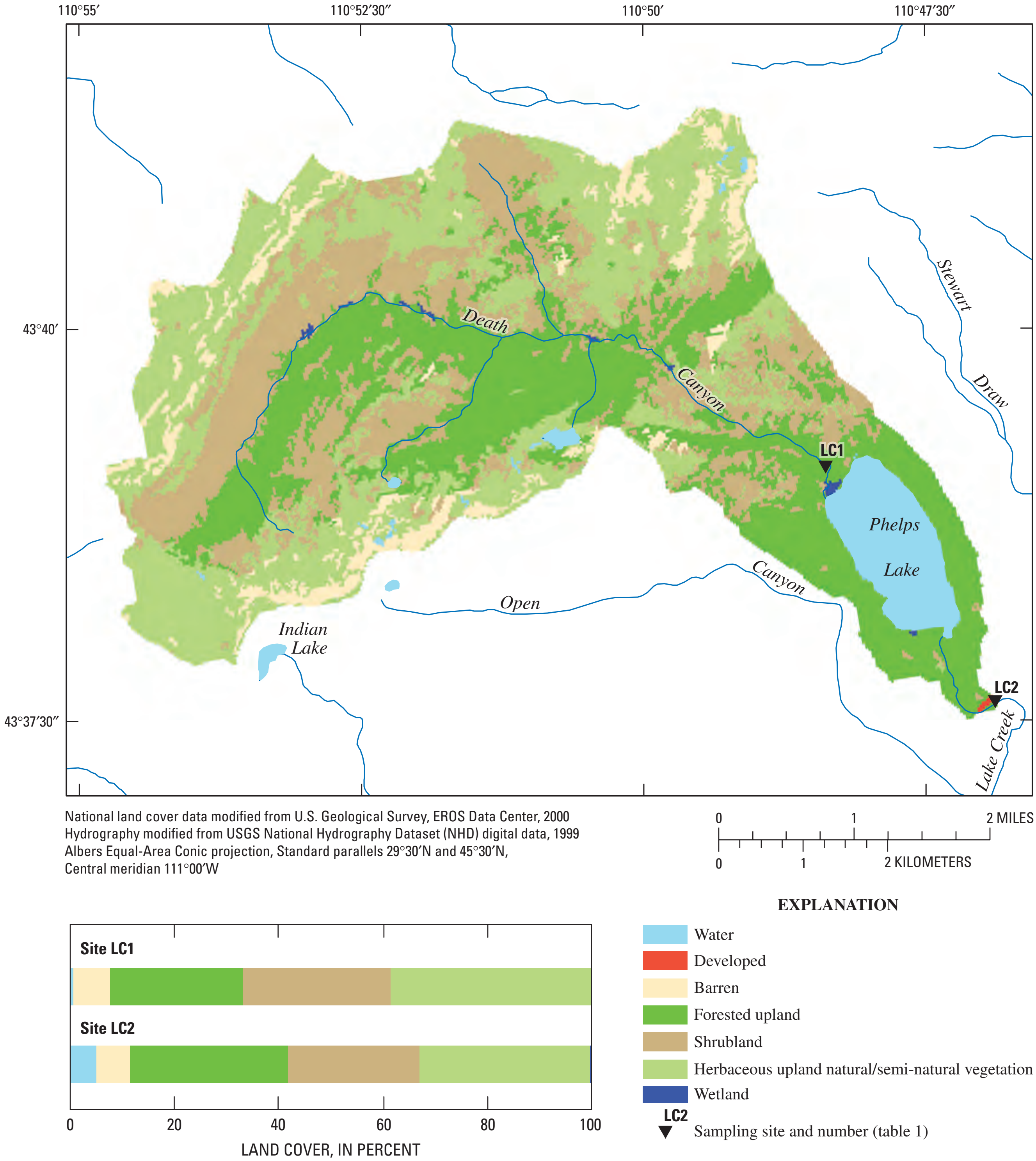

Figure 7. Distribution of land cover in the Lake Creek drainage basin, Grand Teton National Park, Wyoming.

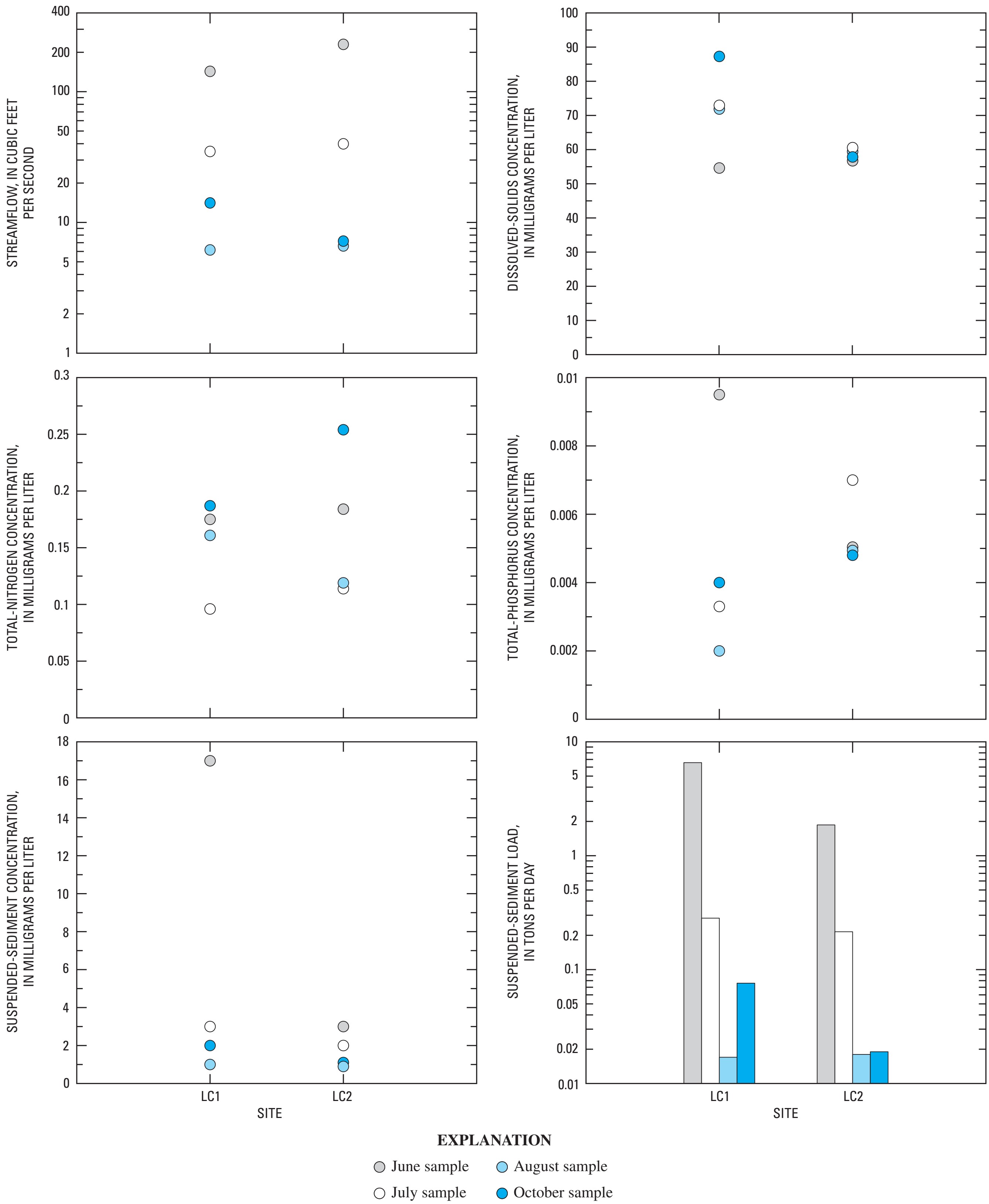

Figure 8. Streamflow; dissolved-solids, total-nitrogen, total-phosphorus, and suspended-sediment concentrations; and suspended-sediment loads for Lake Creek, Grand Teton National Park, Wyoming, 2006.

Granite Creek

The Granite Creek drainage basin is the southernmost drainage basin in the study area. The upstream site (site GC1) on Granite Creek is located near the terminus of Granite Canyon immediately upstream from where the stream gradient abruptly increases to a waterfall that cascades downstream for some distance (fig. 1). The downstream site (site GC2) on Granite Creek is located at a USGS streamflow-gaging station near the boundary of Grand Teton National Park. Granite Creek historically was an undiverted tributary to Lake Creek; however, multiple irrigation diversions exist downstream from site GC2 near the border of Grand Teton National Park. Most of the drainage area for the basin (about 92 percent) is upstream from site GC1. The drainage area at the downstream site GC2 is about 14.9 mi^2 (table 1). Precambrian-era rocks in the lower basin include metasedimentary and metavolcanic rocks, as well as metamorphosed mafic and ultramafic rocks. The upper basin is dominated by Paleozoic-era sedimentary rocks. About 50 percent of the surface area in the Granite Creek drainage basin is underlain by Paleozoic-era sedimentary rocks, which is the largest percentage of the four basins. In addition to Ordovician-period sedimentary rocks, younger Devonian- and Mississippian-period rocks, including the Madison Limestone, are present. Quaternary-period deposits include glacial deposits, and landslide deposits of talus and related materials (Love and others 1992). Granite Creek has a predominantly gravel, cobble, and rock streambed at both sites.

Land cover for both sites is very similar (fig. 9). Forested uplands, herbaceous uplands, and shrubland compose more than 98 percent of the drainage area at both sites. Recreational uses occur in the basin. Granite Canyon is accessed from a trailhead on the Moose-Wilson Road (fig. 1). Recreational uses include hiking and back-country camping. The upper part of Granite Canyon is near a major ski area.

Streamflow for Granite Creek varied during the sampling events (fig. 10). Streamflow ranged from 10 ft^3/s in October to 285 ft^3/s in June at site GC1 and from 9.7 ft^3/s in August to 275 ft^3/s in June at downstream site GC2. The high flows in June are a result of snowmelt runoff. Streamflow values for the upstream and downstream sites were about the same during each sampling event, indicating no substantial gain or loss of streamflow occurs in this reach. Streamflow measured during the October sampling event was slightly higher than the streamflow measured during the August sampling event at site GC2. A small rain event occurred during the October sampling that may have contributed flow to Granite Creek.

Granite Creek is the most alkaline of the western streams sampled for the synoptic study in Grand Teton National Park, as indicated by the larger pH values (8.2 to 8.8) compared to those from the other three streams. Waters of Granite Creek were calcium-bicarbonate type (table 6). Among major cations, the concentration order from largest to smallest for some samples was calcium, magnesium, potassium, and sodium. The concentration order for other samples was calcium, magnesium, sodium, and potassium. Among major anions, the concentration order from largest to smallest was bicarbonate (determined from alkalinity), sulfate, and chloride. Waters of Granite Creek are the most buffered of the four streams sampled for this study. For samples from all four streams, dissolved-sodium, dissolved-potassium, dissolved-chloride, dissolved-fluoride, dissolved-silica, and dissolved-sulfate concentrations generally were not highly variable among sites. Dissolved-calcium, dissolved-magnesium, and alkalinity concentrations were variable among sites; the maximum concentrations of these constituents were in samples from Granite Creek. Alkalinity concentrations in samples collected from Granite Creek ranged from 107 to 116 mg/L as calcium carbonate, nearly 2 times the concentrations measured for Lake Creek and about 10 times the concentrations measured for Cottonwood Creek.

Dissolved-solids concentrations for Granite Creek were the largest of the four streams sampled as part of this study. Concentrations ranged from 108 to 130 mg/L at site GC1 and from 105 to 125 mg/L at downstream site GC2 (fig. 10). Concentrations are smallest during high-flow conditions, when stream waters are diluted by snowmelt runoff, and are largest during low-flow conditions, when ground water that has larger dissolved-solids concentrations contributes to streamflow. As with streamflow, the variability in dissolved-solids concentrations between the two sites was small. The large dissolved-solids concentrations are a result of the large area of the basin being underlain by Paleozoic-era sedimentary rocks. Granite Creek drainage basin is the only basin with a large area underlain by the Madison Limestone and Darby Formation (table 2).

Concentrations of nitrogen and phosphorus species generally were small in samples collected at sites GC1 and GC2 on Granite Creek (table 6, fig. 10). Dissolved-ammonia, dissolved-nitrate, and dissolved-nitrite concentrations in all samples from Granite Creek were less than the water-quality criteria for surface waters in Wyoming (table 5). The dissolved-nitrate concentration (0.11 mg/L) in one sample at site GC1 had a concentration larger than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). The sample was collected in October when subsurface waters of talus slopes may contribute to streamflow and dissolved-nitrate concentrations. Total-nitrogen concentrations in all samples collected at site GC1 and in three of the samples collected at site GC2 were less than the median concentration of 0.26 mg/L determined for undeveloped streams in the United States (Clark and others, 2000) and the ambient total-nitrogen criterion of 0.34 mg/L for forested mountain streams in the Middle Rockies ecoregion recommended by the USEPA to address cultural eutrophication (U.S. Environmental Protection Agency, 2000). The total-nitrogen concentration (largely in the form of ammonia and organic nitrogen) was 0.34 mg/L for a sample collected in July at site GC2 when recreational use in the basin is high. Dissolved-orthophosphate concentrations were less than the laboratory reporting level of 0.006 mg/L, and dissolved-phosphorus concentrations were less than

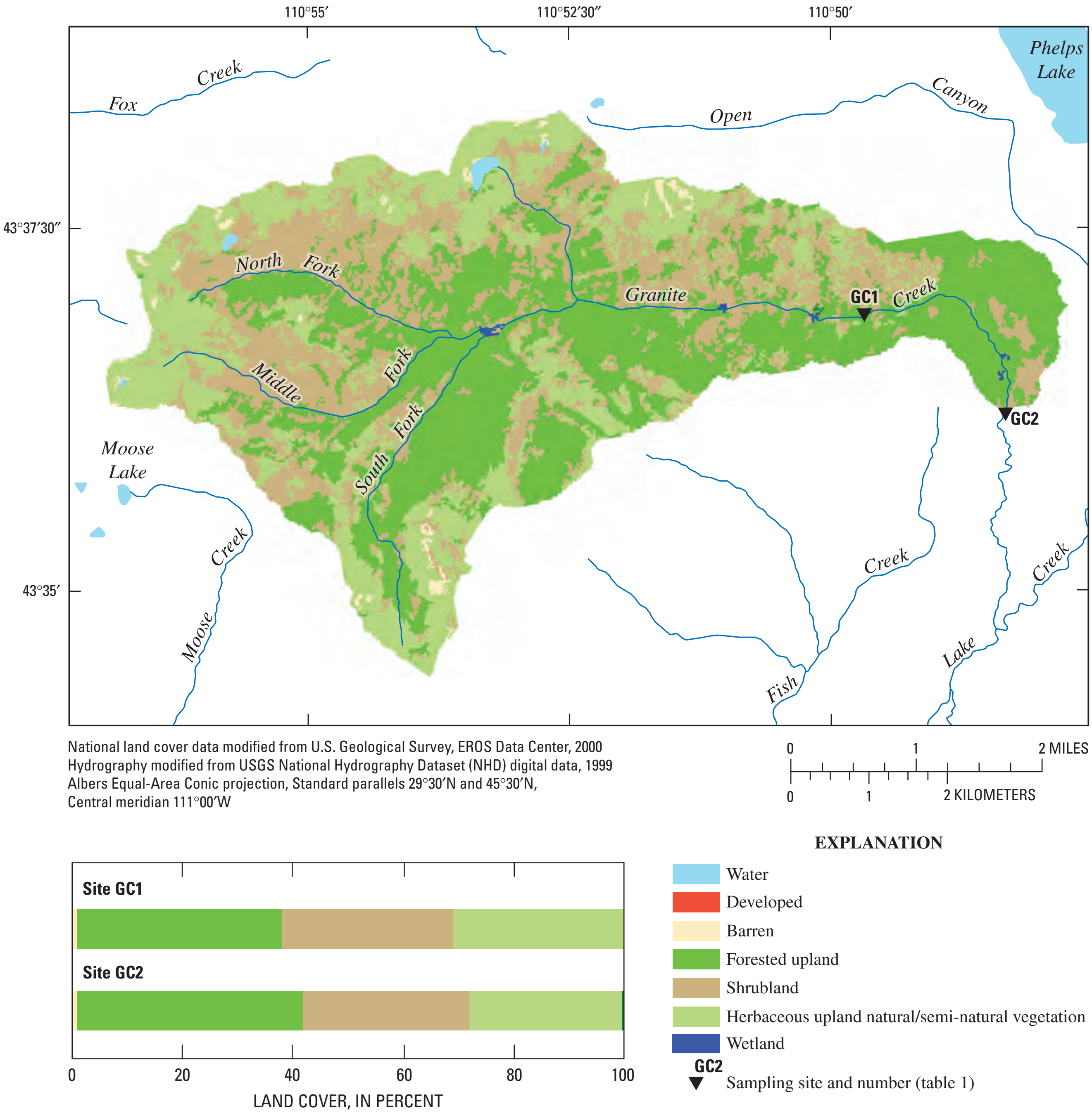

Figure 9. Distribution of land cover in the Granite Creek drainage basin, Grand Teton National Park, Wyoming.

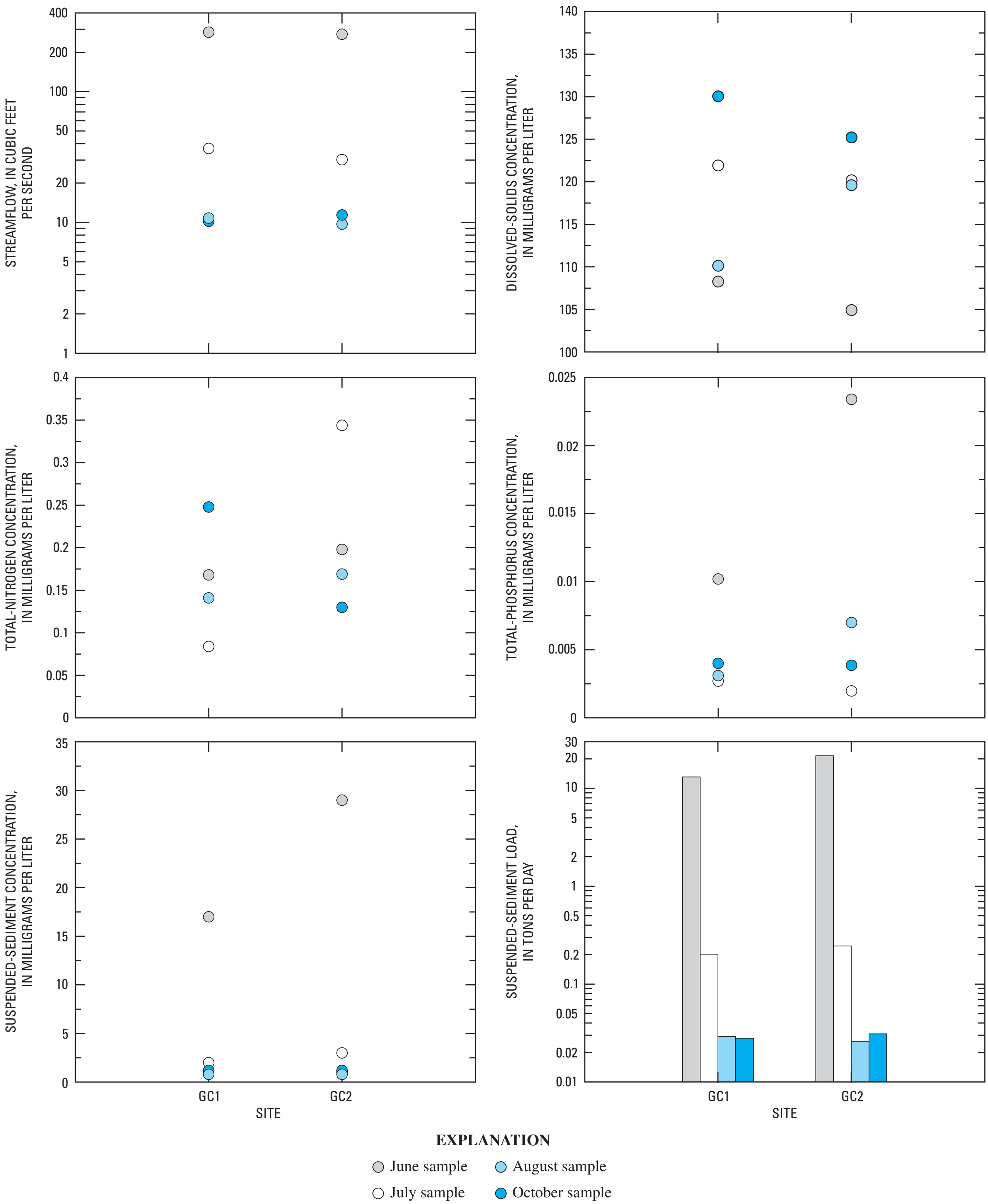

Figure 10. Streamflow; dissolved-solids, total-nitrogen, total-phosphorus, and suspended-sediment concentrations; and suspended-sediment loads for Granite Creek, Grand Teton National Park, Wyoming, 2006.

0.006 mg/L in all samples. Total-phosphorus concentrations in all samples collected at site GC1 and in three samples collected at site GC2 were less than the total-phosphorus median concentration of 0.022 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). The sample with the largest total-phosphorus concentration of 0.023 mg/L was collected in June and was associated with a large suspended-sediment concentration.

Dissolved-iron and dissolved-manganese concentrations were small in the samples collected at sites GC1 and GC2 on Granite Creek (table 6). The dissolved-iron concentrations were less than 6 µg/L, and the maximum dissolved-manganese concentration was 0.6 µg/L (site GC2) for samples collected from Granite Creek. These concentrations were substantially less than the aquatic-life criteria and human-health criteria for dissolved iron and dissolved manganese (table 5). Dissolved-arsenic, dissolved-cadmium, dissolved-chromium, dissolved-copper, dissolved-nickel, dissolved-selenium, and dissolved-zinc concentrations (table 6) were substantially less than aquatic-life acute and chronic criteria (table 5) during the June sampling of Granite Creek. Sources of trace elements in the Granite Creek drainage basin most likely are natural because the basin is mostly undeveloped.

During the June sampling event, one sample was collected at site GC1 and one sample was collected at site GC2 and analyzed for 52 commonly used pesticides or their breakdown products. All of the concentrations in the samples were less than the laboratory reporting levels for the compounds (table 4) and aquatic criteria established for surface waters in Wyoming (table 5).

Suspended-sediment concentrations and loads for Granite Creek (fig. 10) were small for all the sampling events. Suspended-sediment concentrations ranged from less than 1 to 17 mg/L at site GC1 and from 1 to 29 mg/L at downstream site GC2. The largest suspended-sediment concentrations and loads were during snowmelt runoff in June when suspended sediment is carried to streams with overland flow or is resuspended from the stream bottom from turbulent flows. The larger suspended-sediment concentrations for Granite Creek compared to the other streams probably are a result of the sedimentary rocks in the basin.

Comparison of Synoptic Study Results

Results of the synoptic study of the western streams conducted during 2006 in the Snake River headwaters area were compared to results of a synoptic study of the eastern streams in the headwaters area conducted during 2002 (fig. 1). Five tributaries to the Snake River (Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek) were sampled during the 2002 synoptic study of eastern streams. Overall hydrologic conditions for the Snake River varied slightly between sampling periods. For the Snake River at Moose, Wyo., the annual-runoff value of 1,619,000 acre-ft during water year 2002 was slightly less than the annual-runoff value of 1,730,000 acre-ft during water year 2006. Annual-runoff values for both synoptic years were less than the average annual-runoff value of 2,140,000 acre-ft for the period of record for water years 1995–2006. In the western part of the basin, annual runoff for water year 2006 for Granite Creek was about 97 percent of average for the period of record. In the eastern part of the basin, annual-runoff values for Pacific Creek and the Buffalo Fork for water year 2002 were about 77 percent of average for the periods of record. Because hydrologic conditions cannot be directly compared for the two time periods, tests for statistical differences in water-quality constituents were not conducted; however, general comparisons of constituents were made to describe spatial differences in water-quality characteristics in the Snake River headwaters area.

The eastern streams had a larger range of instantaneous streamflows than the western streams during the synoptic studies (fig. 11). Overall, the drainage areas of the eastern streams are substantially larger than the drainage areas of the western streams. For example, the Buffalo Fork, the largest of the eastern streams studied, drains an area of about 378 mi^2 near the confluence with the Snake River; in contrast, Cottonwood Creek, the largest of the western streams studied and the only stream that is directly tributary to the Snake River, drains an area of about 72.3 mi^2 near the confluence with the Snake River. Pilgrim Creek, Spread Creek, and Ditch Creek in the eastern part of the basin and Cottonwood Creek in the western part of the basin had the common characteristic of having streamflow losses between upstream and downstream sites during the synoptic studies. Generally, streams that flow through Jackson Hole are highly connected to the groundwater system because of the highly permeable aquifer materials. If the stream levels are higher than the adjacent water table, the stream loses water; likewise, if the stream level is lower than the adjacent water table, the stream gains water (Cox, 1974).

Dissolved-solids concentrations in samples collected from western streams generally were smaller than dissolved-solids concentrations in samples collected from eastern streams (fig. 11). Dissolved-solids concentrations ranged from 11 to 130 mg/L in samples collected from the western streams and from 75 to 235 mg/L in samples collected from the eastern streams. The median dissolved-solids concentration of 55 mg/L for the western streams was smaller than the median dissolved-solids concentration of 125 mg/L for eastern streams. The small dissolved-solids concentrations in the western streams are a result of the large areas underlain by resistant Precambrian-era rocks that compose the Teton Range and higher annual precipitation in the Teton Range compared to the eastern part of the Snake River headwaters area. The Washakie Range, which forms a large part of the eastern boundary of the upper basin, is largely composed of more erodable Mesozoic-era sedimentary rocks of marine origin, including sandstones, siltstones, and shales (Love and others, 1992). Average annual precipitation in the Teton Range is more than 70 inches compared to generally less than

50 inches in the mountain ranges in the eastern part of the basin (Oregon Climate Service, 2007). The median dissolved-solids concentration of 123 mg/L for the Snake River (Clark and others, 2004) is similar to the median dissolved-solids concentration of the eastern streams. The range of dissolved-solids concentrations (19 to 24 mg/L) for samples collected at site CC2 on Cottonwood Creek were substantially less than the range of dissolved-solids concentrations of 77 to 141 mg/L for the Snake River at Moose, Wyo., (Clark and others, 2004), indicating Cottonwood Creek has a small diluting effect on the Snake River. Overall, dissolved-solids concentrations in the eastern and western streams of the Snake River headwaters area are small compared to dissolved-solids concentrations in other basins in Wyoming (Peterson, 1993).

Concentration ranges of major-ion constituents, which contribute to the dissolved solids, indicate the source of the variability in dissolved solids. Samples collected from the eastern streams had larger ranges of concentrations for all of the major-ion constituents (Clark and others, 2004). In particular, dissolved-sodium, dissolved-chloride, and dissolved-sulfate concentrations generally were substantially larger in the samples collected from the eastern streams compared to those from the western streams. Dissolved-sodium concentrations ranged from 2.54 to 10.3 mg/L for the eastern streams compared to 0.33 to 0.70 mg/L for the western streams. Dissolved-chloride concentrations ranged from less than 0.20 to 4.58 mg/L for the eastern streams compared to less than 0.20 to 0.84 mg/L for the western streams. Dissolved-sulfate concentrations ranged from 2.6 to 64.8 mg/L for the eastern streams compared to 1.46 to 7.08 mg/L for the western streams. Dissolved-silica concentrations, a nonionic contributor to dissolved solids, also were variable. Dissolved-silica concentrations ranged from 6.46 to 22.2 mg/L for the eastern streams compared to 1.50 to 3.71 mg/L for the western streams.

Nutrient concentrations varied between the eastern streams and western streams in the Snake River headwaters area (fig. 11). The median total-nitrogen concentration (0.17 mg/L) for samples collected from streams in the western part of the Snake River headwaters area was larger than the median concentration (0.10 mg/L) for samples collected from streams in the eastern part of the basin. Dissolved-nitrate concentrations were less than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States (Clark and others, 2000) in all 38 samples collected from streams in the eastern part of the basin (Clark and others, 2004). In contrast, dissolved-nitrate concentrations were larger than 0.087 mg/L in about 23 percent of the samples collected from the western tributaries. Dissolved nitrate associated with subsurface waters of talus slopes may be the source of some of the dissolved nitrate in the western streams. Nitrogen may be better utilized in the eastern basins than in the western basins because the eastern basins have more forested upland areas and less barren areas.

In contrast to total nitrogen, the median total-phosphorus concentration (0.025 mg/L) for samples collected from eastern streams was larger than the median concentration (0.004 mg/L) for samples collected from western streams. The median total-phosphorus concentrations for samples collected from the eastern streams was larger than the median total-phosphorus concentration of 0.022 mg/L determined for undeveloped streams in the United States (Clark and others, 2000) and the ambient total-phosphorus criterion of 0.015 mg/L for forested mountain streams recommended by the USEPA (U.S. Environmental Protection Agency, 2000). The median total-phosphorus concentration for samples collected from the western streams was less than the median concentration determined for undeveloped streams in the United States (Clark and others, 2000) and less than the ambient criterion for forested mountain streams recommended by the USEPA (U.S. Environmental Protection Agency, 2000). The larger total-phosphorus concentrations for the eastern streams compared to the western streams generally were in samples from the Buffalo Fork (Clark and others, 2004). Large total-phosphorus concentrations were associated with large suspended-sediment concentrations. Phosphate sorbs to soil particles and is carried to streams with the sediment. The primary source of the phosphorus and sediment probably is the sedimentary rocks of marine origin that underlie parts of the eastern basins.

Suspended-sediment concentrations in samples collected from streams in the eastern part of the Snake River headwaters area generally were larger than suspended-sediment concentrations in samples collected from streams in the western part of the basin (fig. 11). The median suspended-sediment concentration was 5 mg/L for samples collected from eastern streams compared to the median concentration of 1 mg/L for samples collected from western streams. For the eastern streams, the maximum suspended-sediment concentration was 286 mg/L for a sample collected from the Buffalo Fork compared to the western streams where the maximum concentration was 29 mg/L for a sample collected from Granite Creek. The eastern streams carry much larger sediment loads to the Snake River compared to Cottonwood Creek. For example, during snowmelt runoff the sediment load was 347 tons per day (tons/d) for the Buffalo Fork (Clark and others, 2004) compared to a sediment load of 16 tons/d for Cottonwood Creek at site CC2. The geology in the eastern part of the Snake River headwaters area largely is composed of more erodable Mesozoic-era sedimentary rocks, whereas the geology in the western part of the headwaters area largely is composed of resistant Precambrian-era igneous and metamorphic rocks. In addition, four of the study sites on the western streams are downstream from lakes, which trap some of the suspended sediment. Overall, streams in the eastern part and the western part of the Snake River headwaters area have small suspended-sediment concentrations compared to other streams in Wyoming (Peterson, 1993).

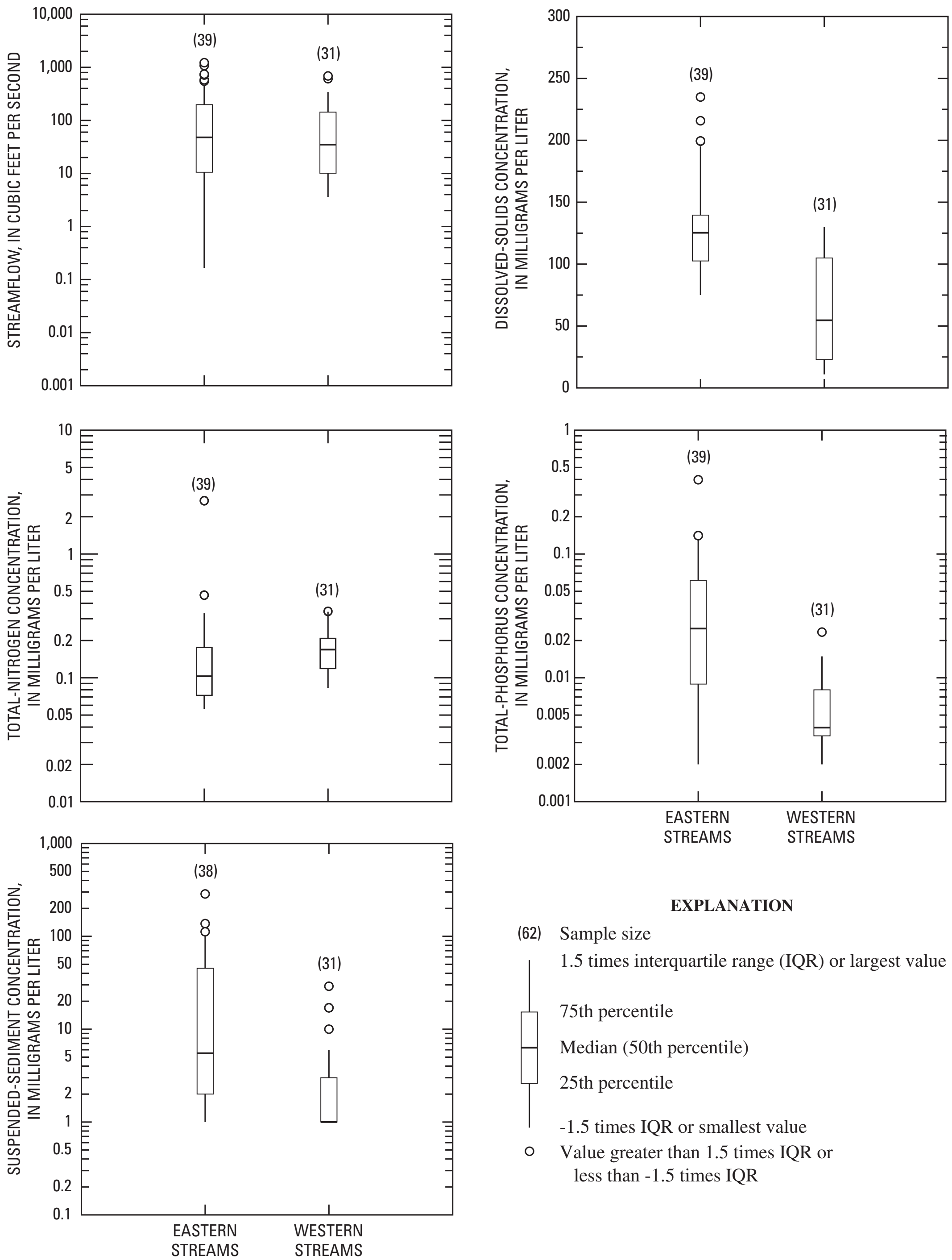

Figure 11. Streamflow and dissolved-solids, total-nitrogen, total-phosphorus, and suspended-sediment concentrations for eastern streams and western streams in the Snake River headwaters area, Grand Teton National Park, Wyoming, 2002–06.

Summary

To address water-resource management objectives of the National Park Service in Grand Teton National Park, the U.S. Geological Survey, in cooperation with the National Park Service, has conducted water-quality sampling on streams in the Snake River headwaters area. A synoptic study of streams in the western part of the headwaters area was conducted during 2006. Sampling sites were located on Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek. Sampling events in June, July, August, and October were selected to characterize different hydrologic conditions and different recreational-use periods. Stream samples were collected and analyzed for field measurements, major-ion chemistry, nutrients, selected trace elements, pesticides, and suspended sediment.

Water types of Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek were calcium bicarbonate. Dissolved-solids concentrations were dilute in Cottonwood Creek and Taggart Creek, which drain Precambrian-era rocks and materials derived from these rocks. Dissolved-solids concentrations ranged from 11 to 31 milligrams per liter for samples collected from Cottonwood Creek and Taggart Creek. Dissolved-solids concentrations ranged from 55 to 130 milligrams per liter for samples collected from Lake Creek and Granite Creek, which drain Precambrian-era rocks and Paleozoic-era rocks and materials derived from these rocks. Alkalinity concentrations were small in Cottonwood Creek and Taggart Creek and ranged from 8 to 22 milligrams per liter as calcium carbonate. The small alkalinity concentrations from Cottonwood Creek and Taggart Creek may indicate potential sensitivity to acidification; however, pH values were near neutral to alkaline.

Nutrient concentrations generally were small in samples collected from Cottonwood Creek, Taggart Creek, Lake Creek, and Granite Creek. Dissolved-nitrate concentrations were the largest in Taggart Creek, which has the largest percentage of barren land cover of the drainage basins. Landslide deposits in the Taggart Creek drainage basin largely are talus and related material. Subsurface waters of talus slopes may contribute to dissolved-nitrate concentrations in Taggart Creek. Because of the small buffering capacity of Taggart Creek, this drainage basin may be the most sensitive to future increases in atmospheric deposition of nitrogen and subsequent eutrophication and acidification. Pesticide concentrations were less than laboratory reporting levels for all samples. Metolachlor was detected in the sample from Cottonwood Creek in June with an estimated concentration of 0.002 microgram per liter, which was less than the laboratory reporting level of 0.006 microgram per liter. Trace-element concentrations were smaller than aquatic-life criteria for all samples. Suspended-sediment concentrations generally were small for all samples. The largest suspended-sediment concentrations occurred during snowmelt runoff.

Water-quality characteristics of streams in the western part of the Snake River headwaters area were compared to water-quality characteristics of streams sampled during 2002 in the eastern part of the headwaters area. The median dissolved-solids concentration (55 milligrams per liter) for samples collected from western streams was smaller than the median dissolved-solids concentration (125 milligrams per liter) for samples collected from eastern streams. The small dissolved-solids concentrations in the western streams are a result of the large areas underlain by resistant Precambrian-era rocks that compose the Teton Range compared to the more erodable Mesozoic-era sedimentary rocks that compose the mountains in the eastern part of the headwaters area. The Teton Range also receives higher annual precipitation than the mountains to the east. The median total-nitrogen concentration (0.17 milligram per liter) in samples collected from streams in the western part of the Snake River headwaters area was larger the median concentration (0.10 milligram per liter) for samples collected from streams in the eastern part of the headwaters area, in part because of larger dissolved-nitrate concentrations in samples from the western streams compared to the eastern streams. In contrast, total-phosphorus concentrations generally were larger for samples collected from eastern streams. Large total-phosphorus concentrations in the eastern streams were associated with large suspended-sediment concentrations. The source of the phosphorus and sediment probably is marine sedimentary rocks that underlie parts of the eastern drainage basins. Overall, concentrations of water-quality constituents are small compared to other Wyoming streams.

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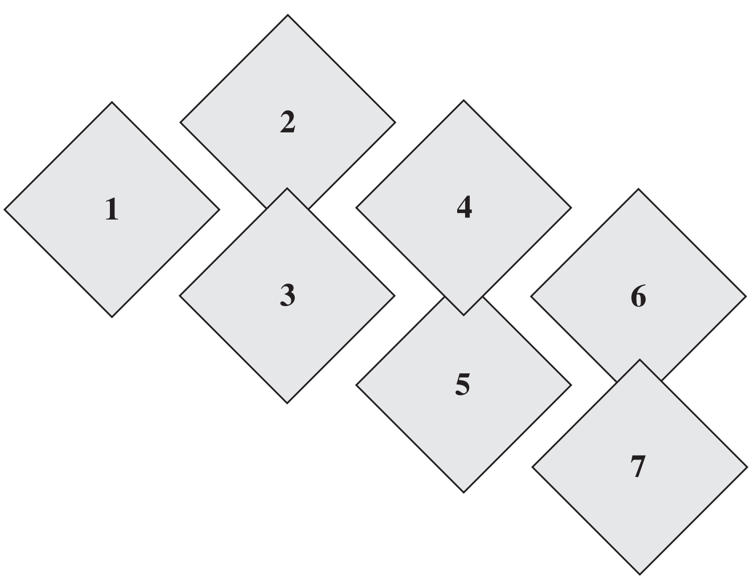

Back cover photographs:

1. Taggart Creek in June 2006.
2. Cascade on Granite Creek in June 2006.
3. Taggart Creek drainage basin in July 2006.
4. Granite Canyon in July 2006.
5. Cottonwood Creek in August 2006.
6. Phelps Lake in October 2006.
7. Death Canyon in October 2006.

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