Water-Quality Characteristics of the Snake River and Five Tributaries in the upper Snake River Basin, Grand Teton National Park, Wyoming, 1998-2002

By Melanie L. Clark, Wilfrid J. Sadler, and Susan E. O'Ney

Prepared in cooperation with the
National Park Service

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TABLES

Conversion Factors, Datum, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
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)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound	0.4536	kilogram

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

°F = (1.8 x °C) + 32

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

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83).

Water year: Water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. Thus, the water year ending September 30, 2002, is called the 2002 water year.

Abbreviated water-quality units used in this report:

col/100 mL	colonies per 100 millimeters
mg/L	milligrams per liter
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
<	less than
>	greater than

Abbreviations used in this report:

GCMS	Gas chromatography and mass spectrometry
NLCD	National Land Cover Data
NPS	National Park Service
NWQL	National Water Quality Laboratory
SMCL	Secondary Maximum Contaminant Level
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Water-Quality Characteristics of the Snake River and Five Eastern Tributaries in the upper Snake River Basin, Grand Teton National Park, Wyoming,1998-2002

By Melanie L. Clark[1], Wilfrid J. Sadler[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 in the upper Snake River Basin. Routine sampling of the Snake River was conducted during water years 1998-2002 to monitor the water quality of the Snake River through time. A synoptic study during 2002 was conducted to supplement the routine Snake River sampling and establish baseline water-quality conditions of five of its eastern tributaries—Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek. Samples from the Snake River and the five tributaries were collected at 12 sites and analyzed for field measurements, major ions and dissolved solids, nutrients, selected trace metals, pesticides, and suspended sediment. In addition, the eastern tributaries were sampled for fecal-indicator bacteria by the National Park Service during the synoptic study.

Major-ion chemistry of the Snake River varies between an upstream site above Jackson Lake near the northern boundary of Grand Teton National Park and a downstream site near the southern boundary of the Park, in part owing to the inputs from the eastern tributaries. Water type of the Snake River changes from sodium bicarbonate at the upstream site to calcium bicarbonate at the downstream site. The water type of the five eastern tributaries is calcium bicarbonate. Dissolved solids in samples collected from the Snake River were significantly higher at the upstream site (p-value<0.001), where concentrations in 43 samples ranged from 62 to 240 milligrams per liter, compared to the downstream site where concentrations in 33 samples ranged from 77 to 141 milligrams per liter. Major-ion chemistry of Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek generally did not change substantially between the upstream sites near the National Park Service boundary with the National Forest and the downstream sites near the Snake River; however, variations in the major ions and dissolved solids existed between basins. Variations probably result from differences in geology between the tributary basins.

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[2]National Park Service

Concentrations of dissolved ammonia, nitrite, and nitrate in all samples collected from the Snake River and the five eastern tributaries were less than water-quality criteria for surface waters in Wyoming. Concentrations of total nitrogen and total phosphorus in samples from the Snake River and the tributaries generally were less than median concentrations determined for undeveloped streams in the United States; however, concentrations in some samples did exceed ambient total-nitrogen and total-phosphorus criteria for forested mountain streams in the Middle Rockies ecoregion recommended by the U.S. Environmental Protection Agency to address cultural eutrophication. Sources for the excess nitrogen and phosphorus probably are natural because these basins have little development and cultivation.

Concentrations of trace metals and pesticides were low and less than water-quality criteria for surface waters in Wyoming in samples collected from the Snake River and the five eastern tributaries. Atrazine, dieldrin, EPTC, or tebuthiuron were detected in estimated concentrations of 0.003 microgram per liter or less in 5 of 27 samples collected from the Snake River. An estimated concentration of 0.008 microgram per liter of metolachlor was detected in one sample from the Buffalo Fork. The estimated concentrations were less than the reporting levels for the pesticide analytical method.

Suspended-sediment concentrations in 43 samples from the upstream site on the Snake River ranged from 1 to 604 milligrams per liter and were similar to suspended-sediment concentrations in 33 samples from the downstream site, which ranged from 1 to 648 milligrams per liter. Suspended-sediment concentrations in 38 samples collected from the tributary streams ranged from 1 to 286 milligrams per liter. Seasonal variations were observed in suspended-sediment concentrations. Concentrations were highest in samples collected during late spring and lowest in samples collected during the fall in response to variations in streamflow.

Concentrations of fecal coliform in samples collected from the five eastern tributary streams ranged from less than 1 colony per 100 milliliters to greater than 200 colonies per 100 milliliters. A microbial source-tracking method determined that ribotype patterns for *Escherichia coli* isolates generally were matched to wildlife sources. Avian, bovine, and deer and elk sources were most frequently identified. Human sources were matched in 6 percent or less of the isolates for each basin.

INTRODUCTION

Over three million people each year visit Grand Teton National Park in northwestern Wyoming. The Park has some of the most stunning mountain scenery and wildlife in the United States. The Snake River is one of the most significant features of the Park, and visitors enjoy the river's aesthetic qualities, use the river for recreation, and consume fish caught from the river. The Snake River and its tributaries are designated as "outstanding waters" (Class 1) through Grand Teton National Park (Wyoming Department of Environmental Quality, 2001a). The maintenance of the Park's good quality waters is one of the highest management objectives for the National Park Service (NPS).

To address water-resource management objectives of the NPS in Grand Teton National Park, the U.S. Geological Survey (USGS) in cooperation with the National Park Service has conducted water-quality sampling in the upper Snake River Basin. Water-quality sampling on the Snake River has been conducted at two sites that were routinely sampled during water years 1998-2002, to meet various objectives of the NPS. To further characterize water quality in the upper Snake River Basin, a synoptic study was conducted during 2002 on five eastern tributaries to the Snake River—Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek. Samples from the Snake River and the five tributaries were collected and analyzed for field measurements, major ions and dissolved solids, nutrients, selected trace metals, pesticides, and suspended sediment. In addition, the eastern tributaries were sampled for fecal-indicator bacteria by the National Park Service during the synoptic study. Land covers or land uses such as low-density residential housing, gravel mining, grazed shrubland, and cultivated lands presently occur within or near the Park's boundaries in these basins. In addition, the basins are heavily used during all seasons for recreation, including hiking, biking, camping, hunting, skiing, and snowmobiling. Baseline water-quality information from these studies will be used by the NPS in the future to assess how proposed land-cover or land-use changes in these basins may affect 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 upper Snake River Basin that flow through Grand Teton National Park. The following characteristics are described in this report:

1. Water types of selected streams in the upper Snake River Basin;
2. Water-quality conditions for streamflow, dissolved solids, nutrients, trace metals, pesticides, and suspended sediment for two sites on the Snake River during water years 1998-2002; and
3. Land cover and baseline water-quality conditions for streamflow, dissolved solids, nutrients, trace metals, pesticides, suspended sediment, and fecal-indicator bacteria for two sites on Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek during a synoptic study in 2002.

Environmental Setting and General Hydrology

The upper Snake River Basin lies within the Middle Rocky Mountain Province (Omernik, 1987) and incorporates parts of Yellowstone National Park, the John D. Rockefeller, Jr. Memorial Parkway, which is administered by Grand Teton National Park, and Grand Teton National Park (fig. 1, table 1). The upper basin is bounded by several mountain ranges and the geology is diverse with rocks that range in age from Precambrian era to Cenozoic era. The Teton Range, which bounds the upper basin to the west, is an upthrown, tilted fault-block composed of granitic rocks with pegmatite, layered gneiss and migmatite, strongly foliated augen gneiss, and ultramafic rocks from the Precambrian era (Love and others, 1992). The steepness of the Teton Range along its eastern fault makes the mountains the focal point of Grand Teton National Park. A volcanic plateau in Yellowstone National Park and the Absaroka Range bound the northern part of the upper basin. The volcanic plateau consists primarily of Quaternary-period rhyolite flows and tuff with intrusive igneous rocks. The Absaroka Range consists of light-colored volcanic conglomerates and andestitic volcaniclastic rocks from the Tertiary period (Love and Christiansen, 1985). The Washakie Range forms the eastern boundary of the upper basin and consists of thrust-faulted, asymmetrical anticlines (Nolan and Miller, 1995). Bedrock geology of the Washakie Range predominantly includes sedimentary rocks of marine origin, including Mesozoic-era sandstones, siltstones, and shales (Love and others, 1992). The Jackson Hole structural basin lies between the mountain ranges. The deposits that compose the surficial geology in the upper basin include Quaternary-period alluvium and colluvium, gravel, pediment, and fan deposits, landslide deposits, and glacial deposits (Love and others, 1992). Relief in the study area in the upper basin ranges in elevation from 13,770 feet at the summit of the Grand Teton to 6,431 feet at the Snake River at Moose, Wyoming in the Jackson Hole structural basin.

The area has cold winters and warm summers. Temperatures at the Moose, Wyoming climate station ranged from -3.4^{o}C in January to 26.7^{o}C in July (Western Regional Climate Center, 2004) during the period 1948-2003, based on average monthly maximum temperatures. Average temperatures decrease with increasing elevation. Annual precipitation, which primarily falls in the form of snow, ranges from about 21 inches near Moose, Wyoming (Western Regional Climate Center, 2004) to more than 70 inches in the Teton Range (Oregon Climate Service, 2000).

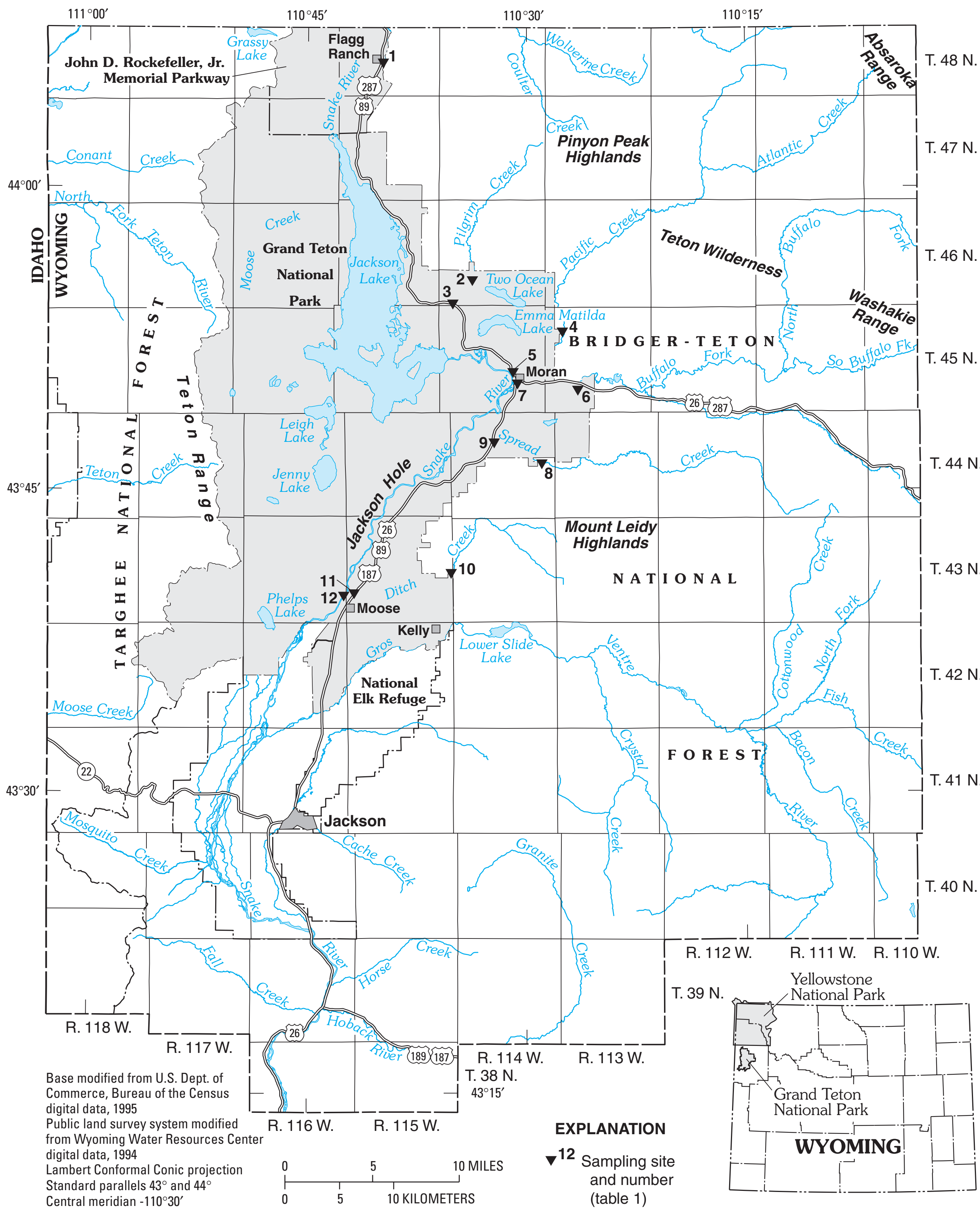

Figure 1. Location of sampling sites in the upper Snake River Basin, Grand Teton National Park, Wyoming.

Table 1. Sampling sites in the upper Snake River Basin, Grand Teton National Park, Wyoming.

Site number (fig. 1)	U.S. Geological Survey station number	Streamflow-gaging station	Site name	Period of record used for analyses in this report
1	13010065	Yes	Snake River above Jackson Lake at Flagg Ranch, Wyoming	water years 1998-2002
2	435529110335101	No	Pilgrim Creek below National Park Service boundary, near Moran, Wyoming	2002
3	13010450	No	Pilgrim Creek near Moran, Wyoming	2002
4	435459110275401	No	Pacific Creek above National Park Service boundary, near Moran, Wyoming	2002
5	13011500	Yes	Pacific Creek at Moran, Wyoming	2002
6	13011900	Yes	Buffalo Fork above Lava Creek near Moran, Wyoming	2002
7	13012000	No	Buffalo Fork near Moran, Wyoming	2002
8	13012490	No	Spread Creek at diversion dam near Moran, Wyoming	2002
9	13012500	No	Spread Creek near Moran, Wyoming	2002
10	13013530	No	Ditch Creek below South Fork near Kelly, Wyoming	2002
11	13013600	No	Ditch Creek near Moose, Wyoming	2002
12	13013650	Yes	Snake River at Moose, Wyoming	water years 1998-2002

The general hydrology of the Snake River, Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek 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 these perennial streams throughout the year, although reaches of some of the tributary streams in the lower parts of their basins may lose water to coarse Quaternary deposits and occasionally become dry for short periods. Hydrologic conditions in the upper Snake River Basin varied substantially during water years 1998-2002 in response to variations in precipitation. Annual runoff for the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1) ranged from 853,600 acre-feet during water year 1999 (Swanson and others, 2000), when annual precipitation was about 120 percent of the 30-year average (1971-2000), to 382,600 acre-feet during water year 2001 (Swanson and others, 2002), when precipitation was about 65 percent of the 30-year average (1971-2000) for the basin. Precipitation was about 90 percent of the 30-year average (1971-2000) in the upper Snake River Basin for water year 2002; however, because of three consecutive years of below average precipitation, hydrologic conditions during 2002 were considered to be drought conditions (Swanson and others, 2003). Hydrographs for water years 1998-2002 for the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1) and for calendar year 2002 for Pacific Creek near Moran, Wyoming (site 5) show the hydrologic conditions during the water-quality sampling events (fig. 2).

Sampling Sites and Description

Water-quality sampling has been conducted at an upstream and downstream site on the Snake River to characterize the water-quality conditions through Grand Teton National Park (fig. 1). The upstream site on the Snake River (site 1) is at Flagg Ranch, located along John D. Rockefeller, Jr. Memorial Parkway and above the Grand Teton National Park boundary and Jackson Lake. The downstream site on the Snake River is at Moose, Wyoming (site 12), near the southern boundary of Grand Teton National Park. The monitoring objectives and sampling frequency for the Snake River sites have been variable through time. The period of record for water-quality data collected by the USGS at site 1 is from 1986 to present (2004). A period of high intensity sampling occurred during 1991-93 as part of the USGS National Water-Quality Assessment Program. Routine water-quality sampling has been conducted from 1998 to present (2004) at site 1. The period of record for water-quality data collected by the USGS at site 12 is from 1971 to present (2004). Routine water-quality sampling has been conducted from 1995 to present (2004) at site 12. Water-quality data for site 1 and site 12 is most comparable during water years 1998-2002, in terms of sampling frequencies and methods for laboratory analyses. Samples collected from the Snake River by the USGS during water years 1998-2002 were analyzed for field measurements, major ions and dissolved solids, nutrients, iron, manganese, pesticides, and suspended sediment.

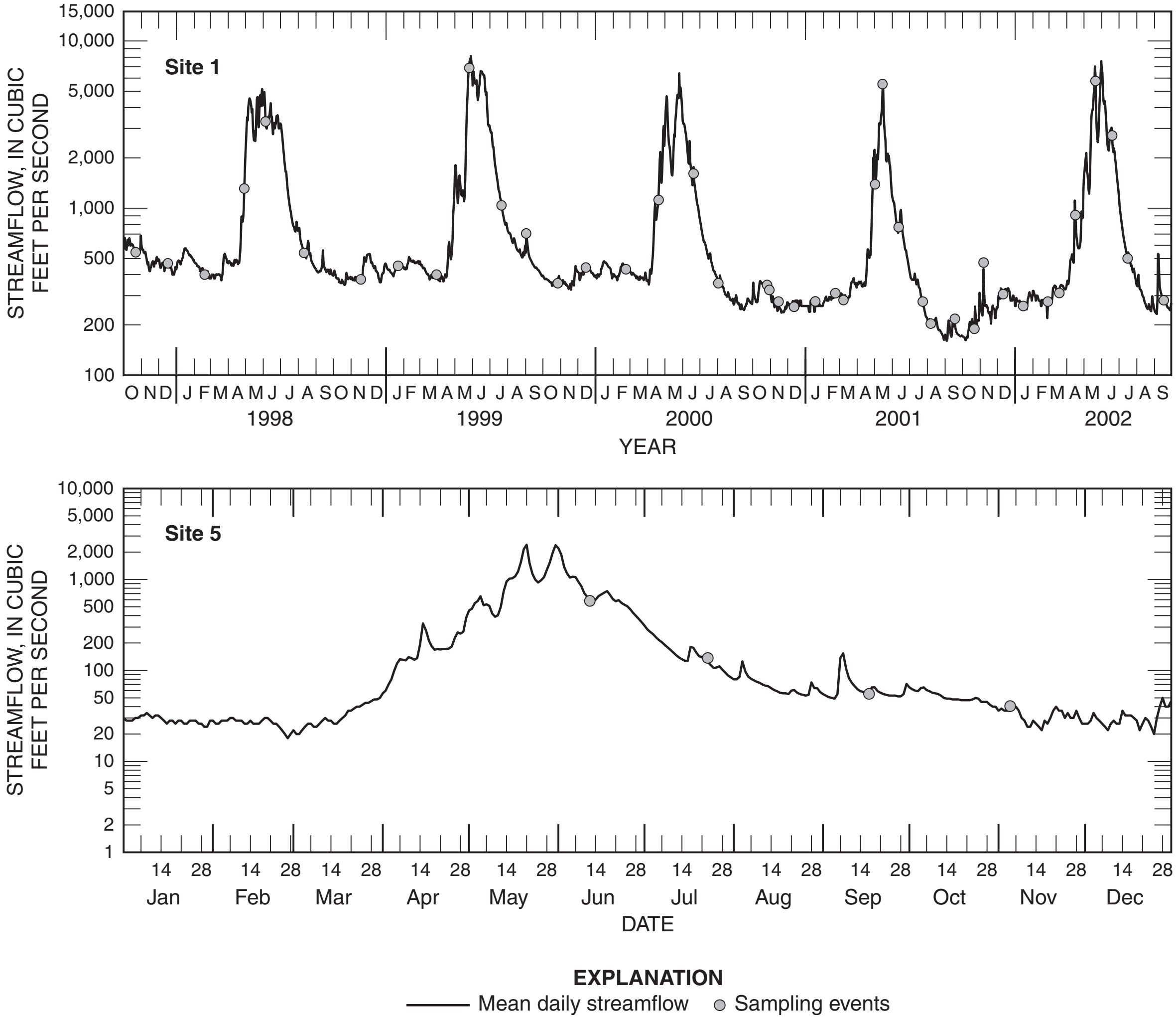

Figure 2. Hydrologic conditions during water-quality sampling events on the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1), water years 1998-2002, and Pacific Creek at Moran, Wyoming (site 5), 2002, Grand Teton National Park.

Water-quality sampling sites for the synoptic study were located on Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek, which flow east to west or southwest from the Absaroka Range, the Washakie Range, or their associated highlands (fig. 1). An upstream site for each tributary was selected near the Bridger-Teton National Forest and Grand Teton National Park boundary (sites 2, 4, 6, 8, 10). Downstream sites were located near the confluence with the Snake River (sites 5, 7, 9, 11), except for the downstream site on Pilgrim Creek (site 3), which was above the confluence with Jackson Lake. Samples were collected during four sampling events in June, July, September, and November 2002. Samples collected from the eastern tributaries (sites 2-11) by the USGS were analyzed for field measurements, major ions and dissolved solids, nutrients, iron, manganese, and suspended sediment during all four sampling events. Synoptic-study samples for selected trace metals and pesticides were analyzed during the June sampling event. In addition to the samples collected by the USGS, the NPS collected fecal-indicator bacteria samples from the eastern tributary sites during the June and July sampling events of the synoptic study. Samples were analyzed for concentrations of fecal coliform, and individual *Escherichia coli* (*E. coli*) isolates were analyzed using a microbial source-tracking method.

Acknowledgments

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METHODS

Field measurements for the Snake River and 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 to 2004). Field measurements included streamflow, dissolved oxygen, pH, specific conductance, and water temperature. For some sampling events, streamflow was computed from stage-streamflow ratings at sites with USGS streamflow-gaging stations. Samples generally were collected with depth-integrating samplers. For wadeable conditions, a DH-81 sampler with an equal-width-integrating or multiple-vertical sampling technique was used to cross-sectionally composite samples. For nonwadeable conditions, which included high flows on the Snake River and Buffalo Fork, a D-77 or D-95 sampler and equal-width- or equal-discharge-integrating sampling techniques were used to cross-sectionally composite samples. A few samples during the synoptic study were collected using a hand-dip method when the streams were too shallow for a sampler. Pesticide samples generally were collected using a hand-dip method. Samples for fecal-indicator bacteria were collected by the NPS using a hand-dip method described by Suess (1982). Five replicate samples of fecal coliform were collected during each sampling event.

Cross-sectionally composited samples were combined in a cone or churn splitter and processed, preserved, and shipped according to USGS standard methods (U.S. Geological Survey, 1997 to 2004). Samples for major ions, nutrients, and trace metals were filtered onsite using a 0.45-micron disposable capsule filter. Data that are reported for filtered constituents in tables are discussed as “dissolved” in the text of this report. Samples were analyzed for major ions, nutrients, trace metals, and pesticides at the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado. Sediment samples were analyzed for suspended concentrations at the USGS sediment laboratory in Helena, Montana (Lambing and Dodge, 1993). Samples for fecal-indicator bacteria were filtered and incubated by the NPS using the membrane filtration procedure for fecal coliform described by the American Public Health Association (1989). Analyses of *E. coli* isolates were conducted at the University of Washington.

Major-ion analyses for filtered constituents included dissolved calcium, magnesium, potassium, sodium, chloride, and sulfate. Analyses for major ions 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). Acid neutralizing capacities, which are unfiltered, were measured at NWQL for some Snake River samples in order to account for bicarbonate and carbonate. Alkalinities, which are filtered, were measured in the field or NWQL for the remaining Snake River samples and the synoptic-study samples. Acid-neutralizing capacities and alkalinities generally were analyzed using fixed end-point titrations. The 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^{o}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.

Nutrient analyses included nitrogen and phosphorus species. Colorimetry and Kjeldahl digestion methods for filtered and unfiltered nutrients are described in Fishman (1993) and Patton and Truitt (2000). Nitrogen species included filtered ammonia plus organic nitrogen as nitrogen, unfiltered ammonia plus organic nitrogen as nitrogen, filtered ammonia as nitrogen, filtered nitrite as nitrogen, and filtered nitrite plus nitrate as nitrogen, referred to as nitrate in this report. Nitrate, the oxidized form of nitrogen, typically is the most common form of dissolved nitrogen in streams. Total nitrogen in this report is the sum of the unfiltered ammonia plus organic nitrogen and nitrate. Phosphorus species included filtered orthophosphate as phosphorus, filtered phosphorus, and unfiltered or total phosphorus. Nutrient data for the Snake River samples were censored to a common reporting level in order to statistically summarize the data for the 5-year sampling period.

Filtered iron and manganese were analyzed for samples collected from the Snake River and during the synoptic study. Additional selected filtered trace metals analyzed during the synoptic study included dissolved arsenic, cadmium, chromium, copper, nickel, selenium, and zinc. Analyses for dissolved arsenic, cadmium, copper, iron, manganese, nickel, selenium, and zinc were conducted using the inductively coupled plasma mass-spectrometry methods as described in Fishman (1993), Faires (1993), and Garbarino (1999). Analyses for chromium were conducted using atomic-absorption spectrophotometry in conjunction with a graphite-furnace method as described by McLain (1993).

Samples for pesticides were filtered at the laboratory through a 0.70-micron filter. Analyses for pesticide compounds included 26 commonly used herbicides, 17 commonly used insecticides, and 4 breakdown products. Analyses for pesticide compounds were made using a gas chromatography and mass spectrometry (GCMS) method (Zaugg and others, 1995). The pesticide compounds and the maximum reporting level reported for each pesticide for the study period are listed in table 2. A lower reporting level may have been reported for some compounds; however, the maximum reporting level for a compound is used in this report in order to compare data among sites and during the 5-year sampling period for the Snake River samples. The GCMS method developed at the NWQL measures pesticide compounds at very low concentrations, often 10 to

Table 2. Pesticide compounds, type, and reporting levels for samples collected in the upper Snake River Basin, Grand Teton National Park, Wyoming, 1998-2002.

Pesticide	Type	Reporting level, in micrograms per liter
2,6-Diethylaniline	Breakdown product	0.006
Acetochlor	Herbicide	.006
Alachlor	Herbicide	.004
Alpha-HCH	Breakdown product	.005
Atrazine	Herbicide	.007
Benfluralin	Herbicide	.01
Butylate	Herbicide	.002
Carbaryl	Insecticide	.041
Carbofuran	Insecticide	.02
Chlorpyrifos	Insecticide	.005
Cyanazine	Herbicide	.018
DCPA	Herbicide	.003
Deethylatrazine	Breakdown product	.006
Diazinon	Insecticide	.005
Dieldrin	Insecticide	.005
Disulfoton	Insecticide	.02
EPTC	Herbicide	.002
Ethalfluralin	Herbicide	.009
Ethoprop	Insecticide	.005
Fonofos	Insecticide	.003
Lindane	Insecticide	.004
Linuron	Herbicide	.035
Malathion	Insecticide	.027
Methyl azinphos	Insecticide	.05
Methyl parathion	Insecticide	.006
Metolachlor	Herbicide	.013
Metribuzin	Herbicide	.006
Molinate	Herbicide	.002
Napropamide	Herbicide	.007
p,p'-DDE	Breakdown product	.006
Parathion	Insecticide	.01
Pebulate	Herbicide	.004
Pendimethalin	Herbicide	.022
cis-Permethrin	Insecticide	.006
Phorate	Insecticide	.011
Prometon	Herbicide	.02
Pronamide	Herbicide	.004
Propachlor	Herbicide	.01
Propanil	Herbicide	.011
Propargite	Insecticide	.02
Simazine	Herbicide	.011
Tebuthiuron	Herbicide	.02
Terbacil	Herbicide	.034
Terbufos	Insecticide	.02
Thiobencarb	Herbicide	.005
Triallate	Herbicide	.002
Trifluralin	Herbicide	.009

1,000 times lower than U.S. Environmental Protection Agency (USEPA) drinking-water standards and method reporting levels commonly used at other analytical laboratories.

Samples collected by the NPS that contained fecal-coliform colonies were sent to Dr. Mansour Samadpour at the University of Washington for further analysis of *E. coli* isolates. *E. coli* isolates were analyzed by a source-tracking method that includes genetic fingerprinting using ribosomal RNA typing. Gel electrophoresis and southern hybridizations were used to compare the ribotype patterns produced for each isolate to a library of known host patterns for human and animals using discriminant analysis (Farag and others, 2001). Isolates in the reference library are from around the country and not specific to the study area, which may cause some isolates to be unidentified and classified as unknown. Results of analysis yielded the presumptive source for the *E. coli* isolates. The percentage of isolates that were matched to a presumptive source are reported.

As part of the synoptic study, the distribution of land cover for the Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek Basins was determined using the National Land Cover Data (NLCD), which is a 30-meter resolution, raster-based dataset that includes land-cover data compiled for Wyoming during 1986-93. Because most of the study area is contained within the National Forest or the 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 (grasslands/herbaceous), herbaceous planted/cultivated (pasture/hay, row crops, small grains, fallow, urban and recreation grasses), and wetlands (woody wetlands, emergent herbaceous wetlands).

Data in this report are summarized using boxplots and nonparametric statistics. 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, and whiskers extend to the minimum and maximum values. Nonparametric statistical techniques were used to test for correlations and statistical differences between data sets because the data distribution was unknown. Spearman's correlation coefficient (Spearman's Rho) was used to measure the strength and direction of the relation between variables (Helsel and Hirsch, 1992). The coefficient is determined using linear correlation of ranks of the data values instead of actual data values and is resistant to the effects of outliers. Spearman's Rho values range between -1 and +1; a negative value indicates an inverse relation between the data ranks. The Wilcoxon rank-sum test was used to test for statistical differences between two data sets. This test determines whether two distributions of ranked data, rather than actual data values, are similar. Statistical significance was determined using a 95 percent confidence level (alpha=0.05).

Water-quality data in this report are compared to State of Wyoming water-quality criteria for surface waters or USEPA water-quality criteria (table 3) that apply to water-column constituents (Wyoming Department of Environmental Quality, 2001b; U.S. Environmental Protection Agency, 2003). Acute concentrations are based on a 1-hour average concentration. Chronic concentrations are based on a 4-day average concentration. Several of the criteria in table 3 are dependent upon other factors and are not a single value. The acute and chronic values for dissolved cadmium, copper, manganese, nickel, and zinc are dependent upon hardness values. For this report, the lowest hardness value reported for any of the tributary waters during the synoptic study was used to calculate the aquatic criteria shown in table 3 and represents a conservative value for comparing the trace metal concentrations for samples collected from the tributaries. Chromium analyses 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 chromium probably is not in the form of chromium (VI). For the chronic criterion for ammonia, the highest reported temperature (23^{o}C) and highest 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). Fecal-coliform concentrations in this report are compared to the USEPA recommended limit for a single sample for recreational contact with water of 400 colonies per 100 milliliters (col/100 mL) (U.S. Environmental Protection Agency, 1976).

Suspended-sediment loads were calculated for the eastern tributaries in the synoptic study using instantaneous streamflow, the suspended-sediment concentration, and a conversion factor. The equation for the load calculation was:

$$SSL = Q \times SSC \times 0.0027 \tag{1}$$

where:

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

Q is the instantaneous streamflow, in cubic feet per second; and

SSC is the suspended-sediment concentration, in milligrams per liter.

Table 3. State of Wyoming water-quality criteria for surface waters and U.S. Environmental Protection Agency water-quality criteria for selected constituents, 2002.

[All criteria are from Wyoming Department of Environmental Quality (2001b) unless otherwise noted. All constituents 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	7
Cadmium[2]	1.88	1.28	[3]5
Chromium (VI)	16	11	[3]100
Copper[2]	6.6	4.7	[4]1,000
Nickel[2]	247	28	[3]100
Selenium	20	5	[3]50
Zinc[2]	62	62	[4]5,000
Dieldrin	0.24	0.056	0.00014
	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)	1.23	[6].38	--
Nitrite (mg/L)	--	--	[3]1
Nitrite plus nitrate (mg/L)	--	--	[3]10
Iron	--	1,000	[7]300
Manganese[2]	1,740	970	[7]50
Alachlor	--	--	[3]9.0
Atrazine	--	--	[3]3.0
Carbofuran	--	--	[3]40
Chlorpyrifos	.083	.041	--
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 47 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]Based on early life stages of fish present and conditions of 23^{o}C and a pH of 8.8.

[7]Criterion is based on U.S. Environmental Protection Agency Secondary Maximum Contaminant Levels, 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

Water-quality characteristics in the upper Snake River Basin are presented in this section. The water types for the Snake River and the five eastern tributaries of Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek, are described. Water-quality characteristics for the Snake River are described for water years 1998-2002. Water-quality characteristics from the synoptic study are summarized by basin for calendar year 2002.

Water Types

Water type is a means of classifying stream waters based on their major-ion chemistry (Hem, 1985). Water type can be determined by plotting water composition consisting of the major cations (generally calcium, magnesium, potassium, and sodium) and the major anions (generally bicarbonate, chloride, fluoride, sulfate, and nitrate) on a trilinear diagram (Piper, 1944). The water type of the Snake River (fig. 3) changes from a sodium bicarbonate type at the upstream site above Jackson Lake at Flagg Ranch (site 1) to a calcium bicarbonate type at the downstream site at Moose, Wyoming (site 12). Sulfate and chloride are about 40 percent of the anion composition at the upstream site (site 1) compared to about 20 percent at the downstream site (site 12). Geothermal waters from Yellowstone National Park may contribute to the relatively high sodium, chloride, and sulfate concentrations in the Snake River at the upstream site (Cox, 1973) in addition to contributions due to variations in geology. Waters from Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek are calcium bicarbonate type. The compositions of most of the eastern tributary waters are very similar except for Ditch Creek, where sulfate is about 20 percent or greater of the anion composition, compared to the other tributaries, where sulfate is less than 10 percent of the anion composition. Variations in the bedrock geology between the basins probably control the differences between the major-ion compositions of the tributaries. The tributary waters contribute to the relatively higher percentage of calcium and bicarbonate in the Snake River at site 12 compared to site 1.

The quality of major-ion analyses was checked using ion balances, and results were considered to be of good quality. About 95 percent of the samples from the Snake River had ion balances within +/- 5.3 percent. The median percent difference for the ion balances for samples from the Snake River was -1.8 percent. About 95 percent of the samples from the eastern tributaries had ion balances within +/- 3.4 percent. The median percent difference for the ion balances for samples from the five eastern tributaries was -1.9 percent. These results indicate that unmeasured constituents or constituents that were measured but were not included in the ion-balance calculation, such as organic anions, nutrients, and trace metals, do not substantially contribute to the ionic composition of the water.

Snake River, Water Years 1998-2002

The headwaters of the Snake River are in Yellowstone National Park and the Bridger-Teton National Forest. The river drains 486 square miles of relatively undeveloped land at the upstream sampling site above Jackson Lake at Flagg Ranch, Wyoming (site 1). Park facilities exist and vehicle traffic and recreational use in the basin is high upstream from site 1. About 7 miles downstream from site 1, the Snake River flows into Jackson Lake, which is a regulated reservoir primarily constructed for agricultural projects in Idaho with a storage capacity of 847,000 acre-feet (Maupin, 1995). The Snake River, as it flows out of Jackson Lake and through Grand Teton National Park, is a braided, meandering stream with a well-developed alluvial system consisting of generally coarse, gravel- and cobble-sized material. The downstream sampling site on the Snake River at Moose, Wyoming (site 12) is about 23 miles downstream from Jackson Lake Dam, along a major road, and near the visitor center for the Park. Between site 1 and site 12, the basin primarily drains undeveloped areas of Grand Teton National Park and the Bridger-Teton National Forest; however, land covers such as developed areas of low-density residential housing, gravel mining, grazed shrubland, and cultivated lands occur within or near the Park's boundaries in some of the tributary basins. The major concessions for Grand Teton National Park are located in the reach between site 1 and site 12, and vehicle traffic and recreational use of the Park is high. The river drains 1,677 square miles at the downstream site, which includes about 770 square miles of area drained by Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek.

Water-quality samples were routinely collected from the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1) and the Snake River at Moose, Wyoming (site 12) during water years 1998-2002 (table 4). Summary statistics for field measurements, major ions and dissolved solids, nutrients, iron, manganese, and suspended sediment for the 43 samples collected at site 1 and the 33 samples collected at site 12 are shown in tables 5 and 6, respectively. Because of the large number of pesticide compounds analyzed with relatively few detections, summary statistics are not presented for pesticides. The data indicate that water in the Snake River generally is of good quality.

Sampling events on the Snake River covered a wide range of streamflows during the period water years 1998-2002 (fig. 4). Instantaneous streamflow measurements made during sampling events ranged from 190 to 6,900 cubic feet per second (ft^3/s) for the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1). Streamflows at Moose, Wyoming (site 12) were significantly higher than site 1 (p-value<0.001) and ranged from 620 to 10,600 ft^3/s. Streamflow at site 12 is highly regulated by reservoir releases from Jackson Lake Dam.

Dissolved-solids concentrations for samples collected from the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1) ranged from 62 to 240 milligrams per liter (mg/L). Dissolved-solids concentrations for samples collected

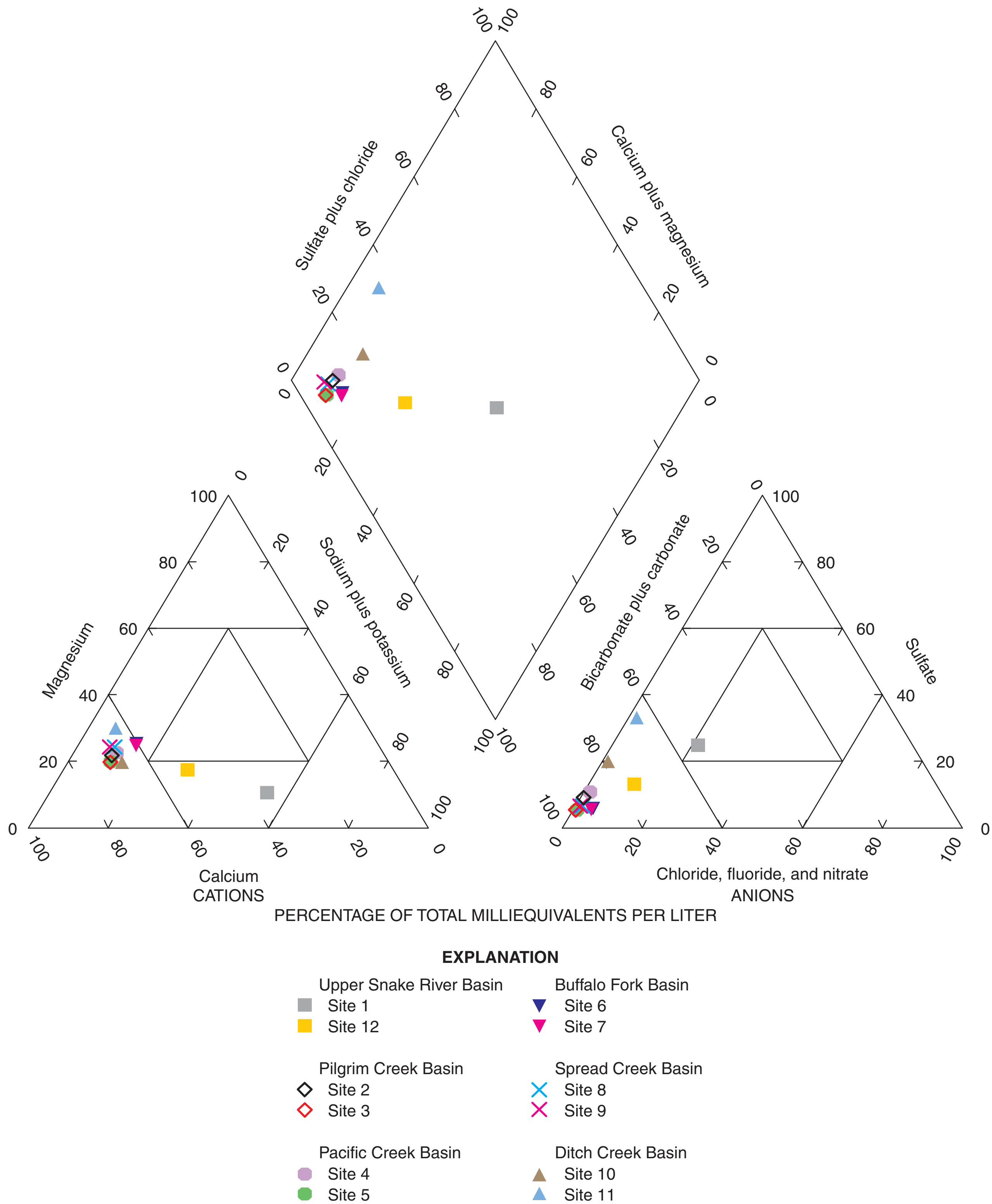

Figure 3. Trilinear diagram (Piper, 1944) showing water composition for streams in the upper Snake River Basin, Grand Teton National Park, Wyoming, 2002.

Table 4. Number of samples collected at the Snake River sites, Grand Teton National Park, Wyoming, water years 1998-2002.

Water year	Number of samples	
	Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1)	Snake River at Moose, Wyoming (site 12)
1998	6	6
1999	6	6
2000	6	6
2001	14	6
2002	11	9

from the Snake River at Moose, Wyoming (site 12) were significantly lower than site 1 and ranged from 77 to 141 mg/L (p-value<0.001). Dissolved-solids concentrations at site 1 probably are higher than at site 12 because of inputs of geothermal waters, which are high in dissolved solids, from Yellowstone National Park (Cox, 1973). In addition, the rocks in the upper basin upstream from site 1 primarily are younger volcanic rocks compared to the diverse geology in the basin at site 12, which includes some volcanic rocks, sedimentary rocks, and the resistant granitic and metamorphic rocks of the Teton Range (Love and Christiansen, 1985).

Dissolved-solids concentrations were higher during water years 2001-2002 compared to water years 1998-2000 for several samples collected at site 1; the higher dissolved-solids concentrations probably are related to the drought conditions in the basin during water years 2001-2002, although sampling frequency also varied during this time period. The dissolved-solids concentrations for samples collected at site 12 generally were less variable than at site 1 during water years 2001-2002, probably as a result of the regulated streamflows from Jackson Lake. Dissolved-solids concentrations and streamflow typically have an inverse relation for streams originating from mountainous areas because the concentrated base flow generally is diluted during increased streamflow resulting from precipitation and snowmelt (fig. 5). Both sites exhibit the flow-dilution relation; however, Spearman's Rho correlation coefficient for dissolved-solids concentrations and streamflow was stronger at the unregulated upstream site (-0.975) compared to the correlation coefficient for the downstream site with regulated flows (-0.771).

Concentrations of nitrogen and phosphorus species generally were low in samples from the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1) and the Snake River at Moose, Wyoming (site 12). All samples of dissolved ammonia and nitrate were less than the water-quality criteria for surface waters in Wyoming. The median dissolved-nitrate concentrations at both sites were less than the reporting level of 0.05 mg/L, which is less than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). Median concentrations of total nitrogen of 0.11 mg/L at site 1 and site 12 were less than the median total-nitrogen concentration of 0.26 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). The maximum concentrations of total nitrogen at both sites were higher 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 over 75 percent of the samples, dissolved-orthophosphate concentrations were less than the reporting level of 0.02 mg/L and total-phosphorus concentrations were less than the reporting level of 0.06 mg/L. Maximum concentrations of total phosphorus at site 1 (0.407 mg/L) and site 12 (0.522 mg/L) were higher than the median concentration of total phosphorus 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 in the Middle Rockies ecoregion recommended by the USEPA (U.S. Environmental Protection Agency, 2000). Sources of nutrients in the basin probably are mostly natural, although a few septic systems exist and agricultural sources of nutrients may exist in the basin, primarily downstream from site 1.

Dissolved iron and manganese were the only trace metals analyzed in samples collected from the Snake River. Neither iron nor manganese is classified as a priority pollutant with aquatic criteria established. The maximum dissolved-iron concentration for 43 samples collected from the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1) was 38 micrograms per liter (µg/L), and the maximum concentration from 33 samples collected at the downstream site at Moose, Wyoming (site 12) was 27 µg/L. These concentrations are substantially less than the Secondary Maximum Contaminant Level (SMCL) of 300 µg/L established by the USEPA (U.S. Environmental Protection Agency, 2003). The maximum dissolved-manganese concentration for 43 samples collected at site 1 was 9.3 µg/L, and the maximum concentration for 33 samples collected at site 12 was 7.0 µg/L. These concentrations are substantially less than the SMCL of 50 µg/L established by the USEPA (U.S. Environmental Protection Agency, 2003).

Table 5. Summary statistics for physical and chemical constituents for the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1), water years 1998-2002.

[mg/L, milligrams per liter; ^{o}C, degrees Celsius; µg/L, micrograms per liter; <, less than. Data reported as filtered are discussed as "dissolved" in the text of this report.]

Constituent	Number of samples	Minimum	25th percentile	Median	75th percentile	Maximum
Streamflow, instantaneous, in cubic feet per second	43	190	281	400	909	6,900
Oxygen, dissolved, in mg/L	43	7.8	9.2	10.4	11.2	12.2
pH, unfiltered, standard units	43	7.0	7.6	7.8	8.0	8.4
Specific conductance, unfiltered, in microsiemens per centimeter at 25^{o}C	43	82	193	250	295	358
Temperature, air, ^{o}C	43	-12.0	-2.0	4.0	11.4	30.0
Temperature, water, ^{o}C	43	0.0	1.5	4.0	9.0	19.0
Hardness, unfiltered, in mg/L as calcium carbonate	43	29	46	52	61	82
Calcium, filtered, in mg/L	43	9.00	14.2	16.1	18.9	25.1
Magnesium, filtered, in mg/L	43	1.56	2.53	2.91	3.32	4.66
Potassium, filtered, in mg/L	43	.90	2.68	4.14	4.96	5.46
Sodium adsorption ratio	43	.4	1.0	1.7	2.0	2.2
Sodium, filtered, in mg/L	43	4.70	18.1	28.4	35.1	43.4
Acid neutralizing capacity, unfiltered, in mg/L as calcium carbonate	17	41	55	63	66	71
Alkalinity, filtered, in mg/L as calcium carbonate	23	13	63	73	84	107
Chloride, filtered, in mg/L	43	2.84	8.99	15.4	18.8	23.4
Fluoride, filtered, in mg/L	43	.23	1.3	2.1	2.4	2.8
Silica, filtered, in mg/L	43	9.83	24.2	33.2	35.8	40.0
Sulfate, filtered, in mg/L	43	4.4	17.2	25.2	33.3	45.6
Dissolved solids, residue on evaporation at 180^{o}C, in mg/L	43	62	129	178	206	240
Ammonia plus organic nitrogen, unfiltered, in mg/L as nitrogen	43	<.10	<.10	0.11	0.19	0.50
Ammonia, filtered, in mg/L as nitrogen	43	<.04	<.04	<.04	<.04	.05
Nitrate, filtered, in mg/L as nitrogen	43	<.05	<.05	<.05	<.05	.12
Orthophosphate, filtered, mg/L as phosphorus	43	<.02	<.02	<.02	<.02	.03
Phosphorus, unfiltered, in mg/L as phosphorus	43	<.06	<.06	<.06	<.06	.407
Iron, filtered, in µg/L	43	8	11	12	17	38
Manganese, filtered, in µg/L	43	<4.0	<4.0	<4.0	4.4	9.3
Suspended sediment, in mg/L	43	1	2	4	14	604

Table 6. Summary statistics for physical and chemical constituents for the Snake River at Moose, Wyoming (site 12), water years 1998-2002.

[mg/L, milligrams per liter; ^{o}C, degrees Celsius; µg/L, micrograms per liter; <, less than. Data reported as filtered are discussed as "dissolved" in the text of this report.]

Constituent	Number of samples	Minimum	25th percentile	Median	75th percentile	Maximum
Streamflow, instantaneous, in cubic feet per second	33	620	941	1,280	4,150	10,600
Oxygen, dissolved, in mg/L	33	7.7	9.0	10.6	11.5	12.6
pH, unfiltered, standard units	33	7.9	8.1	8.2	8.5	8.8
Specific conductance, unfiltered, in microsiemens per centimeter at 25^{o}C	33	127	158	192	202	215
Temperature, air, ^{o}C	33	-8.0	0.5	10.0	17.0	34.5
Temperature, water, ^{o}C	33	0.0	2.0	7.0	13.0	20.0
Hardness, unfiltered, in mg/L as calcium carbonate	33	49	57	80	84	91
Calcium, filtered, in mg/L	33	14.4	17.0	23.8	24.7	26.7
Magnesium, filtered, in mg/L	33	3.05	3.53	5.09	5.41	5.86
Potassium, filtered, in mg/L	33	.57	1.58	1.76	1.88	2.07
Sodium adsorption ratio	33	.3	.4	0.4	0.4	0.6
Sodium, filtered, in mg/L	33	5.14	7.26	7.97	8.72	10.7
Acid neutralizing capacity, unfiltered, in mg/L as calcium carbonate	17	56	63	81	88.5	95
Alkalinity, filtered, in mg/L as calcium carbonate	16	55	63	86.5	90	94
Chloride, filtered, in mg/L	32	.75	3.33	3.99	5.03	5.63
Fluoride, filtered, in mg/L	33	.28	.48	.56	.65	2.3
Silica, filtered, in mg/L	33	11.2	13.9	15.3	15.9	17.4
Sulfate, filtered, in mg/L	32	5.6	8.3	10.2	10.8	12.7
Dissolved solids, residue on evaporation at 180^{o}C, in mg/L	33	77	100	123	126	141
Ammonia plus organic nitrogen, unfiltered, in mg/L as nitrogen	33	<.10	<.10	0.11	.16	.58
Ammonia, filtered, in mg/L as nitrogen	32	<.04	<.04	<.04	<.04	.05
Nitrate, filtered, in mg/L as nitrogen	33	<.05	<.05	<.05	<.05	.12
Orthophosphate, filtered, mg/L as phosphorus	32	<.02	<.02	<.02	<.02	.02
Phosphorus, unfiltered, in mg/L as phosphorus	33	<.06	<.06	<.06	<.06	.522
Iron, filtered, in µg/L	33	<10	<10	<10	<10	27
Manganese, filtered, in µg/L	33	<4.0	<4.0	<4.0	<4.0	7.0
Suspended sediment, in mg/L	33	1	3	7	21	648

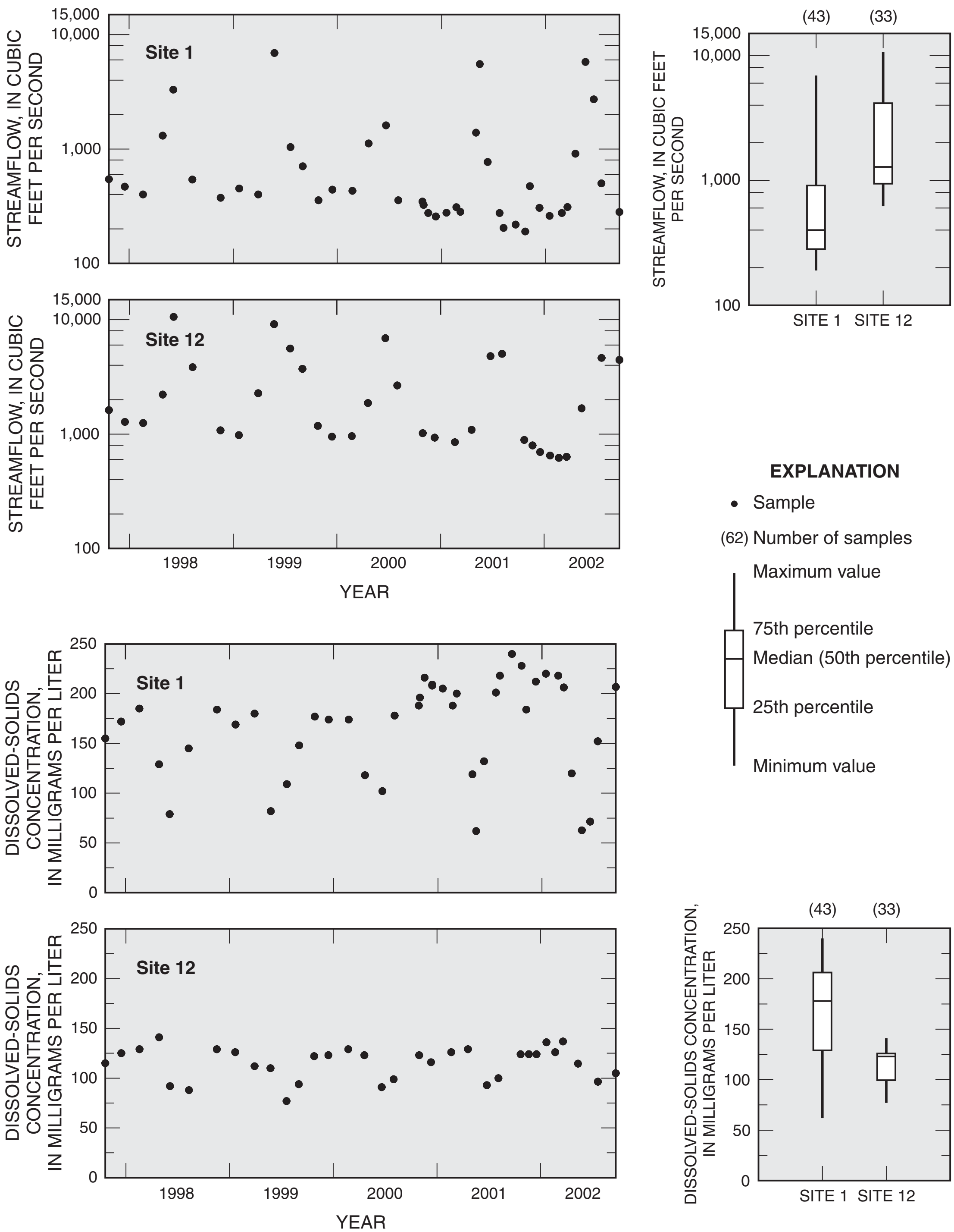

Figure 4. Streamflow and dissolved-solids concentrations for samples collected from the Snake River, Grand Teton National Park, Wyoming, water years 1998-2002.

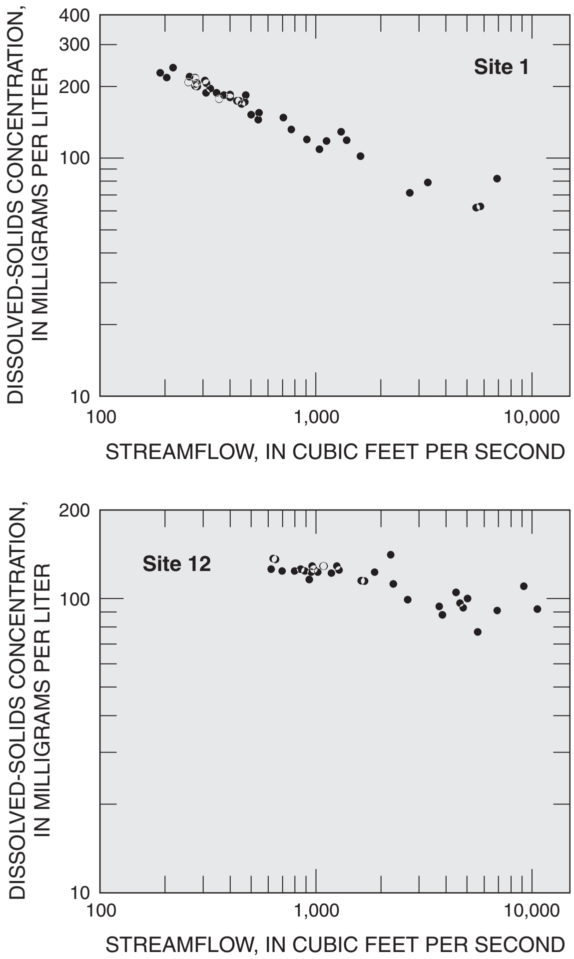

Figure 5. Relation between dissolved-solids concentrations and streamflow for samples collected from the Snake River, Grand Teton National Park, Wyoming, water years 1998-2002.

Seventeen pesticide samples were collected from the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1) and 10 pesticide samples were collected at Moose, Wyoming (site 12). Two samples were collected annually at both sites during water years 1998-2002, including a low-flow sample collected in October, November, or December and a high-flow sample collected in May or June. During 2001, seven additional pesticide samples were collected at site 1. Concentrations for all pesticide compounds were less than the reporting levels shown in table 2 for all 27 samples. One pesticide compound was identified with mass spectrometry in 5 of the 27 samples; however, concentrations were less than the reporting level and, as such, are reported as estimated concentrations (table 7). The estimated concentration of dieldrin (0.003 µg/L) was higher than the State of Wyoming drinking-water standard for human health of 0.00014 µg/L (table 3). Dieldrin is an organochlorine insecticide, which is a class of pesticides that have been banned in the United States since the 1970's and 1980's (Larson and others, 1997). The rate of pesticide detections in samples from the Snake River is low compared to pesticide detections in samples from streams nationwide (Larson and others, 1997) because pesticide use in the basin probably is minimal, particularly upstream from site 1, which drains Forest Service and National Park lands. Atmospheric transport can occur for some pesticides, including atrazine (Goolsby and others, 1995).

Suspended-sediment concentrations for samples collected from the Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1) ranged from 1 to 604 mg/L and were not significantly different (p-value=0.245) from suspended-sediment concentrations for samples collected from the Snake River at Moose, Wyoming (site 12), which ranged from 1 to 648 mg/L. Several samples collected during water years 2001-2002 had low concentrations of suspended sediment of 1 mg/L. The low suspended-sediment concentrations probably are related to drought conditions in the basin. Unlike dissolved-solids concentrations and streamflow, suspended-sediment concentrations and streamflow typically have a direct relation (fig. 6) because suspended sediment is carried to streams during overland flow events or is resuspended from the stream bottom from turbulent flows. Spearman's Rho correlation coefficient for suspended-sediment concentrations and streamflow was 0.814 at site 1 and 0.868 at site 12.

Table 7. Detections of pesticide compounds in samples collected from the Snake River, Grand Teton National Park, Wyoming, water years 1998-2002.

Sample date	Pesticide compound	Estimated concentration, in micrograms per liter
Snake River above Jackson Lake at Flagg Ranch, Wyoming (site 1)		
October 22, 1997	Atrazine	0.003
June 20, 2000	EPTC	.001
October 30, 2000	Dieldrin	.003
Snake River at Moose, Wyoming (site 12)		
October 20, 1997	Atrazine	.003
December 15, 1999	Tebuthiuron	Detected but not quantified

Synoptic Study of Eastern Tributary Basins, 2002

Samples were collected during the synoptic study of five eastern tributary basins in 2002 to include high-flow conditions (June), the period during and following high visitor use in the Park (July and September), and low-flow conditions (November). Results of the field measurements and inorganic constituents for the water-quality sampling conducted by the USGS for the synoptic study are shown in table 8 and indicate water in the eastern tributaries generally is of good quality. Results for the 10 pesticide samples collected in June are not presented for each site because all concentrations were less than the reporting levels for all constituents (table 2). Results of the fecal-coliform-bacteria samples collected by the NPS and the possible source distribution of animal types from the ribotype patterns for the *E. coli* isolates are shown in table 9 and table 10, respectively.

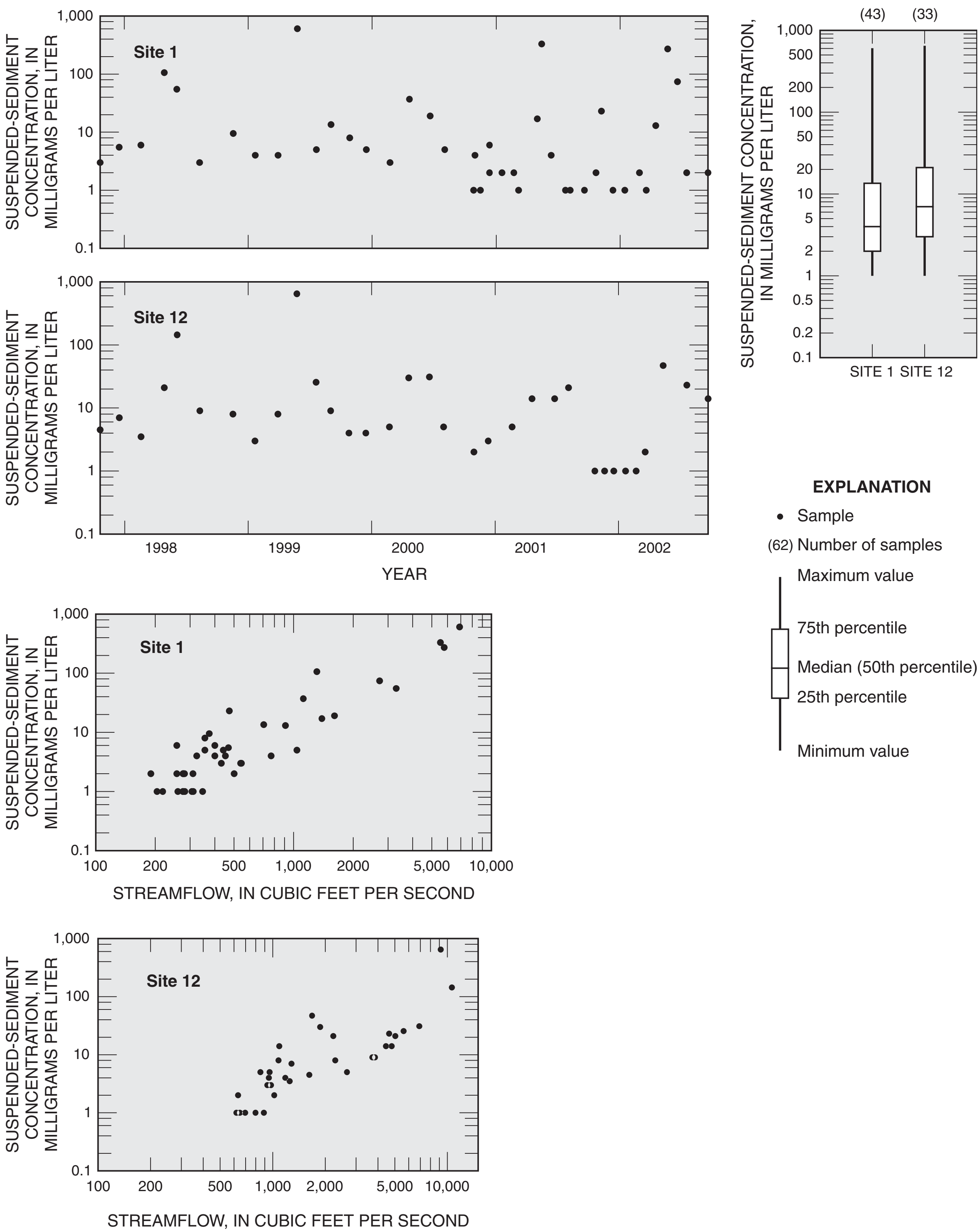

Figure 6. Suspended-sediment concentrations and relation with streamflow for samples collected from the Snake River, Grand Teton National Park, Wyoming, water years 1998-2002.

Table 8. Results for physical and chemical constituents for a synoptic study on Pilgrim Creek, Pacific

[ft^3/s, cubic feet per second; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per

Site number	Date	Time	Instantaneous discharge, ft^3/s	Barometric pressure, mm Hg	Dissolved oxygen, mg/L	Dissolved oxyen, percent of saturation	pH, unfiltered field, standard units	Specific conductance, unfiltered , µS/cm	Temperature, air, °C	Temperature, water, °C
										Pilgrim
2	06-11-02	0930	225	592	10.8	105	8.1	125	5.0	3.5
	07-22-02	1315	34	596	7.8	105	8.3	190	20.0	17.5
	09-16-02	1330	16	591	8.2	103	8.4	205	22.0	14.0
	11-05-02	0900	11	596	11.4	100	8.1	231	-2.0	.0
3	06-11-02	1200	198	596	10.2	105	8.1	126	12.0	6.0
	07-22-02	1500	27	598	6.6	91	8.3	190	19.5	19.0
	09-16-02	1615	10	591	7.6	100	8.6	200	17.0	16.0
	11-05-02	1200	2.2	596	11.5	101	8.3	239	-1.0	.0
										Pacific
4	06-11-02	1500	716	595	10.0	106	7.8	130	9.5	7.0
	07-23-02	0930	119	600	9.0	104	8.0	192	17.0	11.0
	09-16-02	1130	46	594	8.8	103	8.3	226	14.5	11.0
	11-05-02	1500	32	595	11.6	102	7.8	230	.5	.0
5	06-12-02	1330	581	601	9.1	103	7.7	138	15.0	10.0
	07-23-02	1200	137	603	7.5	97	8.1	200	19.0	16.0
	09-17-02	0900	55	593	8.5	99	8.2	236	8.0	11.0
	11-05-02	1330	56	596	10.6	94	7.7	239	.0	.5
										Buffalo
6	06-12-02	0945	1,080	597	11.0	113	7.7	127	10.0	6.0
	07-23-02	1615	548	600	8.2	101	7.4	111	19.0	14.0
	09-17-02	1130	199	592	8.6	98	7.8	180	10.0	10.0
	11-04-02	1445	148	594	11.1	98	8.7	241	-1.0	.0
7	06-12-02	1630	1,220	597	9.2	104	7.8	135	14.0	10.0
	07-23-02	1400	743	605	7.8	98	7.8	122	19.0	15.0
	09-17-02	1345	214	593	8.8	103	7.8	191	7.0	11.0
	11-06-02	1345	175	596	11.7	103	8.1	218	5.0	.0
										Spread
8	06-13-02	0915	175	595	10.1	107	8.2	159	14.0	7.0
	07-24-02	0930	67	595	8.3	101	8.3	211	20.0	13.0
	09-18-02	1100	37	588	9.2	104	8.1	232	8.0	9.0
	11-06-02	0930	24	594	11.1	98	8.1	260	-4.5	.0
9	06-13-02	1115	124	596	8.8	107	8.1	162	16.0	13.0
	07-24-02	1145	4.8	602	7.8	109	8.4	233	26.0	20.0
	09-17-02	1600	1.5	590	8.6	104	8.3	266	9.0	12.0
	11-06-02	1130	11	596	11.4	100	8.0	269	-1.0	.0
10	06-13-02	1700	48	595	8.2	102	8.0	170	17.0	14.0
	07-24-02	1600	5.4	595	7.0	103	8.5	282	32.0	22.0
	09-18-02	1400	3.5	590	8.7	105	8.8	323	10.0	12.0
	11-06-02	1630	3.0	593	11.6	102	8.3	359	1.0	.0
11	06-13-02	1430	46	608	7.5	100	8.4	208	19.0	18.0
	07-24-02	1400	8.2	610	7.6	112	8.6	311	29.0	23.0
	09-18-02	0930	.17	601	9.3	104	8.4	384	8.5	9.5
	11-06-02	1300	.00	--	--	--	--	--	5.0	--

Creek, Buffalo Fork, Spread Creek, and Ditch Creek, Grand Teton National Park, Wyoming, 2002.

centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; <, less than; E, estimated; --, no data]

Hardness, unfiltered mg/L as $CaCO_3$	Calcium, filtered, mg/L	Magnesium, filtered, mg/L	Potassium, filtered mg/L	Sodium adsorption ratio	Sodium, filtered, mg/L	Alkalinity, mg/L as $CaCO_3$	Chloride, filtered, mg/L	Fluoride, filtered, mg/L	Silica, filtered, mg/L
Creek									
58	17.8	3.25	0.49	0.1	2.54	64	0.42	E0.06	6.46
89	27.7	4.84	.70	.2	4.20	96	.49	E.06	7.34
97	30.2	5.20	.77	.2	4.83	E104	E.30	E.07	7.57
100	31.7	5.31	.80	.2	5.11	E112	<.20	<.17	7.91
57	17.6	3.23	.50	.1	2.60	64	.82	E.07	6.51
88	27.4	4.77	.63	.2	4.14	97	E.24	E.08	7.28
94	29.2	5.06	.74	.2	4.74	E102	.56	E.06	6.83
110	35.2	5.95	.84	.2	5.95	122	E.16	<.17	8.75
Creek									
58	17.5	3.60	.80	.1	2.55	62	.68	E.06	11.7
87	26.0	5.34	1.12	.2	4.01	91	.83	E.07	13.3
100	30.7	6.33	1.09	.2	5.10	E105	1.02	E.08	11.9
110	31.8	6.54	.95	.2	5.26	E99	E.11	<.17	11.9
63	18.9	3.78	.87	.2	2.81	67	.65	E.08	11.7
93	28.1	5.61	1.29	.2	4.19	97	E.32	E.07	14.0
110	32.2	6.26	1.19	.2	4.77	E114	.54	E.08	12.8
110	33.7	6.58	1.14	.2	4.91	116	.25	<.17	13.1
Fork									
58	16.5	4.20	1.29	.2	2.88	63	1.15	E.06	18.9
47	12.9	3.53	1.62	.2	2.75	53	1.29	<.10	20.4
76	21.5	5.47	2.00	.2	4.66	E84	2.89	E.10	21.9
95	26.7	6.84	1.91	.3	6.38	109	4.58	<.17	21.5
60	17.1	4.21	1.30	.2	3.09	67	1.93	E.08	17.8
52	14.8	3.72	1.43	.2	3.13	57	2.37	<.10	21.6
81	23.1	5.74	1.91	.3	5.24	E91	2.89	E.08	21.2
94	26.7	6.72	1.90	.3	6.37	103	3.52	<.17	22.2
Creek									
78	22.5	5.18	.70	.2	3.34	80	.77	E.08	7.25
100	29.6	6.53	.86	.2	4.21	106	.95	E.09	7.36
110	32.1	7.14	.98	.2	4.71	E115	1.29	E.10	7.31
120	35.8	8.12	1.02	.2	5.34	129	.23	<.17	8.38
74	21.6	4.97	.71	.2	3.26	81	.50	.11	6.93
110	33.2	7.23	.91	.2	4.31	118	.62	E.09	7.29
130	38.7	8.45	1.07	.2	4.77	E134	.86	E.10	8.34
130	38.1	8.58	1.06	.2	5.62	133	.32	<.17	8.87
Creek									
75	23.4	4.08	1.19	0.3	5.00	78	1.43	E0.11	8.58
120	38.4	7.02	1.29	.3	8.76	122	1.19	E.11	9.75
150	45.3	8.11	1.32	.4	9.82	E138	1.30	.13	10.2
170	52.2	8.67	1.16	.3	10.3	153	.30	<.17	11.6
94	27.5	6.10	1.04	.2	5.05	88	1.11	.21	9.44
150	40.8	11.6	1.30	.2	5.71	114	1.51	.35	7.16
180	49.3	14.5	1.43	.2	6.25	E132	1.99	.42	9.40
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Table 8. Results for physical and chemical constituents for a synoptic study on Pilgrim Creek, Pacific Creek,

Site number	Date	Sulfate filtered, mg/L	Solids, residue on evaporation at 180° C, filtered mg/L	Ammonia + organic, filtered, mg/L as N	Ammonia + organic, unfiltered, mg/L as N	Ammonia filtered, mg/L as N	Nitrite + nitrate filtered, mg/L as N	Nitrite filtered, mg/L as N	Ortho-phosphate, filtered, mg/L as P	Phosphorus, filtered, mg/L
										Pilgrim
2	06-11-02	2.6	77	E0.07	0.17	<0.04	<0.05	<0.008	<0.02	0.008
	07-22-02	4.4	106	E.07	.10	<.04	<.05	<.008	<.02	.007
	09-16-02	5.7	116	E.05	E.09	<.04	<.05	<.008	<.02	E.004
	11-05-02	6.6	125	<.10	E.06	<.04	<.06	<.008	<.02	.006
3	06-11-02	2.7	75	E.07	.17	<.04	<.05	<.008	<.02	.009
	07-22-02	4.5	116	E.08	E.07	<.04	<.05	<.008	<.02	.006
	09-16-02	5.7	114	E.06	E.09	<.04	<.05	<.008	<.02	E.003
	11-05-02	7.4	130	<.10	E.06	<.04	<.06	<.008	<.02	E.004
										Pacific
4	06-11-02	6.1	83	E.08	.13	<.04	E.02	<.008	E.01	.014
	07-23-02	10.0	125	.11	E.06	.07	<.05	<.008	E.01	.013
	09-16-02	12.5	135	<.10	E.07	<.04	<.05	<.008	<.02	.006
	11-05-02	13.4	134	<.10	E.06	<.04	<.06	<.008	<.02	.008
5	06-12-02	6.1	93	E.09	.15	<.04	E.02	<.008	E.01	.014
	07-23-02	9.1	124	E.07	E.06	<.04	<.05	<.008	E.01	.010
	09-17-02	10.9	141	E.05	E.08	<.04	<.05	<.008	<.02	.007
	11-05-02	11.7	137	<.10	E.07	<.04	<.06	<.008	<.02	.008
										Buffalo
6	06-12-02	3.5	89	E.09	.20	<.04	<.05	<.008	.03	.035
	07-23-02	2.8	80	E.07	.47	<.04	<.05	<.008	.05	.053
	09-17-02	5.2	120	<.10	E.08	<.04	<.05	<.008	.03	.042
	11-04-02	8.3	145	E.05	E.07	<.04	<.06	<.008	.04	.045
7	06-12-02	3.7	97	E.07	2.7	<.04	<.05	<.008	.03	.035
	07-23-02	2.8	85	E.07	.18	<.04	<.05	<.008	.04	.044
	09-17-02	5.4	126	E.08	E.09	<.08	<.05	<.008	.03	.040
	11-06-02	7.1	133	E.06	E.07	<.04	<.06	<.008	.04	.044
										Spread
8	06-13-02	5.9	100	.12	.19	<.04	<.05	<.008	<.02	.007
	07-24-02	7.5	124	E.07	.14	<.04	<.05	<.008	<.02	.005
	09-18-02	8.0	129	E.06	E.09	<.04	<.05	<.008	<.02	E.003
	11-06-02	10.8	140	E.05	E.07	<.04	<.06	<.008	<.02	E.003
9	06-13-02	5.9	103	E.06	.19	<.04	<.05	<.008	<.02	.007
	07-24-02	8.2	139	<.10	.12	E.03	<.05	<.008	<.02	E.002
	09-17-02	9.2	156	<.10	.15	<.04	<.05	<.008	<.02	<.004
	11-06-02	10.9	149	E.08	E.08	<.04	<.06	<.008	<.02	E.002
										Ditch
10	06-13-02	11.8	116	0.18	0.24	E0.03	<0.05	<0.008	E0.01	0.022
	07-24-02	27.2	171	E.09	.18	<.04	<.05	<.008	<.02	.013
	09-18-02	33.8	199	E.08	.12	<.04	<.05	<.008	<.02	.006
	11-06-02	37.6	216	E.07	E.07	<.04	<.06	<.008	E.01	.010
11	06-13-02	21.4	139	.19	.24	<.04	<.05	<.008	E.01	.017
	07-24-02	49.5	199	E.06	.15	<.04	<.05	<.008	<.02	E.004
	09-18-02	64.8	235	E.08	.10	<.04	<.05	<.008	<.02	<.004
	11-06-02	--	--	--	--	--	--	--	--	--

Buffalo Fork, Spread Creek, and Ditch Creek, Grand Teton National Park, Wyoming, 2002.--Continued

Phos-phorus, unfiltered, mg/L	Arsenic filtered, µg/L	Cadmium, filtered, µg/L	Chromium, filtered, µg/L	Copper, filtered µg/L	Iron, filtered, µg/L	Manga-nese, filtered, µg/L	Nickel, filtered, µg/L	Selenium, filtered, µg/L	Zinc, filtered, µg/L	Suspended sediment concen-tration, mg/L
Creek--Continued										
0.106	0.3	0.09	<0.8	0.6	11	4.3	0.51	<0.3	3	137
.012	--	--	--	--	<10	E1.7	--	--	--	5
.006	--	--	--	--	<10	<2.0	--	--	--	1
.006	--	--	--	--	<10	E1.4	--	--	--	1
.097	.3	<.04	<.8	.5	E9	5.2	.49	<.3	4	105
.010	--	--	--	--	<10	E1.7	--	--	--	5
E.002	--	--	--	--	<10	<2.0	--	--	--	1
.005	--	--	--	--	<10	E1.6	--	--	--	1
Creek--Continued										
.053	.4	.63	<.8	.6	E9	E2.6	E.03	E.3	6	46
.018	--	--	--	--	<10	E1.2	--	--	--	4
.006	--	--	--	--	<10	E1.1	--	--	--	1
.016	--	--	--	--	<10	E1.3	--	--	--	11
.048	.5	.16	<.8	.5	E10	5.8	.49	<.3	1	45
.015	--	--	--	--	<10	5.2	--	--	--	3
.009	--	--	--	--	<10	7.6	--	--	--	2
.016	--	--	--	--	E5	7.0	--	--	--	5
Fork--Continued										
.141	.6	.12	<.8	.5	E10	6.1	.38	E.2	4	112
.40	--	--	--	--	<10	4.9	--	--	--	286
.045	--	--	--	--	<10	8.4	--	--	--	2
.061	--	--	--	--	E9	12.8	--	--	--	11
.141	.5	.04	<.8	.5	10	8.4	.72	<.3	2	105
.095	--	--	--	--	E5	3.7	--	--	--	43
.045	--	--	--	--	E7	10.9	--	--	--	3
.059	--	--	--	--	<10	10.3	--	--	--	13
Creek--Continued										
.074	.4	.06	<.8	.7	27	5.2	.73	<.3	2	65
.084	--	--	--	--	35	E2.6	--	--	--	81
.026	--	--	--	--	45	E2.5	--	--	--	22
.026	--	--	--	--	13	4.1	--	--	--	20
.062	.4	.13	<.8	.6	20	4.3	.78	E.2	2	51
.007	--	--	--	--	12	E.9	--	--	--	3
<.004	--	--	--	--	<10	<2.0	--	--	--	1
.007	--	--	--	--	<10	E1.6	--	--	--	2
Creek--Continued										
.058	0.5	0.11	<0.8	0.9	16	6.1	0.94	<0.3	45	27
.025	--	--	--	--	<10	3.5	--	--	--	--
.009	--	--	--	--	E8	E1.5	--	--	--	6
.015	--	--	--	--	<10	E2.0	--	--	--	1
.047	1.0	.17	<.8	.8	12	E2.3	.85	E.3	3	24
.010	--	--	--	--	<10	E.9	--	--	--	5
E.002	--	--	--	--	<10	<2.0	--	--	--	1
--	--	--	--	--	--	--	--	--	--	--

Table 9. Results for fecal-coliform-bacteria samples for a synoptic study on Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek, Grand Teton National Park, Wyoming, 2002.

[<, less than; >, greater than]

Site number (fig. 1)	Site name	Number of samples	Minimum concentration, in colonies per 100 milliliters	Maximum concentration, in colonies per 100 milliliters
	Mxqh#5335#vdpsolqj#hyhqw			
2	Pilgrim Creek below National Park Service boundary, near Moran, Wyoming	5	6	17
3	Pilgrim Creek near Moran, Wyoming	5	4	8
4	Pacific Creek above National Park Service boundary, near Moran, Wyoming	5	23	34
5	Pacific Creek at Moran, Wyoming	5	70	130
6	Buffalo Fork above Lava Creek near Moran, Wyoming	5	4	9
7	Buffalo Fork near Moran, Wyoming	5	12	19
8	Spread Creek at diversion dam near Moran, Wyoming	5	<1	<1
9	Spread Creek near Moran, Wyoming	5	13	28
10	Ditch Creek below South Fork near Kelly, Wyoming	5	3	8
11	Ditch Creek near Moose, Wyoming	5	2	4
	Mxo|#5335#vdpsolqj#hyhqw			
2	Pilgrim Creek below National Park Service boundary, near Moran, Wyoming	5	19	33
3	Pilgrim Creek near Moran, Wyoming	5	4	24
4	Pacific Creek above National Park Service boundary, near Moran, Wyoming	5	25	38
5	Pacific Creek at Moran, Wyoming	5	16	39
6	Buffalo Fork above Lava Creek near Moran, Wyoming	5	32	58
7	Buffalo Fork near Moran, Wyoming	5	57	93
8	Spread Creek at diversion dam near Moran, Wyoming	5	17	32
9	Spread Creek near Moran, Wyoming	5	21	82
10	Ditch Creek below South Fork near Kelly, Wyoming	5	63	100
11	Ditch Creek near Moose, Wyoming	5	95	>200

Table 10. Possible source distribution of animal types, in percent, for ribotype patterns of *Escherichia coli* isolates in samples collected during a synoptic study on Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek, Grand Teton National Park, Wyoming, 2002.

[--, not applicable. Percentages in table may not total 100 percent, owing to rounding of individual values.]

Source	Pilgrim Creek (sites 2 and 3)	Pacific Creek (sites 4 and 5)	Buffalo Fork (sites 6 and 7)	Spread Creek (sites 8 and 9)	Ditch Creek (sites 10 and 11)
Avian	32	21	31	6	35
Bear	2	--	2	10	--
Bovine	13	24	6	22	12
Canine	5	5	26	13	2
Deer and elk	11	19	22	25	24
Duck	2	--	--	--	--
Feline	5	7	--	--	--
Horse	2	--	2	3	--
Human	2	5	2	6	--
Rabbit	12	12	--	--	5
Raccoon	7	2	--	--	2
Rodent	2	5	10	3	16
Unknown	5	--	--	10	5

Pilgrim Creek

Pilgrim Creek Basin is the northernmost of the tributary basins that were part of the synoptic study and flows southwest from the Pinyon Peak Highlands. Pilgrim Creek drains the Bridger-Teton National Forest, including the Teton Wilderness Area, and Grand Teton National Park before flowing into Jackson Lake. The upstream site on Pilgrim Creek (site 2) is accessible by gravel road and was sampled in Grand Teton National Park, just downstream from the NPS and Bridger-Teton National Forest boundary (fig. 1). The downstream site near Moran, Wyoming (site 3) is along a major highway, about two miles downstream from site 2 and about 2.5 miles upstream from the entry into Jackson Lake. Pilgrim Creek Basin is the smallest of the eastern tributary basins in the synoptic study and drains about 48 square miles at the downstream site (site 3). Most of the drainage area for the basin (about 97 percent) is above the upstream site (site 2). Land cover for both sites is about 68 percent forested upland and about 29 percent shrubland and herbaceous upland; the remaining area is barren, wetland, and water or ice covered (fig. 7). Pilgrim Creek Basin has no developed lands or cultivated lands; however, recreational use, including horse use, is common in the basin. Pilgrim Creek is braided in some reaches, with an unconsolidated gravel and cobble streambed.

Streamflow for Pilgrim Creek varied during the sampling events, and ranged from 11 ft^3/s in November to 225 ft^3/s in June at the upstream site (site 2) and from 2.2 ft^3/s in November to 198 ft^3/s in June at the downstream site (site 3) (fig. 8). Streamflow was less at site 3 compared to site 2 during all four of the sampling events, indicating that streamflow losses to ground water occur through the coarse alluvial deposits of Pilgrim Creek. The creek occasionally may become dry in the lower reaches.

The waters of Pilgrim Creek were the most dilute of the five tributaries that were sampled. Dissolved-solids concentrations at the upstream site (site 2) ranged from 77 to 125 mg/L and were comparable to dissolved-solids concentrations at the downstream site (site 3), which ranged from 75 to 130 mg/L. For both sites, the samples with the lowest dissolved-solids concentrations were collected during June, when snowmelt runoff that has a short contact time with geologic materials in the basin dilutes the base-flow chemistry. Samples with the highest dissolved-solids concentrations were collected during November when ground water, which has a long contact time with geologic materials in the basin, composes a higher percentage of the streamflow. The range of dissolved-solids concentrations for samples from Pilgrim Creek were comparable to the range of dissolved-solids concentrations for the Snake River at Moose, Wyoming (site 12).

Concentrations of nitrogen and phosphorus species generally were low in samples from both sites (site 2 and site 3) on Pilgrim Creek. All samples of dissolved ammonia, nitrite, and nitrate were less than the water-quality criteria for surface waters in Wyoming. Dissolved-nitrate concentrations were less than 0.06 mg/L in all eight samples and lower than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). Total-nitrogen concentrations in samples from both sites 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 eight samples of dissolved orthophosphate were less than the reporting level of 0.02 mg/L. Dissolved-phosphorus concentrations were low in all samples, ranging from 0.003 to 0.009 mg/L. During high flows in June 2002, total-phosphorus concentrations of 0.106 mg/L at site 2 and 0.097 mg/L at site 3 exceeded the total-phosphorus median concentration of 0.022 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). The high total-phosphorus concentrations in June correspond with the high suspended-sediment concentrations. High total-phosphorus concentrations typically are associated with sediment because phosphate sorbs to soil particles. Sources of nitrogen and phosphorus in the basins most likely are natural because the basin is undeveloped.

Dissolved-iron and -manganese concentrations were low in the samples collected from the upstream site (site 2) and the downstream site (site 3) on Pilgrim Creek. The maximum values of dissolved iron of 11 μg/L (site 2) and dissolved manganese of 5.2 μg/L (site 3) for the eight samples collected from Pilgrim Creek were substantially less than the SMCLs of 300 μg/L and 50 μg/L, respectively. During the June sampling of site 2 and site 3, concentrations of dissolved arsenic, cadmium, chromium, copper, nickel, selenium, and zinc (table 8) were substantially less than chronic and acute aquatic-criteria levels for all of the metals (table 3). Sources of trace metals in the Pilgrim Creek Basin most likely are natural because the basin is undeveloped.

During the June sampling event, one sample was collected from site 2 and from site 3 and analyzed for 47 commonly used pesticides. All of the pesticide concentrations for both samples were less than the reporting levels for the compounds (table 2) and aquatic criteria established for surface waters in Wyoming (table 3). The Pilgrim Creek Basin has no developed or cultivated lands where pesticides typically are applied, so the lack of any pesticide detections is consistent with the undeveloped conditions of the basin.

Suspended-sediment concentrations for samples collected from Pilgrim Creek (fig. 8) varied during the sampling events, and ranged from 1 mg/L in September and November to 137 mg/L in June at the upstream site (site 2) and from 1 mg/L in September and November to 105 mg/L in June at the downstream site (site 3). The highest suspended-sediment concentrations and loads (fig. 8) 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.

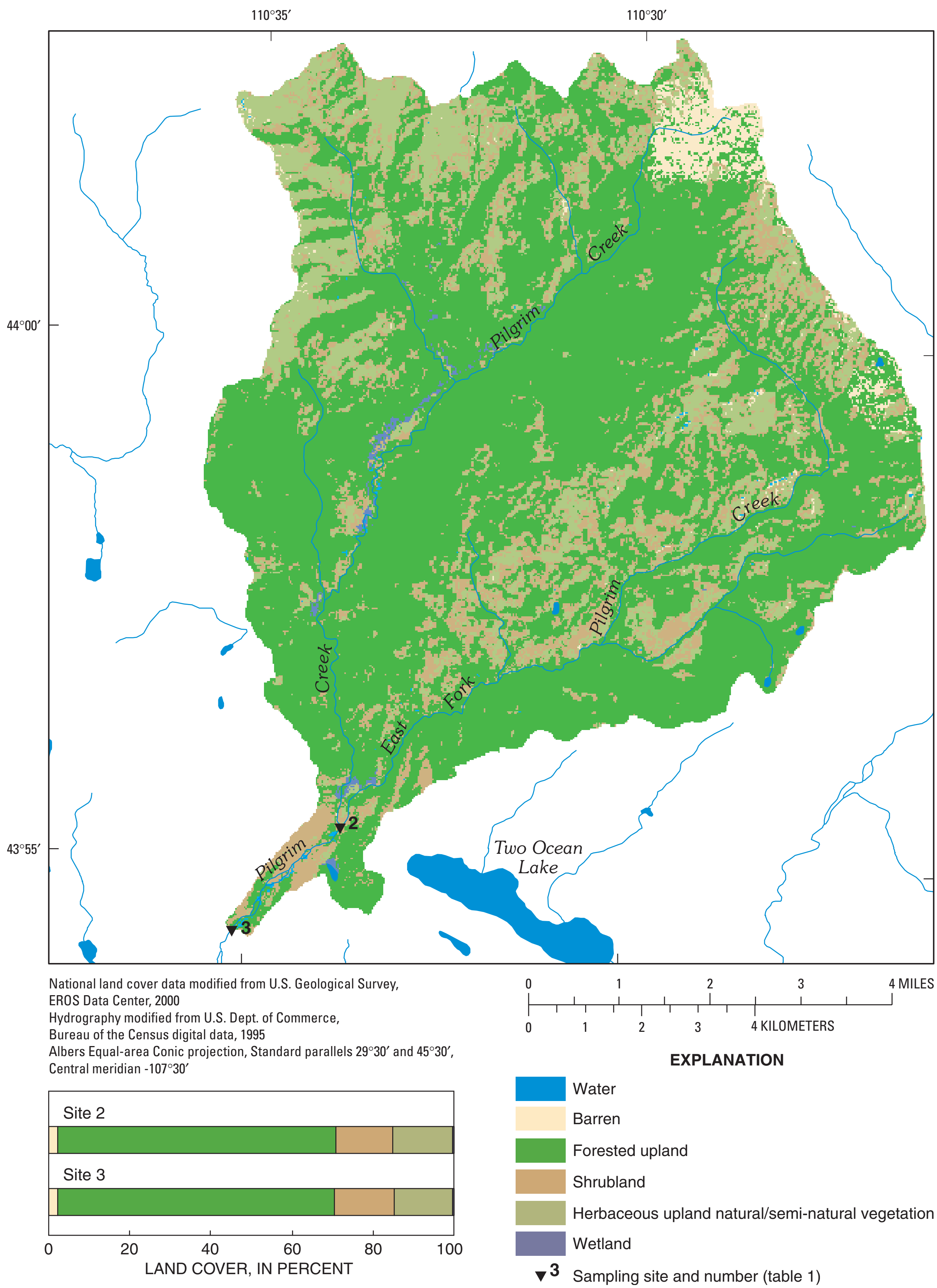

Figure 7. Distribution of land cover in the Pilgrim Creek Basin, Grand Teton National Park, Wyoming.

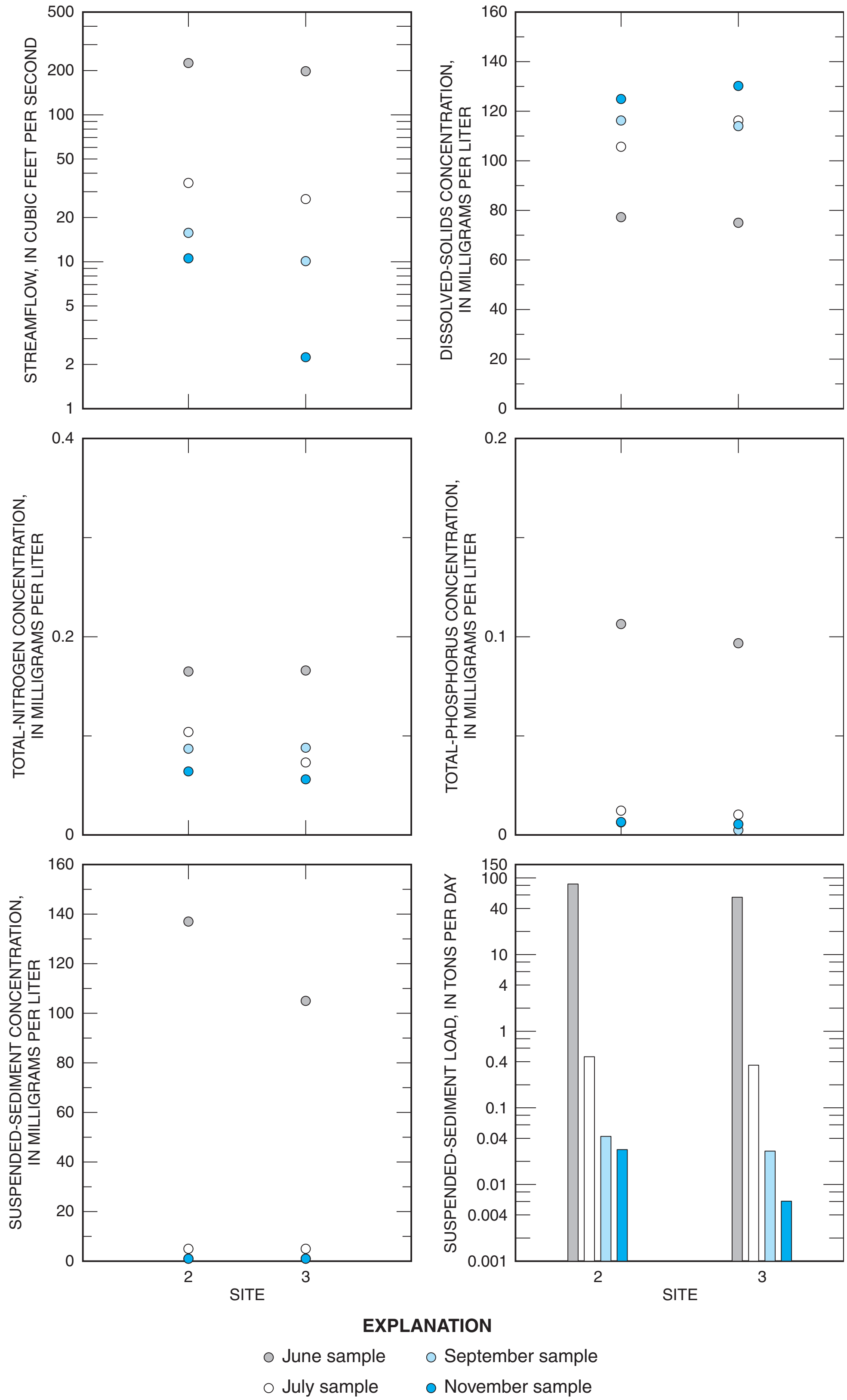

Figure 8. Streamflow and dissolved-solids, total nitrogen, total phosphorus, and suspended-sediment concentrations for Pilgrim Creek, Grand Teton National Park, Wyoming, 2002.

Concentrations of fecal-coliform bacteria in samples collected from Pilgrim Creek (table 9) during the June and July sampling events, ranged from 6 to 33 col/100 mL at the upstream site (site 2) and from 4 to 24 col/100 mL at the downstream site (site 3), which are substantially less than the recommended limit for a single sample for recreational contact of 400 col/100 mL. The ribotype patterns of the *E. coli* isolates for the five eastern tributaries were the most varied in Pilgrim Creek, matching at least 12 different sources. An avian source was the most frequently matched source, composing 32 percent of the isolates (table 10). Only 2 percent of the isolates from Pilgrim Creek samples were matched to a human source indicating that wildlife was the main contributor of fecal-indicator bacteria to Pilgrim Creek for the synoptic study samples.

Pacific Creek

Pacific Creek flows southwest from the Absaroka Range and the Pinyon Peak Highlands to the Snake River. Pacific Creek drains the Bridger-Teton National Forest, including the Teton Wilderness Area, before flowing through Grand Teton National Park (fig.1). The upstream site on Pacific Creek (site 4) is downstream from an established Forest Service campground and several undeveloped camp sites and upstream from the NPS boundary. Site 4 is accessed off a gravel road. The downstream site at Moran, Wyoming (site 5) is along a major highway, about 8 miles downstream from site 4 and about 0.25 mile upstream from the confluence with the Snake River. The Pacific Creek Basin is the second largest of the eastern tributary basins that were part of the synoptic study and drains about 169 square miles at site 5. About 70 percent of the land cover for both sites is forested upland, shrubland, and herbaceous upland (fig. 9); barren highlands that resulted from forest fire account for about 25 percent of the remaining area. The Pacific Creek drainage has very little developed area; however, a few private residential holdings exist between site 4 and site 5. Recreational use, including horse use, is common in the basin. Pacific Creek is braided at site 4 and has an unconsolidated gravel and cobble streambed through the entire reach.

Streamflow for Pacific Creek varied during the sampling events (fig. 10), and ranged from 32 ft^3/s in November to 716 ft^3/s in June at the upstream site (site 4) and from 55 ft^3/s in September to 581 ft^3/s in June at the downstream site (site 5). Except for the site visit made during snowmelt runoff in June, streamflows increased from site 4 to site 5, which is attributable to some inflow from small tributaries, and possibly to groundwater discharge through the coarse alluvium in the lower part of the basin.

Dissolved-solids concentrations at the upstream site (site 4) ranged from 83 to 135 mg/L and were comparable to dissolved-solids concentrations at the downstream site (site 5), which ranged from 93 to 141 mg/L. For both sites, the samples with the lowest dissolved-solids concentrations were collected during June, when snowmelt runoff that has a short contact time with geologic materials in the basin dilutes the base-flow chemistry. Samples with the highest dissolved-solids concentrations were collected during September. Ground water, which has a longer contact time with geologic material in the basin, probably was the primary source of streamflow in September. The range of dissolved-solids concentrations for samples from Pacific Creek were comparable to the range of dissolved-solids concentrations for the Snake River at Moose, Wyoming (site 12).

Concentrations of nitrogen and phosphorus species generally were low in samples from both sites (site 4 and site 5) on Pacific Creek. All samples of dissolved ammonia, nitrite, and nitrate were less than the water-quality criteria for surface waters in Wyoming. Dissolved-nitrate concentrations were less than 0.06 mg/L and lower than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). Total-nitrogen concentrations in all eight samples were 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). Total-phosphorus concentrations of 0.053 mg/L at site 4 and 0.048 mg/L at site 5 for samples collected during June exceeded the total-phosphorus median concentration of 0.022 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). Total-phosphorus concentrations in five samples exceeded the ambient total-phosphorus criterion of 0.015 mg/L for forested mountain streams recommended by the USEPA (U.S. Environmental Protection Agency, 2000). Generally, sources of nitrogen and phosphorus in the basin probably are natural because the basin is mostly undeveloped; however, an established campground and undeveloped camp sites exist and septic systems may exist in the basin, which also could contribute to nutrient concentrations.

Dissolved-iron and -manganese concentrations were low in samples collected from both sites (site 4 and site 5) on Pacific Creek. The maximum values of dissolved iron of 10 μg/L (site 5) and dissolved manganese of 7.6 μg/L (site 5) for the eight samples collected from Pacific Creek were substantially less than the SMCLs of 300 μg/L and 50 μg/L, respectively. During the June sampling of site 4 and site 5, concentrations of dissolved arsenic, cadmium, chromium, copper, nickel, selenium, and zinc (table 8) were less than chronic and acute aquatic-criteria levels for all of the metals (table 3). The highest concentration of cadmium of 0.63 μg/L for all 10 samples collected in June from the eastern tributaries for trace metals was in the sample collected at site 4. Sources of trace metals in the Pacific Creek Basin most likely are natural because the basin is mostly undeveloped.

During the June sampling event, one sample was collected from site 4 and site 5 and analyzed for 47 commonly used pesticides. All of the pesticide concentrations for both samples were less than the reporting levels for the compounds (table 2) and aquatic criteria established for surface waters in Wyoming (table 3). The Pacific Creek Basin has less than 0.01 percent developed land and no cultivated lands where pesticides typi-

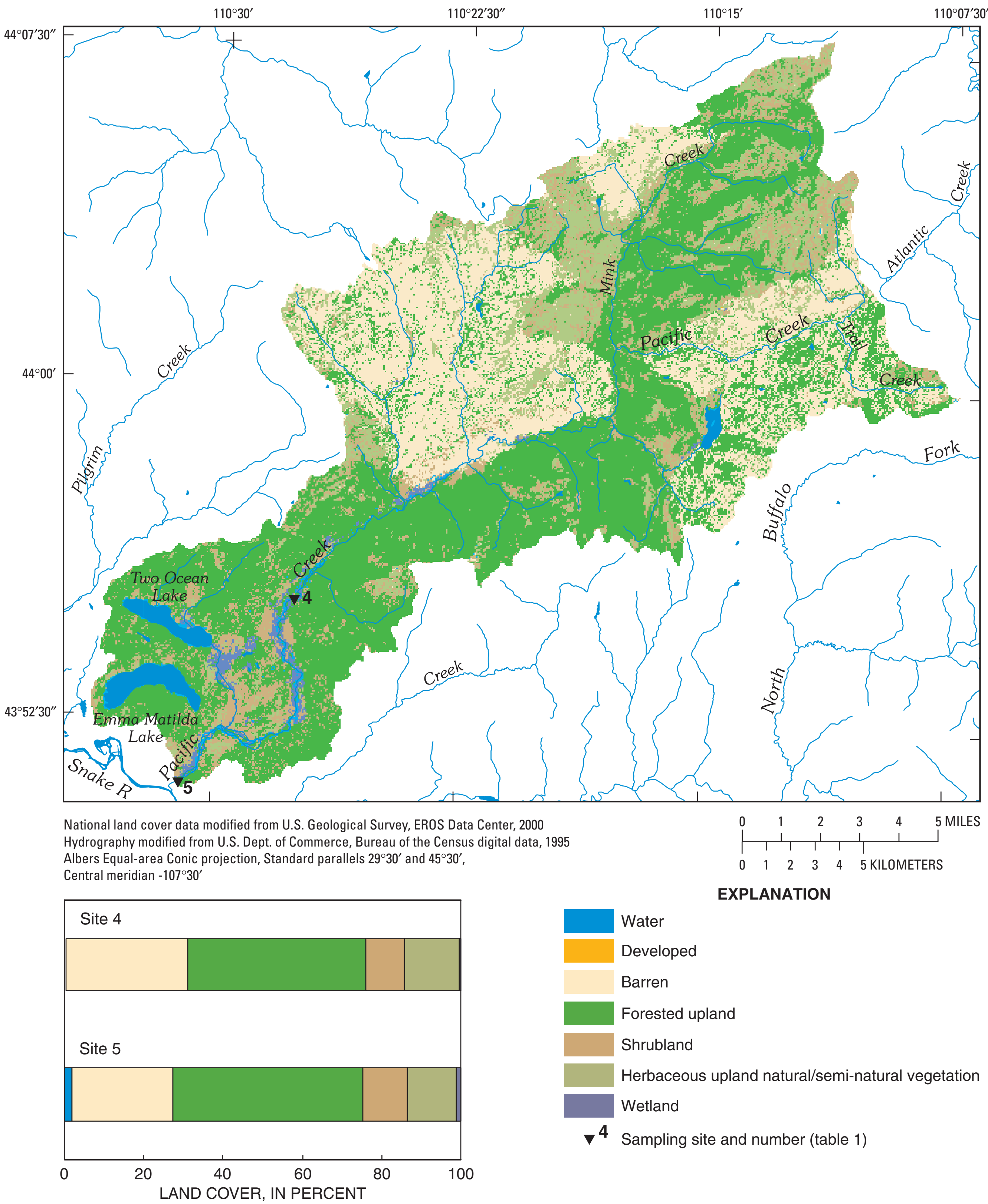

Figure 9. Distribution of land cover in the Pacific Creek Basin, Grand Teton National Park, Wyoming.

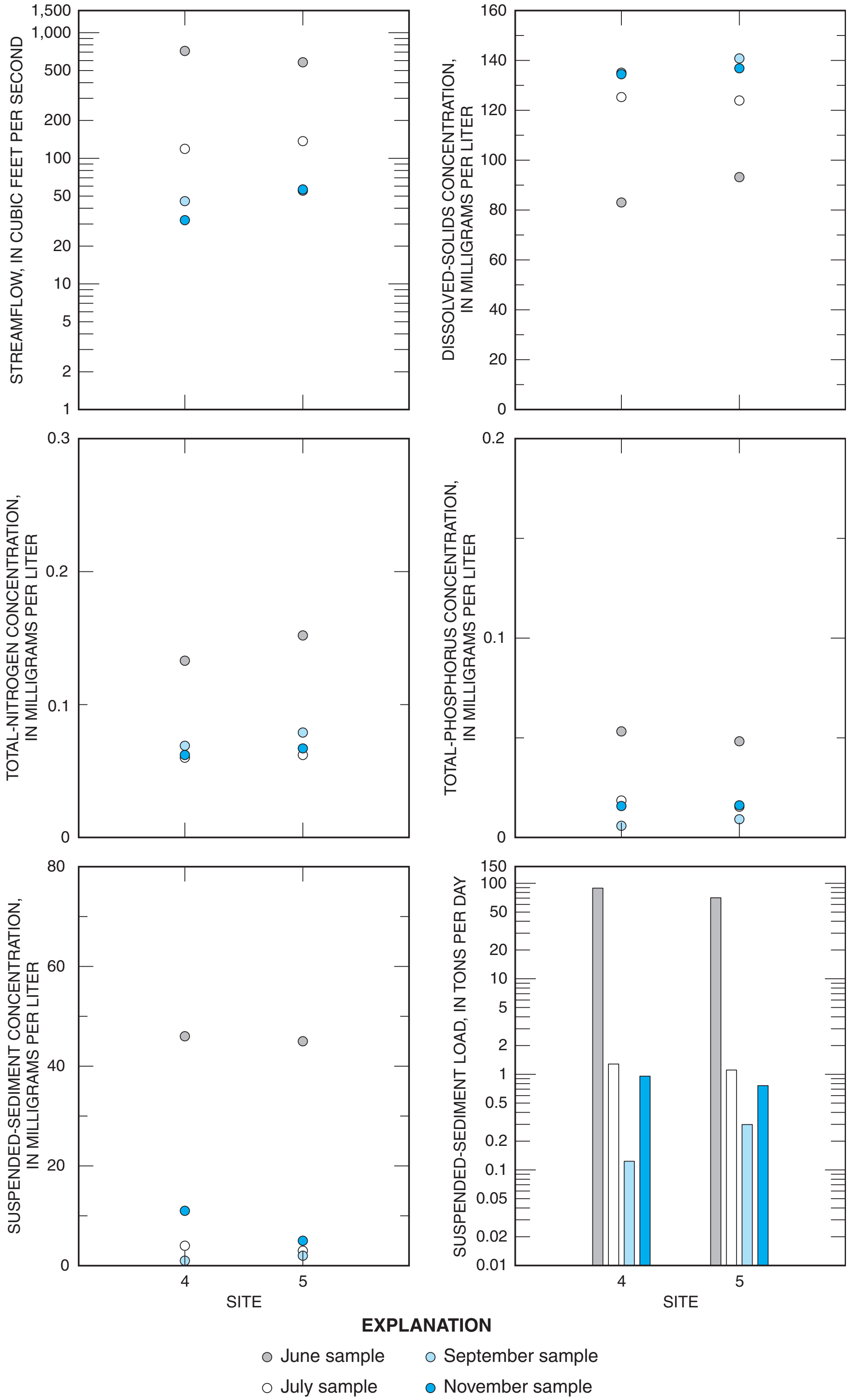

Figure 10. Streamflow and dissolved-solids, total-nitrogen, total-phosphorus, and suspended-sediment concentrations for Pacific Creek, Grand Teton National Park, Wyoming, 2002.

cally are applied, so the lack of any pesticide detections is consistent with the generally undeveloped conditions of the basin.

Suspended-sediment concentrations for Pacific Creek (fig. 10) varied during the sampling events, and ranged from 1 mg/L in September to 46 mg/L in June at the upstream site (site 4) and from 2 mg/L in September to 45 mg/L in June at the downstream site (site 5). The highest suspended-sediment concentrations and sediment loads (fig. 10) 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. Sediment loads were comparable between Pilgrim Creek (fig. 8) and Pacific Creek during June; however, suspended-sediment concentrations were substantially less in Pacific Creek.

Concentrations of fecal-coliform bacteria in samples collected from Pacific Creek (table 9) during the June and July sampling events ranged from 23 to 38 col/100 mL at the upstream site (site 4) and from 16 to 130 col/100 mL at the downstream site (site 5), which are substantially less than the recommended limit for a single sample for recreational contact of 400 col/100 mL. The ribotype patterns of the *E. coli* isolates most frequently matched a bovine source, which composed 24 percent of the isolates (table 10). The bovine source is most likely bison because cattle are not grazed in the basin. A human source was matched in 5 percent of the isolates.

Buffalo Fork

The Buffalo Fork flows west out of the Washakie Range to the Snake River (fig. 1). The upstream site on the Buffalo Fork (site 6) is located along a primary highway that is one of the main routes to Yellowstone National Park and Grand Teton National Park and is at the NPS and Forest Service boundary. About 88 percent of the basin is upstream from site 6. The Buffalo Fork near Moran, Wyoming (site 7) is about 6 miles downstream from site 6, also along the highway, and about 0.5 mile upstream from the confluence with the Snake River. The Buffalo Fork Basin is the largest of the eastern tributary basins that were part of the synoptic study and drains about 378 square miles at site 7. About 61 percent of the land cover is forested upland and about 34 percent is shrubland and herbaceous upland at both sites (fig. 11). Of the five eastern tributary basins, the Buffalo Fork Basin has the highest percentage of developed land, although it accounts for less than 0.05 percent of the land cover. Developed lands, which exist upstream from site 6 and site 7, include private ranches and residences, commercial services, and campgrounds. Cultivated land cover accounts for about 0.4 percent of the Buffalo Fork Basin at site 7. The primary crop grown in Teton County, including the Buffalo Fork Basin, is hay (Wyoming Agricultural Statistics Service, 2003). The remaining drainage area is barren highlands, water or ice covered, and wetlands. Vehicle traffic is high through the Buffalo Fork Basin and recreational use and grazing occur in the basin. The Buffalo Fork is a meandering and braided stream, with a sand, gravel, and cobble streambed.

The Buffalo Fork contributes the most streamflow to the Snake River of the eastern tributaries that were part of the synoptic study. Streamflow for the Buffalo Fork varied during sampling events, and ranged from 148 ft^3/s in November to 1,080 ft^3/s in June at site 6 and from 175 ft^3/s in November to 1,220 ft^3/s in June at site 7 (fig. 12). Streamflows increased from the upstream site to the downstream site during all the sampling events, which is attributable to some inflow from tributaries, including Lava Creek (fig. 11), and possibly to groundwater discharge through the alluvium.

Dissolved-solids concentrations at the upstream site (site 6) ranged from 80 to 145 mg/L and were comparable to dissolved-solids concentrations at the downstream site (site 7), which ranged from 85 to 133 mg/L. For both sites, the samples with the lowest dissolved-solids concentrations were collected during the July sampling period. The reason for the lower dissolved-solids concentrations during July compared to June, when streamflow was higher, could not be determined; however, thunderstorms occurred during the July sampling event in the Buffalo Fork Basin that may have produced some runoff. Samples with the highest dissolved-solids concentrations were collected during November, when ground water, which has a longer contact time with material, contributes to streamflow. The range of dissolved-solids concentrations for samples from Buffalo Fork were comparable to the range of dissolved-solids concentrations for the Snake River at Moose, Wyoming (site 12).

Concentrations of the nutrient species varied in samples collected from site 6 and site 7 on the Buffalo Fork. All samples of dissolved ammonia, nitrite, and nitrate were less than the water-quality criteria for surface waters in Wyoming. The dissolved-nitrate concentrations in all eight samples were less than the median concentration of 0.087 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). Total-nitrogen concentrations in samples from site 6 in July (0.47 mg/L) and site 7 in June (2.7 mg/L) exceeded the median total-nitrogen 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 of 2.7 mg/L was the highest total-nitrogen concentration for all 39 samples collected from all the tributary sites. Phosphorus concentrations were higher in samples from the Buffalo Fork compared to the other four basins. Dissolved-orthophosphate concentrations in all eight of the samples exceeded the orthophosphate median concentration of 0.01 mg/L determined for undeveloped streams in the United States (Clark and others, 2000). Total-phosphorus concentrations for all eight samples collected from the Buffalo Fork exceeded the total-phosphorus median 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

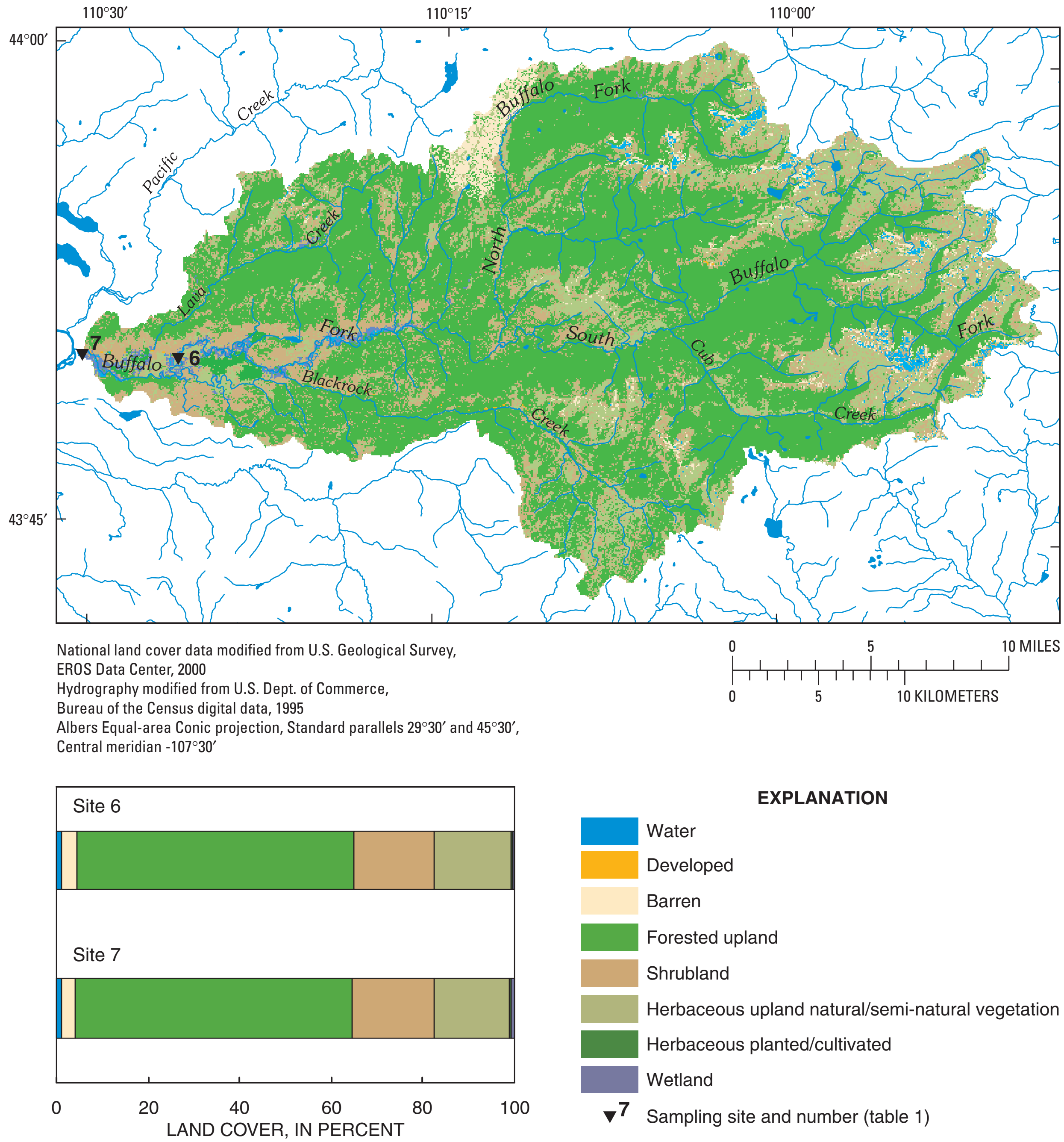

Figure 11. Distribution of land cover in the Buffalo Fork Basin, Grand Teton National Park, Wyoming.

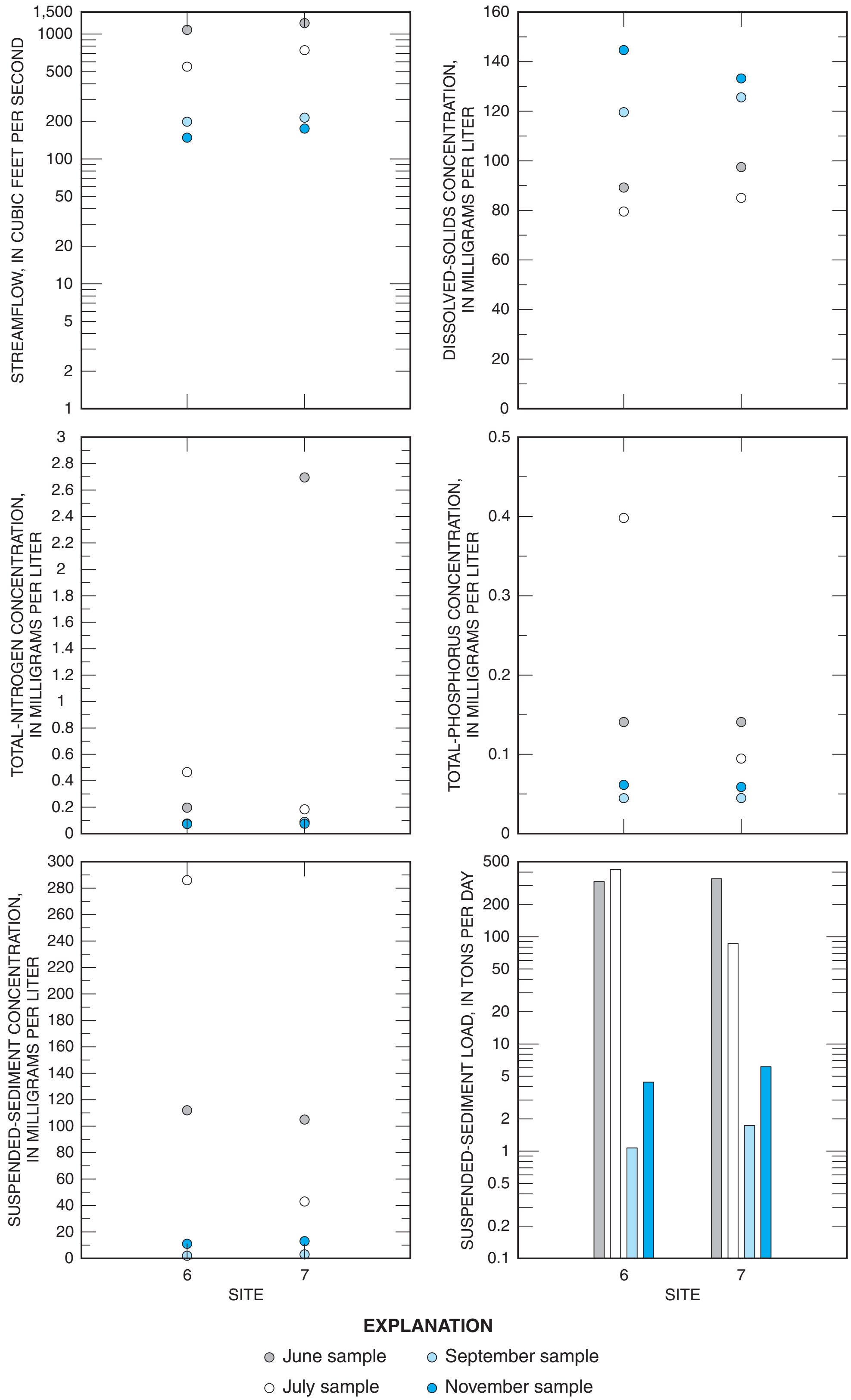

Figure 12. Streamflow and dissolved-solids, total-nitrogen, total-phosphorus, and suspended-sediment concentrations for Buffalo Fork, Grand Teton National Park, Wyoming, 2002.

Protection Agency, 2000). The total-phosphorus concentration of 0.40 mg/L in a sample collected at site 6 in July was the highest total-phosphorus concentration for all 39 samples collected from the tributary sites. The highest concentrations of total phosphorus are associated with high suspended-sediment concentrations in samples from the Buffalo Fork because phosphate sorbs to soil particles. The primary source of the phosphorus may be marine sedimentary rocks in the basin; however, developed areas and cultivated lands also may have contributed to nutrient concentrations.

Dissolved-iron and -manganese concentrations were low in the samples collected from both sites (site 6 and site 7) on the Buffalo Fork. The maximum values of dissolved iron of 10 μg/L (site 6 and site 7) and dissolved manganese of 12.8 μg/L (site 6) for the eight samples collected from Buffalo Fork were substantially less than the SMCLs of 300 μg/L and 50 μg/L, respectively. Manganese concentrations for the Buffalo Fork sites generally were higher compared to the other tributary basins. During the June sampling event for site 6 and site 7, concentrations of dissolved arsenic, cadmium, chromium, copper, nickel, selenium, and zinc (table 8) were substantially less than chronic and acute aquatic-criteria levels for all of the metals (table 3). Concentrations of trace metals in the Buffalo Fork Basin were comparable to concentrations in undeveloped basins, like Pilgrim Creek, indicating that sources of metals probably are natural in this basin.

During the June sampling event, one sample was collected from site 6 and site 7 and analyzed for 47 commonly used pesticides. All of the pesticide concentrations for both samples were less than the reporting levels for the compounds (table 2) and aquatic criteria established for surface waters in Wyoming (table 3). One pesticide, metolachlor, was detected in the sample from site 7 in June; the concentration was less than the reporting level, but was estimated to be 0.008 μg/L. Metolachlor typically is applied to row crops and along highway right-of-ways before plants emerge from the soil to control certain broadleaf and annual grassy weeds.

Suspended-sediment concentrations for Buffalo Fork (fig. 12) varied during the sampling events, and ranged from 2 mg/L in September to 286 mg/L in July at the upstream site (site 6) and from 3 mg/L in September to 105 mg/L in June at the downstream (site 7). The high suspended-sediment concentration and load (fig. 12) in the July sample from site 6 may have been contributed by runoff from isolated thunderstorms that occurred during the sampling event or from irrigation return flows. Buffalo Fork contributed the highest loads of suspended sediment to the Snake River of the five eastern tributaries.

Concentrations of fecal-coliform bacteria in samples collected from the Buffalo Fork (table 9) during the June and July sampling events ranged from 4 to 58 col/100 mL at the upstream site (site 6) and from 12 to 93 col/100 mL at the downstream (site 7), which are substantially less than the recommended limit for a single sample for recreational contact of 400 col/100 mL. The ribotype patterns of the *E. coli* isolates matched an avian source in 31 percent of the isolates (table 10). Although the Buffalo Fork Basin has the most developed land of the eastern tributary basins, a human source was matched by only 2 percent of the isolates during the study, which is similar to the results for the undeveloped basins of Pilgrim Creek and Pacific Creek.

Spread Creek

Spread Creek drains west from the Mount Leidy Highlands and the Bridger-Teton National Forest to the Snake River (fig. 1). The upstream site on Spread Creek (site 8) is in the National Forest about 1 mile upstream from the NPS boundary and is accessed by gravel road. Site 8 is immediately upstream from a small diversion dam that diverts water for irrigation to the lower basin. Site 9 is located along a major highway and about 3 miles downstream from site 8. The drainage area of the basin at site 9 is about 120 square miles, and about 80 percent of that area is upstream from site 8. The upper basin essentially is undeveloped except for some gravel roads. Over 90 percent of the land cover for both sites is forested upland, shrubland, and herbaceous upland (fig. 13); the remaining drainage area is largely barren highlands, and some wetlands and water. The basin at the downstream site on Spread Creek (site 9) drains some areas of developed land and cultivated lands, but they are less than 0.05 percent of the drainage area. A large temporary gravel mining operation was located off the stream channel between site 8 and site 9. Recreational use in the basin is common, and grazing occurs in the lower basin. The streambed at both sites is composed of unconsolidated coarse gravel and cobble, and the stream is typically braided.

Streamflow for Spread Creek varied during the sampling events, and ranged from 24 ft^3/s in November to 175 ft^3/s in June at site 8 and from 1.5 ft^3/s in September to 124 ft^3/s in June at site 9 (fig. 14). Streamflow decreased from upstream to downstream during all sampling events, primarily due to irrigation diversions during June, July, and September and possibly losses to ground water through the coarse alluvium.

Dissolved-solids concentrations at site 8 ranged from 100 to 140 mg/L and were comparable to dissolved-solids concentrations at site 9, which ranged from 103 to 156 mg/L. For both sites, the samples with the lowest dissolved-solids concentrations were collected during June, when snowmelt runoff that has a short contact time with geologic materials in the basin dilutes the base-flow chemistry. Samples with the highest dissolved-solids concentrations were collected during November at the upstream site and during September at the downstream site. Streamflow at the downstream site was lowest during September, when streamflow may still be diverted for irrigation. The minimum and maximum dissolved-solids concentrations were slightly higher in Spread Creek compared to Pilgrim Creek, Pacific Creek, and Buffalo Fork, and probably results from differences in geology that includes a larger area of Cretaceous shale and sandstone in the Spread Creek Basin (Love and others, 1972).

Concentrations of nitrogen species generally were low in samples from site 8 and site 9 on Spread Creek. All samples of

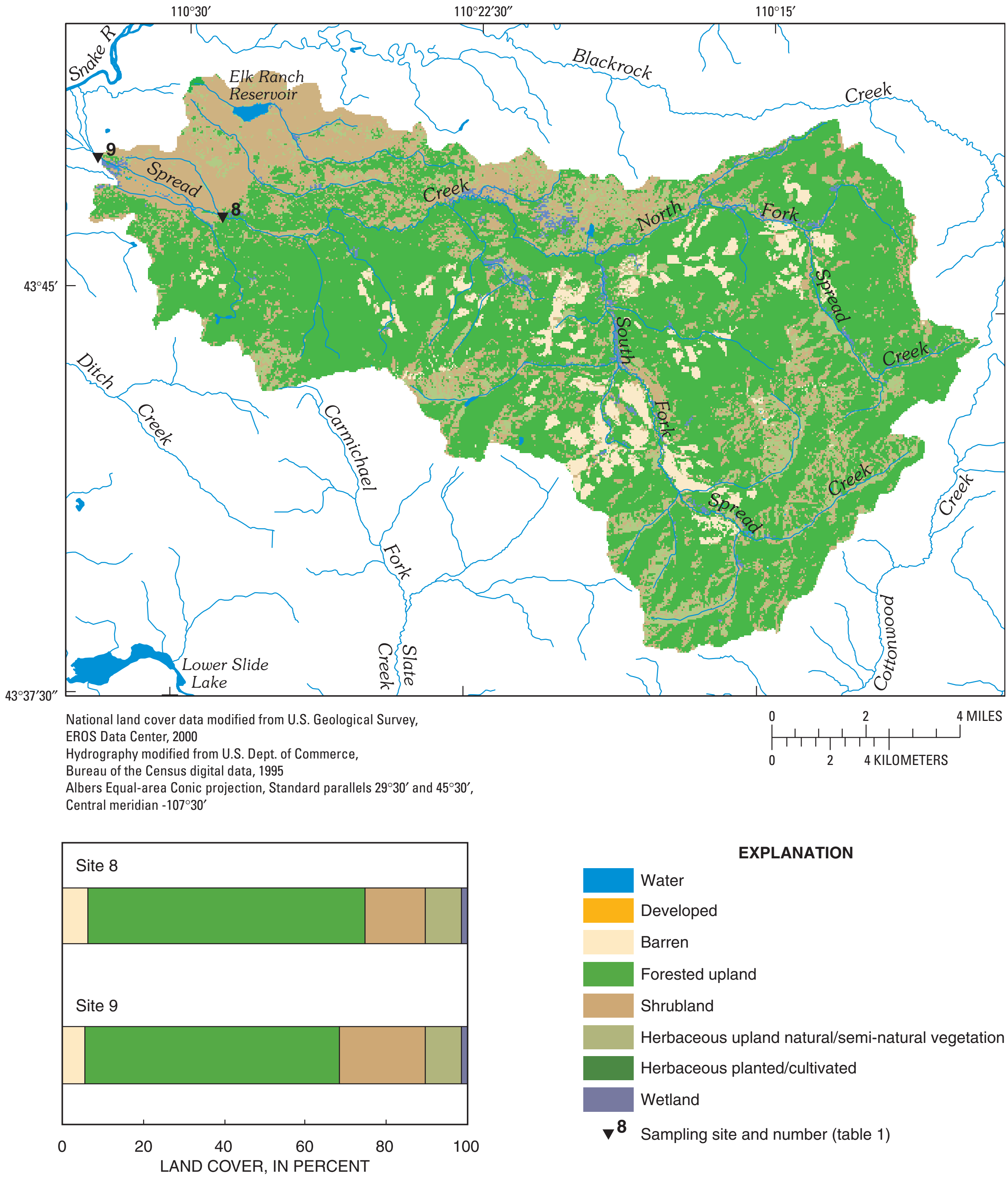

Figure 13. Distribution of land cover in the Spread Creek Basin, Grand Teton National Park, Wyoming.

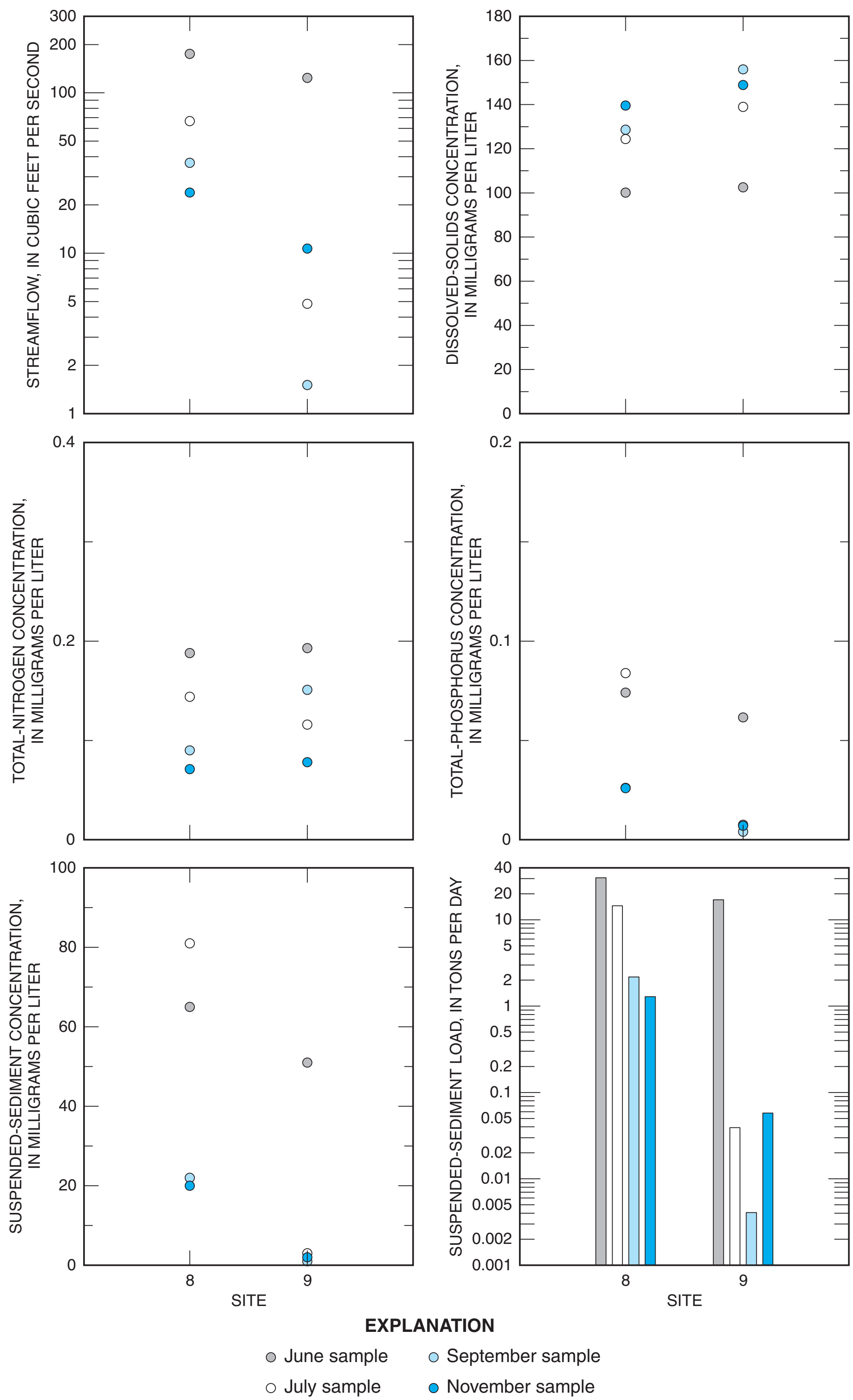

Figure 14. Streamflow and dissolved-solids, total-nitrogen, total-phosphorus, and suspended-sediment concentrations for Spread Creek, Grand Teton National Park, Wyoming, 2002.

dissolved ammonia, nitrite, and nitrate were less than the water-quality criteria for surface waters in Wyoming. Concentrations of dissolved nitrate and total nitrogen in all eight samples were less than median concentrations of 0.087 mg/L and 0.26 mg/L, respectively, 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). A study by Hall and Tank (2003) determined that Spread Creek had a higher gross primary productivity and areal nitrogen uptake rate compared to other streams they studied in Grand Teton National Park. In all four samples from site 8 and the June sample from site 9, concentrations of total phosphorus exceeded the total-phosphorus median 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). Total-phosphorus concentrations generally were higher at site 8 compared to site 9. The sources of phosphorus in Spread Creek probably are natural, because the upper basin is undeveloped.

Dissolved-iron and -manganese concentrations were low in the samples collected from the upstream site (site 8) and the downstream site (site 9) on Spread Creek. The maximum values of dissolved iron of 45 µg/L (site 8) and dissolved manganese of 5.2 µg/L (site 8) for the eight samples collected from Spread Creek were substantially less than the SMCLs of 300 µg/L and 50 µg/L, respectively. The concentrations of dissolved iron were consistently higher in the Spread Creek Basin compared to the other tributary basins. During the June sampling of site 8 and site 9, concentrations of dissolved arsenic, cadmium, chromium, copper, nickel, selenium, and zinc (table 8) were substantially less than chronic and acute aquatic-criteria levels for all of the metals (table 3). Sources of trace metals in the Spread Creek Basin most likely are natural because the basin is mostly undeveloped.

During the June sampling event, one sample was collected from site 8 and site 9 and analyzed for 47 commonly used pesticides. All of the pesticide concentrations for both samples were less than the reporting levels for the compounds (table 2) and aquatic criteria established for surface waters in Wyoming (table 3). The Spread Creek Basin has very little developed and cultivated lands where pesticides typically are applied, so the lack of any pesticide detections is consistent with the generally undeveloped conditions of the basin.

Suspended-sediment concentrations for Spread Creek varied during the sampling events, and ranged from 20 mg/L in November to 81 mg/L in July at the upstream site (site 8) and from 1 mg/L in September to 51 mg/L in June at the downstream site (site 9; fig. 14). The highest suspended-sediment loads (fig. 14) 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. Suspended-sediment concentrations were 3 mg/L or less at site 9 for three of the four samples, indicating that the off-channel gravel mining operation probably was not substantially contributing sediment to Spread Creek during the sampling events of the synoptic study.

Concentrations of fecal-coliform bacteria in samples collected from Spread Creek (table 9) during the June and July sampling events ranged from less than 1 to 32 col/100 mL at the upstream site (site 8) and from 13 to 82 col/100 mL at the downstream (site 9), which are substantially less than the recommended limit for a single sample for recreational contact of 400 col/100 mL. The ribotype patterns of the *E. coli* isolates matched deer and elk sources in 25 percent of the isolates and human sources in 6 percent of the isolates (table 10). The source for about 10 percent of the isolates for Spread Creek was unknown.

Ditch Creek

Ditch Creek is the southernmost of the tributaries that were part of the synoptic study and flows from the Mount Leidy Highlands southwest to the Snake River (fig. 1). The upstream site on Ditch Creek near Kelly, Wyoming (site 10) is in the Bridger-Teton National Forest and drains about 23 square miles. Site 10 is accessed by gravel road and is about 0.5 mile upstream from the NPS boundary. Ditch Creek near Moose, Wyoming (site 11) is about 6 miles downstream from site 10 and about 0.3 mile upstream from the confluence with the Snake River. The site is located downstream from a major highway and parking turn out for Grand Teton National Park. The drainage area at site 11 is about 62 square miles, and is the second smallest of the tributary basins. About 98 percent of the land cover for the upstream site is forested upland, shrubland, and herbaceous upland (fig. 15); most of the remaining area is wetland or barren highland. No developed or cultivated land cover exists upstream from site 10. About 87 percent of the land cover at the downstream site (site 11) is forested upland, shrubland, and herbaceous upland. Most of the remaining land cover in the lower basin is cultivated, primarily with hay meadows and some developed inholdings within Grand Teton National Park and the Bridger-Teton National Forest. Recreational use in the basin is common, and grazing occurs in the lower basin. The stream at site 10 is high gradient and the channel is composed of boulders and large cobbles. The stream at the lower site is incised and has well-embedded cobbles.

Ditch Creek contributes the least flow to the Snake River of the tributaries that were part of the synoptic study. Streamflow for Ditch Creek varied during sampling events, and ranged from 3.0 ft^3/s in November to 48 ft^3/s in June at site 10 and from no flow in November to 46 ft^3/s in June at site 11 (fig. 16). Streamflow was lower at site 11 compared to site 10 during June, September, and November, probably due to diversions and losses to ground water.

The waters of Ditch Creek were the most concentrated of the five tributaries that were part of the synoptic study. Dissolved-solids concentrations at site 10, which ranged from

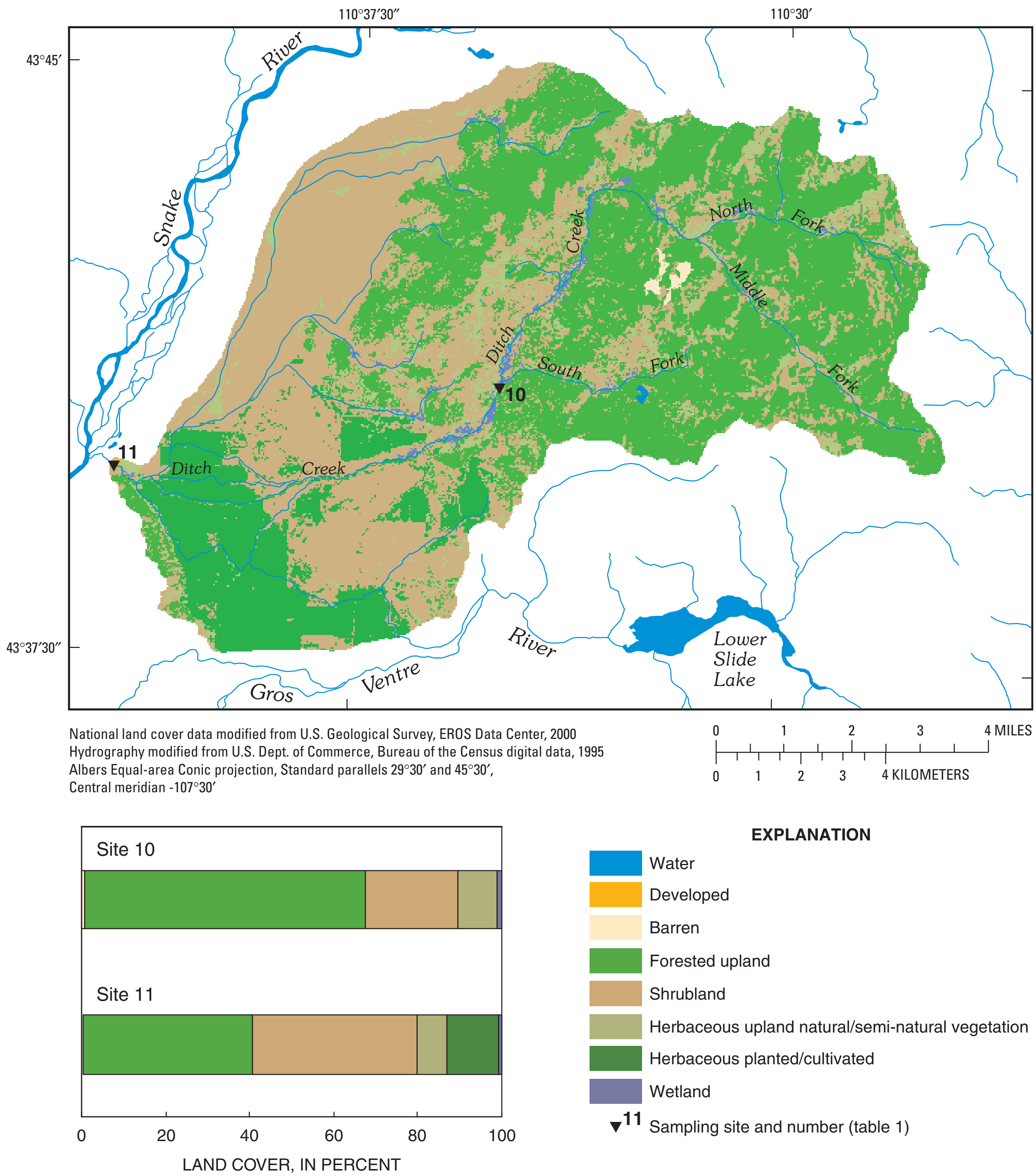

Figure 15. Distribution of land cover in the Ditch Creek Basin, Grand Teton National Park, Wyoming.

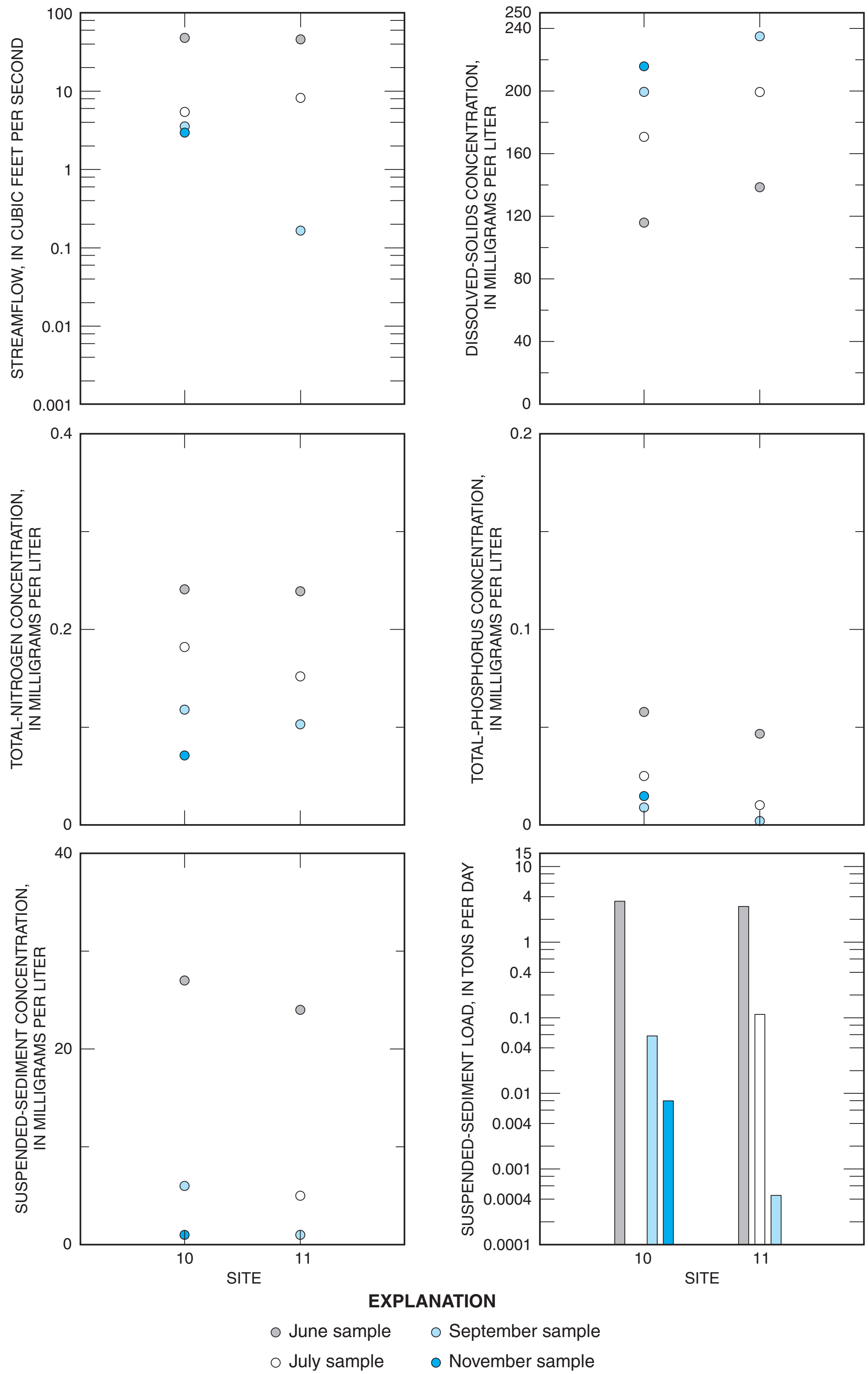

Figure 16. Streamflow and dissolved-solids, total-nitrogen, total-phosphorus, and suspended-sediment concentrations for Ditch Creek, Grand Teton National Park, Wyoming, 2002.

116 to 216 mg/L, were slightly lower than dissolved-solids concentrations at site 11, which ranged from 139 to 235 mg/L. For both sites, the samples with the lowest dissolved-solids concentrations were collected during June, when snowmelt runoff that has a shorter contact time with geologic materials in the basin dilutes the base-flow chemistry. The higher dissolved-solids concentrations, compared to the other eastern tributaries, probably are the result of differences in geology that includes a larger area of Cretaceous and Jurassic rocks, including shale, siltstone, and sandstone (Love and others, 1972). Some thermal springs that exist in the basin may contribute to the dissolved-solids concentrations. The range of dissolved-solids concentrations for samples from Ditch Creek generally were higher than the range of dissolved-solids concentrations for the Snake River at Moose, Wyoming (site 12).

All concentrations of dissolved ammonia, nitrite, and nitrate in samples from Ditch Creek were less than the water-quality criteria for surface waters in Wyoming. 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). 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). All samples of dissolved orthophosphate were less than the reporting level of 0.02 mg/L. Total-phosphorus concentrations in three samples from Ditch Creek exceeded the total-phosphorus median 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 (2000). Although Ditch Creek has the highest percentage of cultivated land cover (over 12 percent at the downstream site), nutrient concentrations generally were comparable to concentrations in samples from the undeveloped basins.

Dissolved-iron and -manganese concentrations were low in the samples collected from the upstream site (site 10) and downstream site (site 11) on Ditch Creek. The maximum values of dissolved iron of 16 μg/L (site 10) and dissolved manganese of 6.1 μg/L (site 10) for the seven samples collected from Ditch Creek were substantially less than the SMCLs of 300 μg/L and 50 μg/L, respectively. Concentrations of dissolved arsenic (1.0 μg/L at site 11), copper (0.90 μg/L at site 10), nickel (0.94 μg/L at site 10) and zinc (45 μg/L at site 10) were higher in samples collected from Ditch Creek compared to the other basins (table 8) during the June sampling event. However, concentrations of dissolved arsenic, cadmium, chromium, copper, nickel, selenium, and zinc were less than chronic and acute aquatic-criteria levels for all of the metals (table 3). The source of trace metals at site 10 probably is natural because the basin is undeveloped upstream from site 10.

During the June sampling event, one sample was collected from site 10 and site 11 and analyzed for 47 commonly used pesticides. All of the pesticide concentrations for both samples were less than the reporting levels for the compounds (table 2) and aquatic criteria established for surface waters in Wyoming (table 3). Although the Ditch Creek Basin has the highest percentage of cultivated lands, the sample from site 11 did not have any more pesticide detections than samples from sites in undeveloped basins.

Suspended-sediment concentrations for Ditch Creek varied during the sampling events, and ranged from 1 mg/L in November to 27 mg/L in June at the upstream site (site 10) and from 1 mg/L in September to 24 mg/L in June at the downstream (site 11). The highest suspended-sediment concentrations 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 sediment load to the Snake River from Ditch Creek during high flow in June (fig. 16) was the lowest from eastern tributaries that were part of synoptic study.

The samples with the highest fecal-coliform concentrations were collected from Ditch Creek (table 9). Concentrations of fecal-coliform bacteria in samples collected from Ditch Creek during the June and July sampling events ranged from 3 to 100 col/100 mL at the upstream site (site 10) and from 2 to greater than 200 col/100 mL at the downstream (site 11). The ribotype patterns of the *E. coli* isolates most frequently matched an avian source, which accounted for 35 percent of the isolates (table 10).

SUMMARY

Water-quality sampling of streams in Grand Teton National Park in the upper Snake River Basin has been conducted by the U.S. Geological Survey in cooperation with the National Park Service to meet various objectives of the National Park Service. Routine sampling of the Snake River was conducted during water years 1998-2002 to monitor the water quality of the Snake River through time. In addition, a synoptic study was conducted during 2002 on five eastern tributaries to the Snake River—Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek. Samples from the Snake River and the five tributaries were collected and analyzed for field measurements, major ions and dissolved solids, nutrients, selected trace metals, pesticides, and suspended sediment. In addition, the eastern tributaries were sampled for fecal-indicator bacteria by the National Park Service during the synoptic study.

Water-quality characteristics are summarized for two sites on the Snake River for water years 1998-2002 and for two sites on each of five eastern tributaries for the synoptic study in 2002. Data from routine monitoring at sites on the Snake River in Grand Teton National Park during water years 1998-2002 indicate that stream-water quality generally is of good quality. Differences in water quality primarily were in response to natural differences in geology and variations in precipitation. Stream-

flow during water years 1998-2002 for the Snake River ranged from above normal to below normal in response to variations in precipitation. Water types for the Snake River ranged from sodium bicarbonate at the upstream site above Jackson Lake to calcium carbonate at the downstream site near Moose, Wyoming. Dissolved-solids concentrations in 43 samples from the upstream site on the Snake River ranged from 62 to 240 milligrams per liter and were significantly higher (p-value<0.001) than dissolved-solids concentrations in 33 samples from the downstream site, which ranged from 77 to 141 milligrams per liter. Geothermal waters from Yellowstone National Park and differences in geology probably are the source of the differences in major-ion chemistry.

Concentrations of nutrients generally were low in samples collected from the Snake River. Concentrations of dissolved ammonia, nitrite, and nitrate in all samples collected from the Snake River during water years 1998-2002 were less than the water-quality criteria for surface waters in Wyoming. The median concentrations of nitrate at both the upstream site (<0.05 milligram per liter) and downstream site (<0.05 milligram per liter) on the Snake River were less than the median concentration of 0.087 milligram per liter determined for undeveloped streams in the United States; however, total-nitrogen and total-phosphorus concentrations in some samples from the Snake River did exceed the ambient criteria of 0.34 milligram per liter and 0.015 milligram per liter, respectively, that are recommended for forested mountain streams in the Middle Rockies ecoregion by the U.S. Environmental Protection Agency to address cultural eutrophication. Sources for the excess nitrogen and phosphorus probably are natural because these basins have little development and cultivation; however, a few anthropogenic sources, such as campgrounds, septic systems, and cultivated lands, do exist in the basins.

Concentrations of trace metals and pesticides were low in samples collected from the Snake River. The maximum dissolved-iron concentration for all Snake River samples (38 micrograms per liter) was substantially less than the Secondary Maximum Contaminant Level of 300 micrograms per liter. The maximum dissolved-manganese concentration (9.3 micrograms per liter) also was substantially less than the Secondary Maximum Contaminant Level of 50 micrograms per liter. Concentrations of all analyzed pesticides were less than the reporting level in 27 samples from the Snake River. Five samples from the Snake River had detectable concentrations of the pesticides atrazine, EPTC, dieldrin, and tebuthiuron. Concentrations of all of the detectable pesticides were 0.003 microgram per liter or less.

Suspended-sediment concentrations in 43 samples from the upstream site on the Snake River ranged from 1 to 604 milligrams per liter and were comparable to suspended-sediment concentrations in 33 samples from the downstream site, which ranged from 1 to 648 milligrams per liter. Concentrations of suspended sediment generally were highest in samples collected during late spring and lowest in samples collected during the fall in response to variations in streamflow.

Data from a synoptic study during 2002 in the upper Snake River Basin indicate that stream water of five eastern tributaries to the Snake River generally is of good quality. The water type of Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek was calcium bicarbonate. Concentrations of dissolved solids ranged from 75 milligrams per liter in a sample from Pilgrim Creek to 235 milligrams per liter in a sample from Ditch Creek. Differences in dissolved-solids concentrations between sites probably are due to differences in geology in the basins. Seasonal variations in dissolved-solids concentrations also occurred as a result of variations in streamflow.

Concentrations of nutrients generally were low in samples collected from the five eastern tributary streams. Concentrations of dissolved ammonia, nitrite, and nitrate in all samples collected from the synoptic study during 2002 were less than the water-quality criteria for surface waters in Wyoming. Concentrations of nitrate in all 39 samples collected during the synoptic study were less than the median concentration of 0.087 milligram per liter determined for undeveloped streams in the United States. Total-nitrogen and total-phosphorus concentrations in some samples from the tributaries exceeded the ambient criteria of 0.34 milligram per liter and 0.015 milligram per liter, respectively, that are recommended for forested mountain streams in the Middle Rockies ecoregion by the U.S. Environmental Protection Agency. Generally, sources for the excess nitrogen and phosphorus probably are natural because these basins have little development and cultivation; however, a few anthropogenic sources, such as campgrounds, septic systems, and cultivated lands, do exist in the basins.

Concentrations of trace metals and pesticides were low in samples collected from Pilgrim Creek, Pacific Creek, Buffalo Fork, Spread Creek, and Ditch Creek. The maximum dissolved-iron concentration for all tributary synoptic study samples was 45 micrograms per liter, which is substantially less than the Secondary Maximum Contaminant Level of 300 micrograms per liter. The maximum dissolved-manganese concentration for all tributary synoptic study samples was 12.8 micrograms per liter, which is substantially less than the Secondary Maximum Contaminant Level of 50 micrograms per liter. Concentrations of dissolved arsenic, cadmium, chromium, copper, nickel, selenium, and zinc in tributary samples collected during June 2002 as part of the synoptic study were less than the aquatic criteria established for these metals for surface waters in Wyoming. Of the 47 pesticides that were analyzed in 10 samples from the tributary sites, only metolachlor was detected in one sample from the Buffalo Fork at a concentration of 0.008 microgram per liter.

Suspended-sediment concentrations ranged from 1 milligram per liter for samples collected from Pilgrim Creek, Pacific Creek, Spread Creek and Ditch Creek to 286 milligrams per liter for a sample collected from Buffalo Fork. Suspended-sediment concentrations generally were comparable between upstream and downstream sites on the tributaries. Concentrations of suspended sediment generally were highest in samples collected during late spring and lowest in samples collected during the fall in response to variations in streamflow.

Concentrations of fecal coliform in samples collected from the eastern tributary streams ranged from less than 1 colony per 100 milliliters in a sample collected from Spread Creek to greater than 200 colonies per 100 milliliters in a sample collected from Ditch Creek. A microbial source-tracking method determined that ribotype patterns for *Escherichia coli* isolates generally were matched to wildlife sources. Avian sources were the dominant match in three of the basins and accounted for 32 percent of the isolates from Pilgrim Creek, 31 percent of the isolates from the Buffalo Fork, and 35 percent of the isolates from Ditch Creek. Bovine sources were the dominant match in Pacific Creek and accounted for 24 percent of the isolates. Deer and elk sources were the dominant match in Spread Creek and accounted for 25 percent of the isolates. Human sources were matched in 6 percent or less of the isolates for each basin.

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