U.S. Department of the Interior
U.S. Geological Survey

Prepared in cooperation with
U.S. Forest Service and Bureau of Land Management

Quantification of Metal Loads and Assessment of Metal Sources in Upper Beaver Creek Watershed, Shoshone County, Idaho, May and June 2002

Water-Resources Investigations Report 03–4206

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By Douglas S. Ott *and* David W. Clark

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CONVERSION FACTORS, OTHER ABBREVIATED UNITS, AND VERTICAL DATUM

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
inch (in.)	2.540	centimeter (cm)
mile (mi)	1.609	kilometer (km)

Temperature is given in degrees Celsius (°C), which may be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F=(1.8)\ (°C)+32$$

Other abbreviated units:

L	liter
µg/L	microgram per liter
µm	micrometer
µg/s	microgram per second
mg/L	milligram per liter

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Quantification of Metal Loads and Assessment of Metal Sources in Upper Beaver Creek Watershed, Shoshone County, Idaho, May and June 2002

By Douglas S. Ott *and* David W. Clark

Abstract

Abandoned mine lands contribute to significant water-quality degradation in the Beaver Creek watershed in northern Idaho. Streams in this watershed drain the northern flank of the Coeur d'Alene mining district, one of the world's largest producers of silver and one of the country's major historical producers of lead and zinc for more than 100 years. Effective cleanup of these streams will depend on accurate characterization of metal concentrations in streams and various sources of these metals.

Cadmium, lead, and zinc loads entering Beaver Creek and its major tributary, Carbon Creek, were quantified, and source areas for these metals were assessed during May and June 2002. Metal loads were calculated for main-stem and surface-inflow sites by combining measured streamflow with dissolved cadmium, lead, and zinc concentrations analyzed in water-quality samples collected during three synoptic sampling events. To assess the effects of surface and shallow subsurface inflows on the gain or loss of streamflow and metal loads, Beaver and Carbon Creeks were divided into subreaches. Four subreaches were defined on Beaver Creek using five main-stem sampling sites (UBC3, UBC5, UBC8, BC10, and BC14); two subreaches were defined on Carbon Creek using three main-stem sampling sites (CC2, CC6, and CC9).

During each of the synoptic sampling events, concentrations of cadmium and zinc were highest in samples collected at the Carlisle Mine adit between sites CC2 and CC6. During two of the three synoptic sampling events, the concentration of lead was highest in samples collected from a left-bank seep downgradient from the Idora Mill between sites UBC3 and UBC5.

The largest identified cadmium and zinc source to Beaver Creek is the surface inflow from Carbon Creek (between sites UBC8 and BC10), which accounted for 45 to 72 percent of the main-stem cadmium load and 49 to 89 percent of the main-stem zinc load in Beaver Creek. Another large source of cadmium and zinc to Beaver Creek is subsurface flow through the tiered flotation tailings pile near Carbon Center (between sites BC10 and BC14) into Beaver Creek.

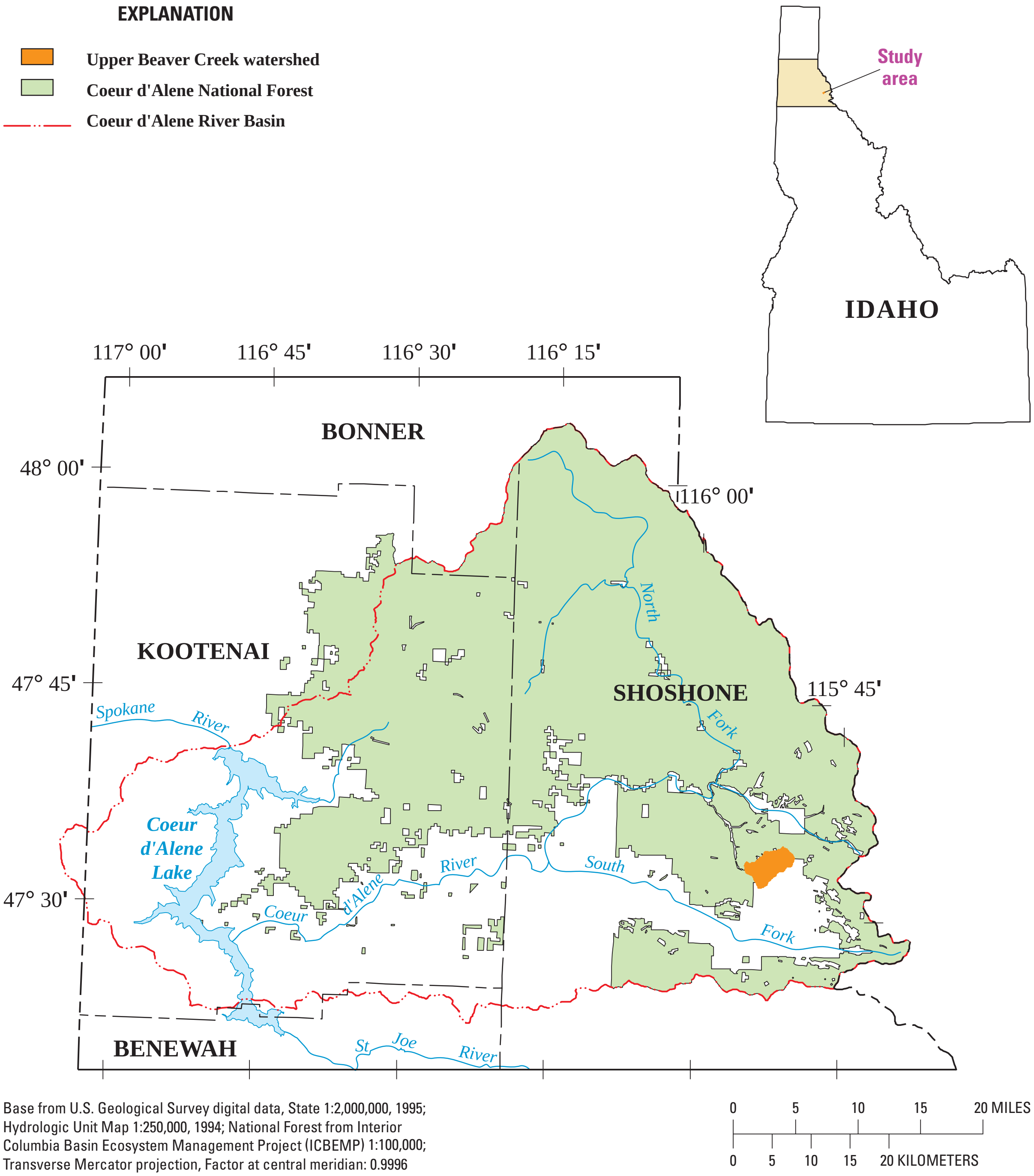
Amounts of lead contributed by source areas to Beaver Creek vary with streamflow conditions. During high streamflow, the largest source of lead to Beaver Creek is the remobilization of fine-grained (less than 0.45-micrometer), lead-enriched particulates from the streambed throughout the study area. During low streamflow, bank seepage of subsurface water into Beaver Creek in the subreach downgradient from the Idora Mill (between sites UBC3 and UBC5) is the major source of lead to Beaver Creek. During each synoptic sampling event, Carbon Creek is a major source of lead to Beaver Creek.

The Carlisle Mine adit (between CC2 and CC6) is the largest source of cadmium and zinc to Carbon Creek and, ultimately, to Beaver Creek, and accounted for 57 to 88 percent of the total main-stem cadmium load and 56 to 88 percent of the total main-stem zinc load in Carbon Creek during each of the synoptic sampling events. Another source of cadmium and zinc to Carbon Creek is resurfacing cadmium- and zinc-enriched hyporheic flow (possibly originating from the Carlisle adit or the Carlisle Mill) between sites CC6 and CC9.

As in Beaver Creek, amounts of lead contributed to Carbon Creek by source areas vary with streamflow conditions. During high streamflows, increased discharge from the Carlisle Mine adit appears to be the largest source of lead to Carbon Creek; during low streamflows, resurfacing lead-enriched hyporheic flow appears to be the major source of lead to Carbon Creek.

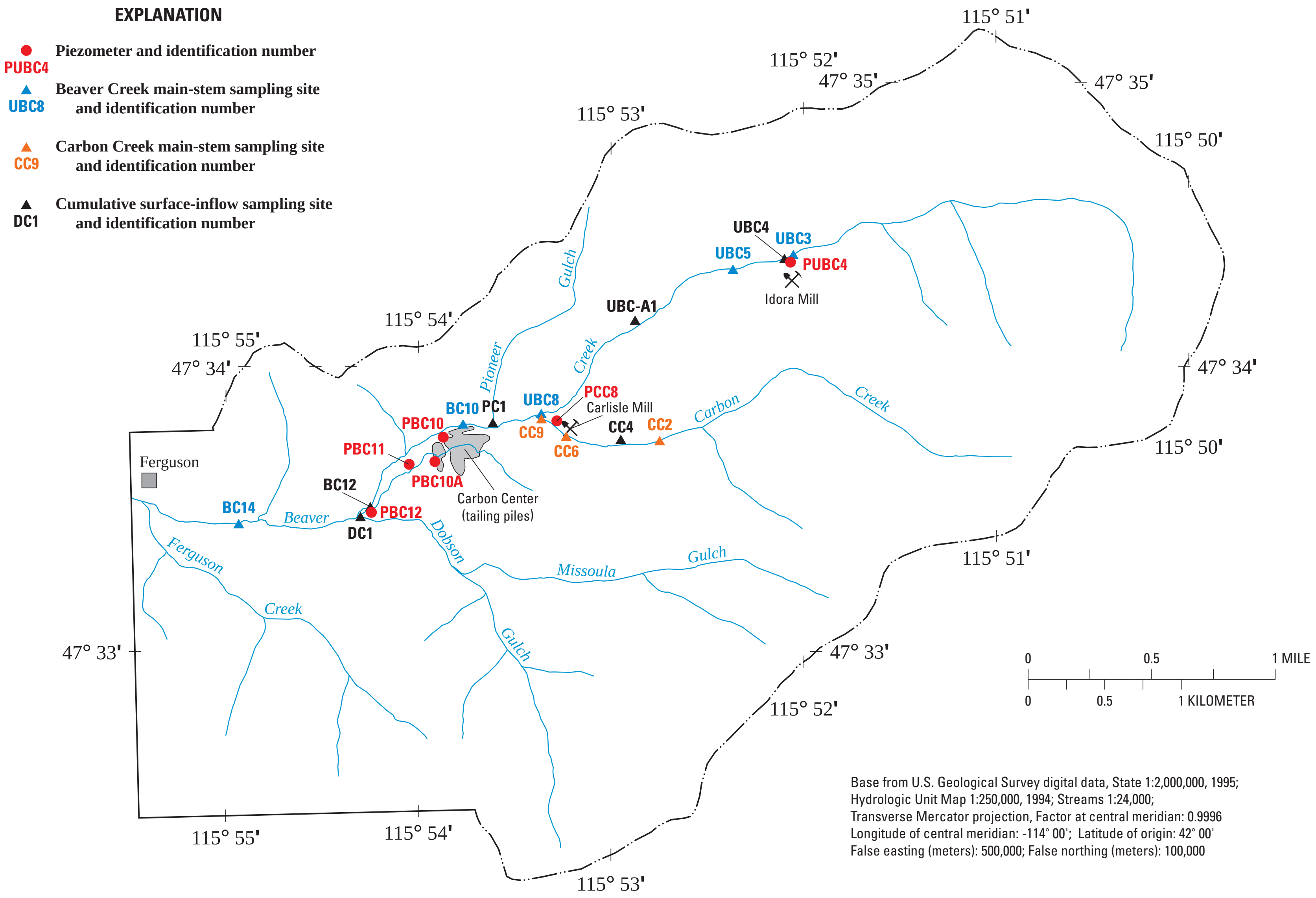
INTRODUCTION

The upper Beaver Creek watershed (figs. 1 and 2), located in the Coeur d'Alene River Basin in north Idaho, drains the northern flank of the famed Coeur



Base from U.S. Geological Survey digital data, State 1:2,000,000, 1995;
Hydrologic Unit Map 1:250,000, 1994; National Forest from Interior
Columbia Basin Ecosystem Management Project (ICBEMP) 1:100,000;
Transverse Mercator projection, Factor at central meridian: 0.9996
Longitude of central meridian: -114° 00'; Latitude of origin: 42° 00'
False easting (meters): 500,000; False northing (meters): 100,000

Figure 1. Location of Coeur d'Alene River Basin, Coeur d'Alene National Forest, and study area in upper Beaver Creek watershed, Shoshone County, Idaho.



Base from U.S. Geological Survey digital data, State 1:2,000,000, 1995;
Hydrologic Unit Map 1:250,000, 1994; Streams 1:24,000;
Transverse Mercator projection, Factor at central meridian: 0.9996
Longitude of central meridian: -114° 00'; Latitude of origin: 42° 00'
False easting (meters): 500,000; False northing (meters): 100,000

Figure 2. Location of synoptic sampling sites and selected mining structures in upper Beaver Creek watershed, Shoshone County, Idaho.

d’Alene mining district. From the late 1800s to the early 1980s, the district was one of the world’s largest producers of silver and one of the Nation’s major producers of lead and zinc. Mining activities over more than 100 years make abandoned and inactive mines, mining-related structures, and mine wastes and tailings a common sight throughout the district, as well as in the upper Beaver Creek watershed. These past mining activities have contributed significantly to the degradation of water quality, aquatic biological, and hydrological conditions throughout the entire Coeur d’Alene River Basin (Horowitz and others, 1995; Woods and Beckwith, 1997; Maret and MacCoy, 2002). Currently, U.S. Environmental Protection Agency Superfund investigations are underway throughout the Coeur d’Alene River Basin, and the U.S. Department of the Interior is conducting Natural Resource Damage Assessments and Abandoned Mine Lands (AML) monitoring and remediation in the basin. Remediation and cleanup actions require an accurate characterization of metal sources. Although many potential metal sources are known to exist in the upper Beaver Creek watershed, information was needed to sufficiently quantify metal inputs to the stream.

Metal-loading studies by Cleasby and others (2000) and Nimick and Cleasby (2001) conducted in Montana streams have been useful for characterizing water quality and identifying metal source areas and pathways in historical mining areas. In these studies, streamflow data and metal-concentration data, collected at sites along a stream bracketing potential metal source areas, were used to create downstream profiles of metal loads. Downstream changes in metal load were attributed to influent sources along the stream, such as surface and subsurface inflows, or to instream geochemical reactions. By comparing loads among many sites, the relative magnitude of metal inputs to a stream from individual source areas was determined. Similar methods were used during this study to quantify metal loading in the upper Beaver Creek watershed.

Purpose and Scope

The purpose of this report is to present the results of a metal-loading study conducted in upper Beaver Creek and Carbon Creek (a major tributary to Beaver Creek) in Shoshone County during May and June 2002. The results describe the streamflow and water quality in Beaver and Carbon Creeks, quantify metal loads entering Beaver and Carbon Creeks, and identify the predominant metal sources. Study results will assist resource managers in planning and conducting effective remediation efforts.

Description of Study Area

The study area comprised Beaver Creek, from a point just upstream from the Idora Mill downstream to the bridge crossing near Ferguson, and Carbon Creek, the largest tributary to Beaver Creek in the study area, from a point just upstream from the Carlisle Mine adit to the confluence with Beaver Creek (figs. 1 and 2).

The headwaters of Beaver Creek originate in the Coeur d’Alene National Forest and the Coeur d’Alene mining district at an altitude of about 5,250 ft above sea level. Beaver Creek is about 12 mi long and flows southwest toward the town of Ferguson, at which point it turns and flows to the northwest into the North Fork Coeur d’Alene River at an altitude of about 2,450 ft. At its headwaters, Beaver Creek is a steep, high-gradient, cascading mountain stream. The streambed in these upper reaches is composed mostly of cobbles and boulders. Just downstream from Carbon Creek, the valley broadens and the topography flattens. The streambed in these lower reaches is a mixture of gravel, cobbles, and boulders. During base flow, streamflow in different reaches throughout the watershed flows below the streambed substrate (hyporheic flow).

The upper Beaver Creek watershed contains several mineshafts and adits, at least two ore mill sites (the Idora Mill on Beaver Creek and the Carlisle Mill on Carbon Creek) and numerous tailings piles (fig. 2). Several unnamed adits are located along the right streambank of Beaver Creek downstream from the Idora Mill. The Carlisle Mine adit is the largest adit in the study area and is located just upstream from the Carlisle Mill on Carbon Creek. Discharge from this adit flows directly into Carbon Creek and appears to be continuous. Field observations during base flow indicate that the adit contributes a substantial amount of the total streamflow in Carbon Creek.

Historically, metal extraction and processing in the Beaver Creek watershed were relatively inefficient, yielding large volumes of metal-rich tailings that were deposited around the mill sites and in the streams. Beaver and Carbon Creeks, during high streamflow, cut through these tailings and transported them downstream, causing aggradation of the stream channel, which is still evident throughout much of the study area.

In the 1940s, an effort was made to move tailings to a central location near Carbon Center (fig. 2), where tailings were deposited in the channel of a small, perennial tributary to Beaver Creek. This large, three-tiered tailings pile parallels Beaver Creek for approximately 800 ft and is within 25 ft of the left streambank. During periods of runoff, streamflow from the unnamed tributary flows onto the tailings pile, where it pools and subsequently seeps downward through the tailings. The original tributary channel is still visible below the tailings pile and enters the main channel of Beaver Creek just upstream from the confluence with Dobson Gulch (fig. 2). Several seeps originate along the length of the tributary channel and contribute a small amount of surface inflow to Beaver Creek.

Acknowledgments

The authors acknowledge with appreciation the many individuals who assisted in this study. The authors thank Ray TeSoro of the U.S. Department of Agriculture, Forest Service (USFS), and Steve Box of the U.S. Geological Survey (USGS) for sharing their knowledge of the study area. Appreciation is extended to Rick L. Backsen, H. Russ Christensen, Sabrina A. Conti, John O. Gralow, Keith L. Hein, and Kevin F. Kirlin of the USGS for assistance in collecting and processing data during this study. The USFS and the Bureau of Land Management (BLM) provided funding for this study.

DATA COLLECTION METHODS

Site Selection

Sampling sites were selected to bracket possible areas of metal sources such as tributary inflows, ground-water seeps, mine adits, mill sites, and tailings or waste-rock piles. Three synoptic sampling events were conducted during spring 2002 to represent different hydrologic conditions. Synoptic samples are those collected in a short amount of time to reduce the effect of chemical changes caused by diel variations in stream-flow. The first synoptic sampling event (S1) was conducted on May 9 and consisted of 8 main-stem sites and 4 surface-inflow sites. The second synoptic sampling event (S2) was conducted during May 21–23 and consisted of 8 main-stem sites, 4 surface-inflow sites, and 6 shallow subsurface sites. The third synoptic sampling event (S3) was conducted during June 17–18 and consisted of 8 main-stem sites, 3 surface-inflow sites, and 4 shallow subsurface sites.

Streamflow

Conventional methods of measuring channel cross-sectional area and flow velocity were used to determine streamflow (Rantz and others, 1982) at all sites except UBC–A1 and UBC4, which lacked sufficient depth and velocity needed to determine streamflow. A standard type AA or pygmy current meter attached to a top-setting, graduated wading rod was used to measure velocity and channel depth. Streamflow measurements were used to determine the streamflow gain or loss between surface-water sampling sites and, in conjunction with water-quality data, were used to calculate instantaneous metal loads at bracketed sampling sites. Streamflow data are presented in table 1 (back of report).

Subsurface Flow

Shallow piezometers were installed to determine the chemical quality of subsurface flow at several points within the study area. Piezometers were constructed from 0.75-in.-diameter stainless steel casing that was pinched shut at one end to create a driving point and capped at the other end. Above the driving point, a series of 0.125-in.-diameter holes were drilled into the casing to allow water to flow into the piezometer. After an area of possible subsurface flow was selected, a piezometer was installed into the ground by using a fencepost driver. Water from the piezometer was purged with a peristaltic pump, equipped with acid-washed tygon tubing, until the purged water was clear. After the well was allowed to recover, the water level was measured. Water-level measurements are presented in table 1.

Synoptic Water-Quality Sampling

Synoptic water samples for chemical analysis were collected from main-stem sites, inflows, and piezometers. Two sampling crews collected samples in downstream order. One crew began at the upstream end of Beaver Creek; the other crew began at the upstream end of Carbon Creek. At the confluence of these two creeks, the crews collected samples at alternate sites toward the downstream end of the study area. All samples were processed onsite.

Surface-water samples were collected in acid-washed, 3-L, polyethylene bottles at a single vertical near midstream. Care was taken to disrupt the streambed as little as possible between the sampling sites. Values of specific conductance and pH were determined onsite using an unfiltered aliquot of sample water. Alkalinity was determined onsite using a second aliquot of sample water. Water temperature was measured instream. Samples for analysis of major ions and trace elements were filtered through a 0.45-μm capsule filter preconditioned with deionized water. Aliquots for analysis of dissolved trace-element concentrations were preserved with ultra-pure nitric acid to a pH of less than 2.

Subsurface-water samples from piezometers were collected using a peristaltic pump, equipped with acid-washed tygon tubing, to purge the volume of standing water until onsite measurements of water temperature, pH, and specific conductance stabilized and values were recorded. Alkalinity, major ions, and trace elements were analyzed using the same procedures and equipment as for surface-water samples.

Samples were processed, filtered, preserved, and shipped according to procedures outlined by Wilde and Radtke (1998) and Wilde and others (1999). Water samples were analyzed by the USGS Geologic Division Laboratory using methods described by Taggart (2002). Minimum reporting levels for major ion, nutrient, and trace-element concentrations are listed in table 2. Selected water-quality data are presented in table 1.

Table 2. Minimum reporting level of major ion, nutrient, and trace-element concentrations analyzed in water-quality samples from upper Beaver Creek watershed, Shoshone County, Idaho, May and June 2002

[mg/L, milligrams per liter; μg/L, micrograms per liter]

Constituent	Minimum reporting level	Constituent	Minimum reporting level	Constituent	Minimum reporting level	Constituent	Minimum reporting level
Calcium, mg/L	0.05	Arsenic, μg/L	1	Iron, μg/L	50	Strontium, μg/L	0.5
Magnesium, mg/L	.01	Barium, μg/L	.1	Lanthanum, μg/L	.01	Thallium, μg/L	.05
Sodium, mg/L	.01	Beryllium, μg/L	.05	Lead, μg/L	.05	Thorium, μg/L	.005
Potassium, mg/L	.03	Bismuth, μg/L	.005	Lithium, μg/L	.1	Titanium, μg/L	.1
Chloride, mg/L	.08	Cadmium, μg/L	.02	Manganese, μg/L	.01	Uranium, μg/L	.005
Sulfate, mg/L	1.6	Cerium, μg/L	.01	Molybdenum, μg/L	.2	Vanadium, μg/L	.1
Fluoride, mg/L	.08	Cesium, μg/L	.01	Nickel, μg/L	.1	Ytterbium, μg/L	.01
Silica, mg/L	.2	Chromium, μg/L	1	Niobium, μg/L	.02	Zinc, μg/L	.5
Nitrate, mg/L	.08	Cobalt, μg/L	.02	Rubidium, μg/L	.01	Zirconium, μg/L	.05
Phosphorus, mg/L	.01	Copper, μg/L	.5	Scandium, μg/L	.1		
Aluminum, μg/L	.1	Gallium, μg/L	.02	Selenium, μg/L	1		
Antimony, μg/L	.1	Germanium, μg/L	.02	Silver, μg/L	3		

Quality Assurance

Quality assurance data to document possible sample contamination and reproducibility of analytical results consisted of field equipment blank samples and sequential replicate environmental samples (considered to be essentially identical in composition). To assess possible contamination from sampling and processing equipment, pre- and post-sample field equipment blank samples were collected and analyzed for major ion, nutrient, and trace-element concentrations (table 1). Water used for each blank was certified free of inorganic constituents and was passed through the same field equipment that was used to collect and process the environmental samples. Constituent concentrations in the blanks were all less than the minimum reporting level (MRL), with the exception of a zinc value (0.9 µg/L), which was about two times the MRL. A zinc concentration larger than the MRL indicates zinc contamination in the blank sample; however, the amount is small compared with zinc concentrations in nearly all the environmental samples. Analytical results for the field equipment blank samples are presented in table 1.

Two sets of replicates were collected for this study; one set at BC10 and one set at PBC11 (table 1). Precision of analytical results for a constituent can be described by calculating the relative percent difference (RPD) of the concentration in replicate sample analyses. The RPD is computed as the absolute value of the difference in concentration between the two replicates, divided by the mean concentration of the two replicates, the quotient of which is multiplied by 100. RPD values for constituents in the replicate samples were all less than 10 percent, with the exception of chloride in the surface-water replicate sample and fluoride in the subsurface-water replicate sample, indicating good overall precision of the analytical results. The RPD for chloride in the surface-water sample (BC10) was 33 percent and, for fluoride in the subsurface replicate sample (PBC11), was 50 percent. These results indicate that the precision for chloride and fluoride was

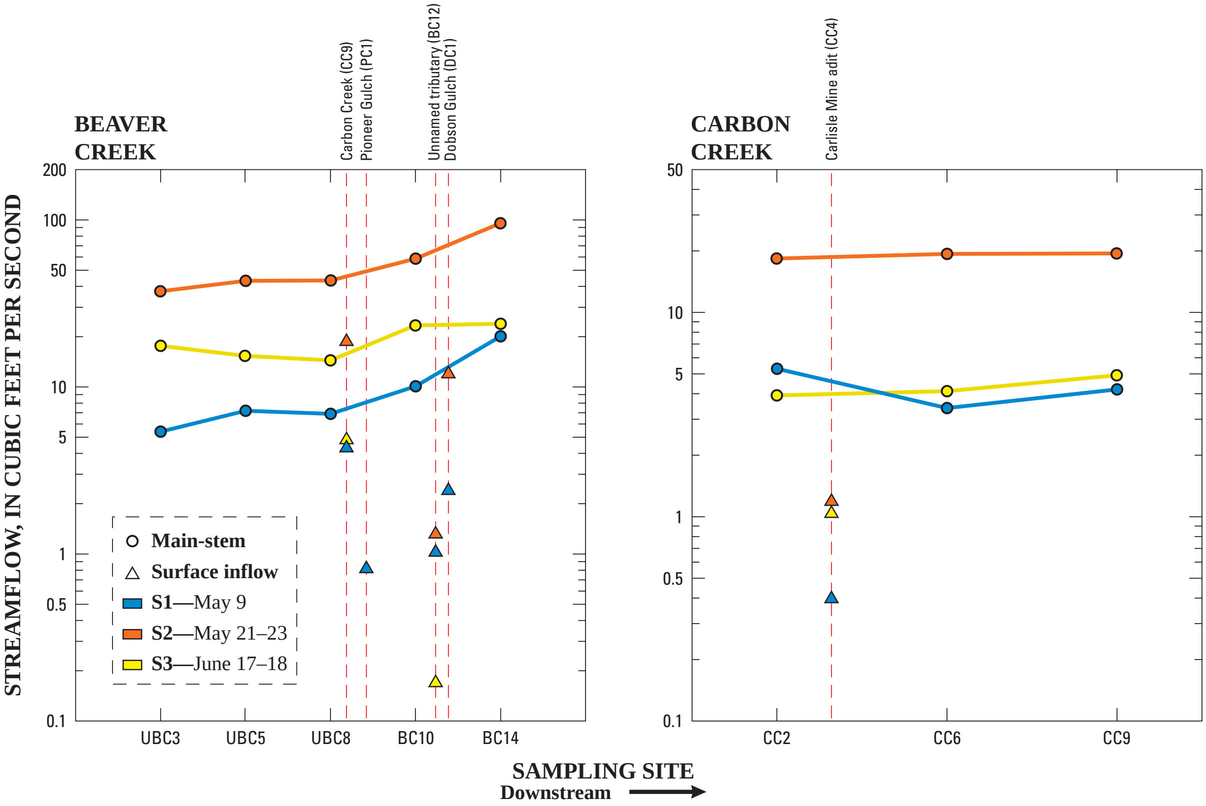


Figure 3. Instantaneous streamflow at sampling sites in upper Beaver Creek and Carbon Creek watersheds, Shoshone County, Idaho, May and June 2002.

poor and that the samples were affected by variability in the sample collection, laboratory imprecision, or both. Analytical results for replicate samples are presented in table 1.

STREAMFLOW

Streamflow during S1 and S3 was low and stable with little change in flow during sample collection (fig. 3). Streamflow measured at the downstream main-stem sampling site (BC14) before and after surface-water sampling increased by 4.1 and 7.3 percent during S1 and S3, respectively (table 1). S2 was conducted during a precipitation event, and streamflow was high and rising. Streamflow increased 53 percent during sample collection as a result of heavy rainfall in the watershed prior to and during S2.

To identify areas that gain or lose streamflow, Carbon and Beaver Creeks were divided into subreaches, and streamflow was quantified within each subreach (figs. 4 and 5). Four subreaches were defined on Beaver Creek using five main-stem sites (UBC3, UBC5, UBC8, BC10, and BC14) that were sampled during S1, S2, and S3 (fig. 4). Two subreaches were defined on Carbon Creek using three main-stem sites (CC2, CC6, and CC9) that were sampled during S1, S2, and S3 (fig. 5). Streamflow gains or losses were determined as the net difference in streamflow between the farthest upstream and downstream sites of each subreach and were calculated by subtracting the streamflow at the farthest upstream site, plus any measured surface inflow, from the streamflow at the farthest downstream site. Consequently, a subreach can be identified as a losing subreach, even though streamflow might increase between the upstream and downstream sites. For example, at subreach UBC8 to BC10 during S2 (fig. 4), the measured streamflow at the upstream site (UBC8) was 43.4 ft^3/s, measured surface inflow (CC9) was 19.4 ft^3/s, and measured streamflow at the downstream site (BC10) was 58.7 ft^3/s. Even though there was an increase of 15.3 ft^3/s between the upstream and downstream sites, the subreach would be identified as a losing subreach (−4.1 ft^3/s). In this example, the 4.1-ft^3/s streamflow loss between sites UBC8 and BC10 was an unaccounted loss of streamflow. Gains are assumed to be attributable to overland surface runoff, subsurface inflow, and unsampled seeps; losses are assumed to be attributable to hyporheic flow and ground-water recharge.

Synoptic Sampling Event S1

Synoptic sampling event S1 was conducted during low streamflow on May 9, 2002. During S1, streamflow in Beaver Creek increased by 14.7 ft^3/s between upstream sampling site UBC3 and downstream sampling site BC14 (fig. 3; table 1). Four measured surface inflows (CC9, PC1, BC12, and DC1) accounted for about half (7.7 ft^3/s) of this increase, leaving 7.0 ft^3/s (48 percent) of the increase attributable to unsampled seeps and subsurface flow.

Of the four defined subreaches in Beaver Creek, streamflow increased in two of the subreaches and decreased in the other two subreaches during S1 (fig. 4). In subreach UBC3 to UBC5, streamflow increased 1.8 ft^3/s. Streamflow loss in subreach UBC5 to UBC8 was negligible (0.3 ft^3/s). Streamflow increased in subreach UBC8 to BC10 by 3.2 ft^3/s; however, surface inflows CC9 (4.2 ft^3/s) and PC1 (0.1 ft^3/s) contributed an amount of flow (4.3 ft^3/s) that was larger than this increase, which indicates that UBC8 to BC10 was a losing subreach (fig. 4). Streamflow increased in subreach BC10 to BC14 by 10 ft^3/s; surface inflows BC12 (1.0 ft^3/s) and DC1 (2.4 ft^3/s) contributed 3.4 ft^3/s, leaving a substantial unaccounted gain of 6.6 ft^3/s (fig. 4).

During S1, streamflow in Carbon Creek (the largest surface inflow to Beaver Creek) decreased by 1.1 ft^3/s between upstream sampling site CC2 and downstream sampling site CC9 (fig. 3; table 1). One measured surface inflow, the Carlisle Mine adit (CC4), contributed 0.4 ft^3/s of streamflow. Of the two defined subreaches on Carbon Creek, streamflow decreased in one subreach and increased in the other (fig. 5). In subreach CC2 to CC6, streamflow decreased by 2.3 ft^3/s, even though surface inflow CC4 contributed 0.4 ft^3/s. Streamflow gain in subreach CC6 to CC9 was minimal (0.8 ft^3/s).

Synoptic Sampling Event S2

Synoptic sampling event S2 was conducted during high streamflow during May 21–23, 2002. During S2, streamflow in Beaver Creek increased by 59.1 ft^3/s between upstream sampling site UBC3 and downstream sampling site BC14 (fig. 3; table 1). Three measured surface inflows (CC9, BC12, and DC1) accounted for more than half (33.7 ft^3/s) of this increase, leaving 25.4 ft^3/s (43 percent) of the increase

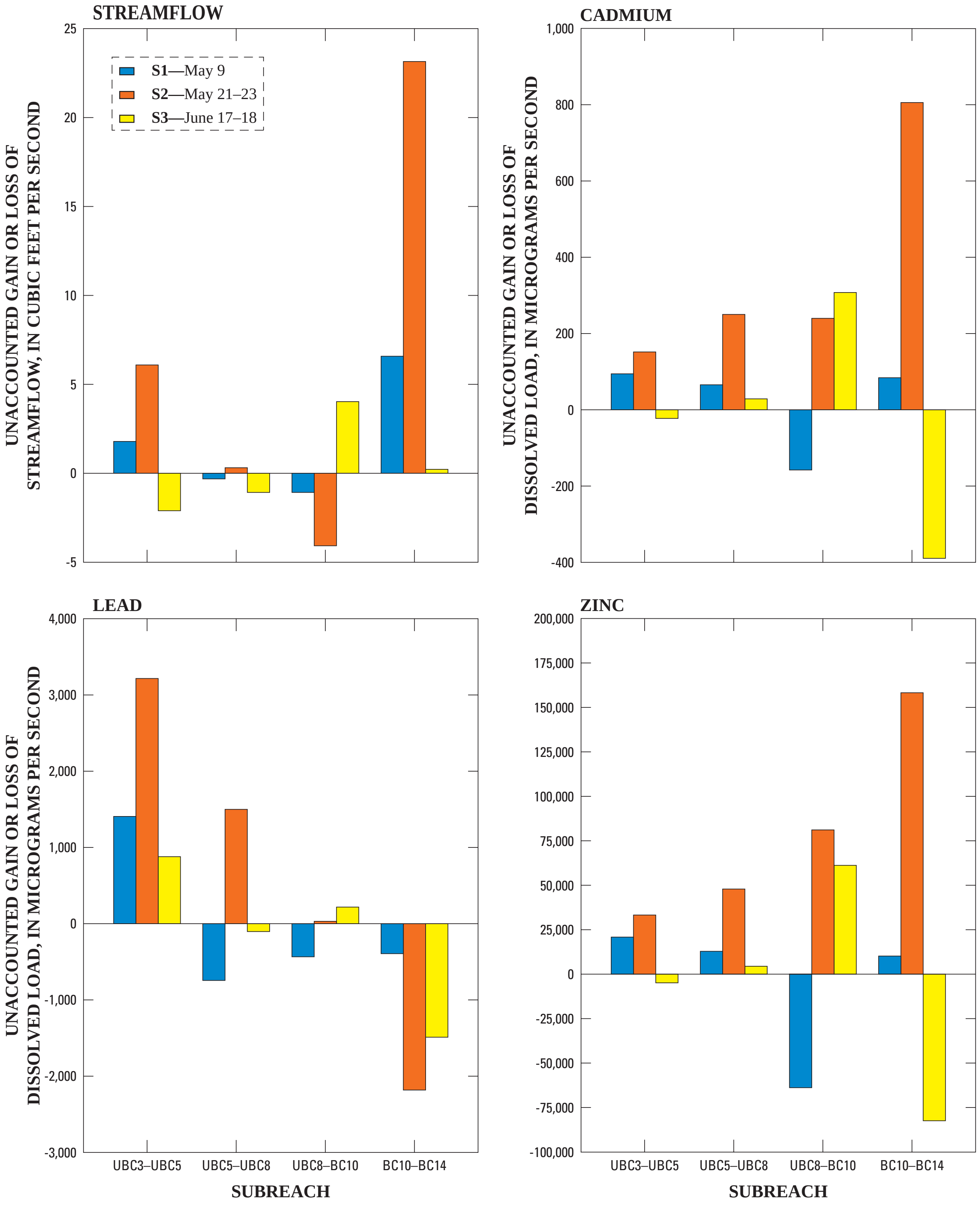


Figure 4. Unaccounted gain or loss of streamflow and dissolved cadmium, lead, and zinc loads for each subreach in upper Beaver Creek, Shoshone County, Idaho, May and June 2002.

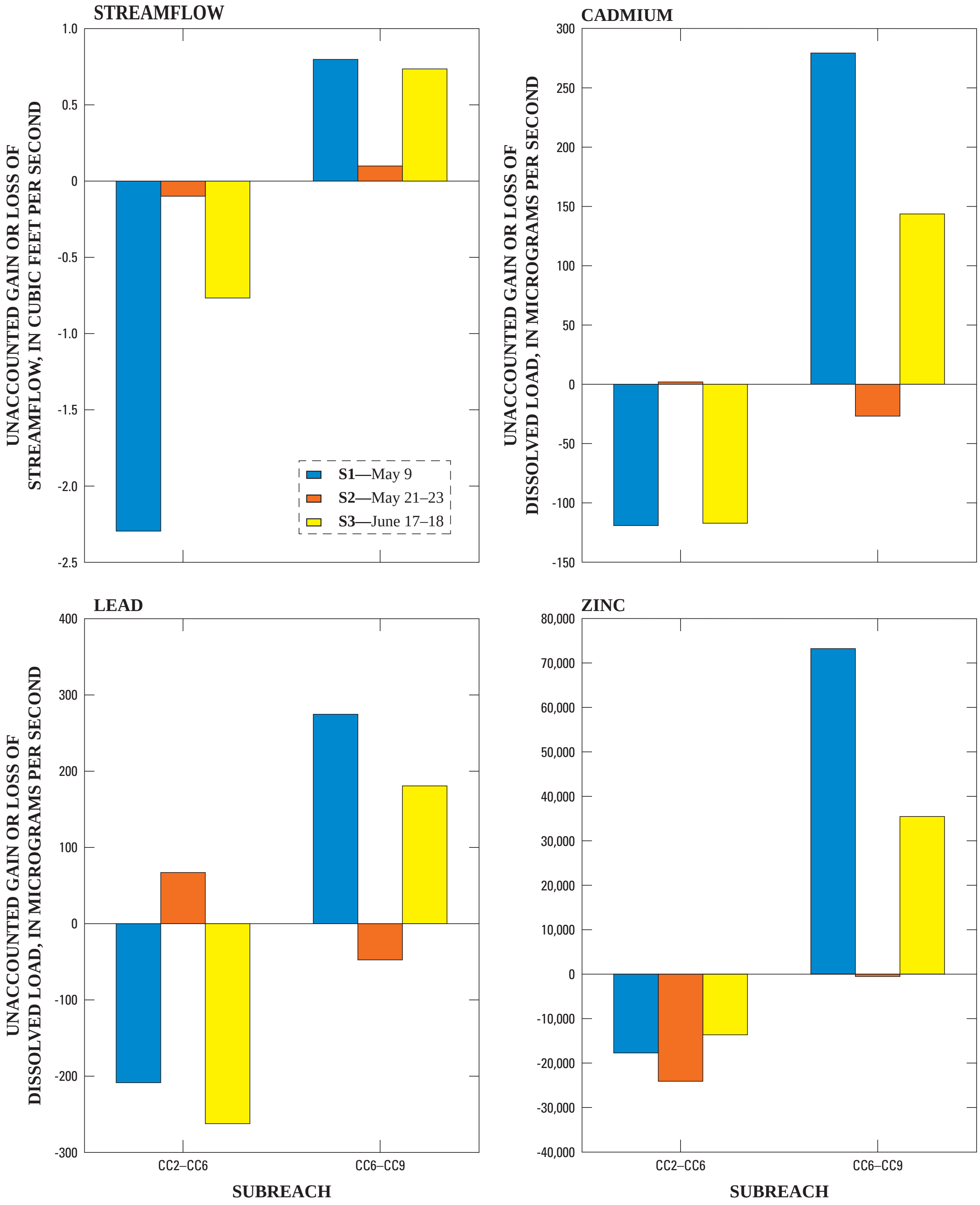


Figure 5. Unaccounted gain or loss of streamflow and dissolved cadmium, lead, and zinc loads for each subreach in Carbon Creek, Shoshone County, Idaho, May and June 2002.

attributable to overland surface runoff, unsampled seeps, and subsurface flow. Pioneer Gulch was dry at sample site PC1.

Of the four defined subreaches in Beaver Creek, streamflow increased in three of the subreaches and decreased in one of the subreaches during S2 (fig. 4). Streamflow gain in subreach UBC3 to UBC5 was 6.1 ft^3/s. Streamflow gain in subreach UBC5 to UBC8 was minimal (0.30 ft^3/s). Streamflow in subreach UBC8 to BC10 increased by 15.3 ft^3/s; however, surface inflow CC9 contributed an amount of flow (19.4 ft^3/s) that was larger than this increase, indicating that UBC8 to BC10 was a losing subreach (fig. 4). Streamflow gain in subreach BC10 to BC14 was substantial (23.1 ft^3/s); more than half of this gain was from surface inflow DC1 (12.9 ft^3/s).

During S2, streamflow in Carbon Creek increased by 1.2 ft^3/s between upstream sampling site CC2 and downstream sampling site CC9; most of the increase was in subreach CC2 to CC6. The only measured surface inflow, CC4, likely accounted for all of this increase (fig. 3; table 1). The unaccounted loss of streamflow in this subreach was negligible (fig. 5) and was entirely regained in subreach CC6 to CC9.

Synoptic Sampling Event S3

Synoptic sampling event S3 was conducted during low streamflow during June 17–18, 2002. During S3, streamflow in Beaver Creek increased 6.1 ft^3/s between upstream sampling site UBC3 and downstream sampling site BC14 (fig. 3; table 1). The two measured surface inflows (CC9 and BC12) accounted for much of this increase (5.1 ft^3/s). Pioneer Gulch was dry at sample site PC1 and Dobson Gulch was dry at sample site DC1.

Of the four defined subreaches in Beaver Creek, streamflow increased in two of the subreaches and decreased in the other two subreaches during S3 (fig. 4). Streamflow loss was 2.1 ft^3/s in subreach UBC3 to UBC5 and was 1.1 ft^3/s in subreach UBC5 to UBC8. Streamflow gain in subreach UBC8 to BC10 was substantial (8.9 ft^3/s); more than half of the gain was from surface inflow CC9 (4.9 ft^3/s), leaving an unaccounted gain of 4.0 ft^3/s (fig. 4). Streamflow gain in subreach BC10 to BC14 was small (0.4 ft^3/s); half of the gain was from surface inflow BC12 (0.2 ft^3/s).

During S3, streamflow in Carbon Creek increased by 1.0 ft^3/s between upstream sampling site CC2 and downstream sampling site CC9 (fig. 3; table 1); all of this increase can be attributed to surface inflow CC4 (1.0 ft^3/s). Even though streamflow increased in both subreaches of Carbon Creek, the streamflow increase in subreach CC2 to CC6 was less than the surface inflow CC4 (1.0 ft^3/s), leaving an unaccounted loss of 0.8 ft^3/s (fig. 5). The unaccounted loss in subreach CC2 to CC6 was entirely regained in subreach CC6 to CC9.

WATER QUALITY

The synoptic samples collected during this study were analyzed for 45 dissolved constituents, consisting of major ions, nutrients, and trace elements. All 45 constituents and minimum reporting levels (MRLs) are listed in table 2. Concentrations of only a few constituents were substantially greater than the MRLs. Although analysis for only the major ions, nutrients, and three of the trace elements (cadmium, lead, and zinc) are presented in table 1, the entire data set is available upon request to the Boise office of the U.S. Geological Survey (see back of title page for contact information).

Synoptic samples for water-quality analysis were collected from 12 surface-water sites during S1; 12 surface-water sites and 6 subsurface-water sites during S2; and 11 surface-water sites and 4 subsurface-water sites during S3.

Cadmium and zinc concentrations in nearly all surface-water samples from Beaver Creek and Carbon Creek were lowest during S2 and were highest during S1 (figs. 6 and 7). Dilution from precipitation, surface runoff, and high streamflow during S2 probably decreased cadmium and zinc concentrations. Low streamflow during S1 and inflows rich in cadmium and zinc likely increased concentrations of these metals in Beaver Creek and Carbon Creek. Nearly all subsurface samples collected during S2 contained higher concentrations of these metals than did samples collected during S3 (fig. 8). Subsurface samples were not collected during S1.

In general, concentrations of cadmium and zinc in Beaver Creek gradually increased between sites UBC3 and UBC8 and sharply increased between sites UBC8 and BC10 as a result of high concentrations in Carbon Creek. Concentrations of cadmium and zinc in Beaver Creek slightly decreased between sites BC10 and BC14. Lead concentrations in Beaver Creek sharply increased between sites UBC3 and UBC5, slightly

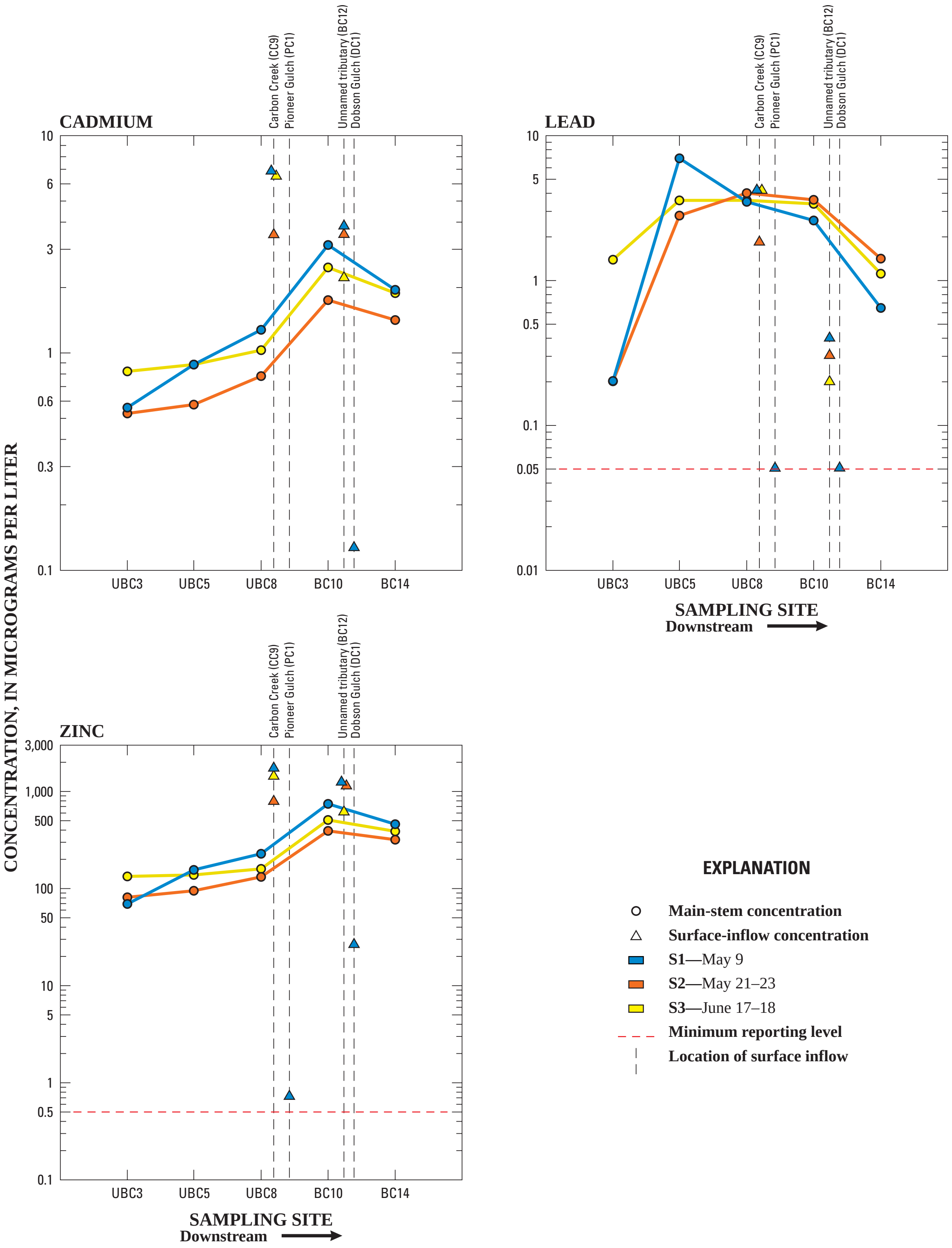


Figure 6. Dissolved concentrations of cadmium, lead, and zinc in upper Beaver Creek, Shoshone County, Idaho, May and June 2002. (Values equal to or less than the minimum reporting level are plotted at the minimum reporting level)

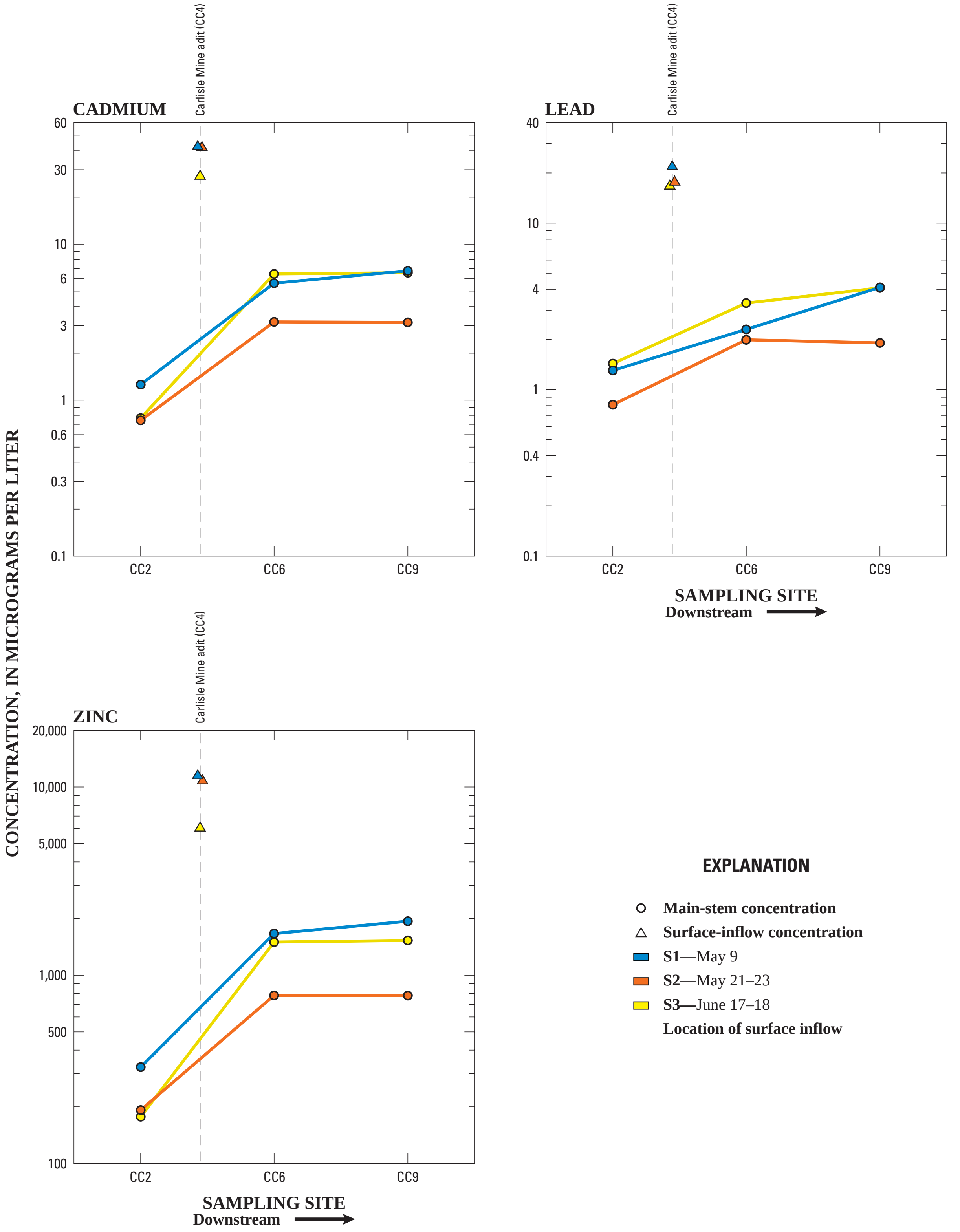


Figure 7. Dissolved concentrations of cadmium, lead, and zinc in Carbon Creek, Shoshone County, Idaho, May and June 2002.

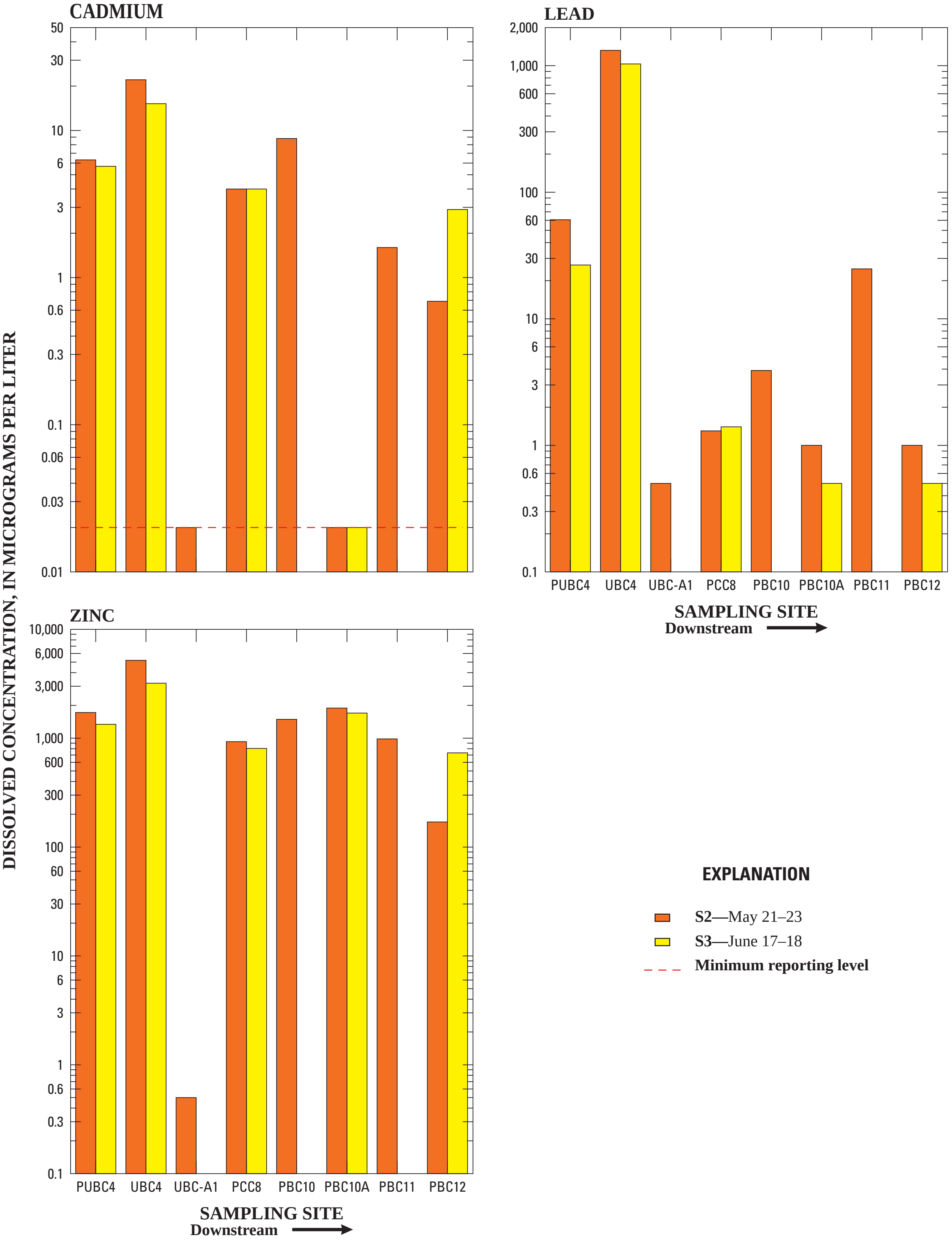


Figure 8. Dissolved concentrations of cadmium, lead, and zinc in subsurface water in upper Beaver Creek watershed, Shoshone County, Idaho, May and June 2002.

decreased between sites UBC5 and UBC10, and then sharply decreased between sites BC10 and BC14 (fig. 6). Concentrations of cadmium, lead, and zinc in Carbon Creek samples sharply increased between sites CC2 and CC6 because of inflow from the Carlisle Mine adit and remained fairly constant between sites CC6 and CC9 (fig. 7). During each of the synoptic sampling events, concentrations of cadmium and zinc were highest (28 to 41 µg/L and 6,000 to 11,300 µg/L, respectively) in samples collected at the Carlisle Mine adit (CC4) (fig. 7; table 1). During S1, the concentration of lead also was highest (21 µg/L) in the sample collected at the Carlisle Mine adit. During S2 and S3, the concentrations of lead were highest (1,300 and 1,000 µg/L, respectively) in samples collected from a left-bank seep (UBC4) downgradient from the Idora Mill.

According to Nimick and Cleasby (2001), metals such as copper, magnesium, and zinc can exhibit diel (24-hour) variations in dissolved concentration in streams affected by mining activities. Results from their studies of streams in Montana have shown that maximum concentrations of these metals occurred in the morning; minimum concentrations occurred in late afternoon or evening. These diel variations in concentration can have the potential to affect the results of metal-loading studies. Therefore, to determine whether any diel variation in zinc concentration occurred during the three synoptic sampling events of this study, samples were collected at the downstream end of the study area (BC14) each morning, prior to the start of sampling, and again at the end of the day (table 1). Results of this sampling indicated that, although zinc concentrations did vary, no two samples varied by more than 2 percent (table 1).

QUANTIFICATION OF METAL LOADS

Loads are calculated as the product of constituent concentration and streamflow. According to Cleasby and Nimick (2002), for stable constituents unaffected by chemical reactions, such as sorption, desorption, or volatilization, loads are additive as inflows contribute their load in a cumulative manner to the receiving stream.

Instantaneous loads of dissolved cadmium, lead, and zinc were calculated for each sample collected during the three synoptic events (table 3). In cases where the constituent concentration was less than the MRL (PC1, cadmium; and DC1, lead), the MRL value was used to calculate the load. Downstream profiles of constituent loads are presented in figures 9 and 10.

Table 3. Instantaneous loads of selected metals in upper Beaver Creek watershed, Shoshone County, Idaho, May and June 2003

[µg/s, micrograms per second]

Site identification	Sample date	Sample time (24-hour)	Cadmium load, dissolved (µg/s)	Lead load, dissolved (µg/s)	Zinc load, dissolved (µg/s)
Beaver Creek					
UBC3	05/09	0940	85.9	30.6	10,700
	05/21	1000	555	210	83,500
	06/18	1045	404	690	65,000
UBC5	05/09	1045	181	1,430	31,400
	05/21	1100	708	3,420	117,000
	06/18	1230	381	1,560	60,200
UBC8	05/09	1200	254	684	44,200
	05/21	1215	959	4,920	165,000
	06/18	1325	402	1,450	64,700
BC10	[1]05/09	1350	915	744	212,000
	[1]05/09	1355	915	744	215,000
	05/21	1430	2,990	5,980	673,000
	06/18	1500	1,640	2,220	338,000
BC14	05/09	0840	1,040	377	248,000
	05/09	1520	1,140	364	260,000
	05/21	0910	2,490	1,720	580,000
	05/21	1550	3,860	3,810	874,000
	06/18	0920	1,180	682	244,000
	06/18	1540	1,260	732	258,000
Carbon Creek					
CC2	05/09	1010	180	195	48,300
	05/21	1130	381	412	97,900
	06/18	1040	83.9	155	19,500
CC4	05/09	1110	464	238	128,000
	05/21	1230	1,390	610	360,000
	06/18	1125	793	481	170,000
CC6	05/09	1210	539	221	161,000
	05/21	1320	1,750	1,090	428,000
	06/18	1215	755	383	174,000
CC9	05/09	1300	809	488	230,000
	05/21	1315	1,700	1,040	427,000
	06/18	1250	902	569	212,000
Pioneer Gulch					
PC1	05/09	1315	.14	.11	1.98
Unnamed tributary to Beaver Creek					
BC12	05/09	1420	108	11.3	35,400
	05/21	1545	139	11.9	43,600
	06/18	1445	12.5	1.13	3,400
Dobson Gulch					
DC1	05/09	1500	8.80	3.40	1,850

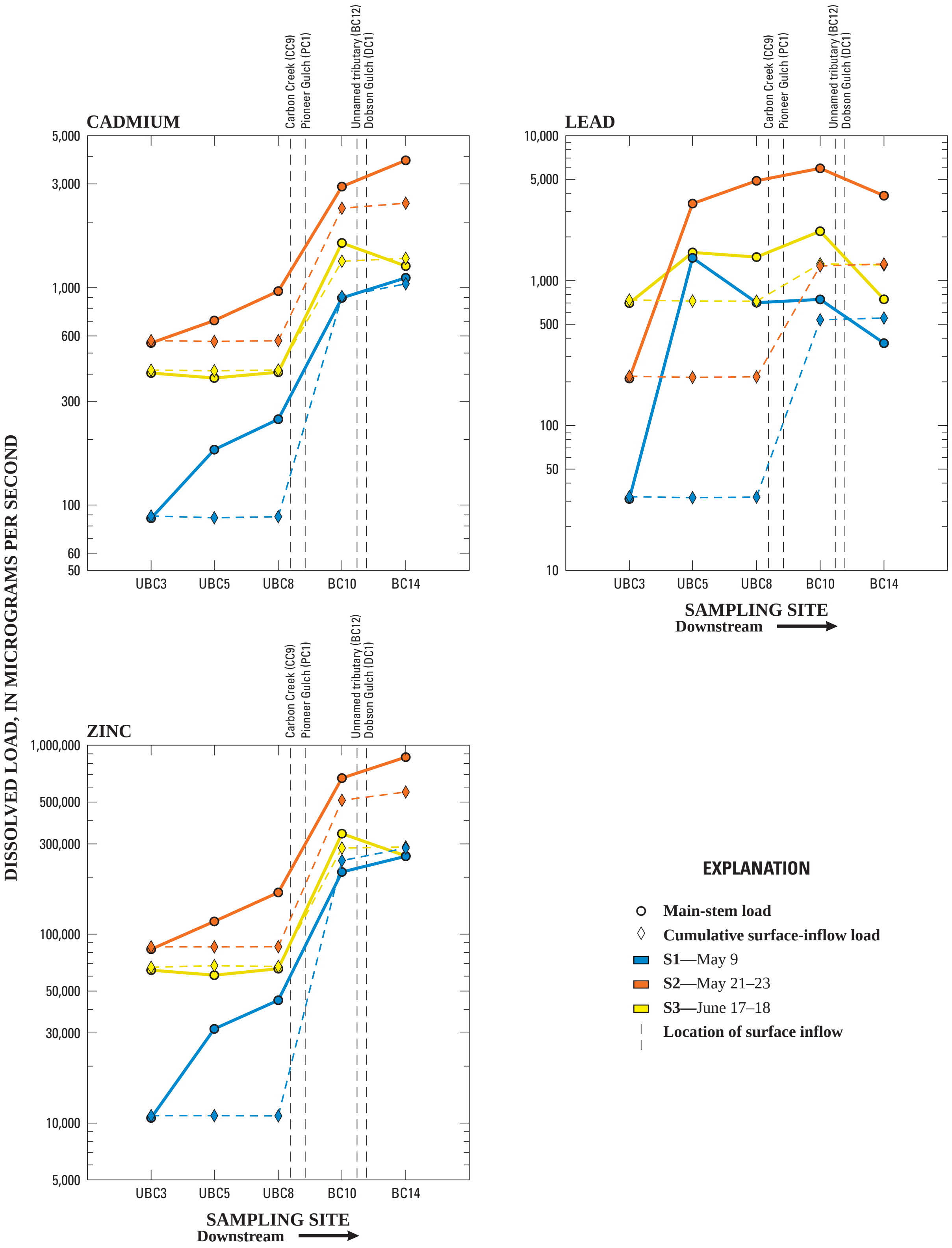


Figure 9. Dissolved cadmium, lead, and zinc loads in upper Beaver Creek, Shoshone County, Idaho, May and June 2002.

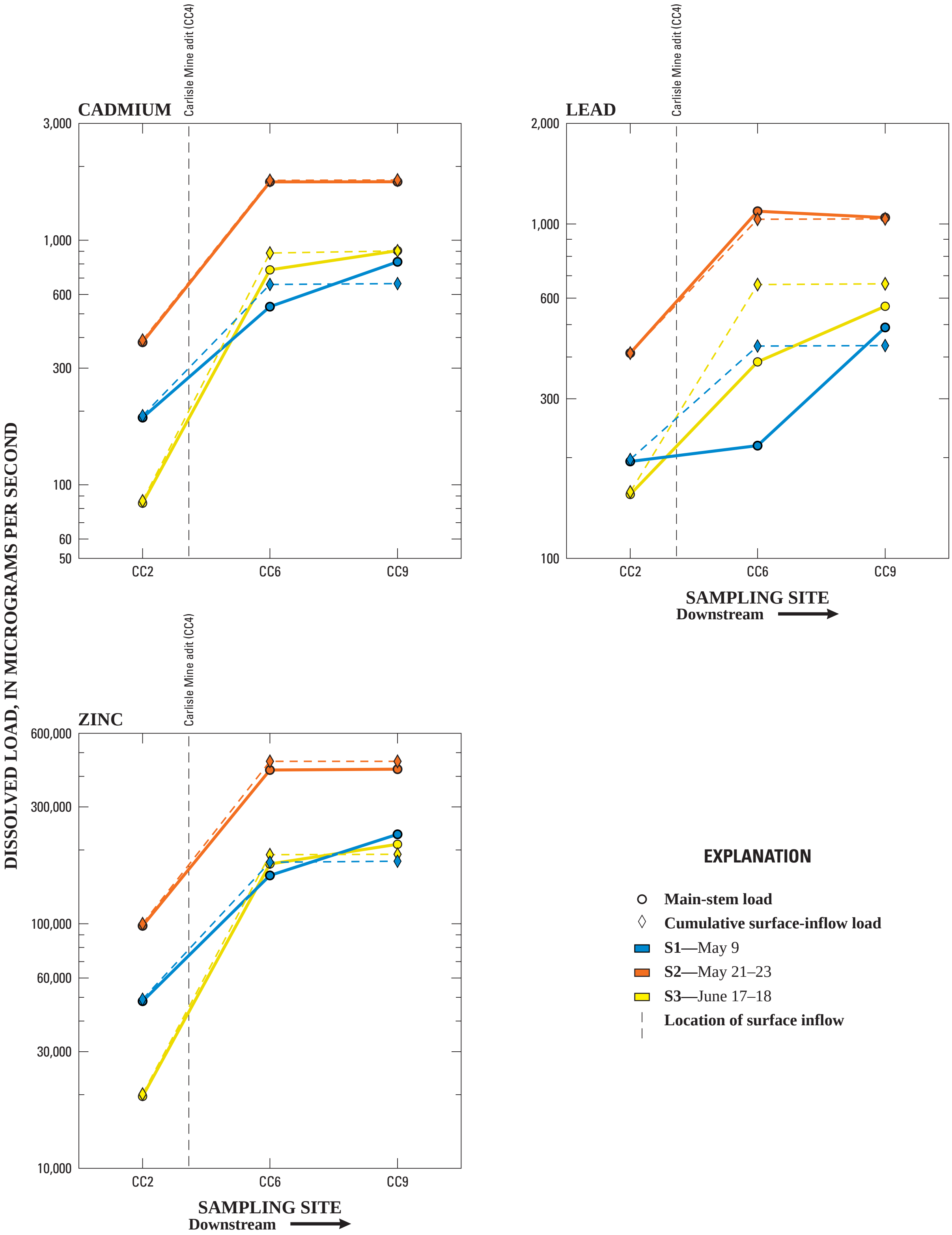


Figure 10. Dissolved cadmium, lead, and zinc loads in Carbon Creek, Shoshone County, Idaho, May and June 2002.

Downstream load profiles for this study illustrate the spatial distribution of loads throughout the study area and are similar to profiles presented by Cleasby and others (2000), Nimick and Cleasby (2001), and Cleasby and Nimick (2002). By comparing two different types of load profiles (the main-stem load and the cumulative surface-inflow load), potential sources and losses of a targeted constituent load within a study area can be determined. The main-stem load represents the actual measurement at each main-stem sampling site. This load is the net result of contributions from the sampled surface inflows and any other unsampled inflow (primarily subsurface inflow and unsampled seeps), as well as the loss in load caused by geochemical reactions, streambed deposition, or streamflow loss through hyporheic flow. The cumulative surface-inflow load is the cumulative downstream sum of all surface inflows that were sampled and quantified. A load increase is implied when the main-stem load is greater than the cumulative surface-inflow load. A loss in load is implied when the cumulative surface-inflow load is greater than the main-stem load.

Downstream load profiles indicate and account for main-stem and surface-inflow load; however, the profiles do not clearly indicate and account for gains or losses in load. To identify these unaccounted gains and losses, loads were quantified for each defined subreach. Gains or losses were determined by subtracting the load at the farthest upstream site of each subreach, plus any surface-inflow load, from the load at the farthest downstream site of each subreach. Unaccounted gains or losses in loads for cadmium, lead, and zinc in Beaver Creek and Carbon Creek are shown in figures 4 and 5. These graphs identify the incremental downstream change in unaccounted metal loads in the upper Beaver Creek watershed.

Cadmium

The main-stem cadmium loads in Beaver Creek (fig. 9) during each synoptic sampling event increased between upstream sampling site UBC3 and downstream sampling site BC14 from 85.9 to 1,140 μg/s during S1, from 555 to 3,860 μg/s during S2, and from 404 to 1,260 μg/s during S3 (table 3). Main-stem cadmium loads increased gradually between sites UBC3 and UBC8 during each of the synoptic sampling events. Main-stem cadmium loads increased substantially between sites UBC8 and BC10 during each of the synoptic sampling events as a result of cadmium loads from Carbon Creek (CC9). Carbon Creek was the largest single contributor of cadmium loads to Beaver Creek and accounted for 71, 45, and 72 percent of the total main-stem cadmium load in Beaver Creek during S1, S2, and S3, respectively (table 3). Main-stem cadmium loads increased between BC10 and BC14 during S1 and S2 and decreased between BC10 and BC14 during S3.

Unaccounted loads among synoptic samples were inconsistent, indicating that varying ground-water/surface-water relations may be a controlling factor. During S1, the main-stem cadmium load in Beaver Creek was higher than the cumulative surface-inflow cadmium load at sites UBC5, UBC8, and BC14, indicating an unaccounted gain of cadmium load between sites UBC3 and UBC8 and between sites BC10 and BC14 (figs. 4 and 9). Slightly higher cumulative surface-inflow cadmium load relative to main-stem cadmium load during S1 at site BC10 indicated an unaccounted loss of cadmium load between sites UBC8 and BC10. During S2, the main-stem cadmium load was higher than the cumulative surface-inflow cadmium load at all sites, indicating there were unaccounted cadmium gains throughout the study area. During S3, the main-stem cadmium load and the cumulative surface-inflow cadmium load were nearly equal at all sites. However, during S3, the main-stem cadmium load was slightly higher than the cumulative surface-inflow cadmium load at BC10, indicating an unaccounted gain of cadmium load between sites UBC8 and BC10. At site BC14 during S3, the cumulative surface-inflow load was slightly higher than the main-stem load, indicating an unaccounted loss of cadmium load between sites BC10 and BC14 (figs. 4 and 9).

During the synoptic sampling events, the main-stem cadmium load increased substantially between CC2 and CC6 as a result of the cadmium loads from the Carlisle Mine adit (CC4). The main-stem cadmium loads in Carbon Creek (fig. 10) during each synoptic sampling event increased between upstream sampling site CC2 and downstream sampling site CC9 from 180 to 809 μg/s during S1, from 381 to 1,700 μg/s during S2, and from 83.9 to 902 μg/s during S3 (table 3). The Carlisle Mine adit was the largest single contributor of cadmium loads to Carbon Creek and accounted for 57, 82, and 88 percent of the total main-stem cadmium load in Carbon Creek during S1, S2, and S3, respectively (table 3).

In general, most of the cadmium loads were accounted for. The main-stem cadmium load and cumulative surface-inflow cadmium load in Carbon Creek were similar during each of the synoptic sampling events (fig. 10). However, surface-inflow cadmium loads during S1 and S3 were slightly higher than main-stem cadmium loads at site CC6, indicating an unaccounted loss of cadmium load between sites CC2 and CC6 (figs. 5 and 10). During S2, the main-stem cadmium load and cumulative surface-inflow cadmium load were very similar; only a slight unaccounted loss of cadmium load was indicated between sites CC6 and CC9. Slightly higher main-stem cadmium loads relative to surface-inflow cadmium loads during S1 and S3 at site CC9 indicated an unaccounted gain of cadmium load between sites CC6 and CC9.

Lead

The largest unaccounted changes in lead load for all three synoptic sampling events were between UBC3 and UBC5 (gaining) and between BC10 and BC14 (losing). The main-stem lead loads in Beaver Creek (fig. 9) during each synoptic event increased between upstream sampling site UBC3 and downstream sampling site BC14 from 30.6 to 364 µg/s during S1, from 210 to 3,810 µg/s during S2, and from 690 to 732 µg/s during S3 (table 3). Main-stem lead loads increased between sites UBC3 and UBC5 during all three synoptic sampling events, most notably during S1 and S2. Main-stem lead loads were higher than the cumulative surface-inflow lead loads during all three synoptic sampling events, indicating an unaccounted gain of lead load between sites UBC3 and UBC5 (figs. 4 and 9). During S1, main-stem lead loads gradually decreased downstream from UBC5, indicating unaccounted losses of lead load between sites UBC5 and BC14. During S2 and S3, main-stem lead loads generally increased between sites UBC5 and BC10. Main-stem lead loads during each synoptic sampling event decreased between sites BC10 and BC14. Cumulative surface-inflow lead loads were higher than main-stem lead loads at BC14 during S1 and S3, indicating an unaccounted loss of lead load (figs. 4 and 9).

The main-stem lead loads in Carbon Creek (fig. 10) during each synoptic sampling event increased between upstream sampling site CC2 and downstream sampling site CC9 from 195 to 488 µg/s during S1, from 412 to 1,040 µg/s during S2, and from 155 to 569 µg/s during S3 (table 3). The increase in main-stem lead load was largest between sites CC6 and CC9 during S1 and between sites CC2 and CC6 during S2 and S3. Cumulative surface-inflow lead loads were higher than main-stem lead loads at CC6 during S1 and S3, indicating an unaccounted loss of lead load between sites CC2 and CC6 (figs. 5 and 10). Main-stem lead loads were higher than cumulative surface-inflow loads at CC9 during S1 and S3, indicating an unaccounted gain of lead load between sites CC6 and CC9.

Zinc

The main-stem zinc loads in Beaver Creek (fig. 9) during each of the synoptic sampling events increased substantially between upstream sampling site UBC3 and downstream sampling site BC14 from 10,700 to 260,000 µg/s during S1, from 83,500 to 874,000 µg/s during S2, and from 65,000 to 258,000 µg/s during S3 (table 3). The load profile for zinc is proportionally similar to the load profile for cadmium. As with cadmium, the main-stem zinc load increased gradually between sites UBC3 and UBC8 during each of the synoptic sampling events, then increased substantially between sites UBC8 and BC10 as a result of zinc loads from Carbon Creek (CC9). Carbon Creek was the largest single contributor of zinc loads to Beaver Creek and accounted for 89, 49, and 82 percent of the total main-stem zinc load in Beaver Creek during S1, S2, and S3, respectively (table 3). Main-stem zinc loads increased between BC10 and BC14 during S1 and S2 and decreased between BC10 and BC14 during S3.

During S1, the main-stem zinc load in Beaver Creek was higher than the cumulative surface-inflow zinc load at site UBC8, indicating an unaccounted gain of zinc load between sites UBC3 and UBC8, whereas higher cumulative surface-inflow zinc load relative to main-stem zinc load at site BC10 indicated an unaccounted loss of zinc load between sites UBC8 and UBC10 (fig. 9). During S2, the main-stem zinc load was higher than the cumulative surface-inflow zinc load at all sites, indicating that there were unaccounted gains of zinc load throughout the study area. During S3, the main-stem zinc load and the cumulative surface-inflow zinc load were nearly equal at all sites. However, during S3, the main-stem zinc load was slightly higher than the cumulative surface-inflow zinc load at BC10, indicating an unaccounted gain of zinc load between sites UBC8 and BC10. At site BC14 during S3, the cumulative surface-inflow zinc load was slightly higher than the main-stem zinc load, indicating an unaccounted loss of zinc load between sites BC10 and BC14 (figs. 4 and 9).

Similar to cadmium, the main-stem zinc load increased substantially between CC2 and CC6 during each of the synoptic sampling events as a result of the zinc loads from the Carlisle Mine adit (CC4). The main-stem zinc loads in Carbon Creek (fig. 10) during each synoptic sampling event increased between upstream sampling site CC2 and downstream sampling site CC9 from 48,300 to 230,000 µg/s during S1, from 97,900 to 427,000 µg/s during S2, and from 19,500 to 212,000 µg/s during S3 (table 3). The Carlisle Mine adit was the largest single contributor of zinc loads to Carbon Creek and accounted for 56, 80, and 88 percent of the total main-stem zinc load in Carbon Creek during S1, S2, and S3, respectively (table 3).

In general, the main-stem zinc load and cumulative surface-inflow zinc load in Carbon Creek were similar during each of the synoptic sampling events (fig. 10). However, surface-inflow zinc loads during all synoptic sampling events were slightly higher than main-stem zinc loads at site CC6, indicating an unaccounted loss of zinc load between sites CC2 and CC6 (figs. 5 and 10). During S2, the main-stem zinc load and cumulative surface-inflow zinc load were very similar, indicating only a slight unaccounted loss of zinc load between sites CC6 and CC9. Higher main-stem zinc loads relative to surface-inflow zinc loads during S1 and S3 at site CC9 indicated an unaccounted gain of zinc load between sites CC6 and CC9.

ASSESSMENT OF METAL SOURCES

Metal sources for Beaver Creek and Carbon Creek can be assessed from load profiles (figs. 9 and 10), subreach load gains and losses (figs. 4 and 5), and subsurface metal concentrations (fig. 8). In general, metal sources in the lower half of the Beaver Creek watershed between sites UBC8 and BC14 contributed more cadmium and zinc than did metal sources in the upper half of the Beaver Creek watershed between sites UBC3 and UBC8. In contrast, metal sources in the upper half of the Beaver Creek watershed contributed more lead than did metal sources in the lower half of the watershed. For Carbon Creek, the Carlisle Mine adit is the primary metal source.

Cadmium

Starting upstream, the first major source area for Beaver Creek is near the Idora Mill (between sites UBC3 and UBC5). On the basis of unaccounted gains of streamflow and cadmium load in this subreach (fig. 4) and large subsurface concentrations of cadmium (22 and 15 µg/L at UBC4; 6.3 and 5.7 µg/L at PUBC4) downgradient from the Carlisle Mill (fig. 8; table 1), it is likely that subsurface flow discharging to Beaver Creek is the source of cadmium between sites UBC3 and UBC5.

Moving downstream, the next source area is in the subreach from the Idora Mill to the confluence with Carbon Creek (between sites UBC5 and UBC8). The source of cadmium in this subreach is unclear. A lack of surface inflows, no unaccounted streamflow gains, and a low subsurface concentration of cadmium (<0.02 µg/L at UBC–A1, table 1) make it difficult to determine the source. Further study in this subreach would be needed to fully assess the cadmium source in this part of the study area.

Moving farther downstream (between sites UBC8 and BC10), the next source of cadmium is Carbon Creek (CC9), which, during each of the synoptic sampling events, was the primary source of cadmium to Beaver Creek (fig. 9). Between sites BC10 and BC14, a substantial source area, second only to Carbon Creek, is the area downgradient from the large, tiered flotation tailings pile near Carbon Center. Unaccounted gains in cadmium load and streamflow in this area (fig. 4) and large subsurface concentrations of cadmium (8.8 µg/L at PBC10, fig. 8; table 1) downgradient from the tailings pile indicate that most of the cadmium in the lower end of the study area is attributable to subsurface flow through the tailings into Beaver Creek. However, this area appears to be a contributor of cadmium only when subsurface flow is discharging to Beaver Creek. When subsurface flow is no longer discharging to Beaver Creek (as evident during S3 by the greater depth to water in the piezometers, table 1), this area no longer is a source area but appears to become an area of cadmium loss (fig. 4).

In the upper subreach (between sites CC2 and CC6) of Carbon Creek, the Carlisle Mine adit (CC4) is the largest source of cadmium to Carbon Creek and, subsequently, to Beaver Creek (fig. 10). The source of cadmium in the lower subreach (between sites CC6 and CC9) is less obvious. Unaccounted losses of streamflow in the upper subreach in Carbon Creek and unaccounted gains of streamflow in the lower subreach (fig. 5) indicate that streamflow becomes hyporheic flow in the upper subreach and partially returns to streamflow in the lower subreach. Large subsurface concentrations of cadmium (4.0 µg/L at PCC8 during S2 and S3, fig. 8; table 1) downgradient from the Carlisle Mill (fig. 2) and in the flowpath of the hyporheic flow indicate that the source of cadmium in the lower subreach of Carbon Creek may be attributable to the resurfacing cadmium-enriched hyporheic flow (possibly originating from the Carlisle Mine adit or the Carlisle Mill).

Lead

The processes controlling lead transport appear to be related to streamflow. Lead tends to adsorb to sediment particles and be deposited on the streambed when streamflow velocities are low. Higher streamflows and, thus, higher velocities, can remobilize lead-enriched particulate matter that has been deposited on the streambed and transport it downstream. Water-quality samples collected during high streamflow can appear to be enriched in dissolved lead that is actually colloidal because dissolved concentrations are operationally defined as the filtrate passing through a 0.45-µm filter pore size; thus, any lead-enriched, fine-grained particulates (<0.45 µm) would be included in the filtrate. Therefore, amounts of lead contributed by source areas to Beaver Creek and Carbon Creek vary with streamflow conditions.

Consequently, during high streamflow (during S2), a major source of lead to Beaver Creek through the study area is the remobilization of lead-enriched particulate matter that has accumulated on the streambed. During low streamflow (during S1), the major source of lead to Beaver Creek is near the Idora Mill (between sites UBC3 and UBC5). Unaccounted gains of lead load and streamflow (fig. 4) and large subsurface lead concentrations (1,300 and 1,000 µg/L at UBC4 and 61 and 27 µg/L at PUBC4, fig. 8; table 1) downgradient from the Idora Mill indicate that the source of lead in this subreach is attributable to seepage of subsurface water into Beaver Creek.

As with cadmium, during each of the synoptic sampling events, Carbon Creek is a major source of lead to Beaver Creek. As with Beaver Creek, source areas of lead to Carbon Creek vary with streamflow. At higher streamflows (during S2), increased loads from the Carlisle Mine adit (CC4) appear to be the largest source of lead to Carbon Creek (fig. 10). However, at lower streamflows (during S1), resurfacing lead-enriched hyporheic flow appears to be the major source of lead to Carbon Creek (fig. 5).

Zinc

Sources of zinc to Beaver Creek are generally similar to sources of cadmium to Beaver Creek (fig. 9). However, large concentrations and subsequent large loads of zinc at site UBC3 indicate sources of zinc upstream from and outside of the study area. Assessing these sources would require further study and extension of the existing study area.

Moving downstream, the next major source area for Beaver Creek is near the Idora Mill (between sites UBC3 and UBC5). On the basis of unaccounted gains of streamflow and zinc load in this subreach (fig. 4) and large subsurface concentrations of zinc (5,190 and 3,200 µg/L at UBC4; 1,720 and 1,340 µg/L at PUBC4) downgradient from the Idora Mill (fig. 8; table 1), it is likely that subsurface flow discharging to Beaver Creek is the source of zinc between sites UBC3 and UBC5.

The next downstream source area is in the subreach from the Idora Mill to the confluence with Carbon Creek (between UBC5 and UBC8). As with cadmium, the source of the zinc in this subreach is unclear, and further study would be needed to assess the source of this zinc.

Between sites UBC8 and BC10, the next and largest source of zinc to Beaver Creek is Carbon Creek (CC9). Between sites BC10 and BC14, a substantial source of zinc, second only to Carbon Creek, is the area downgradient from the flotation tailings pile near Carbon Center. Unaccounted gains in zinc load and streamflow in this subreach (fig. 4) and large subsurface concentrations of zinc (1,490 µg/L at PBC10; 1,890 and 1,700 µg/L at PBC10A, fig. 8; table 1) downgradient from the tailings pile indicate that most of the zinc loading in the lower end of the study area is attributable to the subsurface flow of water through the tailings pile at Carbon Center and the subsequent discharge of this water into Beaver Creek. As with cadmium, this area appears to be a contributor of zinc load only when subsurface flow is discharging to Beaver Creek (fig. 4).

The Carlisle Mine adit (CC4) in the upper subreach (between sites CC2 and CC6) is the largest source of zinc loading to Carbon Creek and, subsequently, to Beaver Creek (fig. 10). Resurfacing hyporheic flow (possibly originating from the Carlisle adit or the Carlisle Mill) is likely the source of zinc to Carbon Creek in the lower subreach (between sites CC6 and CC9). As with cadmium, large subsurface concentrations of zinc (929 and 805 μg/L at PCC8, fig. 8; table 1) downgradient from the Carlisle Mill (fig. 2) and in the flowpath of the hyporheic flow indicate that the source of zinc in the lower subreach of Carbon Creek may be attributable to resurfacing zinc-enriched hyporheic flow.

SUMMARY

The upper Beaver Creek watershed, located in the Coeur d'Alene River Basin in northern Idaho, has been heavily impacted by the dispersion of metal-enriched materials from mining activities over more than 100 years. This report describes streamflow and water quality, quantifies metal loading within the upper Beaver Creek watershed, and identifies metal source areas. Results of this study will assist resource managers in planning and conducting effective remediation efforts. A synoptic water-quality sampling approach was used to assess the effects of surface and shallow subsurface water on the gain or loss of streamflow and metal loads in the upper Beaver Creek watershed.

This metal-loading study consisted of three synoptic water-quality sampling events (S1, S2, and S3) conducted during May and June 2002. Streamflow during S1, conducted May 9, and during S3, conducted June 17–18, was low and stable. Streamflow during S2, conducted May 22–23, was high and rising. In general, concentrations of dissolved cadmium, lead, and zinc during S1 and S3 were higher than those during S2. Surface runoff and high streamflow during S2 contributed to the dilution of cadmium and zinc concentrations in surface-water samples.

Main-stem concentrations of cadmium and zinc in Beaver Creek gradually increased downstream between sites UBC3 and UBC8 and sharply increased between sites UBC8 and BC10 as a result of high concentrations in Carbon Creek. Concentrations of cadmium and zinc slightly decreased between BC10 and BC14. Lead concentrations in Beaver Creek sharply increased between sites UBC3 and UBC5, slightly decreased between UBC5 and BC10, and then sharply decreased between sites BC10 and BC14. Concentrations of cadmium, lead, and zinc in Carbon Creek samples sharply increased between sites CC2 and CC6 and remained fairly constant between sites CC6 and CC9. During each of the synoptic sampling events, concentrations of cadmium and zinc were highest (28 to 41 μg/L and 6,000 to 1,300 μg/L, respectively) in samples collected at the Carlisle Mine adit (CC4). During S1, the concentration of lead also was highest (21 μg/L) in the sample collected at the Carlisle Mine adit. During S2 and S3, the concentration of lead was highest (1,300 and 1,000 μg/L, respectively) in samples collected from a left-bank seep (UBC4) downgradient from the Idora Mill.

In general, main-stem cadmium and zinc loads in Beaver Creek gradually increased downstream between sites UBC3 and UBC8 and substantially increased between sites UBC8 and BC10 during each of the synoptic sampling events. Main-stem cadmium and zinc loads in Beaver Creek increased between sites BC10 and BC14 during S1 and S2 and decreased between sites BC10 and BC14 during S3.

Major source areas of zinc to Beaver Creek include unidentified sources upstream from site UBC3 and outside the study area. Major source areas for both cadmium and zinc include unidentified sources downstream from the Idora Mill between sites UBC3 and UBC8. Substantial unaccounted metal loads in both these areas indicate the need for further study to determine the location, quantify the metal load, and adequately assess the impact of these sources on Beaver Creek. The largest identified cadmium and zinc source to Beaver Creek is surface inflow from Carbon Creek (CC9), which accounted for 45 to 72 percent of the main-stem cadmium load and 49 to 89 percent of the main-stem zinc load in Beaver Creek. Another large source of cadmium and zinc to Beaver Creek is subsurface flow through the tiered flotation tailings pile near Carbon Center (between sites BC10 and BC14) into Beaver Creek. However, this area appears to be a source of cadmium and zinc only when subsurface flow is discharging to Beaver Creek.

In general, main-stem lead loads in Beaver Creek increased downstream between sites UBC3 and UBC5 during each of the synoptic sampling events, most notably during S1 and S2. During S1, main-stem lead loads gradually decreased downstream between sites UBC5 and BC10. During S2 and S3, main-stem lead loads generally increased between sites UBC5 and

BC10. Main-stem lead loads during each of the synoptic sampling events decreased between sites BC10 and BC14.

Amounts of lead contributed by source areas to Beaver Creek vary with streamflow conditions. During high streamflow, the largest source of lead to Beaver Creek is the remobilization of fine-grained (<0.45-µm), lead-enriched particulates from the streambed throughout the study area. During low streamflow, bank seepage of subsurface water into Beaver Creek in the subreach downgradient from the Idora Mill (between sites UBC3 and UBC5) is the major source of lead to Beaver Creek. During each synoptic sampling event, Carbon Creek (CC9) is a major source of lead to Beaver Creek.

Main-stem cadmium and zinc loads in Carbon Creek during each synoptic sampling event increased substantially between sites CC2 and CC6 and, during S1 and S3, continued to increase downstream to site CC9. The Carlisle Mine adit (CC4) is the largest source of cadmium and zinc to Carbon Creek and, ultimately, to Beaver Creek, and accounted for 57 to 88 percent of the total main-stem cadmium load and 56 to 88 percent of the total main-stem zinc load in Carbon Creek during each of the synoptic sampling events. Another source of cadmium and zinc to Carbon Creek is resurfacing cadmium- and zinc-enriched hyporheic flow (possibly originating from the Carlisle Mine adit or the Carlisle Mill) between sites CC6 and CC9.

The largest increase in main-stem lead load in Carbon Creek occurred between sites CC6 and CC9 during S1 and between sites CC2 and CC6 during S2 and S3. As with Beaver Creek, amounts of lead contributed to Carbon Creek by source areas vary with streamflow conditions. During high streamflows, increased loads from the Carlisle Mine adit appear to be the largest source of lead to Carbon Creek and, during low streamflows, resurfacing lead-enriched hyporheic flow appears to be the major source of lead to Carbon Creek.

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Table 1

Table 1. Selected water-quality data for synoptic samples and field blank samples collected in upper Beaver Creek watershed, Shoshone County, Idaho, May and June 2002

[Site type: MB, main-stem Beaver Creek sampling site; P, piezometer subsurface sampling site; I, surface-inflow sampling site; MC, main-stem Carbon Creek sampling site; QC, quality control samples. The terms left bank and right bank refer to side of the creek viewed while looking downstream. ft^3/s, cubic feet per second; ft, feet; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; —, not applicable; <, less than]

Site identification											
Name	**General description**	**Type**	**Latitude**	**Longitude**	**Sample date**	**Sample time (24-hour)**	**Stream-flow (ft^3/s)**	**Depth to water level below land surface (ft)**	**Specific conduct-ance (µS/cm)**	**pH (standard units)**	**Water temper-ature (°C)**
					Beaver Creek						
UBC3	Beaver Creek upstream from Idora Mill	MB	47°34'23"	115°52'03"	05/09 05/21 06/18	0940 1000 1045	5.4 37 17.4	— — —	28 23 22	6.7 6.7 6.9	3.5 4.5 5.5
PUBC4	Piezometer located in tailings and overburden approximately 50 ft southwest of Idora Mill	P	47°34'22"	115°52'04"	05/22 06/18	1350 1145	— —	0.40 .42	28 27	6.5 6.2	4.5 7.0
UBC4	Left-bank seep. Water seeping from tailings lining streambanks downstream from Idora Mill	I	47°34'23"	115°52'06"	05/22 06/18	1400 1130	— —	— —	48 40	5.5 5.7	5.0 8.5
UBC5	Beaver Creek downstream from Idora Mill	MB	47°34'21"	115°52'22"	05/09 05/21 06/18	1045 1100 1230	7.2 43.1 15.3	— — —	28 25 22	6.7 6.6 7.0	4.0 5.0 7.0
UBC-A1	Unnamed mine adit downstream from Idora Mill	I	47°34'10"	115°52'50"	05/21	1130	—	—	195	7.3	5.0
UBC8	Beaver Creek upstream from confluence with Carbon Creek	MB	47°33'50"	115°53'22"	05/09 05/21 06/18	1200 1215 1325	6.9 43.4 14.2	— — —	30 26 25	6.8 6.7 7.1	5.0 5.5 7.0
CC9	Carbon Creek, left-bank inflow to Beaver Creek	MC/I	47°33'49"	115°53'22"	05/09 05/21 06/18	1300 1315 1250	4.2 19.4 4.9	— — —	87 53 84	7.4 6.5 7.3	5.0 5.5 9.0
BC10	Beaver Creek downstream from Pioneer Creek, adjacent to tiered flotation tailings pile	MB	47°33'47"	115°53'46"	[1]05/09 [1]05/09 05/21 06/18	1350 1355 1430 1500	10.1 — 58.7 23.1	— — — —	49 49 35 38	7.1 7.1 6.6 6.9	5.5 5.5 6.0 8.0
PC1	Pioneer Gulch, right-bank inflow to Beaver Creek	I	47°33'48"	115°53'36"	05/09	1315	.1	—	35	7.2	5.0

Table 1. Selected water-quality data for synoptic samples and field blank samples collected in upper Beaver Creek watershed, Shoshone County, Idaho, May and June 2002—Continued

Name	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L)	Nitrate, dissolved (mg/L)	Phosphorus, dissolved (mg/L)	Cadmium, dissolved (µg/L)	Lead, dissolved (µg/L)	Zinc, dissolved (µg/L)
Beaver Creek—Continued														
UBC3	2.8	0.57	1.1	0.33	7.8	0.3	5.8	<0.08	4.9	<0.08	<0.01	0.56	0.20	69.7
	2.0	.45	.94	.30	7.0	.2	4.8	<.08	3.6	<.08	<.01	.53	.20	79.7
	2.1	.46	.77	.20	6.0	.08	7.0	<.08	3.0	<.08	<.01	.82	1.4	132
PUBC4	1.6	.48	.95	.34	6.0	.2	7.3	<.08	3.8	<.08	<.01	6.3	61	1,720
	1.8	.62	.86	.20	6.0	.1	8.0	<.08	3.5	<.08	<.01	5.7	27	1,340
UBC4	2.0	.72	1.0	.34	3.0	.2	18	<.08	4.1	.1	<.01	22	1,300	5,190
	1.7	.69	.99	.30	3.0	.1	14	<.08	3.9	.2	<.01	15	1,000	3,200
UBC5	2.7	.57	1.1	.32	6.6	.2	6.2	<.08	4.8	<.08	<.01	.89	7.0	154
	2.0	.46	.93	.30	8.0	.2	4.8	<.08	3.7	<.08	<.01	.58	2.8	95.7
	2.1	.20	.79	.20	6.0	<.08	6.0	.1	3.0	<.08	<.01	.88	3.6	139
UBC-A1	27	2.7	2.7	.41	50	.3	41	.2	5.7	<.08	<.01	<.02	<.05	<.5
UBC8	3.0	.57	1.1	.33	7.8	.3	6.4	<.08	5.0	<.08	<.01	1.3	3.5	226
	2.1	.49	.98	.30	8.0	.2	5.0	<.08	3.8	.09	<.01	.78	4.0	134
	2.1	.52	.81	.20	13	.1	6.0	<.08	3.1	<.08	<.01	1.0	3.6	161
CC9	10	1.1	1.3	.61	10	.3	24	<.08	5.0	<.08	<.01	6.8	4.1	1,930
	5.2	.72	1.1	.43	10	.2	12	<.08	3.8	.1	<.01	3.1	1.9	778
	8.9	1.2	1.4	.44	12	.2	22	.09	3.9	.2	<.01	6.5	4.1	1,530
BC10	5.6	.77	1.2	.46	8.6	.2	13	<.08	5.1	<.08	<.01	3.2	2.6	743
	5.6	.77	1.1	.46	8.6	.3	13	<.08	5.1	<.08	<.01	3.2	2.6	753
	3.2	.58	1.0	.34	8.0	.2	7.5	<.08	3.7	.1	<.01	1.8	3.6	405
	4.0	.73	.98	.31	8.0	.1	11	<.08	3.4	<.08	<.01	2.5	3.4	516
PC1	3.7	.72	1.3	.60	13	.3	6.4	.08	7.0	<.08	<.01	<.02	.05	.70

Table 1. Selected water-quality data for synoptic samples and field blank samples collected in upper Beaver Creek watershed, Shoshone County, Idaho, May and June 2002—Continued

Site identification			Latitude	Longitude	Sample date	Sample time (24-hour)	Stream-flow (ft^3/s)	Depth to water level below land surface (feet)	Specific conduct-ance (µS/cm)	pH (standard units)	Water temper-ature (°C)
Name	**General description**	**Type**									
Beaver Creek—Continued											
PBC10	Piezometer located in flotation tailings along left streambank, near large, tiered flotation tailings deposit near Carbon Center	P	47°33'45"	115°53'52"	05/23	0800	—	4.42	55	5.9	6.0
PBC10A	Piezometer located in channel of unnamed tributary to Beaver Creek 25 ft southwest of tiered flotation tailings deposit near Carbon Center	P	47°33'40"	115°53'55"	05/23	0830	—	.28	343	6.3	6.0
					06/17	1445	—	.44	372	6.4	8.5
PBC11	Piezometer located in channel of unnamed tributary to Beaver Creek	P	47°33'39"	115°54'02"	[1]05/23	0900	—	1.32	233	6.2	8.0
					[1]05/23	0905	—	—	233	6.2	8.0
PBC12	Piezometer located in channel of unnamed tributary to Beaver Creek	P	47°33'30"	115°54'15"	05/23	0730	—	.28	46	6.3	5.5
					06/17	1630	—	.63	118	6.0	8.5
BC12	Unnamed tributary, left-bank inflow to Beaver Creek	I	47°33'30"	115°54'15"	05/09	1420	1	—	104	6.4	5.0
					05/21	1545	1.4	—	96	7.1	6.0
					06/18	1445	.2	—	73	6.0	7.5
DC1	Dobson Gulch, left-bank inflow to Beaver Creek	I	47°33'29"	115°54'18"	05/09	1500	2.4	—	58	7.0	5.0
					05/21	1530	12.9	—	—	—	—
BC14	Beaver Creek at bridge crossing near Ferguson	MB	47°33'28"	115°54'56"	[2]05/09	0840	19.3	—	58	6.9	4.5
					05/09	1520	20.1	—	59	7.1	5.0
					[2]05/21	0910	62.8	—	40	6.9	5.5
					05/21	1550	96.1	—	40	7.2	5.5
					[2]06/18	0920	21.9	—	48	7.0	8.0
					06/18	1540	23.5	—	47	6.9	8.5

Table 1. Selected water-quality data for synoptic samples and field blank samples collected in upper Beaver Creek watershed, Shoshone County, Idaho, May and June 2002—Continued

Name	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L)	Nitrate, dissolved (mg/L)	Phosphorus, dissolved (mg/L)	Cadmium, dissolved (μg/L)	Lead, dissolved (μg/L)	Zinc, dissolved (μg/L)
Beaver Creek—Continued														
PBC10	4.9	0.77	1.1	0.82	31	0.2	17	<0.08	4.5	<0.08	<0.01	8.8	3.9	1,490
PBC10A	44	5.4	1.5	3.5	6.0	.2	130	.1	6.0	<.08	<.01	.02	1.0	1,890
	46	5.7	1.5	3.2	41	.3	120	.1	6.0	<.08	.01	<.02	.50	1,700
PBC11	30	3.8	1.3	2.8	22	.2	87	.2	5.2	<.08	<.01	1.6	25	986
	32	3.8	1.3	2.9	22	.2	87	.1	5.4	<.08	<.01	1.7	26	1,030
PBC12	4.9	.85	1.3	.55	14	.9	8.8	.08	5.1	.2	<.01	.69	1.0	170
	13	2.3	1.4	1.3	13	.2	35	<.08	5.1	.2	<.01	2.9	.50	733
BC12	12	1.4	1.2	1.5	13	.9	29	<.08	5.9	.2	<.01	3.8	.40	1,250
	11	1.5	1.4	1.3	14	.7	27	<.08	5.3	.1	<.01	3.5	.30	1,100
	5.8	.87	1.2	.73	10	.1	15	<.08	4.3	<.08	<.01	2.2	.20	601
DC1	6.9	1.2	1.2	.68	15	2.7	8.5	.1	6.0	<.08	<.01	.13	<.05	27.2
	—	—	—	—	—	—	—	—	—	—	—	—	—	—
BC14	6.4	.87	1.1	.60	—	.9	12	<.08	5.3	<.08	<.01	1.9	.69	453
	6.5	.86	1.1	.59	11	.9	12	<.08	5.4	<.08	<.01	2.0	.64	457
	3.9	.83	1.3	.42	10	.5	8.0	<.08	4.3	.1	<.01	1.4	.97	326
	3.9	.72	1.1	.42	10	.5	7.9	<.08	4.2	.1	<.01	1.4	1.4	321
	4.8	.97	1.2	.42	—	.3	11	<.08	4.0	<.08	<.01	1.9	1.1	394
	4.6	.88	1.1	.41	11	.3	11	<.08	3.8	<.08	<.01	1.9	1.1	388

Table 1. Selected water-quality data for synoptic samples and field blank samples collected in upper Beaver Creek watershed, Shoshone County, Idaho, May and June 2002—Continued

Site identification												
Name	General description	Type	Latitude	Longitude	Sample date	Sample time (24-hour)	Stream-flow (ft^3/s)	Depth to water level below land surface (feet)	Specific conduct-ance (µS/cm)	pH (standard units)	Water temper-ature (°C)
Carbon Creek											
CC2	Carbon Creek upstream from Carlisle Mine adit discharge	MC	47°33'45"	115°52'45"	05/09 05/21 06/18	1010 1130 1040	5.3 18.2 3.9	— — —	52 31 38	6.9 7.2 6.9	2.5 4.5 7.0
CC4	Carlisle Mine adit discharge, right-bank inflow to Carbon Creek	I	47°33'44"	115°52'56"	05/09 05/21 06/18	1110 1230 1125	.4 1.2 1.0	— — —	324 301 238	7.4 7.2 7.6	8.5 9.0 8.5
CC6	Carbon Creek downstream from Carlisle Mine adit discharge (upstream from Carlisle Mill)	MC	47°33'44"	115°53'14"	05/09 05/21 06/18	1210 1320 1215	3.4 19.3 4.1	— — —	89 50 85	7.6 7.2 7.1	4.5 5.0 8.0
PCC8	Piezometer located in tailings and overburden approximately 50 ft northwest of the Carlisle Mill	P	47°33'47"	115°53'18"	05/22 06/18	1500 1330	— —	0.33 .70	81 76	6.9 6.6	5.5 7.5
Field Blanks											
	Pre-sample field equipment blank	QC	—	—	05/09	0810	—	—	—	—	—
	Post-sample field equipment blank	QC		—	05/09	1550	—	—	—	—	—

Table 1. Selected water-quality data for synoptic samples and field blank samples collected in upper Beaver Creek watershed, Shoshone County, Idaho, May and June 2002—Continued

Name	Calcium, dissolved (mg/L)	Magne-sium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potas-sium, dissolved (mg/L)	Alkalinity (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L)	Nitrate, dissolved (mg/L)	Phosphorus, dissolved (mg/L)	Cadmium, dissolved (µg/L)	Lead, dissolved (µg/L)	Zinc, dissolved (µg/L)
Carbon Creek—Continued														
CC2	5.1	1.1	1.5	0.48	7.8	0.2	13	<0.08	4.9	0.2	<0.01	1.2	1.3	322
	3.0	.63	1.1	.44	7.0	.2	7.0	<.08	3.9	.2	<.01	.74	.80	190
	3.4	.80	1.2	.40	8.0	.2	10	<.08	4.0	<.08	<.01	.76	1.4	177
CC4	46	3.6	3.0	1.1	42	.2	110	.1	3.5	<.08	<.01	41	21	11,300
	40	3.7	3.1	.96	43	.2	97	.1	3.3	.09	<.01	41	18	10,600
	29	2.7	2.4	.67	35	.2	63	.1	3.0	.3	<.01	28	18	6,000
CC6	11	1.2	1.4	.61	12	.3	24	<.08	5.0	<.08	<.01	5.6	2.3	1,670
	5.3	.73	1.1	.43	7.0	.2	12	<.08	3.8	.2	<.01	3.2	2.0	783
	9.2	1.2	1.4	.43	14	.2	22	.1	3.8	.2	<.01	6.5	3.3	1,500
PCC8	9.8	1.1	1.6	.46	15	.2	22	.09	4.2	.3	<.01	4.0	1.3	929
	9.0	1.2	1.5	.42	13	.2	20	.09	4.3	.2	<.01	4.0	1.4	805
Field Blanks—Continued														
	<.05	<.01	<.01	<.03	—	<.08	<1.6	<.08	<.2	<.08	<.01	<.02	<.05	<.5
	<.05	<.01	<.01	<.03	—	<.08	<1.6	<.08	<.2	<.08	<.01	<.02	<.05	.9

[1] Replicate sample.

[2] Sample collected for determination of diel variability only; not plotted on any figures.

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