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Dissolved Cadmium, Zinc, and Lead Loads from Ground-Water Seepage into the South Fork Coeur d'Alene River System, Northern Idaho, 1999

Water-Resources Investigations Report 01–4274

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By Gary J. Barton

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CONVERSION FACTORS, VERTICAL DATUM, AND OTHER ABBREVIATED UNITS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	2.540	centimeter
mile (mi)	1.609	kilometer
pound per day (lb/d)	0.4536	kilogram per day
square mile (mi^2)	2.590	square kilometer

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

$$°F=(1.8)\ (°C)+32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD 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.

Other abbreviated units:

μg/L microgram per liter
μm micrometer
μS/cm microsiemens per centimeter at 25°C
mg/L milligram per liter
mL milliliter

Dissolved Cadmium, Zinc, and Lead Loads from Ground-Water Seepage into the South Fork Coeur d'Alene River System, Northern Idaho, 1999

By Gary J. Barton

Abstract

The valley of the South Fork Coeur d'Alene River and some of its tributaries have been heavily impacted by the dispersion of metal-enriched materials from the Coeur d'Alene mining district since 1884. The valley floor, including the unconsolidated valley-fill/flood-plain aquifers, is a major holding area for mine tailings. The U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency, characterized ground-water and surface-water relations for parts of the South Fork Coeur d'Alene River Basin and quantified the loading of dissolved metals into the South Fork Coeur d'Alene River system from ground-water seepage. This information can be used to determine the effects of dissolved metal from ground-water seepage on the river system and to evaluate the necessity and feasibility of remediation along gaining reaches. This study defines a field approach that can be repeated during and after the implementation of remediation solutions to measure the effectiveness of these efforts in reducing loading to streams.

The study area includes three reaches along the South Fork Coeur d'Alene River valley in the Coeur d'Alene mining district in central Shoshone County, northern Idaho: a 3.3-mile reach of Canyon Creek at Woodland Park, a 4.8-mile reach of the South Fork Coeur d'Alene River near Osburn, and a 6.5-mile reach of the South Fork Coeur d'Alene River near Kellogg and Smelterville. Seepage studies were conducted during July 27–29; September 17–19; and October 15–17, 1999. Each seepage study was conducted over a 3-day period, during which each station was measured on a daily basis for streamflow, and water-quality samples were collected. The consecutive-day approach allowed for an evaluation of variability in streamflow gains and losses and metal loading that resulted from changing hydrologic conditions.

During the July, September, and October seepage studies, ground-water seepage was the predominant source for gains in dissolved cadmium and zinc loads in the three study reaches, whereas tributary inflow loads were a minor source. The overall average net gain in dissolved zinc load from ground-water seepage into the South Fork Coeur d'Alene River near Kellogg and Smelterville was about 730 pounds per day, compared with the net gains in Canyon Creek at Woodland Park and the South Fork Coeur d'Alene River near Osburn, which were roughly similar at 150 and 218 pounds per day, respectively. The net gain in dissolved cadmium load from ground-water seepage into the three river reaches was about two orders of magnitude less than the gain in dissolved zinc.

On the South Fork Coeur d'Alene River study reaches near Osburn and near Kellogg and Smelterville, no pattern associated with an increase or decrease in dissolved lead load along gaining or losing subreaches was recognizable. Canyon Creek at Woodland Park was the only study reach where ground-water seepage contributed appreciably to the dissolved lead load; the average net gain was 1.5 pounds per day.

The average dissolved lead loads leaving South Fork Coeur d'Alene River study reaches

(corrected for tributary inflow along the study reaches) near Osburn and near Kellogg and Smelterville were 1.4 and 0.8 pounds per day less, respectively, than the loads entering the study reaches. The decrease in dissolved lead could be the result of lead adsorbing onto organic and inorganic sediment surfaces and (or) coprecipitating with iron and manganese oxides. These forms of lead likely will be resuspended into the water column at high flows.

INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) is conducting a Remedial Investigation/Feasibility Study (RI/FS) of the Spokane River Basin. One goal of this RI/FS is to improve ground-water and surface-water quality in the South Fork Coeur d'Alene River (SFCDR) valley, specifically, to reduce metal loads to the SFCDR. Since the late 1800s, tailings from mining activities have heavily impacted the valley of the SFCDR system. Streamflow and water-quality data indicate that some of the dissolved metal load in the SFCDR is the result of metal-enriched ground-water seepage from unconsolidated valley-fill/flood-plain aquifers, but the locations of principal gaining reaches and the dissolved metal load associated with ground-water seepage are poorly defined. Although streamflow data have been collected on the SFCDR and its tributaries at continuous measurement and miscellaneous measurement sites established by various entities, the locations and sampling periods of the sites do not allow for a detailed analysis of streamflow and metal loading from ground water in basin aquifers. RI/FS investigators need detailed information on the quantity and chemical quality of ground-water seepage to the SFCDR and its tributaries. In 1999, the U.S. Geological Survey (USGS), in cooperation with the USEPA, characterized ground-water and surface-water relations for parts of the SFCDR valley and quantified the loading of dissolved metals into the SFCDR system from ground-water seepage. This information can be used to determine the effects of dissolved metal sources on the water quality of the river system and to evaluate the necessity and feasibility of remediation along substantially impacted gaining reaches.

Purpose and Scope

The purpose of this report is to describe and quantify gains in streamflow and metal loading from ground water in the principal gaining reaches of the SFCDR and a tributary, Canyon Creek. To meet the overall objective, several goals were established for this investigation: (1) Identify gaining and losing stream reaches in flood-plain basins, (2) define the distribution of ground-water seepage to gaining reaches, and (3) quantify the metal loading to gaining reaches over a range of stream-stage and water-table conditions. Estimates of metal loading were limited to dissolved cadmium, zinc, and lead, generally the principal dissolved metals of concern in the river system. The timing of seepage studies was limited to periods of relatively low and stable flow. The report defines a field approach that can be repeated during and after implementation of remediation actions to measure the effectiveness of these actions in reducing metal loading to streams. This report does not provide a detailed assessment of the chemical and biological reactions taking place in the river or at the interface between the river and aquifer that could affect the fate and transport of metals within reaches of the SFCDR and Canyon Creek.

Description of Study Area

The study area, located in the Coeur d'Alene mining district in central Shoshone County, Idaho (fig. 1), is divided into three study reaches: a 3.3-mi reach of Canyon Creek at Woodland Park (reach A in fig. 1), a 4.8-mi reach of the SFCDR near Osburn (reach B in fig. 1), and a 6.5-mi reach of the SFCDR near Kellogg and Smelterville (reach C in fig. 1). The downstream limit of the study area is the SFCDR near Smelterville. At this downstream point, the SFCDR drains a 260-mi^2 area. Canyon Creek forms the upstream limit of the study area and drains a 22-mi^2 area. The Coeur d'Alene mining district ranks as one of the world's largest producers of silver and one of our Nation's largest producers of lead and zinc. The valley of the SFCDR and some of its tributaries has been heavily impacted by the dispersion of metal-enriched materials from the Coeur d'Alene mining district since the late 1800s. The valley floor is a major holding area for recent controlled-flotation tailings and older uncontrolled tailings.

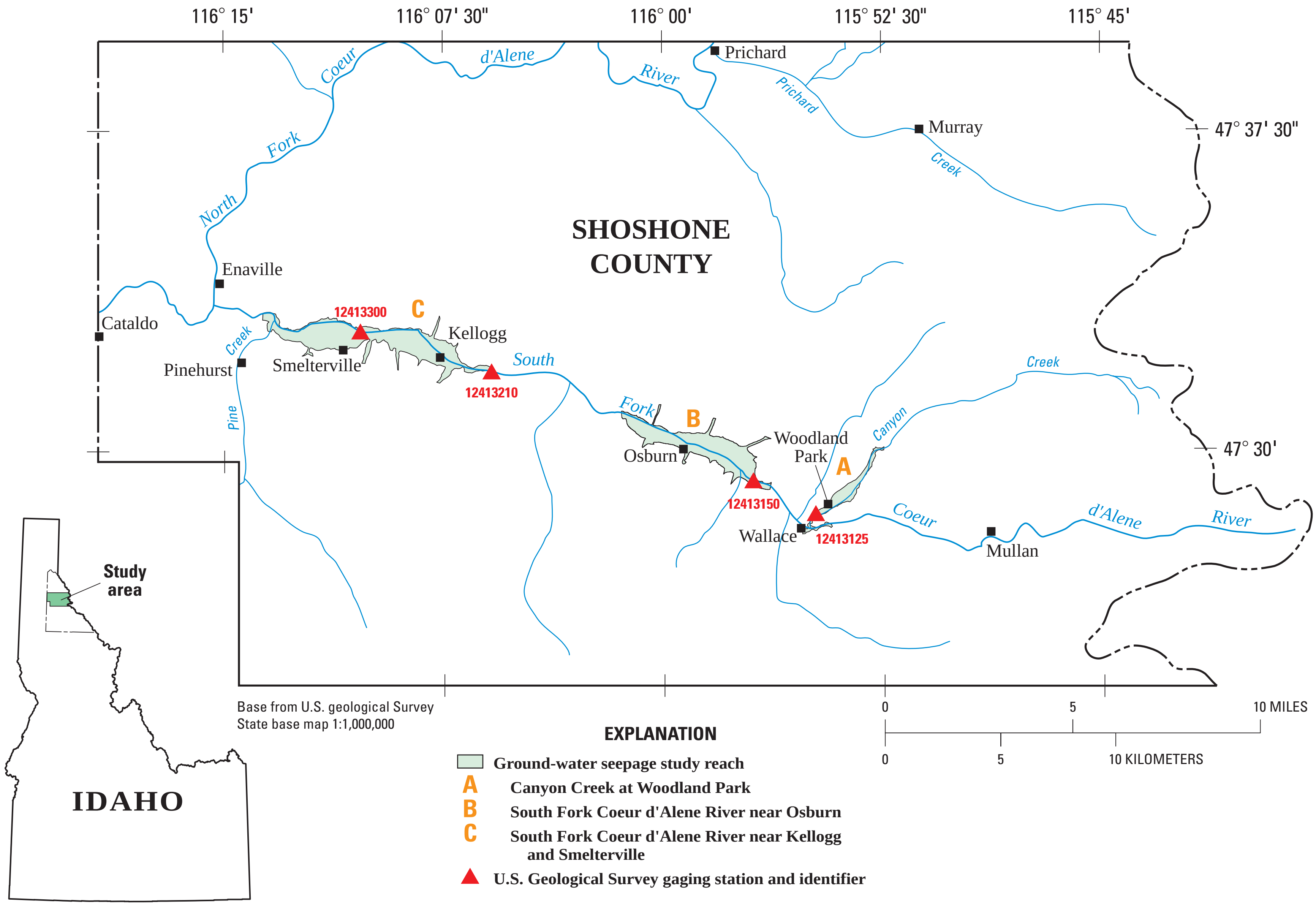

Figure 1. Location of ground-water seepage study reaches and associated gaging stations on the South Fork Coeur d'Alene River system, Idaho.

Valley fill in the Kellogg-Smelterville area consists of a thick sequence of unconsolidated alluvium, colluvium, and lacustrine deposits. Valley fill along the axis of the valley ranges in thickness from about 60 to 140 ft. Valley fill in the Osburn area consists primarily of alluvium and varies in thickness to about 70 ft (Norbeck, 1974; McCulley, Frick, and Gilman, Inc., Osburn, Idaho, written commun., 1996). Valley fill at Woodland Park has a maximum thickness of about 50 ft. Most of the bedrock in these study reaches consists of quartzite, argillite, and minor amounts of carbonate materials.

The bedrock in the Coeur d'Alene mining district has been severely folded and faulted. The Osburn fault traverses the SFCDR valley from the east-northeast side of Osburn to the south side of the valley west of Osburn (Hobbs and others, 1965). The Osburn Fault and Golconda Fault cut across the valley at Woodland Park on Canyon Creek at the valley's widest points. Although these faults predate valley-fill deposition, the movement of the bedrock surface may have caused some structural control on the thickness of valley-fill aquifers. The bedrock geology and structural history are detailed in a report by Hobbs and others (1965).

Recharge to the valley-fill aquifers in each of the study reaches occurs as runoff from mountainsides and underflow from bedrock; infiltration of precipitation on the valley floor; leakage from losing reaches of gulches, creeks, and rivers; and seepage from various impoundments, including tailings ponds. In each of the study reaches, ground-water flow in the valley fill is generally parallel to the valley axis, with minor variations along the mouths of tributaries and near the main stems of rivers (Norbeck, 1974; Dames and Moore, Kellogg, Idaho, written commun., 1990; J.C. Houck, Seattle, Washington, written commun., 1999). Streamflow data from monitoring networks and miscellaneous measurements made during previous studies indicate that river reaches generally lose flow in the upstream part of the valley-fill aquifers and gain flow in the downstream part as the valley-fill aquifers become constricted by shallow bedrock.

Sources of dissolved metals in ground water and surface water in a particular valley could include dispersed tailings, contaminated flood-plain deposits, contaminated gravels in active and abandoned stream channels, active and abandoned tailings piles, and abandoned mill complexes. Water moving through these sources enters the valley-fill aquifers and transports dissolved metals along ground-water flowpaths to gaining stream reaches. Elevated metal concentrations have been documented in some valley-fill aquifers, but the effects of the movement of metal-enriched ground water on metal loading in the river are unclear.

Acknowledgments

J. Chris Pfahl of ASARCO, Inc., Matthew R. Fein of Hecla Mining Company, and Bill Zanetti of Zanetti Bros., Inc., gave the USGS permission to enter their property in order to access the SFCDR system and install instream hydraulic potentiomanometers and instream stainless-steel minipiezometers, measure streamflow, and collect water-quality samples.

Kay Clever and others at Terra Graphics, Inc., assisted USGS scientists by measuring water levels in monitoring wells on the SFCDR flood plain near Smelterville during ground-water seepage studies and provided these data to the USGS. David Fortier, Bureau of Land Management, provided the USGS with information regarding the location of historical mining operations. John Houck of Agri Earth and Environmental, Inc., and Tom Mullen of McCulley, Frick, and Gilman, Inc., provided valuable information regarding the hydrology of Canyon Creek at Woodland Park. URS Greiner-Woodward Clyde, Inc., provided technical support necessary to collect water-level measurements in monitoring wells near Canyon Creek at Woodland Park.

Marti Calabretta of the Silver Valley Natural Resources Trustee and Dave Fields of the Idaho Department of Transportation halted restoration work and channel realignment on Canyon Creek during USGS ground-water seepage studies.

STUDY METHODS

Methods and technologies used for this study, referred to herein as a seepage study, provided accurate measurement and quantification of dissolved metal loads from ground water seeping into the SFCDR system. The study methods and field approach can be repeated during and after remediation to measure the effectiveness of these efforts in reducing metal loading to streams.

The approach included identifying the general location of transition zones between gaining and losing subreaches within a study reach prior to designing the measurement site network. Accurate calculation of gains in streamflow and dissolved metal loads from ground water in gaining subreaches requires that streamflow and water-quality measurement sites be located near the transition zones between gaining and losing subreaches. Three seepage studies were conducted during the summer and fall to evaluate the effects of seasonal changes in hydrologic conditions on observed loading. The ground-water seepage runs were made during summer and early fall when the river stage was sufficiently low to allow instream measurements. Each seepage study consisted of multiple seepage runs conducted over 3 consecutive days and used to evaluate variability in flow and load measurement.

Study methods used to collect and analyze data are described in the following sections. Additional details about study methods are provided in the Quality Assurance Project Plan for USGS studies in support of the Spokane River Basin RI/FS submitted on March 11, 1999, to the USEPA (Administrative Record, on file in Region 10, Seattle, Wash.).

Identifying Gaining and Losing Subreaches

Before seepage studies were conducted, a reconnaissance-level field study was conducted during June and July 1999 to estimate the general locations of the transition zones between gaining and losing subreaches in the three study reaches (fig. 1). Hydraulic potentiomanometers were installed in the riverbed and were used to locate the transition zones. These data helped establish the locations of seepage sites that bounded gaining or losing subreaches. So that the dynamics of the gaining and losing subreaches during the ground-water seepage studies could be better understood, hydraulic potentiomanometers remained installed in the riverbed for the duration of the studies. Measurements were made at each hydraulic potentiomanometer prior to or during each seepage study.

Hydraulic potentiomanometers were used to measure the difference between (1) hydraulic head of ground-water levels and surface-water stage and (2) the specific conductance of ground water and surface water. In addition, specific conductance was measured along a cross section of the river at most hydraulic potentiomanometer sites. Lateral stratification of specific conductance along river cross sections is an indicator of ground water seeping into the surface water. These data were combined to help determine the direction that water was seeping, upward or downward, through the riverbed.

Hydraulic potentiomanometers (fig. 2) consist of a manometer board and a 1/2-in. (inside diameter) steel minipiezometer. The lower 6 in. of the minipiezometer has twenty-four 1/8-in.-diameter openings that behave as a well screen (fig. 2). The potentiomanometers were driven into the riverbed with a portable safety hammer to depths ranging from 1.5 to 4 ft below the river bottom. To ensure that potentiomanometers were in good hydraulic connection with the surrounding aquifer, a portable peristaltic pump was used to inject water into or withdraw water from the minipiezometer, thereby forcing water through the 1/8-in.-diameter openings and removing fine-grained sediments that clogged the openings during installation. Hydraulic potentiomanometer installations were considered complete when pumping action was halted and water levels inside the minipiezometer equilibrated rapidly with water levels in the surrounding aquifer. Water levels inside all piezometers equilibrated rapidly with water levels in the surrounding aquifer. The accuracy for measuring the difference between hydraulic head of ground-water levels and surface-water stage is 1 mm (0.04 in.). Measurement precision—consecutive water-level measurements over a brief period—varied depending on extent of ripple action on the river surface. Typically, measurement precision was roughly 3 mm (0.12 in.). To mute the effects that ripple action and flowing water have on measurement precision, the potentiomanometer's surface-water line was inserted through a small opening in the top an 8-in.-diameter cylinder resting on the river bottom next to the potentiomanometer. The cylinder's bottom was open. Detailed descriptions of the uses of the hydraulic potentiomanometer are provided by Winter and others (1983).

Establishing Ground-Water Seepage Stations

After the field reconnaissance to estimate the general locations of the transition zones between losing and gaining river subreaches in the three study reaches (fig. 1) was completed, seepage stations were established at 25 sites on the SFCDR and Canyon Creek and at the mouths of eight tributaries draining into the SFCDR (figs. 3, 4, 5). Most main-stem seepage stations were located near the transition zone between gaining

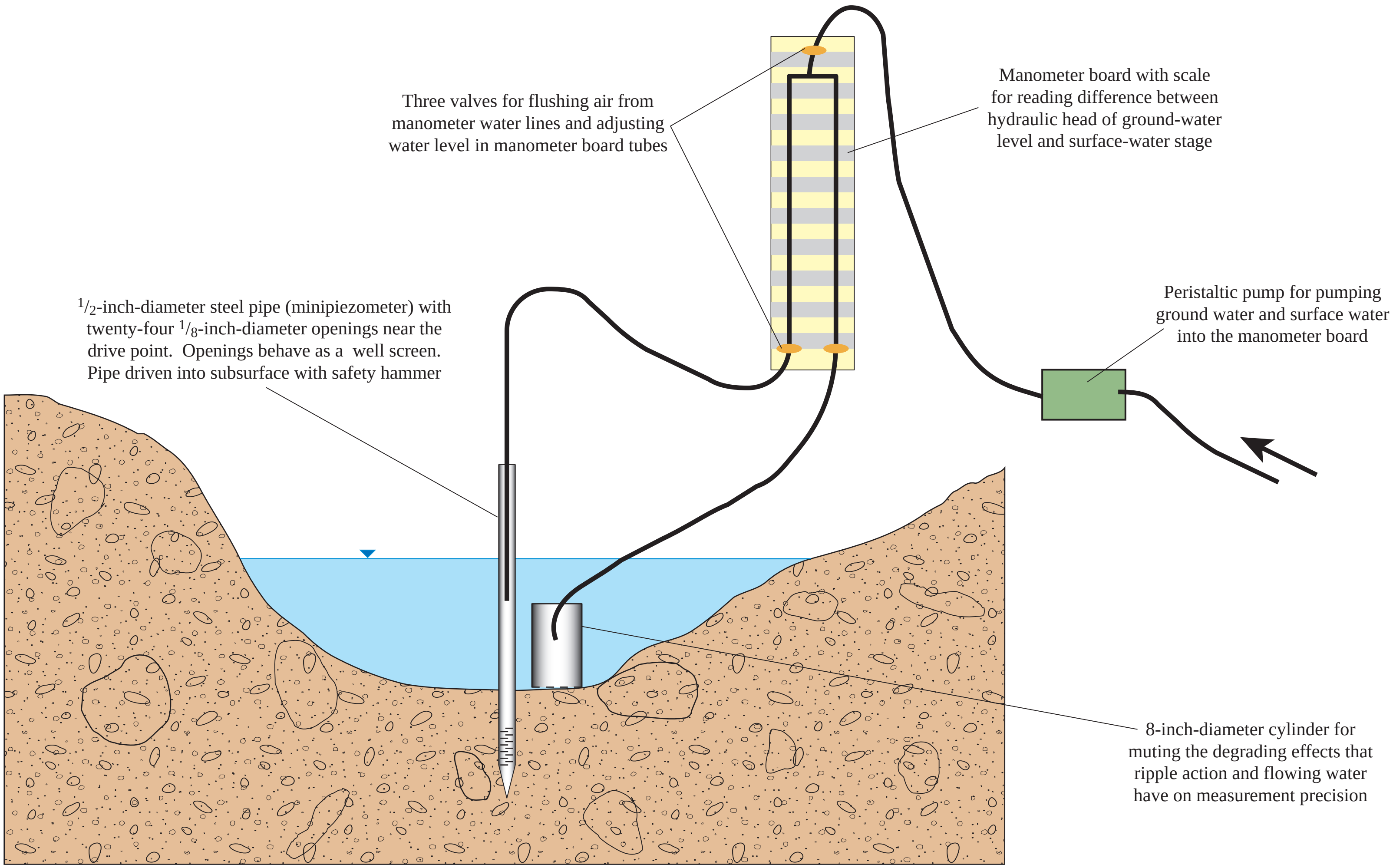

Figure 2. Schematic of hydraulic potentiomanometer.

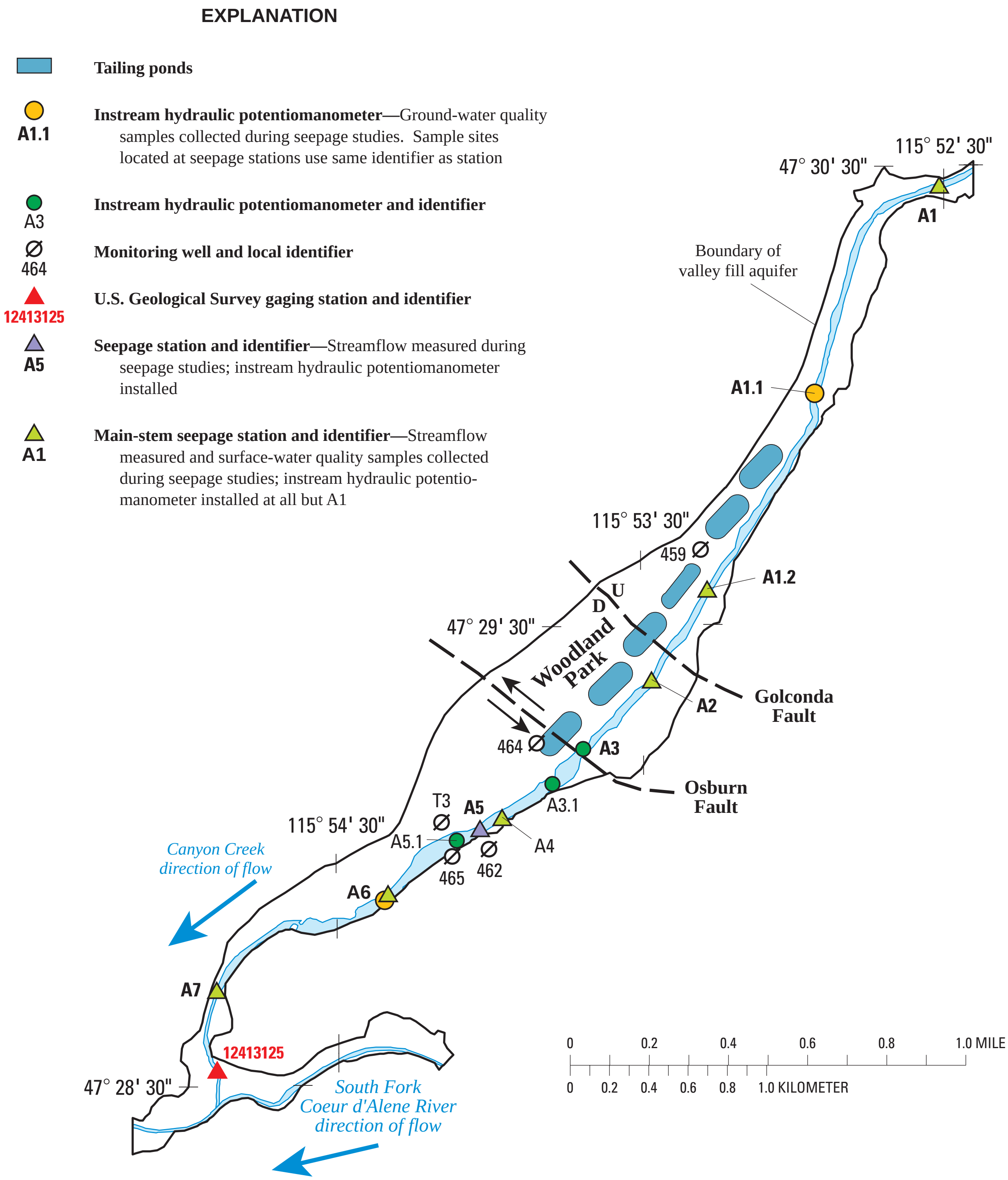

Figure 3. Location of valley-fill aquifer and data collection sites for seepage studies on Canyon Creek at Woodland Park, Idaho, July through October 1999. (Location of study reach shown in figure 1)

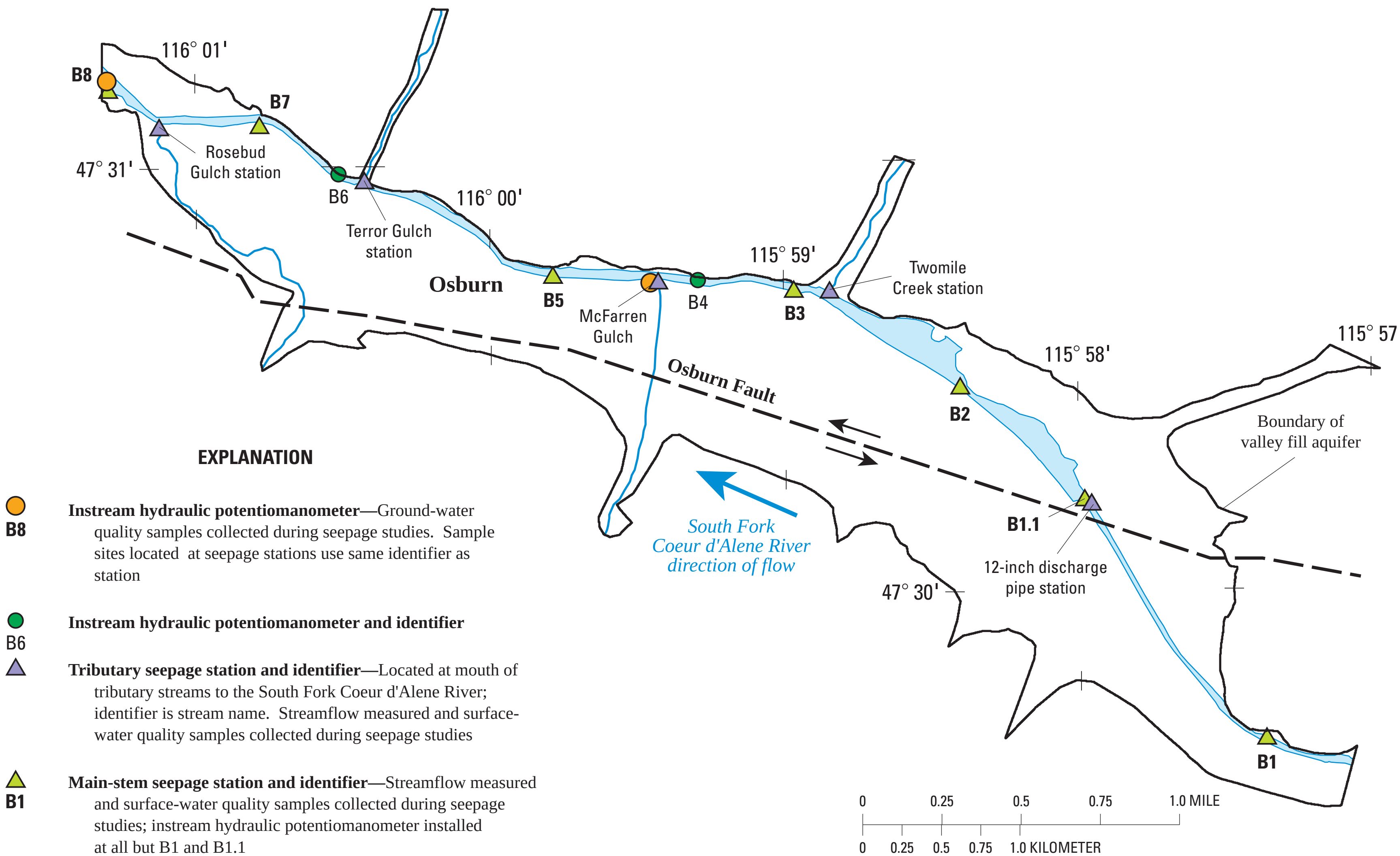

Figure 4. Location of valley-fill aquifer and data collection sites for seepage studies on the South Fork Coeur d'Alene River near Osburn, Idaho, July through October 1999. (Location of study reach shown in figure 1)

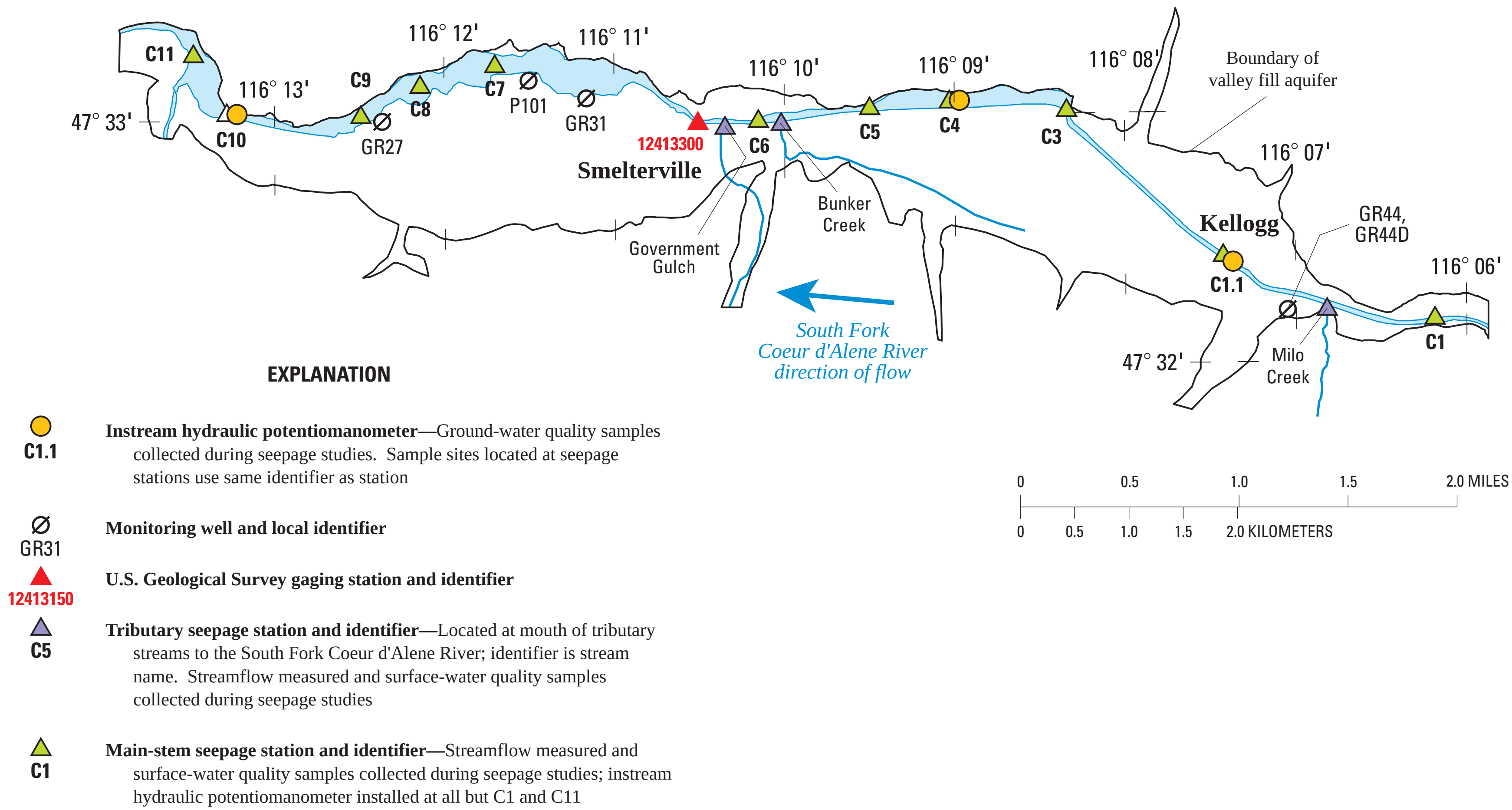

Figure 5. Location of valley-fill aquifer and data collection sites for seepage studies on the South Fork Coeur d'Alene River near Kellogg and Smelterville, Idaho, July through October 1999. (Location of study reach shown in figure 1)

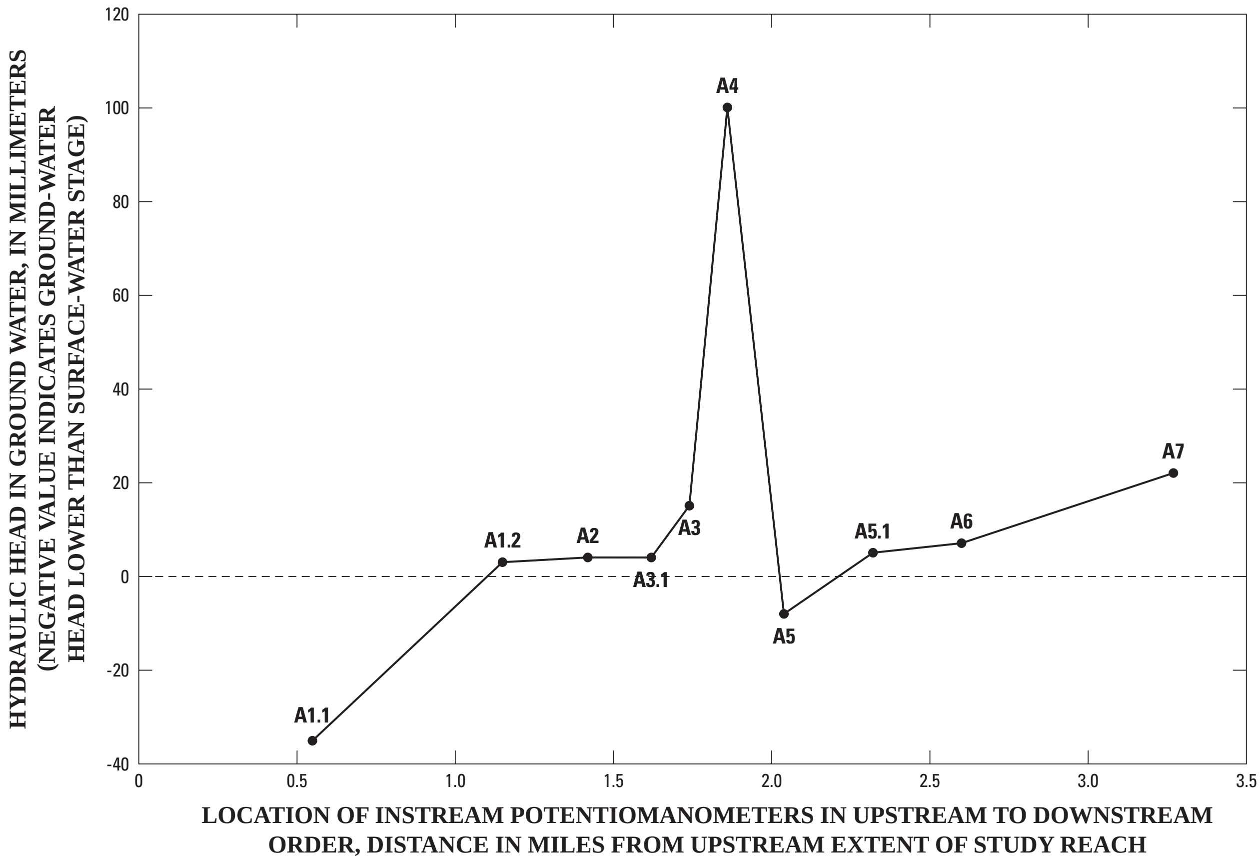

Figure 6. Difference between hydraulic head of ground-water levels and surface-water stage at hydraulic potentiomanometers in Canyon Creek at Woodland Park, Idaho, July 1999. (Station locations shown in figure 3)

and losing subreaches; a few were located within gaining and losing subreaches. To acquire the most accurate streamflow measurements, seepage stations were located where river morphology formed a relatively straight segment with no braiding and minimal turbulence. A local identifier was established for seepage stations, consisting of a single letter that designates the study reach—Canyon Creek at Woodland Park, A; SFCDR near Osburn, B; and SFCDR near Kellogg and Smelterville, C—followed by a sequence number. This sequence number indicates the order of the relative location of the station along a study reach; for example, station A1 is the most upstream station in the Canyon Creek at Woodland Park study reach. Some stations were added later during the study and are numbered as a decimal, for example, B1.1, located between stations B1 and B2.

The following paragraphs describe how some of the data collected at hydraulic potentiomanometers were used to locate the transition zones between gaining and losing river subreaches, and how the data were used to monitor transient changes in the locations of these transition zones. Measurements of differences between hydraulic head of ground-water level and surface-water stage and specific conductance of ground water and surface water at hydraulic potentiomanometers are presented in appendices A1 to A6 (back of report).

Hydraulic head data collected on the main stem in study reaches during the field reconnaissance indicated zones of upward gradient (hydraulic head in the aquifer greater than river stage), zones of downward gradient (river stage greater than hydraulic head in the underlying aquifer), and zones of no gradient. Generally, water moves from zones of high hydraulic head to zones of low hydraulic head; thus, an upward gradient indicates potential seepage of ground water to the river; a downward gradient indicates potential seepage of river water to ground water; no gradient indicates no movement of water across the riverbed. Figure 6 shows the difference between hydraulic head of ground-water levels and surface-water stage measured during the field reconnaissance in Canyon Creek and the locations of seepage stations along that study reach. Seepage stations were located near zones of near-zero head gradient (transition zone) between presumed gaining and losing reaches. For example, stations A3 and A6 were located in transition zones that bracketed a zone of upward hydraulic gradient. Additional stations were added within gaining and losing reaches to better define the distribution of load gain or loss within the subreach.

The measured difference between specific conductance of surface water and ground water also was used to define gaining and losing reaches prior to seepage studies. For those seepage stations where the zones of upward gradient indicated ground-water seepage, the specific conductance of ground water (soon likely to seep into the river) was typically higher than that of surface water. This was observed at hydraulic potentiomanometers located at seepage stations A6, B4, B5, B8, and C8 (except for July) (apps. A2, A4, A6.) This elevated specific conductance indicated that entrained with the ground water were significant concentrations of dissolved metals, particularly zinc. The chemical analyses of ground-water samples from the riverbed and the dissolved metal loads in surface water, presented in the section "Dissolved Cadmium and Zinc Loads," support this interpretation. As river flows decreased in each study reach during the summer and fall months, the specific conductance of the surface water, measured at the hydraulic potentiomanometers, increased. By September, the specific conductance of the surface water roughly equaled or sometimes exceeded the specific conductance of ground water seeping into the SFCDR at stations B8 (app. A4) and C10 (app. A6).

Measurements were collected to develop a profile of specific conductance across the river at hydraulic potentiomanometer sites to detect lateral stratification of water quality. Lateral stratification of surface-water quality is an indicator of ground water seeping into sur-

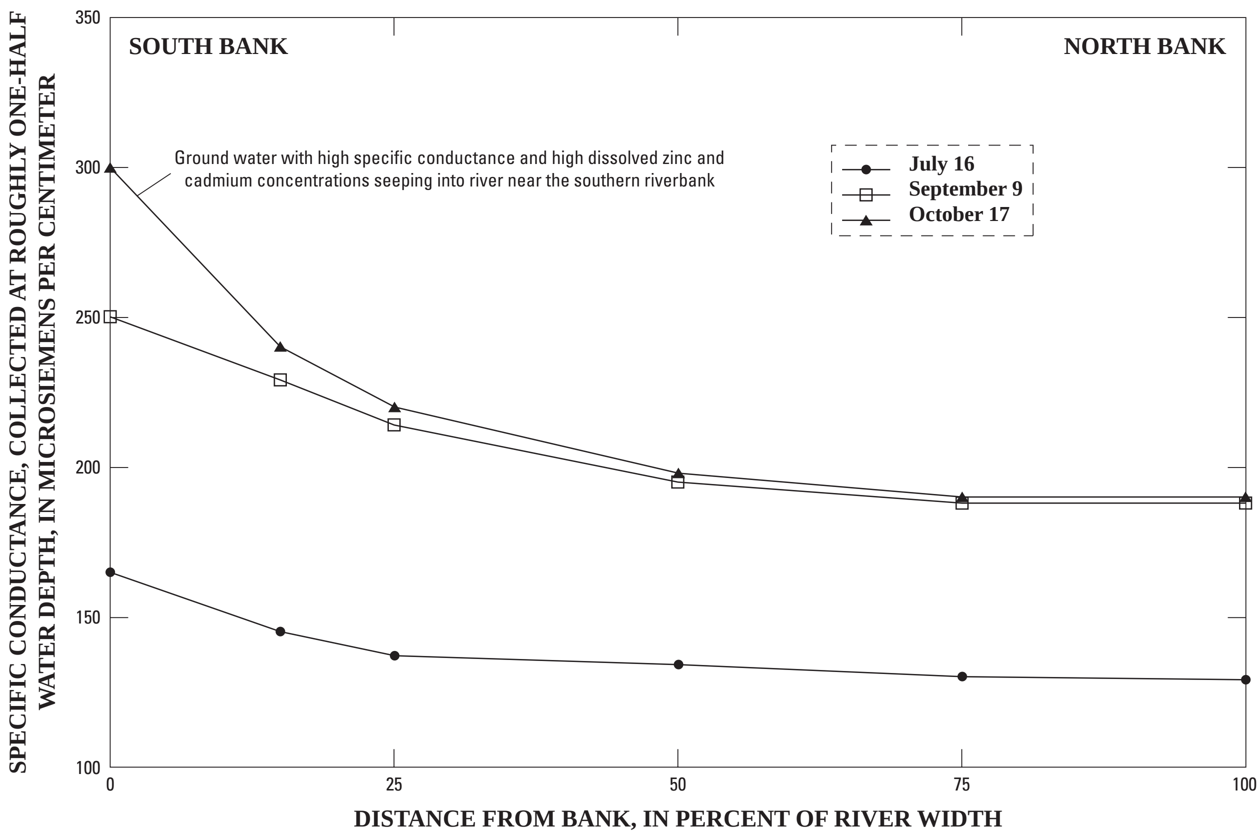

Figure 7. Specific conductance profile across the South Fork Coeur d'Alene River seepage station C4 near Kellogg and Smelterville, Idaho, July through October 1999. (Station location shown in figure 5)

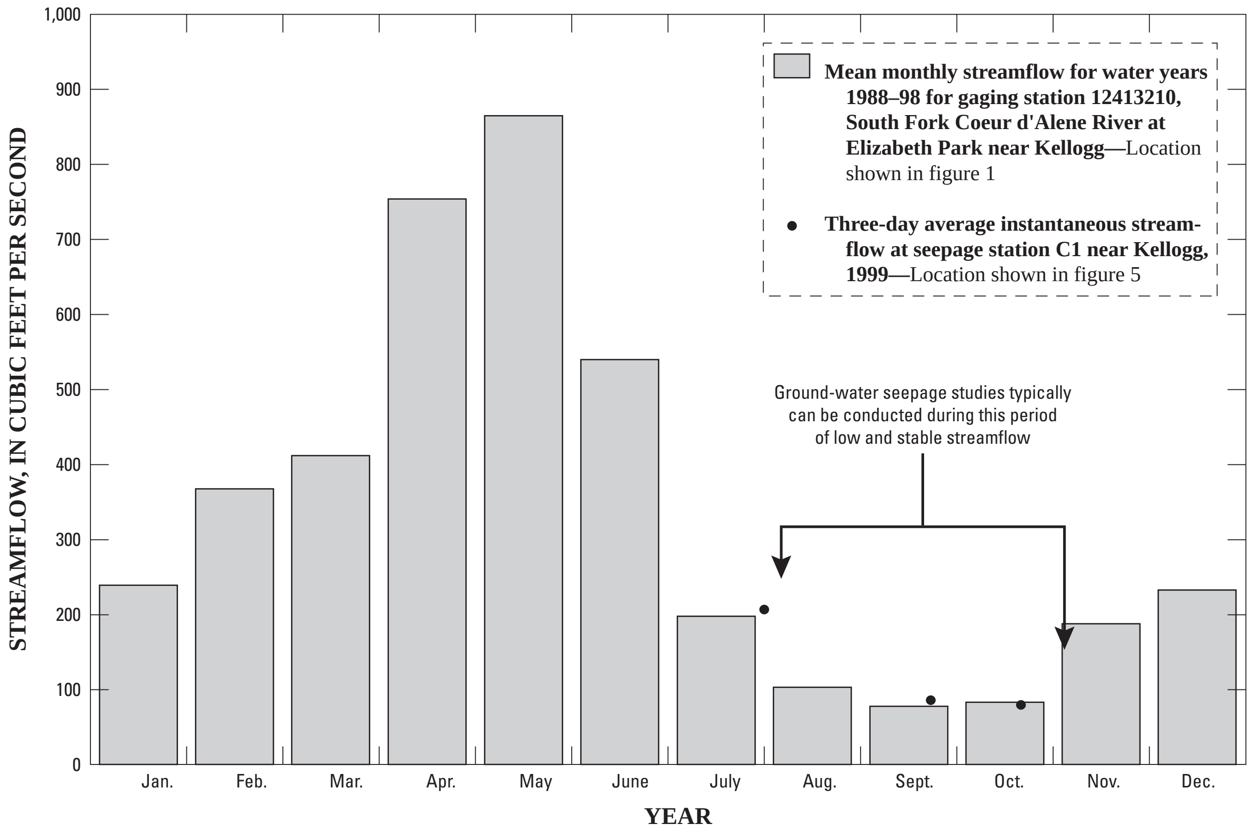

Figure 8. Historical streamflow, 1988–98, and streamflow at seepage station C1 on the South Fork Coeur d'Alene River near Kellogg and Smelterville, Idaho, July through October 1999. (Station location shown in figure 5)

face water. For example, the specific conductance of surface water in the SFCDR near Kellogg and Smelterville at seepage station C4 (fig. 7) was stratified, whereas the surface water at upstream seepage station C3 was not stratified. Specific conductance of water flowing near the southern riverbank at station C4 was higher than that of water flowing near the northern bank, thus indicating that ground water with a relatively higher specific conductance was seeping into the river near the southern bank.

Seepage Studies

The timing of the ground-water seepage studies was dictated by stream conditions and data collection methods. On the basis of decades of continuous USGS streamflow measurements in the study area and the field methods, seepage studies can be conducted on the study reaches from about mid-June to mid-October, a period of relatively low and stable flow (fig. 8). Low flow is necessary for measuring streamflow and for collecting water-quality samples because both activities require personnel to wade the width of the river. Stable streamflow is an important criteria because this is the optimal condition during which streamflow measurements can detect losing or gaining subreaches within a study reach. Streamflow, stage, and ground-water levels did vary slightly during this period. The seepage studies did not begin until late July because of high water. Three seepage studies, referred to as the July, September, and October seepage studies, were conducted during July 27–29; September 17–19; and October 15–17.

Each seepage study within a study reach consisted of three sets of streamflow and water-quality measurements collected during 3 consecutive days, and one set of ground-water quality samples collected from in-stream, stainless-steel potentiomanometers. Each set of streamflow measurements and water-quality sampling assigned to a study reach was completed in a day and is referred to as a seepage run. Streamflow measurements and water-quality sampling were nearly simultaneous. Data collection began at the most downstream seepage station in the study reach, and each subsequent measurement was made at stations located farther upstream. During each seepage run, streamflow measurements and water-quality samples were collected at six sites on Canyon Creek at Woodland Park; at six or seven sites on the main stem of the SFCDR near Osburn, and at six or seven sites on the main stem of the SFCDR near Kellogg and Smelterville (table 1; figs. 3, 4, 5). Nearly all seepage stations were located in the estimated zone of transition between gaining and losing reaches. During each seepage run, one to three extra streamflow measurements were collected within gaining or losing reaches. In addition, during each seepage study, a set of streamflow measurements and water-quality samples were collected at the mouth of any significant tributary or inflow to the main stem of the river: Milo Creek, Government Gulch, and Bunker Creek, which empty into the SFCDR near Kellogg and Smelterville; a tailings discharge pipe, Twomile Creek, McFarren Gulch, Terror Gulch, and Rosebud Gulch, which empty into the SFCDR near Osburn. No inflows were observed on Canyon Creek at Woodland Park.

STREAMFLOW MEASUREMENTS

During each seepage run, the streamflow measurements, computation of streamflow, and quality assurance procedures were completed using standardized USGS methods for collection of streamflow data. Flow measurements were collected using Price-AA current meters. The number of current meter measurements collected at a river cross section ranged from 26 to 34. A summary of the number of streamflow measurements collected in each study reach is given in table 1.

Variance, associated with fluctuating streamflow within a study reach during each 3-day survey, was minimized by using the continuous streamflow data from nearby gaging stations as a basis for removing the effects of short-duration fluctuations on seepage streamflow measurements. Graphs showing the variability of streamflow are provided in appendix B (back of report). USGS gaging stations 12413125 on Canyon Creek near the mouth and 12413150 on the SFCDR at Silverton (fig. 1) were used for this purpose. Of the 221 flow measurements made at seepage stations, only 20 were adjusted for short-duration streamflow fluctuations. Small, short-duration streamflow fluctuations were detected during the July seepage runs on the SFCDR near Smelterville and Kellogg, and some streamflow measurements collected at seepage stations were adjusted. Streamflow measurements at seepage station(s) in a study reach were adjusted by (1) computing the rate of change in streamflow at the USGS gaging station closest to the study reach, and (2) estimating the streamflow time of travel between the USGS gaging station closest to the study reach and the seepage station(s).

WATER-QUALITY SAMPLING

During collection of all water-quality samples, the water temperature, pH, and specific conductance were measured. Meters and probes used for field measurements were calibrated and operated according to manufacturer's instructions. Water-quality samples were collected and field samples were processed using "clean" protocols that ensure noncontamination at the parts-per-billion level (Horowitz and others, 1994). A peristaltic pump with polypropylene tubing was used to pump water samples from the churn splitter through a 0.45-µm Gelman capsule filter for dissolved metals analysis. The filter was prerinsed with 1,000 mL of deionized water. Dissolved metal samples were pre-

Table 1. Number of seepage stations, instantaneous streamflow measurements, and regular water-quality samples in three study reaches of the South Fork Coeur d'Alene River system, Idaho, July through October 1999

[SFCDR, South Fork Coeur d'Alene River; Sta, number of seepage stations; Q, streamflow measurement; Phy, temperature, pH, specific conductance, and alkalinity measurement; dM, analysis of dissolved metals as cadmium, zinc, and lead; dCi, analysis of dissolved common ions, Mn, and Fe]

	Number of seepage stations, streamflow measurements, and regular water-quality samples														
	July 27–29					September 17–19					October 15–17				
Study reaches	Sta	Q	Phy	dM	dCi	Sta	Q	Phy	dM	dCi	Sta	Q	Phy	dM	dCi
Canyon Creek at Woodland Park	6	12	7	0	0	7	21	20	18	6	7	21	18	18	5
SFCDR near Osburn	11	32	21	21	5	11	24	23	23	8	10	25	25	21	6
SFCDR near Kellogg and Smelterville	11	26	24	23	9	11	29	28	21	7	11	31	28	23	8
Total	28	70	52	45	12	29	74	71	61	21	28	77	70	64	19

served with 2 mL of ultrapure Ultrex nitric acid. These metal samples were analyzed at the USGS National Water Quality Laboratory for dissolved cadmium, lead, zinc, and hardness; about one-third of the samples were left untreated for analysis of alkalinity, calcium, magnesium, sodium, chloride, sulfate, fluoride, silica, iron, and manganese.

Surface-water samples were collected using nonmetallic samplers and cross-sectional, depth-integrated sampling procedures described by Edwards and Glysson (1988). At each seepage station on the SFCDR and Canyon Creek, depth-integrated water samples were collected from 10 equal-width segments across the river. These individual samples were composited in a churn sample splitter from which samples were withdrawn for laboratory analyses. The depth-integrated sampling procedure is time and labor intensive because of the number of samples that are needed to form a representative composite. This approach was essential because the water quality in the SFCDR river system was highly stratified in some of the subreaches. An example of this stratification is shown in figure 7. Surface-water quality samples collected at seepage stations are summarized in appendices C1, C2, and C3 (back of report).

Ground-water quality samples were collected from beneath the riverbed at seven seepage stations through hydraulic potentiomanometers constructed with a stainless-steel minipiezometer. Before each minipiezometer was installed in the riverbed, it was rinsed with dilute nitric acid and then rinsed twice with deionized water. A peristaltic pump with polypropylene tubing was used to pump sample water from the instream minipiezometer into a churn sample splitter from which samples were withdrawn for laboratory analyses. To ensure that water samples were representative of ground water, temperature and specific conductance (Koterba and others, 1995) were monitored until they became stable during the purging of water from the minipiezometer prior to collection of the sample. Ground-water sample analyses are summarized in appendices C4, C5, and C6 (back of report).

QUALITY ASSURANCE AND QUALITY CONTROL

To ensure an accurate measurement of pH, specific conductance, and alkalinity, the meters were calibrated at the beginning of each day. Probes were submerged in a standard solution prior to all measurements, and the meters were recalibrated on an as-needed basis during daily operations. More than 15 percent of dissolved cadmium, zinc, and lead samples were quality control samples in the form of field replicates, equipment blanks, and laboratory spikes. The relative percent difference (RPD) was calculated for constituent concentrations in paired regular-replicate samples and paired regular- and laboratory-spiked samples. Also, chain-of-custody forms accompanied shipments of all water-quality samples. Results from quality control samples are described in the section "Quality Control Samples."

Quantification of Dissolved Metal Loads from Ground-Water Seepage

Streamflow measurements were combined with water-quality data to compute dissolved cadmium, zinc, and lead loads at seepage stations. Loads measured at seepage stations were adjusted by subtracting the load contributed from any tributary(s) along the study reach. The difference in the adjusted dissolved metal load from one seepage station to the next downstream seepage station (river subreach) within a river reach was the basis for computing gains and losses in dissolved metal loads along a study reach. Gains in dissolved metal loads from ground-water seepage were quantified (1) for each gaining subreach during a seepage run and (2) as the net gain in dissolved loads from ground-water seepage for an entire study reach. Net gain in the study reach was calculated as the load leaving the study reach minus the load entering the study reach minus loads associated with tributary inflow to the study reach. Gross gain in dissolved loads from ground-water seepage—dissolved metal loads from ground-water seepage along a study reach without accounting for loss in metal load along a losing subreach—was not reported. Gross gain loads would have been higher than the net gain loads.

HYDROLOGIC CONDITIONS AND STREAMFLOW GAINS AND LOSSES DURING SEEPAGE STUDIES

Three seepage studies were conducted during different times to determine whether different hydrologic conditions substantially affected seepage and load in the SFCDR system. Graphs showing difference between hydraulic head and specific conductance of ground water and surface water at instream minipiezometer sites for each study reach are provided in appendix A. Graphs showing streamflow at the seepage stations along each study reach minus inflow from tributaries are provided in appendix B. Streamflow data collected during each seepage study in Canyon Creek and the SFCDR near Kellogg and Smelterville are provided in table 2, figures 9a and 9b, and appendix C2. The hydrologic conditions during each seepage study are described in the following paragraphs.

During the July seepage study, flow in the SFCDR at station C1 (fig. 8) was about 10 ft^3/s above the monthly mean for 1988–98 at nearby USGS gaging station 12413210. This slightly elevated flow was due to above-average runoff from an abnormally thick snowpack in the surrounding mountains. The higher-than-normal flows delayed startup of the first seepage runs by about 3 weeks because of safety concerns for the instream sampling personnel. During the September and October seepage studies, streamflow was nearly identical to the mean monthly flow for that time of year; streamflows were slightly less than half the flow measured during the July seepage runs (figs. 8, 9).

The seepage studies showed the connection between the SFCDR system and the underlying valley-fill aquifer to be dynamic. During July through October, the locations of some gaining and losing subreaches shifted upstream or downstream. For example, by the September seepage study on the SFCDR near Osburn, the gaining subreach between stations B1 and B1.1 had migrated downstream between stations B1.1 and B2 (apps. B4, B5). On the SFCDR near Kellogg and Smelterville, the subreach between seepage stations C1 and C3 did not lose or gain measurable amounts of water during the July seepage study; however, during the September seepage study, this subreach was losing water (apps. B7, B8). These changes occurred because of changes in the relations between river stage and ground-water levels in the valley-fill aquifers; that is, along these subreaches, ground-water levels declined at a faster rate than that of river stage.

By the July seepage study, the valley-fill aquifers had been replenished by spring snowmelt runoff, and ground-water levels had peaked and started to recede. Declining streamflow in the SFCDR study reaches during the July seepage study represented a period of transition from a snowmelt-runoff-dominated streamflow to a ground-water-dominated streamflow known as base flow (fig. 10a). Streamflow during the September and October seepage studies represented base flow conditions (figs. 8, 9). During the October seepage study on Canyon Creek, the river stage was approaching the season minimum and stabilizing, whereas ground-water levels were continuing to decline at a steady rate (fig. 10b). During the October seepage study on the SFCDR near Kellogg and Smelterville, the river stage was approaching the season minimum and stabilizing, and

Table 2. Statistical summary of instantaneous streamflow measurements, field water-quality measurements, concentrations of dissolved metals, and computed loads of dissolved metals for seepage stations in the South Fork Coeur d'Alene River system, Idaho, July through October 1999

[SFCDR, South Fork Coeur d'Alene River; No., number; Inst. Q, instantaneous streamflow measurement; ft^3/s, cubic feet per second, SC, specific conductance, µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; lb/d, pounds per day; dissolved concentration, filtrate passes through a 0.45-µm capsule filter]

		Field measurements				Cadmium		Lead		Zinc	
No. of samples	Descriptive statistical summary	Inst. Q (ft^3/s)	pH	SC (µS/cm)	Alkalinity (mg/L as $CaCO_3$)	Dissolved concentration (µg/L)	Load (lb/d)	Dissolved concentration (µg/L)	Load (lb/d)	Dissolved concentration (µg/L)	Load (lb/d)
	Canyon Creek at Woodland Park										
	median	15	7.5	97	38	9.56	0.7	24.16	1.9	1,412.1	110
	minimum	11	6.9	92	36	5.79	0	9.19	0.6	830	62
36	maximum	19	8.0	118	44	18.29	1.7	33.00	3.2	2,817.2	247
	SFCDR near Osburn										
	median	60	7.9	157	52	7.22	2.5	9.29	3.1	1,001.8	383
	minimum	45	7.0	90	25	3.89	1.9	5.93	1.8	637	236
65	maximum	183	8.2	173	66	9.04	4.8	16.04	13.6	1,462	720
	SFCDR near Kellogg and Smelterville										
	median	89	7.4	205	41	7.41	4.7	5.5	2.6	1,223.5	810
	minimum	73	6.8	121	32	3.15	2.8	1.91	0.9	524	357
67	maximum	239	7.9	525	48	12.88	8.8	8.42	9.2	2,421.1	1,590

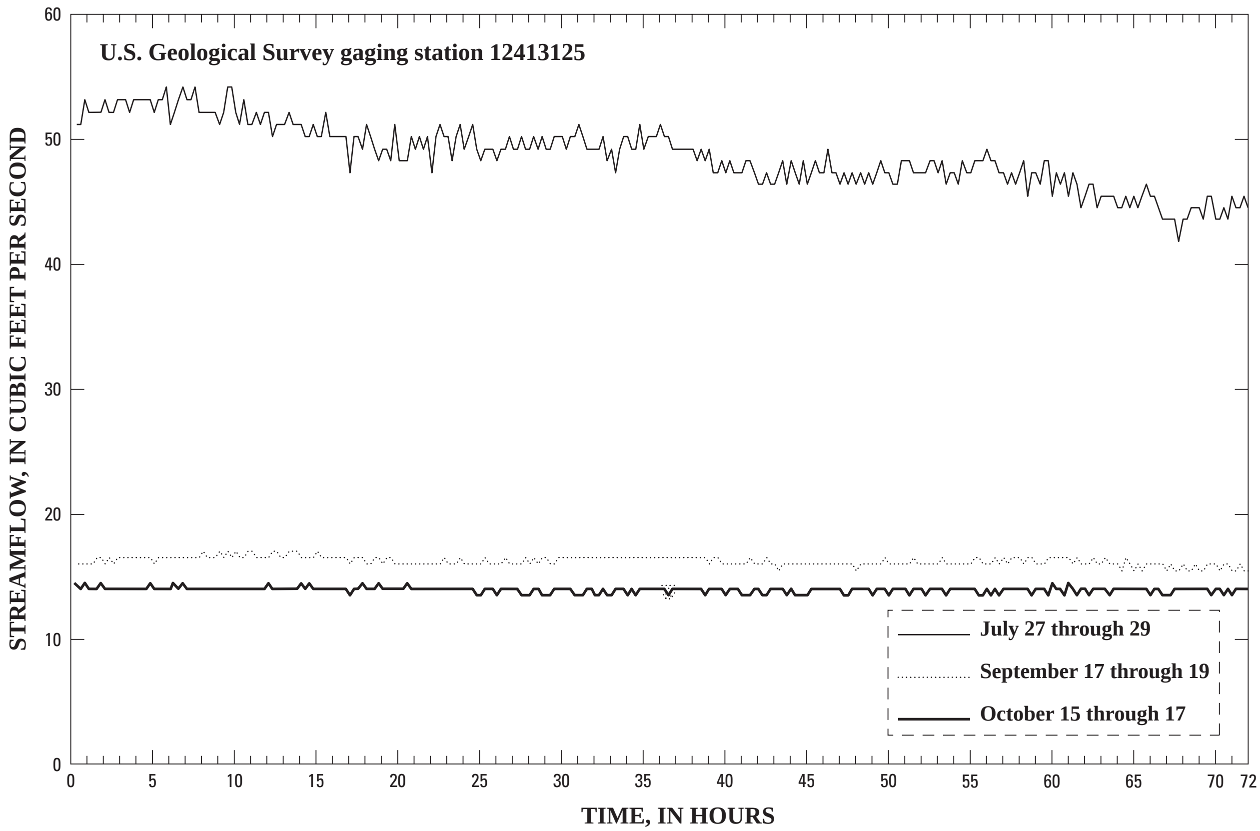

Figure 9a. Streamflow during seepage studies on Canyon Creek at Woodland Park, Idaho, July through October 1999. (Gaging station location shown on figure 1)

ground-water levels were generally stabilizing or beginning to rise (fig. 10c).

There was no measurable precipitation 10 days prior to or during any seepage run. Steady flow in the river system greatly enhanced the ability of the ground-water seepage runs to reliably measure the amount of water gained and lost in the subreaches. During the July seepage study, there were some small daily fluctuations in streamflow, mainly in the Kellogg and Smelterville study reach and, to a lesser degree, on Canyon Creek, that could have been associated with snowmelt runoff. These daily fluctuations in streamflow were accounted for in the metal-loading estimates.

During this study, streamflow entering a study reach was generally less than streamflow exiting the study reach, mainly as a result of runoff from surrounding uplands to study reaches. However, there were several exceptions to this trend. During the July seepage run, the average streamflow entering the Canyon Creek at Woodland Park study reach was greater than streamflow exiting the study reach. During the September seepage run, the average streamflow entering the Canyon Creek at Woodland Park study reach and the average streamflow exiting the study reach were nearly equivalent. Also, during the September seepage studies on the SFCDR near Osburn and near Kellogg and Smelterville, streamflow entering and exiting the study reaches was nearly equivalent. During the period between the July and September seepage studies, several factors contributed to the reduction of gains in streamflow along the study reaches: runoff from the surrounding uplands that contribute flow to this river system approached a minimum because the seasonal snowpack had melted, there was no measurable rainfall, and the evapotranspiration rates had peaked. During the October seepage study, more streamflow was measured exiting the Canyon Creek at Woodland Park study reach than entering the reach, a reversal in the trend of the July and September seepage studies (apps. B1, B2, B3). For the first time, the lowermost subreach on Canyon Creek near its mouth between seepage stations A6 and A7 gained water instead of losing water.

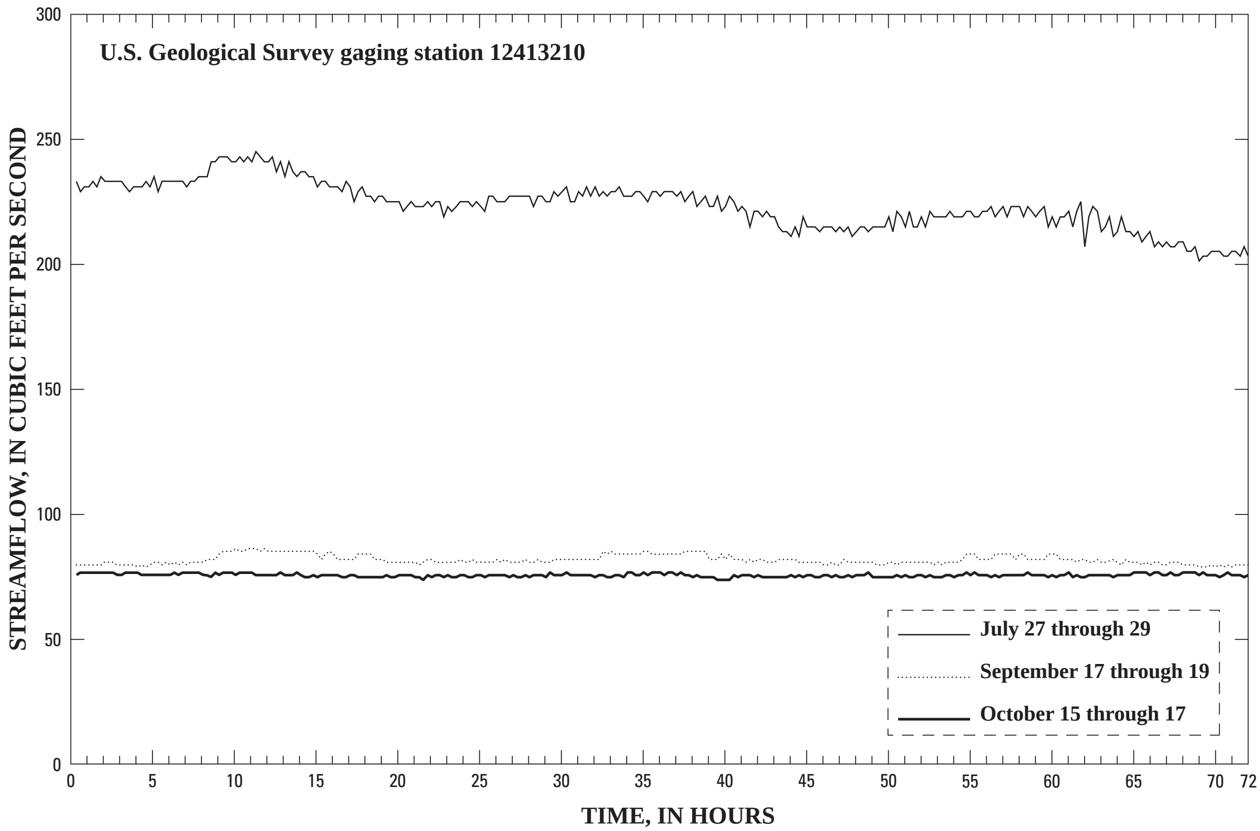

Figure 9b. Streamflow during seepage studies on the South Fork Coeur d'Alene River near Kellogg and Smelterville, Idaho, July through October 1999. (Gaging station location shown in figure 1)

Canyon Creek at Woodland Park

The July and September seepage studies conducted on Canyon Creek at Woodland Park revealed similar subreaches losing and gaining water (apps. B1, B2, B3; figs. 11–16, back of report), from the upstream seepage station A1 to the downstream station A7. The creek lost water to the underlying valley-fill aquifer along the subreach between stations A1 and A1.2, gained ground water discharging from the underlying valley-fill aquifer along the subreach between stations A1.2 and A2, lost surface water between stations A2 and A4, gained ground water between stations A4 and A6, and lost surface water between stations A6 and A7. However, during the October seepage study, all these subreaches gained ground water except the subreach between stations A2 and A4. This change was not expected, given that surface-water levels were still declining (fig. 10b). The fact that the subreach between A1.2 and A2 gained ground water during each seepage study was unexpected because the valley's width increases along this entire subreach. However, the location of this gaining reach might reflect a constriction in the valley-fill aquifer as a result of a higher elevation of bedrock prior to deposition of the valley-fill aquifer, associated with the Osburn and Golconda Faults.

South Fork Coeur d'Alene River Near Osburn

Several significant losing and gaining subreaches were measured during the July and September seepage studies conducted on the SFCDR near Osburn (apps. B4, B5, B6; figs. 17–25, back of report). The locations of gaining and losing subreaches in the upper 1.5 mi of the study reach changed as the water levels slowly declined in the valley during the dry summer and fall months. During the September and October seepage studies, the SFCDR generally lost surface water to the underlying valley-fill aquifer along the subreach between stations B1 and B1.1, gained ground water from the underlying valley-fill aquifer between stations B1.1

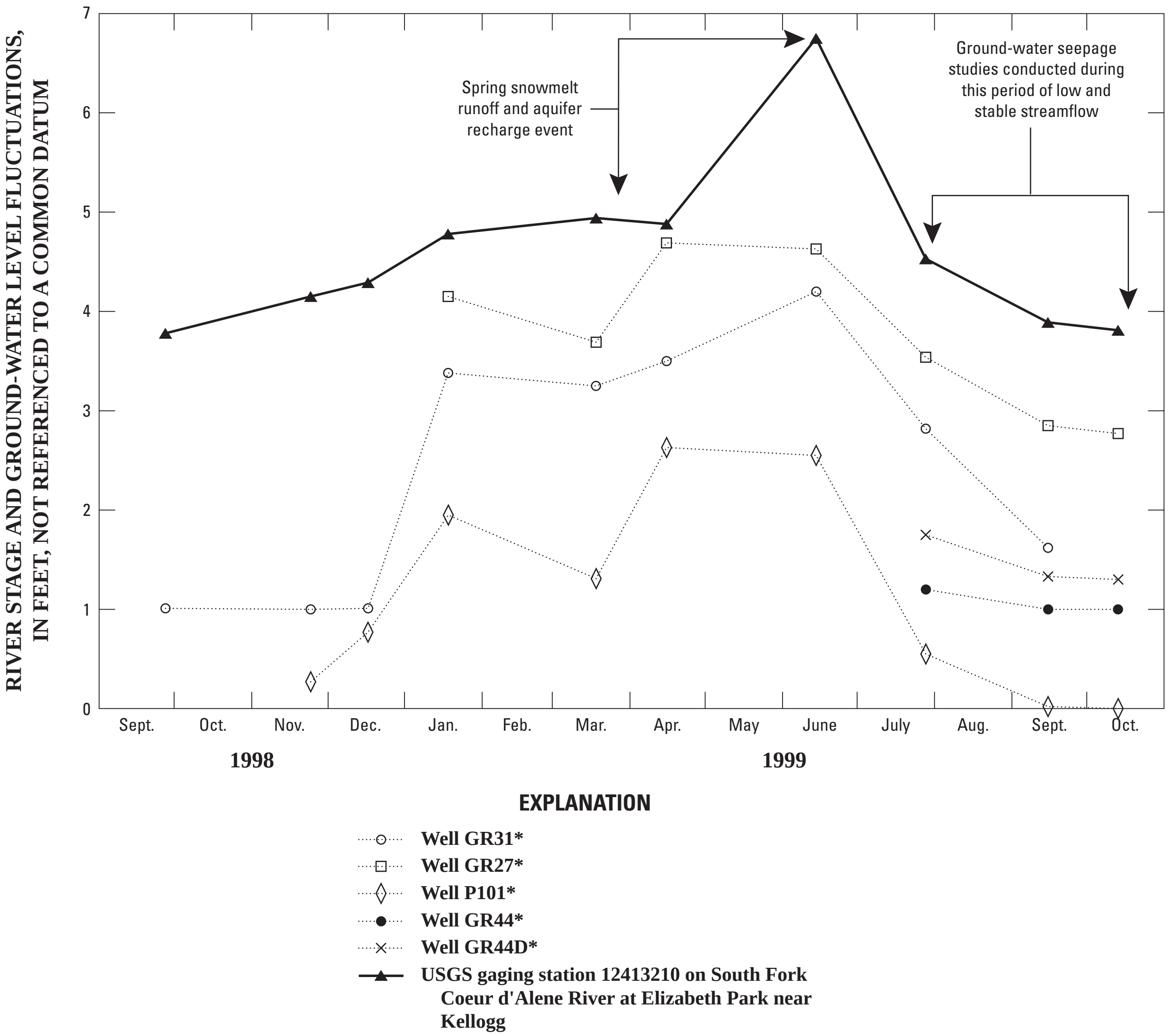

Figure 10a. Relation between river stage and ground-water level fluctuations, South Fork Coeur d'Alene River near Kellogg and Smelterville, Idaho, 1998–99. [Well locations shown in figure 5; gaging station location shown in figure 1. Asterisk indicates water levels measured by Terra Graphics, Inc. (Kay Clever, Kellogg, Idaho, written commun., 1999)]

and B2, lost surface water between stations B2 and B3, gained ground water between stations B3 and B5, lost surface water between stations B5 and B7, and gained ground water between stations B7 and B8. During the October study, the transition zone at B5 between gaining and losing subreaches apparently shifted: the subreach between B3 and B5 showed only a slight gain in ground water and, between B5 and B7, showed no gain or loss of water.

During the September seepage studies, the river gained ground water along the subreach between stations B1.1 and B2. This finding was not expected because the valley widens along this subreach, so ground-water seepage along this subreach might reflect changes in the valley-fill aquifer thickness as a result of movement associated with the Osburn Fault.

Ground-water seepage along the subreach between B3 and B5 is related to a slight narrowing of the river valley along the subreach. Evidence of ground-water seepage along this subreach includes hydraulic potentiomanometer measurements collected at B4 (fig. 4) and B5 during July through October. The ground-water level was 11 to 50 mm (0.4 to 2 in.) higher than the sur-

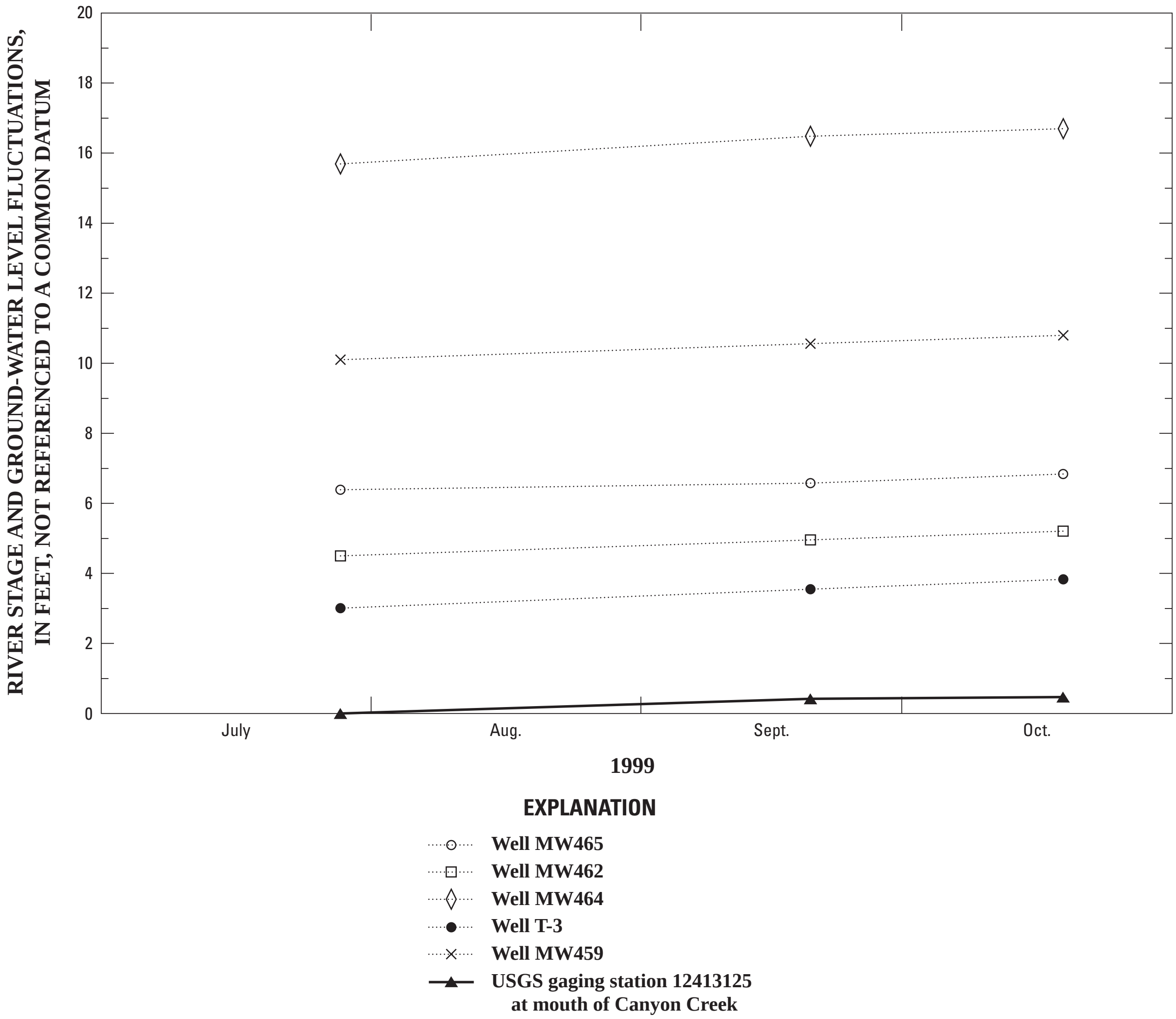

Figure 10b. Relation between river stage and ground-water level fluctuations, Canyon Creek at Woodland Park, Idaho, July through October 1999. (Well locations shown in figure 3; gaging station location shown in figure 1)

face-water stage during the July, September, and October seepage studies (app. A3), and the specific conductance of the ground water seeping into the river was as much as 2.5 times greater than the specific conductance of the surface water (app. A4). Between B3 and B5, specific conductance was higher in ground water than in the surface water, partly because dissolved zinc concentrations in the ground water were high (app. C5, analytical data for instream minipiezometer at McFarren Gulch). Ground water and dissolved solutes, such as zinc, could be flowing a considerable distance through the valley-fill aquifer before reaching this subreach and discharging into the SFCDR.

South Fork Coeur d'Alene River Near Kellogg and Smelterville

Several significant losing and gaining subreaches were identified during seepage studies conducted on the SFCDR near Kellogg and Smelterville during July, September, and October (apps. B7, B8, B9; figs. 26–34, back of report). In general, the river either lost surface water or showed no measurable loss or gain of water along the subreach between stations C1 and C3, gained ground water from the underlying valley-fill aquifer between stations C3 and C6, lost surface water to the underlying valley-fill aquifer between stations C6 and C7, and gained ground water between stations C8 and

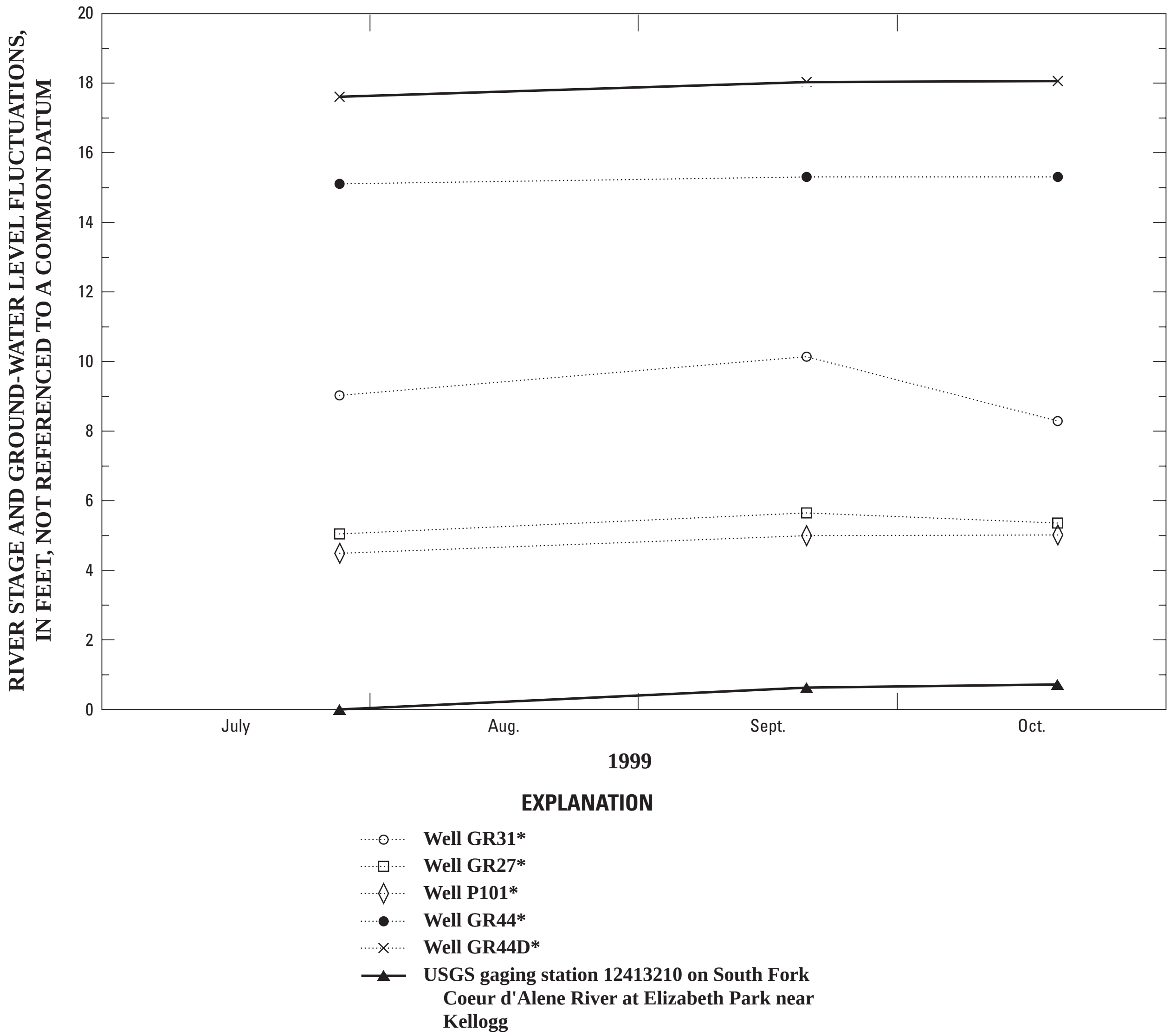

Figure 10c. Relation between river stage and ground-water level fluctuations, South Fork Coeur d'Alene River near Kellogg and Smelterville, Idaho, July through October 1999. [Well locations shown in figure 5; gaging station location shown in figure 1. Asterisk indicates water levels measured by Terra Graphics, Inc. (Kay Clever, Kellogg, Idaho, written commun., 1999)]

C10. The subreach between stations C3 and C6 gained ground water because the valley narrows along the entire subreach, which constricts ground-water flow and forces flow to the river. Evidence of gains along this subreach includes hydraulic potentiomanometer measurements collected at station C4 during July through September that indicated that ground-water levels were 13 to 298 mm (0.5 to 12 in.) higher than the surface-water stage (app. A5), and the specific conductance of the ground water seeping into the river was 1,195 to 1,236 µS/cm higher (app. A6) than the specific conductance of the surface water. The high specific conductance of this water, five times higher than that of surface water, is caused by the high concentration of dissolved solutes, including dissolved zinc (apps. C5, C6).

DISSOLVED CADMIUM, ZINC, AND LEAD LOADS FROM GROUND-WATER SEEPAGE INTO THE SOUTH FORK COEUR D'ALENE RIVER SYSTEM

A statistical summary of the streamflow and surface-water quality data collected during seepage studies for each study reach and of the computed loads for dissolved metals is presented in table 2. Graphs showing the overall average dissolved cadmium and zinc loads gained from ground-water seepage and from tributary inflow along the three study reaches on the SFCDR system during the three seepage studies are shown in figures 35 and 36. A summary of dissolved cadmium, zinc, and lead loads from ground-water seepage during the summer and fall seepage studies in the three study reaches is presented in tables 3, 4, and 5. Also, the average dissolved cadmium, zinc, and lead loads from ground-water seepage during the entire study for all three study reaches are presented in table 6.

Instantaneous streamflow, physical properties, concentrations of dissolved metals in surface-water samples collected from seepage stations, and daily loads are listed in appendix C2. Concentrations of dissolved ions in surface-water samples collected from seepage stations are listed in appendix C3. Physical properties and concentrations of dissolved metals and dissolved ions in ground-water samples collected from instream, stainless-steel minipiezometers are listed in appendices C5 and C6.

Variability of Load Calculations

Graphs were constructed for each study reach for the July, September, and October seepage studies to show the variability in the calculated dissolved metal loads at each seepage station along a study reach. The mean load and ±1 standard deviation associated with the three consecutive seepage runs provide an indication of variability (app. D, back of report). Variability in the dissolved metal load calculations occurs as a result of (1) error in streamflow measurements, (2) fluctuations in discharge at each site during the 3-day seepage study, (3) changes in dissolved metal concentrations during the 3-day seepage study, and (4) and measurement error associated with the collection and analysis of water samples. The variability of the calcu-

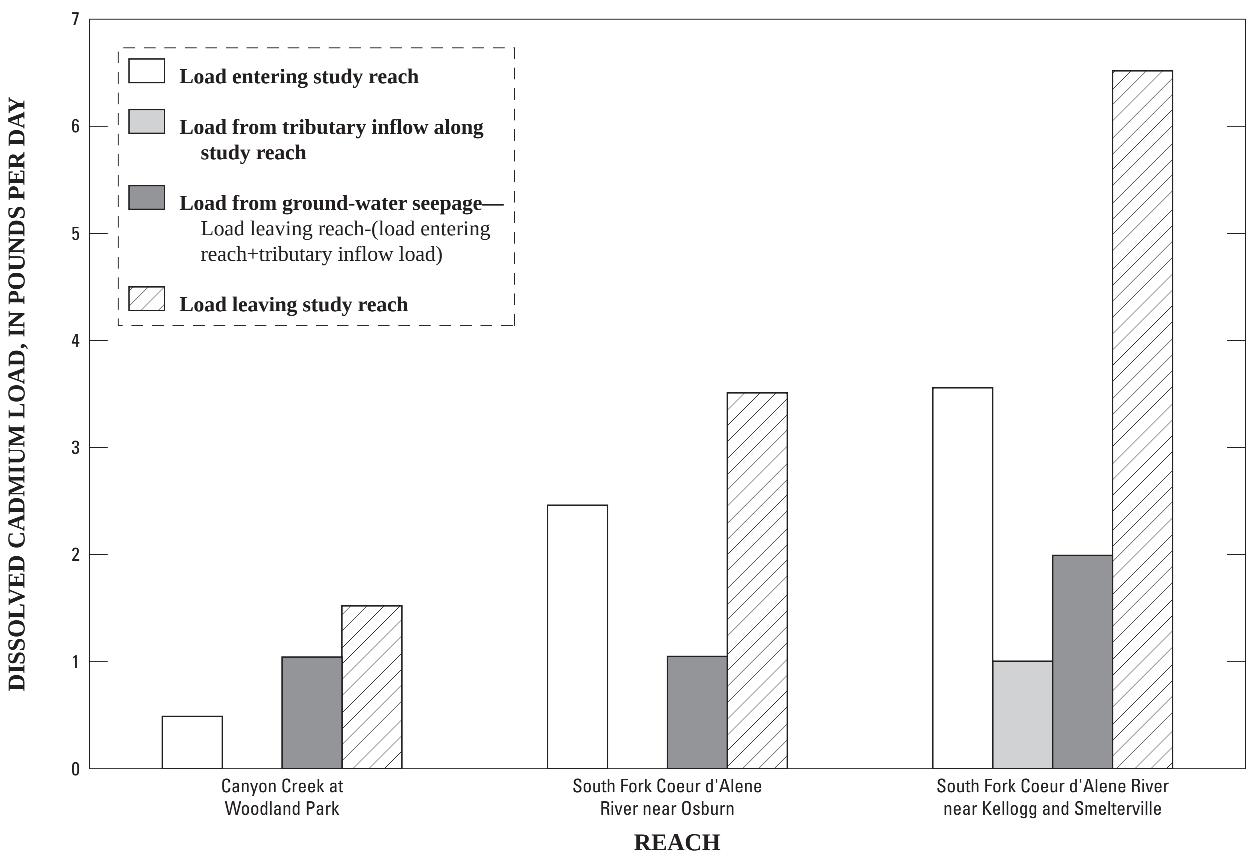

Figure 35. Average dissolved cadmium load gained from ground-water seepage and from tributary inflow along three study reaches on the South Fork Coeur d'Alene River drainage system, Idaho, July through October 1999. (Reach locations shown in figure 1)

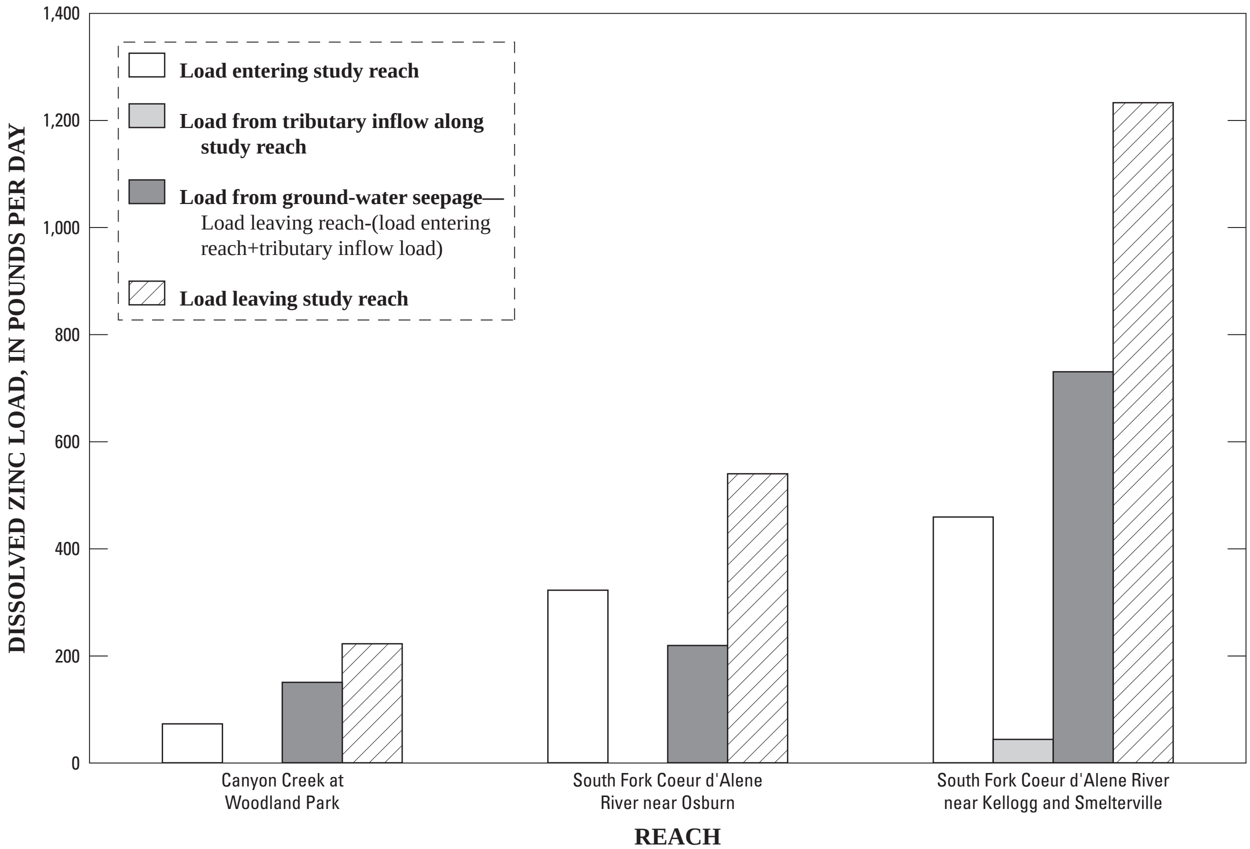

Figure 36. Average dissolved zinc load gained from ground-water seepage and from tributary inflow along three study reaches on the South Fork Coeur d'Alene River drainage system, Idaho, July through October 1999. (Reach locations shown in figure 1)

lated dissolved metal loads at each seepage station for the July, September, and October seepage studies is discussed in the following paragraphs. The variability is compared with the magnitude of the average gain or loss in dissolved metal loads along each study reach. The least amount of relative measurement variability is associated with dissolved zinc loads because (1) these loads are 2 orders of magnitude greater than the dissolved cadmium and lead loads, and the variability at each site is not as important in distinguishing between the change in average values from site to site; and (2) zinc tends to be more soluble in water than do cadmium and lead. The variability of cadmium, zinc, and lead load measurements is acceptable for studying ground-water seepage and transport because the variability of dissolved metal loads at each seepage station is generally smaller than the average gain or loss in dissolved metal load between most seepage stations.

During each seepage study in the Canyon Creek study reach, the variability (±1 standard deviation) of dissolved cadmium and zinc loads at each seepage station (apps. D1–D4) was much smaller than the average gain or loss in load between most seepage stations. The variability of dissolved lead loads at each seepage station along this study reach (apps. D5, D6) was greater than the variability of the cadmium and zinc loads; however, this variability was generally smaller than the average gain or loss in lead load between most seepage stations. During the September seepage study on Canyon Creek at Woodland Park, the lead load increased by about 1.4 lb/d along this study reach, whereas the average standard deviation for the lead load measurements was about ±0.1 lb/d.

During the July, September, and October seepage runs on the SFCDR near Osburn, the variability in dissolved cadmium, zinc, and lead loads (apps. D7–D15) at each seepage station was generally small, compared with the average gain or loss in load between seepage stations. During the September seepage study on the SFCDR near Osburn, ground-water seepage increased

Table 3. Summary of computed loads of dissolved cadmium, lead, and zinc from ground-water seepage in Canyon Creek at Woodland Park, Idaho, September and October 1999

[Net gain of dissolved metals from ground-water seepage is based on the load entering the reach, minus the load leaving the reach, minus loads associated with tributary inflow; NA, not applicable because no tributary inflow to Canyon Creek; flux, the source and transport of dissolved lead are not necessarily related to ground-water seepage; discrepancy between load entering and leaving a reach is the result of rounding]

Load classification	Average load (pounds per day) Sept.	Oct.
Cadmium		
Load entering reach	0.6	0.4
Load leaving reach minus inflow	NA	NA
Load leaving reach	1.5	1.5
Net gain from ground-water seepage	0.9	1.1
Lead		
Load entering reach	1.5	0.8
Load leaving reach minus inflow	NA	NA
Load leaving reach	2.9	2.2
Flux	1.4	1.4
Zinc		
Load entering reach	82	65
Load leaving reach minus inflow	NA	NA
Load leaving reach	217	229
Net gain from ground-water seepage	135	164

the cadmium load in the SFCDR by about 0.7 lb/d, whereas the average standard deviation in the cadmium load measurements was a fraction of the load at about ±0.1 lb/d. There were a few exceptions where the variability of load measurements was high at selected seepage stations, which reduced the ability to determine whether a subreach was gaining or losing metal loads. The variability of lead loads during the July seepage run at seepage station B3 was roughly an order of magnitude greater than the variability of dissolved lead loads at all other seepage stations in the study reach. The variability of dissolved zinc loads during the October seepage run at seepage station B5 was about five times greater than the variability at upstream station B3.

During the September and October seepage runs on the SFCDR near Kellogg and Smelterville, the variability in dissolved cadmium, zinc, and lead loads at each seepage station was small, compared with the average gain or loss in cadmium, zinc, and lead loads between seepage stations (apps. D17, D18, D20, D21, D23, D24). For example, during the September seepage study, ground-water loading of zinc to the SFCDR increased the zinc load in the SFCDR by about 732 lb/d, whereas the average standard deviation in the zinc load measurements was insignificant at about ±38 lb/d. During the July seepage runs, the variability in dissolved cadmium, zinc, and lead loads (apps. D16, D19, D22) at some seepage stations was large; however, the average gain in dissolved cadmium and zinc loads was discernible at most seepage stations. The variability of dissolved lead loads during the July seepage run at seepage stations C5 and C10 was large.

Fluctuation of Turbidity During Seepage Studies

During the field season, there were periods of turbid water flowing through the SFCDR river system. The turbid water generally was associated with efforts to remove mine tailings and metal-enriched sediments from the SFCDR system. Because the release of turbid water could have impacted the concentration of dissolved metal concentrations in the stream water column, a substantial effort was made to ensure that seepage runs were not conducted during remediation activities.

During the July seepage run on Canyon Creek, stream turbidity (fig. 37) increased substantially on July 28 as a result of restoration activities—heavy equipment was moving cobbles and boulders in Canyon Creek upstream from seepage station A2. The

Table 4. Summary of computed loads of dissolved cadmium, lead, and zinc from ground-water seepage in the South Fork Coeur d'Alene River near Osburn, Idaho, July through October 1999

[Net gain of dissolved metals from ground-water seepage is based on the load entering the reach, minus the load leaving the reach, minus loads associated with tributary inflow; NA, not applicable because tributary inflow was negligible; flux, the source and transport of dissolved lead are not necessarily related to ground-water seepage; discrepancy between load entering and leaving a reach is the result of rounding]

Load classification	Average load (pounds per day) July	Sept.	Oct.
Cadmium			
Load entering reach	3.2	2.2	1.9
Load leaving reach minus inflow	NA	NA	NA
Load leaving reach	4.8	3.0	2.8
Net gain from ground-water seepage	1.6	0.8	0.9
Lead			
Load entering reach	9.9	3.7	2.7
Load leaving reach minus inflow	NA	NA	NA
Load leaving reach	6.6	3.2	2.3
Flux	-3.3	-0.5	-0.4
Zinc			
Load entering reach	404	284	280
Load leaving reach minus inflow	NA	NA	NA
Load leaving reach	701	471	448
Net gain from ground-water seepage	297	187	168

Table 5. Summary of computed loads of dissolved cadmium, lead, and zinc from ground-water seepage in the South Fork Coeur d'Alene River near Kellogg and Smelterville, Idaho, July through October 1999

[Net gain of dissolved metals from ground-water seepage is based on the load entering the reach, minus the load leaving the reach, minus loads associated with tributary inflow; flux, the source and transport of dissolved lead are not necessarily related to ground-water seepage; discrepancy between load entering and leaving a reach is the result of rounding]

Load classification	Average load (pounds per day)		
	July	Sept.	Oct.
Cadmium			
Load entering reach	4.5	3.1	3.1
Load leaving reach minus inflow	6.3	5.1	5.2
Load leaving reach	7.3	5.9	6.3
Net gain from ground-water seepage	1.8	2.0	2.1
Lead			
Load entering reach	7.8	3.0	2.4
Load leaving reach minus inflow	7.3	1.4	2.0
Load leaving reach	7.4	2.1	2.5
Flux	-0.5	-1.6	-0.4
Zinc			
Load entering reach	596	385	398
Load leaving reach minus inflow	1,420	1,017	1,130
Load leaving reach	1,460	1,060	1,180
Net gain from ground-water seepage	824	632	732

increase in turbidity coincided with streamflow measurements during a seepage study in Canyon Creek on July 27 and 28. Sampling was suspended on July 29. The water-quality samples that had been collected on July 27 and 28 were not analyzed because the increased turbidity could have resulted in abnormally high dissolved metal concentrations and caused a positive bias in metal loading. There was no noticeable turbidity during the September and October seepage studies on Canyon Creek; these studies were conducted during a temporary cessation of remediation activities.

During August through October 1999, USEPA removed large amounts of tailings and metal-enriched sediments from the study reach on the SFCDR near Kellogg and Smelterville; most of the removal was between seepage stations C3 and C6 (fig. 5). USGS gaging station 12413300, located about 1,400 ft downstream from seepage station C6, continuously monitored turbidity (fig. 38) and, therefore, provided useful data about the short-term effect of sediment runoff from the tailings removal on river turbidity. Although the USGS coordinated its field efforts with USEPA, bank stabilization and tailings removal activities were ongoing during day 1 of the September seepage study. These activities contributed to elevated turbidity conditions in the SFCDR. During the 3-day study, the median turbidity was 2.8 NTU (Nephelometric Turbidity Units; fig. 38). During the October seepage study, which was conducted during a 3-day cessation of bank stabilization and tailings removal, turbidity was higher; median turbidity was 13.0 NTU (fig. 38). During all three seepage studies, Milo Creek intermittently discharged significant amounts of highly turbid water into the SFCDR near Kellogg. These intermittent discharges were the likely cause of spikes (short-duration increases) in turbidity shown on the turbidity record (fig. 38) during each seepage study. The USGS attempted to coordinate its field efforts with the remediation activities of the several governmental agencies working in Milo Creek. The effects of the intermittent turbidity releases on measuring loads of dissolved metals seem negligible because the variability of gains and losses of dissolved cadmium, zinc, and lead to the SFCDR among consecutive 3-day seepage runs for the three seepage studies in the SFCDR near Kellogg and Smelterville was small (apps. D16–D24).

Dissolved Cadmium and Zinc Loads

Along the three study reaches on the SFCDR river system, increases in dissolved cadmium and zinc loads corresponded with gaining subreaches. Cadmium and zinc are soluble in ground water and surface water over a wide range of pH and redox conditions (Hem, 1985, p. 142). Both metals remained, for the most part, dissolved in water as it seeped through the riverbed of the SFCDR system and into the water column. Regardless of changes in the relation between stream stage and ground-water levels during the July, September, and October seepage studies, each study reach contained one or more subreaches where ground-water seepage consistently yielded a significant, measurable load of dissolved cadmium and zinc. These subreaches were located in Canyon Creek at Woodland Park between stations A4 and A6; SFCDR near Osburn between stations B3 and B5, between B7 and B8, and, to a lesser degree, between B1.1 and B2; and SFCDR near Kellogg and Smelterville between stations C3 and C6 and between C8 and C10 (apps. D1–D4, D7–D12, D16–D21).

During the July, September, and October seepage studies, ground-water seepage was the predominant source for gains in dissolved cadmium and zinc loads

Table 6. Summary of average computed loads of dissolved cadmium, lead, and zinc from ground-water seepage in three study reaches of the South Fork Coeur d'Alene River system, Idaho, July through October 1999

[Net gain of dissolved metals from ground-water seepage is based on the load entering the reach, minus the load leaving the reach, minus loads associated with tributary inflow; NA, not applicable because no tributary inflow or negligible inflow; flux, the source and transport of dissolved lead are not necessarily related to ground-water seepage; SFCDR, South Fork Coeur d'Alene River]

Load classification	Average load (pounds per day)		
	Canyon Creek at Woodland Park	SFCDR near Osburn	SFCDR near Kellogg and Smelterville
Cadmium			
Load entering reach	0.5	2.5	3.6
Load leaving reach minus inflow	NA	NA	5.5
Load leaving reach	1.5	3.5	6.5
Net gain from ground-water seepage	1	1.0	2.0
Lead			
Load entering reach	1.1	5.4	4.4
Load leaving reach minus inflow	NA	NA	3.6
Load leaving reach	2.6	4.0	4.0
Flux	1.5	-1.4	-0.8
Zinc			
Load entering reach	74	322	460
Load leaving reach minus inflow	NA	NA	1,190
Load leaving reach	223	540	1,233
Net gain from ground-water seepage	150	218	730

in the three study reaches, whereas tributary inflow loads were a minor source. The Canyon Creek at Woodland Park study reach did not receive tributary inflow; therefore, all the dissolved cadmium and zinc loading was attributed to ground-water seepage. Less than 2 percent of the average gains in dissolved cadmium and zinc loads in the SFCDR near Osburn study reach was attributed to tributary inflow loads. In some cases, the load from tributaries in this valley was too small to accurately measure. On the SFCDR near Kellogg and Smelterville, about 30 percent of the gain in dissolved cadmium load and less than 6 percent of the gain in dissolved zinc load were attributed to tributary inflow loads, mostly from Bunker Creek and Government Gulch.

Gains in dissolved cadmium and zinc loads from ground-water seepage to the SFCDR system are described in terms of net gain (defined in the section "Quantification of Dissolved Metal Loads from Ground-Water Seepage"). The net gain in ground-water loading of dissolved cadmium and zinc for each study reach for the individual July, September, and October seepage studies is presented in tables 3, 4, and 5, and an overall average for the July, September, and October seepage studies is summarized in table 6. In addition, table 6 summarizes the average load entering, average load leaving, and average load leaving minus tributary inflow loads for each study reach during the July, September, and October seepage studies.

The overall average net gain in dissolved zinc load from ground-water seepage into the SFCDR near Kellogg and Smelterville was about 730 lb/d, compared with the net gain in loads in Canyon Creek at Woodland Park and SFCDR near Osburn, which were similar at 150 and 218 lb/d, respectively (table 6). The dissolved zinc load seeping from ground water into the SFCDR near Kellogg and Smelterville along the roughly 10,000-ft subreach between stations C3 and C6 (figs. 29–31, back of report) was consistently greater than the combined zinc load seeping from ground water into Canyon Creek at Woodland Park and the SFCDR near Osburn (tables 3, 4). At Canyon Creek at Woodland Park, ground-water loading of dissolved zinc predominated along a short subreach (approximately 2,800 ft long) between stations A4 and A6 (figs. 13, 14). The net gain in dissolved cadmium load to the SFCDR system was about two orders of magnitude less than the dissolved zinc gain (table 6.) The average net gain in dissolved cadmium load from ground-water seepage in each of the study reaches varied between 1

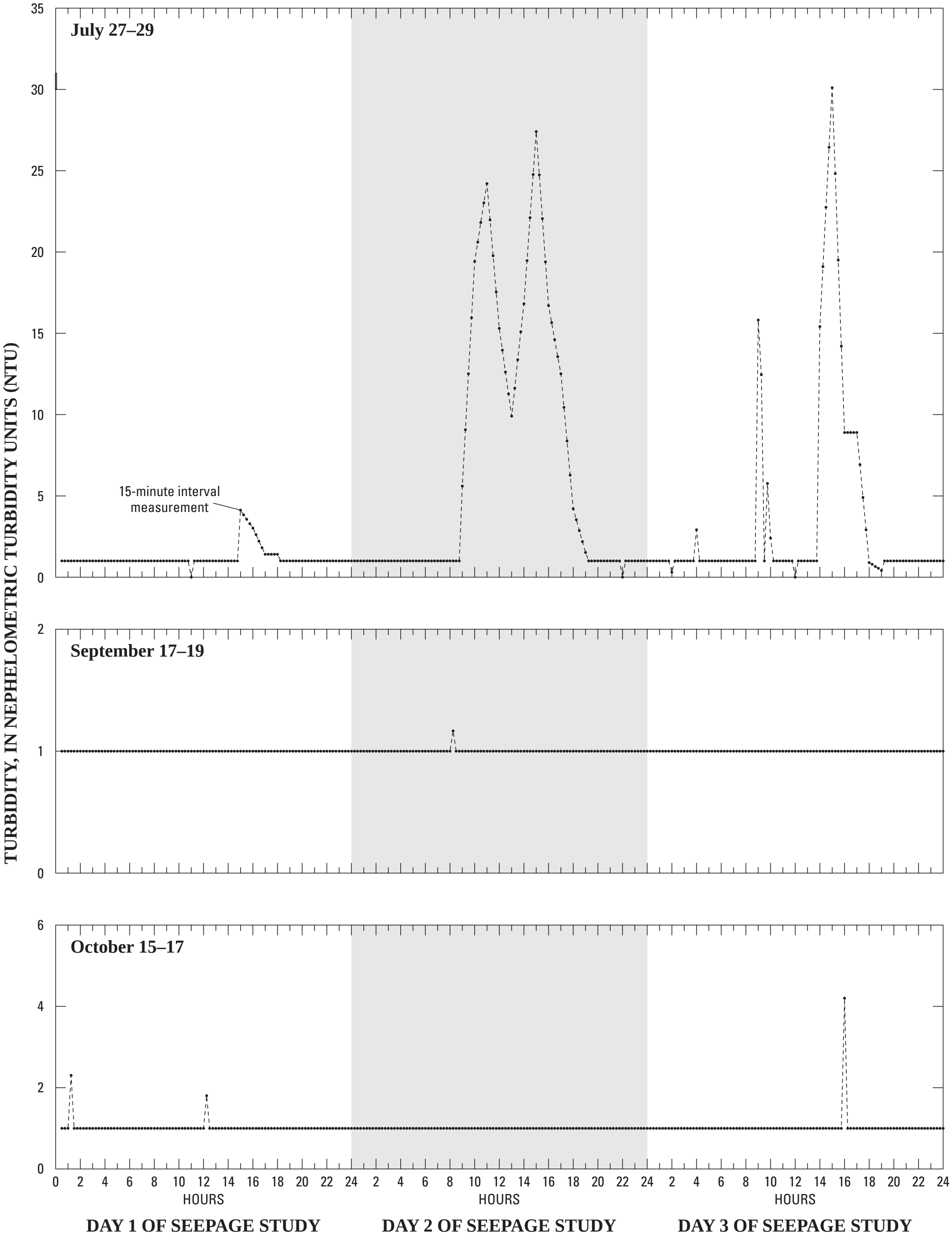

Figure 37. Turbidity in Canyon Creek at Woodland Park, Idaho, at U.S. Geological Survey gaging station 12413125, July through October 1999. (Station location shown in figure 3)

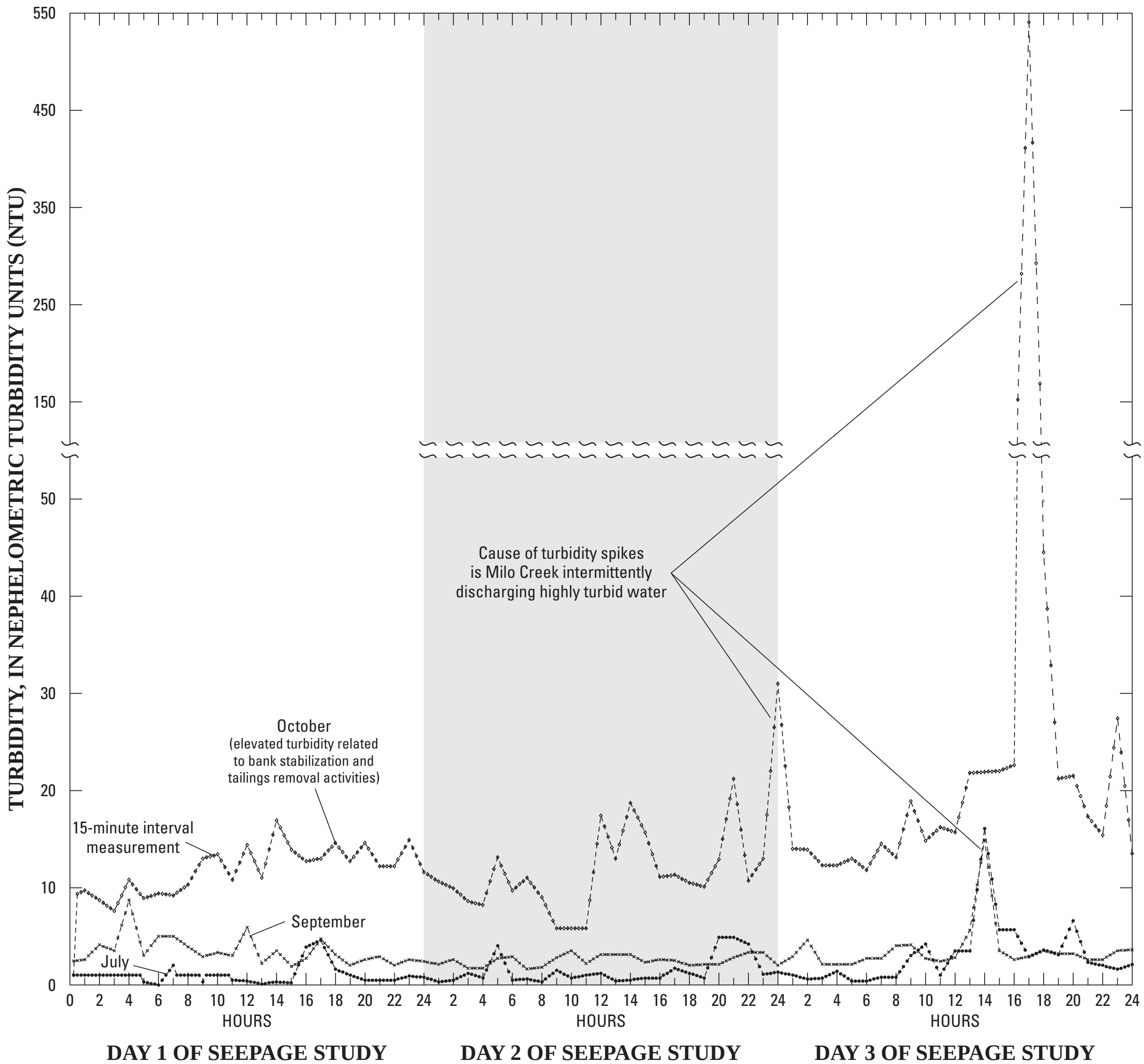

Figure 38. Turbidity in the South Fork Coeur d'Alene River, Idaho, at U.S. Geological Survey gaging station 12413300, July through October 1999. (Station location shown in figure 1)

and 2 lb/d; loading was greatest between stations C3 and C6 on the SFCDR near Kellogg and Smelterville (figs. 26–28, back of report).

Dissolved Lead Loads

On both SFCDR study reaches, no pattern associated with an increase or decrease in dissolved lead load was recognizable (figs. 23–25, 32–34, back of report) along gaining or losing subreaches. Gains in dissolved lead load were observed along some subreaches that gain flow from ground-water seepage and also along some subreaches that lose flow. Losses in dissolved lead load were observed along gaining and losing subreaches. During the course of the 3-day seepage run, the dissolved lead load was generally more variable than the dissolved cadmium and zinc loads at most seepage stations. These observations show that the source and transport processes of dissolved lead are far more complex than those of dissolved cadmium and zinc and consistent with the behavior of lead in the environment. The natural mobility of lead in water is low, compared with that of cadmium and zinc, because of its propensity to adsorb to sediment. The adsorption of lead onto organic and inorganic sediment surfaces and (or) the coprecipitation of lead with iron and manganese oxides tend to maintain low concentrations of lead in surface and ground water. Lead in ground water seeping through riverbeds and into the water column can undergo various transformations such as adsorbing onto inorganic sediment surfaces (Hem, 1985, p. 143–144).

Canyon Creek at Woodland Park was the only study reach where ground-water seepage contributed appreciably to the dissolved lead load; the average net gain from ground water was about 1.5 lb/d (table 6; figs. 15, 16, back of report). Conditions in this reach apparently were more favorable for the solubility and mobility of lead than in the other study reaches.

The average dissolved lead loads leaving SFCDR study reaches (corrected for tributary inflow along the reaches) near Osburn and near Kellogg and Smelterville were 1.4 and 0.8 lb/d less, respectively, than the loads entering the study reaches (table 6). The decrease in dissolved lead could be the result of lead adsorbing onto organic and inorganic sediment surfaces and (or) coprecipitating with iron and manganese oxides. These forms of lead likely will be resuspended into the water column at high flows. In general, tributary inflow contained small, nearly undetectable dissolved lead loads of less than 0.1 lb/d, with the exception of Milo Creek. Dissolved lead loads measured at the mouth of Milo Creek were 0.8 lb/d on September 17 and 0.5 lb/d on October 16, 1999 (figs. 33, 34).

Quality Control Samples

In addition to the 169 regular water-quality samples, quality control samples were collected and consisted of 16 replicate samples, 11 lab-spiked samples, and 11 equipment blank samples. Analyses of paired regular and replicate samples, paired regular and lab-spiked samples, and equipment blank samples collected at seepage stations on the SFCDR system during July through October 1999 are presented in appendix E (back of report).

All water-quality samples met USEPA recommended holding-time criteria. The RPD among dissolved cadmium, zinc, and lead in regular water-quality samples and replicate samples ranged from 0.2 to 10.8 percent, and the median was about 2 percent. There are no apparent data restrictions. As a general qualitative statement, the analytical data for regular water-quality samples are accurate and reliable. This characterization is based on inspection of appendix C2. The appendix C2 table shows that dissolved cadmium and zinc concentrations for regular water-quality samples were consistent at each seepage station during the consecutive 3 days of sampling throughout the entire study area for the July, September, and October seepage studies.

The RPD among concentrations of dissolved cadmium, zinc, and lead in regular and lab-spiked samples ranged from 0.07 to 11.7 percent; one outlier was at about 72 percent (sample collected on October 16 in Canyon Creek at seepage station A7), and the median was about 3.2 percent. The dissolved lead concentration in the laboratory spike collected on October 16 in Canyon Creek at seepage station A7 is probably erroneous. The concentrations for all regular water-quality data collected during the October 16 seepage run were almost identical in value to those collected at the same seepage station on October 15 and 17.

Equipment blank samples did not contain concentrations of cadmium and lead above the reporting level. However, concentrations of dissolved zinc in 6 of the 11 equipment blank samples ranged from 1.0 to 12.9 μg/L. Dissolved zinc concentrations in three of the blank samples approached the reporting level of <1.0 μg/L. Concentrations of dissolved zinc in all regular samples collected from the SFCDR and Canyon Creek were more than an order of magnitude greater than in the equipment blanks; thus, for these samples, there are no apparent data restrictions. Concentrations in the regular sample from Milo Creek were slightly higher than in the blank sample, whereas concentrations in the regular sample from Government Gulch were an order of magnitude greater than concentrations in the blank sample. As previously discussed in the section “Dissolved Cadmium and Zinc Loads,” the tributaries provided inconsequential loads of dissolved zinc compared with loads from ground-water seepage in the SFCDR study reaches.

SUMMARY

The valley of the South Fork Coeur d’Alene River (SFCDR) and some of its tributaries have been heavily impacted by the dispersion of metal-enriched materials from Coeur d'Alene mining activities since the late 1800s. The results of this study can be used to determine the effects of dissolved metal sources on water quality of the river system and to evaluate the necessity and feasibility of remediation along substantially impacted gaining reaches. This study defines a field approach to assess the effects of ground-water/surface-water interaction on dissolved metal loads in the SFCDR system that can be repeated during and after the implementation of remediation solutions to measure the effectiveness of these efforts in reducing loading to streams.

During the July 27–29, September 17–19, and October 15–17, 1999, seepage studies, ground-water seepage was the predominant source for gains in dissolved cadmium and zinc loads in a 3.3-mile reach of Canyon Creek at Woodland Park, a 4.8-mile reach of the SFCDR near Osburn, and a 6.5-mile reach of the SFCDR near Kellogg and Smelterville. Tributary inflow was a minor source of gains in these dissolved metals in the three study reaches. The average net gain in dissolved zinc load from ground-water seepage into the SFCDR near Kellogg and Smelterville was about 730 pounds per day (lb/d); the average net gains in Canyon Creek at Woodland Park and the SFCDR near Osburn were similar at 150 and 218 lb/d, respectively. At the SFCDR near Kellogg and Smelterville, ground-water loading of dissolved zinc along the roughly 10,000-foot subreach near the middle of the study reach (between stations C3 and C6) was greater than the combined ground-water loading for Canyon Creek at Woodland Park and the SFCDR near Osburn. In Canyon Creek at Woodland Park, ground-water loading of dissolved zinc was predominant along a 2,800-foot subreach in the downstream half of the study reach (between stations A4 and A6). Ground-water loading of dissolved cadmium to the SFCDR system was considerably less than dissolved zinc in magnitude. The average net gain in dissolved cadmium load from ground-water seepage in each study reach varied between 1 and 2 lb/d.

There was no apparent pattern associated with an increase or decrease in dissolved lead loads along gaining or losing subreaches on the SFCDR study reaches near Osburn and near Kellogg and Smelterville. Gains in dissolved lead load were observed along some subreaches that gain flow from ground-water seepage and also along some subreaches that lose flow. Losses in dissolved lead load were observed along gaining and losing subreaches. These observations indicate that the transport process of dissolved lead is far more complex than those of dissolved cadmium and zinc and is consistent with the behavior of lead in the environment. The adsorption of lead onto organic and inorganic sediment surfaces and the coprecipitation of lead with iron and manganese oxides tend to maintain low concentrations of lead in surface and ground water. Lead in ground water seeping through streambeds and into the water column can undergo various transformations such as adsorbing onto inorganic sediment surfaces.

The average dissolved lead loads leaving SFCDR study reaches (corrected for tributary inflow along the reaches) near Osburn and near Kellogg and Smelterville were 1.4 and 0.8 lb/d less, respectively, than the loads entering the reaches. The decrease in dissolved lead could be the result of lead adsorbing onto organic and inorganic sediment surfaces and (or) coprecipitating with iron and manganese oxides. These forms of lead likely will be resuspended into the water column at high flows. In general, tributary inflow contained small, nearly undetectable dissolved lead loads, with the exception of Milo Creek.

Canyon Creek at Woodland Park was the only study reach where ground-water seepage contributed appreciably to the dissolved lead load; the average net gain from ground water was 1.5 lb/d. During the 3-month field investigation, this study reach contributed a net gain of nearly 135 lb of dissolved lead. Conditions in this creek were apparently more favorable for the solubility and mobility of lead than in the other study reaches.

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Barton—Cadmium, Zinc and Lead Loads from Ground-Water Seepage, South Fork Coeur d'Alene River, Idaho, 1999—
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