Trace-Element Concentrations and Transport in the Coeur d'Alene River, Idaho, Water Years 1993–94

By Michael A. Beckwith, Paul F. Woods, *and* Charles Berenbrock

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilogram (kg)	2.205	pound, avoirdupois
liter (L)	0.2642	gallon
meter (m)	3.281	foot
metric ton (t)	1.102	ton, short (2,000 lb)
micrometer (µm)	0.00003937	inch
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

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.

TRACE-ELEMENT CONCENTRATIONS AND TRANSPORT IN THE COEUR D'ALENE RIVER, IDAHO, WATER YEARS 1993–94

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ABSTRACT

For almost a century, the U.S. Geological Survey has collected hydrologic data at a network of stream-gaging stations throughout the Coeur d'Alene Lake and River drainage basin. Since 1990, extensive water-quality data have been collected for a comprehensive study of potential eutrophication of Coeur d'Alene Lake and for assessment of the environmental effects of past mining and ore-processing activities in the South Fork Coeur d'Alene River valley.

Although the South Fork Coeur d'Alene River provided only about 20 percent of the Coeur d'Alene River's annual discharge to Coeur d'Alene Lake, it contributed as much as 84 percent of the annual cadmium and 83 percent of the annual zinc loads entering the Lake. The South Fork contributed at most 14 percent of the annual lead and 21 percent of the copper loads carried by the Coeur d'Alene River to Coeur d'Alene Lake. Cadmium, copper, and zinc loads more than doubled between the upstream and downstream boundaries of the Bunker Hill (Kellogg, Idaho) Superfund site in water years 1993 and 1994; lead load increased 24 percent and 33 percent, respectively, in water years 1993 and 1994.

Zinc was transported primarily in a dissolved or colloidal phase, the major source being the South Fork Coeur d'Alene River valley, downstream from the Elizabeth Park gaging station. Lead was transported primarily as particulate material, the major source being sediments eroded from the main-stem Coeur d'Alene River channel and flood plain. Annual lead and zinc loads at Rose Lake were significantly larger than at Harrison or Cataldo, indicating entrainment of trace elements in the reach between Cataldo and Rose Lake, and subsequent deposition or loss in the reach between Rose Lake and Harrison.

INTRODUCTION

From the late 1800's to early 1980's, the Coeur d'Alene Mining District was a major producer of silver, lead, and zinc. Mining and ore-processing activities introduced large amounts of trace-element enriched sediment into the South Fork Coeur d'Alene River (Ellis, 1940; Casner, 1989, 1991). Extensive timber harvest, wildfire, and airborne smelter emissions (which caused substantial localized devegetation) also caused significant erosion, sedimentation, and stream-channel alteration throughout the Coeur d'Alene River and Lake basin over the past century (Rabe and Flaherty, 1974).

Large amounts of sediment, highly enriched in trace elements such as cadmium, lead, and zinc, are associated with the channels and flood plains of the South Fork and main-stem Coeur d'Alene Rivers (Arthur J. Horowitz, U.S. Geological Survey, oral commun., 1995; Steve Box, U.S. Geological Survey, oral commun., 1997). These sediments continue to be eroded and redistributed, especially during spring runoff and floods.

Purpose and Scope

As part of an integrated assessment of natural resource damages associated with past mining and ore-processing activities, the U.S. Geological Survey (USGS) collected hydrologic and water-quality data at six USGS gaging stations on the North Fork, South Fork, and main stem of the Coeur d'Alene River (fig. 1) during water years 1993 and 1994. These data were used to characterize trace-element concentrations and estimate transport (loading, or flux) through the lower Coeur d'Alene River Basin and into Coeur d'Alene Lake.

Physiography and Climate

The Coeur d'Alene River drains 3,810 km^2 of the western slope of the Bitterroot Range in northern Idaho

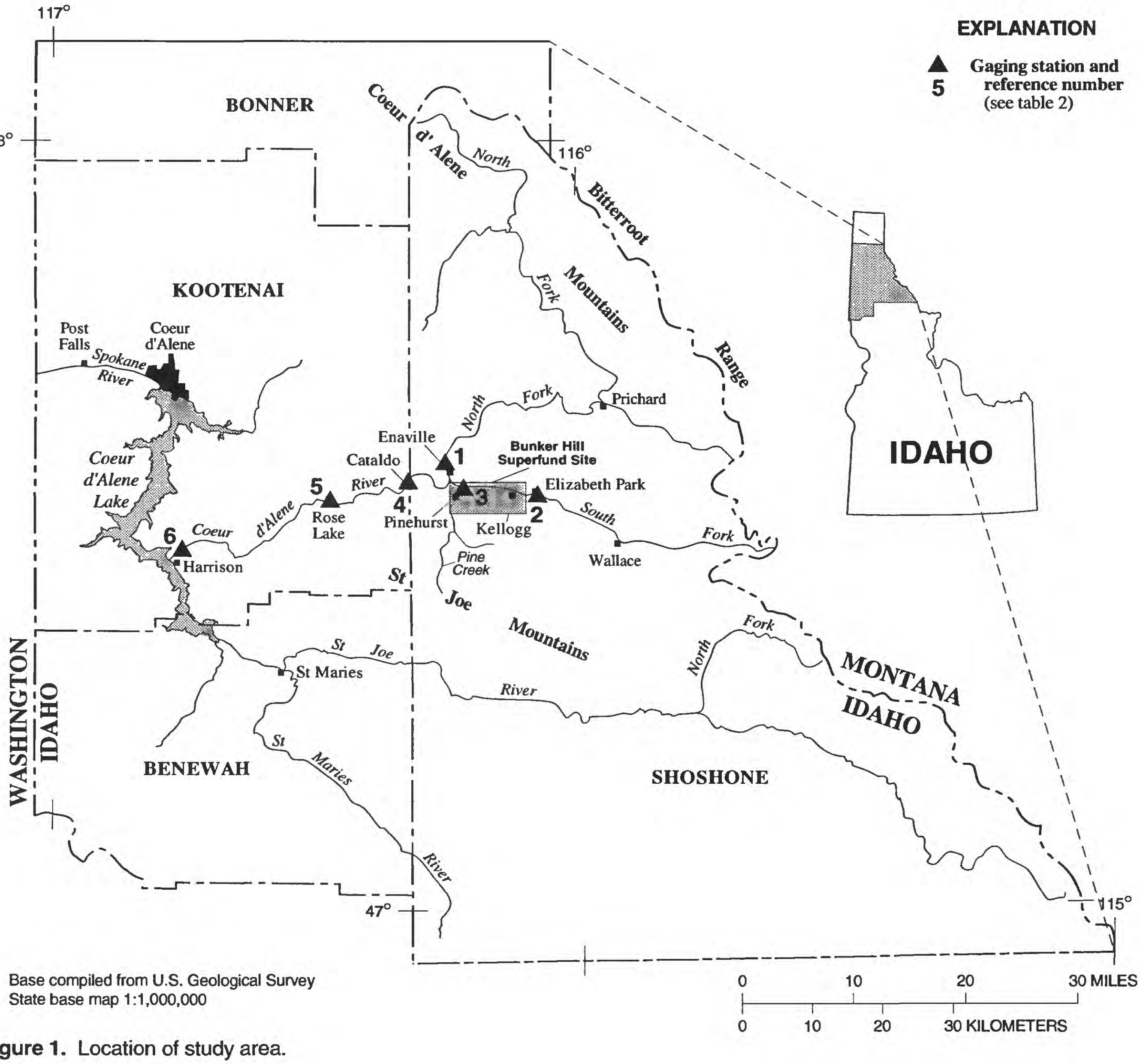

Figure 1. Location of study area.

(fig. 1). Much of the area is mountainous and covered by dense, coniferous forests. Land surface in the Coeur d'Alene River Basin is more than 2,000 m above sea level at the Idaho-Montana border to 648 m above sea level at Coeur d'Alene Lake. Climate in the study area is subject to both marine and continental influences. Most precipitation occurs between November and April. Average annual precipitation is about 645 mm in the valleys and more than double that amount in the mountains. Occasional floods are due primarily to winter storms from the Pacific Ocean, when warm winds and heavy rains melt accumulated mountain snowpack.

Upper reaches of the Coeur d'Alene River are characterized by rocky, high-gradient stream channels, with numerous small tributaries and narrow flood plains confined by steep mountains. Downstream from the confluence of the North and South Forks, the Coeur d'Alene River is a meandering, low-gradient, valley-bottom river. The deep silt/sand channel is in places confined by natural and constructed levees. The well-developed flood plain contains 12 shallow lateral lakes and includes extensive areas of wetland.

DATA COLLECTION AND ANALYSIS

Discharge at six gaging stations was determined from continuous monitoring of stage (water-surface elevation) and periodic measurements of streamflow using standard USGS methods (Buchanan and Somers, 1968, 1969; Carter and Davidian, 1968; Kennedy, 1983, 1984). Streamflow measurements generally were made weekly during spring runoff (March through May), biweekly to monthly during other times of the year, and also during significant floods.

In the lower main-stem Coeur d'Alene River, backwater conditions are created by seasonal regulation of Coeur d'Alene Lake level by the outlet dam at Post Falls (fig. 1). Backwater prevents correlation of river stage with streamflow. Therefore, daily discharge at the Rose Lake and Harrison gaging stations was estimated with the computer model FourPt. The model was developed by the USGS and is based on one-dimensional, partial-differential equations of continuity and momentum, which govern unsteady open-channel flow (DeLong and others, 1997). Model input included continuous discharge data at the Cataldo gaging station (fig. 1), continuous stage data at the Rose Lake and Harrison gaging stations, differences in elevation between these two stations and at 26 surveyed stream-channel cross sections located between them, and stream-channel characteristics such as shape and roughness. The model was calibrated to actual discharge measurements periodically made at the Cataldo, Rose Lake, and Harrison gaging stations.

Water samples were collected at the six gaging stations at fixed time intervals, generally weekly during spring runoff and monthly during the rest of the year. Samples also were collected during significant floods, because floods transport large quantities of dissolved and sediment-associated chemical constituents in short

Table 1. Trace-element concentrations in samples collected at mid-depth at several verticals across the channel using a Van Dorn sampler, Coeur d'Alene River, Idaho

[m, meters; µg/L, micrograms per liter]

Gaging station (date)	Distance from right bank (m)	Whole-water recoverable concentrations (µg/L)			
		Cadmium	Copper	Lead	Zinc
Coeur d'Alene River at Rose Lake (Mar. 5, 1993)	26.8	3	4	160	300
	32.3	3	3	130	280
	37.8	3	3	130	290
	43.3	3	3	130	280
	48.8	3	4	150	300
	54.2	3	3	130	280
	59.7	3	3	130	270
	65.2	3	4	140	290
	70.7	3	3	130	280
	76.2	3	3	140	290
	Mean	3	3.3	137	286
Coeur d'Alene River near Harrison (Oct. 20, 1993)	21.3	3	1	23	
	25.9	2	1	21	530
	30.5	2	1	21	540
	35.0	2	1	20	520
	39.6	2	1	19	530
	44.2	3	1	21	530
	48.8	2	1	19	510
	53.3	2	1	18	510
	57.9	2	1	19	520
	62.5	2	1	19	520
	67.1	2	1	20	520
	71.6	2	1	19	510
	76.2	2	1	19	510
	80.0	2	1	19	520
	85.3	2	1	18	520
	Mean	2.1	1	19.7	520

time periods. In water years 1993–94, 14 to 33 samples were collected at each of the six gaging stations.

Water samples were collected using standard USGS samplers and depth- and cross-section integrating methods (Edwards and Glysson, 1988). Depth-integrated sampling was not possible in the lower main-stem Coeur d'Alene River because channel depths of almost 15 m and velocities of less than 0.03 m/s exceeded the design parameters of all generally available, noncontaminating, flow-integrating samplers. At the Rose Lake and Harrison stations, samples were collected at mid-depth, at the deepest point of the channel, using a 2.2-L Van Dorn sampler. On the basis of comparisons of individual samples collected at mid-depth, at 3 to 15 evenly spaced points (verticals) across the river channel, and collected on several occasions under various flow conditions, samples obtained in this manner adequately represented trace-element conditions throughout the channel. Table 1 presents selected data from these comparisons.

Samples were preserved with ultra-pure nitric acid at the time of collection. Whole-water (unfiltered) samples were analyzed for total recoverable concentrations of cadmium, copper, lead, and zinc by the USGS National Water Quality Laboratory (Fishman, 1993; Hoffman and others, 1996). This method employs an acid digestion step; it recovers dissolved trace elements and those adsorbed to particulate material in the water sample.

The quantity of trace elements transported annually at the six gaging stations was computed using the computer program FLUX (Walker, 1996). Program input included daily and instantaneous discharge, and total recoverable trace-element concentration data. The program computes loads by (1) direct mean loading, (2) flow-weighted concentration, (3) modified ratio estimate, (4) first-order regression, (5) second-order regression, and (6) individual daily streamflows. It includes data stratification and error analysis routines. The method that yielded the smallest coefficient of variation was considered the best estimate. FLUX also includes several diagnostic tools to assess results, such as plots of residuals, hypothesis tests for various model parameters, and data stratification scenarios.

TRACE-ELEMENT CONCENTRATIONS AND TRANSPORT

Mean annual discharge, mean trace-element concentrations, and total annual trace-element loads at six USGS gaging stations on the lower Coeur d'Alene River in water years 1993–94 are shown in tables 2 and 3. Trace-element concentrations in the South Fork Coeur d'Alene River are highly elevated compared with

Table 2. Mean concentrations and total annual loads of cadmium, copper, lead, and zinc at U.S. Geological Survey gaging stations on the Coeur d'Alene River, Idaho, water year 1993

[No., number; m³/s, cubic meters per second; µg/L, micrograms per liter; kg, kilograms; NF, North Fork; SF, South Fork]

Gaging station and reference No.	Annual mean streamflow (m^3/s)	Cadmium: Mean concentration (µg/L)	Cadmium: Load (kg)	Copper: Mean concentration (µg/L)	Copper: Load (kg)	Lead: Mean concentration (µg/L)	Lead: Load (kg)	Zinc: Mean concentration (µg/L)	Zinc: Load (kg)
NF Coeur d'Alene River at Enaville (1)	43.3	1.0	1,370	2.5	3,440	4.5	6,190	17.1	23,320
SF Coeur d'Alene River at Elizabeth Park (2)	7.5	5.8	1,370	4.5	1,060	72.5	17,120	810.0	190,700
SF Coeur d'Alene River near Pinehurst (3)	12.1	8.0	3,040	7.7	2,920	55.8	21,190	1,130.0	430,500
Coeur d'Alene River at Cataldo (4)	57.1	2.0	3,520	3.0	5,420	29.4	52,930	258.0	464,200
Coeur d'Alene River at Rose Lake (5)	57.6	2.3	4,630	3.9	7,860	142.0	286,300	347.0	699,500
Coeur d'Alene River near Harrison (6)	57.6	2.3	4,640	6.9	13,830	116.0	234,800	301.0	607,600

Table 3. Mean concentrations and total annual loads of cadmium, copper, lead, and zinc at U.S. Geological Survey gaging stations on the Coeur d'Alene River, Idaho, water year 1994

[No., number; m^3/s, cubic meters per second; µg/L, micrograms per liter; kg, kilograms; NF, North Fork; SF, South Fork]

Gaging station and reference No.	Annual mean streamflow (m^3/s)	Cadmium		Copper		Lead		Zinc	
		Mean concentration (µg/L)	Load (kg)	Mean concentration (µg/L)	Load (kg)	Mean concentration (µg/L)	Load (kg)	Mean concentration (µg/L)	Load (kg)
NF Coeur d'Alene River at Enaville (1)	26.5	1.0	840	2.4	1,990	2.9	2,420	13	10,900
SF Coeur d'Alene River at Elizabeth Park (2)	5.0	6.6	1,050	3.5	560	42.0	6,670	1,000	159,600
SF Coeur d'Alene River near Pinehurst (3)	7.8	8.7	2,150	3.8	940	35.8	8,840	1,310	324,400
Coeur d'Alene River at Cataldo (4)	35.8	2.2	2,440	3.0	3,360	20.0	22,650	323	365,500
Coeur d'Alene River at Rose Lake (5)	38.5	2.2	2,670	2.8	3,460	86.7	105,300	376	456,800
Coeur d'Alene River near Harrison (6)	38.5	2.1	2,550	5.4	6,520	51.6	62,580	323	392,300

average or background conditions expected to exist in waters throughout the Nation (Arthur J. Horowitz, U.S. Geological Survey, oral commun., 1997). Trace-element concentrations are not significantly elevated in the North Fork Coeur d'Alene River, where little mining activity took place. Trace-element concentrations also are elevated in the main-stem Coeur d'Alene River. Hardness data for the Coeur d'Alene River (collected from other USGS activities) are presented in table 4.

Figure 2 is a graphical comparison of annual discharge and annual loads of lead and zinc at six gaging stations in the lower Coeur d'Alene River Basin; loads entering Coeur d'Alene Lake at Harrison serve as the benchmark (or 100 percent). Although the South Fork Coeur d'Alene River provided only about 20 percent of the river's annual discharge into Coeur d'Alene Lake, it contributed 66 to 84 percent of the annual cadmium load and 71 to 83 percent of the annual zinc load, respectively, in water years 1993–94 (tables 2 and 3; fig. 2). In water years 1993–94, cadmium, copper, and zinc loads carried by the South Fork Coeur d'Alene River more than doubled between Elizabeth Park and Pinehurst (tables 2 and 3; fig. 2); lead load increased by 24 and 33 percent, respectively, in water years 1993–94. In contrast, the South Fork contributed 9 to 14 percent of the Coeur d'Alene River's total annual lead load, and 14 to 21 percent of the copper load to Coeur d'Alene Lake, respectively, in water years 1993–94 (tables 2 and 3; fig. 2).

Table 4. Hardness in water samples collected at U.S. Geological Survey gaging stations on the Coeur d'Alene River, Idaho

[mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; No., number; m^3/s, cubic meters per second]

Gaging station	Period of record	No. of samples	Hardness (as mg/L $CaCO_3$)		
			Mean	Maximum (at discharge, m^3/s)	Minimum (at discharge, m^3/s)
North Fork Coeur d'Alene River at Enaville	1971–94	39	20.5	24 (5.66)	10 (416)
South Fork Coeur d'Alene River near Pinehurst	1987–95	20	71.8	100 (2.12)	27 (71.9)
Coeur d'Alene River at Cataldo	1986–95	42	38.4	55 (8.83)	17 (173)

The proportions of cadmium, copper, and zinc loads that can be attributed solely to the 54-km^2 Bunker Hill Metallurgical Complex Superfund site could not be determined in this study because contributions from the Pine Creek drainage (fig. 1), where mining and ore processing also took place, were not determined. Annual lead and zinc loads at Rose Lake (tables 2 and 3; fig. 2) were considerably larger than those at Cataldo and Harrison, indicating entrainment of trace elements between Cataldo and Rose Lake, and subsequent deposition or loss between Rose Lake and Harrison.

Cadmium, copper, lead, and zinc loads in water year 1993 (table 2) were nearly two to four times larger than in 1994 (table 3). Annual discharge of the Coeur d'Alene River in water years 1993 and 1994 was about 80 and 50 percent, respectively, of the long-term average. Loads reported in tables 2 and 3 are probably less than what would be carried by higher discharges. They are probably substantially less than what actually occurred, because total sediment-associated trace-element transport was not accounted for in this study. Therefore, loads reported in tables 2 and 3 are most likely conservative estimates.

Data presented in table 5 suggest that cadmium and zinc are transported primarily in dissolved or solid-phase associated (colloidal) form, which passes through a 0.45-µm filter. The major source of cadmium, copper, and zinc in the lower Coeur d'Alene River Basin is the South Fork Coeur d'Alene River valley, downstream from the Elizabeth Park gaging station. Lead transport is associated with particulate material, to a greater degree than is copper. The primary source of lead and copper is deposits of trace-element enriched sediment eroded from the channels, banks, and flood plain of the main-stem Coeur d'Alene River (downstream from the confluence of the North and South Forks).

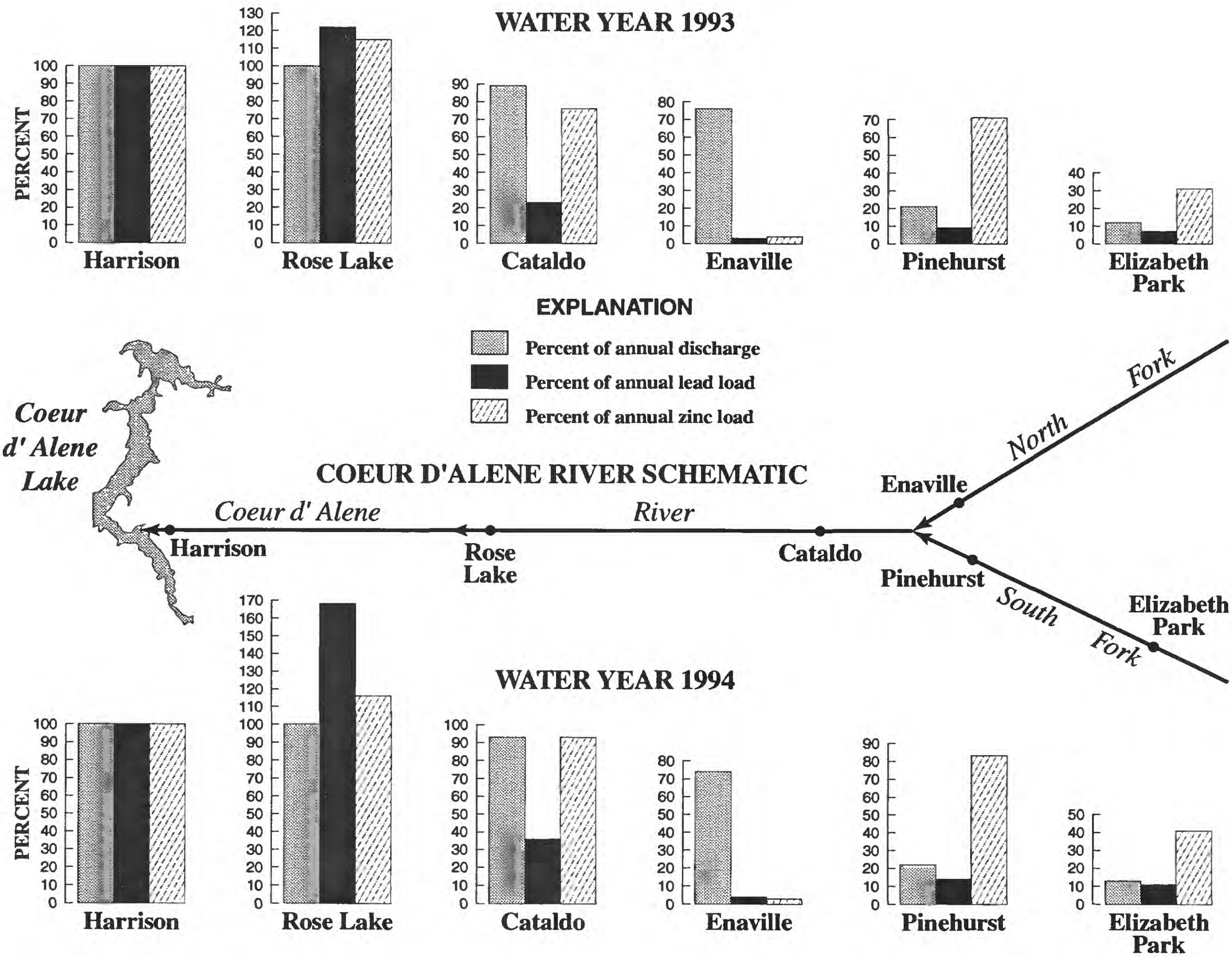

Figure 2. Comparison of annual discharge and trace-element (lead and zinc) loads at U.S. Geological Survey gaging stations on the Coeur d'Alene River, Idaho, water years 1993–94. (Loads entering Coeur d'Alene Lake at Harrison serve as the benchmark, or 100 percent)

Table 5. Comparison of trace-element concentrations in filtered and whole-water samples collected at U.S. Geological Survey gaging stations on the Coeur d'Alene River, Idaho (Data from National Stream-Quality Accounting Network and other U.S. Geological Survey monitoring activities)

[μg/L, micrograms per liter; WWR, whole-water recoverable; <, less than]

Gaging station	Date sampled	Cadmium (μg/L)		Copper (μg/L)		Lead (μg/L)		Zinc (μg/L)	
		Filtered	WWR	Filtered	WWR	Filtered	WWR	Filtered	WWR
North Fork Coeur d'Alene River	9/21/93	<1	<1	4	4	<1	<1	13	<10
at Enaville..................	5/20/93	<1	<1	3	3	2	4	23	20
	3/24/93	<1	<1	1	5	1	7	20	40
South Fork Coeur d'Alene River	9/23/94	11	12	1	1	9	24	2,500	2,400
near Pinehurst...............	5/26/94	5	5	<1	3	7	19	890	870
	3/16/94	7	7	1	3	5	17	1,100	1,000
	11/17/93	15	11	2	2	<1	14	2,500	2,500
	3/23/93	7	9	3	8	6	160	970	1,100

This information can be used to develop and implement sound environmental cleanup actions and natural resource management strategies in the Coeur d'Alene River Basin. The approach used and the data base developed in this study also can serve as the basis for determining the effectiveness of ongoing and future cleanup actions and resource management strategies.

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