CHAPTER 3
TRANSPORT AND EXPOSURE PATHWAYS

3.1 INTRODUCTION

This chapter presents the pathways by which natural resources of the Coeur d'Alene River basin are exposed to hazardous substances released from mining and mineral processing operations. *Pathway* refers to the route or medium through which hazardous substances are transported from the source of their release to the injured resource [43 CFR §11.14 (dd)]. *Pathway determination* is a component of injury determination [43 § 11.61 (c)(3)] in that it establishes the connection between the release and the injury.

Pathway determination involves consideration of (1) the chemical and physical characteristics of the released hazardous substances, (2) the rate or mechanism of transport of the released hazardous substance, and (3) the combinations of pathways that transport hazardous substances to the exposed natural resources [43 CFR § 11.63 (a)(1)].

Pathways may be determined by demonstrating the presence of the hazardous substance in "sufficient concentrations" in the pathway resource or through the use of models that demonstrate the exposure route [43 CFR § 11.63 (a) (2)]. Figure 3-1 presents a generalized overview of the transport and exposure pathways that transport and redistribute hazardous substances in the basin. The pathway determination approach involved demonstrating the presence of elevated concentrations of hazardous substances in pathway resources and documenting exposure to those pathway resources.

The pathway determinations presented in this chapter are based on data collected by the Trustees and by other researchers in the basin. However, in 1932, Ellis (1940) described the pathway of metals contamination of the Coeur d'Alene River basin, from the introduction of tailings containing toxic materials to the rivers, transport to downstream reaches and lakes, and exposure and adverse effects on aquatic biota. Ellis (1940) documented releases of tailings from the mines in the upper basin, transport of tailings downstream, and deposition and remobilization of contaminated sediments throughout the floodplains of the basin:

> In the region of Cataldo and Mission Flats large quantities of mining tailings settled out and the deposits in the river channel itself and along its banks where the waste have settled out during high water are today acres in extent. In fact the entire Mission Flats of several square miles is now (1932) very largely covered with these tailings and slimes . . . The continued operation of the mines in the upper Coeur d'Alene District so loaded the South Fork of the Coeur d'Alene

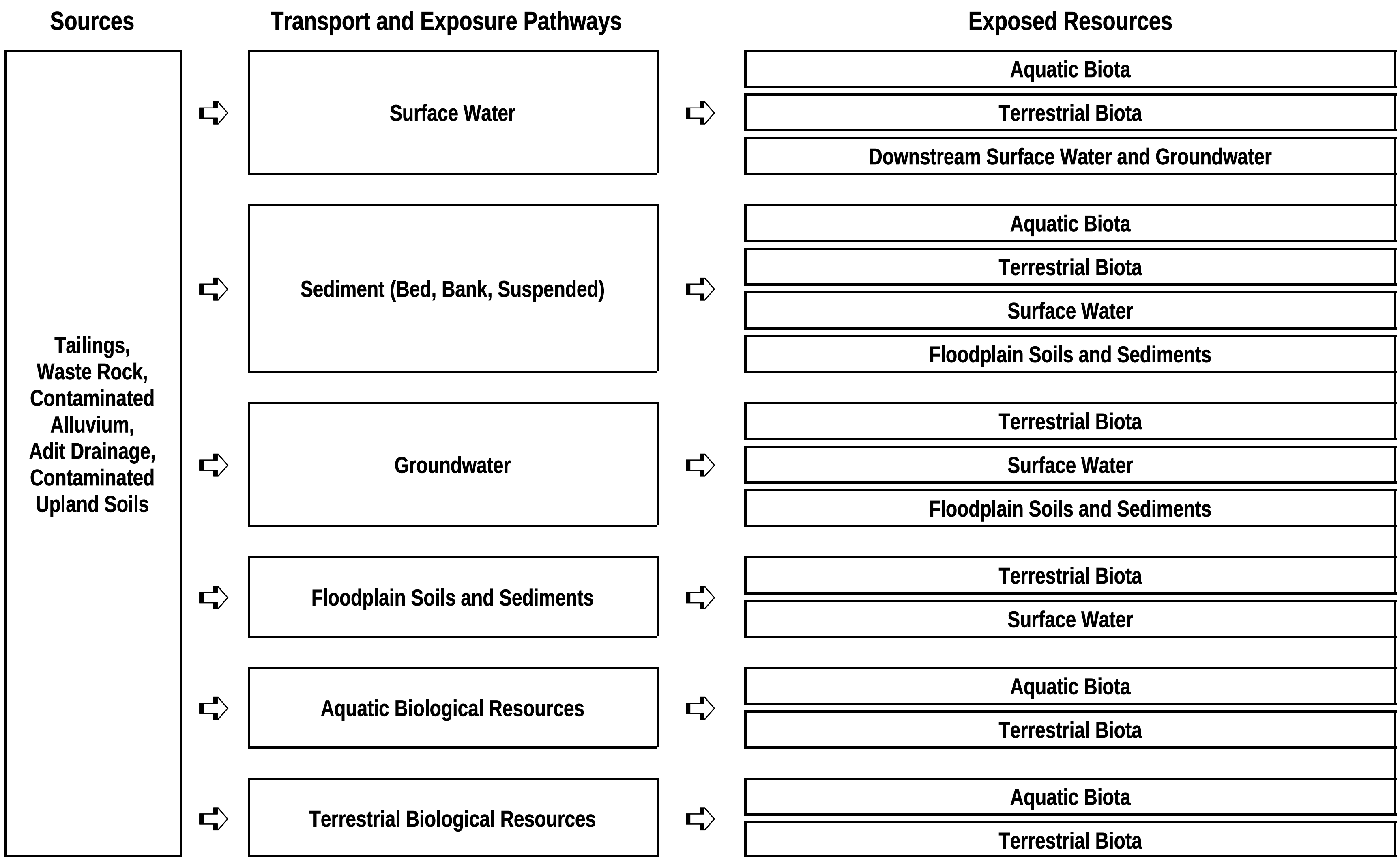

Figure 3-1. Overview of transport and exposure pathways.

> River with mine wastes that masses of rock powder not only covered the Mission Flats but were carried down stream beyond Mission Flats and Cataldo . . . gradually contaminating the entire Coeur d'Alene River between Mission Flats and its mouth near Harrison, Idaho.

And:

> These slimes as deposited in the lower part of the Coeur d'Alene valleys constitute an additional pollution hazard in that as left on the banks and low lands the slimes are subsequently returned to the stream in parts by rains and winds, constituting a repolluting of the river by material which it has deposited. In addition crystalline substances, freely soluble in water, are formed in these slimes when they are exposed to the action of air on the low flats after the recession of the river, and these soluble substances also are washed back into the stream by each rain.

And:

> The mobility of the mine wastes and mine slimes carried by the Coeur d'Alene River has made possible the pollution of considerable lateral areas, as the flats and low lands adjacent to the river, because large quantities of these wastes are swept out onto the flats during high water, and left there as the river recedes . . . In addition to forming a constant source of materials with which the stream can be repolluted through the action of rain and wind, these exposed masses of mine slimes present a new hazard to aquatic life because of the chemical natural of several of the substances comprising these particular mine wastes.

Ellis (1940) also described the release of adit drainage as a pathway of contaminants to surface water:

> As the mining operations became more extensive the stopes were enlarged and mine waters were encountered. These natural waters in running out of the mines pass over various rocks as well as the ore deposits and become a pollution hazard, particularly if they flow over iron deposits.

Ellis (1940) concluded that the wastes deposited on the floodplains, beds, and banks comprised an "enormous lateral supply of potentially toxic material which as they now stand (1932) will continue to poison the waters of the Coeur d'Alene River for a considerable period of time."

Thus, as early as 1940, environmental pathways in the Coeur d'Alene River basin had been identified and described.

In addition to these early data and conclusions, pathways were described as part of the remedial investigation for the Bunker Hill Superfund site. MFG (1992a) documented specific contaminant migrations pathways in surface water and groundwater. MFG (1992a) also documented:

- surface water erosion of hillside soils and wastes and discharge of surface runoff containing dissolved and particulate contaminants to the South Fork Coeur d'Alene River and tributaries

- contamination of groundwater through seepage from surface impoundments, infiltration through site-wide tailings deposits, and inflow from contaminated tributary groundwater sites

- leaching of metals from contaminated soils on the hillsides and contaminated tailings in the floodplain and discharge of contaminated groundwater to the South Fork Coeur d'Alene River and tributaries

- surface water and groundwater interactions along the river channel

- surface water scouring, erosion, and remobilization of streambed and streambank materials.

Again, these earlier studies identified and confirmed pathways in the Coeur d'Alene River basin. In this chapter, we further describe pathways using more recently collected data, and thus confirm that the pathways and their underlying mechanisms continue to operate in the basin.

The information presented in this chapter demonstrates the following:

- Surface water serves as a critical transport and exposure pathway of dissolved and particulate hazardous substances to soil, aquatic, and terrestrial biological resources and downstream surface water resources. Surface waters of the Coeur d'Alene River basin downstream of mining and mineral processing facilities have been and continue to be exposed to elevated concentrations of hazardous substances, including cadmium, lead, and zinc. Because of natural downstream transport mechanisms, surface waters throughout much of the Coeur d'Alene River basin — including the South Fork Coeur d'Alene River, the Coeur d'Alene River, Coeur d'Alene Lake, and Canyon, Ninemile, Moon, and Pine creeks and other tributaries to the South Fork Coeur d'Alene River — are exposed to elevated concentrations of hazardous substances.

- Sediment in the water column and in the beds and banks of Coeur d'Alene River basin drainages downstream of mining and mineral processing facilities has been and continues to be a transport and exposure pathway. Bed and bank sediments throughout the basin contain elevated concentrations of hazardous substances, including cadmium, lead, and zinc. Contaminated sediments are an ongoing pathway for downstream movement of hazardous substances through natural processes. Contaminated streambed sediment exposes fish, periphyton, and aquatic invertebrates to hazardous substances. Contaminated sediment re-deposited on floodplains and on vegetation surfaces is an important cause of exposure of wildlife and vegetation to hazardous substances.

- Floodplain soils have been and continue to be a transport and exposure pathway. Floodplain soils and wetland sediments have become contaminated with hazardous substances in direct discharge of wastes to the floodplain, and through deposition of contaminated sediments in natural hydrological processes. Floodplain soils are contaminated with hazardous substances such as cadmium, lead, and zinc in riparian areas downstream of mining and mineral processing facilities, including riparian areas of the South Fork Coeur d'Alene River, the Coeur d'Alene River, and Canyon, Ninemile, Moon, and Pine creeks. Contaminated floodplain soils serve as an ongoing transport pathway to downstream resources through mobilization by surface waters. Floodplain soils contaminated with hazardous substances serve as a pathway by which vegetation and soil biota are exposed to hazardous substances. Wildlife are exposed to hazardous substances through direct ingestion of soil/sediment and ingestion of soil/sediment adhering to vegetation.

- Although data are not available throughout the Coeur d'Alene River basin, available information illustrates that groundwater in certain locations is a pathway by which hazardous substances are leached from contaminated floodplain deposits and transported to downgradient surface waters. In addition, surface waters containing hazardous substances are in contact with shallow groundwater aquifers in floodplains. Surface waters containing hazardous substances also serve as a pathway to shallow groundwater.

- Biological resources serve as contaminant exposure pathways through dietary exposure. Contaminated periphyton, aquatic invertebrates, and fish are exposure routes of hazardous substances to higher trophic level consumers. Aquatic vegetation containing or coated with elevated concentrations of lead exposes waterfowl through their diets. Wildlife also are exposed to hazardous substances through consumption of prey that have become contaminated through alternative pathways.

3.2 DATA SOURCES

Data relied on for the determination of exposure and transport pathways include historical information collected by state and federal resource agencies, information from university researchers, information collected by the U.S. EPA, information collected by mining companies, and information collected by the Trustees as part of the NRDA. Key data sources are identified in Table 3-1.

Table 3-1
Transport and Exposure Pathway Data Sources

Authors	Study Overview
Surface Water (these and other data sources described in Chapter 4)	
Balistrieri et al., 1998	Seep and adit sampling in the upper basin
Beckwith et al., 1997	Surface water data (1993 and 1994), characterizing trace-element transport
Beckwith, 1996	Surface water and suspended sediment data collected during the 1996 flood
CCJM, 1994	Draft preliminary assessment of Pine Creek
CH2M Hill & URSGWC, 1998	Draft database containing surface water, seep, and adit data, 1997-1998
Dames & Moore, 1990	Surface water sampling for the Bunker Hill Superfund Site RI/FS
Hartz, 1993	Point and nonpoint source investigation upstream of Canyon Creek
Hornig et al., 1988	U.S. EPA long-term monitoring program
Harvey, 1993	IDEQ trace elements monitoring program, monthly sampling 1994-1996
MFG, 1991, 1992b	Surface water, seep, and adit data collected during high and low flow, 1991
Stratus Consulting, 1999	Surface water sampling for aquatic biota monitoring
U.S. BLM (undated)	Lower CdA River water quality monitoring program (1991-1993)
USGS (ID district database)	Water quality data collected since the 1960s
(Various)	Various historical data collected by university and state investigators
Sediment (these and other data sources described in Chapter 5)	
Beckwith, 1996	Surface water and suspended sediment data collected during the 1996 flood
Beckwith et al., 1997	Surface water data (1993 and 1994), characterizing trace-element transport
Campbell et al., 1999a	Sediment samples from palustrine and lacustrine wetlands
Hagler Bailly Consulting, 1995	Floodplain soils, upper and lower basin
Horowitz, 1995	Floodplain sediment sampling in the lateral lakes area
Horowitz et al., 1993	Subsurface sediment samples from CdA Lake
Horowitz et al., 1992	Surface sediment samples from CdA Lake
URSG and CH2M Hill, 1998	Floodplain and river channel sediment core samples
Groundwater	
Box et al., 1997	Sources and processes of dissolved metal loading in CdA basin
Dames & Moore, 1991	Groundwater data from Bunker Hill Remedial Investigation
Houck and Mink, 1994	Characterization of the Canyon Creek aquifer
Paulson and Girard, 1996	Groundwater samples from Moon Creek
(Various)	Numerous historical studies

Table 3-1 (cont.)
Transport and Exposure Pathway Data Sources

Authors	Study Overview
Aquatic Biota (these and other data sources described in Chapters 7 and 8)	
Farag et al., 1998	Sediment, biofilm, benthic invertebrate, and fish data from CdA basin
Woodward et al., 1997	Sediment, biofilm, benthic invertebrate, and fish data from CdA basin
(Various)	Numerous historical studies collected by university and state investigators
Terrestrial Biota (these and other data sources described in Chapters 6 and 9)	
Audet et al., 1999b	Lead exposure in waterfowl
Audet, 1997	Biological reconnaissance of CdA basin
Audet et al., 1999a	Lead exposure in bald eagle prey
Beyer et al., 1998	Sediment ingestion by waterfowl
Beyer et al., 1997	Sediment ingestion by waterfowl
Blus et al., 1999	Metal exposure in waterfowl
Campbell et al., 1999b	Metal contamination in tubers
Hagler Bailly Consulting, 1995	Investigation of riparian resources
(Various)	Numerous historical studies collected by university and state investigators

3.3 SURFACE WATER

Surface water resources include water and the sediments suspended in the water or lying on the bank, bed, or shoreline and sediments in or transported through coastal and marine areas [43 CFR 11.14 (pp)]. For pathway determination, suspended, bed, and bank sediments are discussed separately from surface water to distinguish these two major, though interconnected, pathways.

3.3.1 Surface Water Exposure to Hazardous Substance Releases

Historically, surface water was exposed to hazardous substances in mine wastes that were discharged directly to surface waters (see Chapter 2 — Hazardous Substance Sources). Mine wastes were transported downstream by surface water and deposited throughout the floodplains of the South Fork and mainstem Coeur d’Alene rivers, throughout the lateral lakes area, and in Coeur d’Alene Lake.

The predominant mechanisms by which surface water has been exposed to hazardous substances are:

- discharge of contaminated groundwater from mine adits to surface water
- discharge of contaminated groundwater through seep and diffuse floodplain sources to surface
- surface deposit runoff/erosion of floodplain wastes
- erosion of contaminated bed and bank sediments
- downstream transport of dissolved and particulate metals.

Tables 2-18 through 2-23 in Chapter 2 present concentrations of hazardous substances measured in adit drainage and the rate of flow at each. Although those data are not a comprehensive characterization of adits in the Coeur d'Alene River basin that function as sources and pathways of hazardous substances to surface waters, they do provide evidence that hazardous substances are released from adits. Adits that drain directly or indirectly to streams in the basin are a pathway of hazardous substances to surface water. For example, zinc loading from the Success adit ranges from 3 to 12 lb/day, and from the Gem adit, 18 to nearly 100 lb/day. This example is evidence that releases from adits are a pathway of hazardous substances to surface water.

Tables 2-18 through 2-23 in Chapter 2 also present concentrations of hazardous substances in seeps from waste piles and floodplain tailings deposits. Drainage from the Success and Interstate Callahan millsites in Ninemile Creek and from the CIA in the Bunker Hill Superfund site contribute significant dissolved metal loading (60, 40, and 200 lb zinc/day, respectively) to surface water (Box et al., 1997). In addition to these point seeps, diffuse seeps and groundwater inflow from contaminated floodplain deposits contribute hazardous substances to surface waters of the basin. An estimated 80% of the dissolved metal load to the South Fork Coeur d'Alene River is derived from floodplain tailings, mixed tailings, and alluvium deposits (Box et al., 1997).

Hazardous substances are transported in surface water as dissolved and particulate substances. Mechanisms resulting in releases of dissolved metals to surface water include weathering of sulfide minerals in floodplain wastes, leaching of metals from floodplain wastes to groundwater, and transfer of groundwater to surface water. Once in surface water, dissolved hazardous substances are transported in the water column to downstream surface water and groundwater resources. Particulate substances transported in the water column include sediments ranging in size from colloidal clays to boulders. Particulate hazardous substances are derived from erosion of waste materials on hillsides and in floodplains, and from entrainment in the water column of contaminated materials in bed and bank deposits.

Once entrained or dissolved in the water column, hazardous substances are carried downstream, exposing downstream surface water, groundwater, beds, banks, and, during high water, floodplains to the transported dissolved and particulate hazardous substances.

3.3.2 Mobility and Transport of Hazardous Substances in Surface Water

Data confirming that surface water mobilizes and transports hazardous substances are presented in Table 3-2. Mean annual concentrations (unfiltered) and total annual loads (kilograms per year) of cadmium, lead, and zinc were calculated from annual mean stream flow measured at USGS gauging stations on the Coeur d'Alene River during water years 1993 and 1994 (Beckwith et al., 1997). Hazardous substance concentrations in the South Fork and mainstem Coeur d'Alene rivers were greatly elevated relative to concentrations in the North Fork Coeur d'Alene River.

Table 3-2
Mean Concentrations (total) and Annual Loads of Cadmium, Lead, and Zinc in the North Fork, South Fork, and Mainstem Coeur d'Alene Rivers during Water Years 1993 and 1994

USGS Gauging Station	Water Year	Cadmium		Lead		Zinc	
		Mean Concentration (g/L)	Load (kg/yr)	Mean Concentration (g/L)	Load (kg/yr)	Mean Concentration (g/L)	Load (kg/yr)
North Fork Coeur d'Alene River at Enaville	1993 1994	1.0 1.0	1,370 840	4.5 2.9	6,190 2,420	17.1 13	23,320 10,900
South Fork Coeur d'Alene River at Elizabeth Park	1993 1994	5.8 6.6	1,370 1,050	72.5 42.0	17,120 6,670	810 1,000	190,700 159,600
South Fork Coeur d'Alene River near Pinehurst	1993 1994	8.0 8.7	3,040 2,150	55.8 35.8	21,190 8,840	1,130 1,130	430,500 324,400
Coeur d'Alene River at Cataldo	1993 1994	2.0 2.2	3,520 2,440	29.4 20.0	52,930 22,650	258 323	464,200 365,500
Coeur d'Alene River at Rose Lake	1993 1994	2.3 2.2	4,630 2,670	142.0 86.7	286,300 105,300	347 376	699,500 456,800
Coeur d'Alene River near Harrison	1993 1994	2.3 2.1	4,640 2,550	116.0 51.6	234,800 62,580	301 323	607,600 392,300

Source: Beckwith et al., 1997.

Between Cataldo and Rose Lake there is substantial entrainment of lead and zinc. In 1993, the lead load in that reach increased approximately five fold and the zinc load nearly doubled. Subsequent deposition or loss occurs between Rose Lake and Harrison. Comparison of filtered (not presented) and unfiltered samples indicated that cadmium and zinc are transported primarily in dissolved or colloidal form and lead primarily as particulate material (Beckwith et al., 1997).

Floods transport very large quantities of hazardous substances through the lower Coeur d'Alene River basin and into Coeur d'Alene Lake. Data collected by the USGS during the February 1996 flood indicated that the Coeur d'Alene River transported an estimated 69,000 metric tons of sediment, 720 metric tons of lead, and 180 metric tons of zinc, and 111 kg of cadmium to Coeur d'Alene Lake on a single day (February 10), the day after the peak flow (Beckwith, 1996; Beckwith et al., 1997). Concentrations of hazardous substances in the South Fork and mainstem Coeur d'Alene rivers were substantially greater than concentrations in the North Fork Coeur d'Alene River, and concentrations of hazardous substances and suspended sediment generally increased with distance downstream (Table 3-3). Comparison of concentrations in unfiltered and filtered samples collected at Caltado, Rose Lake, and Harrison showed that during the flood, hazardous substances were primarily transported as suspended sediment rather than dissolved in the water (Beckwith, 1996; Beckwith et al., 1997).

These and other surface water data (see Chapter 4) confirm that surface water transports hazardous substances in both dissolved and particulate forms.

Table 3-3
Concentrations of Trace Metals and Suspended Sediment in Unfiltered Samples, Coeur d'Alene River Basin, February 8-10, 1996

Sample Location	Date, Time	Cd (g/L)	Pb (g/L)	Zn (g/L)	Suspended Sediment (mg/L)
North Fork CdA at Enaville	Feb. 8, 1300	<1	10	30	68
South Fork CdA at Elizabeth Park	Feb. 8, 1130	5	410	820	180
	Feb. 9, 1210	13	3,500	2,000	1,900
South Fork CdA near Pinehurst	Feb. 8, 1330	7	420	780	410
CdA River at Cataldo	Feb. 8, 0910	2	66	190	76
	Feb. 9, 1600	9	840	690	890
	Feb. 10, 1000	3	340	330	290
CdA River at Rose Lake	Feb. 8, 1430	3	500	390	96
	Feb. 9, 0915	11	4,500	1,700	980
	Feb. 10, 1040	6	3,700	850	440
CdA River at Harrison	Feb. 8, 1400	6	3,100	890	260
	Feb. 10, 0730	11	6,500	1,600	620

Source: Beckwith, 1996.

3.3.3 Surface Water Is Exposed to Hazardous Substances

Concentrations of hazardous substances in surface waters of the Coeur d'Alene River basin downstream of major mining-related sources of hazardous substances are elevated relative to concentrations in reaches upstream of major mining related sources. Table 3-4 presents a summary of surface water data collected between 1966 and 1998 by Idaho Department of Health and Welfare, Idaho Department of Environmental Quality, USGS, U.S. EPA, U.S. BLM, and the Silver Valley Natural Resource Trustees (data sources described further in Chapter 4). The summary shows dissolved cadmium, lead, and zinc data collected during high flow and low flow at several sites in each reach. A clear pattern of increasing concentrations with distance downstream is evident, reflecting the sequential addition of mining-related sources of hazardous substances with distance downstream. Concentrations in headwater reaches upstream of mining activity (South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, Pine Creek) are typically low. Downstream, median concentrations of cadmium, lead, and zinc increase by one to more than two orders of magnitude. The influence of uncontaminated diluting waters of the West Fork of Pine Creek on the mainstem Pine Creek, and the North Fork Coeur d'Alene River on the mainstem Coeur d'Alene River is apparent.

Figure 3-2 presents total and dissolved concentrations of cadmium, lead, and zinc in surface water samples collected during low flow in 1998 from the South Fork Coeur d'Alene River (Stratus Consulting, 1999). Samples were collected upstream of the Canyon Creek confluence and from the upper 11 miles of the South Fork Coeur d'Alene River downstream of the Canyon Creek confluence. The precipitous increase in concentrations measured in the South Fork Coeur d'Alene River downstream of the Canyon Creek confluence is evident. Data presented in Figure 3-2 and Table 3-4 thus confirm that surface waters downstream of major mining related sources are exposed to hazardous substances in sufficient concentrations for surface water to serve as an exposure pathway [43 CFR § 11.63(b)(2)(j)], and that hazardous substances are transported in surface water to downstream surface water resources.

3.3.4 Resources Exposed to Surface Water

Surface water serves as both a physical and a chemical transport and exposure pathway of dissolved and particulate hazardous substances to:

- downstream surface water and groundwater resources
- floodplain soils and sediments and lake bed sediments
- aquatic biological resources (periphyton, aquatic invertebrates, and fish)
- terrestrial biological resources (soils, vegetation, wildlife).

Table 3-4
Concentrations (median, range) of Dissolved Cadmium, Lead, and Zinc in Surface Waters of the Coeur d'Alene River Basin[a]

Reach	Cadmium (µg/L) Median	Cadmium (µg/L) Range	Lead (µg/L) Median	Lead (µg/L) Range	Zinc (µg/L) Median	Zinc (µg/L) Range
South Fork Coeur d'Alene River						
Headwaters to Larson (above Daisy Gulch)	0.25	0.01u-2.5	1.5	0.1u-5.0	13.0	4.5-117
Larson to Canyon Creek	0.88	0.04u-6.0	3.0	0.32-45.0	1.7	4.0-339
Canyon Creek to Elizabeth Park	7.3	0.2-18.0	10	2.0-45.0	1,025	269-2,840
Elizabeth Park to Pinehurst	9.6	1.2-220	8.0	0.8u-185	1,700	140-19,000
Pinehurst to the North Fork confluence	78	8.0-390	15.0	5.0-400	4,590	400-23,000
Canyon Creek						
Headwaters to O'Neill Gulch	0.25	0.04u-1.0	1.5	0.12-3.0	20.0	0.3-42.0
O'Neill Gulch to the mouth	5.5	0.25u-408	15.0	1.5u-578	836	29.3-9,463
Ninemile Creek						
Headwaters to above Interstate-Callahan mine	0.2	0.04u-0.46	0.6	0.1u-3.95	16.0	4.7-77.0
Interstate-Callahan to the mouth	23	0.2u-90	45.9	0.2u-378	3,570	10.0-12,400
Pine Creek						
East Fork Pine Creek above Constitution Mine	0.04	0.04u-0.2u	0.1	0.1u-0.5u	4.7	1.9u-10.0u
Constitution Mine to West Fork	3.2	0.38-18.3	4.0	0.61-30.9	1,240	107-7,410
Mainstem Pine Creek to South Fork	0.25	0.04-2.0	1.5	0.2-20.0	100	20.0u-402
Coeur d'Alene River						
Confluence to Cataldo	3.0	1.0-120	5.0	1.0u-24.0	468	20.0-3,300
Cataldo to Rose Lake	20	1.1-122	23.5	1.6-770	1,800	69.0-13,200
Rose Lake to Harrison	2.0	0.94-19.0	7.4	1-100	346	122-1,824
Coeur d'Alene Lake	1.0	0.2u-2.0	5.0	1.0u-12.0	120	10.0u-190

a. For data sources, see Chapter 4.

u — undetected at the reported concentration.

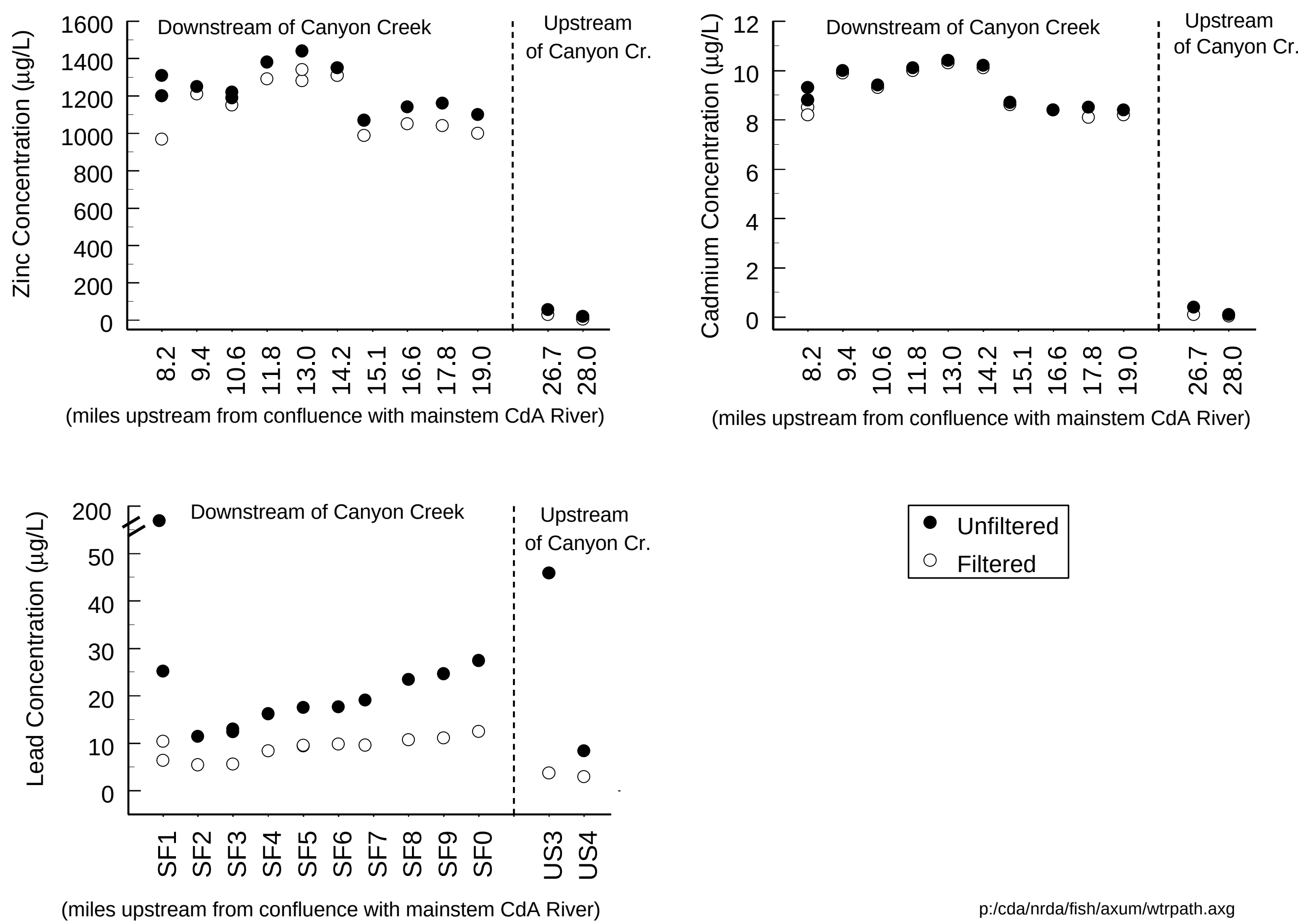

Figure 3-2. Concentrations of the hazardous substances cadmium, lead, and zinc measured in filtered and unfiltered water samples collected from the South Fork Coeur d'Alene River in Fall, 1998 (low flow).

Source: Stratus Consulting, 1999.

Surface Water/Groundwater

Surface water acts as a pathway to downstream surface water resources in flowing river systems. In addition, surface water can act as a pathway to shallow alluvial groundwater, which, in turn, can recharge to downgradient surface waters. Surface water/groundwater interactions are evident in gaining and losing sections of the river, as seasonal and perennial seeps, and during seasonal flooding and subsequent receding of floodwaters.

In losing stream reaches where the valley floor widens, such as at Woodland Park on Canyon Creek and at Osburn Flats on the South Fork Coeur d'Alene River, water leaves the stream channel and enters the floodplain aquifer (Dames & Moore, 1991). Where the valley constricts, groundwater discharges back to the stream (Dames & Moore, 1991). Hazardous substances leached from the floodplain tailings deposits in these wider reaches of the valley are transferred to the stream with the returning groundwater. Streams may also be losing streams during high flow, and gaining during low flow. For example, in the lower Coeur d'Alene River basin, following seasonal flooding and saturation of wetland sediments, groundwater stored in the sediments slowly drains to the river and lakes as the water table lowers during the drier months and hazardous substances leached from the mixed tailings and alluvium are transferred back to surface waters.

Floodplain Soils and Sediments

Exposure of floodplain soils and sediments to hazardous substances transported by surface water is ongoing. For example, Horowitz et al. (1995) identified a Mt. St. Helen's ash layer in sediment samples collected from the 0.3 to 21.5 cm depth in the lower basin floodplain. Sediments overlying the ash layer were analyzed separately from sediments below the ash layer. Concentrations in sediments deposited since 1980 are similar to concentrations in sediments deposited previously. The data confirm that since 1980, highly contaminated sediments have continued to be deposited on the floodplain.

In the lower basin, sediment cores from the floodplain and river channel show that a thick layer of metals enriched sediments overlies sediments with low metals concentrations (URSG and CH2M Hill, 1998). Figure 3-3 presents an example of the lead concentrations from a single core collected near Medimont. Although the sediment layers were not dated, the pattern, coupled with historical information regarding tailings disposal methods and resulting effects (Long, 1998; Casner, 1991) and the dredging history of the Coeur d'Alene River at Cataldo, indicates that the lower layer consists of premining sediments. The superposition of metals contaminated sediments over premining sediments is evidence that water has transported particulate hazardous substances and has exposed floodplain soils and sediments to hazardous substances.

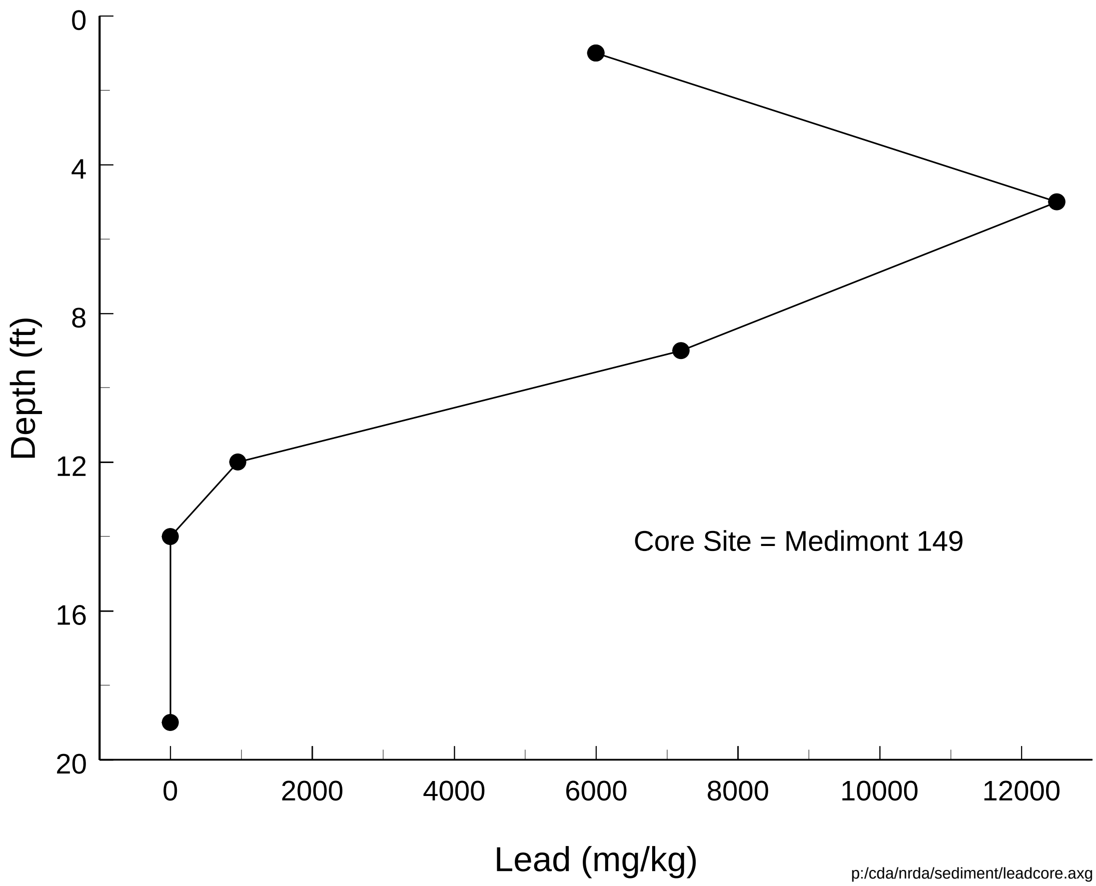

Figure 3-3. Lead concentrations at depth in a sediment core collected near Medimont.
Source: URSG and CH2M Hill, 1998**.**

Aquatic Biological Resources

Aquatic biological resources, including biofilm, benthic invertebrates, and fish, are exposed to dissolved and particulate hazardous substances in surface water by direct contact (Figure 3-4). Biofilm, which includes attached algae, bacteria, and associated fine detrital material that adheres to substrates in water, is a food source for invertebrates that scrape mineral and organic substances (Farag et al., 1998). Hazardous substances are present as abiotic components (in trapped sediments) and biotic components (in algal tissues) of the biofilm (Farag et al., 1998). Concentrations of hazardous substances in biofilm in the South Fork and mainstem Coeur d'Alene rivers are similar (Table 3-5), indicating a close link between the two (Farag et al., 1998). Concentrations of hazardous substances in benthic invertebrates and fish tissues were lower, but concentrations in composite samples of benthic invertebrates generally increased with

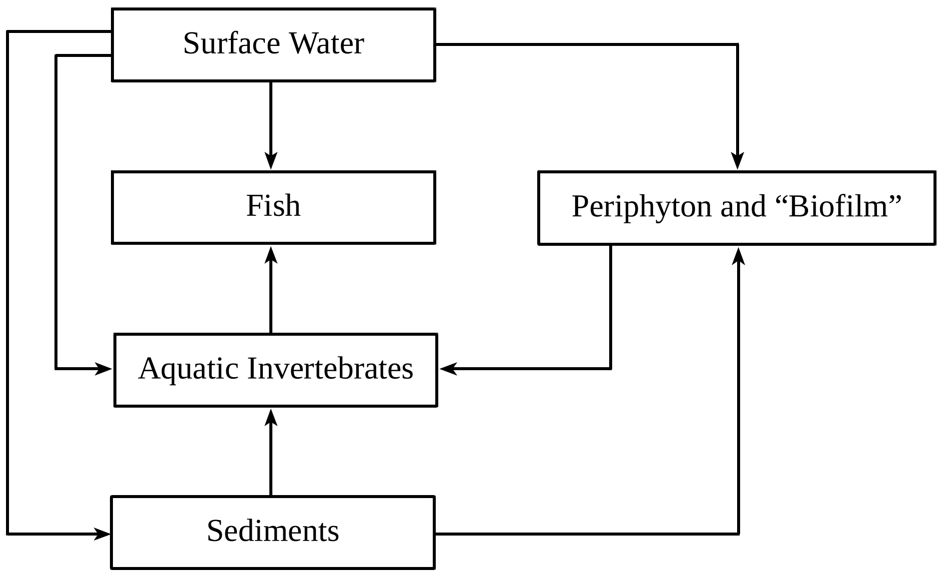

Figure 3-4. Surface water and sediment pathways to aquatic biological resources. Also illustrated are foodchain exposure pathways that result from surface water and sediment pathways.

Table 3-5
Mean Concentrations of Zinc (g/g dry weight) in Pathway Components of the Coeur d’Alene River Basin

Pathway Component	South Fork CdA River near Pinehurst	Mainstem Coeur d’Alene River	
		Cataldo	Harrison
Sediments	8,130	2,543	3,895
Biofilm	11,578	83,300	4,543
Benthic Invertebrates	2,658	1,735	746
Whole Perch	—	—	252
Trout Kidney	499 (brook trout)	440 (rainbow trout)	—
Trout Gill	594	1,233	—
Source: Farag et al., 1998.			

increasing sediment concentrations (Farag et al., 1998). Elevated concentrations of metals in biofilm, invertebrates, and fish confirm that metals from water (and sediments) are a pathway to biofilm, invertebrates, and fish throughout the basin (Farag et al., 1998).

Terrestrial Biological Resources

Wetland and riparian vegetation of the Coeur d'Alene River basin is exposed to surface water directly during seasonal flooding, and indirectly (to shallow groundwater) during other times of the year. Exposure of plants to hazardous substances occurs through root uptake of dissolved substances in soil water (or open water for aquatic vegetation). In addition, surface water seasonally deposits suspended sediment on the floodplain. These sediments expose vegetation to additional hazardous substances. In addition, wildlife resources that use contaminated reaches of the Coeur d'Alene River basin are exposed to hazardous substances in surface water through ingestion (drinking) and dermal contact (e.g., swimming and diving behavior in birds and furbearers such as mink).

In summary, surface water is exposed to dissolved and particulate hazardous substances throughout the Coeur d'Alene River basin. Surface water interacts with groundwater, sediment, and biological resources throughout the basin. Sufficient concentrations exist in surface water resources for surface water to serve as a pathway to other resources.

3.4 SEDIMENTS

Sediments are defined by the DOI regulations as a component of the surface water resource (bed, bank, and suspended sediments) [43 CFR § 11.14 (pp)] and as a component of geologic resources [43 CFR §11.14 (s)]. Data confirm that sediments are contaminated with hazardous substances at concentrations sufficient to expose surface water and aquatic and terrestrial biological resources, and that sediments serve as a transport and exposure pathway of hazardous substances to injured resources.

3.4.1 Sediment Exposure to Hazardous Substance Releases

Sediments are materials deposited by water and include suspended sediments in the water column, and bed, bank, and floodplain sediments. Sediments carried in the water column are suspended sediments. Bed sediments are deposits on lake and river bottoms, but in rivers, bed sediments continue to move downstream. Bank sediments and floodplain sediments are materials deposited by the stream, beyond the main channel. Bank sediments are remobilized through erosion (cut banks), and created by deposition (point bars). Floodplain sediments may be historical bank sediments (alluvial terraces), or part of the active floodplain which receives seasonally deposited sediments as a result of flooding.

Sediments have been exposed to concentrations of hazardous substances by historical dumping of mine wastes in the streams and on the floodplains of the basin. Tailings originally released to the streams and floodplains have become intermixed with native alluvium (Chapter 2 — Hazardous Substance Sources). Sediments also are exposed to hazardous substances as a result of exposure to contaminated surface and groundwater, through surface erosion and mass wasting of tailings and waste piles, and through naturally occurring erosion of streambed and banks contaminated with mixed tailings and alluvium. Data presented in the previous section (Tables 3-2 and 3-3) confirmed that hazardous substances are transported in suspended sediment in surface waters.

Data presented in Chapter 2 confirm that floodplain deposits of tailings and mixed tailings and alluvium occur throughout the basin, and that concentrations of cadmium, lead, and zinc are consistently elevated in these materials. Sediments with elevated lead concentrations are distributed throughout sloughs, marshes, and lakes of the lower basin (Figure 3-5). In addition, in Coeur d'Alene Lake from near the mouth of the Coeur d'Alene River to the lake's outlet at the Spokane River, metals-enriched sediments cover the bed (see Figure 5-5, Chapter 5 — Sediment Resources).

These data confirm that sediments are exposed to sufficient concentrations of hazardous substances to act as a pathway.

3.4.2 Resources Exposed to Sediments

Sediments serve as a pathway to downstream surface water resources through natural hydrological processes. In addition, contaminated sediments serve as a pathway to biological resources, including terrestrial and aquatic biota.

Terrestrial Biota

Food chain exposure is an important pathway for lead and other metals in the Coeur d'Alene area, as evidenced by the following:

- ***Sediment lead contaminates vegetation.*** Lead contamination of vegetation in the Coeur d'Alene River basin is caused primarily by sediments adhering to the surface of plants (Neufeld, 1987; Krieger, 1990; Beyer et al., 1997; Campbell et al. 1999b). Waterfowl are exposed to high lead concentrations when feeding on vegetation that holds the sediment on plant surfaces or when the vegetation is partially buried in the sediment (Beyer et al., 1998).

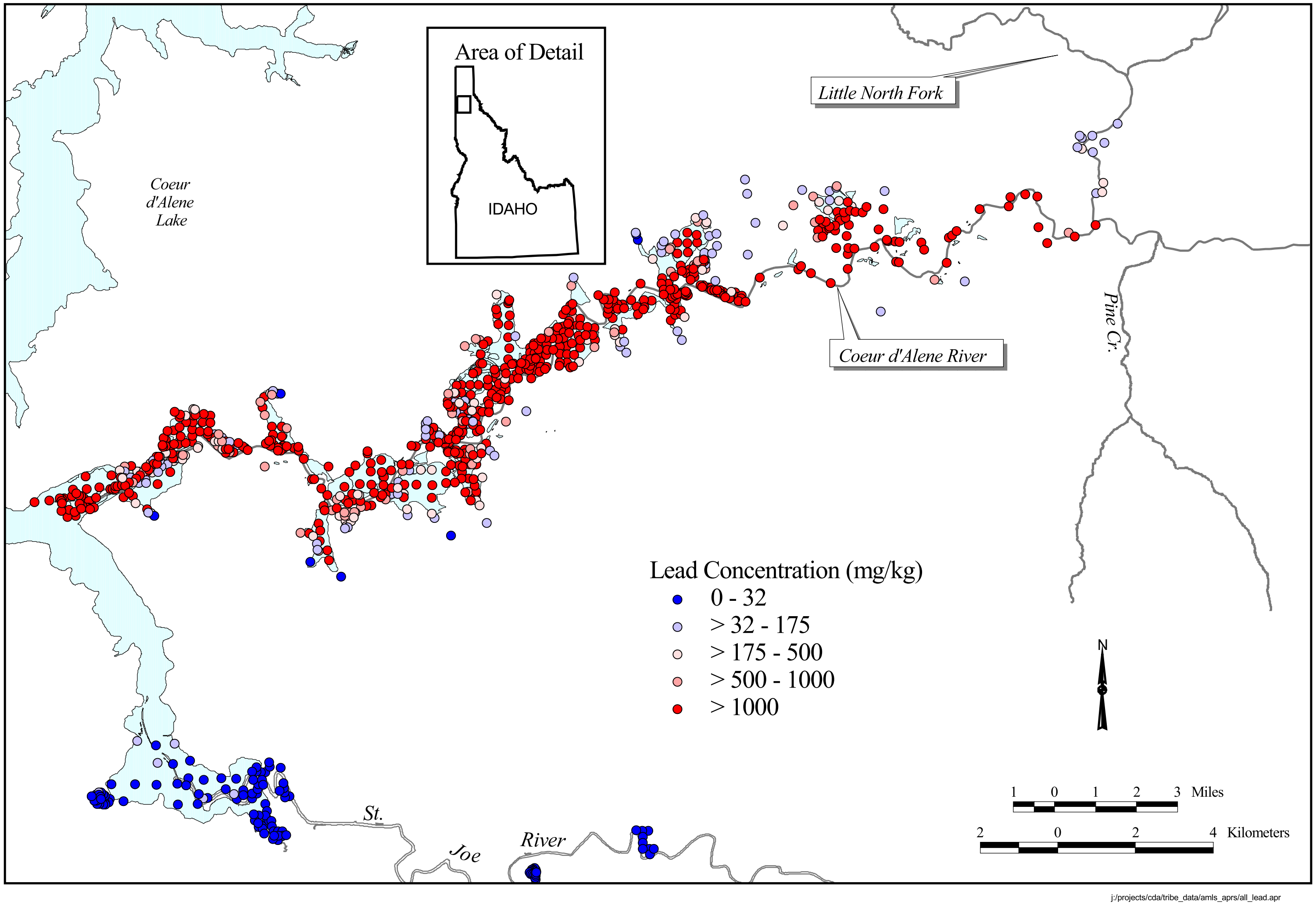

Figure 3-5. Distribution of lead concentrations in surface bed, bank, and floodplain sediments of the lower Coeur d'Alene River basin. See Chapter 5 for a description of data sources.

- ***Wildlife forage and prey items are contaminated.*** Lead and other metals accumulate in dietary items of fish (aquatic invertebrates) (Woodward et al., 1997; Farag et al., 1998) and dietary items of dabbling and diving ducks (aquatic vegetation) (e.g., Krieger, 1990; Audet, 1997; Farag et al., 1998). Lead and other metals accumulate in dietary items of birds of prey and carnivorous mammals, including small mammals, fish, and avian species. Concentrations of lead in prey items are substantially elevated in the Coeur d'Alene River basin compared to concentrations in reference area prey items. For example, lead concentrations in meadow voles and brown bullheads were 38 and 85 times higher, respectively, in the Coeur d'Alene River basin than in the St. Joe River basin (Audet, 1997).

- ***Wildlife tissues are contaminated.*** Lead and other metals have bioaccumulated in the wildlife of the Coeur d'Alene River basin, including multiple species of waterfowl (without the presence of lead artifacts), bald eagles, mammals, species of cultural significance (cutthroat trout, beaver, muskrat, and deer), and songbirds (robins). In contrast, lead levels in tissues of wildlife (without the presence of lead artifacts) from reference areas are generally low. Many of the wildlife species with elevated tissue concentrations are species that do not ingest lead shot. Songbirds, for example, feed on organisms that live in sediment and floodplain soils, and muskrats and beavers feed on vegetation.

Aquatic Biota

Data on concentrations of metals in biofilm, invertebrates, and fish confirm that metals from water (and sediments) are a pathway to biofilm, invertebrates, and fish throughout the basin (Farag et al., 1998). These data confirm that metals in the Coeur d'Alene River basin are bioavailable and that sediments, biofilm, invertebrates, and fish are exposed to hazardous substances, and provide evidence of the sediment-invertebrate dietary exposure pathway to fish.

These data confirm that sediments are an important pathway to both aquatic and terrestrial resources.

3.5 GROUNDWATER

Groundwater data for Coeur d'Alene River basin are not comprehensive. However, available data illustrate that groundwater is contaminated with hazardous substances at concentrations sufficient to expose surface water resources and that contaminated groundwater discharges to surface water. Thus, groundwater serves as a transport and exposure pathway of hazardous substances to injured resources. More information on aquifer properties and concentrations of hazardous substances in groundwater is provided in Chapter 4. Information on concentrations of hazardous substances in adit and seep discharge, which is pathway to surface water, is provided in Chapter 2.

3.5.1 Groundwater Exposure to Hazardous Substance Releases

The predominant mechanisms by which groundwater becomes exposed to hazardous substances from mining and mineral processing facilities are:

- infiltration of precipitation and snow melt through sources of contamination in the unsaturated zone, which leaches hazardous substances in the unsaturated zone to downgradient groundwater

- rising of capillary groundwater to sources of contamination in the unsaturated zone, which leaches and transports hazardous substances to downgradient groundwater during an infiltration event

- inundation and leaching of source materials in the saturated zone to groundwater via groundwater flow through sources or changes in groundwater level

- transport of contaminated water (i.e., from contaminated alluvial groundwater) through the unsaturated or saturated zone to downgradient groundwater and surface water

- weathering of metallic sulfides releases metals and sulfuric acid (H_2SO_4) through oxidation catalyzed by iron- and sulfur-oxidizing bacteria (*Thiobacillus ferroxidans* and *T. oxidans*)

- loss of contaminated stream water to alluvial groundwater during high flow.

3.5.2 Groundwater Is Exposed to Hazardous Substances

Limited groundwater sampling conducted in the Coeur d'Alene River Basin confirms the presence of hazardous substances at elevated concentrations in shallow groundwater in the floodplain. Samples of mine adits and seeps from streamside tailings and waste rock piles confirm the presence of elevated concentrations of hazardous substances in groundwater (see Chapter 2, Tables 2-18 through 2-23).

In a study of the lower Canyon Creek valley, Houck and Mink (1994) concluded that Canyon Creek gains water from groundwater inflow adjacent to and downstream of Woodland Park. Similar conclusions were reached by Paulson and Girard (1996) in a study performed in the East Fork of Moon Creek. They found that groundwater in the vicinity of the Silver Crescent millsite contained elevated concentrations of metals and acid, and that groundwater flow was a "dominant process affecting metal transport" (Paulson and Girard, 1996).

Box et al. (1997) concluded that groundwater was an important pathway of metals input into the South Fork Coeur d'Alene River, as well as Canyon Creek. These authors concluded:

> Dissolved metals are leached into the underlying floodplain aquifer by percolating rainfall and snowmelt or rising groundwater. The permeable floodplain aquifer rapidly routes water from losing stream reaches (where the valley floor widens) to gaining stream reaches (where the valley narrows), efficiently transferring dissolved metals from floodplain soils to the stream.

The shallow aquifer in Canyon Creek is no longer used (officially) for domestic water supply because of the poor groundwater quality (Ridolfi, 1995). Similarly, groundwater samples collected from the perimeter of the CIA as part of the Bunker Hill RI/FS show a pattern of elevated metals concentrations (Chapter 2, Table 2-19).

The above information illustrates that groundwater in many areas of the basin is contaminated with hazardous substances and that groundwater is an important pathway for movement and discharge of hazardous metals in portions of the Coeur d'Alene basin.

3.5.3 Resources Exposed to Groundwater

Contaminated groundwater in floodplains throughout the basin serves as a pathway to surface water resources. Limited groundwater sampling performed in conjunction with surface water loadings analyses has identified areas of contributions of dissolved metal loading from groundwater to the South Fork Coeur d'Alene River and tributaries. As metals-contaminated groundwater discharges to surface water either at distinct seeps or as diffuse seepage along the banks and stream bed, surface water is exposed to metals.

3.6 SOILS

Soils are part of the geologic resources [43 CFR § 11.14 (s)]. Soils in the assessment area include riparian soils in the floodplains of the South Fork Coeur d'Alene River and its tributaries, and upland soils, including the hillsides and valleys of the Bunker Hill Superfund Site. Surface water and sediments containing elevated concentrations of hazardous substances serve as transport and exposure pathways of hazardous substances to floodplain soils of the Coeur d'Alene River basin. Floodplain soils and sediments contain elevated concentrations of hazardous substances, and concentrations are sufficient to expose riparian vegetation to hazardous substances. Riparian resources of Canyon Creek, Ninemile Creek, the South Fork Coeur d'Alene River, and the lower Coeur d'Alene River, including soils and vegetation, are exposed to elevated concentrations of cadmium, lead, and zinc.

3.6.1 Soils Exposure to Hazardous Substance Releases

The predominant pathways of exposure of soils to hazardous substances are:

- surface waste deposits/erosion of surface waste deposits
- deposition of contaminated sediments by surface water on floodplain soils
- infiltration/inundation by contaminated surface and groundwater
- historical deposition of smelter emissions.

Information presented in the Chapter 2 (Hazardous Substance Sources) confirms that historical sources discharged tailings to the basin, and that hazardous substances have come to be located in bed, bank, and floodplain sediments (and floodplain soils) throughout the basin. These contaminated floodplain, bed, and bank sediments are remobilized and re-released, and serve as ongoing sources of contamination (Chapter 9, Figure 9-24). Mixed alluvium and tailings now constitute floodplain soils. Hazardous substances are transported by surface water as dissolved and suspended sediments and deposited on floodplain surfaces (Chapters 4 and 5 — Surface Water Resources, and Sediment Resources). Floodplains have been and continue to be exposed to deposition of hazardous substances transported by surface water.

Historically, emissions from the Bunker Hill smelters released to the air were transported by air and deposited on soils in the vicinity. Upland soils remain contaminated with aerially deposited smelter emissions that contained elevated concentrations of hazardous substances. Over time, the erosion of these metals-contaminated soils becomes an exposure pathway to downgradient resources.

3.6.2 Mobility and Transport of Hazardous Substances in Soils

Hazardous substances in soils are transported in soil pore water. Riparian vegetation is exposed to hazardous substances by root exposure to and uptake from contaminated soils and sediments. Pathways were determined by demonstrating that sufficient concentrations exist in surface water and floodplain soils and sediments to expose riparian resources of the Coeur d'Alene River basin to hazardous substances. Exposure of vegetation was confirmed by demonstrating the correlation between concentrations of hazardous substances soils and the growth response of plants (see Chapter 9 — Riparian Resources). As concentrations of hazardous substances in soils increase, plant growth is inhibited, vegetation cover, species richness, and structural heterogeneity in the field decrease, and bare ground increases. Data presented in Chapter 9 and Chapter 2 confirm that concentrations in floodplain soils are sufficient for floodplain soils to serve as an exposure pathway to riparian resources [43 CFR 11.63 (a)(2)].

3.6.3 Soils Are Exposed to Hazardous Substances

Concentrations of hazardous substances in Coeur d'Alene River basin floodplain soils contain elevated concentrations of cadmium, lead, and zinc and other hazardous substances. Data presented in Tables 2-9 through 2-11 and 2-14 through 2-17 (see Chapter 2 — Hazardous Substance Sources) and Table 3-6 confirm that concentrations in assessment soils are elevated.

Table 3-6
Mean (standard error) Concentrations (mg/kg) of Hazardous Substances in Soils of the Coeur d'Alene River Basin

Site	Arsenic	Cadmium	Copper	Lead	Zinc
Canyon Creek (n = 6)	44.8 (6.7)	22.6 (7.5)	147 (12.9)	18,300 (6,310)	3,840 (1,260)
Ninemile Creek (n = 5)	34.2 (8.5)	9.0 (2.0)	235 (51.0)	27,300 (8,180)	2,580 (352)
South Fork CdA River (n = 29)	163 (12.3)	40.5 (3.8)	250 (21.5)	12,400 (1,420)	5,500 (540)
Mainstem CdA River (n = 43)	71.1 (13.0)	11.3 (1.4)	60.8 (6.9)	2,220 (329)	1,230 (233)

Source: Hagler Bailly Consulting, 1995; Chapter 9, assessment samples only.

3.7 BIOLOGICAL PATHWAYS

Biological resources are exposed to hazardous substances through direct exposure to contaminated surface water and sediments (see preceding sections) or through consumption of contaminated prey (referred to as "foodchain" or "dietary" exposure). Data confirming these foodchain pathways are presented in Chapter 6 (Wildlife Resources), Chapter 7 (Fish Resources), and Chapter 8 (Benthic Macroinvertebrates), and also were summarized in Section 3.3.4 (Table 3-5) and Section 3.4.2. These data confirm that:

- aquatic benthic invertebrates and fish contain elevated concentrations of metals and serve as a pathway to fish and other organisms that consume them (Farag et al., 1998)

- forage and prey items of waterfowl (e.g., vegetation, water potatoes), shore birds (e.g., invertebrates), and birds of prey (e.g., fish, small mammals, waterfowl) contain elevated concentrations of metals and serve as a pathway to the wildlife that consume them (Audet, 1997; Audet et al., 1999a and 1999b; Campbell et al., 1999b).

3.8 CONCLUSIONS

Pathway resources for which exposure to sufficient concentrations of hazardous substances has been confirmed are listed in Table 3-7.

Table 3-7
Pathway Resources for Which Exposure to Sufficient Concentrations of Hazardous Substances Has Been Confirmed [43 CFR § 11.63 (a)(2)]

Pathway Resource	Chapters	Example References
Surface water	Surface Water Resources (4)	Beckwith et al., 1997; Ridolfi, 1995; Dames & Moore, 1990
Groundwater	Hazardous Substance Sources (2), Surface Water Resources (4)	Dames & Moore, 1991; Box et al., 1997
Sediments	Hazardous Substance Sources (2), Sediment Resources (5)	Horowitz, 1995; URSG and CH2M Hill, 1998; Campbell et al., 1999a
Soils	Hazardous Substance Sources (2), Riparian Resources (9)	Hagler Bailly, 1995
Vegetation	Riparian Resources (9)	Hagler Bailly, 1995
Invertebrates	Benthic Macroinvertebrates (8)	Farag et al., 1998; Woodward et al., 1997
Fish	Fish Resources (7)	Farag et al., 1998; Woodward et al., 1997
Wildlife	Wildlife (6)	Audet, 1997; Campbell et al., 1999b

The information presented in this chapter demonstrates the following:

▸ Surface water serves as a critical transport and exposure pathway of dissolved and particulate hazardous substances to soil, aquatic and terrestrial biological resources, and to downstream surface water and groundwater resources. Surface waters of the Coeur d'Alene River basin downstream of mining and mineral processing facilities have been and continue to be exposed to elevated concentrations of hazardous substances, including cadmium, lead, and zinc. As a result of natural downstream transport mechanisms, surface waters throughout much of the Coeur d'Alene River basin — including the South Fork Coeur d'Alene River, the Coeur d'Alene River, Coeur d'Alene Lake, and Canyon, Ninemile Creek, Moon Creek, Pine Creek, Milo Creek, Portal Creek, Deadwood Gulch/Bunker Creek, Grouse Gulch, Government Gulch, Gorge Gulch, Highland Creek, Denver Creek, and Nabob Creek — are exposed to elevated concentrations of hazardous substances.

- Sediment in the water column and in the beds and banks of Coeur d'Alene River basin drainages downstream of mining and mineral processing facilities has been and continues to be a transport and exposure pathway. Bed and bank sediments throughout the basin contain elevated concentrations of hazardous substances, including cadmium, lead, and zinc. Contaminated sediments are an ongoing pathway for downstream movement of hazardous substances through natural processes. Contaminated streambed sediment results in exposure of fish, periphyton, and aquatic invertebrates to hazardous substances. Contaminated sediment redeposited on floodplains and on vegetation surfaces is an important cause of exposure of wildlife and vegetation to hazardous substances.

- Floodplain soils have been and continue to be a transport and exposure pathway. Floodplain soils and wetland sediments have become contaminated with hazardous substances through direct discharge of wastes to the floodplain, and through deposition of contaminated sediments through natural hydrological processes. Floodplain soils are contaminated with hazardous substances such as cadmium, lead, and zinc in riparian areas downstream of mining and mineral processing facilities, including in riparian areas of the South Fork Coeur d'Alene River, the Coeur d'Alene River, and Canyon, Ninemile, Moon, and Pine creeks. Contaminated floodplain soils serve as an ongoing transport pathway to downstream resources through mobilization by surface waters. Floodplain soils contaminated with hazardous substances serve as a pathway by which vegetation and soil biota are exposed hazardous substances. Wildlife are exposed to hazardous substances through direct ingestion of soil/sediment and ingestion of soil/sediment adhering to vegetation.

- Although comprehensive data are not available throughout the Coeur d'Alene River basin, available information illustrates that groundwater in certain locations acts as a pathway by which hazardous substances are transported through leaching of hazardous substances in contaminated floodplain deposits. Groundwater transports hazardous substances to downgradient surface waters.

- Biological resources serve as contaminant exposure pathways through dietary, food-chain relationships. Contaminated periphyton, aquatic invertebrates, and fish act as exposure routes of hazardous substances to higher trophic level consumers. Aquatic vegetation containing or coated with elevated concentrations of lead expose waterfowl through their diets. Wildlife also are exposed to hazardous substances through consumption of prey that have become contaminated through alternative pathways.

3.9 REFERENCES

Audet, D.J. 1997. Coeur d'Alene Basin Natural Resource Damage Assessment Biological Reconnaissance Investigation. U.S. Fish and Wildlife Service, Spokane, WA.

Audet, D.J., J.L. Kaiser, D.J. Hoffman, L. McDonald, and T. McDonald. 1999a. Lead Exposure of Bald Eagles and Prey Items in Northern Idaho and Eastern Washington. U.S. Fish and Wildlife Service, Spokane, WA.

Audet, D.J., L.H. Creekmore, L. Sileo, M.R. Snyder, J.C. Franson, M.R. Smith, J.K. Campbell, C.U. Meteyer, L.N. Locke, L.L. McDonald, T.L. McDonald, D. Strickland, and S. Deeds. 1999b. Wildlife Use and Mortality Investigation in the Coeur d'Alene Basin 1992-1997. U.S. Fish and Wildlife Service, Spokane, WA.

Balistrieri, L.S., A.A. Bookstrom, S.E. Box, and M. Ikramuddin. 1998. Drainage From Adits and Tailings Piles in the Coeur d'Alene Mining District, Idaho: Sampling, Analytical Methods, and Results. U.S. Geological Survey Open-File Report 98-127.

Beckwith, M.A. 1996. Water-Quality Data Collected During Floods in the Coeur d'Alene River, Northern Idaho, February 1996. U.S. Geological Survey Fact Sheet FS-219-96.

Beckwith, M.A., P.F. Woods, and C. Berenbrock. 1997. Trace-Element Concentrations and Transport in the Coeur d'Alene River, Idaho, Water Years 1993-94. U.S. Geological Survey Open-File Report 97-398.

Beyer, W.N., L.J. Blus, C.J. Henny, and D. Audet. 1997. The role of sediment ingestion in exposing wood ducks to lead. *Ecotoxicology* 6:181-186.

Beyer, W.N., D.J. Audet, A. Morton, J.K. Campbell, and L. LeCaptain. 1998. Lead exposure of waterfowl ingesting Coeur d'Alene River basin sediments. *Journal of Environmental Quality* 27:1533-1538.

Blus, L.J., C.J. Henny, D.J. Hoffman, L. Sileo, and D.J. Audet. 1999. Persistence of high lead concentrations and associated effects in tundra swans captured near a mining and smelting complex in northern Idaho. *Ecotoxicology* 8:125-132.

Box, S.E., A.A. Bookstrom, L.S. Balistrieri, and M. Idramuddin. 1997. Sources and Processes of Dissolved Metal Loading, Coeur d'Alene River, Idaho. Unpublished report prepared by U.S. Geological Survey, Spokane, WA.

Campbell, J.K., D.J. Audet, J.W. Kern, M. Reyes, and L.L. McDonald. 1999a. Metal Contamination of Palustrine and Lacustrine Habitats in the Coeur d'Alene Basin. U.S. Fish and Wildlife Service, Spokane, WA. Final Draft. May.

Campbell, J.K., D.J. Audet, T.L. McDonald, J. Kern, D. Strickland, and P.J. Cernera. 1999b. Heavy Metal Concentrations in *Sagittaria spp.* Tubers (water potato) in the Coeur d'Alene Basin, Idaho. U.S. Fish and Wildlife Service, Spokane, WA. Final draft. May.

Casner, N.A. 1991. Toxic river: Politics and Coeur d'Alene mining pollution in the 1930s. *Idaho Yesterday* 35(3): 2-19.

CCJM. 1994. Draft Preliminary Assessment Report, Pine Creek Mill Sites, Coeur d'Alene District, Idaho. Prepared by C.C. Johnson & Malhotra, P.C. for the U.S. Bureau of Land Management.

CH2M Hill and URSGWC. 1998. Draft Database Containing Surface Water, Seep, and Adit Data from the Coeur d'Alene River Basin, 1991-1998. Prepared by URS Greiner, Seattle, WA, for U.S. EPA Region 10.

Dames & Moore. 1990. Bunker Hill RI/FS, Revised Data Evaluation Report, Surface Water. Prepared by Dames and Moore, Denver, CO.

Dames & Moore. 1991. Bunker Hill RI/FS Draft Remedial Investigation Report, Volume I. Prepared by Dames and Moore, Denver, CO. Document No. 15852-070/PD194/92010. June 7.

Ellis, M.M. 1940. Pollution of the Coeur d'Alene River and Adjacent Waters by Mine Wastes. U.S. Bureau of Fisheries.

Farag, A.M., D.F. Woodward, J.N. Goldstein, W. Brumbaugh, and J.S. Meyer. 1998. Concentrations of metals associated with mining waste in sediments, biofilm, benthic macroinvertebrates, and fish from the Coeur d'Alene River basin, Idaho. *Archives of Environmental Contamination and Toxicology* 34: 119-127.

Hagler Bailly Consulting. 1995. Riparian Resources Injury Assessment: Data Report. Prepared for the Natural Resource Trustees: Coeur d'Alene Tribe, U.S. Department of Agriculture, U.S. Department of the Interior by Hagler Bailly Consulting, Inc., Boulder, CO.

Hartz, M. 1993. Point and Nonpoint Source Contributions of Trace Heavy Metals to the South Fork Coeur d'Alene River, Shoshone County, Idaho, 1989-1990. Water Quality Status Report No. 111. Idaho Department of Health and Welfare, Division of Environmental Quality.

Harvey, G.W. 1993. Examination of the Impact of Trace (Heavy) Metals and Sediment Monitoring of Mine Waste Remediation Projects Project Effectiveness Monitoring: South Fork Coeur d'Alene River Watershed, Idaho. Idaho Division of Environmental Quality. August 11.

Hornig, C.E., D.A. Terpening, and M.W. Bogue. 1988. Coeur d'Alene Basin EPA Water Quality Monitoring 1972-1986. EPA-910/9-88-216. U.S. Environmental Protection Agency, Region 10. September.

Horowitz, A.J. 1995. Coeur d'Alene Basin NRDA Surficial Flood Plain Data (Draft Report). Prepared by the U.S. Geological Survey. Available from the Coeur d'Alene Tribe, Plummer, ID.

Horowitz, A.J., K.A. Elrick, and R.B. Cook. 1992. Effect of Mining-Related Activities on the Sediment-Trace Element Geochemistry of Lake Coeur d'Alene, Idaho, USA — Part 1: Surface Sediments. Open-File Report 92-109. Prepared for U.S. Geological Survey.

Horowitz, A.J., K.A. Elrick, J.A. Robbins, and R.B. Cook. 1993. The Effect of Mining and Related Activities on the Sediment-Trace Element Geochemistry of Lake Coeur d'Alene, Idaho: Part II: Subsurface Sediments. U.S. Geological Survey Open-File Report 93-656.

Houck, J.C. and L.L. Mink. 1994. Characterization of a Shallow Canyon Aquifer Contaminated by Mine Tailings and Suggestions for Constructed Wetlands Treatment. Prepared for the Trustees for the Idaho Natural Resources Damage Trust Fund.

Krieger, R.I. 1990. Toxicity and Bioavailability Studies of Lead and Other Elements in the Lower Coeur D'alene River. Sacramento, CA. Bureau of Land Management Technical Bulletin 90-3. Prepared for Coeur d'Alene District.

Long, K.R. 1998. Production and Disposal of Mill Tailings in the Coeur d'Alene Mining Region, Shoshone County, Idaho; Preliminary Estimates. U.S. Geological Survey Open-File Report 98-595.

MFG. 1991. Draft Interim Report, Upstream Surface Water Sampling Program, Spring 1991 High Flow Event, South Fork Coeur d'Alene Basin above the Bunker Hill Superfund Site. McCulley, Frick, and Gilman, Inc. August 8.

MFG. 1992a. Bunker Hill Superfund Site Remedial Investigation Report. Volumes I and II. Prepared for Gulf Resources and Chemical Corporation/Pintlar Corporation by McCulley, Frick & Gilman, Inc. May. (Also issued as Dames and Moore. 1991. Bunker Hill RI/FS Draft Remedial Investigation Report. Volumes I and II. Document No. 15852-070/PD194/92010.)

MFG. 1992b. Draft Interim Report, Upstream Surface Water Sampling Program, Fall 1991 Low Flow Event, South Fork Coeur d'Alene Basin above the Bunker Hill Superfund Site. McCulley, Frick, and Gilman, Inc. March 24.

Neufeld, J. 1987. A Summary of Heavy Metal Contamination in the Lower Coeur d'Alene River Valley with Particular Reference to the Coeur d'Alene Wildlife Management Area. Idaho Department of Fish and Game.

Paulson, A.J. and J. Girard. 1996. Groundwater Data From the Silver Crescent Millsite, East Fork of Moon Creek, Idaho. Report of Investigations 9628. U.S. Department of Energy Spokane Research Center.

Ridolfi. 1995. Surface Water Quality Data Compilation and Evaluation. Prepared for the Natural Resource Trustees: Coeur d'Alene Tribe, U.S. Department of Agriculture, U.S. Department of Interior by Ridolfi Engineers and Associates, Inc. August.

Stratus Consulting. 1999. Data Report: 1998 Fish Population Monitoring Coeur d'Alene River Basin NRDA. Prepared for U.S. Department of the Interior, Coeur d'Alene Tribe, and U.S. Department of Agriculture by Stratus Consulting Inc., Boulder, CO.

URSG and CH2M Hill. 1998. Bunker Hill Facility Basin-Wide RI/FS Data Report: Sediment Contamination in the Lower Coeur d'Alene River Basin (LCDARB): Geophysical and Sediment Coring Investigations in the River Channel, Lateral Lakes, and Floodplains. Prepared for the U.S. Environmental Protection Agency Region 10. October.

U.S. BLM. Undated. Untitled draft preliminary assessment report for BLM properties along the Lower Coeur d'Alene River, conducted in 1992. Prepared for U.S. Bureau of Land Management Coeur d'Alene Office by IDHW-DEQ.

Woodward, D.F., A. Farag, D. Reiser, and B. Brumbaugh. 1997. Metals Accumulation in the Food-Web of the Coeur d'Alene Basin, Idaho: Assessing Exposure and Injury to Wild Trout. Draft. USGS-BRD, Midwest Science Center, Jackson Field Station, Jackson, WY. December 1.

Next