CHAPTER 7
FISH RESOURCES

7.1 INTRODUCTION

This chapter presents the assessment of injury to fish resources of the Coeur d'Alene River basin. Previous chapters of this report (Chapter 3, Pathways; Chapter 4, Surface Water; Chapter 5, Sediment Resources) have shown that supporting habitats for fish (i.e., surface water and sediments) have been exposed to and injured by hazardous substances — particularly the substances cadmium, lead, and zinc — released from mining and mineral processing operations. In addition, subsequent chapters of this report present information that documents exposure and injuries to other components of the ecosystem supporting fish resources. Chapter 8 describes the exposure to hazardous substances and effects of hazardous substances on aquatic invertebrate communities, which are an important component of the prey base for fish. Chapter 9 describes injuries to riparian corridors in the Coeur d'Alene River basin. Riparian corridors are important to fish because they provide channel stability, physical habitat for fish (e.g., streamside vegetation provides shade, cover, channel complexity), and energetic inputs (food) to the riverine habitat. Thus, the results presented in this chapter should be interpreted in the context of the information and conclusions presented in these other chapters as well.

The information presented in this chapter (and previous and subsequent chapters, as discussed above) demonstrates that fish resources of the Coeur d'Alene River basin are injured as a result of exposure to hazardous metals (particularly cadmium and zinc, which are highly toxic to fish). Fish resources have been injured in the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, and the mainstem Coeur d'Alene River, as well as other stream and river reaches affected by releases of hazardous substances from mining and mineral processing operations. Injured fish resources include resident, fluvial, and adfluvial species of the South Fork Coeur d'Alene River, the lower Coeur d'Alene River, and Coeur d'Alene Lake.

Injuries to fish include death [43 CFR § 11.62 (f)(4)(i)], as confirmed by *in situ* bioassays [43 CFR § 11.62 (f)(4)(i)(D)] and laboratory toxicity testing [43 CFR § 11.62 (f)(4)(i)(E)]; behavioral avoidance [43 CFR § 11.62 (f)(4)(iii)(B)], as confirmed by laboratory tests using fish placed in testing chambers in controlled laboratory conditions, and by field tests; and physiological malfunctions, including effects on growth [43 CFR § 11.62 (f)(4)(v)], and other physical deformations, such as histopathological lesions [43 CFR § 11.62 (f)(4)(vi)(D)], as confirmed by laboratory testing.

Sufficient concentrations of hazardous substances, particularly cadmium and zinc, exist in pathway resources now, and have existed in the past, to expose and injure fish of the Coeur d'Alene River basin. Concentrations of hazardous substances in surface water (including suspended and bed sediments), biofilm (attached algae and associated detritus), and aquatic invertebrates are elevated and are pathways of metals exposure and injury to fish. As noted previously, concentrations of cadmium, lead, and zinc in surface water exceed chronic and acute aquatic life criteria (ALC) for the protection of aquatic life.

Concentrations of cadmium and zinc in surface water of the South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek are sufficient to cause acute mortality to trout. In *in situ* bioassays in the South Fork Coeur d'Alene River, laboratory bioassays using field collected waters, and laboratory bioassays using waters formulated to simulate conditions in the basin, concentrations of hazardous substances that occur in the South Fork Coeur d'Alene River caused acute mortality of rainbow trout and cutthroat trout.

Salmonids avoid water containing zinc at concentrations that occur in the South Fork Coeur d'Alene River and the lower Coeur d'Alene River as far downstream as Harrison. *In situ* trials using chinook salmon and laboratory exposures using cutthroat trout have demonstrated behavioral avoidance of Coeur d'Alene River basin waters, and preference for water containing lower concentrations of zinc. The combination of laboratory and field studies demonstrated that salmonids would avoid zinc-contaminated water of the South Fork Coeur d'Alene River, the lower Coeur d'Alene River as far downstream as Harrison, Canyon Creek, and Ninemile Creek. Therefore, avoidance injuries occur throughout these areas.

In controlled laboratory studies, ingestion by juvenile cutthroat trout of aquatic invertebrates from the South Fork and lower Coeur d'Alene rivers that were contaminated with cadmium, lead, and zinc was found to cause increased mortality, reduced feeding activity, and histopathological lesions.

Populations of trout species and other fish species have been reduced or eliminated by elevated concentrations of hazardous substances in the South Fork Coeur d'Alene River and its tributaries. Canyon Creek and Ninemile Creek are nearly devoid of all fish life downstream of mining releases of hazardous substances. Canyon Creek upstream of mining influences at Burke supports a population of native cutthroat trout. Similarly, other tributaries in the Coeur d'Alene system unaffected by mine wastes typically support populations of trout and sculpin, a native fish that resides on stream bottoms. Fish populations in the South Fork Coeur d'Alene River are depressed downstream of the Canyon Creek confluence with the South Fork Coeur d'Alene River. A clear upstream-downstream pattern is apparent in the river. Populations of sculpin and mountain whitefish are depressed in stream reaches affected by mining, whereas in reaches not affected by releases of hazardous substances from mining, these species are abundant. These fish population data are consistent with the conclusion that hazardous substances released from mining operations are causing injuries to fish. Thus, the population data are confirmatory of the toxicological information.

Other possible causes of fish injuries (such as channelization, logging, fires, introduction of exotic species, etc.) were evaluated. Field studies were designed to include sampling of reference locations to enable explicit consideration of many of these possible factors. Further, the nature, extent, and pattern of fish injuries and population responses, coupled with data showing that surface water causes acute lethality and other injuries to fish, demonstrate that releases of metals (particularly zinc and cadmium) injure fish.

7.2 DESCRIPTION OF FISH RESOURCES

The current fish resources of the Coeur d'Alene River basin include both native and introduced (i.e., intentionally stocked or unintentionally or illegally introduced) fish species (Table 7-1). Native fish species include westslope cutthroat trout, bull trout, sculpin, and mountain whitefish. Introduced fish species include the cold water species rainbow trout, kokanee salmon, eastern brook trout, and chinook salmon, and the warm water species smallmouth bass, largemouth bass, sunfish, yellow perch, black crappie, bullhead, channel catfish, tiger muskellunge, and northern pike (Apperson et al., 1988; IDFG, 1996b; USGS, 1998). Streams of the upper basin, including tributaries to the Coeur d'Alene and South Fork Coeur d'Alene rivers, are dominated by cold water fish species. The mainstem Coeur d'Alene River and Coeur d'Alene Lake contain a mix of cold water and warm water species. The lateral lakes contain primarily warm water species, with cold water species occurring less frequently (R2 Resource Consultants, 1995b).

Trout, char, and salmon species (collectively "salmonids") have been and continue to be important recreational and consumptive use fish (IDFG, 1996b). Native trout species of the basin include westslope cutthroat trout and bull trout (Rieman and Apperson, 1989). The Coeur d'Alene River basin supports populations of resident, fluvial (river run), and adfluvial (lake run) westslope cutthroat trout and bull trout (Graves et al., 1990; Lillengreen et al., 1993; IDFG, 1996a; IDFG, 1996b; Cernera et al., 1997, P. Cernera, Coeur d'Alene Tribe, pers. comm., June, 2000). Resident cutthroat trout inhabit small headwater streams year-round. Fluvial and adfluvial cutthroat trout rear in small streams for two to four years, but move downstream to larger streams and lakes, respectively, to mature. Mature fluvial and adfluvial cutthroat trout return to natal streams to spawn in the early spring.[1]

1. In 1996, the Coeur d'Alene Tribe monitored the migration of post spawned cutthroat trout in the Coeur d'Alene River and Lake to evaluate use of the Coeur d'Alene River by adfluvial cutthroat trout (Cernera et al., 1997). Cernera et al. (1997) concluded that observed fish passage from the South Fork Coeur d'Alene River to Harrison at Coeur d'Alene Lake confirmed ongoing adfluvial behavior in cutthroat trout of the Coeur d'Alene River basin.

Table 7-1
Fish Resources of the Coeur d'Alene River Basin

Resident Status	Habitat Designation	Common Name	Scientific Name
Native	Cold water	Westslope cutthroat trout	*Oncorhynchus clarki lewisi*
		Bull trout (historically referred to as Dolly Varden)	*Salvelinus confluentus*
		Mountain whitefish	*Prosopium williamsoni*
		Longnose dace	*Rhinichthys cataractae*
		Speckled dace	*Rhinichthys osculus*
		Northern pike minnow	*Ptychocheilus oregonensis*
		Largescale sucker	*Catostomus macrocheilus*
		Longnose sucker	*Catostomus catostomus*
		Peamouth	*Mylocheilus caurinus*
		Redside shiner	*Richardsonius balteatus*
		Sculpin	*Cottus* spp.
Introduced	Cold water	Rainbow trout	*Oncorhynchus mykiss*
		Brown trout	*Salmo trutta*
		Eastern brook trout	*Salvelinus fontinalis*
		Cutbow (cutthroat/rainbow trout hybrid)	*Oncorhynchus clarki x mykiss*
		Kokanee salmon	*Oncorhynchus nerka*
		Coho salmon	*Oncorhynchus kisutch*
		Chinook salmon	*Oncorhynchus tschawytscha*
	Warm water	Smallmouth bass	*Micropterus dolomieui*
		Largemouth bass	*Micropterus salmoides*
		Green sunfish	*Lepomis cyanellus*
		Yellow perch	*Perca flavescens*
		Black crappie	*Pomoxis nigromaculatus*
		Tench	*Tinca tinca*
		Black bullhead	*Ictalurus melas*
		Brown bullhead	*Ictalurus nebulosus*
		Channel catfish	*Ictalurus punctatus*
		Tiger muskellunge	*Esox lucius x masquinongy*
		Northern pike	*Esox lucius*
		Pumpkinseed	*Lepomis gibbosus*

Sources: Apperson et al., 1988; Maiolie and Davis, 1995; IDFG, 1996b; USGS, 1998.

Bull trout were present historically in the Kootenai, Priest, Pend Oreille, and Spokane River drainages in northern Idaho (IDFG, 1996a). The Coeur d'Alene Tribe has confirmed the presence of bull trout in the Coeur d'Alene River basin (P. Cernera, Coeur d'Alene Tribe, pers. comm., June, 2000). Currently bull trout populations are declining, and many population segments recently have been listed as threatened under the Endangered Species Act (63 FR 31647).

Factors thought to have contributed to bull trout population declines include impaired reproduction, habitat loss, migration barriers, and competition with nonnative species (Goetz, 1989; 63 FR 31647). In the Idaho governor's bull trout conservation plan, the Coeur d'Alene River basin is not listed as a "key watershed" because of degraded habitat and water quality conditions (IDFG, 1996a). The conservation plan outlines strategies to maintain and/or increase bull trout population in Idaho by improving water quality through the Idaho Water Quality Law (§ 39-3601) and using an "ecosystem approach to management of riparian and aquatic ecosystems" (IDFG, 1996a).

The composition of the native salmonid population in the basin has been altered as a result of actions undertaken by resource management agencies. A variety of salmonid species historically have been stocked in the Coeur d'Alene River basin by the Idaho Department of Fish and Game (IDFG, 1998), including kokanee, chinook, and coho salmon, and cutthroat, rainbow, and cutbow (rainbow and cutthroat hybrid) trout. Kokanee salmon were introduced in the basin in 1937 and have become the dominant species in Coeur d'Alene Lake (IDFG, 1996b). Kokanee stocking continued through 1974, when it was determined that the population was self-sustaining (Maiolie and Davis, 1995; IDFG, 1998). In 1982, chinook salmon were introduced to the basin to help control kokanee salmon populations; chinook salmon are now reproducing naturally (Horner et al., 1988; Maiolie and Davis, 1995; IDFG, 1996b). Chinook salmon redds have been observed in the mainstem Coeur d'Alene River upstream of Cataldo and in the North Fork Coeur d'Alene River (Maiolie and Davis, 1995). Rainbow trout are currently stocked in the South Fork Coeur d'Alene River as a put-and-take fishery to supplement wild cutthroat trout production. Approximately 1,500 to 3,000 catchable rainbow trout are stocked annually between Mullan and Wallace. However, since hatchery rainbow trout compete with and are hybridizing with wild cutthroat trout, the IDFG will no longer stock hatchery rainbow trout in rivers with wild cutthroat trout populations beginning in 2000 (N. Hoener, IDFG, pers. comm., 1999).

In addition to salmonid stocking, a variety of warm water species have been introduced into the lower basin (e.g., channel catfish, smallmouth and largemouth bass, bluegill, tiger muskellunge) (IDFG, 1998). Pike were illegally introduced to the Coeur d'Alene River basin in the early 1970s and now occur throughout the lower basin (Rich, 1992). Pike in the basin have high growth rates and prey on perch, salmonids, and suckers (Rich, 1992).

7.3 ACCOUNTS OF FISH POPULATIONS IN THE COEUR D'ALENE RIVER BASIN BY INVESTIGATORS OUTSIDE THE NRDA PROCESS

Before mining began in the basin, cutthroat trout, bull trout, and mountain whitefish were abundant in Coeur d'Alene Lake and its tributaries (Graves et al., 1990). The Coeur d'Alene tribe used canoes and constructed fish traps on tributaries to Coeur d'Alene Lake to fish for these species (Graves et al., 1990; Lillengreen et al., 1993). The tribe historically harvested an estimated 42,000 cutthroat trout, 1,050 bull trout, 29,400 whitefish, and 10,500 suckers per year (Scholz et al., 1985). In a report on the construction of a military road from Fort Walla-Walla to Fort Benton, Captain John Mullan described Coeur d'Alene Lake as "a noble sheet of water . . . filled with an abundance of delicious salmon trout" and the Coeur d'Alene River as providing enough fish to sustain a tribe of 300 individuals (Mullan, 1863). Stoll (1932) claimed the Coeur d'Alene River "teemed with trout."

In the late 1800s, trout served as a major source of protein to settlers and were commonly sold in local butcher shops (IDFG, Region 1 Files, as cited in Rieman and Apperson, 1989). At that time it was not uncommon for people to fish with multiple hooks on a line, with "giant powder," or with clubs (Magnuson, 1968). During mine shutdowns, "there wasn't much to do in the district except for fishing and picking huckleberries" (Magnuson, 1968). Catches of greater than 200 fish in a single day were reported for basin tributaries (Magnuson, 1968). A local newspaper editor was concerned with the number of fish coming to the Wallace meat market and called for more stringent regulations and enforcement on fish harvesting (Magnuson, 1968).

Following the onset of large-scale mining, a marked change was observed in the condition of fish resources. In response to public concerns raised about "toxic substances" in "mine slimes," the State of Idaho commissioned a series of studies to investigate "pollution problems in the Coeur d'Alene District" (Ellis, 1940), including a study of fisheries effects directed by Dr. M.M. Ellis of the U.S. Bureau of Fisheries. In this survey, conducted in July 1932, no live fish were found in the mainstem Coeur d'Alene River from its mouth to the confluence of the North and South Forks or in the South Fork Coeur d'Alene River from its mouth to near Wallace (Ellis, 1940). In addition, no benthic macroinvertebrate (i.e., aquatic insect) fauna, phytoplankton, or zooplankton were observed in the mainstem Coeur d'Alene River and South Fork Coeur d'Alene River downstream of Wallace (and the Canyon Creek confluence) except at the mouths of tributaries (Ellis, 1940). However, a rich benthic macroinvertebrate assemblage was observed in the South Fork Coeur d'Alene River above Wallace. Ellis concluded that "the 50 miles of the Coeur d'Alene River carrying mine wastes are essentially without a fish fauna" (Ellis, 1940, p. 33). Ellis (1940, pp. 32-33) also noted:

> As several species of fish were found regularly in the unpolluted streams and lakes of the region and as fish were taken in streams and lakes tributary to the Coeur d'Alene River quite close to their junctions with the River, although always above the backwater from the Coeur d'Alene, the correlation between mine waste pollution and the distribution of fish in the Coeur d'Alene District is an evident

> one. Local residents stated that at times fish had been seen to enter the polluted portion of the Coeur d'Alene River from tributary streams, and that dead or dying fish were often found in the Coeur d'Alene River just below the mouths of tributary streams, but that there was no evidence that fish entering that portion of the Coeur d'Alene River carrying mine wastes ever survive any length of time. This statement was confirmed experimentally by the writer. . . .

Ellis concludes his report by stating that ". . . the mine wastes in the Coeur d'Alene River have destroyed the fish fauna and the plants and animals on which fishes feed . . ." (Ellis, 1940, p. 121).

After tailings disposal into the river stopped, some recovery of fish in the basin was observed. The regional fisheries division of IDFG conducted surveys before and after the Hecla channel construction on the South Fork Coeur d'Alene River in the upper reaches of the South Fork Coeur d'Alene River near Mullan (Ortmann, 1972; Goodnight, 1973). In April 1972, 14 sections of stream were electrofished in the area of stream proposed for relocation. A total of 106 fish were observed, including 67 cutthroat trout, 3 brook trout, 3 rainbow trout, 29 juvenile coho salmon presumed to have escaped from the fish hatchery, and 4 sculpin (Ortmann, 1972). In November 1972, 1,359 fish (including 568 cutthroat trout, 74 brook trout, 9 hatchery rainbow trout, 663 hatchery coho salmon, and 75 sculpin) were salvaged from the natural channel of the South Fork Coeur d'Alene River. Later that month, 677 (566 cutthroat trout, 73 brook trout, 8 hatchery rainbow trout, and 30 sculpin) of the salvaged fish were released into the new artificial channel (Goodnight, 1973). The artificial channel was electrofished eight months after the relocation to evaluate the holding capacity of the new channel. In total, 359 (229 cutthroat trout, 40 brook trout, 6 hatchery rainbow trout, 3 hatchery coho salmon, and 81 sculpin) fish were captured, which was approximately 50% of those released in November.

Bauer (1975) conducted fish surveys in the mainstem and South Fork Coeur d'Alene rivers and tributaries in the spring of 1974 to document the passage of adfluvial cutthroat trout through the lower mainstem of the Coeur d'Alene River. The surveys were conducted to confirm the observations by local residents of trout migrating upstream through the mainstem Coeur d'Alene River and its tributaries, and of cutthroat trout longer than 406 mm from the South Fork Coeur d'Alene River upstream of Wallace (Bauer, 1975). Bauer (1975) tagged a total of 413 rainbow and cutthroat trout in various tributaries to the Coeur d'Alene River (i.e., Clark, Willow, Evans, Robinson, Pine, Latour, Little Baldy, and Teepee creeks), the South Fork Coeur d'Alene River, and the mainstem Coeur d'Alene River. Spawning adfluvial cutthroat trout were observed in Willow, Evans, and Clark creeks. However, electrofishing in the mainstem Coeur d'Alene River immediately downstream of the confluence with the South Fork yielded a total of only six fish (one cutthroat trout, four tench, one bullhead), and two charges of primacord explosive in the same area yielded only two additional cutthroat trout. At three of the four locations sampled using primacord on the South Fork Coeur d'Alene River (near Smelterville, Kellogg, Big Creek), no fish were observed. At the fourth location (near Osburn), three brook trout and one cutthroat/rainbow trout hybrid were collected. Upstream of Wallace, several cutthroat trout were collected. Bauer (1975) concluded that an adfluvial run of cutthroat trout was present in the mainstem

Coeur d’Alene River, but he found only indirect evidence that adfluvial cutthroat trout could survive “perhaps long enough to migrate to unpolluted areas” in the South Fork Coeur d’Alene River.

In September 1976, IDFG evaluated the presence or absence of fish populations in the South Fork Coeur d’Alene River (Goodnight and Mauser, 1977). The results of the study were consistent with those reported by Bauer (1975). No fish were observed during electrofishing at three sites in the South Fork Coeur d’Alene River downstream of Wallace (near Smelterville, Kellogg, Big Creek). Upstream of Wallace, cutthroat trout, rainbow trout, brook trout, chinook salmon fry, and sculpin were captured. The authors concluded that “those areas below Osburn are devoid of fish due to heavy metals toxicity” and that the “South Fork above major mine effluent inflow supports good trout populations.”

Between 1984 and 1987, IDFG conducted fish population surveys of mainstem and South Fork Coeur d’Alene River tributaries, the South Fork Coeur d’Alene River near Mullan (in the Hecla channel), and the mainstem Coeur d’Alene River between Harrison and the confluence of the North Fork and South Fork Coeur d’Alene rivers (Horton, 1985; Apperson et al., 1988). Creel surveys, trapping, electrofishing, snorkeling, and tagging were conducted. Creel surveys indicated capture of various salmonids from the mainstem Coeur d’Alene River in May and June 1986 and 1987 (Apperson et al., 1988). Cutthroat trout (160 to 400 mm) were the largest percentage of the catch during both years. Other salmonid species captured included kokanee salmon, cutthroat/rainbow trout hybrids, rainbow trout, brook trout, and bull trout. Drift boat electrofishing was conducted on four occasions (May, June, July, October) in 1986 in a 12.5 km section of the mainstem Coeur d’Alene River between Cataldo Mission and the confluence of the North and South forks of the Coeur d’Alene River. In 38 hours of electrofishing, 393 salmonids were captured (Apperson et al., 1988). Mountain whitefish were the most abundant species captured, followed by kokanee salmon, cutthroat trout, brook trout, rainbow trout, and cutthroat/ rainbow trout hybrids. Cutthroat trout, rainbow trout, and hybrids were captured during all four sampling events. Kokanee salmon were captured in June and July only. Mountain whitefish were not captured in October and brook trout were not captured in June. Trapping was conducted in the mainstem Coeur d’Alene River in 1984 at Harrison and in 1985 near Bull Run Lake (Apperson et al., 1988). Bullheads were 79% of the catch at the Harrison site. Tench constituted 8.5% of the catch, followed by pumpkinseeds (6.4%), kokanee salmon (2.0%), northern squawfish (1.9%), and others (2.6%; black crappie, yellow perch, suckers, largemouth bass, redside shiners, northern pike). At the Bull Run Lake location, tench were 56% of the catch and bullheads 38% of the catch, followed by northern squawfish (3%). Pumpkinseeds, yellow perch, and kokanee salmon each were 1% of the catch.

A survey of fish presence in mainstem and South Fork Coeur d’Alene River tributaries and the South Fork Coeur d’Alene River near Mullan (Hecla channel) was conducted by IDFG in 1984. (Horton, 1985; Apperson et al., 1988). Eleven mainstem tributaries (West Fork Thompson, Thompson, Blue Lake, Willow, Evans, Clark, Robinson, Fortier, Rose, Latour, and French Gulch creeks), two South Fork tributaries (East Fork Pine and Trapper creeks), and the South Fork Coeur d’Alene River near Mullan (Hecla channel) were surveyed. Species composition as determined by electrofishing in the tributaries included cutthroat trout, brook trout, sculpin, and suckers. In addition to the species observed in the tributaries, rainbow trout, cutthroat/rainbow trout hybrids, kokanee salmon, and chinook salmon were observed in the South Fork Coeur d'Alene River near Mullan. Density values are not reported, but Apperson et al. (1988, pp. 1-2) concluded that "trout densities in the lower Coeur d'Alene River tributaries are comparable to those in Pend Oreille and Priest river drainages."

As part of the Bunker Hill Superfund Site Remedial Investigation/Feasibility Study, quantitative fish population monitoring was conducted in the South Fork Coeur d'Alene River in 1987 and 1988 (Dames & Moore, 1989). Fish population surveys were conducted during low flow (September 1987) and spring runoff (June 1988) periods using multiple pass depletion methodologies and a gas-powered backpack or boat-mounted electroshocker. Four sites on the South Fork Coeur d'Alene River between Elizabeth Park and Pinehurst and one site on the North Fork Coeur d'Alene River near Enaville were surveyed. A 100 m section of stream was selected at each of the five sites based on similar habitat for fish. Trout densities were low (typically $\leq$0.005 trout/m^2) at South Fork Coeur d'Alene River locations. However, sampling near Elizabeth Park in June 1988 yielded an estimated trout density of 0.021 trout/m^2, and sampling near Pine Creek in June 1988 yielded an estimate trout density of 0.018 trout/m^2 (Table 7-2). Trout densities at the North Fork site were some tenfold higher than most of the South Fork Coeur d'Alene sites at both samplings (0.05 trout/m^2). Densities of all fish combined also were considerably higher at the North Fork site (Table 7-2). Sculpin were found at only the North Fork Coeur d'Alene River site.

In the ecological risk assessment performed by U.S. EPA for the Bunker Hill Superfund Site (SAIC and EP&T, 1991), it was concluded that:

> risks to aquatic organisms continue throughout the South Fork. Comparisons to relatively unimpacted ecosystems indicate a depression in aquatic community structure and function. Populations of benthic organisms and fish are low . . . with apparent harsh impacts to certain groups such as benthic carnivores and salmonid fish.

A fish population survey was conducted by the U.S. Bureau of Mines (USBM) at sites in the Pine Creek basin in August 1993 (McNary et al., 1995). Zinc concentrations ranged from 5.1 µg/L at the East Fork Pine Creek site upstream of the Constitution mine to 562 µg/L in the East Fork Pine Creek downstream of Highland Creek (Table 7-3). Three electrofishing passes were made in each of nine 150 ft sampling sites. The total number of fish captured ranged from 0 at the two Highland Creek sites downstream of mines to 35 at the East Fork Pine Creek site upstream of the Constitution mine (Table 7-3). Cutthroat trout were captured at four sites, brook trout at six sites, and sculpin at two sites (Table 7-3). Analysis of the population data relative to measured zinc concentrations demonstrates a concentration-response relationship, with higher fish numbers at sites with lower zinc concentrations (Figure 7-1). This relationship illustrates the effects of waterborne zinc on trout density at zinc concentrations substantially lower than concentrations routinely measured in Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River.

Table 7-2
Results of 1987-1988 Fish Population Monitoring Studies Conducted as Part of Bunker Hill RI/FS

Site	Date	Number of Fish Captured				Density (fish/m^2)			
		Trout	Other[a]	Sculpin	Total	Trout	Other[a]	Sculpin	Total
SFCdA near Elizabeth Park (RM 9)	Sept. 1987	6	21	0	27	0.005	≥0.014	0	≥0.020
	June 1988	29	12	0	41	≥0.021	≥0.009	0	0.049
SFCdA near Bunker Creek (RM 6.8)	Sept. 1987	4	75	0	79	0.002	0.055	0	0.057
	June 1988	4	8	0	12	0.002	≥0.004	0	0.010
SFCdA near Government Creek (RM 5)	Sept. 1987	2	21	0	23	0.001	0.010	0	≥0.011
	June 1988	6	4	0	10	≥0.002	≥0.002	0	0.004
SFCdA near Pine Creek (RM 2.2)	Sept. 1987	1	4	0	5	≥0.000	0.002	0	≥0.002
	June 1988	34	13	0	47	0.018	≥0.007	0	0.023
NF CdA near Enaville (RM 0.2)	Sept. 1987	33	8	402	443	0.050	0.005	1.447	1.430
	June 1988	22	23	285	330	0.053	0.041	≥0.200	≥0.293

a. Other fish included tench, yellow perch, brown bullhead, mountain sucker, pumpkinseed, pigmy whitefish, longnosed dace, and speckled dace.

Source: Dames & Moore, 1989.

In Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River, zinc frequently is measured at concentrations greater than 1,000 µg/L (see Chapter 4).

7.4 BACKGROUND: EFFECTS OF HAZARDOUS METALS ON FISH AND RELATIONSHIP TO INJURY ENDPOINTS

The hazardous substances cadmium, lead, and zinc are known to cause a number of toxic injuries to fish, including death, behavioral avoidance, physiological damage, and reduced growth. There is extensive scientific literature documenting these toxic effects on salmonids and other aquatic biota. As described in Chapter 4, for each of these hazardous substances, the U.S. EPA has promulgated water quality criteria for the protection of aquatic life. The water quality criteria

Table 7-3
Number of Fish Captured in Pine Creek Basin by USBM in 1993

Site	Cutthroat Trout	Brook Trout	Sculpin	Total Fish	Dissolved Zinc in Surface Water (µg/L)
East Fork Pine Creek					
Upstream of Constitution Mine	1	2	32	35	5.1
Downstream of Gilbert Creek	4	14	0	18	137
Downstream of Douglas Creek	0	15	5	20	128
Downstream of Highland Creek	0	3	0	3	562
Downstream of Trapper Creek	0	5	0	5	491
Mainstem Pine Creek					
Upstream of Pinehurst[a]	1	13	0	20	147
Highland Creek					
Upstream of Red Cloud Creek	7	0	0	7	NA
Confluence of Red Cloud Creek	0	0	0	0	NA
Downstream of Red Cloud Creek	0	0	0	0	NA

a. Estimated from a single pass.
NA: not analyzed.

Source: McNary et al., 1995.

incorporate toxicological data for a large number of aquatic species. The toxicological database upon which the water quality criteria are based reveals that salmonid species are among the most sensitive aquatic organisms to the toxic effects of cadmium, lead, and zinc. Salmonid species typically are more sensitive than warm water fish species to these metals (Table 7-4).

As shown in Chapter 4, cadmium, lead, and zinc water quality criteria have been exceeded routinely in the Coeur d'Alene River basin downstream of mining influences. The exceedences — and the frequency and magnitude of the exceedences (see Chapter 4) — are strong evidence of the potential for adverse effects on fish. This section provides a brief overview of the nature of the toxic effects of cadmium, lead, and zinc, and identifies the endpoints assessed for injury.

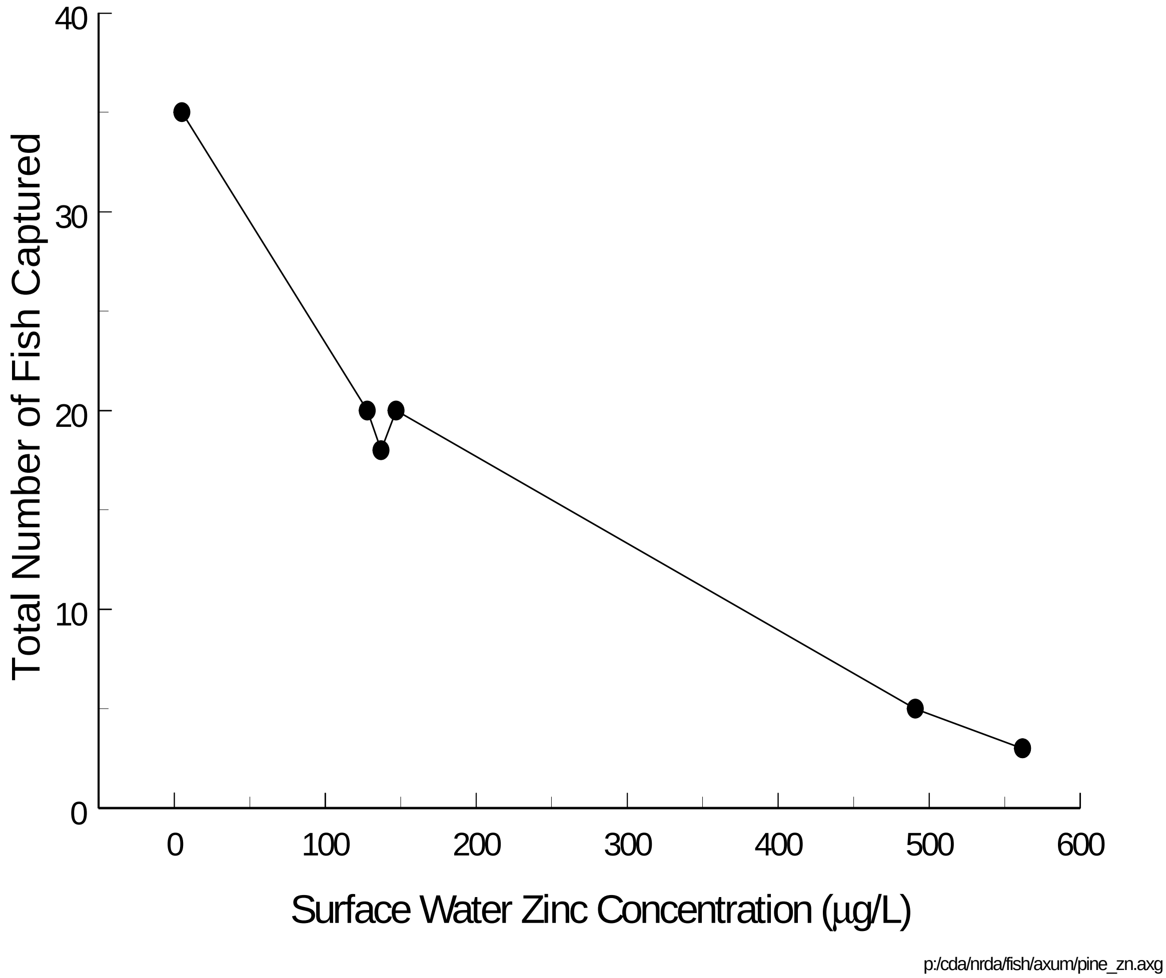

Figure 7-1. Concentration-response relationship of total fish numbers and measured zinc concentrations in surface water.
Source: McNary et al., 1995.

7.4.1 Mortality

Cadmium, lead, and zinc all have been shown to be lethal to fish (e.g., Mount, 1966; Benoit et al., 1976; Carroll et al., 1979; Chakoumakos et al., 1979; Hodson et al., 1979, 1983; Watson and Beamish, 1980; Bradley and Sprague, 1985; Cusimano et al., 1986; Everall et al., 1989; Marr et al., 1995; EVS, 1997b; Hansen et al., 1999a). The primary mechanisms of metal-induced mortality are disruption of ionoregulation and respiratory failure. The gills are the primary site of ionoregulation (Evans, 1987), the process that drives many cellular metabolic functions. Hazardous metals such as cadmium and zinc can disrupt ionoregulation by injuring the gill membrane so that ions leak across the membrane, and by disrupting essential enzymes (Lauren and McDonald, 1985; 1986). For example, cadmium alters calcium balance by disrupting essential ion transport enzymes (Roch and Maly, 1979; Verbost et al., 1989).

Table 7-4
Relative Ranking of Metals Sensitivity of Fish Species Present in the Coeur d'Alene River Basin Based on U.S. EPA Ambient Water Quality Criteria Documents

Common Name	Scientific Name	Cd	Pb	Zn
Rainbow trout	*Oncorhynchus mykiss*	3	4	6
Coho salmon	*Oncorhynchus kisutch*	3	—	6
Chinook salmon	*Oncorhynchus tschawytscha*	3	—	6
Kokanee salmon	*Oncorhynchus nerka*	—	—	6
Brook trout	*Salvelinus fontinalis*	—	5	14
Green sunfish	*Lepomis cyanellus*	25	—	—
Pumpkinseed	*Lepomis gibbosus*	25	—	29
Northern pike minnow	*Ptychocheilus oregonensis*	26	—	23
Channel catfish	*Ictalurus punctatus*	38	—	—
Total number of species included in sensitivity ranking		43	10	36
Sources: U.S. EPA 1985a, 1985b, 1987, 1996, 1999.				

Continued disruption of ionoregulation leads to mortality. The gills are also the primary site of respiration (Evans, 1987). Exposure to hazardous metals causes physiological damage to respiratory gill tissues (Wilson and Taylor, 1993). This damage impairs the transfer of respiratory gases (e.g., oxygen) by increasing the distance that respiratory gas must diffuse between blood and water (Hughes and Perry, 1976; Mallatt, 1985; Satchell, 1984), causing asphyxiation, cardiovascular failure (Wilson and Taylor, 1993), and death.

The DOI NRDA regulations identify death as a relevant injury endpoint. Specifically, mortality is confirmed when:

- A statistically significant difference can be measured in the total mortality and/or mortality rates between population samples exposed *in situ* bioassays to a release of hazardous substance and those in a control site [43 CFR § 11.62 (f)(4)(i)(D)].

- A statistically significant difference can be measured in the total mortality and/or mortality rates between population samples of test organisms placed in laboratory exposure chambers containing concentrations of hazardous substances and those in a control chamber [43 CFR § 11.62 (f)(4)(i)(E)].

As discussed in subsequent sections of this chapter, the Trustees have confirmed death injuries using both of these injury tests.

7.4.2 Sublethal Endpoints

Exposure to metals at concentrations below those that cause mortality can induce sublethal adverse effects on fish. These adverse effects can include behavioral avoidance, reduced growth, and physiological impairment.

Avoidance

The ability of fish to detect and avoid hazardous substances has been shown for a number of substances (e.g., Atchison et al., 1987). Behavioral avoidance can occur at concentrations lower than concentrations that cause effects on survival and growth (Little et al., 1993). Behavioral avoidance of metals such as copper, lead, and zinc has been suggested as a cause of reduced fish populations in natural systems (Woodward et al., 1995b). In addition, behavioral avoidance can impair normal migratory behaviors and effectively result in habitat loss if fish avoid stream reaches (Lipton et al., 1995). Saunders and Sprague (1967) showed that introduction of copper and zinc (via mine runoff) into a salmon spawning tributary caused repulsion of ascending salmon, and reduction in salmonid population size relative to the population size before mine waste releases to the tributary began.

DOI NRDA regulations identify behavioral avoidance as an injury. Behavioral avoidance injuries can be confirmed when:

- A statistically significant difference can be measured in the frequency of avoidance behavior in population samples of fish placed in testing chambers with equal access to water containing a hazardous substance and water from the control area [43 CFR § 11.62 (f)(4)(iii)(B)].

The Trustees confirmed avoidance injuries to trout using this injury test. In addition, the Trustees performed field testing to confirm avoidance injuries.

Growth, Immune Impairment, and Other Physiological Effects

Growth reduction in fish is an indicator of adverse effects on reproductive fitness (USFWS and University of Wyoming, 1987) and a sensitive measure of metals toxicity during sublethal exposures to copper and zinc mixtures (Finlayson and Verrue, 1980), and to copper, zinc, cadmium, and lead mixtures (Marr et al., 1995). Exposure to cadmium causes growth reductions at concentrations similar to those that cause mortality (Pickering and Gast, 1972; Eaton, 1974). Hansen et al. (1999b) observed 20% growth reductions in bull trout exposed to a cadmium concentration that caused 35% mortality (0.79 µg Cd/L), and milder growth reductions (6-9%) at sublethal cadmium concentrations (0.05-0.38 µg Cd/L). Growth reduction can be caused by physiological or behavioral stress during exposure to hazardous substances. Physiological or behavioral stress can result from a reduction in food consumption or assimilation (Lorz and McPherson, 1977; Waiwood and Beamish, 1978) or from increased metabolic costs of detoxification and homeostasis during chronic, sublethal hazardous substance exposures (Dixon and Sprague, 1981; Marr et al., 1995). Fish consumption of metal-contaminated prey can also cause sublethal injuries, including reduced growth (e.g., Woodward et al., 1994, 1995c).

Sublethal exposure has been shown to affect the immune system function in fish, with resulting increases in disease, tumors, and lesions (Zelikoff, 1994). For example, cadmium can cause suppressed antibody function (e.g., O'Neill, 1981), and alteration of macrophage-mediated immune function (Zelikoff et al., 1995).

Exposure to metals can cause physiological impairment of fish. Cadmium has been shown to cause both respiratory impairment (Pascoe and Mattey, 1977, as cited in Sorenson, 1991; McCarty et al., 1978) and muscular and neural abnormalities (e.g., Bengtsson et al., 1975; Pascoe and Mattey, 1977, as cited in Sorenson, 1991). Cadmium tends to bind to calcium binding sites on the surface of animal cells. In fish cells, cadmium apparently has a high affinity for calcium-ATPase of cell membranes. Low cadmium exposure concentrations have been shown to cause depressed plasma calcium, leading to hypocalcemia of freshwater fish (Wicklund, 1990). Calcium deficiencies increase the absorption and deposition of cadmium into intestinal mucosa, liver, and kidneys (SAIC and EP&T, 1991).

Lead causes hematological (anemia), neuronal, and muscular impairments in fish. Signs of lead intoxication include black tails, lordosis/scoliosis (lordoscoliosis), changes in pigment patterns, and coagulation of surface mucus (Sorenson, 1991). Lead reacts with sulfhydryl groups in ALAD, inactivating the enzyme. Since ALAD is a key enzyme in heme synthesis, inactivation of ALAD results in less hemoglobin production (Johansson-Sjobeck and Larsson, 1979; Tewari et al., 1987). At elevated concentrations, lead exposure can result in fish asphyxiation as a result of a thick mucous film over the gills (Varanasi et al., 1975). Lead results in muscle spasms, paralysis, hyperactivity, and loss of equilibrium (Davies et al., 1976; Holcombe et al., 1976).

Zinc causes structural injury to fish gills, reducing the ability of fish to transfer oxygen across the secondary lamellae, basement membrane, and flanges of pillar cells. Zinc toxicity probably results from decreased gill oxygen permeability. Decreased gill oxygen permeability results from both increased barrier thickness (caused by detachment of chloride cells from underlying epithelium and curling of the secondary lamellae; Skidmore and Tovell, 1972) and decreased functional surface area for oxygen transfer (Skidmore, 1970; Hughes, 1973; Hughes and Perry, 1976; Hughes and Adeney, 1977). Zinc does not appear to alter gill membrane permeability to other cations (e.g., Na, K, Ca, Mg) (Skidmore, 1970). Zinc has also been shown to cause histopathological lesions, inhibition of spawning (Sorenson, 1991), reduced growth (Finlayson and Verrue, 1980; Hobson and Birge, 1989), and behavioral avoidance (Saunders and Sprague, 1967).

DOI NRDA regulations identify physiological malfunctions (including ALAD inhibition and reduced fish reproduction) and physical deformations (including tissue malformations and histopathological lesions) as injuries [43 CFR § 11.62 (f)(4)(v-vi)]. The Trustees assessed various fish health parameters, including growth, as indicators of physiological malfunction and physical deformation injuries.

7.4.3 Exposure Pathways

Two distinct pathways result in exposure of fish to hazardous substances (Figure 7-2): surface water pathways and food chain pathways. The surface water pathway involves direct contact by fish with hazardous substances in surface water. Surface water resources in the Coeur d'Alene River basin are exposed to and injured by the hazardous substances cadmium, lead, and zinc (see Chapter 4). The contact mechanism involves exposure to hazardous substances in surface water that flows across the gills or, in the case of avoidance behaviors, olfactory sensation of hazardous substances in water.

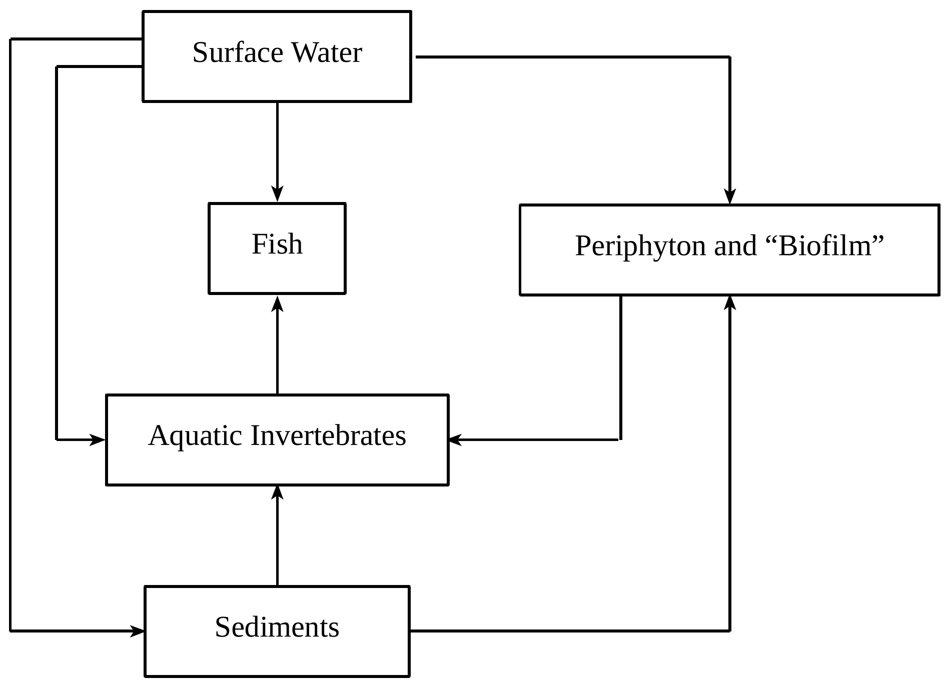

Figure 7-2. Conceptual diagram of exposure pathways to fish.

The food chain pathway involves contact with hazardous substances through consumption of contaminated food. Benthic macroinvertebrates accumulate hazardous substances from contaminated sediments, surface water, and periphyton. When consumed by fish, contaminated invertebrates serve as a dietary exposure pathway. Sediments of the Coeur d'Alene River basin have been exposed to and injured by the hazardous substances cadmium, lead, and zinc (Chapter 5). Benthic macroinvertebrates live in and on bed sediments and thus are exposed directly to hazardous substances contained in sediments and periphyton (see Chapter 8). Benthic macroinvertebrates serve as a primary food source for fish. Thus, contaminated sediments and periphyton act as the principal pathway of hazardous substances to benthic macroinvertebrates, which, in turn, serve as a pathway to fish via food chain exposure.

These pathways were confirmed through analysis of metals in surface water and sediments (Chapters 4 and 5) and analysis of dietary pathway components (see Section 7.6.3).

7.5 TOXICOLOGICAL DATA COLLECTED FROM THE ASSESSMENT AREA BY INVESTIGATORS OUTSIDE THE NRDA PROCESS

A number of investigators outside the NRDA process have conducted aquatic toxicological studies in the Coeur d'Alene River basin over the past decades.

7.5.1 *In Situ* Studies

In situ bioassays (or livebox bioassays) involve placing fish (or other organisms) in holding containers in a water body and observing the responses of the test organisms. *In situ* tests provide the most direct indication of the toxicity of site waters. Several researchers have observed significant mortality of biota in *in situ* exposures to the South Fork Coeur d'Alene River and its mining impacted tributaries (Ellis, 1940; Hornig et al., 1988; Dames & Moore, 1989; Lockhart, 1993).

Ellis (1940) conducted an *in situ* caged fish experiment in July 1932 with longnosed dace and redside shiners collected from Coeur d'Alene Lake near Conkling Park. Twenty fish of each species were selected and placed in wooden liveboxes with metal screen sides. The fish were exposed to waters in Coeur d'Alene Lake near Harrison and to mainstem Coeur d'Alene River water one-quarter mile upstream of Harrison. No fish died in the Coeur d'Alene Lake water after 120 hours of exposure. The Coeur d'Alene River water was acutely lethal to the fish: after 72 hours of exposure, all the fish were dead. The gills and bodies of the dead fish exposed to the Coeur d'Alene River water were covered with a heavy coating of mucous slime, a condition indicative of aqueous metal exposure (e.g., Sorensen, 1991).

In situ bioassays were conducted by the U.S. EPA in June 1973, July 1974, September 1979, and September 1982 (U.S. EPA, undated; Kreizenbeck, 1973, as cited in Bauer, 1975; Bauer, 1975). During the summers of 1973 and 1974, rainbow trout were placed in liveboxes at six locations along the South Fork Coeur d'Alene River, at three locations along the mainstem Coeur d'Alene River, at one location in the North Fork Coeur d'Alene River, and at three locations in Coeur d'Alene Lake. In 1973, at least 50% of the fish were dead within 72 hours, except fish in the North Fork Coeur d'Alene River and in the headwaters of the South Fork Coeur d'Alene River near Mullan. In 1974, at least 50% of the fish were dead within 20 hours at South Fork Coeur d'Alene River locations near Smelterville and Enaville. No mortality was observed for other test locations along the South Fork Coeur d'Alene River or the mainstem Coeur d'Alene River in the first 40 to 70 hours. The fish escaped before subsequent mortality checks were made.

In 1979, *in situ* bioassays were conducted at four locations on the South Fork Coeur d'Alene River, at two locations on the mainstem Coeur d'Alene River, and at one location on the North Fork Coeur d'Alene River (U.S. EPA, undated). Within 12 hours, at least 50% of the test fish were dead in the South Fork sites near Big Creek, Bunker Hill, and Enaville. Within 48 hours, at least 50% of the test fish were dead at both mainstem sites. No fish died in the North Fork or in the headwaters of the South Fork Coeur d'Alene River near Mullan during the 72-hour exposure.

In 1982, liveboxes were placed at eight locations in the South Fork Coeur d'Alene River, at one location in the mainstem Coeur d'Alene River, and at one location in the North Fork Coeur d'Alene River. Greater than 60% mortality occurred within 72 hours at five of the South Fork sites (Big Creek, Kellogg, Bunker Hill, Smelterville, Pine Creek). Less than 10% mortality occurred at the two South Fork sites upstream of Canyon Creek, the mainstem site, and the North Fork site.

Substantial mortality of fish in livebox exposures was observed in testing performed by the U.S. EPA in September 1986 (Hornig et al., 1988). Six to 10 hatchery rainbow trout 10-15 cm long were placed in liveboxes at eight locations in the South Fork Coeur d'Alene River, at one location in the mainstem Coeur d'Alene River, and at one location in the North Fork Coeur d'Alene River. In the South Fork Coeur d'Alene River, 96 hour mortality of hatchery rainbow trout fingerlings ranged from 40 to 100% downstream of the confluence of Canyon Creek. No fish died in the South Fork Coeur d'Alene River headwaters (upstream of the confluence of Canyon Creek) (Figure 7-3). Water chemistry data are not reported, so values were estimated by visual inspection of low flow concentrations presented in Figures 5 and 6 in Hornig et al. (1988). Zinc concentrations in the South Fork Coeur d'Alene River downstream of Canyon Creek during the low flow period ranged from 1,480 µg Zn/L at Bunker Avenue Bridge (RM 6.9) to 2,800 µg Zn/L upstream of Pine Creek (RM 2.4). Zinc concentrations measured in the mainstem Coeur d'Alene River, the North Fork Coeur d'Alene River, and the South Fork Coeur d'Alene River upstream of Canyon Creek were approximately 800, 0, and 300 µg/L, respectively. Cadmium concentrations measured in the South Fork Coeur d'Alene River downstream of Canyon Creek during the same low flow period ranged from approximately 15 µg Cd/L at Bunker Avenue Bridge (RM 6.9) to 29 µg Cd/L near Smelterville (RM 4.9). Cadmium concentrations measured in the mainstem, the North Fork, and the South Fork Coeur d'Alene River upstream of Canyon Creek were approximately 7, 1, and 3 µg/L, respectively.

As part of the RI/FS studies for the Bunker Hill Superfund Site, Dames & Moore (1989) conducted *in situ* 96 hour rainbow trout bioassays during low flow (September 1987), transient high flow (December 1987), and spring runoff (June 1988) periods on the South Fork Coeur d'Alene River. Two replicate cages were placed at each of four locations on the South Fork Coeur d'Alene River between Elizabeth Park and Pinehurst. Two cages were also placed in the North Fork Coeur d'Alene River near Enaville. Ten approximately 13 cm long hatchery rainbow trout were placed in each cage. At test initiation a water sample was collected for analysis of dissolved metals (Table 7-5). Water temperature, conductivity, and pH were measured each time the cages were checked for fish mortality (Table 7-5). At 96 hours, mortality was 100% at all South Fork Coeur d'Alene River locations tested. Mortality at the North Fork ranged from

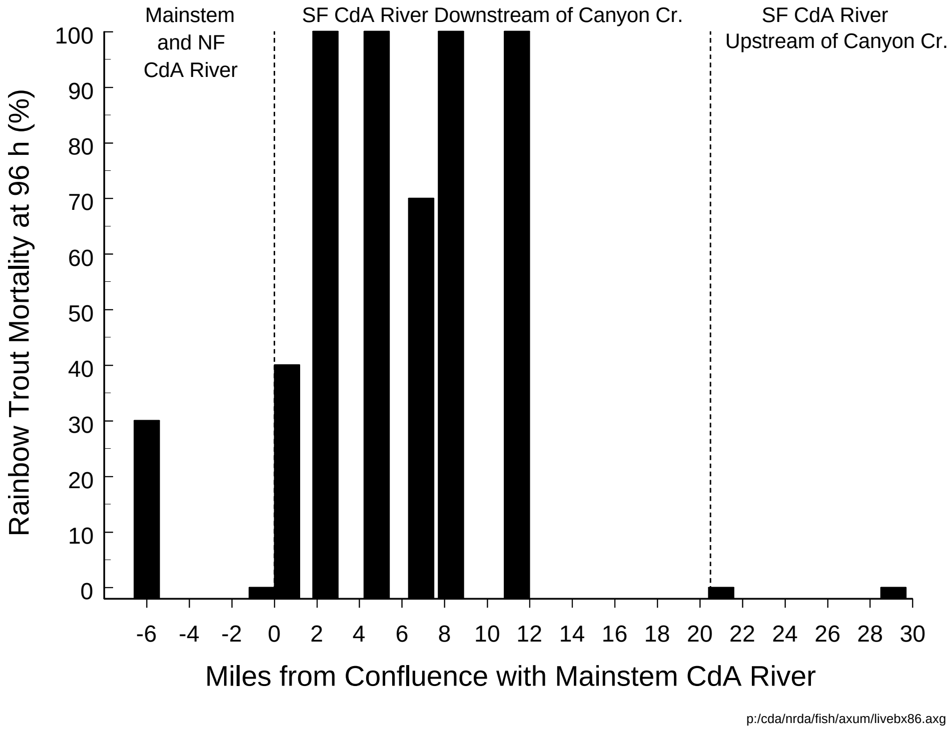

Figure 7-3. Rainbow trout mortality (96-hour) in livebox tests conducted by the U.S. EPA in September 1986. Source: Hornig et al., 1988.

approximately 30 to 60% at test completion (Figure 7-4). Dames & Moore (1989, p. 81) concluded that:

> clearly, the fish populations throughout the SFCDR study reach are heavily stressed. Despite the tolerance of a limited number of fish to the conditions present, the densities of fish are well below what would be expected in an unpolluted Idaho stream of similar physical characteristics and elevation.

The Idaho Department of Health and Welfare, Division of Environmental Quality (IDHW-DEQ) conducted a study in the spring of 1993 to determine the effect of water quality on salmonid emergence (i.e., an indicator of survival of young of year trout) (Lockhart, 1993). The study was conducted on the west and east forks of Moon Creek, a tributary to the South Fork Coeur d'Alene River. West Fork Moon Creek is believed to be upstream of substantial mining and milling operations in the Moon Creek drainage, whereas East Fork Moon Creek flows through a historical flotation tailings impoundment. During the spring snowmelt, 100 eyed cutthroat trout eggs from the Clark Fork fish hatchery were placed in each of 16 artificial egg baskets with capping devices to capture emerging trout fry. Two to three egg baskets were positioned in each of six artificial redds (three in the West Fork and three in the East Fork). The artificial redds were monitored over a 5.5 week period. At the end of this period, the West Fork redds had an average emergence of 13.6% and the East Fork redds had an average emergence of 2.5%.

Table 7-5
Water Chemistry Measurements during 1987-1988 *In Situ* Testing Performed by Dames & Moore as Part of the Bunker Hill RI/FS

Site	Date	Temp. (C)	Cond. (µmhos/cm)	pH	Hardness (mg/L)	Dissolved Cd (µg/L)	Dissolved Pb (µg/L)	Dissolved Zn (µg/L)
SFCdA near Elizabeth Park (RM 9)	Sept. 1987	7-16	165-202	7.4-7.9	84	12	21	1,800
	Dec. 1987	5-6	50-117	6.4-7.3	80	6	13	2,190
	June 1988	11-17	115-148	6.6-7.6	67	10	<5	1,230
SFCdA near Bunker Creek (RM 6.8)	Sept. 1987	7-18	210-244	7.3-7.6	104	10	<19	2,200
	Dec. 1987	5-8	80-130	6.2-7.2	88.7	7	25	2,760
	June 1988	11-19	132-152	7.1-7.4	74.4	10	<5	1,490
SFCdA near Government Creek (RM 5)	Sept. 1987	7-17	271-343	7.3-7.5	168	11	<19	2,400
	Dec. 1987	5-7	120-200	6.2-7.2	141	7	<25	3,000
	June 1988	11-19	152-230	6.9-7.3	78.5	13	9	1,710
SFCdA near Pine Creek (RM 2.2)	Sept. 1987	7-17	250-320	7.2-7.4	120	8	<19	2,100
	Dec. 1987	6-8	101-180	6.3-7.2	121	6	18	2,780
	June 1988	12-20	151-235	6.9-7.3	73.8	9	<5	1,480
NF CdA near Enaville (RM 0.2)	Sept. 1987	8-14	30-50	7.2-7.9	18	<2	31[a]	9.4
	Dec. 1987	4-8	20-25	6.6-7.6	17.4	<4	<5	<20
	June 1988	8-17	30-65	6.8-7.5	17.1	<4	<5	30

a. Sample suspected to have been contaminated during analysis (Dames & Moore, 1989).

Source: Dames & Moore, 1989.

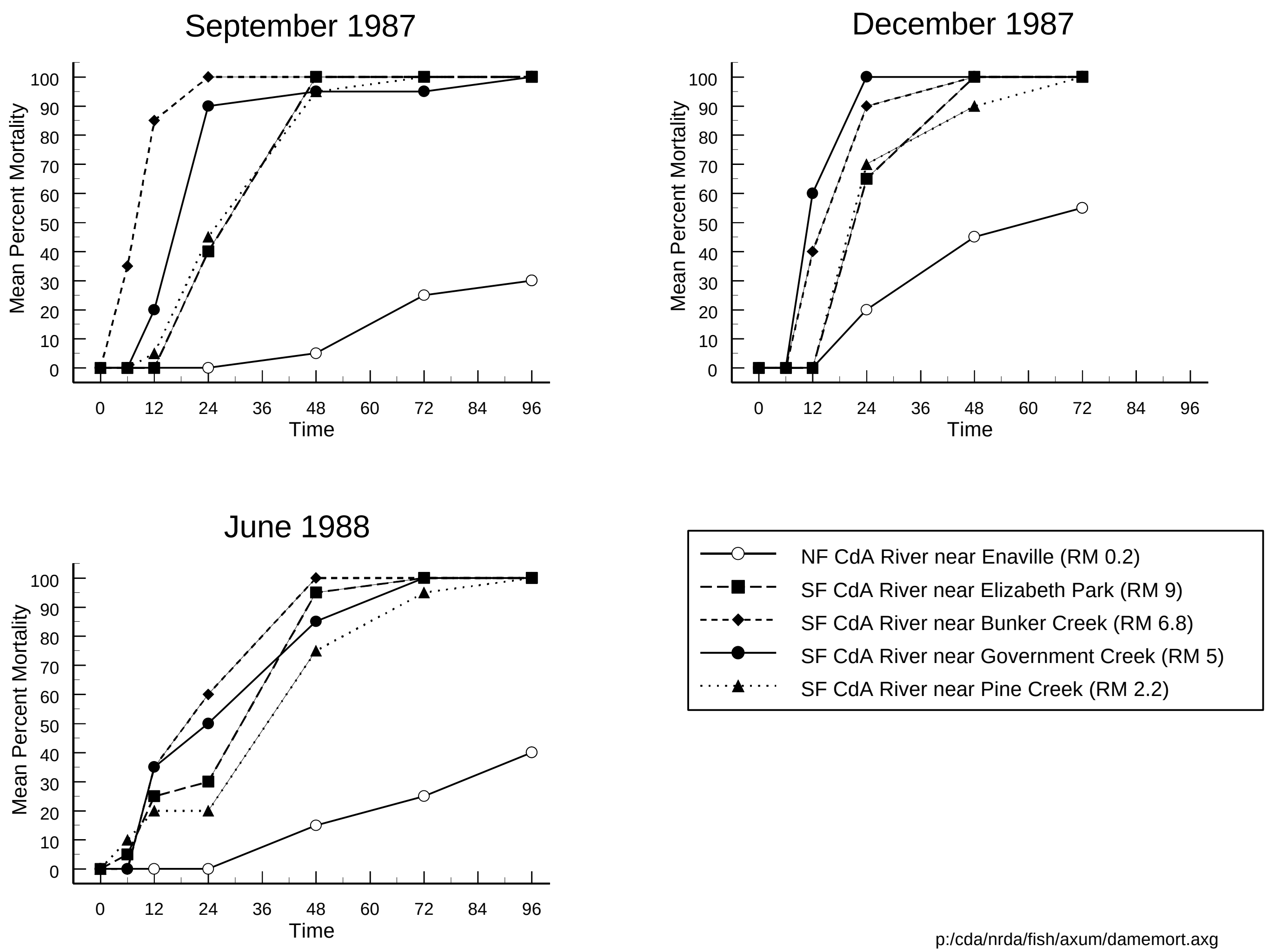

Figure 7-4. Rainbow trout mortality in livebox tests conducted by Dames & Moore (1989) as part of the Bunker Hill RI/FS.

Concentrations of metals in the West Fork ranged from 3.6 to 4.8 µg/L cadmium, 3.9 to 5.4 µg/L zinc, and 1.0 µg/L lead. Concentrations of metals in the East Fork were higher, ranging from 7.2 to 10.5 µg/L cadmium, 326.0 to 430.0 µg/L zinc, and 3.3 to 4.5 µg/L lead. The author concludes that "there is reason for concern of the existing metals concentrations and fine sediments in the streams and its crippling effects on the incubation of cutthroat trout" (Lockhart, 1993, p. 12).

In summary, *in situ* bioassays conducted in the 1930s and between 1973 and 1988 consistently showed reduced survival of test fish in the South Fork Coeur d'Alene River downstream of the Canyon Creek confluence and in the mainstem Coeur d'Alene River, relative to survival in the North Fork Coeur d'Alene River and the headwaters of the South Fork Coeur d'Alene River. Concentrations of hazardous substances in the reaches where reduced survival consistently has been observed are known to be elevated and to exceed water quality criteria (Chapter 4). In addition, the emergence study conducted in 1993 (Lockhart, 1993) confirmed that reduced cutthroat trout emergence was associated with elevated concentrations of cadmium, lead, and zinc.

7.5.2 Laboratory Studies

Laboratory bioassays have been conducted by numerous researchers using mixtures of mine wastes collected from the Coeur d'Alene River basin and laboratory waters (Ellis, 1940), toxicants added to Coeur d'Alene River basin waters (Sappington, 1969; Rabe and Sappington, 1970; EVS, 1996b, 1996c, 1997b), dilutions of Coeur d'Alene River basin water (Hornig et al., 1988), and toxicants added to laboratory waters formulated to simulate Coeur d'Alene River basin conditions (Hansen et al., 1999a, 1999b).

Early laboratory tests were performed by Ellis in 1932 with lead and zinc ores and waste incrustations collected along the South Fork Coeur d'Alene River from the streambanks and flats between Cataldo and Enaville (Ellis, 1940). Test organisms included goldfish, plankton, frogs, turtles, and freshwater mussels. Test endpoints included death, digestive function, heart beat, and mucus production. Ore products were washed with tap water and extracted with alcohol before use in testing. The washed ore powders comprised lead sulphide, zinc sulphide, and small amounts of other metallic sulfides. No goldfish mortality was observed during the 31 day exposure to the washed ore powders; however, plankton died within 48 hours of exposure. Flume water was toxic to plankton within 48 hours. Exposure of fish, frogs, and turtles to solubilized waste incrustations resulted in immediate paralysis of the digestive tract, cessation of heart beat, and disturbances in swallowing, swimming, and gill movements. Extended exposure of goldfish to waste incrustations (10 days) resulted in death.

As part of a master's thesis at the University of Idaho, Sappington (1969) performed static bioassays to determine the acute toxicity thresholds of zinc to cutthroat trout fingerlings (see also Rabe and Sappington, 1970). Test waters were prepared by adding a range of doses of zinc sulphate to water collected from the North Fork Coeur d'Alene River, approximately five miles upstream of the confluence with the South Fork Coeur d'Alene River. Test waters were renewed every 24 hours. Fish were acclimated to North Fork Coeur d'Alene River water for at least seven days before testing and were not fed for one day before testing or during the test. The zinc concentration that caused mortality of 50% of the fingerling cutthroat trout in 96 hours (the 96 h LC50) was 90 µg/L total zinc. Concentrations of total and dissolved zinc in the South Fork Coeur d'Alene River and mining impacted tributaries regularly exceed 90 µg/L (Chapter 4).

Hornig et al. (1988) conducted acute toxicity tests with 3-4 cm hatchery cutthroat trout using water collected from the Bunker Hill Central Impoundment Area (CIA) seep and the South Fork Coeur d'Alene River upstream of Pine Creek. Both tests included exposures of fish to a range of mixtures of test water with North Fork Coeur d'Alene River water. The Bunker Hill CIA tests included exposure to 100% Bunker Hill CIA seep water, and mixtures containing 50%, 25%, 12%, 6.2%, 3.1%, 1.6%, 0.8%, and 0% Bunker Hill CIA seep water. The South Fork Coeur d'Alene River tests included exposure to 100% South Fork Coeur d'Alene River water, and mixtures containing 50%, 25%, 12%, 6.2%, 3.1%, and 0% South Fork Coeur d'Alene River water. For both tests, each mixture was replicated twice, and each replicate contained 10 fish. In both series of tests, fish mortality was concentration-dependent (i.e., more seep or river water caused more lethality; Figures 7-5 and 7-6). Hornig et al. (1988) reported 96 h LC50s of 2.2% Bunker Hill CIA seep water and 9.4% South Fork Coeur d'Alene River water. Water chemistry data were not provided.

Hornig et al. (1988) conducted similar survival tests with fathead minnows using mixtures of North Fork Coeur d'Alene River water and Bunker Hill CIA seep water. Mixtures included 30%, 10%, 25%, 3%, 1%, 0.3%, and 0% Bunker Hill CIA seep water. No fish survived after seven days in mixtures containing 30% and 10% Bunker Hill CIA seep water. Sixty percent of the fish exposed to 3% CIA seep water were dead by seven days. Fifteen percent of the fish exposed to the 1% and the 0.3% CIA seep water were dead by seven days. No mortality occurred in the dilution control water.

More recently, EVS Environmental Consultants, under contract to the State of Idaho, Division of Environmental Quality, conducted toxicity tests with water collected from the South Fork Coeur d'Alene River, from Canyon Creek, and from the Little North Fork of the South Fork Coeur d'Alene River (EVS, 1996a; 1996b; 1996c; 1996d; 1997a; 1997b). The tests were conducted using both hatchery reared fish and fish collected from the South Fork Coeur d'Alene River. Since fish in the South Fork Coeur d'Alene River have been exposed to elevated metal concentrations — and hence represent tolerant individuals capable of surviving in metal contaminated waters — the results of the toxicity tests using the field collected fish are extremely conservative.

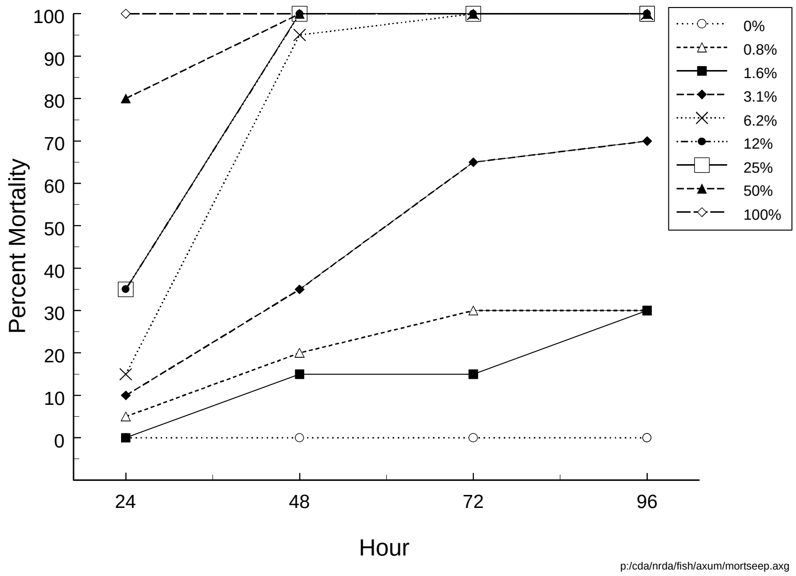

Figure 7-5. Cutthroat trout mortality in acute toxicity tests conducted by the U.S. EPA in August 1986 with Bunker Hill central impoundment area seep water.
Source: Hornig et al., 1988.

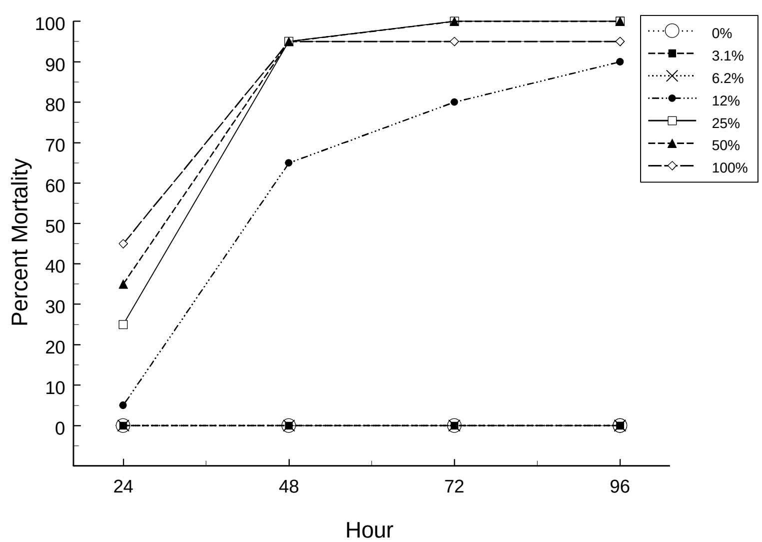

Figure 7-6. Cutthroat trout mortality in acute toxicity tests conducted by the U.S. EPA in September 1986 with South Fork Coeur d'Alene River water collected upstream of Pine Creek.
Source: Hornig et al., 1988.

Preliminary acute bioassays with South Fork Coeur d'Alene River site water were conducted using hatchery rainbow trout (EVS, 1996b). Water for use in testing was collected from three sites on the South Fork Coeur d'Alene River, upstream of Wallace (SF8), downstream of Mullan (SF9), and downstream of Shoshone Park (SF10), and from the Little North Fork of the South Fork Coeur d'Alene River. Fish were exposed to each test water, and to the South Fork test waters with three concentrations of cadmium (0.1, 1.0, 5.0 mg/L), zinc (0.1, 1.0, 10.0 mg/L), and lead (0.1, 1.0, 10.0 mg/L). Ten fish were placed in each of three replicate test chambers per exposure condition. The pH values ranged from 6.72 to 7.86 during the tests. Hardness values were not reported.

At 96 hours, no mortality had occurred in the Little North Fork of the South Fork Coeur d'Alene River water, SF9, or SF10 control waters (Figure 7-7). Substantial mortality was observed in South Fork Coeur d'Alene River water from upstream of Wallace (SF8 control), and South Fork Coeur d'Alene River water from SF8, SF9, and SF10 with added cadmium, lead, and zinc. Forty-seven percent of the fish in the SF8 control water died. One hundred percent mortality occurred by 96 hours in all cadmium exposures in all three South Fork Coeur d'Alene River waters (SF8, SF9, and SF10). One hundred percent mortality occurred by 96 hours in all zinc exposures in SF8 site water. Greater than 50% mortality occurred in SF9 water at the 1.0 mg/L zinc treatment and in the SF10 water at the 0.1 mg/L zinc treatment. No mortality occurred in the 0.1 mg/L zinc or lead treatment in SF9 water. Greater than 50% mortality occurred in the SF8 0.1 mg/L lead treatment and in the SF9 and SF10 1.0 mg/L lead treatment.

EVS also conducted a toxicity test using hatchery rainbow trout exposed to Canyon Creek water. The exact collection site on Canyon Creek is not provided. No metals were added to the water. The Canyon Creek water was serially diluted with water collected from station SF9 on the South Fork Coeur d'Alene River (near Mullan). Rainbow trout mortality was 44% in the 10% Canyon Creek water and increased to 100% in 100% Canyon Creek water (Figure 7-8). The toxicity in 10% Canyon Creek water was associated with 2.9 µg/L dissolved Cd, 5 µg/L dissolved Pb, and 429 µg/L dissolved Zn (EVS, 1996b). No information was provided on the hardness of the water.

Subsequent toxicity tests were conducted by EVS in water collected from the Little North Fork of the South Fork Coeur d'Alene River (EVS, 1996c, 1997b). Tests were conducted with six concentrations of each metal and a control from the Little North Fork of the South Fork Coeur d'Alene River (hardness = 18-21 mg/L; alkalinity = 18-22 mg/L; pH = 6.30-7.45; temperature = 8.4-11.9 C). Tests were conducted with each of the three metals (cadmium, zinc, lead) on sculpin and cutthroat trout collected from the South Fork Coeur d'Alene River upstream of Mullan and on hatchery reared cutthroat trout and rainbow trout (EVS, 1996c). A second set of tests were conducted with hatchery rainbow trout only (EVS, 1997b). Five to 10 fish were placed in each of two replicate test chambers per exposure condition.

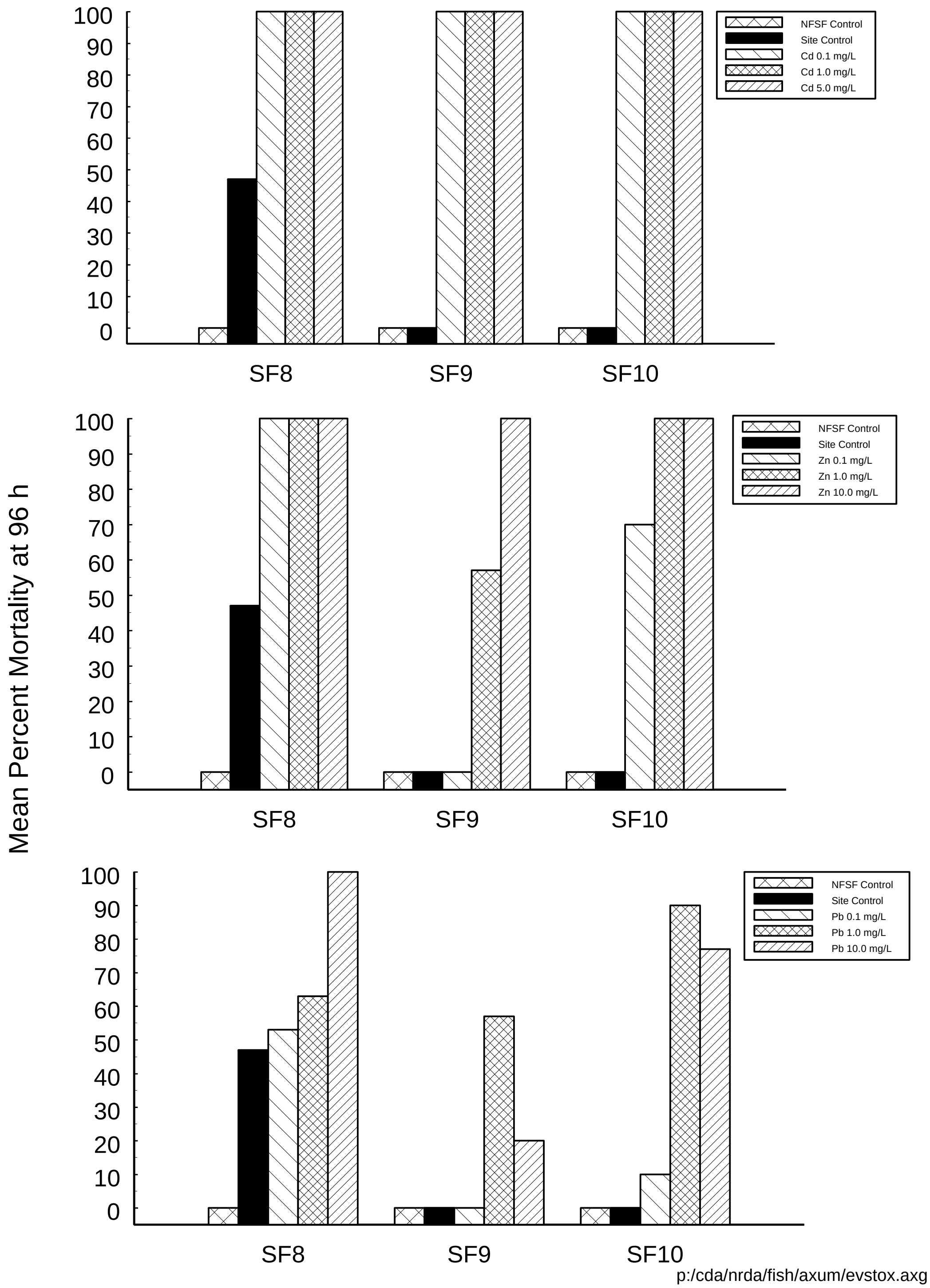

Figure 7-7. Hatchery rainbow trout mortality (96 hours) in acute toxicity tests conducted by EVS with South Fork Coeur d'Alene River water.
Source: EVS, 1996b.

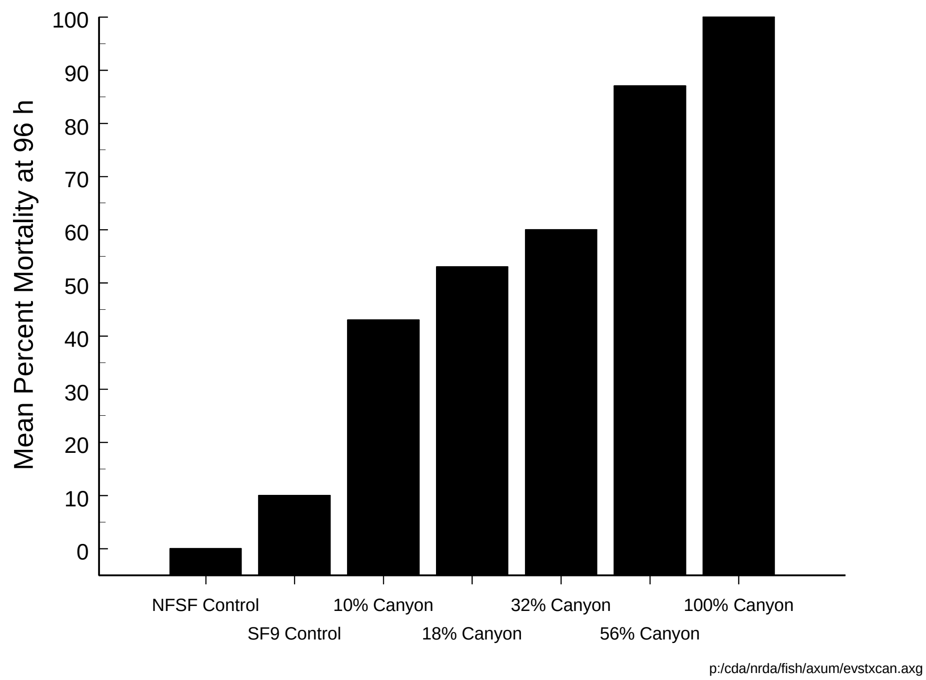

Figure 7-8. Hatchery rainbow trout mortality (96 hours) in acute toxicity tests conducted by EVS with dilutions of Canyon Creek water.
Source: EVS, 1996b.

Exposure to cadmium caused acute lethality to all test species at the lowest concentration tested (0.75 µg Cd/L). In order of decreasing sensitivity to cadmium, species mortality at 0.75 µg Cd/L was hatchery cutthroat trout (~90% mortality) > hatchery rainbow trout (~70% mortality) > field-collected cutthroat trout (~20% mortality) > sculpin (~10% mortality) (Figure 7-9). The toxicity of zinc was greatest in hatchery rainbow and cutthroat trout (~30-40% mortality for exposure to 50 µg Zn/L), and lower in field-collected cutthroat trout (~30% mortality for exposure to 250 µg Zn/L).

Virtually no zinc toxicity was observed with the field-collected sculpin (Figure 7-9). Consistent lead toxicity was observed with the two hatchery trout species at concentrations > 100 µg Pb/L (Figure 7-9). Virtually no mortality was observed in any of the lead exposures with the field-collected fish. However, as noted previously, the results with the field-collected fish may be conservative.

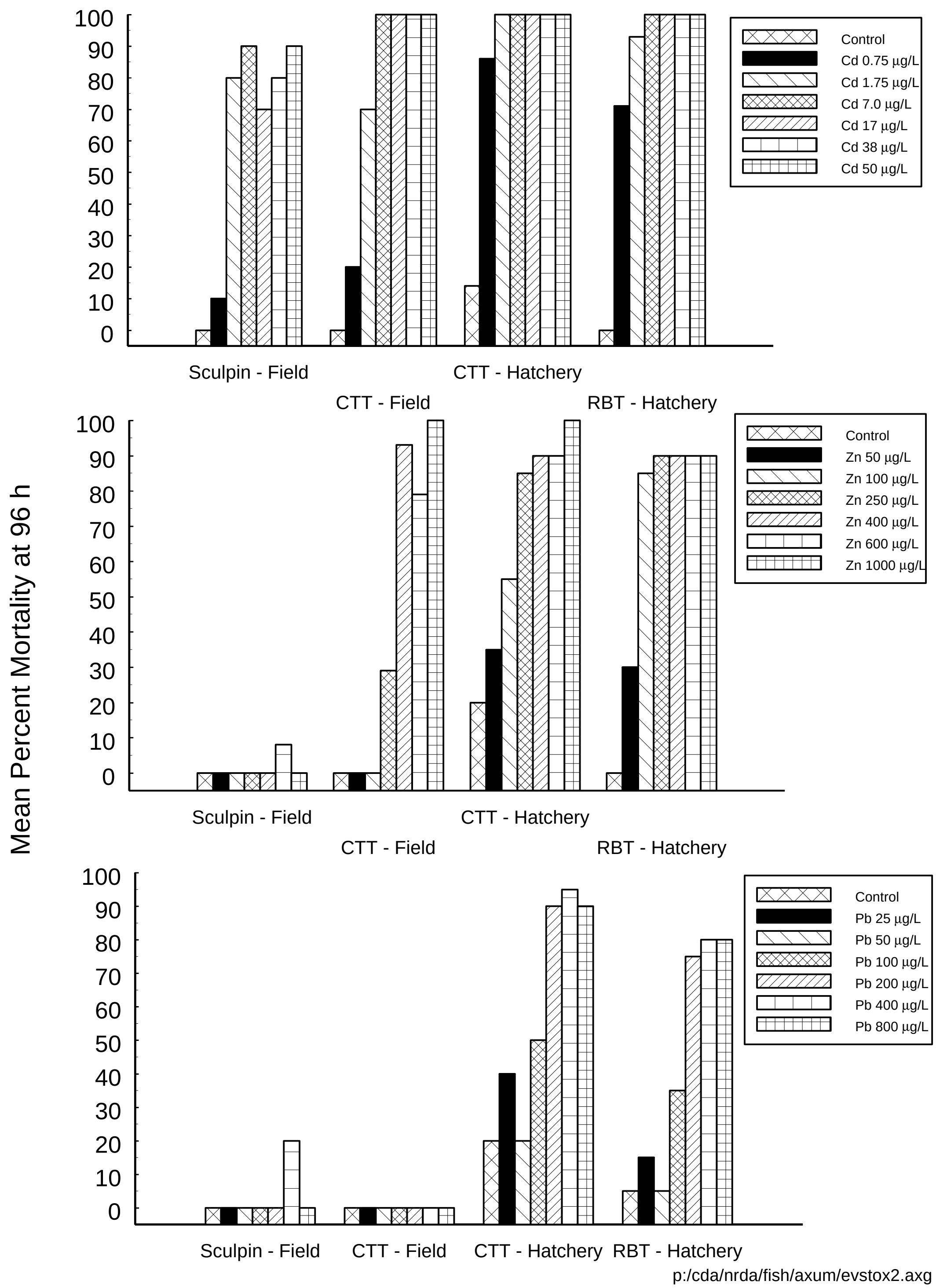

Figure 7-9. Mortality in acute toxicity tests conducted by EVS with Little North Fork of the South Fork Coeur d'Alene River water using field collected sculpin and cutthroat trout (CTT) and hatchery reared cutthroat and rainbow trout (RBT).
Source: EVS, 1996c.

In the testing performed in 1997 (EVS, 1997b) with hatchery rainbow trout only, 60% mortality was observed at a cadmium concentration of 0.90 µg/L, and mortality was 90-100% for Cd ≥ 1.2 µg/L (Figure 7-9). Testing with lead resulted in mortality rates of 30% at 100 µg/L, 80% at 185 µg Pb/L, and 100% at 247 µg Pb/L (Figure 7-10). EVS also conducted a series of 68 day chronic toxicity tests with hatchery rainbow trout (EVS, 1997b). Both survival and growth effects were measured in the test fish. The concentrations that killed 50% of the test fish by 68 days (i.e., the 68-d LC50s) were 1.83 µg Cd/L, 56.8 µg Pb/L, and 156 µg Zn/L. However, in all of these chronic tests, EVS had problems with the dosing apparatus. Therefore, the specific numerical results of these tests should be interpreted with caution.

In testing performed in 1999, Hansen et al. (1999a) conducted a series of acute lethality studies using juvenile rainbow and bull trout with cadmium and zinc at different pH, hardness, and temperature water conditions. Water quality parameters were selected across a range of values intended to simulate conditions in the Coeur d'Alene River basin. Sixteen separate acute toxicity bioassays with cadmium and/or zinc were performed. The influence of water quality variables on metals toxicity was evaluated by varying test hardness (30 or 90 mg/L, as $CaCO_3$), pH (6.5 or 7.5), and temperature (8 or 12 C).

The results of the Hansen et al. (1999a) acute testing are summarized in Table 7-6. Water quality variables generally had a similar qualitative influence on the two species. Higher hardness and lower pH water produced lower toxicity (i.e., higher LC50 concentrations) and slower rates of toxicity (Hansen et al., 1999a). LC50 values for cadmium ranged from roughly 0.35-0.95 µg/L for the two species at a hardness of 30 mg/L, and 2.18-5.01 µg Cd/L at a hardness of 90 mg/L. At pH 6.5, the reported LC50 values were 0.92 and 2.42 µg Cd/L for rainbow and bull trout, respectively. LC50 values for zinc ranged from roughly 24 to 82 µg/L at a hardness of 30 mg/L. At a hardness of 90 mg/L, LC50 values were considerably higher (roughly 200-400 µg Zn/L for the two species). At pH 6.5, reported LC50 values were 123-146µg Zn/L for rainbow trout and 204-207µg Zn/L for bull trout.

Increased temperature did not have a strong influence on toxicity (i.e., roughly similar LC50 concentrations), but it did increase the rate of toxicity in both species. However, temperature had a somewhat stronger influence on bull trout sensitivity to zinc than on rainbow trout; in paired tests, bull trout were marginally more sensitive to zinc than rainbow trout when tests were conducted at 12 C (Hansen et al., 1999a). Notably, at a hardness of 30 mg/L, the toxicity values measured by Hansen et al. for both species were lower than federal water quality criteria for protection of aquatic life. Hansen et al. (1999b) also recently completed a 55-day subchronic study in which bull trout were exposed to cadmium at pH 7.5 and a hardness of 30 mg/L. In this test, exposure to 0.79 µg Cd/L caused 36% mortality and 28% growth reduction (relative to growth of control fish). Exposure to lower cadmium concentrations (0.05-0.37 µg Cd/L) did not affect survival. However, growth was marginally reduced (9-13%) in the lower cadmium treatments.

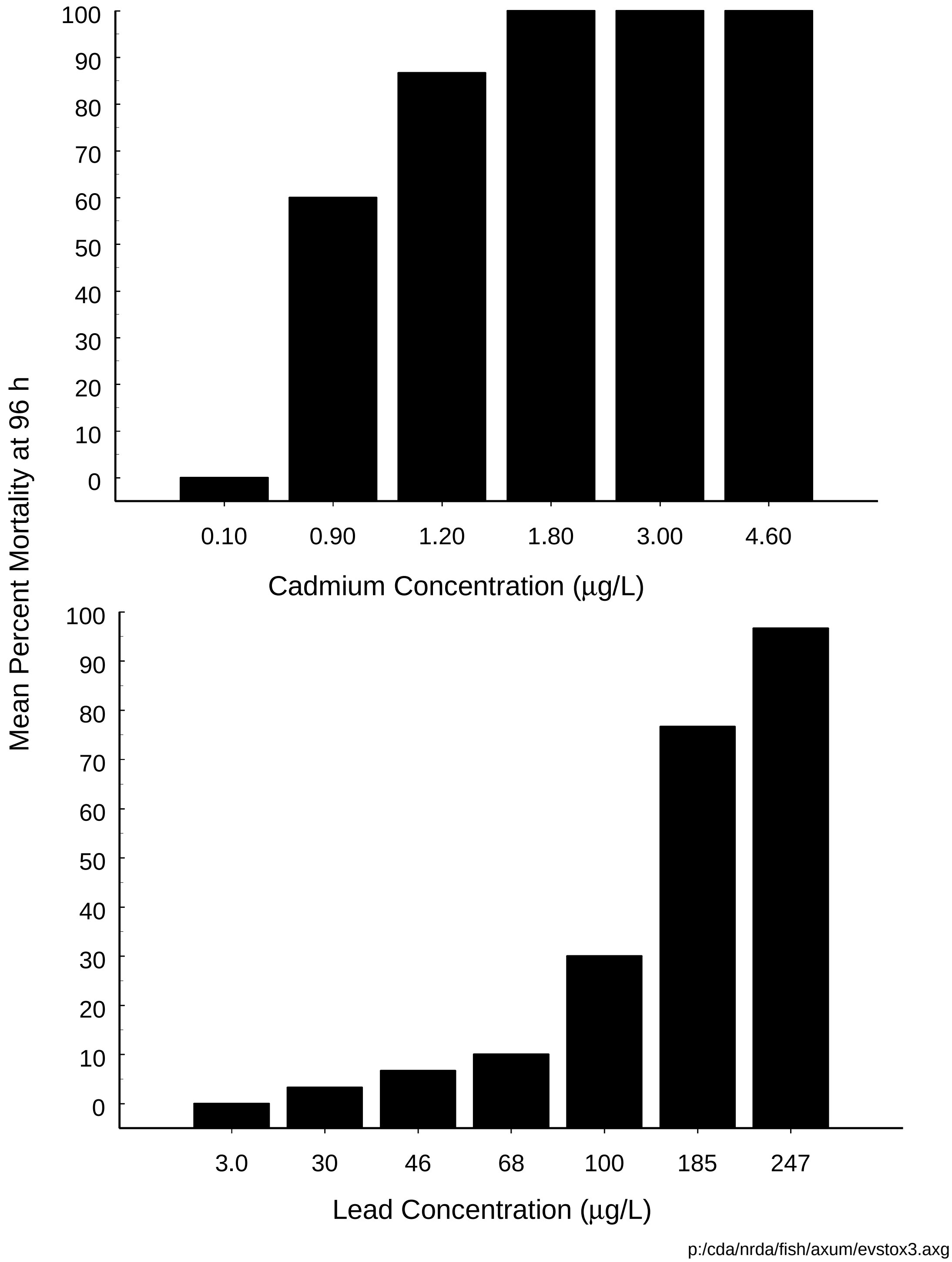

Figure 7-10. Hatchery rainbow trout mortality in acute toxicity tests conducted by EVS with Little North Fork of the South Fork Coeur d'Alene River water. Control data not reported.
Source: EVS, 1997b.

Table 7-6
Toxicity Values for Cadmium and Zinc in Acute Testing Conducted with Juvenile Rainbow Trout and Bull Trout[a]

Toxicant	Test Conditions	Rainbow Trout		Bull Trout	
		LC50[b] (μg/L)	LC20[a] (μg/L)	LC50 (μg/L)	LC20 (μg/L)
Cadmium	pH = 7.5 Hardness = 30 Temp = 8 C	0.35-0.54 (3 tests)	0.25-0.37 (3 tests)	0.90-0.95 (3 tests)	0.60-0.63 (2 tests)
	pH = 7.5 Hardness = 90 Temp = 8 C	2.18	1.33	5.01	2.57
	pH = 6.5 Hardness = 30 Temp = 8 C	0.92	0.57	2.42	1.38
	pH = 7.5 Hardness = 30 Temp = 12 C	0.35	0.28	0.90	0.71
Zinc	pH = 7.5 Hardness = 30 Temp = 8 C	24.3-54.0 (3 tests)	16.0-36.7 (3 tests)	37.2-81.6 (3 tests)	30.2-56.5 (3 tests)
	pH = 7.5 Hardness = 90 Temp = 8 C	202-270 (2 tests)	112-134 (2 tests)	315-413 (2 tests)	162-256 (2 tests)
	pH = 6.5 Hardness = 30 Temp = 8 C	123-146 (2 tests)	51.7-63.3 (2 tests)	204-207 (2 tests)	74.4-113 (2 tests)
	pH = 7.5 Hardness = 30 Temp = 12 C	33.4	21.9	30.1[c]	—

a. Values calculated using log-dose Probit procedures (Toxstat V. 3.5).
b. 50% and 20% lethality effects concentrations for 120-h exposures.
c. Value presented using log-dose Spearman-Karber analysis (Toxstat V. 3.5).

Source: Hansen et al., 1999a.

7.5.3 Summary of Previously Conducted Toxicity Studies

The various toxicity studies conducted over the past four decades have included both *in situ* bioassays and laboratory tests performed with water and mine waste effluents collected from the site. Both types of studies have consistently demonstrated that exposure to water from the Coeur d'Alene River and contaminated tributaries is acutely lethal to fish.

In addition, laboratory tests in which metals were added to water collected from clean tributaries and laboratory tests using waters formulated to simulate conditions in the Coeur d'Alene system have demonstrated that Cd and Zn are acutely toxic to salmonids at concentrations lower than federal water quality criteria concentrations, and at concentrations substantially lower than concentrations of hazardous metals — particularly cadmium and zinc — measured in surface waters of the Coeur d'Alene River basin.

7.6 SUPPLEMENTAL TRUSTEE STUDIES

As described above, existing site data provide evidence that fish are injured by metals in Coeur d'Alene River basin streams. Concentrations of hazardous substances in surface water exceed chronic and acute ambient water quality criteria for cadmium, lead, and zinc toxicity thresholds. In addition, *in situ* bioassays and laboratory bioassays with site water have shown that the surface water in the South Fork Coeur d'Alene River and metal-contaminated tributaries are acutely toxic to various fish species.

To supplement the above data, the Trustees conducted several additional studies to further evaluate injuries to salmonids and other fish (Table 7-7). Injury determination studies included both field and laboratory components. The field components included supplemental *in situ* bioassays, evaluation of fish health impairment, studies of behavioral avoidance responses, and evaluation of exposure pathways. These field studies provide direct and compelling evidence of injuries to fish under ambient conditions as well as documentation of exposure pathways. Laboratory studies were performed to evaluate, under controlled conditions that facilitate evaluation of causal relationships, behavioral avoidance responses and the effects of consumption of contaminated invertebrates collected from the Coeur d'Alene River.

In addition to the above injury determination studies, a series of fish monitoring studies were undertaken (Table 7-7). These studies, discussed in Section 7.7, permit evaluation of whether observed fish population density and composition is consistent with the hypothesis that fish are injured.

Table 7-7
Supplemental Fish Injury Studies

Study Title	Study Objectives	Reference
Concentrations of Metals Associated with Mining Waste in Sediments, Biofilm, Benthic Macroinvertebrates, and Fish from the Coeur d'Alene River Basin, Idaho	Determine metals concentrations in components of dietary pathway to fish	Farag et al. (1998a)
Dietary Effects of Metals Contaminated Invertebrates from the Coeur d'Alene River, Idaho, on Cutthroat Trout	Determine the effects of trace metals in water and food on survival, growth, and physiological functions of cutthroat trout	Farag et al. (1999)
Distribution of Metals during Digestion by Cutthroat Trout Fed Invertebrate Diets Contaminated in the Clark Fork River, Montana and Coeur d'Alene River, Idaho, USA	Determine if the accumulation of metals in fish was related to variations in metal-organic complexes in the invertebrate diets of fish	Farag et al. (1998b)
Metals Accumulation in the Food-Web of the Coeur d'Alene Basin, Idaho: Assessing Exposure and Injury to Wild Trout	Measure the accumulation of metals in the food web to evaluate the exposure and health of trout at the tissue, individual and population level	Woodward et al. (1997b)
Acute Toxicity of Coeur d'Alene River Water to Cutthroat Trout: Exposures in Live Containers In-Situ and in Laboratory Dilution Water	Determine the reason for fish mortality observed in the field during streamside avoidance experiments	Woodward et al. (1995a)
Cutthroat Trout Avoidance of Metals and Conditions Characteristic of a Mining Waste Site: Coeur d'Alene River, Idaho	Test the hypothesis that cutthroat trout avoid water with higher metal concentrations in preference for water with lower metal concentrations	Woodward et al. (1997a)
Movements of Adult Chinook Salmon during Spawning Migration in a Metals-Contaminated System, Coeur d'Alene River, Idaho	Investigate behavioral avoidance of elevated metal concentrations with natural fish populations and to corroborate laboratory testing of the avoidance response	Goldstein et al. (1999)
Monitoring Migration of Post Spawned Adfluvial Cutthroat Trout in the Coeur d'Alene River Basin	Evaluate the use of the Coeur d'Alene River basin by adfluvial cutthroat trout	Cernera et al. (1997)

Table 7-7 (cont.)
Supplemental Fish Injury Studies

Study Title	Study Objectives	Reference
Coeur d'Alene Basin Natural Resource Damage Assessment: Aquatic Resource Injury Determination and Quantification, 1994 Data Report — Draft	Describe the current conditions of the aquatic resources in the Coeur d'Alene River basin through fish population and habitat surveys	R2 Resource Consultants (1995a)
Coeur d'Alene Basin Natural Resource Damage Assessment: Aquatic Resource Injury Determination and Quantification, 1995 Data Report — Draft		R2 Resource Consultants (1996)
Coeur d'Alene Basin Natural Resource Damage Assessment: Aquatic Resource Injury Determination and Quantification, 1996 Data Report — Draft		R2 Resource Consultants (1997)
Data Report: 1998 Fish Population Monitoring, Coeur d'Alene River Basin NRDA	Supplement aquatic biota data collected previously in the Coeur d'Alene River basin	Stratus Consulting (1999b)
Application of a Limiting Factors Analysis for Defining the Determinants of Reduced Wild Trout Production in the South Fork Coeur d'Alene River, Idaho	Identify the primary factors limiting trout production in the South Fork Coeur d'Alene River	Reiser et al. (1999)

7.6.1 *In Situ* and Site Water Bioassays

In situ bioassays with cutthroat trout were conducted as part of two studies in the Coeur d'Alene River basin: Woodward et al. (1997b) and Woodward et al. (1995a).

The objective of the Woodward et al. (1997b) study was to measure the accumulation of metals in the food web from test and reference sites and to evaluate the exposure and health of trout at the tissue, individual, and population level. The study was conducted during the summer of 1996 at five test locations on the South Fork Coeur d'Alene River (0, 8, 16, 24, 32 miles upstream from the confluence with the North Fork Coeur d'Alene River) and at five reference locations on the St. Regis River (0, 8, 16, 24, 32 miles upstream from the Clark Fork River). Test and reference sites were paired based on geology, habitat, land use, and flow. The sites were generally erosional environments dominated by gravel riffles and runs.

Toxicity testing was conducted at each of the South Fork Coeur d'Alene River and St. Regis River study sites. Ten to 16 hatchery reared westslope cutthroat trout (110-155 mm; 10-30 g) were placed in a 1 gallon, flow-through plastic livebox in the rivers until death or for 96 hours.

Mortality, temperature, and dissolved oxygen were monitored daily, and water was collected for chemical analysis.

Trout survival was reduced in the South Fork test sites compared to the St. Regis reference sites at sites 0, 8, 16, and 24 (the four downstream-most sites). Mortality at the sites was 100% for the three sites downstream of Canyon Creek in the South Fork Coeur d'Alene River (sites 0, 8, and 16), 30% at the South Fork Coeur d'Alene River site upstream of Wallace (site 24), and 0% at the most upstream South Fork Coeur d'Alene River location near Mullan (site 32). No mortality occurred at any of the St. Regis River sites (Figure 7-11).

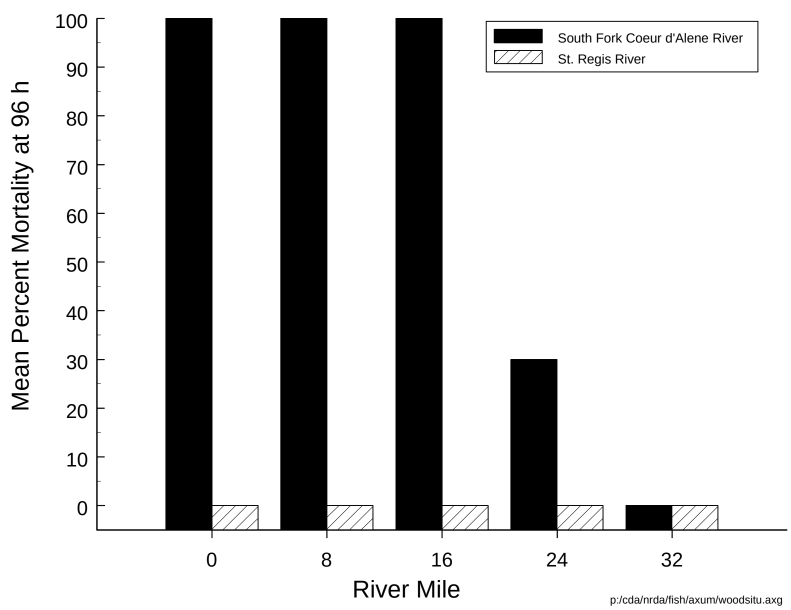

Figure 7-11. Cutthroat trout mortality (96-hour) in *in situ* tests conducted at paired locations in the South Fork Coeur d'Alene River and the St. Regis River.
Source: Woodward et al., 1997b.

Concentrations of cadmium and zinc were elevated above lethal levels (see Section 7.4) at sites where mortality was observed and were correlated with the mortality results (Figure 7-12). This relationship provides strong indication that these metals caused the observed mortality. In contrast, other water quality variables (e.g., dissolved oxygen, temperature, ammonia) were not at concentrations expected to cause adverse effects (data in Woodward et al., 1997b).The results of this study confirm that the elevated concentrations of the hazardous metals cadmium and zinc are acutely lethal to cutthroat trout.

Woodward et al. (1995a) conducted a separate set of *in situ* bioassays. In June 1995, two attempts were made to hold cutthroat trout in site water until subsequent behavioral avoidance tests were conducted. Trout were placed in a holding tank beside the stream containing 70% North Fork Coeur d'Alene River water and 30% South Fork Coeur d'Alene River water.

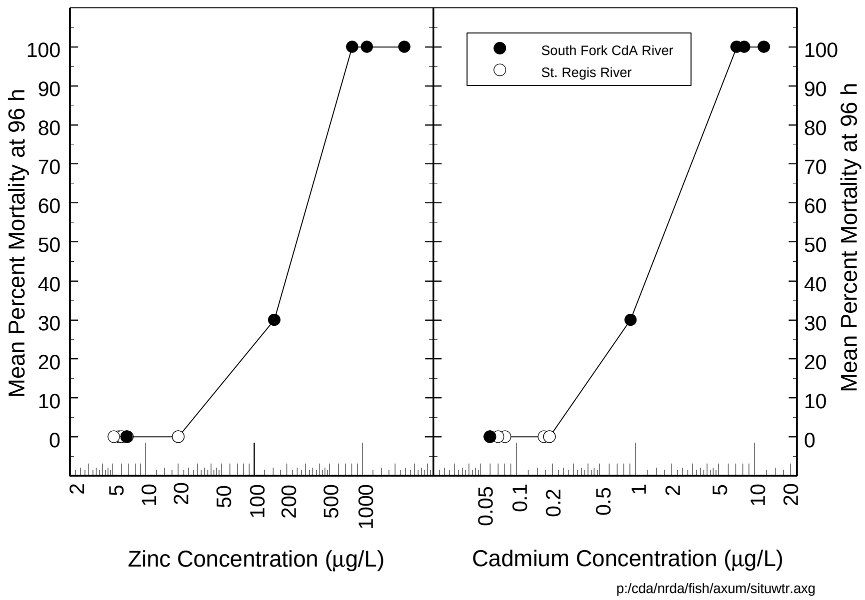

Figure 7-12. Relationship between measured concentrations of cadmium and zinc and cutthroat trout mortality in *in situ* bioassays at locations in the South Fork Coeur d'Alene and St. Regis rivers.
Source: Woodward et al., 1997b.

On both occasions, all fish in the holding tank died within 48 to 72 hours. In July 1995, 100 cutthroat trout and 50 rainbow trout were placed in the mainstem Coeur d'Alene River in a livebox approximately 1 mile downstream of the confluence of the North Fork and South Fork Coeur d'Alene rivers. In addition, five fish were placed in smaller live jars at two locations on the North Fork Coeur d'Alene River and one location on the South Fork Coeur d'Alene River. Woodward et al. (1995a) observed 100% mortality of fish held in South Fork Coeur d'Alene River water, and 97% mortality of fish held in water the mainstem Coeur d'Alene River. No mortality was observed in 96 hours in the North Fork Coeur d'Alene River water, but when the livebox was moved to the South Fork Coeur d'Alene River site, all fish died within 48 hours (Woodward et al., 1995a). These data provide additional indication that exposure to surface waters of the South Fork Coeur d'Alene River and the mainstem Coeur d'Alene River causes acute lethality to trout.

Woodward et al. (1995a) then collected water from the North Fork and South Fork Coeur d'Alene rivers and transported it to Jackson, Wyoming, for testing. Cutthroat trout were exposed in 96 hour bioassays to mixtures of South Fork Coeur d'Alene River water and North Fork Coeur d'Alene River water. Ten fish were tested at each dilution. Concentrations of metals measured during the acute toxicity study are presented in Table 7-8. All fish in test chambers containing 15%, 30%, 60%, and 100% South Fork Coeur d'Alene River water, and 90% of the fish in chambers containing 7.5% South Fork Coeur d'Alene River water, died within 60 hours (Figure 7-13). No fish in the control (North Fork Coeur d'Alene River) water died during the test.

Table 7-8
Concentrations of Metals Measured during the Cutthroat Trout Toxicity Tests with Dilutions of South Fork Coeur d'Alene River Water

Dilution	Cadmium (µg/L)	Lead (µg/L)	Zinc (µg/L)
0%	<0.05	4.92	40
7.5%	0.65	4.74	170
15%	1.49	6.68	340
30%	2.82	8.77	615
60%	5.26	14.86	1,130
100%	8.40	20.02	1,810

Source: Woodward et al., 1995a.

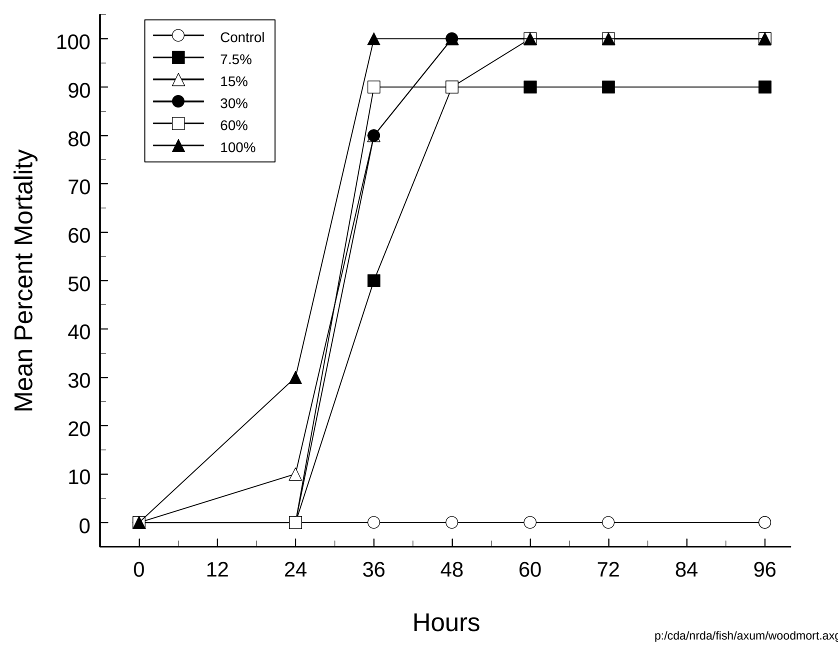

Figure 7-13. Cumulative mortality (96 hours) in cutthroat trout exposed to serial dilutions of South Fork Coeur d'Alene River water.
Source: Woodward et al., 1995a.

These latter dilution tests performed with site water were not conducted in a secure laboratory facility because of practical limitations associated with transporting site waters to the secure U.S. Geological Survey/Biological Resources Division facility in Jackson, Wyoming (D. Woodward, USGS, pers. comm., June 1999). As a consequence, although the methods used were consistent with routine laboratory practices for conducting bioassays, the results of the testing could have been influenced by deviations from strict quality control standards.

Nevertheless, the results of the testing are consistent with (a) previous bioassays performed using site waters, (b) results of *in situ* bioassays, and (c) expected trout mortality given the measured metals concentrations in the test waters. Given the strong consistency of these data with other studies, the results of this study provide additional confirmatory evidence of the toxicity of South Fork Coeur d'Alene River site waters to trout.

7.6.2 Behavioral Avoidance Testing

Behavioral avoidance of hazardous substances was evaluated in the laboratory with cutthroat trout (Woodward et al., 1997a), and in the field with chinook salmon (Goldstein et al., 1999).

Laboratory Avoidance Testing (Woodward et al., 1997a)

The objective of the laboratory study was to test the hypothesis that cutthroat trout would avoid water with elevated metal concentrations, to examine the effect of individual metals on the avoidance response, and to examine the influence of acclimation to metals on the avoidance response (Woodward et al., 1997a). Avoidance behaviors can impede movement of adfluvial trout from Coeur d'Alene Lake into tributary streams of the South Fork Coeur d'Alene River for rearing purposes, can impede movement of fish from tributaries with limited available habitat into larger mainstem habitats for rearing purposes, and can cause movement of fish into smaller tributary streams that have limited habitat. Hence, avoidance responses can effectively cause habitat loss and can contribute to reductions in trout populations.

To determine whether cutthroat trout avoid, and therefore are injured by, the hazardous substances in the surface water of the South Fork Coeur d'Alene River, controlled laboratory avoidance tests were performed at the USGS/Biological Resources Division, Jackson Field Station, Jackson, Wyoming, using simulated Coeur d'Alene River water and control water. Cutthroat trout were obtained as eggs from the Jackson National Fish Hatchery, Jackson, Wyoming, and reared for 3 to 5 months after hatching at the Jackson Field Station. Fish were exposed to a mixture of cadmium, lead, and zinc, as well as to each metal individually. Multiple sets of experiments were conducted.

In the first study, fish were exposed to a control water (simulating the uncontaminated North Fork Coeur d'Alene River) without elevated metals and one of several "test" waters spiked with cadmium, lead, and zinc at concentrations typical of various locations in Coeur d'Alene Lake, the mainstem Coeur d'Alene River, and the South Fork Coeur d'Alene River (Table 7-9). Both test and reference waters were formulated to water chemistry characteristics similar to the Coeur d'Alene River (hardness 50 mg/L, alkalinity 50 mg/L, pH 7.0 to 7.4), with the only difference being metal content. Responses of individual fish to the choice of waters (test versus reference) then were monitored to evaluate whether any preference or avoidance was demonstrated.

Table 7-9
Mean (standard deviation) Concentrations of Metals and Cutthroat Trout Responses in Metal Mixture Avoidance Tests (20 minute test period)

Test Water Designation (simulated location)	Concentration (µg/L)			Mean Total Time in Test Water (seconds)	Mean Percent Time in Test Water	Mean Number of Trips into Test Water	Mean Trip Duration in Test Water (seconds)	Significant Avoidance Observed?
	Cd	Pb	Zn					
NF CdA at Enaville[a] (control)	0.10 (0.09)	0.65 (0.16)	22 (11)	571 (126)	48	52 (16)	13 (7.2)	No
Lake CdA[a]	0.31 (0.12)	0.67 (0.22)	52 (16)	191 (81)[b]	16[b]	36 (13)[b]	4.7 (1.4)[b]	Yes
Mainstem CdA at Harrison[c]	0.69 (0.29)	1.2 (0.25)	74 (9.1)	168 (112)[b]	14[b]	33 (7.3)[b]	4.5 (2.4)[b]	Yes
Mainstem CdA at Cataldo[a]	1.2 (0.07)	2.2 (0.68)	125 (12)	86 (45)[b]	7.2[b]	34 (6.6)[b]	2.3 (0.9)[b]	Yes
Pinehurst (SFCdA) — Low metals[d]	2.3 (0.10)	3.2 (0.21)	221 (10)	87 (87)[b]	7.2[b]	27 (5.6)[b]	2.6 (2.0)[b]	Yes
Pinehurst (SFCdA) — Medium metals[d]	5.8 (0.24)	9.5 (0.46)	530 (19)	33 (11)[b]	2.8[b]	25 (7.3)[b]	1.4 (0.6)[b]	Yes
Pinehurst (SFCdA) — High metals[d]	13 (1.6)	19 (0.84)	1041 (12)	51 (32)[b]	4.3[b]	26 (5.5)[b]	1.8 (1.3)[b]	Yes

a. n = 12.
b Significant difference from Enaville reference water using Fisher's least significant difference, $p \leq 0.05$.
c. n = 19.
d. n = 6.

Source: Woodward et al., 1997a.

The results of the testing (Table 7-9) demonstrate that cutthroat trout significantly ($p \leq 0.05$) avoid waters containing mixtures of hazardous substances (cadmium, lead, and zinc) representative of metals conditions in the Coeur d'Alene River basin. Significant avoidance ($p \leq 0.05$) of each test water was observed. When fish were offered a choice of control water entering both ends of the testing apparatus, no preference or avoidance was observed, confirming that the responses to test water were not an artifact of the testing apparatus but were, rather, a response to the elevated metals in the test water. The lowest concentrations avoided, which were in the mixture representing Coeur d'Alene Lake, contained 0.31 µg/L Cd, 0.67 µg/L Pb, and 52 µg/L Zn.

Additional avoidance testing was performed to evaluate the role of the individual metals in the metal mixture. Exposure concentrations are provided in Table 7-10. The results of testing with single metals indicated that at the concentrations tested in the mixture testing, only zinc caused avoidance responses. Therefore, for the metal mixture study, zinc, rather than cadmium or lead, was primarily responsible for the avoidance responses observed. Based on the results of the individual metal avoidance tests, cutthroat trout avoided waters containing 66 µg/L zinc, spending only 8.2% of the test period in the elevated zinc treatment, preferring the control water (simulating the North Fork Coeur d'Alene River) 91.8% of the test period. These data indicate that the responses observed in the first test (Table 7-9) were caused by exposure to zinc rather than cadmium or lead.

The role of acclimation of fish to sublethal metal concentrations with regard to the avoidance response was also tested to ascertain whether long-term exposure to metals would eliminate the avoidance response. In the acclimation test, fish were raised until 90 days post-hatch in water representative of the Coeur d'Alene River at Harrison (0.69 µg/L cadmium, 1.2 µg/L lead, and 74 µg/L zinc). Avoidance was then tested using the Harrison water as the "reference" water and contrasted with one of three test waters simulating metal conditions in the Coeur d'Alene Lake, the Coeur d'Alene River at Harrison, and the Coeur d'Alene River at Cataldo. The measured exposure concentrations were similar to the concentrations in Table 7-9. Acclimated trout preferred the less metal contaminated Coeur d'Alene Lake water and avoided the more metal contaminated Coeur d'Alene River water at Cataldo (Table 7-11). Thus, acclimation did not eliminate the ability of cutthroat trout to detect differences in metal concentrations (Woodward et al., 1997a).

Table 7-10
Mean (standard deviations) Concentrations of Metals and Cutthroat Trout Responses in Single Metal and Metal Mixture Avoidance Tests (20 minute test period)

Test Water Designation (simulated location)	Concentration (μg/L)			Mean Total Time in Test Water (seconds)	Mean Percent Time in Test Water	Mean Number of Trips into Test Water	Mean Trip Duration in Test Water (seconds)	Significant Avoidance Observed?
	Cd	Pb	Zn					
NF CdA at Enaville[a] (control)	0.05 (0.03)	0.70 (0.09)	20 (8.5)	523 (109)	44	50 (9.4)	12 (0.9)	No
Mainstem CdA at Harrison[c]	**0.61 (0.03)**	**1.7 (0.74)**	**68 (4.8)**	76 (18)[b]	6.3[b]	35 (6.5)	2.2 (0.2)[b]	Yes
Mainstem CdA at Harrison-Cd[c]	**0.58 (0.04)**	0.84 (0.26)	24 (17)	657 (150)	55[b]	46 (10)	19 (9.6)	No
Mainstem CdA at Harrison-Pb[c]	0.07 (0.07)	**1.3 (0.21)**	41 (15)	570 (81)	48	47 (8.4)	16 (4.8)	No
Mainstem CdA at Harrison-Zn[c]	0.06 (0.05)	0.72 (0.10)	**66 (6.7)**	98 (50)[b]	8.2[b]	29 (9.0)	3.2 (0.7)[b]	Yes

a. n = 10.
b. Significant difference from Enaville reference water using Fisher's least significant difference, $p \leq 0.05$.
c. n = 5.

Note: Bold numbers indicate individual metal(s) tested.

Source: Woodward et al., 1997a.

Table 7-11
Mean (standard deviation) Avoidance Response of Cutthroat Trout Following Acclimation to Metal Contaminated Water Representative of the Coeur d'Alene River at Harrison (20 minute test period)

Test Designation (simulated location)	Mean Total Time in Test Water (seconds)	Mean Percent Time in Test Water	Mean Number of Trips into Test Water	Mean trip Duration in Test Water (seconds)	Observed Response (preference/ avoidance)
Mainstem CdA at Harrison (reference)	606 (78)	51	44 (5.2)	21 (12)	None
CdA Lake	909 (178)[a]	76	34 (14)	102 (163)	Preference
Mainstem CdA at Cataldo	142 (42)[a]	12[a]	38 (13)	4.0 (0.4)[a]	Avoidance

a. Significant difference from Harrison reference water using Fisher's least significant difference, $p \leq 0.05$.

Source: Woodward et al., 1997a.

The study authors noted in their conclusions that downstream migration of trout from relatively uncontaminated areas may be affected by avoidance responses (Woodward et al., 1997a, p. 705):

> Headwater tributaries of the South Fork contain fish populations residing upstream of the influence of mining, but downstream migration may be blocked by the high concentration of metals in the water column. Canyon Creek above Burke, Idaho, contained a population of cutthroat trout; but below Burke . . . where mining activity begins and metals concentrations were elevated in the water column, trout populations were nonexistent (C. Corsi, Idaho Fish and Game, unpublished). Similar results were observed on the upper South Fork near Mullan, Idaho. Trout were present above the area of mining influence, but the reduced numbers below that area may suggest a behavioral avoidance response to increased metals loading (SAIC and EP&T, 1991).
>
> In addition, downstream fish movements (e.g., from tributaries) avoidance responses would impede upstream movement of adfluvial fish from Coeur d'Alene Lake into the upper basin.

Field Testing (Goldstein et al., 1999)

Adult chinook salmon were used to investigate behavioral avoidance of elevated metals concentrations in a field setting (Goldstein et al., 1999). In the fall, chinook salmon migrate from Coeur d'Alene Lake to the Coeur d'Alene River, the St. Joe River, and Wolf Lodge Creek. Forty-five adult chinook salmon males were trapped on Wolf Lodge Creek and implanted with radio transmitters. The fish were released into the mainstem Coeur d'Alene River approximately 2 km downstream from the confluence of the North Fork and the South Fork Coeur d'Alene rivers between September 15 and 29, 1994. Fish from Wolf Lodge Creek were used because they would not favor a "home-cue" from either the North Fork or the South Fork Coeur d'Alene rivers. Telemetry receivers were stationed at the confluence, on the North Fork Coeur d'Alene River, and on the South Fork Coeur d'Alene River. A mobile receiver was used to verify the data collected from the stationary receivers. The fish were tracked from September 15 through October 5, 1994. During this period, daily samples for water quality (temperature, pH, dissolved oxygen) and water chemistry (cadmium, copper, lead, zinc) were collected from the mainstem, the North Fork, and the South Fork Coeur d'Alene rivers.

During the tracking period, mean concentrations of total recoverable metals were greatest in the South Fork Coeur d'Alene River (cadmium = 6.90 µg/L, copper = 2.0 µg/L, lead = 23.0 µg/L, zinc = 2,220 µg/L) followed by the mainstem Coeur d'Alene River (cadmium = 1.80 µg/L, copper = 1.0 µg/L, lead = 6.1 µg/L, zinc = 600 µg/L), and lowest in the North Fork Coeur d'Alene River (cadmium = 0.05 µg/L, copper = 1.0 µg/L, lead = 0.5 µg/L, zinc = 9 µg/L). Mean temperatures ranged from 13.7 C in the South Fork Coeur d'Alene River to 14.1 C in the mainstem and North Fork Coeur d'Alene rivers. Mean pH ranged from 7.0 in the South Fork Coeur d'Alene River to 7.4 in the mainstem Coeur d'Alene River. Conductivity ranged from 32 µS/cm in the North Fork Coeur d'Alene River to 274 µS/cm in the South Fork Coeur d'Alene River. Hardness ranged from 27 mg/L in the North Fork Coeur d'Alene River to 108 mg/L in the South Fork Coeur d'Alene River. During the study period, flow in the North Fork Coeur d'Alene River was approximately two times greater than flow in the South Fork Coeur d'Alene River.

Fifteen of the 45 chinook salmon chose neither the North Fork nor the South Fork and were therefore excluded from the analysis. An additional seven fish were not tracked successfully. Of the remaining 23 chinook salmon, 16 fish (70%) moved up the North Fork, and seven fish (30%) moved up the South Fork.

The results of this field study are consistent with the laboratory findings of Woodward et al. (1997a) and suggest that natural fish populations will avoid water with elevated concentrations of metals.

7.6.3 Dietary Effects Studies

Studies were conducted to characterize the pathway of metals into water, sediments, biofilm, invertebrates, and fish: one by Farag et al. (1998a), and to document the effect of functional group and size on the accumulation of metals in benthic invertebrates, another by Woodward et al. (1997b).

Dietary Pathway Determination (Farag et al., 1998a)

In this study, sediments and biofilm (organic and inorganic film consisting of attached algae, fine sediment, bacteria, and detritus that adheres to rocks in streams) were collected from 10 sites on the South Fork and mainstem Coeur d’Alene rivers and South Fork tributaries, 1 site on the North Fork Coeur d’Alene River, 1 site on the Spokane River, and 1 site on the St. Joe River. Benthic macroinvertebrates also were collected from all sites except the St. Joe River. Perch were collected from four sites on the Coeur d’Alene River and from one site on the St. Joe River. Trout were collected from the North Fork Coeur d’Alene River site, the South Fork Coeur d’Alene River at Pinehurst, and the mainstem Coeur d’Alene River at Cataldo. Four replicate locations were selected at each of the 13 sites.

All sediment, biofilm, and benthic macroinvertebrate samples were collected in acid-washed plastic vials. Sediments were collected with either a plastic scoop or a petite ponar dredge sampler. Biofilm samples were collected by scraping the surface of rocks. Benthic macroinvertebrates were collected in a net and then removed from the net with plastic forceps. Fish were collected by electrofishing. All samples were analyzed for arsenic, cadmium, copper, mercury, lead, and zinc using atomic absorption spectroscopy.

The results of metals analysis of these pathway components indicated that metals concentrations were greatest in biofilm sediments > invertebrates > whole fish (Figure 7-14a, b, and c). The elevated concentrations of metals in the biofilm suggest an important food chain link for metals transfer; biofilm serves as a food source for invertebrates, which, in turn, are consumed by fish (Farag et al., 1998a). Metals measured in invertebrate tissues also confirm an important exposure pathway to fish, which eat invertebrates (Farag et al., 1998a). Whole fish (perch) from the lower Coeur d’Alene River and trout kidneys and gills contained elevated Cd, Pb, and Zn concentrations relative to North Fork Coeur d’Alene River and St. Joe River fish and tissues. 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. These data provide evidence of the sediment-invertebrate dietary exposure pathway to fish.

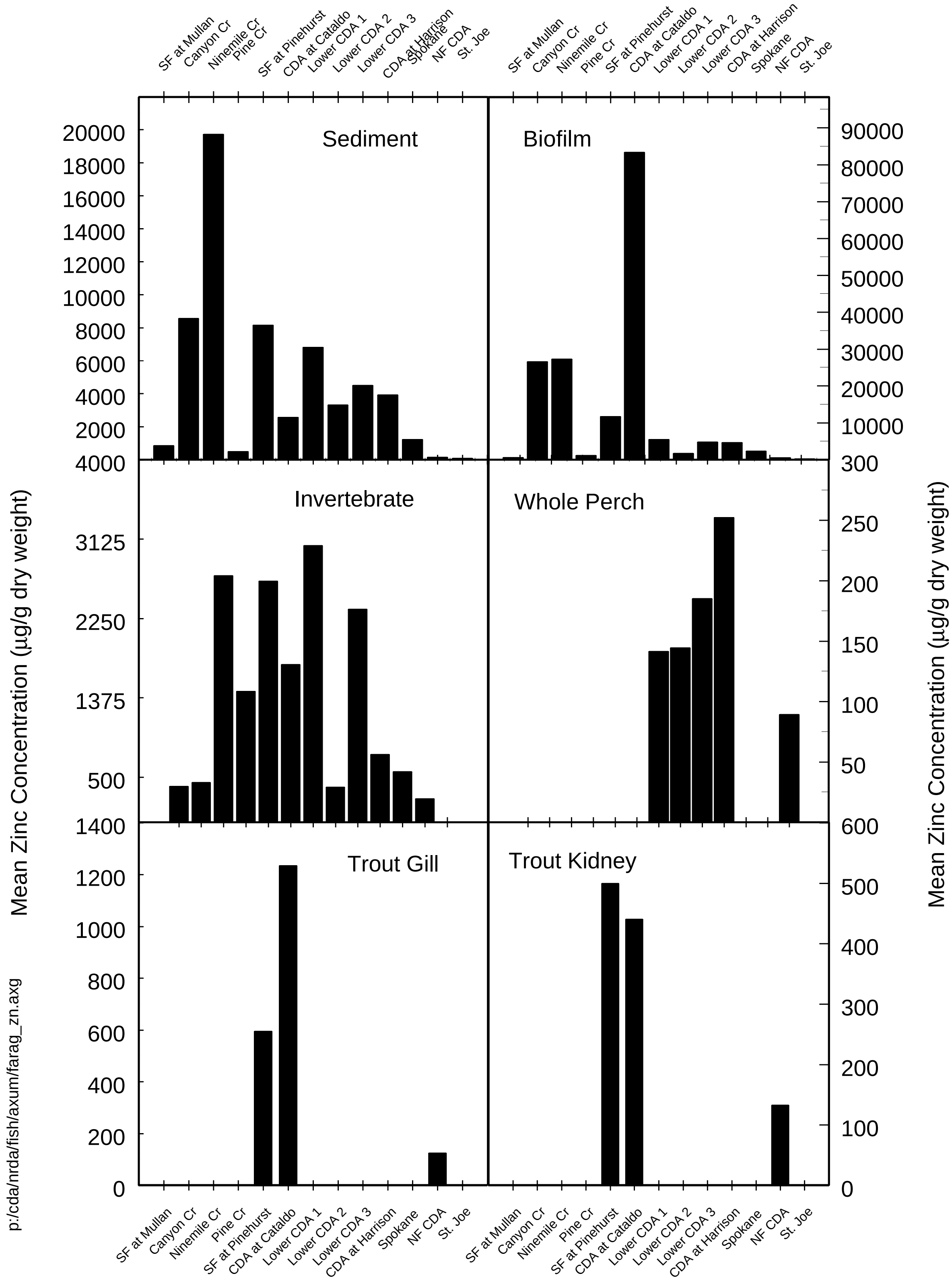

Figure 7-14a. Concentrations of zinc in sediments, biofilm, benthic macroinvertebrates, and fish.
Source: Farag et al., 1998a.

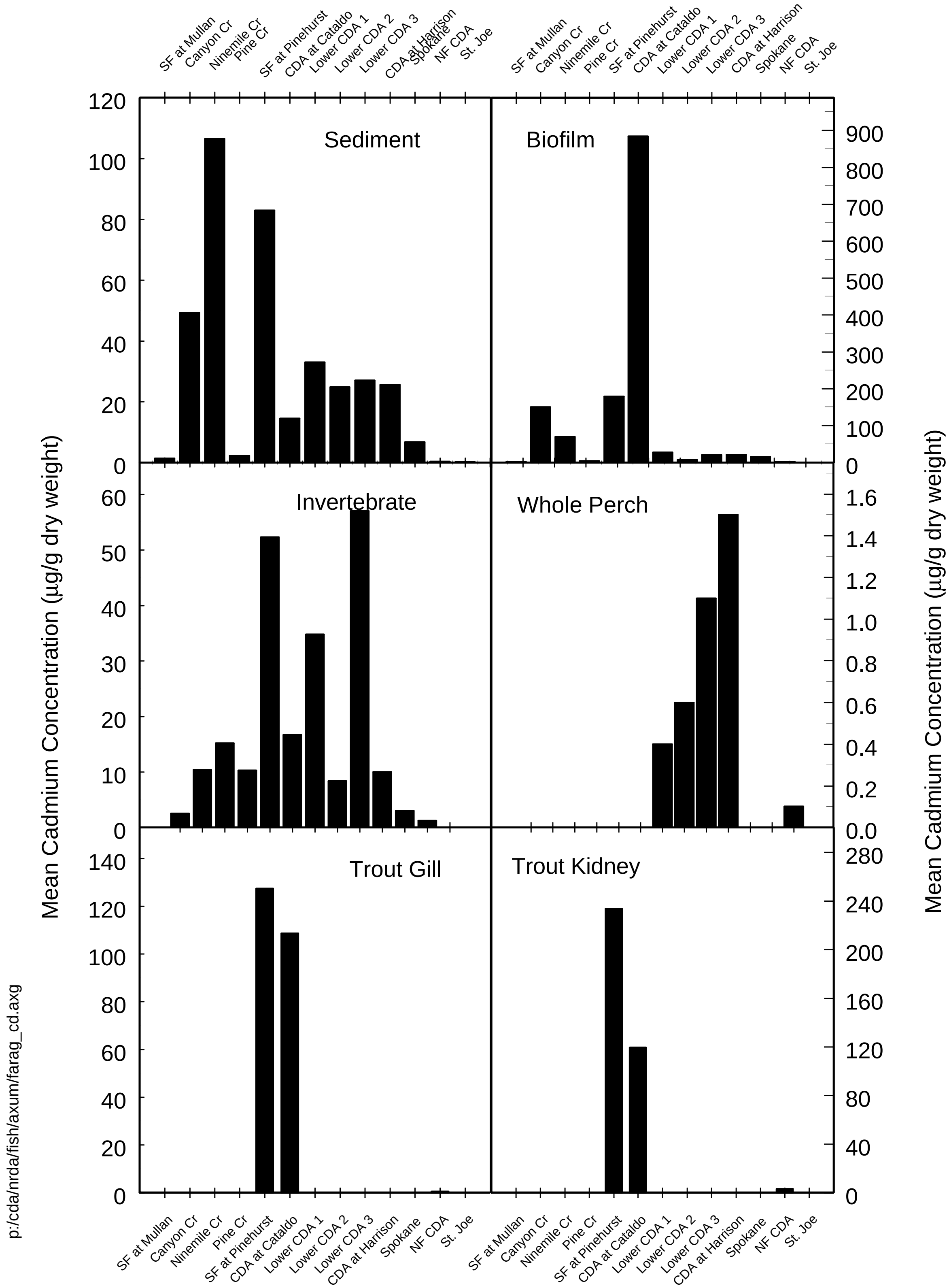

Figure 7-14b. Concentrations of cadmium in sediments, biofilm, benthic macroinvertebrates, and fish.
Source: Farag et al., 1998a.

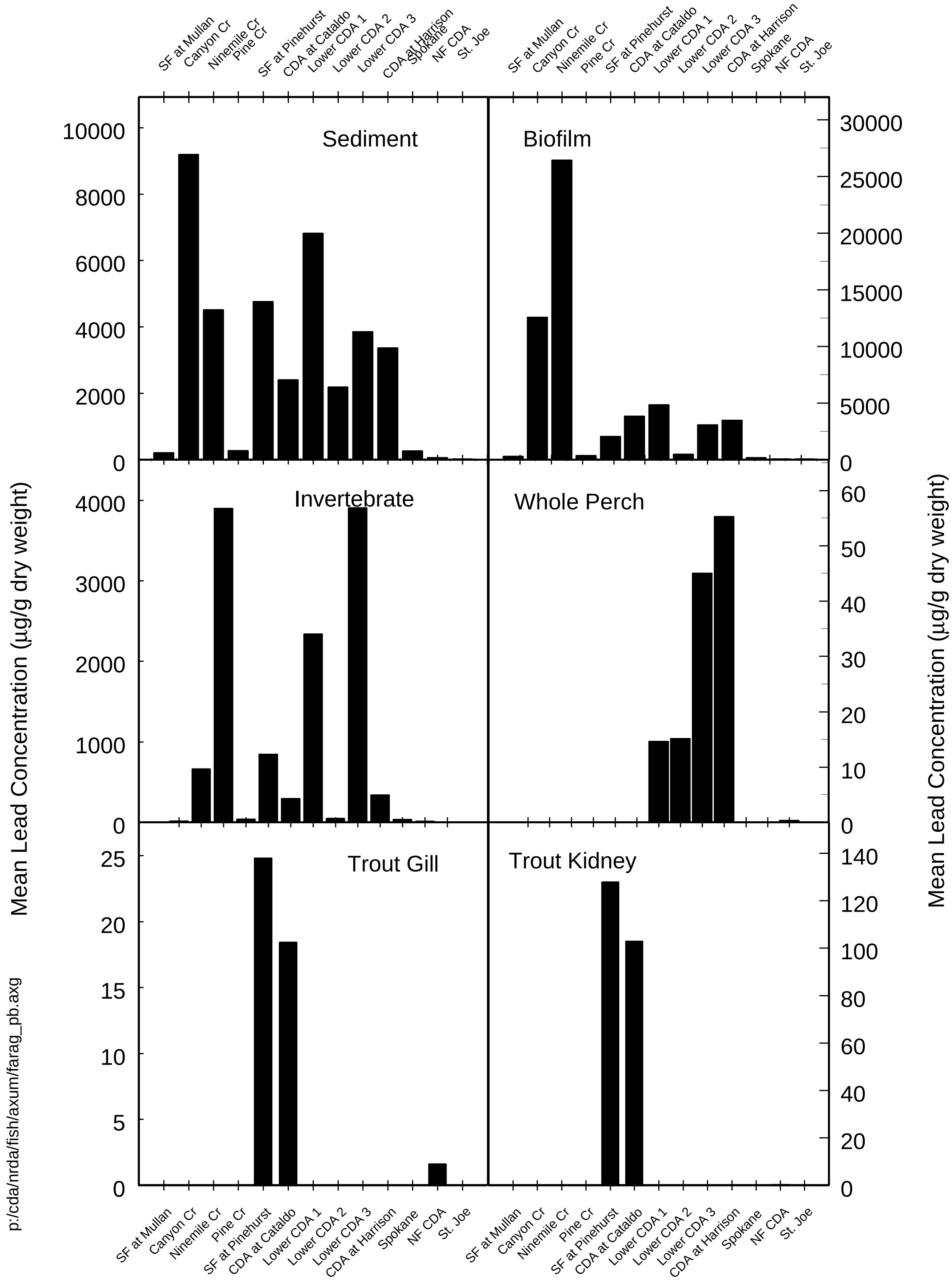

Figure 7-14c. Concentrations of lead in sediments, biofilm, benthic macroinvertebrates, and fish.
Source: Farag et al., 1998a.

Accumulation of Metals in the Food Web (Woodward et al., 1997b)

In a study performed during the summer of 1996 at each of the paired sites on the South Fork Coeur d'Alene and St. Regis rivers described in Section 7.5.1,[2] up to 10 resident trout were collected, sacrificed, and weighed, and tissue samples (gill, liver, and intestine) were collected for metals and metallothionein[3] analysis (Woodward et al., 1997b). Water, sediment, biofilm, and invertebrates also were collected for metal analysis.

As noted previously (Section 7.6.1), water samples were collected in conjunction with *in situ* bioassay testing. Water samples were analyzed for total (unfiltered) and dissolved (0.45 µm filtered) arsenic, cadmium, copper, lead, and zinc. Concentrations of dissolved arsenic, cadmium, lead, and zinc were elevated in the three test sites downstream of Canyon Creek (0, 8, and 16) relative to the paired reference sites. At South Fork Coeur d'Alene River site 24, zinc and cadmium also were somewhat elevated.

Four riffle habitats at each of the 10 sites were sampled for sediment, biofilm, and benthic macroinvertebrates. Sediments were collected from depositional areas with plastic scoops. Biofilm was collected by scraping rocks. Benthic macroinvertebrates were collected by disturbing the substrate in a 6 m^2 section of the riffle and collecting the organisms in a 3 mm mesh net. These samples were acid digested and analyzed for arsenic, cadmium, copper, mercury, lead, and zinc. Concentrations of cadmium, copper, lead, and zinc in biofilm were significantly greater at four South Fork Coeur d'Alene River test sites (0, 8, 16, and 24) relative to the paired St. Regis River reference sites (Figure 7-15a, b, and c). Concentrations of cadmium, copper, lead and zinc in benthic macroinvertebrates were significantly greater in the three downstream South Fork Coeur d'Alene River sites (0, 8, and 16) than in the paired St. Regis River reference sites (Figure 7-15a, b, and c). Cadmium was also elevated in benthic macroinvertebrates at South Fork Coeur d'Alene River site 24. South Fork Coeur d'Alene River site 0 had elevated concentrations of cadmium, copper, lead, and zinc in sediments, site 8 had elevated concentrations of copper and lead, and sites 16 and 24 had elevated concentrations of lead and zinc in sediments.

Gills, intestines, and livers removed from 5 to 12 fish from each of the 10 study sites were analyzed for metallothionein. Metallothionein was statistically significantly elevated in gills, liver, and intestine samples of the three downstream test sites (0, 8, and 16) relative to the paired reference sites (Figure 7-16). These data provide additional evidence of metal exposure at the biological level at the test locations.

---

2. Study sites included five test locations on the South Fork Coeur d'Alene River (0, 8, 16, 24, 32 miles upstream from the confluence with the mainstem Coeur d'Alene River) and five reference locations on the St. Regis River (0, 8, 16, 24, 32 miles upstream from the Clark Fork River).

3. Metallothionein is a metal-binding protein that is induced in response to exposure to various metals, including cadmium and zinc. Metallothionein induction has been associated with reduced growth in trout (e.g., Dixon and Sprague, 1981; Marr et al., 1995).

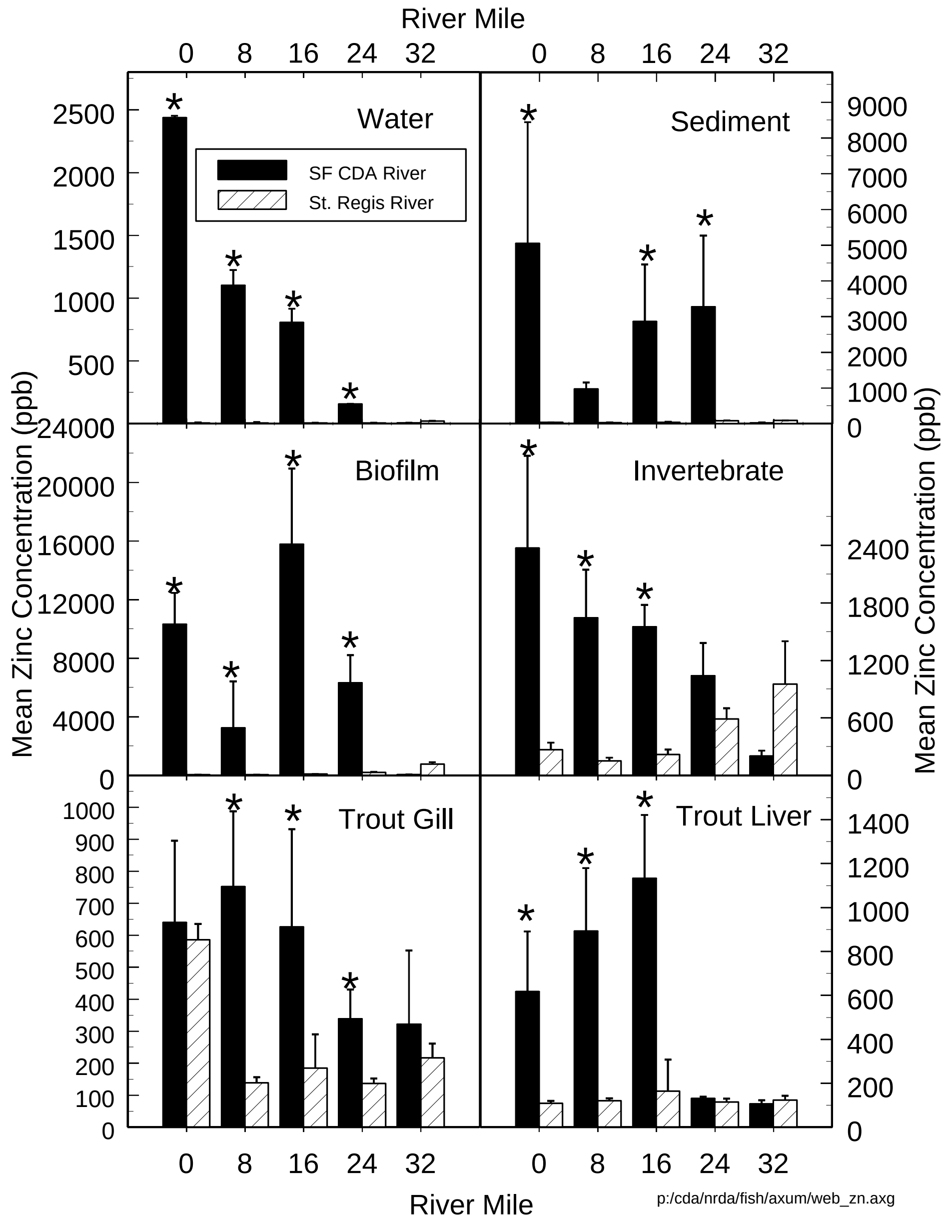

Figure 7-15a. Mean concentrations (standard deviation) of zinc in the South Fork Coeur d'Alene River food web. An asterisk indicates that concentrations are significantly greater than in the paired reference site. Source: Woodward et al., 1997b.

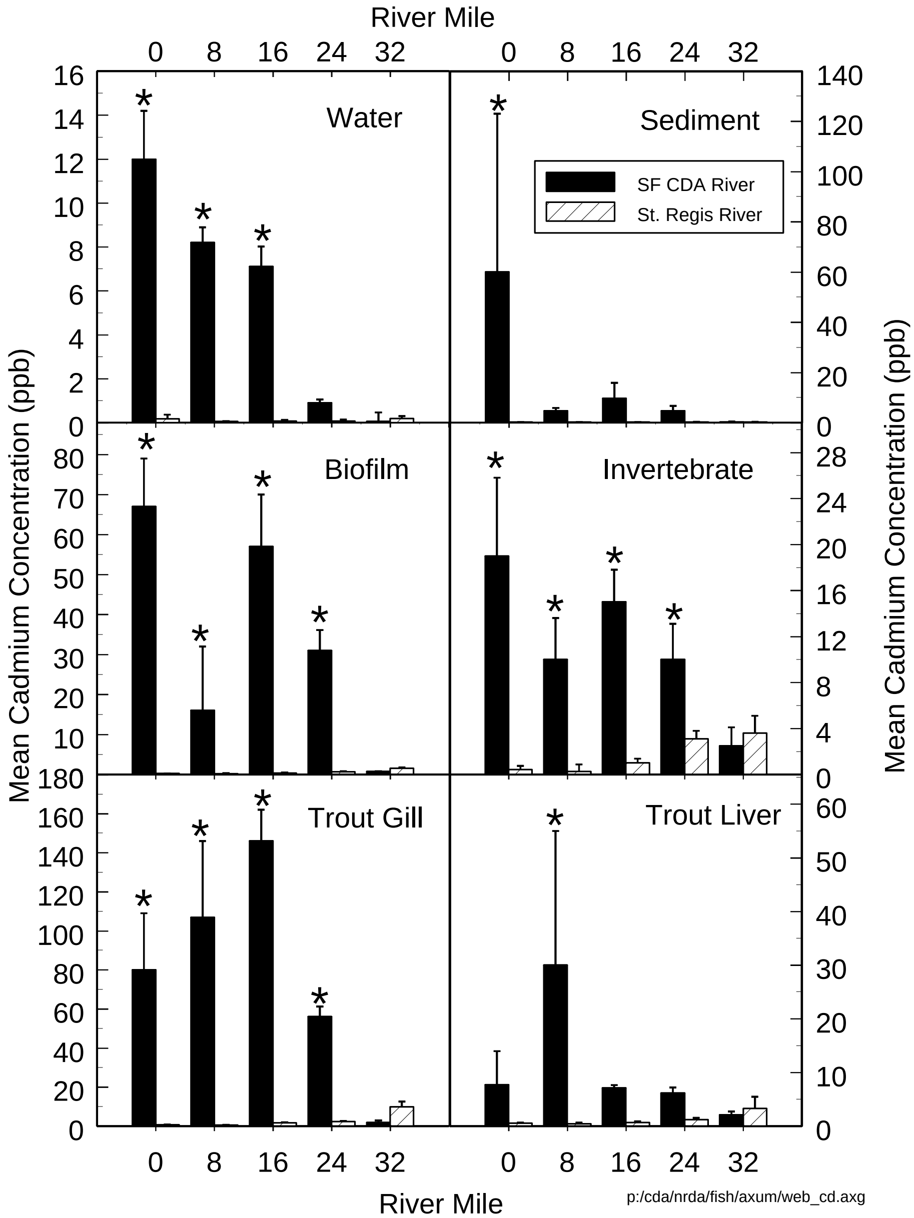

Figure 7-15b. Mean concentrations (standard deviation) of cadmium in the South Fork Coeur d'Alene River food web. An asterisk indicates that concentrations are significantly greater than in the paired reference site. Source: Woodward et al., 1997b.

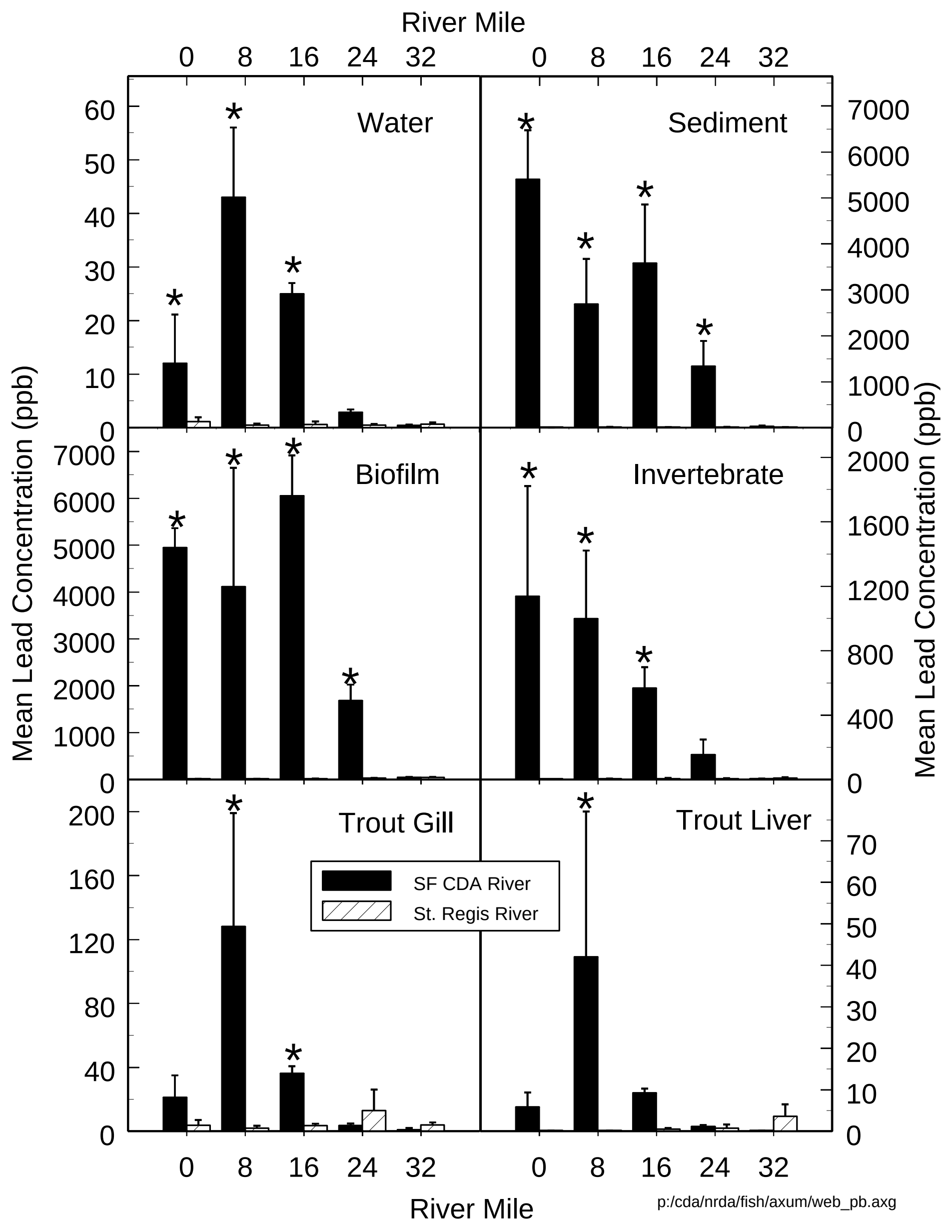

Figure 7-15c. Mean concentrations (standard deviation) of lead in the South Fork Coeur d'Alene River food web. An asterisk indicates that concentrations are significantly greater than in the paired reference site.
Source: Woodward et al., 1997b.

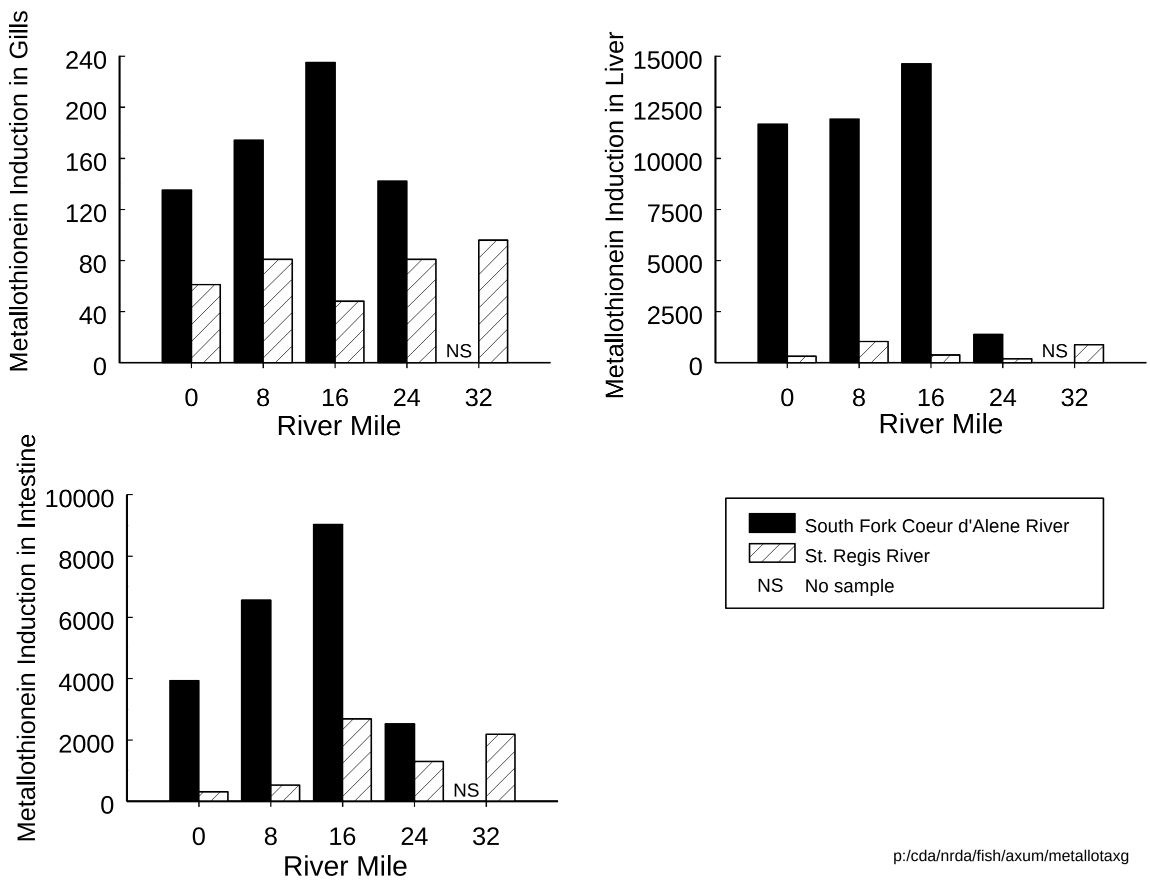

Figure 7-16. Metallothionein induction in fish tissues.
Source: Woodward et al., 1997b.

Dietary Effects Study (Farag et al., 1999)

A study was conducted to determine the chronic effects of trace metals in water and food on survival, growth, and physiological functions of cutthroat trout (Farag et al., 1999).

The dietary exposure pathway was assessed for chronic toxicity effects by feeding early lifestage hatchery cutthroat trout with metal-contaminated benthic invertebrates collected from the South Fork Coeur d'Alene River, the mainstem Coeur d'Alene River, and the North Fork Coeur d'Alene River (control diet), as well as a commercial trout diet (Biodiet). Invertebrate samples were frozen, pasteurized, and supplemented with vitamins and minerals. The field-collected diets had generally similar, but not perfectly matched, levels of protein (42.7-54.4% wet weight), fat (5.6-9.9% wet weight), moisture (7-9% wet weight), and ash (10.5-13.3% wet weight). The diets differed somewhat in carbohydrates (18.2-29.4% wet weight) and nutritional content (North Fork diet had 320 kcal/100g, the South Fork diet had 267 kcal/100g, and the mainstem diet had 272 kcal/100g). Fish were overfed by 25% (at 6.25% body weight /day) to ensure that they were receiving an adequate quantity of food.

Fish were exposed to two types of water in a flow-through testing system and four types of dietary treatments (Table 7-12). Each treatment was replicated four times. Cutthroat trout fry were exposed from start of feeding until 90 days after hatching to either an aqueous mixture of cadmium, lead, and zinc, where each metal was present at four times the concentration of water quality criteria established by the U.S. EPA (designated as 4X, Table 7-12), or water with no metals added (0X).

Table 7-12
Measured Metals Exposure in Diet and Test Water

	Mean Concentration in Diet ± Standard Error of the Mean (µg/g dry weight)				Test Water Dissolved Concentration ± Standard Deviation (µg/L)	
Metal	**Biodiet**	**North Fork CdA River**	**SF CdA River near Pinehurst**	**Mainstem CdA River near Cataldo**	**0X**	**4X**
Arsenic	3.5 ± 0.2	2.6 ± 0.2	50.8 ± 3.2	13.5 ± 1.0	—	—
Cadmium	0.21 ± 0.01	0.97 ± 0.01	29.9 ± 0.27	29.1 ± 0.43	0.05 ± 0.03	2.18 ± 0.12
Copper	9.9 ± 0.5	32.9 ± 0.8	61.5 ± 1.3	43.8 ± 1.9	—	—
Lead	0.20 ± 0.01	7.37 ± 0.26	791.67 ± 18.19	451.67 ± 5.17	0.55 ± 0.40	3.63 ± 0.71
Mercury	0.17 ± 0.02	0.04 ± 0.01	0.51 ± 0.01	0.41 ± 0.01	—	—
Zinc	135 ± 3	384 ± 9	2,336 ± 35	2,119 ± 41	12 ± 3	218 ± 10

Source: Farag et al., 1999.

Fish were weighed and tissue metals analyzed at days 19, 44, and 90 (test termination). Mortality observations were performed daily, behavior (feeding activity) was monitored weekly by video, and fish health measurements (external necropsy, metallothionein analysis) were performed on survivors from each treatment at test termination.

Diet type, but not water exposure (i.e., 0X versus 4X), had a significant effect on survival and growth after 90 days of exposure. Fish survival was reduced (68.2% survival) with the mainstem Coeur d'Alene River diet, but not with the South Fork Coeur d'Alene River diet (97.7% survival) (Table 7-13). Similarly, growth relative to the North Fork reference list was reduced for the mainstem Coeur d'Alene River diet (mean weight = 163 g), but not the South Fork Coeur d'Alene River diet (mean weight = 570 g) (Table 7-13).

Table 7-13
Tissue Concentrations, Survival, and Growth in Cutthroat Trout at Test Termination (mean ± standard error of the mean)

Diet	Tissue Metal Concentrations (µg/g dry weight)			Survival (%)	Weight (g)
	Cd	Pb	Zn		
Biodiet	0.92 ± 0.35	2.3 ± 0.8	130 ± 9	98.0 ± 0.5	1,294 ± 20
North Fork CdA River	1.16 ± 0.40	3.6 ± 0.9	190 ± 12	97.9 ± 0.4	587 ± 13
South Fork CdA River	4.06 ± 0.52	44.0 ± 3.4	417 ± 26[a]	97.7 ± 0.6	570 ± 23
Mainstem CdA River	6.93 ± 1.10	60.1 ± 5.6	621 ± 54[a]	68.2 ± 2.6[a]	163 ± 6[a]

a. Significantly different from North Fork at $p \leq 0.05$. Biodiet was not included in statistical analyses.

Source: Farag et al., 1999.

Diet also affected feeding behavior, independent of water concentration (Farag et al., 1999). The South Fork Coeur d'Alene River diet caused 18-40% fewer feeding strikes/minute than the North Fork on all of nine observation dates (Farag et al., 1999). The mainstem Coeur d'Alene River diet produced 38-60% fewer feeding strikes on all nine observation dates (Farag et al., 1999).

Fish tissue concentrations (whole fish) of cadmium, lead, and zinc at test termination were related to diet type, with concentrations in mainstem Coeur d'Alene River > South Fork Coeur d'Alene River > North Fork Coeur d'Alene River, for all three metals (Table 7-13). This pattern is interesting because metal concentrations in the invertebrate diets were greater in the South Fork Coeur d'Alene River than in the mainstem Coeur d'Alene River diet, indicating that the metals in the mainstem Coeur d'Alene River invertebrate diets were more bioavailable to fish than the metals in the South Fork Coeur d'Alene River invertebrate diets.[4]

Consumption of both contaminated diets caused an increase in metallothionein in trout livers (Table 7-14), indicating physiological exposure to metals. Histological effects were most pronounced in fish fed the Cataldo diet, but were also observed in fish fed the South Fork diet, as well as in fish fed the North Fork (control) diet in the presence of 4X metals concentrations (Table 7-14). No histological effects were observed in fish fed the control diet and exposed to 0X (no metals) in water.

Table 7-14
Physiological/Histological Measurements in Cutthroat Trout Fed Invertebrate Diets from North Fork (NF) Coeur d'Alene River, South Fork Coeur d'Alene River near Pinehurst (SF), or the Mainstem Coeur d'Alene River near Cataldo (CT)

Water	Diet	Hepatic Metallothionein (µg/g)	Vacuolization of Glial Cells	Degeneration of Pyloric Caeca	Hyperplasia of Kidney Hematopoietic Cells	Macrophage Accumulation
0X	NF	46 ± 8	0 of 8	0 of 8	0 of 8	0 of 8
	SF	99 ± 16	0 of 8	5 of 8 (+, ++)	4 of 8 (+, +++)	3 of 8 (+, ++)
	CT	200 (n = 1)	2 of 8 (+,++)	8 of 8 (+, +++)	0 of 8	4 of 8 (+, ++)
4X	NF	86 ± 7	3 of 8 (++, +++)	0 of 8	2 of 8 (+, ++)	0 of 8
	SF	299 ± 0	3 of 8 (++, +++)	1 of 8 (+, ++)	3 of 8 (+, ++)	0 of 8
	CT	221 (n = 1)	6 of 8 (++, +++)	6 of 8 (+, +++)	0 of 8	3 of 8 (+, ++)

+ denotes minimal effect.
++ denotes moderate effect.
+++ denotes severe effect.

Source: Farag et al., 1999.

4. To investigate the bioavailability of metals, an additional study was conducted to determine if bioavailability could be biochemically determined. The objective of this study was to determine if the accumulation of metals in fish was related to variations in metal-organic complexes in the invertebrate diets of the fish (Farag et al., 1998b). This biochemical method did not prove to be effective for determining the bioavailability of metals.

Vacuolization of glial cells (i.e., formation of vacuoles, or spaces, within the cells that surround and insulate neurons in the fish brain) was observed in mainstem Coeur d'Alene River 0X and 4X treatments, as well as the North Fork and South Fork Coeur d'Alene River 4X treatments. Farag et al. (1999) note that this histological response could compromise neurological integrity of affected fish.

Degeneration of mucosal cells in the pyloric caeca (a primary digestive organ in fish) was observed for both contaminated diets, but was not affected by water concentrations of metals. These digestive effects were most pronounced in the mainstem Coeur d'Alene River diet (Table 7-14).

Effects were also observed in trout kidneys: both hyperplasia of hematopoietic cells (degenerative swelling of kidney cells that are involved in the production of blood cells) and accumulation of macrophages (build up of cells involved in immune responses) was noted (Table 7-14). These responses were concluded to be indicative of chronic stress in the exposed fish (Farag et al., 1999).

Overall, the results of the dietary effects studies indicate that metals in site invertebrates are bioavailable, and that consumption of contaminated invertebrates represents both an exposure pathway to fish and a cause of adverse physiological effects, including death, reduced growth, and sublethal, histopathological effects on digestive, neurological, and immune systems.

7.6.4 Summary of Results of Trustee Toxicity Studies

The toxicological information provided above confirms the following:

- Waters from Canyon Creek, the South Fork Coeur d'Alene River downstream of Canyon Creek, and the Coeur d'Alene River are acutely lethal to trout, as demonstrated by *in situ* bioassays.

- Concentrations of hazardous metals in water downstream of mining releases, particularly cadmium and zinc, are substantially greater than concentrations found to be acutely lethal to fish in controlled laboratory studies.

- Salmonids actively avoid zinc at concentrations typical of those in exposed areas of the South Fork Coeur d'Alene River, the Coeur d'Alene River, and Lake Coeur d'Alene. Avoidance was confirmed both in laboratory and field studies.

- Trout suffer lethal and sublethal effects from consumption of contaminated invertebrates from the Coeur d'Alene River basin.

All of the above information clearly points to the presence of both lethal and sublethal toxicological injuries to fish as a result of exposure to elevated metal concentrations in surface waters downstream of mining influences. In the next section of this report, we discuss the results of population studies performed in the field to evaluate whether information on fish population density and diversity is consistent with the presumptive toxic effects of metals in the Coeur d'Alene system.

7.7 TRUSTEE POPULATION STUDIES

In addition to the toxicity studies described in Sections 7.5 and 7.6, the Trustees undertook a number of studies to characterize fish populations and habitat conditions in the Coeur d'Alene River basin. These studies, identified in Table 7-7, supplement the historical data previously discussed (Section 7.2) and reflect more current conditions in the basin.

7.7.1 Use of Fish Population Data

A considerable amount of data on fish communities and habitat features was collected as part of the population evaluation studies (R2 Resource Consultants, 1995a, 1996, 1997; Reiser et al., 1999; Stratus Consulting; 1999b). The data characterize aquatic biological resources in the Coeur d'Alene River basin. The data were analyzed to evaluate a specific question related to injury determination: Are spatial patterns of fish population density and diversity consistent with the conclusion that fish are injured as a result of exposure to metals?

To address this question, data characterizing fish populations in three areas substantially affected by metal contamination are presented:

- Canyon Creek downstream of mining influences near Burke
- Ninemile Creek downstream of mining influences
- the South Fork Coeur d'Alene River downstream of its confluence with Canyon Creek.[5]

Fish populations in these affected stream reaches were compared to fish populations in reference (control) areas. The analysis included two types of comparisons:

- comparison to reference sites within the same stream, but upstream of extensive mining influences (upstream-downstream comparison)

5. Because of potential limitations associated with quantitative fish sampling in large water bodies, sufficient fish population data were not collected to support similar analyses of population conditions for the mainstem Coeur d'Alene River downstream of Cataldo or for Coeur d'Alene Lake.

- comparison to reference streams that are similar to the affected stream reach in terms of basic hydrological and ecological conditions, but without mining influences (test-reference comparisons).

For Canyon Creek, populations downstream of mining influences were compared to populations upstream of Burke in areas unaffected by mining. In addition, for both Canyon Creek and for Ninemile Creek, for which no upstream comparison data were available, data were compared to a group of tributary streams to the South Fork Coeur d'Alene and the mainstem Coeur d'Alene rivers unaffected by major mining influences. Tributary streams that were sampled for fish populations and that are believed to be upstream of substantial mining and milling operations (or in drainages in which mining is not known to have occurred) include lower Latour Creek, upper Big Creek, lower and upper Placer Creek (no producing underground mines or mills are known to have operated on Placer Creek, but the name suggests historical placer mining), upper Canyon Creek, lower and upper Little North Fork Coeur d'Alene River, lower Steamboat Creek, upper Prichard Creek, and lower Shoshone Creek (Figure 7-17). Sampling in these tributaries characterized the range of fish population densities that exist in the Coeur d'Alene River basin in tributary streams unaffected by mining.

For the South Fork Coeur d'Alene River, fish populations downstream of Canyon Creek were compared to conditions in the South Fork Coeur d'Alene River upstream of the Canyon Creek confluence, thus providing a direct upstream-downstream comparison. In addition, South Fork Coeur d'Alene River sites sampled in 1996 (including locations up- and downstream of Canyon Creek) were compared to a set of paired reference locations on the St. Regis River. Like the South Fork Coeur d'Alene River, the St. Regis River originates on Lookout Pass along the Idaho-Montana border. However, the St. Regis River flows east to its confluence with the Clark Fork River (Figure 7-17). Much of the St. Regis River has been channelized as a result of railroad and Interstate Highway 90 construction (Reiser et al., 1999; R2 Resource Consultants, 1997).

Selection of the St. Regis River as a reference stream involved review of USGS topographic maps, aerial photographs, and USGS discharge records (Reiser et al., 1999). Physical characteristics of each watershed (South Fork Coeur d'Alene River, St. Regis River) were assessed, including elevation, drainage area, drainage density (tributary length/area), and precipitation. Other parameters examined included stream discharge, sinuosity, gradient, percent channelization, number of tributaries, and number of municipalities. Habitat-level parameters examined included pool, riffle, and run distribution, depth, width, and substrate composition. Because of the similarity between the above parameters for the two streams (Tables 7-15 to 7-17), a paired-site approach was selected. Study sites were distributed systematically along both rivers, with approximate placement at 0, 8, 16, 24, and 32 river miles above the confluences with the North Fork Coeur d'Alene River and the Clark Fork River (Reiser et al., 1999) (Figure 7-17).

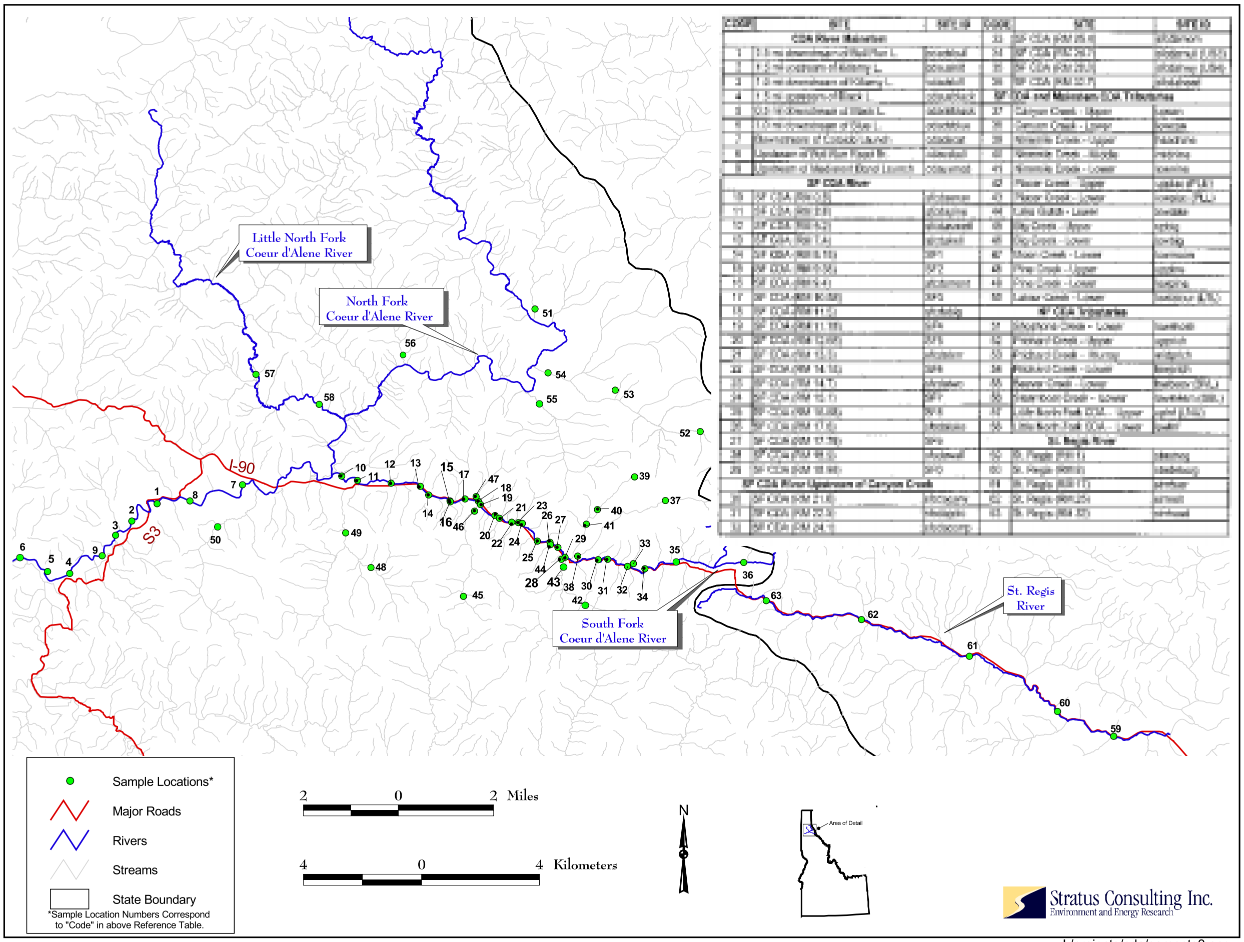

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Figure 7-17. Fish population monitoring locations.

Several types of population data are presented: multiple-pass depletion (MPD) electrofishing, single-pass ("qualitative") electrofishing, and mark-recapture sampling. MPD sampling involves repeated passes through a stream segment, with fish density (e.g., number of fish/unit area) quantified using a standard numerical approach (e.g., Leslie Method; Ricker, 1975). Because multiple passes often are required to estimate accurately the number of fish present, the single-pass method tends to underestimate actual fish populations. However, single-pass electrofishing data are comparable to the results obtained from the first pass in MPD sampling. When comparing single-pass and MPD data, only first pass results are presented from the MPD data.

Table 7-15
Watershed Parameters of the St. Regis River, Montana, and the South Fork Coeur d'Alene River, Idaho

Parameter	St. Regis River	South Fork CdA River
Elevation (m)	677-1,829	792-1,692
Drainage area (km^2)	780	788
Mean annual discharge (m^3/s)	47	54
Minimum annual discharge (m^3/s)	6.6	3.8
Stream length (km)	57.4	62.7
Stream sinuosity	1.1	1.1
Gradient		
lower 48 km	0.87	0.64
lower 32 km	0.45	0.41
Channelization (%)	39	77
Number of tributaries	81	94
Number of municipalities	4	7
Source: Reiser et al., 1999.		

Mark recapture methods involve marking fish (e.g., by fin clip or tag), releasing the fish back to the stream, and resampling the same area after some time (e.g., 10-14 days). Population size is calculated based on recovery rates of the marked fish (e.g., Chapman, 1951).

Population data are presented as densities (number of fish/m^2) of all fish (i.e., all species combined) and all trout (all trout species combined). Data on fish species diversity also are presented.

Table 7-16
Paired Comparisons of Channel (elevation, stream order, gradient) and Habitat (habitat types and frequency, mean habitat depths, width-depth ratios, and substrate composition) between Five Sites Selected in the South Fork Coeur d'Alene River (SFCdA), Idaho, with Five Reference Sites Selected in the St. Regis River (STR), Montana

Parameter	STR 0	SFCdA 0	STR 8	SFCdA 8	STR 16	SFCdA 16	STR 24	SFCdA 24	STR 32	SFCdA 32
Elevation (m)	829	676	872	715	962	765	1,053	951	1,107	1,075
Gradient (%)	0.4	0.3	0.5	0.5	0.6	0.6	1.1	1.4	0.7	1.5
Stream Order	5	5	5	5	5	5	4	4	3/2	3/2
Percent Pool	4	0	0	4	10	2	12	5	0	4
Percent Riffle	55	45	62	29	48	64	48	75	43	45
Percent Run	41	55	38	37	42	34	42	20	57	51
Pool-Riffle Ratio	0.1	0.0	0.0	0.1	0.2	0.0	0.2	0.1	0.0	0.1
Habitat Unit Frequency	14	32	20	28	37	20	40	48	42	69
Mean Pool Depth (m)	0.6	-	-	2.0	0.5	0.9	0.6	0.4	-	0.4
Mean Riffle Depth (m)	0.3	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.1	0.2
Mean Run Depth (m)	0.4	0.5	0.4	0.3	0.4	0.4	0.3	0.3	0.2	0.2
Mean Depth (m)	0.4	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.2	0.2
Mean Wetted Width (m)	26	14	15	17	10	13	11	6	7	5
Width to Depth Ratio	72	45	38	40	34	35	40	20	42	21
Percent Boulder	10	1	33	3	7	15	10	32	8	16
Percent Cobble-Rubble	44	44	48	48	55	51	64	44	60	39
Percent Coarse Gravel	29	39	14	37	30	26	14	17	25	25
Percent Fine Gravel	10	12	3	5	5	8	3	7	4	12
Percent Sand	2	1	1	3	1	0	3	0	3	2
Percent Silt	4	2	1	0	1	0	6	0	1	5
Percent Channelization	35	49	55	56	25	71	57	80	25	6

Source: Reiser et al., 1999.

Table 7-17
Paired Comparisons of Minimum, Mean, and Maximum Average Monthly Water Temperatures in 1996 between Five Sites in the South Fork Coeur d'Alene River (SFCdA) and Five Reference Sites in the St. Regis River (STR)

Parameter	STR 0	SFCdA 0	STR 8	SFCdA 8	STR 16	SFCdA 16	STR 24	SFCdA 24	STR 32	SFCdA 32
July										
minimum (C)	10	10	10	10	9	9	8	8	8	8
mean (C)	13	16	13	16	12	15	12	13	11	11
maximum (C)	18	21	18	22	16	20	18	17	15	14
August										
minimum (C)	9	11	9	9	8	10	7	9	7	8
mean (C)	13	15	13	15	11	14	12	14	10	11
maximum (C)	18	21	18	22	16	20	16	21	13	14
September										
minimum (C)	8	10	8	8	8	8	7	9	6	7
mean (C)	11	13	11	12	10	13	10	13	9	10
maximum (C)	15	18	15	16	13	18	14	20	15	13

Source: Reiser et al., 1999.

7.7.2 Results of Fish Population Sampling

Canyon and Ninemile Creeks

Sampling was performed on lower Canyon Creek (approximately 0.5 miles upstream from the South Fork Coeur d'Alene River confluence) in August 1994 (MPD), June 1995 (trapping), and July 1995 (MPD) (R2 Resource Consultants, 1995a, 1996). No fish of any species were collected at the lower Canyon Creek site during the electrofishing surveys; two fish were collected during trapping (Table 7-18). At the upper Canyon Creek location (approximately 8 miles upstream from the South Fork Coeur d'Alene River confluence), MPD sampling was performed in August 1994 and July 1995. In 1994, 38 trout and sculpin (<25 total) were observed. In 1995, 22 trout were found (Table 7-18). Trout density estimates based on the MPD sampling were 0 fish/m^2 downstream of mining influences, and 0.08 and 0.03 trout/m^2 upstream.

Table 7-18
Results of Fish Population Monitoring in Canyon Creek Conducted by R2 Resource Consultants in 1994-1995

Location	Date	Method	Number of Species Captured	Number of Trout Captured	Estimated Trout Population Density (fish/m^2)
Upper Canyon Creek (mile 8)	8/2/94	MPD	2	38	0.08
	7/12/95	MPD	2	22	0.03
Lower Canyon Creek (mile 0.5)	8/1/94	MPD	0	0	0
	6/9/95-6/18/95	Trapping	2	2	—
	7/12/95	MPD	0	0	0

Source: R2 Resource Consultants, 1995a, 1996.

Sampling was performed in 1994 and 1995 at three locations in Ninemile Creek downstream of mining influences (approximately miles 2.5, 4, and 8 from the confluence with the South Fork Coeur d'Alene River). No fish were captured at any of the locations during either year of sampling (Table 7-19).

Figures 7-18a and b present trout and total fish density estimates (from MPD sampling) calculated for the various unmined tributary sites. These data demonstrate that population densities in tributaries unaffected by mining releases contain substantially more fish than Ninemile and Canyon creeks, both of which are nearly devoid of fish life.

Table 7-19
Results of Fish Population Monitoring in Ninemile Creek
Conducted by R2 Resource Consultants in 1994-1995

Location	Date	Method	Number of Species Captured	Number of Trout Captured	Estimated Trout Population Density (fish/m^2)
Upper Ninemile Creek (mile 8)	8/1/94	MPD	0	0	0
	8/1/95	MPD	0	0	0
Middle Ninemile Creek (mile 0.4)	7/13/95	MPD	0	0	0
Lower Ninemile Creek (mile 2.5)	8/1/94	MPD	0	0	0
	7/13/95	MPD	0	0	0
Source: R2 Resource Consultants, 1995a, 1996.					

South Fork Coeur d'Alene River

Table 7-20 summarizes the results of fish population surveys performed in the South Fork Coeur d'Alene River by R2 Resource Consultants (1995a, 1996, 1997; Reiser et al., 1999) and Stratus Consulting (1999b), as well as surveys performed in 1996 by R2 Resource Consultants in the paired site locations in the St. Regis River (Woodward et al., 1997b). Results of fish population studies are presented as "total fish," "trout," "wild trout," and "all salmonids." Total populations were estimated based on all sizes of all fish species captured. "Total fish" estimated for 1994 does not include sculpin because sculpin presence was reported qualitatively that year (R2 Resource Consultants, 1995a). "Trout" populations were estimated based on all sizes of all species of trout and char captured. "Wild trout" populations were estimated based on all sizes of all species of trout and char (i.e., brook trout) captured, excluding rainbow trout that were designated as a hatchery fish in the field notes. "All salmonids" includes all trout, char, salmon, and whitefish, excluding young-of-the-year.

Trout population density in the South Fork Coeur d'Alene River downstream of Canyon Creek was generally low in all years of sampling (Table 7-20 and Figure 7-19a). Trout densities ranged from 0.001 to 0.068 trout/m^2. Sixteen of the 17 quantitative sampling events in the South Fork Coeur d'Alene River downstream of Canyon Creek yielded estimated trout populations of fewer than 0.050 trout/m^2, and 14 of the 17 surveys yielded trout densities of fewer than 0.025 trout/m^2 (Table 7-20). In contrast, in the South Fork Coeur d'Alene River upstream of Canyon Creek, estimated trout densities ranged from 0.034 to 0.204 trout/m^2, with 8 of 10 surveys yielding

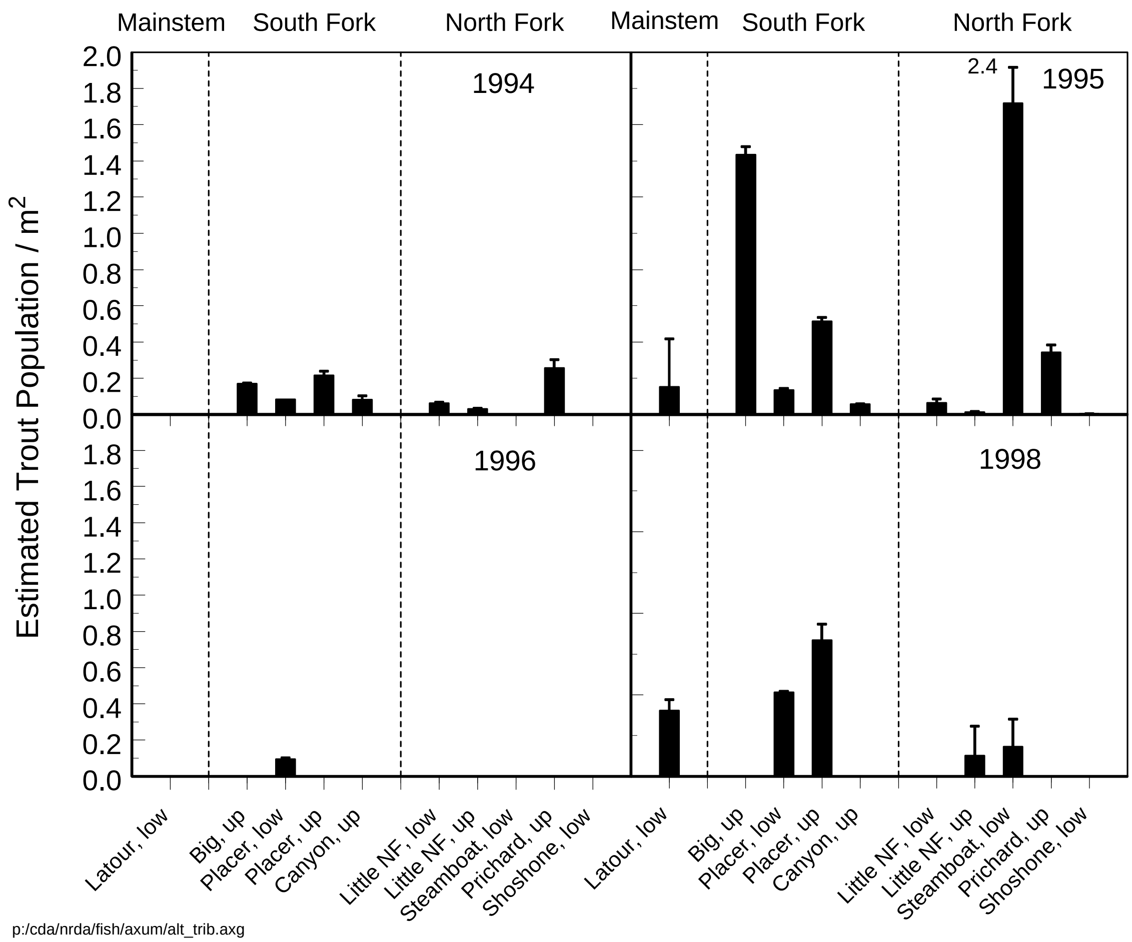

Figure 7-18a. Estimated trout populations from tributary surveys conducted by MPD between 1994 and 1998.
Note: No bar indicates site not sampled.
Sources: R2 Resource Consultants, 1995a, 1996c, 1997; Stratus Consulting, 1999a, 1999b.

density estimates of at least 0.07 trout/m^2 (Table 7-20). Thus, over four different sampling years, there was a pattern of higher trout population densities upstream of mining influences than downstream of mining influences (Canyon Creek) (Figure 7-19a). Total fish and wild trout population densities in the South Fork Coeur d'Alene River downstream of Canyon Creek also were low relative to upstream in all years of sampling (Table 7-20, Figure 7-19b). Again, there was a pattern of higher total fish and wild trout population densities upstream of mining influences.

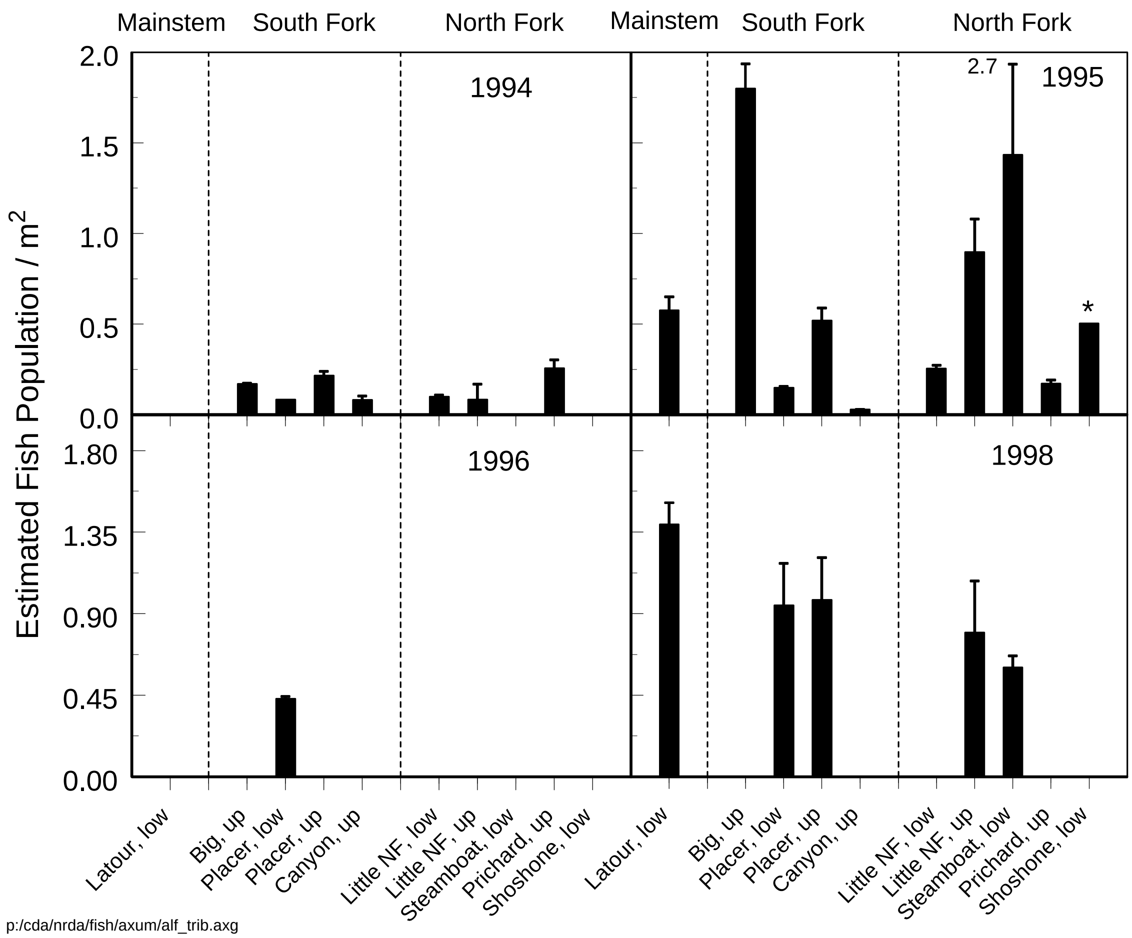

Figure 7-18b. Estimated fish populations from tributary surveys conducted by MPD between 1994 and 1998.
Note: 1994 estimates do not include sculpin. No bar indicates site not sampled.
Sources: R2 Resource Consultants, 1995a, 1996, 1997; Stratus Consulting, 1999a, 1999b.

A similar pattern is observed with the addition of qualitative data from the 1995 study. Figure 7-20 presents qualitative data collected on the South Fork Coeur d'Alene River along with data collected from the first electrofishing pass of the quantitative MPD sampling. Fewer than 0.01 trout/m^2 were captured at all locations downstream of Canyon Creek. Upstream of Canyon Creek, capture rates were several-fold higher, ranging from 0.02 to 0.06 trout/m^2. The mean trout capture rate downstream of Canyon Creek, 0.003 trout/m^2, was approximately 17 times lower than the corresponding trout capture rate at locations upstream of Canyon Creek (0.05 trout/m^2).

Table 7-20
Results of Fish Population Monitoring: South Fork Coeur d'Alene River[a]

Map Code[b]	Site	River Mile[c]	Date	Method[d]	Area Sampled (m^2)[e]	Number of Species Captured	Number of Fish Captured			Estimated Population Density[g] (#/m^2)		
							Trout	Sculpin	Other[f]	Trout	Total Fish	Wild Trout
SFCdA River Downstream of Canyon Creek												
10	SFCdA near Enaville	0.8	8/8/95	Qualitative	2,508	2	3	0	1	—	—	—
11	SFCdA near Pine Creek	2.8	7/30/94	MPD	1,033	3	10	0	17	0.010	0.027	0.008
			8/4/95	MPD	1,252	2	8	0	6	0.006	0.011	0.003
			8/6/96	Mark	7,726	3	5	0	1	0.004	—	0.004
			8/15/96	Recapture		6	15 (2)[h]	0	7			
12	SFCdA near Smelterville	5.2	8/8/95	Qualitative	976	2	1	0	1	—	—	—
13	SFCdA near Kellogg	7.4	8/8/95	Qualitative	2,230	3	6	0	1	—	—	—
			8/6/96	Mark	13,735	1	2	0	0	0.001	—	0.001
			8/15/96	Recapture		5	12 (1)[h]	0	9			
14		8.18	10/1/98	MPD	1,900	7	32	0	15	0.021	0.034	0.021
15	SFCdA near Montgomery Creek	9.38	10/2/98	MPD	1,190	6	17	0	9	0.015	0.026	0.015
16		9.4	8/8/95	Qualitative	1,533	3	6	0	1	—	—	—
17	SFCdA near Moon Creek	10.58	10/2/98	MPD	1,260	3	5	0	0	0.004	0.004	0.004
18	SFCdA near Big Creek	11.5	8/2/94	MPD	1,825	3	16	0	3	0.009	0.011	0.007
			8/7/95	Qualitative	1,394	2	4	0	0	—	—	—
19		11.78	10/2/98	MPD	1,290	4	8	0	0	0.008	0.008	0.008
20	SFCdA near Terror Gulch	12.98	10/5/98	MPD	1,660	3	14	0	0	0.009	0.009	0.009
21		13.3	8/1/95	MPD	1,536	3	27	0	0	0.068	0.068	0.004
22	SFCdA near Osburn	14.18	10/5/98	MPD	1,820	3	18	0	0	0.010	0.010	0.010
23	SFCdA near Twomile Creek	14.7	8/7/95	Qualitative	1,394	2	4	0	0	—	—	—
24		15.1	10/5/98	MPD	1,800	2	5	0	0	0.003	0.004	0.003
25	SFCdA near Argentine Creek	16.58	10/1/98	MPD	1,330	2	27	0	0	0.024	0.024	0.012

Table 7-20 (cont.)
Results of Fish Population Monitoring: South Fork Coeur d'Alene River[a]

Map Code[b]	Site	River Mile[c]	Date	Method[d]	Area Sampled (m^2)[e]	Number of Species Captured	Number of Fish Captured			Estimated Population Density[g] (#/m^2)		
							Trout	Sculpin	Other[f]	Trout	Total Fish	Wild Trout
26	SFCdA near Lake Gulch	17.6	8/7/95	Qualitative	1,672	3	5	0	0	—	—	—
			8/8/96	MPD	1,170	1	3	0	0	0.003	0.003	0.003
27		17.78	10/6/98	MPD	1,450	2	56	0	0	0.049	0.049	0.039
28	SFCdA near Wallace	18.5	8/6/95	Qualitative	1,394	2	7	0	0	—	—	—
29		18.98	10/6/98	MPD	1,220	2	50	0	0	0.045	0.045	0.036
SFCdA River Upstream of Canyon Creek												
30	SFCdA near Canyon Creek	21.6	4/20/95-5/10/95	Trapping	—	2	6	0	0	—	—	—
			8/6/95	Qualitative	836	2	35	0	0	—	—	—
31	SFCdA near Golconda	22.5	7/26/94	MPD	548	2	27	0	0	0.172	0.172	0.044[i]
			7/31/95	MPD	475	4	48	0	0	0.111	0.111	0.068
32	SFCdA near Compressor District	24.1	8/6/95	Qualitative	446	2	28	0	0	—	—	—
			8/5/96	MPD	567	2	38	0	0	0.080	0.080	0.061
33	SFCdA near Morning District	25.4	8/6/95	Qualitative	557	3	28	117	0	—	—	—
34	SFCdA near Mullan	26.7	7/27/94	MPD	527	3	99	25-100	0	0.204	0.241	0.029
			8/6/95	Qualitative	557	4	11	127	0	—	—	—
			10/6/98	MPD	650	3	112	251	0	0.185	0.813	0.088
35	SFCdA near Highway Department	28.0	7/28/95	MPD	557	3	54	310	0	0.153	0.822	0.033
			10/7/98	MPD	653	3	46	385	0	0.071[h]	1.950	0.134
36	SFCdA near Headwaters	32.7	7/27/94	MPD	438	3	34	25-100	0	0.087	0.135	0.077
			7/27/95	MPD	420	3	29	372	0	0.081	1.494	0.077
			8/2/96	MPD	475	3	16	130	0	0.034	0.392	0.034

Table 7-20 (cont.)
Results of Fish Population Monitoring: South Fork Coeur d'Alene River[a]

Map Code[b]	Site	River Mile[c]	Date	Method[d]	Area Sampled (m^2)[e]	Number of Species Captured	Number of Fish Captured			Estimated Population Density[g] ($\#/m^2$)		
							Trout	Sculpin	Other[f]	Trout	Total Fish	Wild Trout
St. Regis River												
59	St. Regis near Twomile Creek	1	7/31/96	Mark	20,129	5	47	2	12	0.010	—	0.010
			8/14/96	Recapture		5	71 (16)[g]	8	8 (1)[g]			
60	St. Regis near DeBorgia	8	7/30/96	Mark	8,224	5	82	9	41	0.076	—	
			8/13/96	Recapture		6	98 (15)[g]	6	52 (14)[g]			0.062
61	St. Regis near Haugan	17	8/13/96	MPD	2,377	6	15	4	41	0.026	0.026	0.026
62	St. Regis near Saltese	25	8/12/96	MPD	1,032	5	10	74	6	0.010	0.120	0.010
63	St. Regis near Headwaters	32	8/8/96	MPD	640	3	18	351	0	0.028	0.805	0.028

a. Data and results originally presented in R2 Resource Consultants (1995a, 1996, 1997; Reiser et al. 1999) and Stratus Consulting (1999b). Data summarized in Stratus Consulting (1999a).
b. See Figure 7-1 for locations.
c. River mile = number of miles upstream from stream mouth. NR = river mile information not reported for this site.
d. MPD = multiple pass depletion electrofishing; 1994-1996 monitoring conducted by R2 Resource Consultants; 1998 monitoring conducted by Stratus Consulting.
e. Area sampled is the area reported for fish population sampling sites for 1994, 1995, and 1998. For 1996, pedestrian habitat survey areas are presented.
f. Other fish include bullhead, dace, bass, mountain whitefish, perch, pumpkinseed, squawfish, suckers, and tench.
g. Population estimates were calculated for MPD and mark/recapture data only. All fish estimates in 1994 do not include sculpin.
h. Subset of the fish captured that were previously marked.
i. Because of insufficient depletion, the estimated population is a minimum estimate and represents the actual number of fish captured.

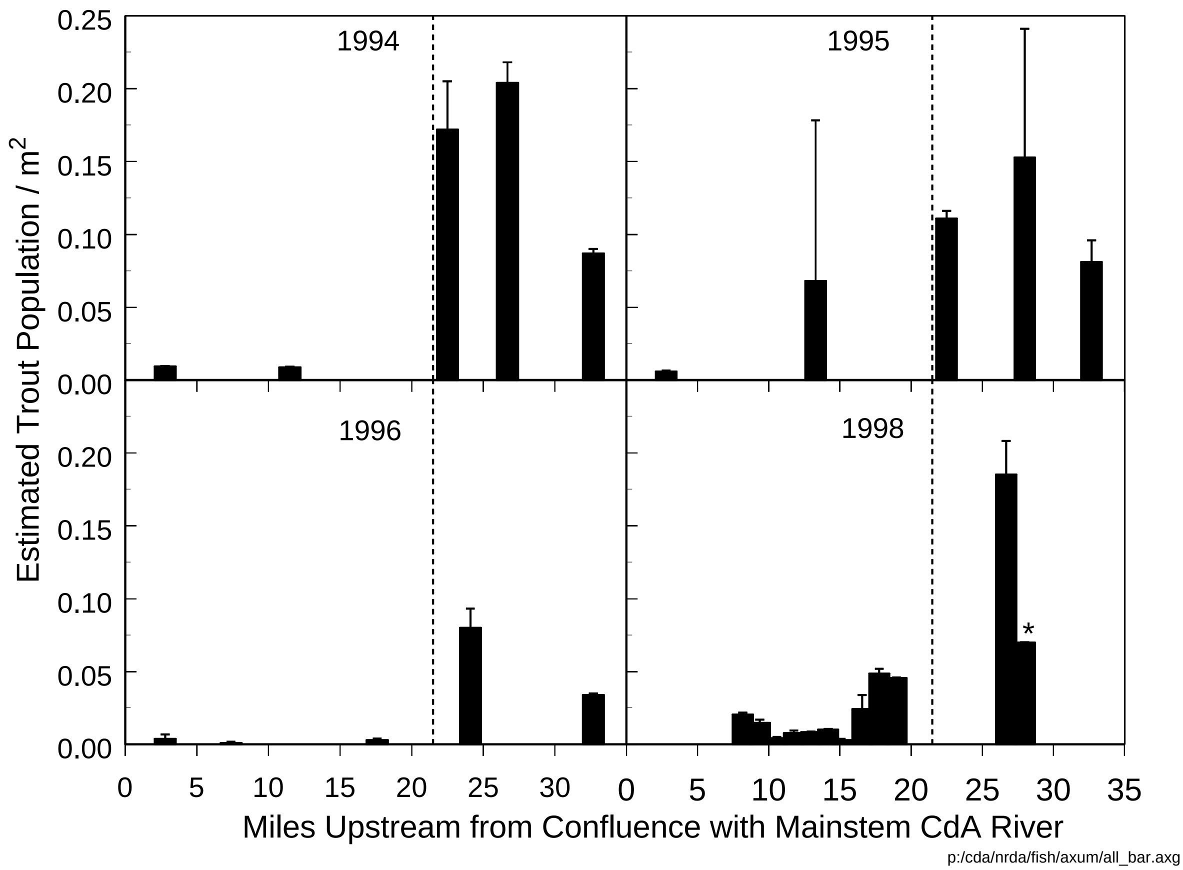

Figure 7-19a. Estimated trout populations in the South Fork Coeur d'Alene River from MPD and mark/ recapture data. Note: Vertical dashed line indicates where Canyon Creek enters the South Fork Coeur d'Alene River.
Sources: R2 Resource Consultants, 1995a, 1996, 1997; Reiser et al., 1999; Stratus Consulting, 1999a, 1999b.

When the data are expressed as total fish, upstream-downstream differences are even more pronounced. Fewer than 0.01 fish/m^2 (mean of 0.004 fish/m^2) were captured in the South Fork Coeur d'Alene River downstream of Canyon Creek during the qualitative and first electrofishing pass of the MPD sampling during 1995. Upstream of Canyon Creek, an average of 0.21 fish/m^2 were captured during this process. The mean catch rate downstream of Canyon Creek for total fish was approximately 52 times lower than the corresponding catch rate upstream of Canyon Creek.

The data confirm that a clear pattern exists in the South Fork Coeur d'Alene River: fish densities are greater in the reach upstream of mining influences than in the metal contaminated stream reach from Canyon Creek to the confluence with the North Fork Coeur d'Alene River. This pattern of fish abundance is consistent with the hypothesis that releases of hazardous substances from mining facilities are injuring fish resources.

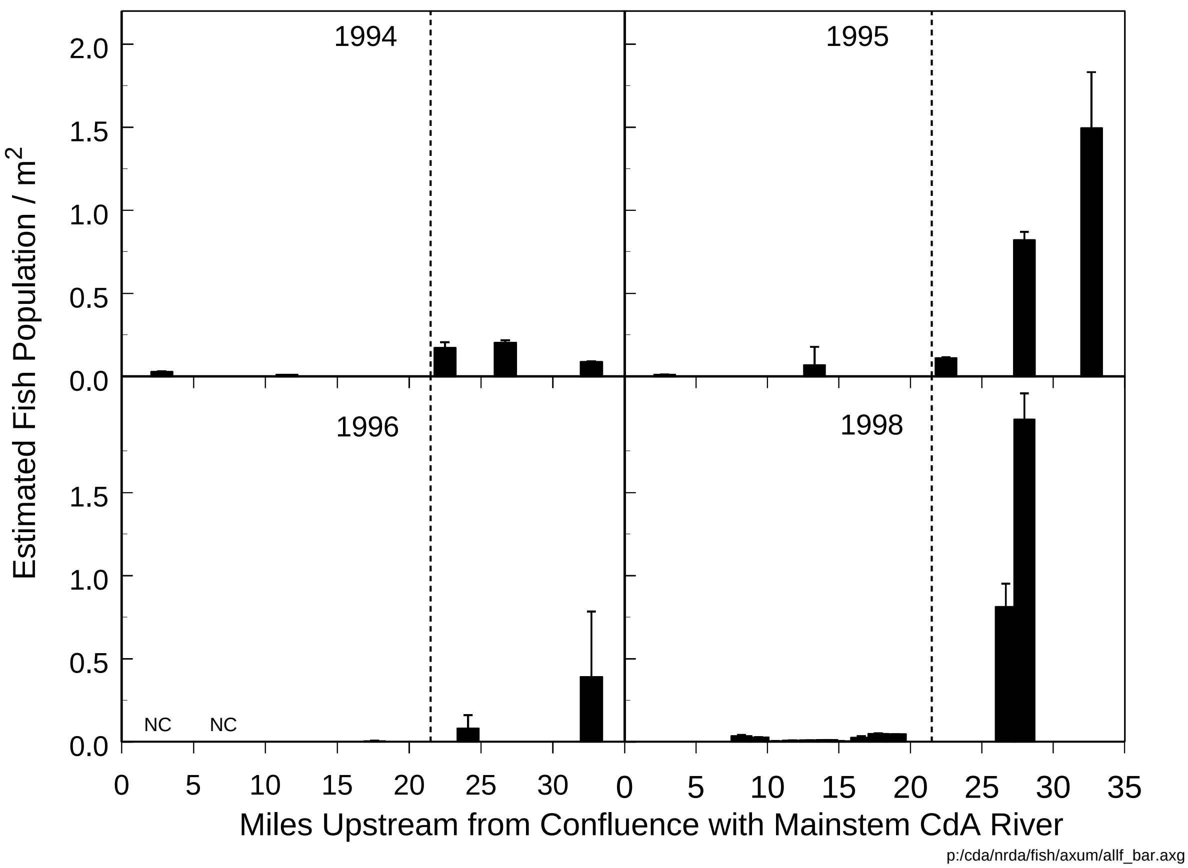

Figure 7-19b. Estimated total fish populations in the South Fork Coeur d'Alene River from MPD and mark/recapture data. Note: Vertical dashed line indicates where Canyon Creek enters the South Fork Coeur d'Alene River. NC = total fish population estimates were not calculated for mark/recapture data. 1994 estimates do not include sculpin.
Sources: R2 Resource Consultants, 1995a, 1996, 1996; Reiser et al., 1999; Stratus Consulting, 1999a, 1999b.

South Fork Coeur d'Alene River fish data were also compared to St. Regis River reference sites using a paired-site comparison approach. Table 7-20 summarizes the results of the sampling at the St. Regis River sites. The results of the paired comparison with the St. Regis River sites indicate that fish populations are reduced at the three South Fork Coeur d'Alene River locations downstream of Canyon Creek (miles 0, 8, and 16). Upstream of Canyon Creek, populations did not appear to be reduced and were somewhat higher in the South Fork Coeur d'Alene River sites 24 and 32 than in the matching St. Regis River sites (Figure 7-21). As with the upstream-downstream comparisons presented above, these data are consistent with the conclusion that releases of metals from mine wastes cause injuries to fish that result in population reductions. Reiser et al. (1999) conducted an analysis of the paired sampling locations that further integrates the results of the population monitoring, chemical analysis of water and pathway items, synoptic *in situ* bioassays, and biological monitoring (Table 7-21).

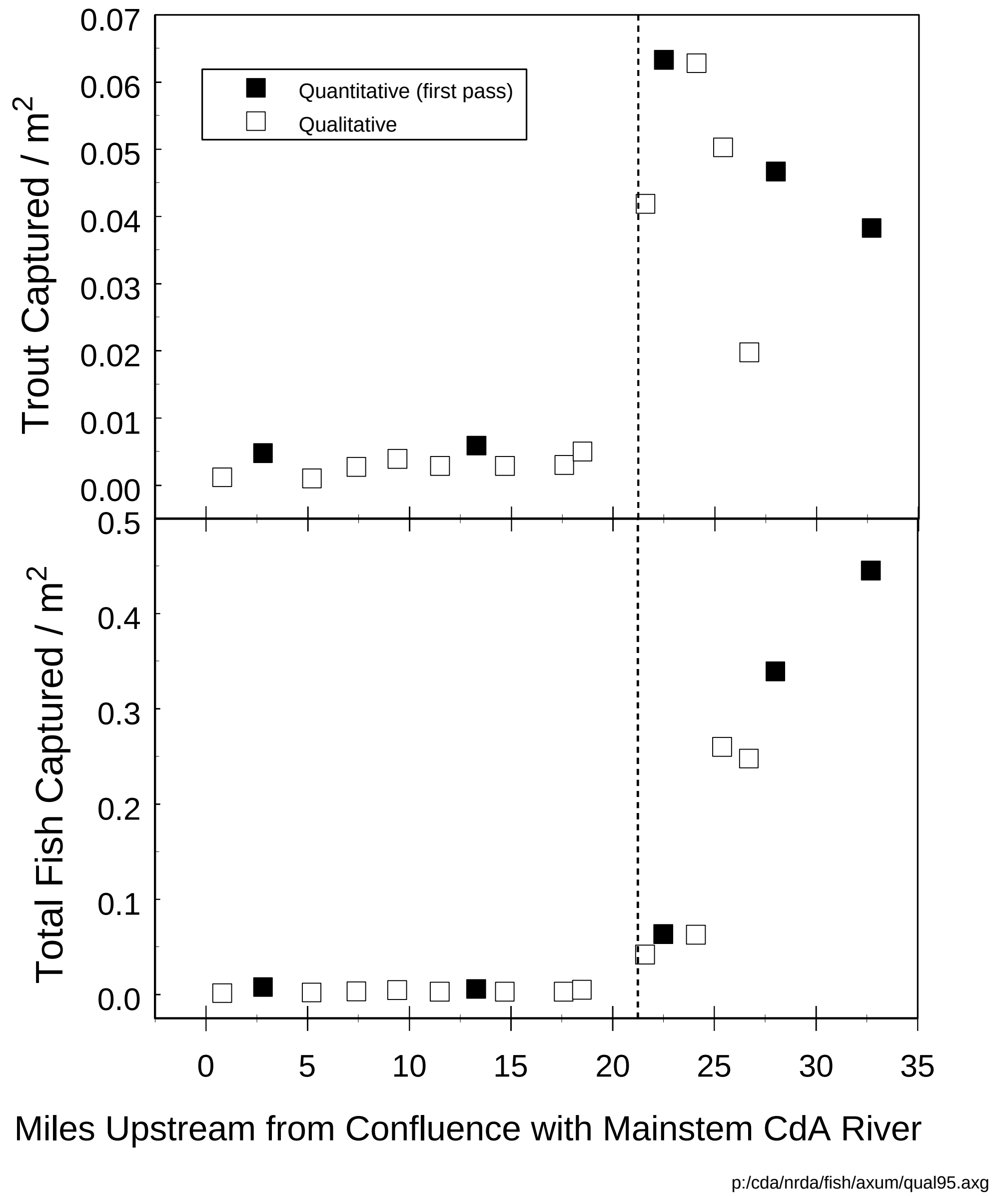

Figure 7-20. Trout (top panel) and all fish combined (bottom panel) collected in the South Fork Coeur d'Alene River during 1995 qualitative (open symbols) and first pass MPD (solid symbols).
Source: R2 Resource Consultants, 1996.

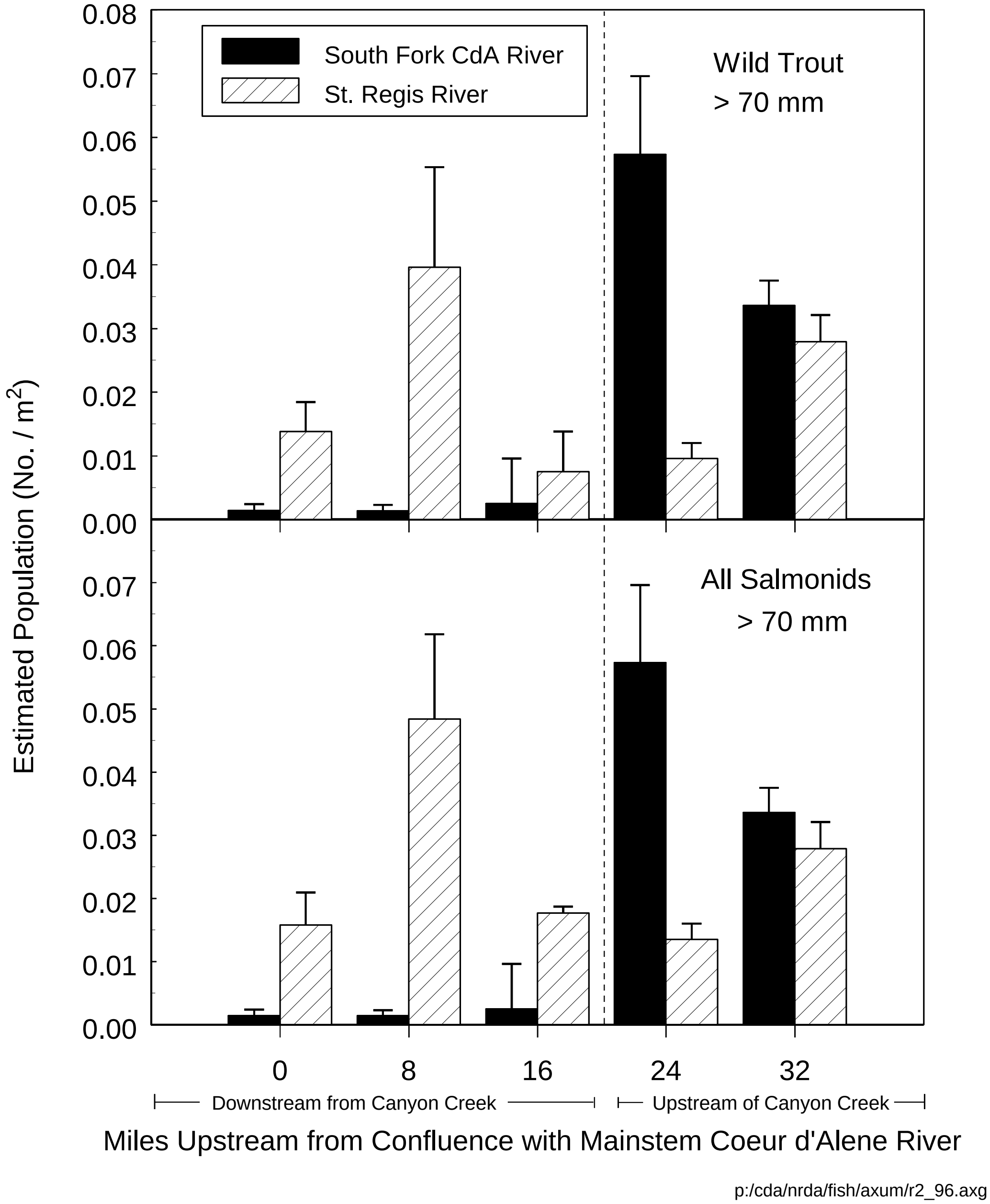

Figure 7-21. Estimated wild trout and all salmonid populations.
Source: Reiser et al., 1999.

Table 7-21
Connectivity Accumulation of Metals in the Food Web, Exposure of Resident Trout, and Injury to Wild Trout at Five Sites on the South Fork Coeur d'Alene River

Measurement	South Fork Sites				
	0	8	16	24	32
Food-web accumulation					
Zn in water	+	+	+	+	+
Zn in sediment	+	+	+	+	-
Zn in biofilm	+	+	+	+	-
Zn in invertebrates	+	+	+	-	-
Pb in water	+	+	+	-	-
Pb in sediment	+	+	+	+	-
Pb in biofilm	+	+	+	+	-
Pb in invertebrates	+	+	-	-	-
Cd in water	+	+	+	-	-
Cd in sediment	+	-	-	-	-
Cd in biofilm	+	+	+	+	-
Cd in invertebrates	+	+	+	+	-
Cu in water	-	+	-	-	-
Cu in sediment	+	+	-	-	-
Cu in biofilm	+	+	+	+	-
Cu in invertebrates	+	+	+	-	-
Trout exposure					
Zn in gills	-	+	+	+	-
Zn in intestine	-	+	-	-	-
Zn in liver	+	+	+	-	-
Pb in gills	-	+	+	-	-
Pb in intestine	-	+	+	-	-
Pb in liver	-	+	-	-	-
Cd in gills	+	+	+	+	-
Cd in intestine	-	+	+	-	-
Cd in liver	-	+	-	-	-
Cu in gills	-	+	-	-	-
Cu in intestine	+	+	+	-	-
Cu in liver	-	+	-	-	-
Trout injury					
MT in gill	+	+	+	-	-
MT in intestine	+	+	+	-	-
MT in liver	+	+	+	-	-
Number of trout/acre	+	+	+	-	-
Trout mortality	+	+	+	+	-

+ Indicates measurement in the South Fork Coeur d'Alene River site is significantly different ($p < 0.05$) from the paired St. Regis River, Montana, reference site.
MT — metallothionein.

Sources: Woodward et al., 1997b; Reiser et al., 1999.

Sites with the greatest concentrations of metals in water, sediment, biofilm, and benthic macroinvertebrates were also the sites where fish populations were reduced, mortality was observed, tissues contained elevated concentrations of metals, and metallothionein was induced.

Fish Diversity Data

An observation made consistently across the various fish sampling studies was the absence of sculpin, a native fish, in stream reaches downstream of mining influences. No sculpin were collected in the South Fork Coeur d'Alene River downstream of Canyon Creek, at the lower Canyon Creek site, at any of the Ninemile Creek sites, or in sampling conducted in mine-influenced reaches of Pine and Moon creeks. In contrast, sculpin were found in the South Fork Coeur d'Alene River upstream of Canyon Creek at densities up to 1.5 sculpin/m^2. In tributaries other than those influenced by mining, sculpin were present at all sites, and densities were greater than 1.0 sculpin/m^2 at upper Big Creek, lower Shoshone Creek, and Latour Creek. Sculpin were collected from all St. Regis River sites sampled. Similarly, mountain whitefish, another native species, was abundant in the St. Regis River but was not observed in the South Fork Coeur d'Alene River.

These data indicate that these native species have effectively been eliminated from the basin downstream of mining influences, thus providing further evidence that is consistent with the conclusion that releases from mining facilities injure fish.

7.7.3 Summary: Fish Population Density Results

The results of the fish population surveys indicate the following:

- Canyon Creek and Ninemile Creek are essentially devoid of all fish life downstream of mining releases of hazardous substances. Canyon Creek upstream of mining influences at Burke supports a population of native cutthroat trout. Similarly, other tributaries in the Coeur d'Alene system unaffected by mine wastes typically support populations of trout and sculpin.

- Fish populations in the South Fork Coeur d'Alene River are depressed downstream of the Canyon Creek confluence. A clear upstream-downstream pattern is apparent in the river, with higher densities of total fish, trout, wild trout, and sculpin in the South Fork Coeur d'Alene River upstream of Canyon Creek than downstream. Comparisons of data from South Fork Coeur d'Alene River sites with data from paired sites on the St. Regis River also indicate that fish populations in South Fork Coeur d'Alene River sites downstream of the Canyon Creek confluence are reduced. Further, the fact that fish populations in the South Fork Coeur d'Alene River upstream of Canyon Creek were as abundant as in the paired St. Regis sites indicates that conditions in the South Fork Coeur d'Alene River are not intrinsically unfavorable to fish, absent the effects of mining.

- Sculpin, a native fish that resides on stream bottoms, and mountain whitefish, a native salmonid, have essentially been eliminated from stream reaches affected by mining releases. In reaches not affected by mine releases, sculpin are abundant. Whitefish were abundant in the St. Regis River reference locations that provide habitat similar to lower reaches of the South Fork Coeur d'Alene.

- Fish population and water quality data from Pine Creek indicate a dose-response relationship between zinc concentration and trout numbers (Section 7.3). The relationship was observed at zinc concentrations lower than those that frequently occur in Canyon and Ninemile creeks, and the South Fork Coeur d'Alene River.

- Fish population data in the Coeur d'Alene River basin are consistent with the hypothesis that hazardous substances released from mining facilities are causing injuries to fish. Thus, the population data are confirmatory of the toxicological information presented previously in this chapter.

7.8 INJURY DETERMINATION

This section presents the determination of injury for fish resources of the Coeur d'Alene River basin. In this section, we present relevant DOI NRDA injury definitions, evidence available for evaluation of injuries, and an assessment in which alternative causes of adverse effects to fish are evaluated. Finally, the regulatory determination of injury is presented.

7.8.1 Injury Definitions

Based on the information presented above, injuries specifically tested in this determination were:

- death [43 CFR § 11.62 (f)(4)(i)]
- behavioral avoidance [43 CFR § 11.62 (f)(4)(iii)(B)]
- physiological malfunctions, including affects on growth [43 CFR § 11.62 (f)(4)(v)], and other physical deformations such as histopathological lesions [43 CFR § 11.62 (f)(4)(vi)(D)].

7.8.2 Lines of Evidence

Various data are available to evaluate the injury definitions listed above. These include surface water concentrations of hazardous metals relative to toxicity thresholds, site-specific toxicity data, and field data on fish populations.

Comparison of Toxicity Thresholds with Water Quality Data

One approach to evaluating injuries to fish is to compare concentrations of hazardous substances measured in surface waters to toxicity thresholds for the metals. As discussed in Chapter 4, the U.S. EPA has developed aquatic life criteria (ALC) that are designed to be protective of aquatic organisms and their uses (Stephen et al., 1985). Both acute (criterion maximum concentration, CMC) and chronic (criterion continuous concentration) ALCs have been developed for cadmium, lead, and zinc, and the ALCs for all three metals are based on the hardness of the exposure water (U.S. EPA, 1996). These ALCs can be used as screening-level effects thresholds; however, because they are based on a variety of species and are intended for nationwide application, the precision of these thresholds to different watersheds can vary.

Chapter 4 presents an analysis of exceedences of ALC for cadmium, lead, and zinc in stream reaches of the Coeur d'Alene River basin. Cadmium and zinc at ALC values are exceeded in the overwhelming majority of the samples collected from the South Fork Coeur d'Alene River downstream of Canyon Creek; in lower Ninemile, Canyon, and Pine creeks; in the mainstem Coeur d'Alene River; and in Coeur d'Alene Lake (Chapter 4, Tables 4-8, 4-10, 4-11, and 4-13). The frequency of lead ALC exceedences was lower (Chapter 4, Tables 4-9 and 4-12). These results demonstrate that ALC screening thresholds are routinely exceeded in many portions of the basin. The tables also indicate that the magnitudes of the exceedences often are substantial. For example, in the South Fork Coeur d'Alene River downstream of Pinehurst, cadmium concentrations range from 0.28 to 189 times the chronic cadmium ALC and 0.12 to 103 times the acute cadmium ALC (Chapter 4, Tables 4-8 and 4-11). In lower Canyon Creek, zinc concentrations have ranged as high as 199 times the acute zinc ALC (Chapter 4, Table 4-10). The frequency and magnitude of the ALC exceedences provide strong evidence of the likelihood of adverse effects to fish.

An alternative set of thresholds can be derived using toxicological data relating exposures of site-relevant species to water quality conditions that are representative of the site. As described in Section 7.5.2, two useful data sources for this analysis are the studies performed by EVS (1996c, 1997b) using water collected from the Little North Fork of the South Fork Coeur d'Alene River, and the studies performed by Hansen et al. (1999a) in which rainbow trout and bull trout were exposed to zinc and cadmium in laboratory waters formulated to represent various water quality conditions that occur in the Coeur d'Alene River basin. Table 7-22 summarizes toxicity threshold values derived from the above studies. The toxicity thresholds presented in Table 7-22 were derived following the convention used by the U.S. EPA of calculating effects *thresholds* as a value equal to one-half the LC50 value (G. Chapman, Paladin Water Quality Consulting, pers. comm., December 1997). Effects thresholds varied depending on hardness and pH. Threshold values for cadmium ranged from 0.35 to 5.01 µg/L for 50% mortality; effects thresholds for zinc ranged from 24.3 to 413 µg/L.

Surface water quality data were compared with these adverse effects thresholds (Figure 7-22). Water chemistry median and maximum values from Chapter 4 (Tables 4-11 and 4-13) for three reaches in the South Fork Coeur d'Alene River, lower Canyon Creek, lower Ninemile Creek, two reaches in lower Pine Creek, three reaches in the mainstem Coeur d'Alene River, and Coeur d'Alene Lake are presented in Figure 7-22. In Figure 7-22a, mean LC50 values for studies conducted at a hardness of 20 to 30 mg/L and a pH range of 7.0-7.5 (Table 7-22) are presented as adverse effects thresholds. In Figure 7-22b, the effects thresholds presented are equal to one-half the mean LC50 value presented in Figure 7-22a. Stream reaches referenced in Figure 7-22 are shown in Figure 7-23. The data presented in Figure 7-22 provide clear indication that metal concentrations exceed lethality thresholds in the South Fork Coeur d'Alene River downstream of Canyon Creek, Canyon, Ninemile, and Pine creeks, the lower Coeur d'Alene River, and Coeur d'Alene Lake. For example, in the South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek reaches, *median* concentrations of cadmium and zinc exceeded lethality thresholds by 10 to greater than 1,000 times. Substantial exceedences of lethality thresholds were observed in Pine Creek and the lower Coeur d'Alene River.

Thus, comparison of water quality data with toxicological effects thresholds indicates that fish are injured by metals in the Coeur d'Alene River basin.

Site-Specific Toxicity Data

Site-specific toxicity data include various *in situ* bioassays conducted by different investigators (U.S. EPA, date unknown; Bauer, 1975; Hornig et al., 1988; Dames & Moore, 1989; Woodward et al., 1997b) and toxicity tests performed with field collected waters (Sappington, 1969; Rabe and Sappington, 1970; Hornig et al., 1988).

In situ bioassays have confirmed that exposure to surface waters of the South Fork Coeur d'Alene River and Canyon Creek causes acute toxicity to trout (U.S. EPA, date unknown; Bauer, 1975; Hornig et al., 1988; Dames & Moore, 1989; Woodward et al., 1997b). Bioassays also confirm the toxicity of the Bunker Hill CIA seep water (Hornig et al., 1988). In addition, toxicity tests using waters collected from the site and toxicity tests using field collected waters with added metals confirm the lethality of site waters to fish species. The results of these tests provide direct and compelling evidence that exposure to site waters is acutely lethal to fish.

Table 7-22
Toxicity Threshold Values for Trout Species[a]

Toxicant	Species	LC50 (µg/L)	LC50÷2 (µg/L)	Hardness (mg/L as $CaCO_3$)	Comments	Data Source
Cadmium	Bull trout	0.90-0.95	0.45-0.48	30	pH = 7.5	Hansen et al., 1999a
		2.42	1.21	30	pH = 6.5	
		5.01	2.51	90	pH = 7.5	
	Rainbow trout	0.35-0.54	0.18-0.27	30	pH = 7.5	
		0.92	0.46	30	pH = 6.5	
		2.18	1.09	90	pH = 7.5	
		0.84	0.42	20	pH = 7	EVS, 1997b
		0.50	0.25	20	pH = 7	EVS, 1996c
	Cutthroat trout	0.93	0.47	20	pH = 7; field collected fish	
		0.35	0.18	20	pH = 7; hatchery fish	
Zinc	Bull trout	37.2-81.6	18.6-40.8	30	pH = 7.5	Hansen et al., 1999a
		204-207	102-104	30	pH = 6.5	
		315-413	158-207	90	pH = 7.5	
	Rainbow trout	24.3-54.0	12.2-27.0	30	pH = 7.5	
		123-146	62.0-73.0	30	pH = 6.5	
		202-270	101-135	90	pH = 7.5	
		69.3	34.7	20	pH = 7	EVS, 1996c
	Cutthroat trout	325	163	20	pH = 7; field collected fish	
		125	62.5	20	pH = 7; hatchery fish	

a. See text for description of data sources.

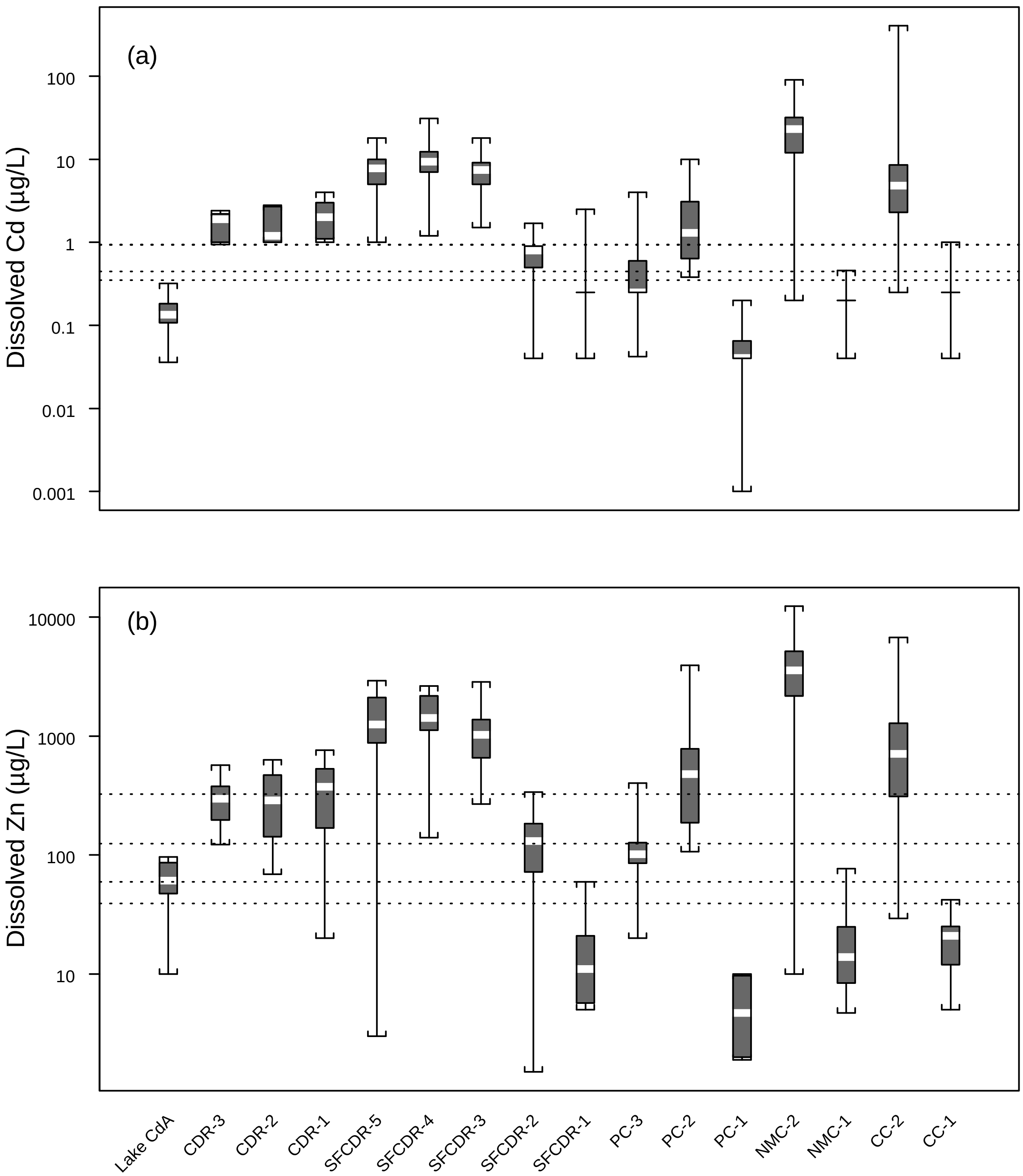

Figure 7-22a. Comparison of dissolved cadmium and zinc concentrations in surface water (1991-1999) and adverse effects concentrations from site-relevant bioassays. Horizontal dashed lines are LC50 values for bull trout (0.94 µg Cd/L and 59.4 µg Zn/L) (Hansen et al., 1999a), rainbow trout (0.445 µg Cd/L and 39.2 µg Zn/L) (Hansen et al., 1999a), hatchery cutthroat trout (0.35 µg Cd/L and 125 µg Zn/L) (EVS, 1996c), and field collected cutthroat trout (0.93 µg Cd/L and 325 µg Zn/L) (EVS, 1996c). Boxes show median, interquartile range, and data range by stream reach. See Figure 7-23 and Table 4-4 for a description of the reaches.

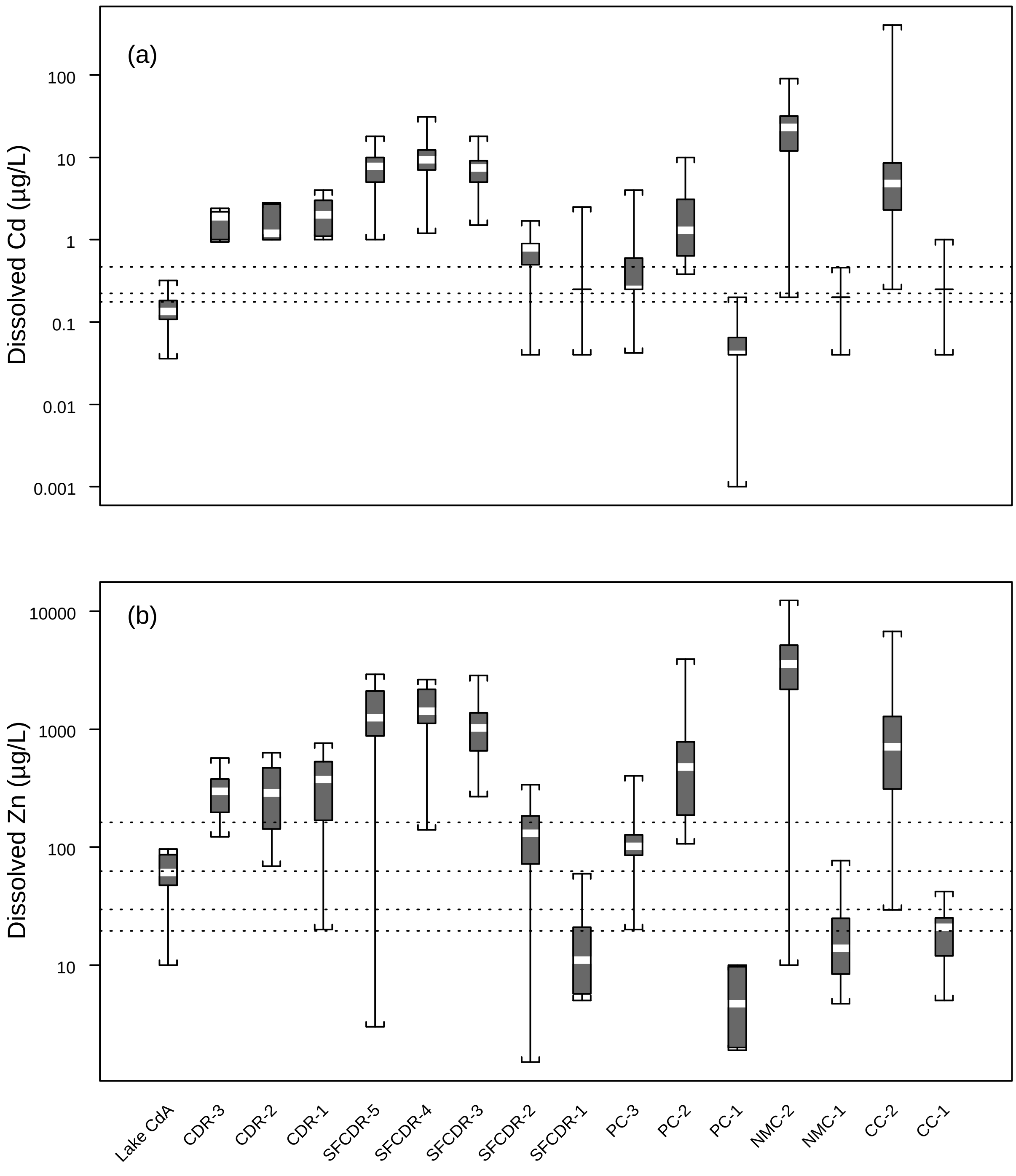

Figure 7-22b. Comparison of dissolved cadmium and zinc concentrations in surface water (1991-1999) and adverse effects concentrations from site-relevant bioassays. Horizontal dashed lines represent one-half the LC50 values identified in Figure 7-22a for bull trout (Hansen et al., 1999a), rainbow trout (Hansen et al., 1999a), hatchery cutthroat trout (EVS, 1996c), and field collected cutthroat trout (EVS, 1996c). Boxes show the median, interquartile range, and data range by stream reach. See Figure 7-23 and Table 4-4 for a description of the reaches.

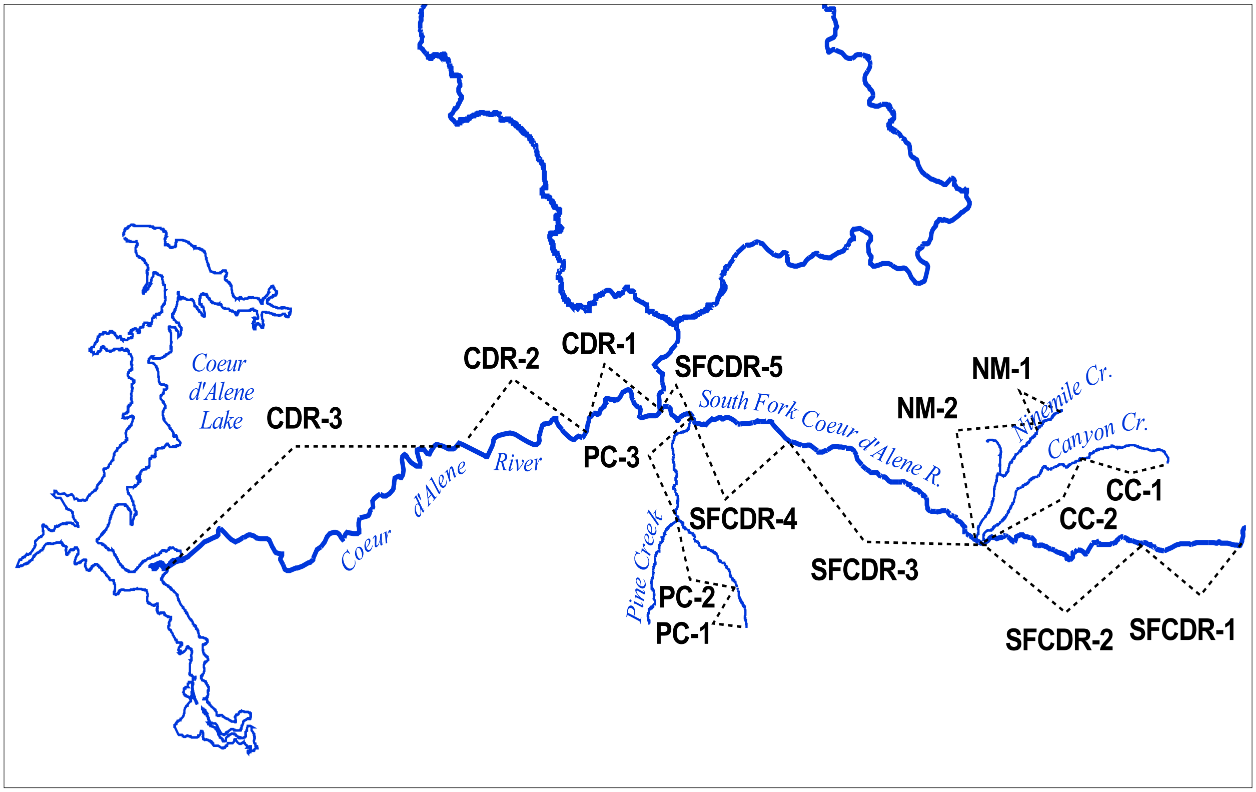

Figure 7-23. Stream reaches referenced in Figure 7-22a and b. See Table 4-4 for descriptions of the reaches.

In addition to the lethality bioassays, paired laboratory and field tests were performed to evaluate behavioral avoidance (Woodward et al., 1997a; Goldstein et al., 1999). The tests indicated that salmonids avoided zinc concentrations as low as 28 µg/L (Woodward et al., 1997a). In field tests in which chinook salmon had the option of selecting between water from the South Fork Coeur d'Alene River containing 2,220 µg Zn/L or water from the North Fork containing 9 µg Zn/L, 70% of the fish selected the water with the lower zinc concentration. These data provide evidence from both the laboratory and the field of behavioral avoidance, particularly of zinc.

In addition to studies of effects of waterborne exposure to metals which showed that site waters are toxic, studies of dietary exposure also confirmed toxicity. Farag et al. (1998a, 1999) performed a series of studies evaluating effects associated with dietary exposure pathways. In the 1998a study, Farag et al. found that aquatic invertebrates that are a food source for fish are exposed to elevated concentrations of metals. In the 1999 laboratory feeding study, Farag et al. found that consumption of contaminated invertebrate diets collected from the field caused adverse effects. Consumption of the invertebrate diet collected from the mainstem Coeur d'Alene River near Cataldo caused lethality, reduced growth, and a suite of histopathological lesions to neural, digestive, and kidney cells. Consumption of the invertebrate diet collected from the South Fork Coeur d'Alene River caused a reduced degree of adverse effects; only histopathological lesions were observed. Although this latter diet contained higher concentrations of metals than the mainstem Coeur d'Alene River diet, uptake of metals was greater in the mainstem Coeur d'Alene River diet, indicating increased bioavailability. Therefore, the invertebrate diet that contained the more bioavailable metals caused more severe effects. This series of studies provides evidence that dietary exposures represent a potentially important exposure pathway to fish that can result in adverse effects.

Population Data

Examination of fish population data provides a useful means of evaluating whether the condition of the fish resource is consistent with the presence of metals injuries. The population data presented in Section 7.7 indicate that downstream of mining influences, fish populations are adversely affected. Specifically, Canyon Creek and Ninemile Creek are nearly devoid of all fish life downstream of mining releases of hazardous substances. Canyon Creek upstream of mining influences supports a population of native cutthroat trout. Similarly, other tributaries in the Coeur d'Alene system unaffected by mine wastes typically support populations of trout and sculpin.

Fish populations in the South Fork Coeur d'Alene River also are depressed downstream of the Canyon Creek confluence. A clear upstream-downstream pattern is apparent in the river, with higher densities of total fish, trout, wild trout, and sculpin in the South Fork Coeur d'Alene River upstream of Canyon Creek than downstream. Comparison of data collected at South Fork Coeur d'Alene River sites and paired sites on the St. Regis River also indicates that fish populations, including trout, whitefish, and sculpin, are reduced in South Fork Coeur d'Alene River sites downstream of the Canyon Creek confluence. Further, the fact that fish populations in the South Fork Coeur d'Alene River upstream of Canyon Creek were as abundant as in the paired St. Regis River sites indicates that conditions in the South Fork Coeur d'Alene River are not intrinsically unfavorable to fish, absent the effects of mining.

Other relevant population data include the observation that sculpin and whitefish, two native fish species, were not present in stream reaches affected by mining releases, but were abundant in locations not affected by mining releases. Data on fish populations and water quality in Pine Creek provide additional evidence of a dose-response relationship between zinc concentration and trout numbers. This relationship was observed at zinc concentrations lower than those that frequently occur in Canyon and Ninemile creeks, the South Fork Coeur d'Alene River, and the lower Coeur d'Alene River.

All of the data presented above are consistent with the hypothesis that hazardous substances released from mining facilities are causing injuries to fish. Thus, the population data are confirmatory of the toxicological information and provide an independent line of evidence indicating that fish are injured.

7.8.3 Causation Evaluation

An important component of injury determination is assessment of whether adverse effects have resulted from exposure to hazardous substances, or from some other factor.

Results can be evaluated using two approaches: consideration of results within a study, and consideration of results across studies.

Within Study Assessment

Consideration of results within studies focuses on various factors that could reasonably be interpreted as possible causes of study outcomes.

In Situ Bioassays

Lethality has been observed in a variety of *in situ* bioassays and in studies performed using field collected waters (Hornig et al., 1988; Dames & Moore, 1989; Woodward et al., 1995; Woodward et al., 1997b). In these studies, metals were inferred to be the cause of the observed mortality because metal concentrations during testing were extremely elevated (maximum concentrations ranged from 1,770 to 3,000 µg Zn/L and 9 to 29 µg Cd/L *in situ* bioassays conducted by Hornig et al., 1988; Dames & Moore, 1989; Woodward et al., 1995; Woodward et al., 1997b) and because the observed results (death) were consistent with the expected effects of elevated metal concentrations. Also, a dose-response relationship between metal concentration and mean percent mortality was apparent in the *in situ* tests conducted in 1996 (Figure 7-12; Woodward et al., 1997b). Alternative explanations do not appear to be equally plausible. For example, during their bioassays, Woodward et al. (1997b) measured temperature (10.0-18.8 C), dissolved oxygen (8.9-10.6 mg/L), pH (7.5-8.2), and ammonia (0.06-0.12 mg/L). Each of these parameters was below adverse effects thresholds reported in the literature, and they were generally similar in both impact and control locations. No other stressor has been measured in the water of these sites that would plausibly explain the increased mortality at the Coeur d'Alene River basin locations. Therefore, it is concluded that exposure to lethal concentrations of metals, particularly cadmium and zinc, caused the observed mortality.

Laboratory and Field Bioassays

Laboratory studies of acute mortality (EVS, 1996c; 1997b; Hansen et al., 1999a) were each conducted in a controlled manner to specifically assess the effects of metals. Other factors that could conceivably cause mortality were strictly controlled at favorable levels, and mortality responses were related to metal concentration in a typical dose-dependent fashion indicative of causation. Therefore, the metals tested clearly were the cause of the observed effects. Similarly, the laboratory avoidance study provided clear evidence that the dosed toxicant (particularly zinc) caused the avoidance response.

Results from the field avoidance study were consistent with those from the laboratory avoidance study in that fish tended to avoid the water with elevated metals. Other water quality parameters (temperature 13.7-14.1 C, dissolved oxygen 8.0-9.7 mg/L, pH 7.0-7.4) were generally similar in both the North Fork and the South Fork Coeur d'Alene rivers. Given the larger size of the North Fork Coeur d'Alene River (approximately twice the flow of the South Fork Coeur d'Alene River), it is possible that the increased frequency of fish selecting the North Fork Coeur d'Alene River could have resulted from the differences in stream size rather than metal-related responses. Nonetheless, considering the similarity of the results of the field and laboratory studies, the results of field study are deemed to provide confirmatory, but not independent, evidence that metals cause avoidance.

In the bioassays conducted to evaluate dietary effects (Farag et al., 1998a), control over the dosing system was not undertaken as part of the study design because fish were exposed to field collected invertebrates. Although adverse effects were greater in the fish that accumulated more metals, which indicates that metals were the cause of the effects, alternative causes are plausible. Specifically, differences in dietary quality of the invertebrate diets, particularly with respect to differences in carbohydrate and energy, could have contributed to the adverse effects. Overall, metals are the more plausible cause of the effects observed in this study, but the possibility that effects were caused by dietary quality cannot be rejected.

Population Assessment

In the fish population studies, populations of fish in sites downstream of mining influences were found to be lower than those in sites upstream of mining influences. Although these results are consistent with the toxic effects of metals, they do not necessarily provide *independent* confirmation that metals caused the population impairments because the studies were observational field studies, rather than controlled laboratory tests. Nevertheless, certain lines of evidence point to metals as the most plausible cause:

- The within-stream population comparisons provide evidence of changes in fish abundance and diversity up- and downstream of mining releases, with reduced abundance at locations exposed to elevated concentrations of metals.

- The analysis of paired test sites presented in Woodward et al. (1997b) and Reiser et al. (1999) was coupled with *in situ* bioassays, pathway monitoring, and biological effects monitoring. These data provide an integrated assessment of pathways, mortality, and population differences.

- The dose-response relationships between populations measured in the field and concentrations of metals in water (e.g., McNary et al., 1995; Woodward et al., 1997b) suggest a direct causal relationship between metals and reduced fish populations.

Notwithstanding these lines of evidence, alternative causes of the observed fish population reductions were considered, including the influence of urban development, agriculture and timber harvest, recreation, and the influence of channelization.

Urban development can influence fish populations through inputs of organic enrichments from sewage effluents. Organic enrichments can affect fish populations by depressing dissolved oxygen levels or by increasing ammonia levels. However, data collected in the paired assessment of South Fork Coeur d'Alene v. St. Regis River (Reiser et al., 1999) do not support the hypothesis that such adverse effects are occurring. Dissolved oxygen concentrations in the South Fork Coeur d'Alene exceeded 8 mg/L (Woodward et al., 1999), which exceeds the minimum level of 5 mg/L considered safe for trout. Therefore, depressed dissolved oxygen concentrations are not a plausible cause of observed fish population reductions. Similarly, ammonia concentrations were substantially lower than the maximum safe limit reported for salmonids (Rahel, 1999) indicating that ammonia is not the cause of reduced fish populations. These data, coupled with the fact that the majority of the Coeur d'Alene basin is not urbanized, indicates that urban development is not a plausible cause of the observed population reductions.

Agriculture and timber harvest similarly are concluded to not be plausible causes of observed population reductions. Agriculture is virtually absent in the upper Coeur d'Alene basin (e.g., South Fork Coeur d'Alene, Canyon Creek, Ninemile Creek). Therefore, impacts on fish populations are negligible. Although timber harvesting occurs in the basin, the clear upstream-downstream pattern of fish population reductions in the South Fork Coeur d'Alene River at the Canyon Creek confluence argues strongly against the likelihood that timber harvesting is the cause of the observed population trends.

Recreation, specifically fishing pressure, can influence trout populations. However, Reiser (1999) indicates that over three years of field investigations, no fishing activity was observed in the South Fork Coeur d'Alene River downstream of Canyon Creek; fishing activity was observed upstream of Canyon Creek and in the St. Regis River reference location. These observations, coupled with the fact that sculpin is not a recreationally harvested fish species, indicate the recreational fishing is not the cause of observed fish population reductions.

Channelization can have detrimental effects on fish populations. However, the South Fork Coeur d'Alene River is channelized both upstream and downstream of the Canyon Creek confluence. Therefore, channelization is not a plausible cause of the upstream-downstream pattern of fish abundance. Similarly, when comparing the extent of channelization against trout abundance measured in the 1996 South Fork-St. Regis paired study, trout abundance was not related to the degree of channelization (Rahel, 1999).

Therefore, it is concluded that these alternative factors are not the cause of the observed fish population reductions. Rather, elevated concentrations of metals, particularly cadmium and zinc, are concluded to be the cause.

Across Study Assessment

An alternative means of evaluating results is a deductive, or weight-of-evidence, assessment. In this approach, the consistency of evidence *across studies* is considered.

Various studies provide strong evidence that exposure to metal-contaminated surface waters downstream of mining influences causes trout mortality. These studies include various *in situ* bioassays, studies performed using waters collected from the field, and even tests in which more resistant surviving fish collected from the field were tested. All of these studies, together with toxicity thresholds derived from a large number of laboratory studies, provide consistent evidence of mortality injuries.

In addition, evidence is strong that behavioral avoidance injuries are occurring. This evidence includes laboratory and field studies. As noted above, the field study, although not necessarily providing independent confirmation of avoidance, is consistent with the avoidance predicted from the laboratory studies. Therefore, the weight of evidence indicates that avoidance injuries are occurring.

Dietary effects studies provide strong evidence that consumption of contaminated invertebrates is a pathway of exposure to metals. In addition, laboratory studies provide evidence of adverse effects associated with this dietary pathway, although alternative explanations associated with dietary quality cannot be rejected.

Population studies and monitoring of fish in the field provide evidence that confirms the laboratory and *in situ* bioassay results that metals cause injury to fish. Fish population numbers and diversity are reduced in locations where concentrations of cadmium and zinc are elevated. Moreover, fish health was found to be impaired (Farag et al., 1998a; 1999; Woodward et al., 1999) in locations with higher metal concentrations in water and diet. The observed impairment of fish health is reasonably attributable to exposure to metals, given the effects observed in the laboratory dietary studies. Therefore, the fish population patterns provide strong field evidence that is consistent with metals as the cause of injuries to fish in the Coeur d’Alene system. Alternative factors are not a plausible cause of the observed reduced fish populations.

Overall, the combination of laboratory toxicity studies, data on exposure to metals in water, sediment, and dietary pathways, field toxicity data, and fish population assessments provides consistent evidence of injuries caused by metals.

7.8.4 Regulatory Determination

Fish resources have been injured in the South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek, as well as other stream and river reaches affected by releases of hazardous substances from mining and mineral processing operations.

Specifically, the following injuries were determined:

- death [43 CFR § 11.62 (f)(4)(i)], as confirmed by *in situ* bioassays [43 CFR § 11.62 (f)(4)(i)(D)] and laboratory toxicity testing [43 CFR § 11.62 (f)(4)(i)(E)]

- behavioral avoidance [43 CFR § 11.62 (f)(4)(iii)(B)], as confirmed by laboratory tests using fish placed in testing chambers in controlled laboratory conditions, as well as by field tests

- physiological malfunctions, including affects on growth [43 CFR § 11.62 (f)(4)(v)], and other physical deformations such as histopathological lesions [43 CFR § 11.62 (f)(4)(vi)(D)], as confirmed by laboratory testing.

7.9 CONCLUSIONS

The information in this chapter demonstrates the following:

- Fish resources of the Coeur d'Alene River basin have been injured as a result of exposure to hazardous substances (particularly cadmium, lead, and zinc) released from mining and mineral processing operations. Resident, fluvial, and adfluvial fish have been injured, including native and introduced salmonids as well as nonsalmonid fish species (e.g., sculpin).

- Sufficient concentrations of hazardous substances exist in pathway resources now, and have existed in the past, to expose and injure fish of the Coeur d'Alene River basin.

    - Concentrations of hazardous substances in surface water (including suspended and bed sediments), biofilm, and benthic macroinvertebrates are elevated and represent pathways of metal exposure and injury to fish.

    - Benthic macroinvertebrates accumulate hazardous substances in tissues and serve as a pathway of metal exposure and injury to fish.

- Concentrations of hazardous substances in surface water exceed chronic and acute ALC for cadmium, lead, and zinc (see Chapter 4) and are sufficient to cause injury to fish of the Coeur d'Alene River basin.

- Concentrations of hazardous substances in surface water of the South Fork Coeur d'Alene River, the lower Coeur d'Alene River, and Canyon, Ninemile, and Pine creeks are sufficient to cause acute mortality to trout. Lethality injuries are demonstrated by *in situ* bioassays, laboratory bioassays using field collected waters, and laboratory bioassays using waters formulated to simulate conditions in the basin.

- Salmonids avoid water containing hazardous substances at concentrations that occur in the South Fork Coeur d'Alene River, the lower Coeur d'Alene River, and Coeur d'Alene Lake. *In situ* trials using chinook salmon and laboratory exposures using cutthroat trout have demonstrated behavioral avoidance of Coeur d'Alene River basin waters, and preference for water containing lower concentrations of hazardous substances.

- Ingestion of contaminated macroinvertebrates from the South Fork and lower Coeur d'Alene rivers causes increased mortality, reduced feeding activity, and histopathological lesions in cutthroat trout.

- Populations of trout species and other fish species have been reduced or eliminated by elevated concentrations of hazardous substances in the South Fork Coeur d'Alene River and its tributaries. Specifically:

    - Canyon Creek and Ninemile Creek are nearly devoid of all fish life downstream of mining releases of hazardous substances. Canyon Creek upstream of mining influences at Burke supports a population of native cutthroat trout. Similarly, other tributaries in the Coeur d'Alene system unaffected by mine wastes typically support populations of trout and sculpin.

    - Fish populations in the South Fork Coeur d'Alene River are depressed downstream of the Canyon Creek confluence with the South Fork Coeur d'Alene River. A clear upstream-downstream pattern is apparent in the river. Densities of fish, including trout and sculpin, are higher in the South Fork Coeur d'Alene River upstream of Canyon Creek than downstream. Comparison of data from South Fork Coeur d'Alene River sites with data from paired sites on the St. Regis River also indicates that fish populations in South Fork Coeur d'Alene River sites downstream of the Canyon Creek confluence are reduced. Further, the fact that fish population sizes in the South Fork Coeur d'Alene River upstream of Canyon Creek were as great as, or greater than, population sizes in the paired St. Regis River sites indicates that conditions in the South Fork Coeur d'Alene River are not intrinsically unfavorable to fish, absent the effects of mining.

- Sculpin and whitefish have not been found in stream reaches affected by mining releases but are abundant in reaches not affected by releases of hazardous substances from mining.

- Data on fish populations and water quality on Pine Creek indicate a dose-response relationship between zinc concentration and trout numbers. The relationship was observed at zinc concentrations lower than those that frequently occur in Canyon and Ninemile creeks, and the South Fork Coeur d'Alene River.

- Population data are consistent with the hypothesis that hazardous substances released from mining operations are causing injuries to fish. Thus, the population data are confirmatory of the toxicological information.

7.10 REFERENCES

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