Report of Injury Assessment and Injury Determination: Coeur d'Alene Basin Natural Resource Damage Assessment

September 2000

Prepared for:

United States Department of the Interior, Fish and Wildlife Service
United States Department of Agriculture, Forest Service
Coeur d Alene Tribe

Prepared by:

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CONTENTS

FIGURES

TABLES

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ACRONYMS AND ABBREVIATIONS

AB-DTPA	ammonium-bicarbonate diethylenetriaminepentaacetic acid
ALAD	delta-aminolevulinic acid dehydratase
ALC	aquatic life criteria
ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CIA	Central Impoundment Area
CMC	criterion maximum concentration
CWA	Federal Water Pollution Control Act (Clean Water Act)
DEQ	Division of Environmental Quality
DOC	dissolved organic carbon
DOI	U.S. Department of the Interior
dw	dry weight
EDTA	ethylenediametetraacetic acid
ep&t	Ecological Planning and Technology, Inc.
GIS	geographic information system
HY	hatch year
ICBEMP	Interior Columbia Basin Ecosystem Management Project
IDEQ	Idaho Department of Environmental Quality
IDHW	Idaho Department of Health and Welfare
KNWR	Klamath National Wildlife Refuge
LOAEL	lowest observed adverse effect level
MNWR	Malheur National Wildlife Refuge
MPD	multiple pass depletion
MWMA	McArthur Wildlife Management Area
NCP	National Oil and Hazardous Substances Pollution and Contingency Plan
NOAA	National Oceanic and Atmospheric Administration
NRDA	natural resource damage assessment
NTR	National Toxics Rule
PCA	principal components analysis
QA/QC	quality assurance/quality control
RBP	rapid bioassessment protocol
RI/FS	remedial investigation/feasibility study
RIIB	renal intranuclear inclusion body
RM	river mile
RNA	Research Natural Area
ROW	right of ways
RPD	relative percent difference
SEAM	Surface Environment and Mining

STORET	Storage and Retrieval of U.S. Waterways Parametric Data
SVNRT	Silver Valley Natural Resource Trustees
TNWR	Turnbull National Wildlife Refuge
tpd	tons per day
TSA	temporary storage area
TSS	total suspended sediment
UCL	upper confidence limit
U.S. BLM	U.S. Bureau of Land Management
USDA	U.S. Department of Agriculture
U.S. EPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Next

EXECUTIVE SUMMARY OF DETERMINATIONS

The U.S. Department of the Interior (DOI), U.S. Department of Agriculture, and the Coeur d'Alene Tribe (collectively, the Trustees) have undertaken a natural resource damage assessment (NRDA) to assess injuries resulting from releases of hazardous substances from mining and mineral processing operations in the Coeur d'Alene River basin, Idaho. Section 107 of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) [42 U.S.C. § 9607], Section 311 of the Federal Water Pollution Control Act [33 U.S.C. § 1321], and the National Oil and Hazardous Substances Pollution Contingency Plan [40 CFR Part 300] provide authority to the Trustees to seek such damages.

This Report of Injury Assessment and Injury Determination presents a comprehensive evaluation of injuries to natural resources in the Coeur d'Alene River basin resulting from releases of mining-related hazardous substances. Natural resources of the Coeur d'Alene River basin that were assessed for injury include surface water; groundwater; bed, bank, and shoreline sediments; riparian and floodplain soils; aquatic biota, including both fish and aquatic invertebrates; wildlife, including birds, mammals, reptiles, amphibians; and vegetation. The area assessed for natural resource injuries includes the South Fork Coeur d'Alene River basin, tributary drainages to the South Fork Coeur d'Alene River in which mining and milling has occurred, the mainstem Coeur d'Alene River and lateral lakes and wetlands that border the lower river, and Coeur d'Alene Lake from the area near Conkling Point to the lake's outlet at the Spokane River.

The DOI has promulgated regulations for conducting NRDAs [43 CFR Part 11]. The Trustees relied on these regulations in assessing the natural resource damages. The application of these regulations is not mandatory, and the Trustees have the option of diverging from them as appropriate. However, assessments performed in compliance with these regulations have the force and effect of a rebuttable presumption in any administrative or judicial proceeding under CERCLA [42 U.S.C. § 9607 (f)(2)(C)].

S.1 RELEASE AND PATHWAY

Hazardous substances have been released from mining and mineral processing operations in the Coeur d'Alene River basin. Antimony, arsenic, cadmium, copper, lead, mercury, silver, and zinc. In particular, cadmium, lead, zinc, and compounds of these hazardous metals have been released from mining facilities. Sources of these releases of hazardous substances include smelter emissions, mill tailings, tailings piles and impoundments, waste rock piles, adit and seep drainage, and surface water, groundwater, sediments, and soils contaminated by releases.

Many of the releases went directly into the South Fork Coeur d'Alene River or its tributaries. The river's flow carried these hazardous substances downstream and deposited them in river, lake, and wetland sediments and on the banks and floodplains downstream. As a result of natural river flow and chemical processes, hazardous substances released from mining and mineral processing operations have been and continue to be remobilized and transported throughout the Coeur d'Alene River basin. These natural processes by which hazardous substances are transported in the basin are considered to be "pathways" [43 CFR § 11.14 (dd)].

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

Sediments suspended in the water column and deposited on the beds and banks of Coeur d'Alene River basin drainages downstream of mining and mineral processing facilities also have been, and continue to be, a transport and exposure pathway of hazardous substances, and in particular, cadmium, lead, and zinc. Measurements of metals in suspended sediments have demonstrated transport of elevated concentrations of cadmium, lead, and zinc in both the South Fork Coeur d'Alene River and the mainstem Coeur d'Alene River as far downstream as Harrison. Bed and bank sediments throughout the basin, including Canyon and Ninemile creeks, the South Fork Coeur d'Alene River, the mainstem Coeur d'Alene River and associated lateral lakes, and Coeur d'Alene Lake, contain elevated concentrations of cadmium, lead, and zinc and other hazardous substances.

Contaminated streambed sediment results in exposure of fish, periphyton (algae attached to rocks in streams and rivers), and aquatic invertebrates to cadmium, lead, and zinc and other hazardous substances. Contaminated sediment re-deposited on floodplains and on vegetation surfaces is the predominant cause of exposure of wildlife and vegetation to cadmium, lead, and zinc and other hazardous substances.

Floodplain soils and sediments have been and continue to be a transport and exposure pathway.[1] Floodplain and wetland soils and sediments have become contaminated with hazardous substances through direct discharge of wastes to the floodplain, and through deposition of contaminated sediments through natural hydrological processes. Floodplain soils are contaminated with hazardous substances, in particular cadmium, lead, and zinc, in riparian and wetland areas downstream of mining and mineral processing facilities, including in riparian areas of the South Fork Coeur d'Alene River, the mainstem Coeur d'Alene River to its mouth near Harrison, the lateral lakes of the Coeur d'Alene River, and Canyon, Ninemile, Moon, and Pine creeks. Contaminated floodplain soils serve as an ongoing transport pathway to downstream resources through mobilization by surface waters and through leaching by groundwater. Contaminated floodplain soils also serve as a pathway by which vegetation and wildlife are exposed to cadmium, lead, and zinc.

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

Biological resources serve as contaminant exposure pathways through dietary, food-chain relationships. Contaminated periphyton, aquatic and terrestrial invertebrates, and fish act as exposure routes of cadmium, lead, and zinc to higher trophic level consumers. Aquatic vegetation containing or coated with elevated concentrations of lead exposes waterfowl to lead through their diets.

S.2 EXPOSURE OF NATURAL RESOURCES TO HAZARDOUS SUBSTANCES

As a result of the above pathways, natural resources in the Coeur d'Alene Basin have been and continue to be exposed to elevated concentrations of the cadmium, lead, and zinc and other hazardous substances at and downgradient of releases from mining and mineral processing facilities.

1. The description of materials in a floodplain as soils or sediments is largely related to scientific discipline. Sediment is the term most frequently used by geologists, and soil by ecologists and biologists. Regardless of the nomenclature, soils and sediments are closely related spatially and functionally in riverine and riparian ecosystems. Both include substrates developed in place from weathering of parent materials and transported substrates, plus incorporated organic materials. Both are influenced by parent material in the uplands, weathering and erosion, fluvial mixing and sorting, deposition and burial, remobilization and redeposition, incorporation of organic materials, and geochemical transformations related to saturation and redox state. In this report, the terms "soils" and "sediments" are both used to describe substrate in the floodplains, banks, and wetlands of the basin.

Elevated concentrations of hazardous substances have been measured in surface waters, bed, bank, wetland, and shoreline sediments, and in riparian (streamside) soils downgradient of mining facilities in the South Fork Coeur d'Alene River, the mainstem Coeur d'Alene River, lateral lakes and wetlands of the Coeur d'Alene River, Canyon Creek, Ninemile Creek, Pine Creek, Moon Creek, Milo Creek, Portal Creek, Highland Creek, Denver Creek, and Nabob Creek, Grouse Gulch, Deadwood Gulch, Government Gulch, and Gorge Gulch. In addition, elevated concentrations of cadmium, lead, and zinc and other hazardous substances have been measured in surface waters and bed sediments of Coeur d'Alene Lake.

"Baseline"[2] concentrations of cadmium, lead, and zinc in surface water and sediments of the Coeur d'Alene River basin are low relative to concentrations in surface water and sediments near and downstream of sources of mining related waters. The elevated concentrations of hazardous substances measured downstream of mining sources are not naturally occurring. The metals that contaminate the basin are derived from mining and mineral processing operations.

Biological resources (such as fish, vegetation, wildlife) that rely on media such as surface water, soil, and sediments as part of their critical habitat are exposed to cadmium, lead, and zinc and other hazardous substances when these media are contaminated with hazardous metals. This exposure of biological resources to hazardous substances downstream of mining sources also has been confirmed through measurement of cadmium, lead, and zinc in biological tissues.

S.3 NATURAL RESOURCE INJURIES

As a result of this exposure to elevated concentrations of hazardous substances, and particularly cadmium, lead, and zinc, natural resources in the Coeur d'Alene River basin have been and continue to be injured.

Surface Water Injury

Surface water in the Coeur d'Alene River basin has been and continues to be injured as a result of releases of the hazardous substances cadmium, lead, and zinc. Surface waters of the Coeur d'Alene River basin are injured when concentrations and duration of hazardous substances exceed water quality criteria established by section 304(a)(1) of the Clean Water Act in surface waters that before the release met the criteria and are a committed use for aquatic life [43 CFR § 11.62 (b)(1)(iii)]. A committed use in this context means a current public use, including use as habitat for aquatic life [43 CFR § 11.14 (h)]. Based on State of Idaho use designations, U.S. Environmental Protection Agency water quality standards, and Coeur d'Alene Tribe water quality standards, the surface waters of the Coeur d'Alene River basin are currently designated for the protection and support of aquatic biota and therefore have a committed use.

2. Baseline concentrations are the concentrations of metals that would have existed absent the releases from mining and mineral processing operations.

Applicable water quality criteria are referred to as "Aquatic Life Criteria," or ALC. ALC include both "acute" and "chronic" criteria. The acute and chronic criteria specify concentrations of substances in water that cannot be exceeded for a specified average duration. The duration of exposure to water containing substances in concentrations exceeding the acute ALC is a 1-hour average. The exposure duration for chronic criteria is defined as a 4-day average concentration. Both values may not be exceeded more than once in a 3-year period. ALC for the hazardous substances cadmium, lead, and zinc are dependent on the "hardness"[3] of the water body. In general, the toxicity of cadmium, lead, and zinc to aquatic organisms decreases as water hardness increases. Therefore, exceedences of ALC are evaluated using the measured hardnesses of the surface water in question.

Concentrations of hazardous substances in surface water resources of the Coeur d'Alene River basin now exceed ALC, and have in the past have exceeded ALC, and the duration of exceedences also is sufficient to trigger exceedences of ALC. Given the substantial magnitude of the exceedences, as well as the very high percentage of samples collected during the past 30 years that exceed the ALC, the measured concentrations clearly meet both the 1-hour and 4-day average concentration standards. Moreover, exceedences are sufficiently frequent (approaching 100% of samples collected between 1967 and 1998) to indicate that the 3-year recovery period clearly is exceeded. Based on the concentration and duration of cadmium, lead, and zinc in surface water, these three hazardous substances exceed ALC and therefore cause injury.

Baseline water quality values for cadmium, lead, and zinc in the Coeur d'Alene River basin are low, as shown by the low concentrations of metals in stream segments upstream of mining operations in the basin and in streams draining unmined but mineralized tributary basins. Moreover, absent mining and mineral processing operations, even drainages with mineralized outcrops or near-surface mineral veins had low concentrations of cadmium, lead, and zinc in surface water. The ALC exceedences, and thus the surface water injuries, are caused by mining and mineral processing operations rather than by naturally occurring releases of metals.

Exceedences of ALC, and therefore surface water injuries, have been documented from the upper reaches of the South Fork Coeur d'Alene River (downstream of Daisy Gulch) to at least the lake outlet to the Spokane River (the downstream boundary of the assessment area). Exceedences also have been documented at the U.S. Geological Survey gauge station at Post Falls Dam on the Spokane River. Surface waters of the mainstem Coeur d'Alene River from the North Fork Coeur d'Alene River confluence to Coeur d'Alene Lake are injured, and surface waters of Coeur d'Alene Lake are injured. Exceedences of ALC have also been documented in tributaries of the South Fork Coeur d'Alene River, including Canyon Creek from approximately Burke to the mouth and Gorge Gulch downstream of the Hercules No. 3 adit; the East Fork and mainstem Ninemile Creek from the Interstate-Callahan Mine to the mouth; Grouse Gulch from the Star Mine waste rock dumps to the mouth; Moon Creek from the Charles Dickens Mine/Mill to the

3. Hardness is a measure of the concentration in water of two naturally occurring ions (calcium and magnesium), and is expressed in terms of concentrations of calcium carbonate.

mouth; Milo Creek from the Sullivan Adits to the mouth; Portal Gulch from the North Bunker Hill West Mine to the mouth; Deadwood Gulch/Bunker Creek from the Ontario Mill to the mouth; Government Gulch from the Senator Stewart Mine to the mouth; East Fork and mainstem Pine Creek from the Constitution Upper Mill to the mouth; Highland Creek from the Highland Surprise Mine/Mill and the Sidney (Red Cloud) Mine/Mill to the mouth; Denver Creek from the Denver Mine to the mouth; and Nabob Creek from the Nabob Mill to the mouth.

These exceedences of ALC confirm that surface waters have been injured as a result of releases of cadmium, lead, and zinc from mining and mineral processing operations. In addition, concentrations of hazardous substances in surface water are sufficient to cause injury to aquatic biological resources of the South Fork Coeur d'Alene River, the mainstem Coeur d'Alene River, and Coeur d'Alene Lake.

Sediment Injury

Sediment resources of the Coeur d'Alene Basin also are injured. Sediments include suspended sediments in the water column, and bed, bank, and floodplain sediments. Sediments carried in the water column are suspended sediments. Sediment resources are defined by DOI NRDA regulations both as geologic resources [43 CFR §11.14 (s)] and as a component of surface water resources [43 CFR § 11.14 (pp)]. However, because sediments represent a distinct component of the ecosystem, data on sediments are discussed separately from surface water. Injuries to sediments occur when concentrations and duration of hazardous substances are sufficient to have caused injury to other natural resources when exposed to sediments [43 CFR §11.62 (b)(1)(iv) and 43 CFR § 11.62 (e)(11)].

Coeur d'Alene River basin sediments containing elevated concentrations of lead and other hazardous substances are ingested by migratory birds. Ingestion of lead-contaminated sediments injures migratory birds in the Coeur d'Alene River basin, causing death and other adverse biological effects. Ingestion of prey contaminated by ingestion of lead-contaminated sediments also causes injury to predators. Therefore, sufficient concentrations of lead are present in sediments to cause injury to biological resources. In addition, concentrations of cadmium, lead, and zinc in sediments are sufficient such that sediments serve as a pathway of injury to surface water resources. As a result, sediments are injured.

Sediment injuries occur throughout the lateral lakes area and other wetland habitats in the basin where concentrations of lead in sediments exceed concentrations determined to cause both sublethal injuries and death to migratory birds. In addition, sediments throughout the floodplains of the South Fork Coeur d'Alene River and several of its tributaries, the mainstem Coeur d'Alene River, and Coeur d'Alene Lake contain hazardous substances in concentrations sufficient to serve as a pathway of injury to surface water.

Riparian Resources Injury

Surface water and sediments containing elevated concentrations of cadmium, lead, and zinc and other hazardous substances serve as transport and exposure pathways to floodplain soils of the Coeur d'Alene River basin. Floodplain soils and sediments in Canyon Creek, Ninemile Creek, Moon Creek, Pine Creek, the South Fork Coeur d'Alene River, and the lower Coeur d'Alene basin, including the Coeur d'Alene River and lateral lakes, contain elevated concentrations of cadmium, lead, and zinc. As a result, riparian vegetation is exposed to those hazardous substances.

Injury to riparian soils and vegetation is confirmed when hazardous substances are sufficient to cause a phytotoxic response (i.e., toxicity to plants), specifically, retardation of plant growth [43 CFR § 11.62 (e)(10)]. Injury also occurs when riparian vegetation suffers adverse changes in viability, specifically, reductions in vegetation cover, and simplification of community structure and composition [43 CFR § 11.62 (f)(1)(i)].

Floodplain soils of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River were found to be phytotoxic (i.e., cause toxicity to plants) relative to control soils. Plant growth performance in field-collected assessment soils was measured under controlled laboratory conditions. Plant growth in contaminated soils was reduced relative to control soils, and plant growth was significantly negatively correlated with concentrations of hazardous substances in the soils. Concentrations of cadmium, lead, and zinc in floodplain soils of Canyon Creek, Ninemile Creek, the South Fork Coeur d'Alene River, Moon Creek, and Pine Creek exceed phytotoxic threshold concentrations identified in the scientific literature, and the observed reductions in plant growth are consistent with the phytotoxic effects of cadmium, lead, and zinc as reported in the scientific literature.

In the riparian zones of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River, field studies show that extent of vegetation cover, species richness, and vegetation structural complexity are significantly negatively correlated with concentrations of cadmium, lead, and zinc in soils; percent cover of bare ground is significantly positively correlated with concentrations of these hazardous substances. In other words, increased concentrations of cadmium, lead, and zinc were related to increased bare ground and reduced vegetation.

Phytotoxic concentrations of cadmium, lead, and zinc in floodplain soils have resulted in significant and substantial reductions in riparian vegetative cover and an increase in the amount of bare ground in the riparian zones of Canyon Creek, Ninemile Creek, Moon Creek, Pine Creek, and the South Fork Coeur d'Alene River. The soil phytotoxicity and reductions in vegetation cover have resulted in significant reductions of habitat complexity and availability for wildlife species that inhabit riparian areas, and in deterioration of ecological functions.

Factors other than hazardous substances can cause impacts to vegetation. These factors include effects of fire, road construction, logging, grazing, road building and industrialization in the urban corridor, and other land uses. These other factors were considered as potential causes of the injuries observed in the Coeur d'Alene River basin. Riparian injury assessment studies were designed to sample vegetation cover, structure, and composition in reference stream reaches as well as in contaminated stream reaches. These reference areas were selected based on similarity of natural physical environmental controls on vegetation and on similarity of major nonmining environmental factors that affect plant growth and vegetation development. Reference areas incorporated historical effects of logging, splash dams and related erosion, road building, and channelization. Reference areas did not incorporate effects of urbanization, but sampling was not conducted in, and the riparian injury claim for vegetation, soils, and habitat does not include, urban riparian zones. Therefore, these other factors were considered in the design of the injury studies and are not the cause of the observed loss of vegetation in contaminated areas. The only factor that consistently explains the toxicity of the soils to plants and the continued preclusion of plant growth is the elevated concentrations of hazardous substances such as cadmium, lead, and zinc in the soils. Soil chemistry data, vegetation community measurements, phytotoxicity test results, and negative correlations between cadmium, lead, and zinc concentrations and plant growth in the laboratory, vegetative cover, species richness, and structural complexity in the field indicate that it is the elevated concentrations of these hazardous substances in floodplain soils of the upper Coeur d'Alene River basin that cause injury to riparian vegetation communities.

Injuries to riparian soils and vegetation caused by releases of the hazardous substances cadmium, lead, and zinc have occurred at and downstream of mining operations in the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, Pine Creek, and Moon Creek. The injuries to riparian soils and vegetation have substantially reduced the quality of riparian habitat. This, in turn, injures critical habitat that supports wildlife, aquatic biota, and other ecosystem functions.

Fish Injury

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 are exposed to hazardous substances through direct contact with surface water containing elevated concentrations of cadmium and zinc, and through food chain exposure. 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/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 water quality 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, the lower Coeur d'Alene River as far downstream as Harrison, and in 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 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, Coeur d'Alene Lake, 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 in fish population density is apparent in the river. Fish density is much greater in the South Fork Coeur d'Alene River upstream of the Canyon Creek confluence than downstream of it. 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.

Bird Injury

Migratory birds that rely on riparian, wetland, and open water habitats in the Coeur d'Alene River basin have been injured by hazardous substances. In the upper Coeur d'Alene River basin, birds such as migratory songbirds that rely on riparian habitats for food and cover have been injured as a result of the loss of vegetation in riparian zones of Canyon Creek, Ninemile Creek, Pine Creek, and Moon Creek, and the South Fork Coeur d'Alene River downstream of Canyon Creek. Migratory bird species (such as tundra swans, Canada geese, and various other species) have been injured as a result of direct ingestion of lead-contaminated sediments. In addition, migratory songbirds, which feed on insects, worms, and other invertebrates, exhibit physiological malfunctions from lead exposure, and are injured by ingestion of hazardous substances through dietary pathways.

Injuries to migratory birds include death [43 CFR § 11.62(f)(4)(v)], as demonstrated through wildlife kill investigations [43 CFR § 11.62(f)(4)(i)(C)] and controlled laboratory experiments [43 CFR § 11.62 (f)(4)(i)(E)]; physiological malfunctions [43 CFR § 11.62(f)(4)(v)], including inhibition of the blood-enzyme ALAD [43 CFR § 11.62(f)(4)(v)(D)], decreases in hemoglobin and hematocrit, increases in protoporphyrin (another chemical element of blood formation), and loss of body weight; and physical deformations [43 CFR § 11.62(f)(4)(vi)] such as lesions caused by exposure to lead at toxic concentrations.

The results of field investigations and controlled laboratory experiments demonstrate that death, physiological malfunctions, and physical deformation injuries to wildlife of the Coeur d'Alene River basin have occurred and continue to occur as a result of exposure to lead in Coeur d'Alene River basin sediments. Adverse effects that have been caused by lead exposure and have been observed in migratory birds in the field include death; physiological malfunctions, including changes in parameters related to impaired blood formation and impaired growth; and physical deformations, including gross and histopathological lesions in multiple tissues.

Laboratory studies have demonstrated a dose-response relationship between the magnitude of exposure to Coeur d'Alene River basin sediment and physiological malfunctions such as biochemical changes in waterfowl. The injury assessment studies demonstrated a causal relationship between increasing sediment ingestion and adverse changes in parameters related to blood formation in multiple species of waterfowl.

Ingestion of lead-contaminated soil and sediment is the pathway and cause of the injuries to migratory birds in the basin. Injury studies were designed to explicitly assess whether the observed deaths and sublethal injuries were caused by other agents, including lead artifacts (e.g., shot/sinkers), disease (e.g., aspergillosis, avian cholera), or other factors (e.g., trauma). Detailed evaluation of field observations and diagnostic histological studies demonstrated that the cause of the injuries was exposure to lead-contaminated sediments. Therefore, injuries to migratory birds are caused by hazardous substances, particularly lead, released from mining and mineral processing facilities.

Benthic Invertebrate Injury

Benthic invertebrates (invertebrates that live in and on the bottoms of streams, lakes, and wetlands) are an important source of food for juvenile and small fish. Benthic macroinvertebrates in the assessment area are exposed to elevated cadmium, lead, and zinc concentrations in surface water, sediment, and biofilm. Concentrations of cadmium and zinc to which assessment area benthic macroinvertebrates are exposed exceed concentrations shown to cause toxicity. Toxicity tests using water and sediment collected from the assessment area demonstrate that assessment area surface water and sediment are toxic to invertebrates under controlled laboratory conditions.

Benthic macroinvertebrate communities in the South Fork Coeur d'Alene, Canyon Creek, Ninemile Creek, and other stream/river reaches are injured by metals. Specifically, metal-sensitive species are largely absent from the invertebrate communities of these waterways downstream of mining activity. Community composition was found to be inversely related to zinc concentrations in surface water. Historical data also demonstrate that the invertebrate communities in the mainstem Coeur d'Alene River and Coeur d'Alene Lake were adversely affected in the past, but more recent data on the communities in these areas are not available to confirm that the effects are continuing. However, physical deformation injuries, specifically, chironomid mouthpart deformities resulting from metals exposure, may be ongoing in the South Fork and mainstem Coeur d'Alene rivers.

Natural Resource Injury Conclusions

The above-referenced information demonstrates that hazardous substances (particularly cadmium, lead, and zinc) have been released from mining and mineral processing facilities; that the released hazardous substances are mobile in the environment and have been transported downgradient via natural processes such as water and sediment flow; that the transported hazardous substances have, in turn, caused substantial contamination in surface water, groundwater, sediments, soils, vegetation, and biota; that this contamination has resulted from releases from mine facilities and is not naturally occurring; that exposure to the hazardous substances released has resulted in, and continues to result in, substantial injuries to surface water, sediments, riparian soils, riparian vegetation, riparian wildlife habitat, fish, aquatic invertebrates, and wildlife; that exposure to hazardous substances has caused substantial losses of habitat and habitat services for various species of fish, aquatic invertebrates, vegetation, and wildlife; and that the injuries observed to natural resources have been caused by exposure to metals as opposed to some other factor.

S.4 INJURY QUANTIFICATION

Injury quantification includes determination of the baseline condition and baseline services of the injured resources, determination of the extent of the injuries and the reduction in services resulting from the injuries, and determination of the recoverability of the injured resources [43 CFR 11.70 (c)].

The purpose of injury quantification is "for use in determining the appropriate amount of compensation" in an NRDA [43 CFR § 11.70 (b)]. Because the Trustees' claim for compensation (i.e., damages) will be based on calculation of restoration costs and must include consideration and estimation of losses residual to any remedial or response actions undertaken in the Coeur d'Alene River basin by the U.S. Environmental Protection Agency or other response agencies, final injury quantification cannot be performed until remedial and response actions are determined and the Trustees prepare a restoration plan. Thus, the initial quantification of injury presented in this report is subject to change.

Baseline Conditions

Baseline refers to the conditions that would have existed had the releases of hazardous substances not occurred [43 CFR § 11.14 (e)]. Baseline services normally provided by the injured resources [43 CFR 11.72 (a)] include:

- ***Surface water services,*** such as habitat for migratory birds and their supporting ecosystem; habitat for fish and their supporting ecosystem; habitat for benthic macroinvertebrates and aquatic, semiaquatic, and amphibious animals; water, nutrients, sediments for riparian vegetation and its supporting ecosystem; nutrient cycling; geochemical exchange processes; primary and secondary productivity and transport of energy (food) to downstream/downgradient organisms; growth media for aquatic and wetland plants; a migration corridor; and cultural services.

- ***Sediment services,*** such as providing habitat services for all biological resources that are dependent upon the aquatic habitats in the basin. In addition, bed sediment services contribute to services provided by surface water, including suspended sediment transport processes, security cover for fish and their supporting ecosystems, primary and secondary productivity, geochemical exchange processes, nutrient cycling and transport, and cultural services.

- ***Services provided by floodplain soils and sediments,*** such as habitat for all biological resources that are dependent upon riparian or floodplain wetland habitats in the basin. Floodplain soils and sediments provide habitat for migratory birds and mammals; habitat for soil biota; growth media for plants and invertebrates; primary productivity, carbon storage, nitrogen fixing, decomposition, and nutrient cycling; soil organic matter and energy (food) to streams; hydrograph moderation; geochemical exchange processes; and cultural services.

- ***Migratory bird services***, including providing prey for carnivorous and omnivorous wildlife, as well as existence values, food, recreational opportunities for humans, and cultural services.

- ***Fish services***, including providing food for other biota, existence values and recreational opportunities for humans, and cultural services.

- ***Riparian vegetation*** provides primary productivity; food and cover (thermal cover, security cover) for fish and migratory birds and mammals; feeding and resting areas for fish, and migratory birds and mammals; the migration corridor provided by the riparian zone; habitat for macroinvertebrates; nutrient cycling; soil/bank stabilization and erosion control; hydrograph moderation; and cultural services.

The services listed above are interdependent [43 CFR 11.71 (b)(4)] and interact to create a functional ecosystem. The injuries to natural resources have reduced individual resource services and services provided at the ecosystem level. The high degree of overlap in services affected by the injuries results from the fact that contaminated surface water and soil/sediment resources are now ubiquitous in parts of the basin downgradient of mining and milling operations, and the services provided by these resources are integral parts of an ecologically interdependent ecosystem. For this reason, injuries were quantified at the habitat level [43 CFR 11.71 (l)(1)]. The area where hazardous metal concentrations in surface water and soils/sediment resources exceed baseline concentrations and have reduced ability to sustain aquatic biota, vegetation, and habitat for wildlife was quantified relative to baseline [43 CFR 11.71 (h)(4)(i) and (k)(1,2)]. Baseline conditions for riparian vegetation cover, structure, and composition were also determined, since restoration of riparian vegetation in the upper basin is crucial to restoration of the Coeur d'Alene River basin ecosystem.

For baseline determination, floodplain soils and sediments and bed, bank, and suspended sediments from the Coeur d'Alene River basin were assessed collectively. Mean baseline concentrations for soil and sediment are 30 mg lead/kg dry weight of sediment (dw), 0.61 mg cadmium/kg dw, and 63 mg zinc/kg dw.

For surface water baseline determination, the Coeur d'Alene River basin was divided into three areas of ore deposit type. Median values for dissolved cadmium, lead, and zinc in the upper South Fork Coeur d'Alene River basin were 0.06, 0.15, and 5.35 μg/L, respectively. Median values for dissolved cadmium, lead, and zinc in the Page-Galena mineral belt area were 0.1, 0.44, and 9.04 μg/L, respectively. Median values for dissolved cadmium, lead, and zinc in the Pine Creek drainage were 0.03, 0.11, and 3.68 μg/L, respectively. For the South Fork Coeur d'Alene River basin as a whole, median baseline concentrations for the three metals were 0.06, 0.18, and 6.75 μg/L, respectively.

The riparian vegetation baseline data represent a range of site types reflecting elevational gradients, hydrologic gradients, valley shape, width, and orientation, and successional stages of patches of vegetation within the areas sampled. The characterization of riparian vegetation baseline condition focuses on parameters directly related to the injuries quantified: mean percent cover of bare ground (3.0%), mean percent cover of vegetation (139%),[4] mean species richness (17 total species), and mean structural complexity (4 layers present).

Surface Water Injury Quantification

The area of injured surface water resources was quantified as the area over which dissolved concentrations of cadmium, lead, or zinc exceed water quality criteria for the protection of aquatic biota (ALC). Within the assessment area, injured surface waters include a total of 181 km (113 miles):

- 107 km (67 miles) of the South Fork and mainstem Coeur d'Alene rivers from downstream of Daisy Gulch to the mouth at Coeur d'Alene Lake
- 11.3 km (7.0 miles) of Canyon Creek from approximately Burke to the mouth
- 11.6 km (7.2 miles) of East Fork and mainstem Ninemile Creek from the Interstate-Callahan Mine to the mouth
- 2.7 km (1.7 miles) of Milo Gulch from the Sullivan Adits to the mouth
- 4.0 km (2.3 miles) of Grouse Gulch from the Star Mine waste rock dumps to the mouth
- 5.0 km (3.1 miles) of Moon Creek from the Charles Dickens Mine/Mill to the mouth

4. The cover of vegetation can exceed 100% where multiple layers of vegetation overlap vertically.

- 0.9 km (0.5 miles) of Portal Gulch from the North Bunker Hill West Mine to the mouth
- 4.7 km (2.9 miles) of Deadwood Gulch/Bunker Creek from the Ontario Mill to the mouth
- 4.1 km (2.5 miles) of Government Gulch from the Senator Stewart Mine to the mouth
- 16.8 km (10.4 miles) of the East Fork and mainstem Pine Creek from the Constitution Upper Mill to the mouth
- 5.2 km (3.2 miles) Highland Creek from the Highland Surprise Mine/Mill and the Sidney (Red Cloud) Mine/Mill to the mouth
- 5.3 km (3.3 miles) Denver Creek from the Denver Mine to the mouth
- 0.5 km (0.3 miles) Nabob Creek from the Nabob Mill to the mouth.

In addition, injured surface waters include:

- the lateral lakes
- Coeur d'Alene Lake from near Conkling Point to the lake's outlet at the Spokane River.

Floodplain Soil and Sediment Injury Quantification

The extent of injury to floodplain soil and sediment in the upper basin was quantified as the area over which hazardous substance concentrations exceed baseline and have reduced the soil's ability to sustain vegetation and habitat for wildlife relative to baseline [43 CFR § 11.71 (h)(4)(i) and (k)(1-2)]. Vegetation cover mapping was used as a conservative indicator of soils with reduced ability to sustain vegetation and habitat for biota relative to baseline. The total area of barren or substantially devegetated floodplains along the South Fork Coeur d'Alene River downstream of the Canyon Creek confluence, Canyon Creek, Ninemile Creek, Moon Creek, and Pine Creek is 1,522 acres. This barren or sparsely vegetated area comprised greater than 80% of the available nonurban floodplain. Floodplains of the upper basin underlying urban development, which were not included in the riparian resources injury claim, also contain contaminated soils and sediments that may serve as a pathway of injury to surface water, via leaching by groundwater.

The extent of injury to soils and sediments of the lower basin was quantified as the area in the floodplain in which hazardous substance concentrations exceed baseline concentrations and have reduced ability to provide suitable (nontoxic) habitat for wildlife relative to baseline [43 CFR 11.71 (h)(4)(i) and (k)(1-2)]. Modeled predictions of lead concentration in surficial sediments were used to estimate the area of contaminated sediments that exceeded four threshold concentrations: 30 ppm lead, the geometric mean baseline concentration; 175 ppm lead, the upper 90th percentile of baseline concentration; 530 ppm lead, a lowest observed effect level for waterfowl; and 1,800 ppm lead, a lethal effect level for waterfowl. The area in which sediment lead concentrations exceed the lethal threshold is 15,368 acres, the area in which sediment lead concentrations exceed the lowest observed effect level for waterfowl is 18,298 acres, and the area in which sediment lead concentrations exceed the 90th percentile of baseline concentration is 18,558 acres. The area in which sediment lead concentrations exceed the geometric mean baseline concentration is 18,608 acres.

Resource Recoverability

Existing surface water data do not indicate declining hazardous substance concentrations with time during the past two decades. There is no clear evidence that maximum, minimum, or mean zinc concentrations have declined during that period. The data do not indicate that water quality is improving, nor do they allow projection of a date when conditions will return to baseline without cleanup or restoration actions.

Similarly, sediment data do not indicate that concentrations of cadmium, lead, and zinc in sediments are decreasing with time, nor do they allow projection of a date when conditions will return to baseline. Concentrations of cadmium, lead, and zinc in lower Coeur d'Alene River basin sediment samples collected recently (1990s) from the lower basin are similar to concentrations in samples collected previously, during the 1970s and 1980s.

Recovery of fish, benthic invertebrate, wildlife, and riparian resources is dependent on suitable habitat quality, which requires recovery of surface water, sediment, and floodplain soil resources. Once surface water, sediment, and floodplain soil resources have recovered to a condition that will support biological resources, recovery of the Coeur d'Alene River basin ecosystem will be constrained by the rate of natural physical and biological recovery (vegetation reestablishment and physical habitat rebuilding by natural hydrologic, geologic, and biological processes).

For wildlife resources of the lower basin, recovery will occur rapidly once sediments are nontoxic, since physical modifications resulting from sediment injuries are not negatively affecting habitat use. For fish and benthic macroinvertebrates, when surface water and sediment conditions improve, both can move from upstream clean reaches and clean tributaries to recolonize the recovered areas. Recovery time for fish also will include time required for reestablishment of physical features of habitats that were degraded as a result of the injuries, such as overhanging banks, vegetative overhang, and pools created by woody debris and roots. Natural recovery of the aquatic physical habitat of the upper basin will depend strongly on recovery of riparian resources.

Natural recovery time for riparian resources will depend on time required for floodplain soils to become diluted to nonphytotoxic levels, followed by primary vegetation succession, organic soil development, and development of vertically and horizontally diverse vegetation communities. Natural recovery of riparian resources includes development of vegetation that will overhang the stream, modulate stream temperatures, and provide security cover for fish. It includes recovery of riparian vegetation to the point where the vegetation provides habitat structure (e.g., large woody debris; bank stabilization) and a source of energy (i.e., detritus) to the aquatic ecosystem. It also includes reestablishment of diverse early and late successional vegetation and the expected range of terrestrial habitat features (e.g., mature tree boles for tree-cavity nesting birds).

Throughout the Coeur d'Alene River basin, the hazardous substances cadmium, lead, and zinc are the cause of the injuries described in this report. Existing concentrations of cadmium, lead, and zinc in the basin, ongoing releases of these hazardous substances from sources, and ongoing transport and exposure pathways limit natural recovery of the injured resources. There will be little recovery unless releases from sources are eliminated and transport and exposure pathways are eliminated. Existing surface water and sediment data show no evidence of either elimination of sources or pathways over the last 20 to 30 years. Therefore, it is reasonable to expect that natural recovery of the Coeur d'Alene River basin ecosystem will take hundreds of years.

Next

CHAPTER 1
INTRODUCTION

The U.S. Department of the Interior (DOI), U.S. Department of Agriculture (USDA), and Coeur d'Alene Tribe (collectively, the Trustees) have undertaken a natural resource damage assessment (NRDA) to assess damages resulting from releases of hazardous substances from mining and mineral processing operations in the Coeur d'Alene River basin, Idaho. Section 107 of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) [42 U.S.C. § 9607], Section 311 of the Federal Water Pollution Control Act (CWA) [33 U.S.C. § 1321], and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) [40 C.F.R. Part 300] provide authority to the Trustees to seek such damages.

This report presents the results of the injury determination studies, as well as an initial quantification of the injuries to natural resources.

The DOI has promulgated regulations for conducting NRDAs [43 CFR Part 11]. The Trustees have relied on these regulations in assessing the natural resource damages. The application of these regulations is not mandatory, and the Trustees have the option of diverging from them as appropriate. However, assessments performed in compliance with these regulations have the force and effect of a rebuttable presumption in any administrative or judicial proceeding under CERCLA [42 U.S.C. § 9607 (f)(2)(C)].

This report of injury assessment and injury determination follows the 1991 "Preassessment Screen of Natural Resource Damages in the Coeur d'Alene Watershed Environment from Mining and Related Activities Taking Place in and about the Bunker Hill Superfund Site," the Phase 1 (Injury Determination) Assessment Plan (Ridolfi, 1993), and the Phase II (Injury Quantification and Damage Determination) Assessment Plan of 1996 (U.S. Fish and Wildlife Service, U.S. Department of the Interior and Coeur d'Alene Tribe, 1996).

In subsequent reports, the results of the damage determination and restoration planning phases of the NRDA will be documented. Figure 1-1 presents an overview of this regulatory process.

1.1 INJURY ASSESSMENT

The purpose of the injury determination phase of an NRDA is to determine whether natural resources of the Coeur d'Alene River basin have been injured as a result of releases of hazardous substances [43 CFR § 11.61], and to identify the environmental pathways by which injured resources have been exposed to hazardous substances [43 CFR § 11.63]. DOI regulations define "injury" as a:

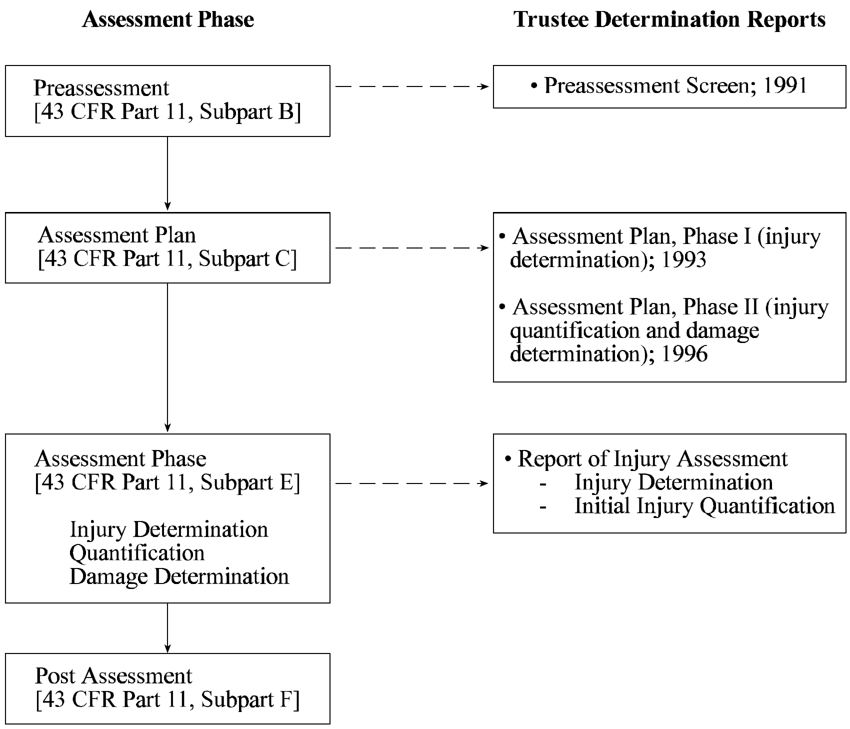

Figure 1-1. Overview of regulatory process and relationship to release of key NRDA determination reports. See 43 CFR § 11.13.

> . . . measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a release of a hazardous substance, or exposure to a product of reactions resulting from the release of a hazardous substance [43 CFR § 11.14 (v)].

The overall injury assessment process includes the following phases:

1. **Injury Definition.** In the injury definition phase, adverse effects to natural resources that have resulted from releases of hazardous substances, and that meet the definitions of injury in 43 CFR § 11.62, as well as other relevant injury categories, are determined.

2. **Pathway Determination.** In the pathway determination phase, exposure pathways for transport of hazardous substances to injured natural resources are identified [43 CFR § 11.63]. The pathway determination phase connects the injury to the releases of hazardous substances.

These first two steps constitute the "injury determination" phase of the injury assessment and are the focus of this report.

The final component of the injury assessment phase is "injury quantification," in which the injuries that have been determined are quantified in terms of changes from "baseline conditions" [43 CFR § 11.70 (a)]. Specific steps in the quantification phase included measuring the extent of injury relative to baseline conditions[1] and quantifying the spatial and temporal extent of injury [43 CFR § 11.71 (b)]. This report presents an initial quantification of injury. However, the purpose of injury quantification is "for use in determining the appropriate amount of compensation" in an NRDA [43 CFR § 11.70 (b)]. Because the Trustees' claim for compensation (i.e., damages) will be based on calculation of restoration costs and must include consideration and estimation of losses residual to any remedial or response actions undertaken in the Coeur d'Alene River basin by the U.S. Environmental Protection Agency or other response agencies, final injury quantification cannot be performed until remedial and response actions are determined and the Trustees prepare a restoration plan. Thus, the initial quantification of injury presented in this report is subject to change.

1.2 CONTENTS OF THE REPORT OF INJURY ASSESSMENT

This report of injury assessment describes the results of the injury determination studies and the initial quantification of those injuries. Sources of hazardous substances released into the Coeur d'Alene River basin environment are identified and described, and environmental pathways by which hazardous substances have been transported throughout the Coeur d'Alene River basin, and by which natural resources have come to be exposed to released hazardous substances, are identified and described. Injuries to natural resources are defined, and information and data used in the determination of injuries to various natural resources are presented.

Natural resources include the land, fish, wildlife, biota, air, and water belonging to, managed, held in trust, appertaining to, or otherwise controlled by the United States, any state or local government, or any Indian tribe [43 CFR § 11.14 (z)]. The natural resources addressed in this report include:

- surface water
- sediments
- wildlife
- fish

1. Baseline conditions are the conditions that "would have existed at the assessment area had the . . . release of the hazardous substance . . . not occurred" [43 CFR § 11.14 (e)] and are the conditions to which injured natural resources should be restored [43 CFR § 11.14 (ll)].

- aquatic invertebrates
- riparian soils and vegetation.

The area assessed for natural resource injuries includes the South Fork Coeur d'Alene River basin, tributary drainages to the South Fork Coeur d'Alene River in which mining and milling has occurred, the mainstem Coeur d'Alene River and lateral lakes and wetlands that border the lower river, and Coeur d'Alene Lake from the mouth of the Coeur d'Alene River at Harrison to the lake's outlet at the Spokane River.

Finally, an initial quantification of the injuries determined to have occurred is presented. The quantification includes an analysis of baseline conditions, quantification of the extent of injury, and an initial determination of resource recoverability without other response or restoration actions.

1.3 DESCRIPTION OF THE COEUR D'ALENE RIVER BASIN AND NATURAL RESOURCES ASSESSED

The Coeur d'Alene River originates near the Idaho-Montana border and flows west, draining approximately 3,810 km^2 of the western slope of the Bitterroot Mountains (Beckwith et al., 1997) (Figure 1-2). The North and South Forks of the Coeur d'Alene River are rocky, high-gradient streams in narrow valleys confined by steep hillsides. The North and South Forks converge to form the mainstem Coeur d'Alene River. The mainstem Coeur d'Alene River is a fine substrate, low gradient, meandering river in a broad valley. In the broad valley, 12 shallow lateral lakes and thousands of acres of wetlands are hydraulically connected to the mainstem Coeur d'Alene River. The mainstem Coeur d'Alene River flows into Coeur d'Alene Lake near Harrison. Coeur d'Alene Lake is a large natural lake fed mainly by the Coeur d'Alene River and the St. Joe River. Coeur d'Alene Lake discharges to the Spokane River at the north end of the lake.

In the headwater and tributary areas, predominant land uses include mining, mineral processing, forestry, and urban and residential land use. The towns of Mullan and Wallace, a discontinued railroad, a state highway, and Interstate 90 parallel border the South Fork Coeur d'Alene River. In the narrow tributary canyons, small communities, dispersed residences, and roads border the streams.

The floodplain of the South Fork Coeur d'Alene River from Wallace to Pinehurst is characterized by urban and industrial land uses. These include a discontinued railroad, a state highway, the interstate, and the towns of Osburn, Kellogg, Smelterville, and Pinehurst. The river has been channelized along much of this reach by the railroad and roads.

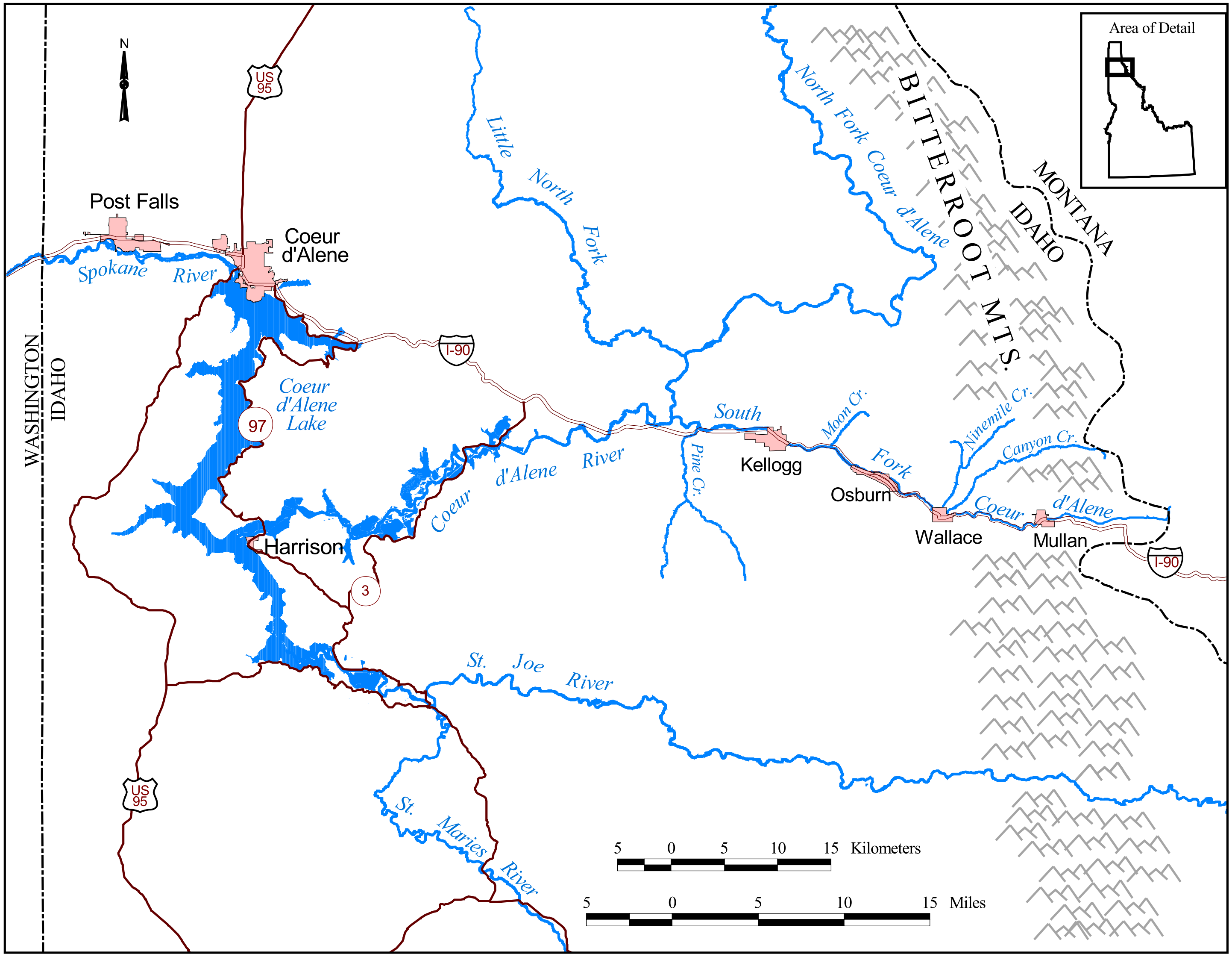

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Figure 1-2. Map of Coeur d'Alene River basin.

Land use along the lower Coeur d'Alene River, its floodplain, and the lateral lakes area is predominantly agricultural, residential, and recreational. The discontinued railroad runs through the floodplain, and associated berming has modified water flow between several of the lakes and the river. Agricultural use is largely hay and pasture.

1.3.1 General Geology and Mineralogy of the Coeur d'Alene District

The geology of the Coeur d'Alene District is dominated by partially metamorphosed sedimentary rocks of late Precambrian age belonging to the Belt Supergroup. These rocks are predominantly argillite (sedimentary rock composed of silt and/or clay) and quartzite, with lesser amounts of disseminated dolomite and limestone in the upper part of the section. The Belt Supergroup rocks were originally deposited in a geosyncline and cover a large area, including north and central Idaho, western Montana, southeastern British Columbia, and Alberta. Belt rocks in the Coeur d'Alene area are the host rock for the ore deposits that have been mined in the basin. Igneous monzonite intrusions (a granite-like rock) of Cretaceous age cut through the Belt rocks north of the South Forth Coeur d'Alene River in the Ninemile/Canyon Creek area (known as the "Gem Stocks") and the area to the west of Ninemile Creek ("Dago Stocks") (Hobbs et al., 1965; Gott and Cathrall, 1980). Detailed geologic maps of the district are shown in Chapter 10.

The Belt rocks in the Coeur d'Alene District are cut by a complex series of faults, the largest of which is the 100-mile-long Osburn fault. This fault follows the valleys of the South Fork Coeur d'Alene River in Idaho and the St. Regis River and parts of the Clark Fork River in Montana (Hobbs et al., 1965). The Osburn fault is part of an extensive fault called the Lewis and Clark line, which extends for approximately 500 miles from south-central Montana to Spokane, Washington (Hobbs et al., 1965). The Osburn fault is a strike-slip fault with approximately 16 miles of lateral (roughly east-west) displacement. It is widely believed that the ore bodies were originally formed in this "structural knot" and then separated and moved along the Osburn fault. For example, the two main areas of mineralization — Kellogg south of the fault and the Mullan-Burke area north of the fault — are separated by approximately 16 miles.

The ore deposits of the Coeur d'Alene District occur predominantly as high grade veins consisting of variable amounts of sphalerite (zinc sulfide, ZnS), galena (lead sulfide, PbS) and argentiferous tetrahedrite (an arsenic-antimony sulfide with varying proportions of copper, iron, zinc and/or silver) ($(Cu,Fe,Zn,Ag)_{12}(Sb,As)_4S_{13}$) (White, 1998). The non-ore minerals in the veins consist mostly of quartz (SiO_2) or siderite (ferrous iron carbonate, $FeCO_3$).

1.3.2 Valley Morphology

Valley shape in the Coeur d’Alene River basin can be grouped as V-shaped canyons, U-shaped canyons, and broad basins. The South Fork Coeur d’Alene River upstream of Wallace is confined by a V-shaped canyon. Canyon, Ninemile, Moon, Lake, Big, and upper Pine creeks are also V-shaped canyons. These reaches have high gradients, are largely incised, and are channelized in places, either naturally by bedrock, or by roads, railroads, and mining-related disturbances.

Downstream of Wallace, the South Fork flows through a U-shaped canyon. Stream and valley gradients in these areas decrease relative to gradients upstream. The valley bottom and floodplains widen, although topographic features impose localized channel constriction. Near Osburn and from Kellogg to Smelterville, the canyon widens further. Within these depositional reaches, the gradient is lower and the floodplain is substantially wider. These areas are highly modified by industrial, urban, and residential land use. The lower North Fork of the Coeur d’Alene River (the North Fork) and Little North Fork, lower Canyon Creek, lower Big Creek, and lower Pine Creek also open into U-shaped canyons.

Downstream of Enaville and the confluence with the North Fork, the Coeur d’Alene River is deeper, slower moving, and the sinuosity increases. The valley opens into a broad alluvial basin, with the floodplain width exceeding one mile in places. The river is bordered by 12 lateral lakes ranging in size from less than 85 acres to over 600 acres (Ridolfi, 1993). Thousands of acres of wetlands are associated with the lateral lakes.

The Coeur d’Alene River flows into Coeur d’Alene Lake near Harrison, ID. Coeur d’Alene Lake is a large natural lake fed mainly by the Coeur d’Alene River and the St. Joe River. The drainage area of Coeur d’Alene Lake is approximately 3,440 square miles (Woods and Beckwith, 1997). Coeur d’Alene Lake discharges to the Spokane River at the north end of the lake. Lake elevation is controlled by the Post Falls Dam on the Spokane River near the Idaho-Washington state line. The normal full pool elevation for the Coeur d’Alene Lake is 2,128 feet msl (WWPC, 1996). At this elevation, the lake’s surface area is approximately 50 square miles, mean depth is about 72 feet, and maximum depth is about 209 feet (CLCC, 1996). Operation of the Post Falls Dam also affects the surface water elevation and hydraulics of the lower segments of the mainstem Coeur d’Alene River and lateral lakes.

1.3.3 Ecological Communities

Terrestrial and Wetland Communities

In the high-gradient, headwater, V-shaped canyons, and in the medium gradient, U-shaped canyons, terrestrial communities include riparian and upland communities. Where local gradient allows, wetland communities may also occur (or may have been present in the past). Riparian communities in the narrow V-shaped canyons (based on sampling conducted in reference areas for the riparian resources injury assessment, see Chapter 9) are dominated by thinleaf alder (*Alnus incana*), snowberry (*Symphoricarpos albus*), bush honeysuckle (*Lonicera involucrata*), and goldenrod (*Solidago* spp.) in the shrub layer, and wild ginger (*Asarum caudatum*), aster (*Aster modestus*), lady fern (*Athyrium filix-femina*), red top bentgrass (*Agrostis stolonifera*), violet (*Viola glabella*), bluebell (*Mertensia paniculata*), fescues (*Festuca* spp.), and oxeye daisy (*Chrysanthemum leucanthemum*) in the herbaceous layer (Table 1-1). Black cottonwood (*Populus trichocarpa*) and conifers such as grand fir (*Abies grandis*), white pine (*Pinus monticola*), and, in higher elevations, western hemlock (*Tsuga heterophylla*) may also be present in the riparian zone.

In U-shaped, open riparian reference areas where the stream meanders more, willow (*Salix* spp.) communities develop on point bars. Black cottonwood, Rocky Mountain maple (*Acer glabrum*), grand fir, western hemlock, and western red cedar (*Thuja plicata*) are typical canopy layer dominants (Table 1-2). Historically, the valley flats along the South Fork Coeur d'Alene River were dominated by western red cedar stands. Dominant shrub species in reference areas include willows, thinleaf alder, cascara (*Rhamnus purshiana*), ninebark (*Physocarpus malvaceous*), serviceberry (*Amelanchier alnifolia*), snowberry, red-osier dogwood (*Cornus stolonifera*), and mockorange (*Philadelphus lewisii*). Typical herbaceous layer dominants include mosses, bluebell, lady fern, redtop bentgrass, reed canarygrass (*Phalaris arundinacea*), sedges (*Carex* spp.), marsh cinquefoil (*Potentilla palustris*), and Solomon-seal (*Smilacina stellata*).

The structure and composition of upland plant communities are strongly influenced by the length of the growing season, moisture availability, and the seasonal distribution of moisture. Gross physical factors that control moisture availability and growing season length include elevation, slope, and aspect. High points near the headwaters of the South Fork Coeur d'Alene River (upstream of Mullan) and in the upstream reaches of Canyon and Ninemile creeks range from approximately 5,000 to 6,600 ft. Between Wallace and Kellogg, high points adjacent to the riparian corridor are generally within the 3,000 to 4,500 ft elevation range, and between Kellogg and Cataldo, 2,000 to 3,500 ft. South facing slopes are typically warmer and drier and support more xeric shrubland and grassland communities. North facing slopes tend to be heavily forested with conifers. Valley bottoms generally stay cooler than slopes with a southerly or westerly aspect, partially a result of diurnal temperature fluctuation and cold air drainage down valley. Additional orographic effects may produce cold-air pockets that result in localized vegetation response.

Table 1-1
Typical Dominant Vegetation Species in Coeur d'Alene River Reference Riparian Communities

Narrow V-Shaped Canyons			Open U-Shaped Canyons		
Herbaceous layer:	wild ginger	*Asarum caudatum*	Herbaceous layer:	bluebell	*Mertensia paniculata*
	aster	*Aster modestus*		lady fern	*Athyrium filix-femina*
	lady fern	*Athyrium filix-femina*		redtop bentgrass	*Agrostis stolonifera*
	red top bentgrass	*Agrostis stolonifera*		reed canarygrass	*Phalaris arundinacea*
	violet	*Viola glabella*		sedges	*Carex* spp.
	bluebell	*Mertensia paniculata*		marsh cinquefoil	*Potentilla palustris*
	fescues	*Festuca* spp.		Solomon-seal	*Smilacina stellata*
	oxeye daisy	*Chrysanthemum leucanthemum*		moss spp.	
Shrub layer:	thinleaf alder	*Alnus incana*	Shrub layer:	willows	*Salix* spp.
	snowberry	*Symphoricarpos albus*		thinleaf alder	*Alnus incana*
	bush honeysuckle	*Lonicera involucrata*		cascara	*Rhamnus purshiana*
	goldenrod	*Solidago* spp.		ninebark	*Physocarpus malvaceous*
				serviceberry	*Amelanchier alnifolia*
				snowberry	*Symphoricarpos albus*
				redosier dogwood	*Cornus stolonifera*
				mockorange	*Philadelphus lewisii*
Tree layer:	black cottonwood	*Populus trichocarpa*	Tree layer:	black cottonwood	*Populus trichocarpa*
	grand fir	*Abies grandis*		grand fir	*Abies grandis*
	white pine	*Pinus monticola*		western hemlock	*Tsuga heterophylla*
	western hemlock	*Tsuga heterophylla*		western red cedar	*Thuja plicata*
				Rocky Mountain maple	*Acer glabrum*

Table 1-2
Typical Dominant Upland Vegetation Species in the Coeur d'Alene River Basin

North, east facing slopes:	western hemlock	*Tsuga heterophylla*
	western red cedar	*Thuja plicata*
	western white pine	*Pinus monticola*
	western larch	*Larix occidentalis*
	lodgepole pine	*Pinus contorta*
South, west facing slopes:	Douglas fir	*Pseudotsuga menziesii*
	grand fir	*Abies grandis*
	Ponderosa pine	*Pinus ponderosa*
Dry south facing slopes:	redtop bentgrass	*Agrostis stolonifera*
	bluebunch wheatgrass	*Agropyron spicatum*
	pinegrass	*Calamagrostis rubescens*
	tufted hairgrass	*Deschampsia cespitosa*
	ceanothus	*Ceanothus velutinus*
	huckleberry	*Vaccinium membranaceum*
	serviceberry	*Amelanchier alnifolia*
	chokecherry	*Prunus virginiana*
	mountain ash	*Sorbus* spp.
	ninebark	*Physocarpus malvaceous*
	snowberry	*Symphoricarpos albus*
	wild rose	*Rosa* spp.

Upland forest communities characteristic of north and east facing slopes are often dominated by western hemlock and western red cedar, along with western white pine, western larch (*Larix occidentalis*), and lodgepole pine (*Pinus contorta*) (Table 1-2). On south and west facing slopes, Douglas fir (*Pseudotsuga menziesii*), grand fir, and Ponderosa pine (*Pinus ponderosa*) are typical dominants. On the dry south facing slopes, grasses such as redtop bentgrass, bluebunch wheatgrass (*Agropyron spicatum*), pinegrass (*Calamagrostis rubescens*), and tufted hairgrass (*Deschampsia cespitosa*) and the shrub species ceanothus (*Ceanothus velutinus*), huckleberry (*Vaccinium membranaceum*), serviceberry, chokecherry (*Prunus virginiana*), mountain ash (*Sorbus* spp.), ninebark, snowberry, and wild rose (*Rosa* spp.), among others, are common.

Along the lower Coeur d'Alene River and lateral lakes, and the bays of Coeur d'Alene Lake, community types include riparian, palustrine, and lacustrine communities. These community types are differentiated by the predominant vegetation species and, particularly, the moisture tolerance of the dominant vegetation species. Riparian communities are typically dominated by black cottonwoods and willows in the overstory, and Douglas spiraea (*Spiraea douglasii*), willows, and red-osier dogwood in the shrub layer. The herbaceous layer may be quite diverse, with no single species dominant, although typical species include redtop, reed canarygrass, and sedges.

Palustrine and lacustrine communities are the dominant communities of the lateral lake wetlands. Palustrine wetlands are dominated by emergent wetland vegetation. Dominant species include sedges, rushes (*Juncus* spp.), horsetail (*Equisetum arvense*), cattail (*Typha latifolia*), wild rice (*Zizia aquatica*), common reeds (*Phragmites australis*), bulrushes (*Scirpus microcarpus*), and water potatoes (*Sagittaria latifolia*). Lacustrine vegetation is characterized by submergent and floating vegetation, including duckweed, potamogeton, and algae.

The riverine community also provides habitat for terrestrial wildlife (e.g., moose, elk, white-tailed deer, mule deer, beaver, bats, frogs, dippers). Agricultural communities, predominantly pastureland and hayfields, also provide habitat for migratory birds such as bobolink (*Dolichonyx oryzivorus*) during the summer and waterfowl when fields are flooded in the spring.

Each of these vegetation community types is inhabited by mammalian and avian populations, and to a lesser extent, amphibian and reptilian populations. The wildlife inhabitants are an integral part of the riparian, wetland, and upland communities. Wildlife may use several vegetation community types, and habitat use may extend into the aquatic environment. Wildlife species typical of each of the community types are described in more detail below. In addition to the visible flora and fauna, associated with each of these communities is the below-ground community of macro- and microinvertebrates and fungi that are essential to decomposition, nutrient cycling, and soil formation.

Aquatic Communities

Aquatic communities include high-gradient cold water, midgradient cold water, low-gradient cool and cold water, and warm, cool, and cold water lake communities.

High-gradient cold water communities are characterized by native cutthroat and bull trout, sculpin, possibly whitefish, and introduced rainbow and brook trout. Benthic macroinvertebrate communities include craneflies (Tipulidae), stoneflies (Plecoptera), mayflies (Ephemeroptera), and caddisflies (Tricoptera). Periphyton and some zooplankton are also present.

Midgradient reaches support the fish species listed above, plus whitefish, suckers, squawfish, dace, stonerollers, and introduced salmon. Brown trout are present in the Spokane River. Benthic invertebrate communities include the taxa identified above. Periphyton and zooplankton are also present.

Low-gradient communities include native cutthroat trout, bull trout, and whitefish, and introduced rainbow trout, brook trout, kokanee salmon, and chinook salmon. The lateral lakes also support warm water fish, including largemouth bass, northern pike, yellow perch, black crappie, brown bullhead, and pumpkinseed.

In Coeur d’Alene Lake, both cold and warm water species are present. Native species include cutthroat trout, bull trout, and tench. Introduced cold water species include chinook and kokanee salmon. Warm water species include largemouth bass, northern pike, crappie, yellow perch, bluegill, brown bullhead, pumpkinseed, squawfish, and smallmouth bass.

1.3.4 Trophic Relationships

Figures 1-3 and 1-4 illustrate trophic relationships in the Coeur d’Alene ecosystem. While these figures do not identify rates or magnitudes of energy transfer or specific species essential to the food chain, they do identify groups of organisms essential to maintenance of energy transfer in ecological systems of the basin. These groups must be functional (surviving, reproducing, storing carbon) to provide a food base for the next level. These figures also identify potential exposure pathways of metals to organisms in the environment and potential pathways for indirect exposure or effects. Species characteristic of the more visible trophic groups in each geographic unit are discussed as examples. The species listings are not intended to be complete.

Energy flows from the vegetation, the primary producers, through a web of herbivorous and carnivorous invertebrates to avian and mammalian insectivores, e.g., woodpecker (*Picoides* sp.), robin (*Turdus migratorius*), song sparrow (*Melospiza melodia*), Swainson thrush (*Passerculus sandwichensis*), shrews (*Sorex* sp.). At the top of the upland insectivorous food web (the bottom of Figure 1-4) are avian and mammalian carnivores. Energy also flows from riparian vegetation to mammalian and avian herbivores (e.g., white tailed deer [*Odocoileus virginianus*], mule deer [*Odocoileus hemionus*], elk [*Cervus elaphus*], red squirrel [*Tamiasciurus hudsonicus*], deer mouse [*Peromyscus maniculatus*], meadow vole [*Microtus pennsylvanicus*], cedar waxwing [*Bombycilla cedrorum*], and other neotropical migrants) to mammalian carnivores (e.g., cougar [*Felis concolor*], wolf [*Canis lupus*], marten [*Martes americana*], fisher [*Martes pennanti*]). Omnivorous wildlife species (e.g., ruffed grouse [*Bonasa umbellus*], jays [e.g., *Perisoreus canadensis*], black bear [*Ursus americanus*], coyote [*Canis latrans*]) feed on invertebrates, avian and mammalian insectivores and herbivores, as well as vegetation. In the riparian community, amphibians (frogs) may also be present. These feed on both vegetation and invertebrates, and are preyed upon by avian and mammalian carnivores and omnivores. Soil biota/decomposers appear at the primary level of both the upland and riparian food webs as an energy and nutrient source to vegetation, but at all levels of the food chain, arrows could return to the soil biota/decomposer category, representing energy cycling in the ecosystem.

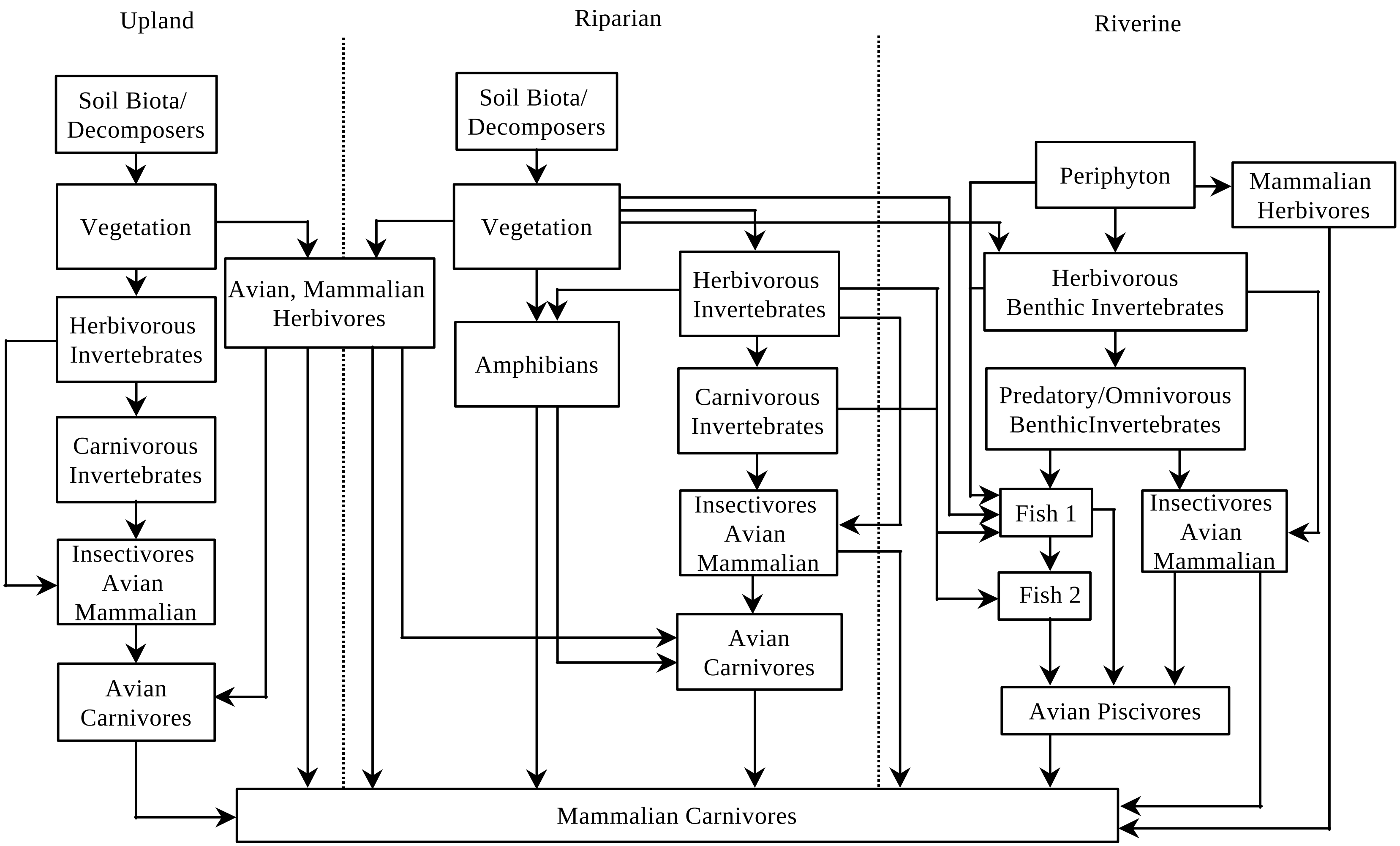

Figure 1-3. Trophic relationships in upland, riparian, and riverine communities of Coeur d'Alene River basin.

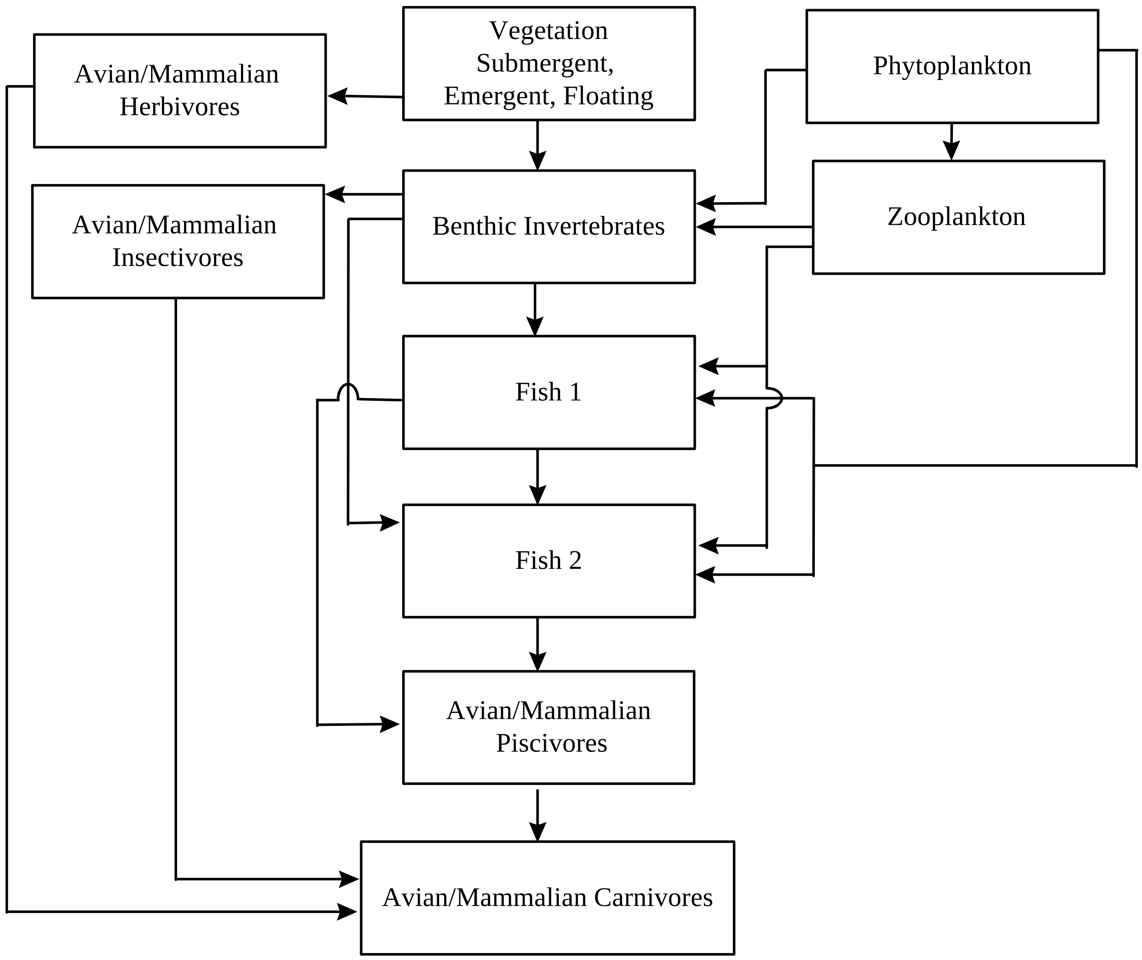

Figure 1-4. Trophic relationships of palustrine and lacustrine communities of the Coeur d'Alene River lateral lakes and Coeur d'Alene Lake.

The riverine food chain derives energy from allochthonous inputs[2] by riparian vegetation as well as phytoplankton and periphyton. Energy generally flows from the primary producers to herbivorous and omnivorous benthic invertebrates, then to carnivorous and omnivorous benthic invertebrates. The aquatic food chain is strongly size dependent — for benthic organisms, predator-prey relationships are constrained by organism size. Benthic invertebrate functional feeding groups include collectors/carnivores, grazers, scrapers, shredders, piercers/suckers, and filter feeders. Water column/benthic feeders (e.g., suckers) feed directly on phytoplankton, periphyton, and detritus. Small fish, insectivorous birds (e.g., dippers [*Cinclus mexicanus*] on headwater and tributary streams; spotted sandpipers [*Actitis macularia*] and swallows

2. Allochthonous material is derived from outside the community. Allochthonous input to streams is organic material derived from the adjacent or upstream terrestrial ecosystem, or material transported from upstream aquatic primary producers.

[e.g., *Hirundo pyrrhonota*] on midgradient streams), and mammals (e.g., bats [*Myotis* sp.]) feed on benthic and terrestrial invertebrates. As with invertebrates, feeding relationships among fish are more dependent on size than species: small fish (e.g., <100 mm) feed primarily on benthic invertebrates (and some terrestrial invertebrates) and periphyton; larger fish (e.g., >100 mm) feed on smaller fish. Avian piscivores (e.g., common merganser [*Mergus merganser*], osprey [*Pandion haliaetus*]) more typically inhabit midgradient reaches of the basin than high-gradient headwater and tributary reaches. Omnivores (e.g., mallards [*Anas platyrhynchos*], wood ducks [*Aix sponsa*], and long-toed salamanders [*Ambystoma macrodactylum*]) feed on invertebrates as well as vegetative food items. Species that are primarily terrestrial also comprise a part of the riverine food chain: mammalian herbivores such as moose *(Alces alces)*, elk, white-tailed deer, and mule deer feed on rooted aquatic macrophytes and periphyton. These species, along with avian piscivores, may ultimately be preyed upon by mammalian carnivores.

In the lower basin, primary producers include aquatic macrophytes, phytoplankton, and periphyton. Allochthonous inputs are substantial as well. Mammalian herbivores in the lower reaches include beaver *(Castor canadensis)* and the larger mammals listed previously. Riparian insectivores include neotropical migrants (e.g., robin, song sparrow, Savannah sparrow [*Passerculus sandwichensis*]), swallows, shrews, long-toed salamanders, toads *(Bufo boreas)*, and bats. The diversity of piscivores is greater in the lower river than in the upper river. Lower river piscivores include birds (e.g., common merganser, red-necked grebe [*Podiceps grisegena*], osprey, loon [*Gavia immer*], great blue heron [*Ardea herodias*], kingfisher [*Megaceryle alcyon*]), mammals (e.g., mink [*Mustela vison*], river otter [*Lutra canadensis*]), and reptiles. Avian and mammalian carnivores in the lower river system include great horned owl *(Bubo virginianus)*, western screech owl *(Otus asio)*, northern harrier *(Circus cyaneus)*, other accipiters, and wolf. Omnivores inhabiting the lower river system include bald eagle *(Haliaeetus leucocephalus)*, red tailed hawk *(Buteo jamaicensis)*, sharp shinned hawk *(Accipiter striatus)*, common goldeneye *(Bucephala clangula)*, raccoon *(Procyon lotor)*, coyote (*Canis latrans*), black bear (*Ursus americanus*), king snake (*Lampropeltis getula*), garter snake (*Thamnophis sirtalis*), and long-toed salamander.

In the palustrine and lacustrine communities of the lateral lakes and Coeur d'Alene Lake, primary producers include abundant submergent, emergent [e.g., horsetail, cattail, wild rice, giant reed grass (*Phragmites communis*), and water potatoes], and floating (e.g., duckweed, potamogeton, algae) vegetation, as well as phytoplankton. Shrub-scrub vegetation (e.g., spiraea, alder) in adjacent palustrine areas provides riparian habitat and allochthonous inputs to the aquatic system. Avian herbivores in the lateral lakes communities include the Canada goose (*Branta canadensis*), mallard, tundra swan (*Cygnus columbianus*), American wigeon (*Anas americana*), green-winged teal (*Anas crecca*), and American coot (*Fulica americana*). Mammalian herbivores include muskrat (*Ondatra zibethicus*), beaver, deer, elk, and moose. Insectivores include snipe (*Capella gallinago*), killdeer (*Charadrius vociferus*), black tern (*Chlidonias niger*), swallows, blackbirds (e.g., *Agelaius* spp.), bats, and dragonflies (Odonata). The piscivores common to the lower river also feed in the lateral lakes. Carnivores include peregrine falcon (*Falco peregrinus*), American kestrel (*Falco sparverius*), northern harriers (*Circus cyaneus*), and mink. Omnivores include the diving ducks (ruddy duck [*Oxyura jamaicensis*], canvasback [*Aythya valisineria*], redhead

[*Aythya americana*], common goldeneye, lesser scaup [*Aythya affinis*]) in the lacustrine areas; red-tailed hawk, raven (and other corvids), snakes, amphibians, coyote and raccoon in the palustrine areas; and gulls (California [*Larus californicus*], ring-billed [*Larus delawarensis*]) and bald eagle in both lacustrine and palustrine communities.

1.4 DATA SOURCES

The large amount of data relied upon by the Trustees and presented in this report of injury assessment derive from numerous sources, including existing/historical data, reports, and scientific literature. Data sources included:

- State of Idaho data and reports on water quality, suspended sediments, fisheries, and wildlife

- federal agencies, including U.S. Environmental Protection Agency (U.S. EPA) Bunker Hill Remedial Investigation/Feasibility Study (RI/FS) documents, Coeur d'Alene Basinwide RI/FS reports and databases, U.S. DOI wildlife data, U.S. Forest Service (USFS) forestry, stream, and mine inventory data, U.S. Bureau of Land Management (U.S. BLM) mine and mine waste inventory and removal data and vegetation mapping data, U.S. Geological Survey (USGS) surface water monitoring data and minerals exploration data

- the Coeur d'Alene Tribe, fisheries and lake management data

- university research, including work by faculty and graduate students at the University of Idaho, as well as other colleges and universities

- private (industry) data, including nonproprietary documents prepared by the mine companies and contractors for the mine companies.

The above information was supplemented, as necessary, with data collected as part of focused NRDA studies designed to answer specific questions related to evaluation of injuries to natural resources and determination of pathways of exposure to hazardous substances.

Sources of data and information used in each chapter are cited at the end of each chapter. Studies conducted as part of the NRDA injury assessment are identified and the final reports are provided on the enclosed compact disc. During the preparation of this document, many of the NRDA injury studies were published or accepted for publication in peer-reviewed scientific journals. The versions included on the enclosed compact disc are the versions that were used in preparing this document and are not necessarily the final versions submitted for publication.

Collection and analysis of environmental samples from the Coeur d'Alene River basin, and in particular, collection and analysis of samples for the Coeur d'Alene Basin Remedial Investigation/Feasibility Study, was ongoing at the time that this document was prepared. In general, data that were available for use by fall 1999 were included in the analyses presented in this report; data collected or released for public use subsequently were not included.

1.5 REPORT ORGANIZATION AND SUMMARY OF PRINCIPAL FINDINGS

Chapter 2 characterizes the multiple **sources** from which hazardous substances have been released in the Coeur d'Alene River basin and describes the nature of the releases.
Sources that have released or continue to release hazardous substances to the Coeur d'Alene River basin include mining and mineral processing operations; waste rock, tailings dumps, and adits at mine and mill sites; floodplains, and river and lake beds and banks containing tailings and mixed tailings and alluvium; and eroding hillsides historically contaminated by smelter emissions. Source materials include waste rock, mill tailings, mixed tailings and alluvium, concentrates, mine drainage waters, smelter emissions, and flue dust. Hazardous substances released are the metals and metalloids in mining waste. Types of releases include historical disposal of tailings to creeks, rivers, and floodplains; historical smelter emissions; and ongoing releases of hazardous substances from waste rock and tailings deposits and sites where tailings have come to be located throughout the Coeur d'Alene River basin.

The information presented in Chapter 2 demonstrates the following:

- Hazardous substances, including cadmium, lead, zinc, and other hazardous metals and metalloids, have been and continue to be released as a result of mining and mineral processing operations in the Coeur d'Alene River basin. Releases of hazardous substances to the Coeur d'Alene River basin began in the 1880s and continue to the present. Releases will continue for the foreseeable future absent large-scale remediation or restoration.

- Waste rock, mill tailings, and drainage from underground mine workings are the primary sources of hazardous substances in the Coeur d'Alene River basin. Historically, smelter emissions, transported by air pathways, were a primary source of hazardous substances to the hillsides surrounding the Bunker Hill smelter. The predominant secondary sources of hazardous substances are bed, bank, and floodplain sediments and upland soils of the Coeur d'Alene River basin that have been contaminated by releases from the primary sources.

- The many releases of hazardous substances from mines and mineral processing facilities to hillsides, floodplains, and streams of the basin and subsequent transport of wastes from source areas via pathways have resulted in the inextricable commingling of hazardous substances from numerous sources, with subsequent distribution of hazardous substances throughout the Coeur d'Alene River basin.

Chapter 3 presents the **pathways** by which natural resources of the Coeur d'Alene River basin are exposed to hazardous substances released from mining and mineral processing operations. The pathway determinations presented in this chapter are based on data collected by the Trustees and by other researchers in the basin.

The information presented in Chapter 3 demonstrates the following:

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

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

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

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

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

Chapter 4 presents the determination of injury to **surface water resources**. Surface water resources addressed include the South Fork Coeur d’Alene River, certain tributaries to the South Fork Coeur d’Alene River, the lower Coeur d’Alene River, the lateral lakes, and Coeur d’Alene Lake.

The information presented in Chapter 4 demonstrates the following:

- Sufficient concentrations of hazardous substances exist in pathway resources now, and have in the past, to expose surface water resources to hazardous substances.

- Sufficient concentrations of hazardous substances exist in surface water resources now, and have existed in the past, to exceed federal, state, and tribal water quality criteria developed for protection of aquatic life. Therefore, surface water resources are injured.

- Exceedences of water quality criteria have been documented from the upper reaches of the South Fork Coeur d’Alene River and its tributaries to the mainstem Coeur d’Alene River, including the lateral lakes, and in Coeur d’Alene Lake. Surface water is injured in the South Fork Coeur d’Alene River from downstream of Daisy Gulch to the confluence with the North Fork Coeur d’Alene River. Canyon Creek, Ninemile Creek, and Pine Creek are also injured from locations in each stream adjacent to the uppermost mine or mill site to the confluence of each tributary with the South Fork Coeur d’Alene River. Surface waters of the lower Coeur d’Alene River from the North Fork Coeur d’Alene River confluence to Coeur d’Alene Lake are injured. Surface waters of the lateral lakes and Coeur d’Alene Lake are also injured. In addition, the following tributaries of the South Fork Coeur d’Alene River, Canyon Creek, and Pine Creek are injured from the location of the uppermost mine or mill site to the mouth: Grouse Gulch, Moon Creek, Milo Creek, Portal Creek, Deadwood Gulch/Bunker Creek, Government Gulch, Gorge Gulch, Highland Creek, Denver Creek, and Nabob Creek.

- Concentrations of hazardous substances in surface water resources downstream of releases are sufficiently elevated that surface water serves as a pathway of injury to downstream surface waters.

- Concentrations of hazardous substances in surface water resources are sufficient to cause injury to aquatic biological resources, and to serve as a pathway of injury to wildlife and to aquatic biological resources.

Chapter 5 presents data on the condition of the **sediment** resources of the Coeur d'Alene River basin. Sediments are materials deposited by water and include suspended sediments in the water column, and bed, bank, and floodplain sediments. Sediments carried in the water column are suspended sediments. Sediment resources are defined by DOI NRDA regulations both as geologic resources [43 CFR §11.14 (s)] and as a component of surface water resources [43 CFR § 11.14 (pp)]. However, because sediments represent a distinct component of the ecosystem, data on sediments are discussed separately from surface water.

The information presented in Chapter 5 demonstrates the following:

- Metals in streambeds, banks, and floodplains are remobilized through natural hydrologic processes such as scouring, erosion, and resuspension during high water events.

- Sediments of the Coeur d'Alene River basin at and downstream of mining and mineral processing facilities contain substantially elevated concentrations of hazardous substances, including cadmium, lead, and zinc. Sediment contamination is pervasive in the beds, banks, and floodplains of the basin.

- Concentrations of hazardous substances in Coeur d'Alene River basin sediments exceed thresholds associated with adverse effects for benthic invertebrates. As concentrations of hazardous substances in these sediments increase, concentrations of hazardous substances in biofilm (attached algae, bacteria, and associated fine detrital material that adheres to substrates in surface waters and is a food source for higher trophic level consumers), benthic invertebrates, and fish in the basin increase. Sites with the highest concentrations of metals in water, sediment, biofilm, and benthic invertebrates were also the sites where fish populations were reduced, mortality was observed, and tissues contained elevated concentrations of metals.

- Coeur d'Alene River basin sediments containing elevated concentrations of lead and other hazardous substances are ingested by migratory waterfowl. Ingestion of contaminated sediments causes death, physiological malfunction, and physiological deformation of wildlife resources. Sufficient concentrations of hazardous substances are present in sediments to cause injury to biological resources, and therefore sediments are injured.

Chapter 6 describes injuries to **wildlife** resources of the Coeur d'Alene River basin that have resulted from exposure to hazardous metals released from mining and mineral processing facilities.

The information presented in Chapter 6 demonstrates the following:

- Sufficient concentrations of hazardous substances exist in pathway resources to expose wildlife resources. The sources of hazardous substance exposure to wildlife are releases of lead and other metals from mining and mineral processing activities. Hazardous substances are transported from the South Fork Coeur d'Alene River basin in surface water, soil, and sediment to the lower Coeur d'Alene River basin.

- Hazardous substances in sediments are accumulated in plants, invertebrates, fish, mammals, and birds that are consumed by other species of birds and mammals in the Coeur d'Alene River basin. Food chain exposure is an important pathway for lead and other metals in the Coeur d'Alene River basin. Hazardous substance concentrations in pathway resources are sufficient to expose wildlife via ingestion of contaminated sediment and forage and prey items.

- The results of field investigations and controlled laboratory experiments demonstrate that death, physiological malfunctions, and physical deformation injuries to wildlife of the Coeur d'Alene River basin have occurred and continue to occur as a result of exposure to lead in Coeur d'Alene River basin sediments. Adverse effects that have been caused by lead exposure and have been observed in migratory birds in the field include death; physiological malfunctions, including changes in parameters related to impaired blood formation and impaired growth; and physical deformations, including gross and histopathological lesions.

- Laboratory studies demonstrated a dose-response relationship between the magnitude of exposure to Coeur d'Alene River basin sediment and physiological malfunctions such as biochemical changes in waterfowl. The injury assessment studies demonstrated a causal relationship between increasing sediment ingestion and adverse changes in parameters related to blood formation in multiple species of waterfowl.

- Ingestion of lead-contaminated sediments is the pathway and cause of the injuries to migratory birds in the basin. Injury studies were designed to explicitly assess whether the observed deaths and sublethal injuries were caused by other agents, including lead artifacts (e.g., shot/sinkers), disease (e.g., aspergillosis, avian cholera), or other factors (e.g., trauma). Detailed evaluation of field observations and diagnostic histological studies demonstrated that the cause of the injuries was exposure to lead-contaminated sediments. Therefore, injuries to migratory birds are caused by hazardous substances, particularly lead, released from mining and mineral processing facilities.

Chapter 7 presents the assessment of injury to **fish** resources of the Coeur d'Alene River basin, focusing on the South Fork Coeur d'Alene River, the Coeur d'Alene River, and tributaries to the South Fork Coeur d'Alene and Coeur d'Alene rivers. Fish resources have been injured in the South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek, as well as other stream/river reaches affected by releases of hazardous substances from mining and mineral processing operations.

The information in Chapter 7 demonstrates the following:

- 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.

- 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.

- Concentrations of cadmium and zinc in surface water of the South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek exceed chronic and acute water quality criteria for the protection of aquatic life and are sufficient to cause acute mortality to trout.

- Laboratory and field studies demonstrated that salmonids avoid water containing zinc at concentrations that occur in the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, and the lower Coeur d'Alene River as far downstream as Harrison, and Coeur d'Alene Lake.

- 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 (a behavioral abnormality), and histopathological lesions (physiological deformation).

- Injuries to fish include death, as confirmed by *in situ* bioassays and laboratory toxicity testing; behavioral avoidance, 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, and other physical deformations such as histopathological lesions, as confirmed by laboratory testing.

- 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. The fish population data are consistent with the conclusion that hazardous substances released from mining operations are causing injuries to fish.

- Other possible causes of fish injuries (such as channelization, logging, fires, introduction of exotic species) were evaluated. Field studies were designed to include sampling of reference locations to enable explicit consideration of many of these possible factors. 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.

Chapter 8 presents the determination of injury to **benthic macroinvertebrate** resources of the Coeur d'Alene basin. Benthic macroinvertebrates are invertebrates that live on stream or lake bottoms. Benthic macroinvertebrate 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 information presented in Chapter 8 demonstrates the following:

- Benthic macroinvertebrates in the South Fork Coeur d'Alene, the Coeur d'Alene River, Coeur d'Alene Lake, Canyon Creek, and Ninemile Creek, as well as other tributary reaches, are exposed to elevated concentrations of cadmium, lead, and zinc in surface water, sediment, and biofilm.

- The metal concentrations to which benthic macroinvertebrates of the South Fork Coeur d'Alene, the Coeur d'Alene River, Coeur d'Alene Lake, Canyon Creek, and Ninemile Creek are exposed are well above concentrations shown to cause toxicity.

- Toxicity tests using water and sediment demonstrate that water and sediment collected from the Coeur d'Alene River basin downstream of mining activity are toxic to invertebrates under controlled laboratory conditions.

- Benthic macroinvertebrate communities in the South Fork Coeur d'Alene, Canyon Creek, Ninemile Creek, and other stream/river reaches are adversely affected by metals. Specifically, metal-sensitive species are largely absent from the invertebrate communities of these waterways downstream of mining activity. Historical data also demonstrate that the invertebrate communities in the mainstem Coeur d'Alene River and Coeur d'Alene Lake have been adversely affected in the past. Recent data on the communities in these areas are not available to confirm that the effects are continuing, but hazardous substance concentrations in surface water and sediment of the Coeur d'Alene River and Lake remain elevated. In addition, chironomid mouthpart deformities resulting from metals exposure may be ongoing in the South Fork and mainstem Coeur d'Alene rivers.

- The adverse effects on the invertebrate community have been occurring since at least the 1930s. Reductions in metals concentrations over time have resulted in an improvement in the benthic macroinvertebrate community, but the communities of the South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek remain adversely affected.

Chapter 9 presents the determination of injury to **riparian resources**. The information presented in this chapter and previous chapters demonstrates that riparian resources of the Coeur d'Alene River basin have been injured by releases of hazardous substances from mining and mineral processing operations. Specifically:

- Sufficient concentrations of cadmium, lead, and zinc exist in pathway resources to transport hazardous substances to floodplains of the Coeur d'Alene River basin.

- Concentrations of hazardous substances, particularly cadmium, lead, and zinc, in exposed floodplain soils of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River are significantly greater than concentrations in reference area soils. Concentrations of hazardous substances in lower Coeur d'Alene River basin sediments are also substantially elevated relative to the reference soils.

- Floodplain soils of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River are phytotoxic (i.e., cause toxicity to plants) relative to control soils. Plant growth performance in field-collected assessment soils was measured under controlled laboratory conditions. Plant growth in contaminated soils was reduced relative to control soils, and plant growth was significantly negatively correlated with concentrations of hazardous substances in the soils.

- Concentrations of hazardous substances in floodplain soils of assessment reaches exceed phytotoxic thresholds identified in the scientific literature, and the observed reductions in plant growth are consistent with the phytotoxic effects of zinc and other heavy metals reported in the scientific literature.

- In the riparian zones of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River, extent of vegetation cover, species richness, and vegetation structural complexity are significantly negatively correlated with concentrations of hazardous substances in soils; percent cover of bare ground is significantly positively correlated with concentrations of hazardous substances. In other words, increased concentrations of soil metals were related to increased bare ground and reduced vegetation.

- Phytotoxic concentrations of hazardous substances in floodplain soils have resulted in significant and substantial reductions in riparian vegetative cover and an increase in the amount of bare ground in the riparian zones of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River.

- The sources and pathways of metals to floodplain soils of Pine and Moon creeks are similar to the sources and pathways of metals to floodplain soils of Canyon and Ninemile creeks and the South Fork Coeur d'Alene River, and the concentrations of hazardous substances are similar to concentrations determined to be phytotoxic on Canyon and Ninemile creeks and the South Fork Coeur d'Alene River. Therefore, injury to riparian resources of Pine and Moon creeks is inferred to have resulted from phytotoxic concentrations of hazardous substances in floodplain soils.

- Soil phytotoxicity and reductions in vegetation cover have resulted in deterioration of ecological functions, including habitat for all biological resources that are dependent on riparian habitats in the basin; growth media for plants and invertebrates; primary and secondary productivity, carbon storage, nitrogen fixing, decomposition, and nutrient cycling; soil organic matter and allocthonous energy (i.e., carbon from decomposing plant matter) to streams; geochemical exchange processes; food and cover (thermal cover, security cover) for fish, migratory birds, and mammals; feeding and resting areas for fish, migratory birds, and mammals; the migration corridor provided by the riparian zone; habitat for macroinvertebrates; soil/bank stabilization and erosion control; and hydrograph moderation.

Chapter 10 presents an initial **quantification of injury** to natural resources, including an analysis of **baseline conditions**. The effects of the releases of hazardous substances are quantified in terms of the reduction from the baseline condition in the quantity and quality of services provided by the injured resources [43 CFR 11.70 (a)]. Injury quantification includes determination of the baseline condition and baseline services of the injured resources, determination of the extent of the injuries and the reduction in services resulting from the injuries, and determination of the recoverability of the injured resources [43 CFR 11.70 (c)].

Baseline refers to the conditions that would have existed had the releases of hazardous substances not occurred [43 CFR § 11.14 (e)]. The injured resources of the Coeur d'Alene River basin, including surface water, soil and sediment, wildlife, aquatic biota, and riparian resources, are ecologically interdependent and provide interdependent services. The baseline services provided collectively by these resources are inseparable at the ecosystem level. Individually, services include the following:

- *Surface water services*, such as habitat for migratory birds and their supporting ecosystem; habitat for fish and their supporting ecosystem; habitat for benthic macroinvertebrates and aquatic, semiaquatic, and amphibious animals; water, nutrients, and sediments for riparian vegetation and its supporting ecosystem; nutrient cycling; geochemical exchange processes; primary and secondary productivity and transport of energy (food) to downstream and downgradient organisms; growth media for aquatic and wetland plants; a migration corridor; and cultural services.

- *Sediment services*, such as providing habitat services for all biological resources that are dependent upon the aquatic habitats in the basin. In addition, bed sediment services contribute to services provided by surface water, including suspended sediment transport processes, security cover for fish and their supporting ecosystems, primary and secondary productivity, geochemical exchange processes, nutrient cycling and transport, and cultural services.

- *Services provided by floodplain soils and sediments*, such as habitat for all biological resources that are dependent upon riparian or floodplain wetland habitats in the basin. Floodplain soils and sediments provide habitat for migratory birds and mammals; habitat for soil biota; growth media for plants and invertebrates; primary productivity, carbon storage, nitrogen fixing, decomposition, and nutrient cycling; soil organic matter and energy (food) to streams; hydrograph moderation; geochemical exchange processes; and cultural services.

- *Migratory bird services*, including providing prey for carnivorous and omnivorous wildlife, as well as existence values, food, and recreational opportunities for humans, and cultural services.

- *Fish services*, including providing food for other biota, as well as existence values and recreational opportunities for humans, and cultural services.

- *Riparian vegetation* provides primary productivity; food and cover (thermal cover, security cover) for fish and migratory birds and mammals; feeding and resting areas for fish, and migratory birds and mammals; the migration corridor provided by the riparian zone; habitat for macroinvertebrates; nutrient cycling; soil and bank stabilization and erosion control; hydrograph moderation; and cultural services.

The services listed above are interdependent and interact to create a functional ecosystem. The injuries to natural resources described in previous chapters have reduced individual resource services and services provided at the ecosystem level. The high degree of overlap in services affected by the injuries results from the fact that contaminated surface water and soil/sediment resources are now ubiquitous in parts of the basin downgradient of mining and milling operations, and the services provided by these resources are integral parts of an ecologically interdependent ecosystem. Although there are numerous attributes and services that have been reduced and that could be quantified individually, instead, injuries were quantified at the habitat level [43 CFR 11.71 (l)(1)].

Surface water and soil/sediment resources provide an intrinsic part of the habitat for aquatic biota, wildlife, and vegetation, but in the Coeur d'Alene River basin, injuries to fish and other aquatic biota, wildlife, and riparian vegetation are *caused* by hazardous substances to which they are exposed in injured surface water, soils, and sediments. The injured surface water, soils, and sediments therefore have diminished ability to sustain aquatic biota, vegetation, and habitat for wildlife relative to baseline. The area where hazardous metal concentrations in surface water and soils/sediment resources exceed baseline concentrations and that have reduced ability to sustain aquatic biota, vegetation, and habitat for wildlife was quantified relative to baseline [43 CFR 11.71 (h)(4)(i) and (k)(1,2)]. As part of this determination, baseline conditions for riparian vegetation cover, structure, and composition were also determined, since restoration of riparian vegetation in the upper basin is crucial to restoration of the Coeur d'Alene River basin ecosystem and services provided collectively by the injured resources.

For baseline determination, floodplain soils and sediments, and bed, bank, and suspended sediments, from the Coeur d'Alene River basin were assessed collectively. Mean baseline concentrations for soil and sediment are 30 mg lead/kg dry weight of sediment (dw), 0.61 mg cadmium/kg dw, and 63 mg zinc/kg dw.

For surface water baseline determination, the Coeur d'Alene River basin was divided into three areas of ore deposit type. Median values for dissolved cadmium, lead, and zinc in the upper South Fork Coeur d'Alene River basin were 0.06, 0.15, and 5.35 µg/L, respectively. Median values for dissolved cadmium, lead, and zinc in the Page-Galena mineral belt area were 0.1, 0.44, and 9.04 µg/L, respectively. Median values for dissolved cadmium, lead, and zinc in the Pine Creek drainage were 0.03, 0.11, and 3.68 µg/L, respectively. For the South Fork Coeur d'Alene River basin as a whole, median baseline concentrations for the three metals were 0.06, 0.18, and 6.75 µg/L, respectively.

The riparian vegetation baseline data represent a range of site types reflecting elevational gradients, hydrologic gradients, valley shape, width, and orientation, and successional stages of patches of vegetation within the areas sampled. The characterization of riparian vegetation baseline condition focuses on parameters directly related to the injuries quantified: mean percent cover of bare ground (3.0%), mean percent cover of vegetation (139%), mean species richness (17 total species), and mean structural complexity (four layers present).

Injury to surface water and soils/sediment resources and the associated service reductions were quantified as the total area where hazardous metal concentrations exceed baseline and have reduced the ability to sustain aquatic biota, vegetation, and habitat for wildlife relative to baseline [43 CFR § 11.71 (h)(4)(i) and (k)(1-2)]. This approach recognizes the multiple primary and secondary service losses.

Surface water injury was quantified as the river miles in which dissolved concentrations of cadmium, lead, or zinc exceed water quality criteria for the protection of aquatic biota. Injured riverine surface waters include a total of 181 km (113 miles):

- 107 km (67 miles) of the South Fork and mainstem Coeur d'Alene rivers from downstream of Daisy Gulch to the mouth at Coeur d'Alene Lake
- 11.3 km (7.0 miles) of Canyon Creek from approximately Burke to the mouth
- 11.6 km (7.2 miles) of East Fork and mainstem Ninemile Creek from the Interstate-Callahan Mine to the mouth
- 2.7 km (1.7 miles) of Milo Gulch from the Sullivan Adits to the mouth
- 4.0 km (2.3 miles) of Grouse Gulch from the Star Mine waste rock dumps to the mouth
- 5.0 km (3.1 miles) of Moon Creek from the Charles Dickens Mine/Mill to the mouth
- 0.9 km (0.5 miles) of Portal Gulch from the North Bunker Hill West Mine to the mouth
- 4.7 km (2.9 miles) of Deadwood Gulch/Bunker Creek from the Ontario Mill to the mouth
- 4.1 km (2.5 miles) of Government Gulch from the Senator Stewart Mine to the mouth
- 16.8 km (10.4 miles) of the East Fork and mainstem Pine Creek from the Constitution Upper Mill to the mouth
- 5.2 km (3.2 miles) Highland Creek from the Highland Surprise Mine/Mill and the Sidney (Red Cloud) Mine/Mill to the mouth
- 5.3 km (3.3 miles) Denver Creek from the Denver Mine to the mouth
- 0.5 km (0.3 miles) Nabob Creek from the Nabob Mill to the mouth.

In addition, injured surface waters include:

- the lateral lakes and wetlands
- Coeur d'Alene Lake from near Conkling Point to the lake's outlet at the Spokane River.

The extent of injury to floodplain soils and sediments in the upper basin was quantified as the area over which hazardous substance concentrations exceed baseline and have reduced the soil's ability to sustain vegetation and habitat for wildlife relative to baseline [43 CFR § 11.71 (h)(4)(i) and (k)(1-2)]. Based on the known patterns of hazardous substance release, transport, contamination, and toxicity at the vegetation community level, vegetation cover mapping was used as a conservative indicator of soils with reduced ability to sustain vegetation and habitat for biota relative to baseline. The total area of barren or substantially devegetated floodplains along the South Fork Coeur d'Alene River downstream of the Canyon Creek confluence, Canyon Creek, Ninemile Creek, Moon Creek, and Pine Creek is 1,522 acres. This barren or sparsely vegetated area comprised greater than 80% of the available nonurban floodplain.

The extent of injury to soils and sediments of the lower basin was quantified as the area in floodplain in which hazardous substance concentrations exceed baseline concentrations an have reduced ability to provide suitable (nontoxic) habitat for wildlife relative to baseline [43 CFR 11.71 (h)(4)(i) and (k)(1-2)]. Modeled predictions of lead concentration in surficial sediments were used to estimate the area of contaminated sediments that exceeded four threshold concentrations: 30 ppm lead, the geometric mean baseline concentration; 175 ppm lead, the upper 90th percentile of baseline concentration; 530 ppm lead, a lowest observed effect level for waterfowl; and 1,800 ppm lead, a lethal effect level for waterfowl. The area in which sediment lead concentrations exceed the lethal threshold is 15,368 acres, the area in which sediment lead concentrations exceed the lowest observed effect level for waterfowl is 18,298 acres, and the area in which sediment lead concentrations exceed the 90th percentile of baseline concentration is 18,558 acres. The area in which sediment lead concentrations exceed the geometric mean baseline concentration is 18,608 acres.

None of the existing surface water data indicate declining hazardous substance concentrations with time during the past two decades. There is no evidence that maximum, minimum, or mean zinc concentrations have declined: almost all of the concentrations measured in the South Fork Coeur d'Alene River downstream of Canyon Creek, and all of the concentrations measured at the mouths of Canyon and Ninemile creeks, exceeded acute zinc aquatic water quality criteria at all times that samples were collected over the last 30 years. Although patterns of recovery may be obscured by variability in flow and climate, the data overall do not indicate that water quality is improving.

There has been no consistent sampling of sediments over time at designated locations as there has been for surface water. In general, however, sediment data collected recently (1990s) from the lower basin are consistent with data collected previously (1970s and 1980s). There is no indication that sediment concentrations of cadmium, lead, and zinc are decreasing.

Recovery of fish, benthic invertebrate, wildlife, and riparian resources is dependent on recovery of suitable habitat quality, which requires recovery of surface water, sediment, and floodplain soil resources. Once surface water, sediment, and floodplain soil resources have recovered to a condition that will support biological resources, recovery of the Coeur d'Alene River basin ecosystem will be constrained by the rate of natural physical and biological recovery (vegetation reestablishment and physical habitat rebuilding by natural hydrologic, geologic, and biological processes).

For wildlife resources of the lower basin, recovery will occur rapidly once sediments are nontoxic, since physical modifications resulting from sediment injuries are not negatively affecting habitat use. When surface water and sediment conditions improve, benthic macroinvertebrates and fish from upstream clean reaches and clean tributaries will colonize recovered areas naturally and rapidly. Recovery time for fish also will include time required for natural reestablishment of physical features of habitats that were degraded as a result of the injuries, such as overhanging banks, vegetative overhang, and pools created by woody debris and roots. Natural recovery of the aquatic physical habitat of the upper basin will depend strongly on recovery of riparian resources.

Natural recovery time for riparian resources will depend on time required for floodplain soils to become diluted to nonphytotoxic levels, followed by primary vegetation succession, organic soil development, and development of vertically and horizontally diverse vegetation communities. Natural recovery of riparian resources includes development of vegetation that will overhang the stream, modulate stream temperatures, and provide security cover for fish. It includes recovery of riparian vegetation to the point where the vegetation provides habitat structure (e.g., large woody debris; bank stabilization) and a source of energy (i.e., detritus) to the aquatic ecosystem. It also includes reestablishment of diverse early and late successional vegetation and the expected range of terrestrial habitat features (e.g., mature tree boles for tree-cavity nesting birds).

Throughout the Coeur d'Alene River basin, the hazardous substances cadmium, lead, and zinc are the cause of the injuries described in this report. Existing concentrations of cadmium, lead, and zinc in the basin, ongoing releases of these hazardous substances from sources, and ongoing transport and exposure pathways limit natural recovery of the injured resources. There will be little recovery unless releases from sources are eliminated and transport and exposure pathways are eliminated. Existing surface water and sediment data show no evidence of either elimination of sources or pathways over the last 20 to 30 years. Therefore, it is reasonable to expect that natural recovery of the Coeur d'Alene River basin ecosystem will take hundreds of years.

Studies conducted as part of the NRDA injury assessment are identified and the final reports are provided on discs 2 and 3 of this report.

1.6 REFERENCES

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Next

CHAPTER 2
HAZARDOUS SUBSTANCE SOURCES

2.1 INTRODUCTION

This chapter describes the multiple sources from which hazardous substances have been released in the Coeur d'Alene River basin.

Sources that have released or continue to release hazardous substances to the Coeur d'Alene River basin include mining and mineral processing operations; waste rock, tailings dumps, and adits at former mine and mill sites; floodplains, river and lake beds and banks containing tailings and mixed tailings and alluvium; and eroding hillsides historically contaminated by smelter emissions. Source materials include waste rock, mill tailings, mixed tailings and alluvium, concentrates, mine drainage waters, smelter emissions, and flue dust. Types of releases include historical disposal of tailings to creeks, rivers, and floodplains, and historical smelter emissions, and ongoing releases of hazardous substances from waste rock and tailings deposits and sites where tailings have come to be located throughout the Coeur d'Alene River basin.

The information presented in this chapter demonstrates the following:

- Hazardous substances, including cadmium, lead, zinc, and other hazardous metals and metalloids, have been and continue to be released as a result of mining and mineral processing operations in the Coeur d'Alene River basin. Releases of hazardous substances to the Coeur d'Alene River basin began in the 1880s and continue to the present. Releases will continue for the foreseeable future absent large-scale remediation or restoration.

- Waste rock, mill tailings, and drainage from underground mine workings are the primary sources of hazardous substances in the Coeur d'Alene River basin (MFG, 1994). Historically, smelter emissions, transported by air pathways, were a primary source of hazardous substances to the hillsides surrounding the Bunker Hill smelter. The predominant secondary sources of hazardous substances are bed, bank, and floodplain sediments and upland soils of the Coeur d'Alene River basin that have been contaminated by releases from the primary sources.

- The many releases of hazardous substances from mines and mineral processing facilities to hillsides, floodplains, and streams of the basin and subsequent transport of wastes from source areas via pathways have resulted in the commingling of hazardous substances from numerous sources, with subsequent distribution of hazardous substances throughout the Coeur d'Alene River basin.

More detailed information on source locations and volumes and area estimates is presented in the Restoration Alternatives Plan for the Coeur d'Alene Basin Natural Resource Damage Assessment (Gearheart et al., 1999). More detailed information on mining and milling history in the Coeur d'Alene River basin is presented in Quivik (1999), and more detailed information on selected mineral processing plants in the Coeur d'Alene River basin, tonnages milled, and characteristics of the milling wastes is presented in Bull (1999).

2.2 HAZARDOUS SUBSTANCES RELEASED

Hazardous substances, as defined in 40 CFR §302.4, Table 302.4 List of Hazardous Substances and Reportable Quantities, include metals and metalloids contained in mining and mineral processing wastes. Hazardous substances that have been released from mining and mineral processing operations in the Coeur d'Alene River basin include:

- antimony and compounds of antimony
- arsenic and compounds of arsenic
- cadmium and compounds of cadmium
- copper and compounds of copper
- lead and compounds of lead
- mercury and compounds of mercury
- silver and compounds of silver
- zinc and compounds of zinc.

The Clean Water Act lists additional hazardous substances at 40 CFR § 116.4 Table 116.4. Hazardous substances listed in Table 116.4 that are and have been released in reportable quantities (Table 117.3) in sediment, runoff, and leachate discharges in the Coeur d'Alene River basin include lead sulfide (galena), lead sulfate, zinc carbonate, zinc chloride, zinc sulfate, arsenic trioxide, cupric chloride, cupric sulfate, ferrous sulfate, nickel hydroxide, nickel chloride, cadmium chloride, and lead chloride (Maest, 2000). In addition, the following compounds listed in Table 116.4 are predicted to precipitate as solids from seeps: antimony trichloride, antimony trifluoride, antimony trioxide, cupric chloride, cupric sulfate, ferrous sulfate, nickel hydroxide, nickel sulfate, cadmium chloride, lead chloride, lead sulfate, and lead carbonate (Maest, 2000).

These substances occur naturally in bedrock, soils, sediments, and waters. However, as a result of mining and ore processing in the basin, the hazardous substances identified above have become highly concentrated in mining and milling wastes, in milling wastes discharged to surface waters, and in smelter emissions, and have been released into the environment.

The injury assessment focused on the hazardous substances cadmium, lead, and zinc. These three substances are prevalent and found in consistently high concentration in wastes, contaminated soils and sediments, and adit and seep drainage throughout the Coeur d'Alene River basin; their concentrations are highly correlated with concentrations of other hazardous substances in mine wastes and contaminated soils and sediments in the Coeur d'Alene River basin; and these substances are known to be toxic to biological resources.

2.3 HISTORICAL RELEASES OF HAZARDOUS SUBSTANCES

Mechanisms by which hazardous substances have been and continue to be released to the Coeur d'Alene River basin include historical disposal of waste rock in dumps adjacent to mine shafts and adits; historical disposal of tailings to creeks, rivers, and floodplains; and historical smelter emissions.

2.3.1 Historical Disposal of Waste Rock and Tailings

What follows is a summary of ore and tailings production histories relevant to releases of hazardous substances to natural resources in the Coeur d'Alene River basin. Mines, mining complexes, and mills are described by the following geographic areas: the South Fork Coeur d'Alene River and its tributaries upstream of Elizabeth Park (excluding Canyon Creek, Ninemile Creek, and Moon Creek) and the South Fork Coeur d'Alene River and its tributaries downstream of Elizabeth Park (excluding Pine Creek) (Figure 2-1), and the mainstem Coeur d'Alene River and the lateral lakes area, Canyon Creek, Ninemile Creek, Moon Creek, and Pine Creek (Figure 2-2).

The ore deposits in the Coeur d'Alene mining region are steeply dipping veins, many of which terminate below ground (Gott and Cathrall, 1980). Mining these subsurface ores involved tunneling and removing the ore from the deposit, leaving underground cavities. Waste rock associated with the removed ore was dumped near mine adits (horizontal entryways) and shafts (vertical entryways). Waste rock dumps are associated with most, if not all, adits and shafts at both producing and nonproducing mines in the Coeur d'Alene River basin (Ridolfi, 1998).

Much of the ore produced in the basin required concentration before smelting. The first mill in the basin, built to process ore from the Bunker Hill Mine, began operations in 1886 (Casner, 1991). Between 1886 and 1997, at least 44 mills are known to have operated in the South Fork Coeur d'Alene River basin. Initially, ores were concentrated by pulverization and gravity separation. Pulverized material was mixed with water and agitated or "jigged." This separated the heavier ores from the lighter host rock. The valuable ores were collected as concentrates, and the waste materials, or jig tailings, were sluiced to dumps or to nearby flowing surface water. Gravity separation was an inefficient recovery process, and jig tailings contained as much as 10% lead or zinc (Long, 1998). Some small operators established operations to reprocess these tailings deposits and extract more lead, zinc, and silver (Quivik, 1999). However, until new technologies such as flotation made the jig tailings profitable sources of mineral wealth, it was more profitable for larger operations to work fresh ore than to re-work tailings (Quivik, 1999).

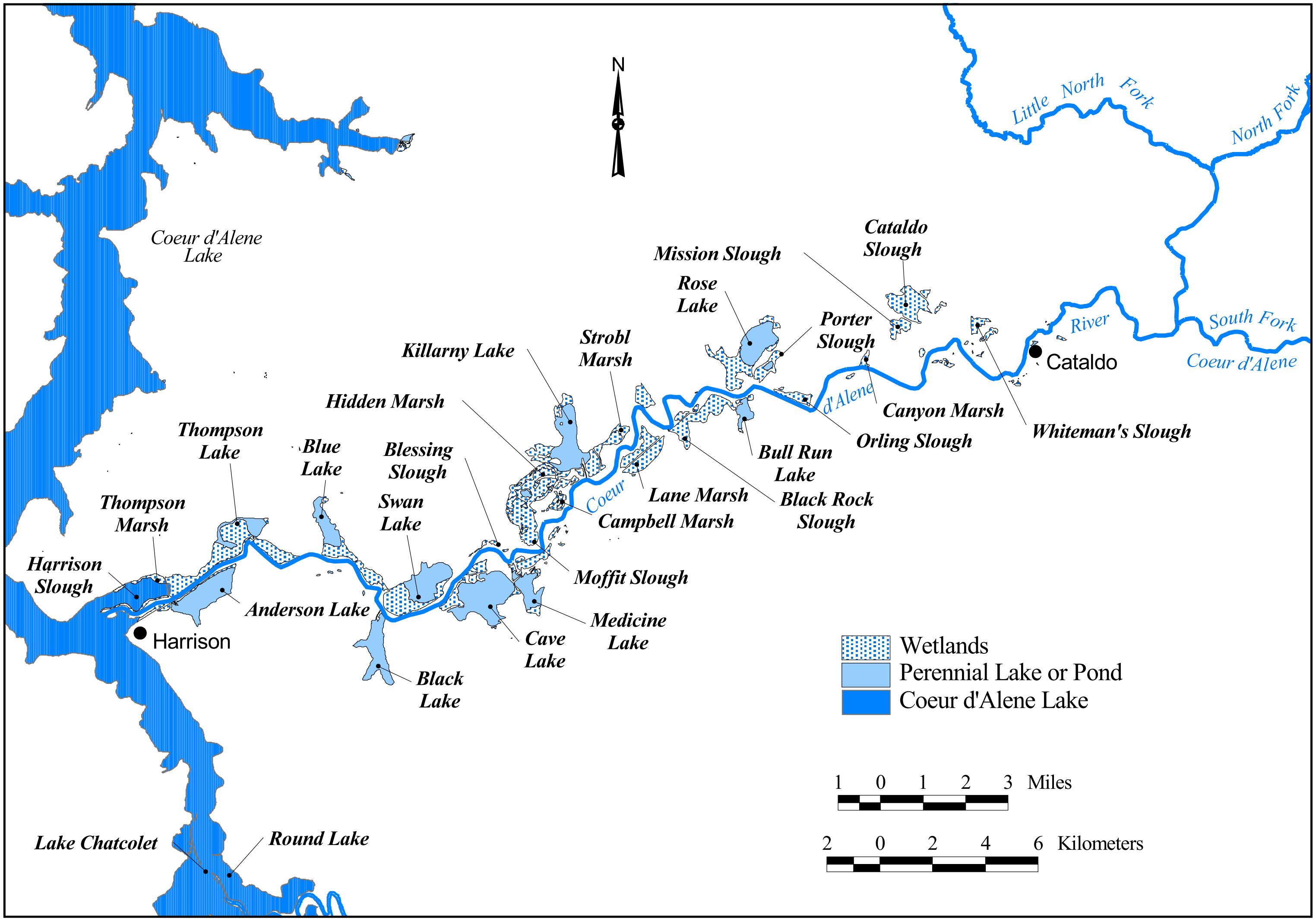

Figure 2-1. Geographic areas referred to in descriptions of sources of hazardous substances in the mainstem Coeur d'Alene River and the lateral lakes area.

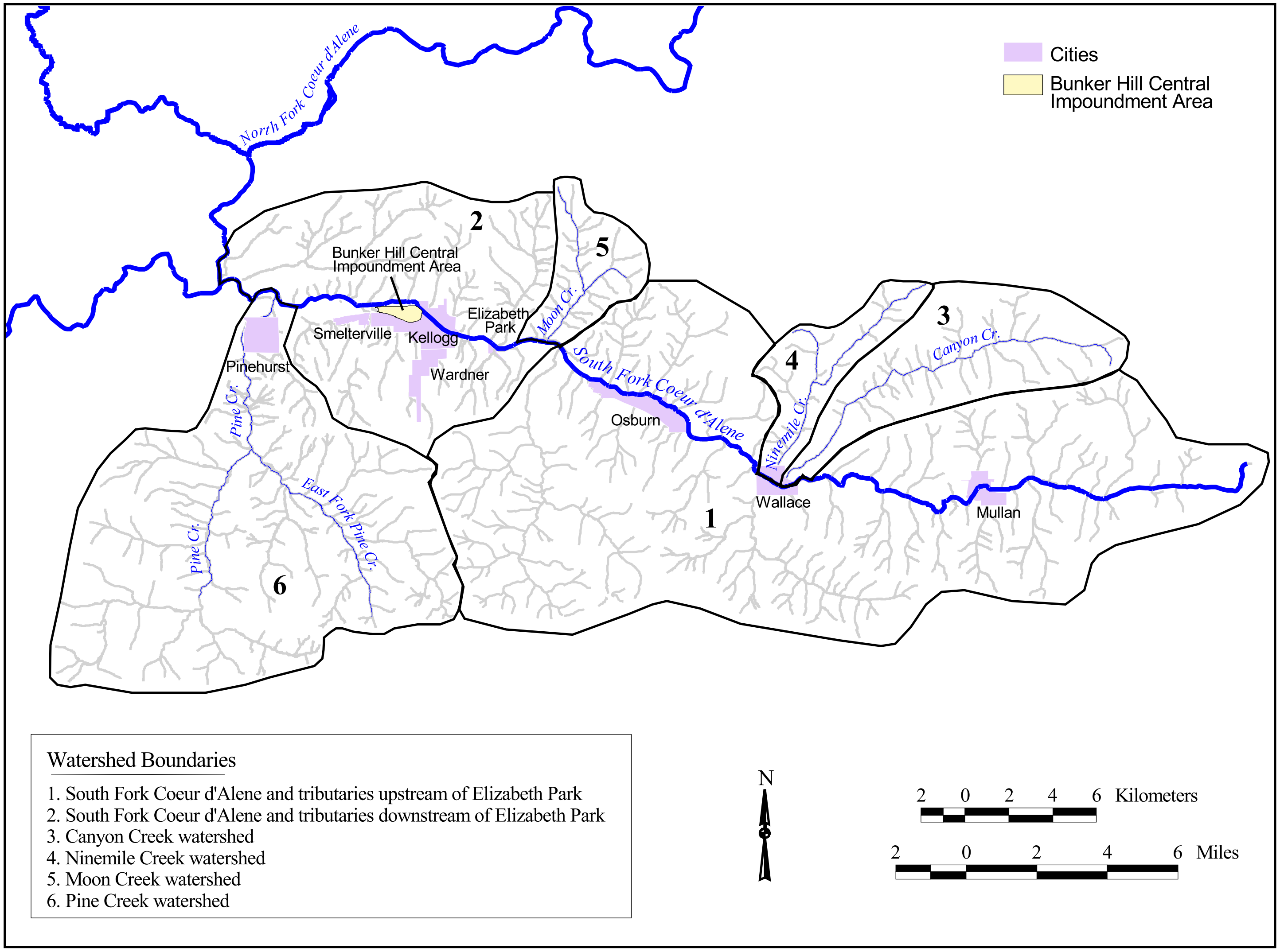

Figure 2-2. Geographic areas used to describe sources of hazardous substances in the South Fork Coeur d'Alene River basin.

In about 1912, flotation milling was introduced to the basin (Casner, 1991). Flotation milling involved finer pulverization of ores and mixing with water, a frothing agent (usually pine oil or cresylic acid), and a collecting agent (usually xanthate) to attract the ore minerals to the froth (Mitchell, 1996). When the mixture was agitated and aerated, metal sulfides adhered to the froth on top and were drawn off as concentrates. The host material settled and was sluiced as tailings to dumps or to nearby flowing surface water. Flotation milling greatly enhanced the efficiency of recovery of minerals, so the remaining tailings had lower concentrations of valuable minerals than did jig tailings. This advancement in technology made it profitable to reprocess old tailings, and companies began re-treating many of the tailings deposited in creeks, dumps, and impoundments in the Coeur d'Alene mining region.

The waste material from the mills contained sulfide and oxide compounds of antimony, bismuth, cadmium, copper, gold, lead, iron, silver, and zinc. The oxide and sulfide forms (when weathered) are leachable and subject to mobilization (MFG, 1992a).

Since milling required large volumes of water, the mills were constructed near sources of surface water. Many were located in steep narrow canyons with little area available for tailings disposal, so tailings were discharged to the streams or sluiced to the South Fork Coeur d'Alene River (Fahey, 1990). Mills along the South Fork Coeur d'Alene River discharged most processing wastes directly to the river. Tailings dumped in the floodplain often subsequently eroded to the stream (Casner, 1991). For over 80 years, from 1886 when milling began in the basin until 1968, when mills were required to impound tailings, the predominant tailings disposal method upstream of Elizabeth Park was discharge to nearby streams (Fahey, 1990; Long, 1998). Downstream of Elizabeth Park, tailings were deposited in the current locations of the Central Impoundment Area (CIA) and Page Pond beginning in 1926 (MFG, 1992a).

In 1901, in response to complaints from downstream landowners, the Mine Owners Association built a plank and pile dam near the village of Osburn to settle tailings on the Osburn flats reach of the South Fork Coeur d'Alene River (Fahey, 1978; Quivik, 1999). The original dam was 1,100 feet wide with a 12 foot head and an anticipated reservoir of 300-400 acres (Quivik, 1999). By 1909, the Osburn impoundment was filled, and tailings were flowing over the spillway. A second line of pilings and planks was added downstream of the original because the first was deteriorating. A series of high flows and floods in 1917 breached the dam. Subsequent flows eroded a deep channel through the tailings that had been impounded behind the dam. The dam was not rebuilt.

In 1902, the Mine Owners Association built a second pile and plank dam across the South Fork Coeur d'Alene River near the mouth of Pine Creek to impound tailings and prevent damage to downstream floodplains. The reservoir created by the dam covered approximately 2,000 acres of the river bottom from the dam upstream as far as Kellogg. By the summer of 1909, tailings had accumulated to the level of the spillway and slimes washed over the dam (Quivik, 1999). The dam washed out during the floods of 1917 and early 1918. It was not repaired.

In 1906, in response to complaints related to flooding and property damage in Wallace caused by tailings deposits near the mouth of Canyon Creek, the companies operating the Frisco, Hecla, Hercules, and Tiger mills formed the Canyon Creek Tailings Association. The association completed construction of a tailings impoundment in lower Canyon Creek in 1907. This dam was also damaged in the 1917 flood and not repaired.

Tailings have been mixed with alluvium and redistributed throughout the South Fork and lower Coeur d'Alene River basins (MFG, 1992a). Jig and flotation tailings were transported downstream from sources and deposited on the floodplains, banks, and beds of the South Fork and lower Coeur d'Alene rivers (MFG, 1992a). In 1903, the first of a series of pollution damage suits was filed by a Shoshone County farmer (Casner, 1991). By the mid-1920s, a visible tailings plume had extended the length of the Coeur d'Alene River, across Coeur d'Alene Lake, and as far as the Spokane River (Casner, 1991).

Estimates of the volume of tailings produced in the Coeur d'Alene River basin range from 110 million tons (through 1990; SAIC, 1993c) to 120 million tons (1884-1997; Long, 1998). SAIC (1993c) estimated that of the 110 million tons of tailings generated, an estimated 64.5 million tons of tailings were discharged to the Coeur d'Alene River or tributaries, 28.8 million tons of tailings remain in dumps and impoundments, and 16.8 million tons of tailings have been returned to underground mine workings as backfill (SAIC, 1993c). Tailings production was estimated by SAIC (1993c) based on ore tonnage, metal production, and the ratio of lead to gangue[1] minerals in the concentrate. Tailings production then was estimated as the difference between ore and concentrate tonnage.

Mill records that contain information on the tonnage and grade of ore milled and the tonnage and grade of concentrates recovered allow for a more precise estimate of the tonnage of tailings produced and the tonnage of metals in the tailings produced. Long (1998), in an open-file report, summarized from individual mill records the total tailings tonnage produced in the Coeur d'Alene mining region from 1886 to 1997, tons of metals contained in the tailings produced, and the percentage of the total tailings production that was disposed to creeks, dumps, and impoundments, or returned to mines as backfill (Table 2-1). Long (1998) estimated that 970,000 tons of lead and over 720,000 tons of zinc have been discharged to surface waters of the basin, and that 220,000 tons of lead and over 320,000 tons of zinc remain in unconfined tailings dumps in the floodplains.

The tailings estimates that follow are based on ore quality and metal recovery by mine. Ores were not necessarily milled in the drainages in which they were produced. Therefore, the estimated tailings produced by each mine were not necessarily disposed of within the reach where the ores were mined. However, the tailings estimates do provide an estimate of total tailings tonnages released in the basin. Between 1884 and the late 1960s, tailings disposal was uncontrolled upstream of Elizabeth Park; therefore, mill locations can be used to estimate the spatial extent of

1. Gangue is the rock surrounding the valuable metals in veins.

Table 2-1
Preliminary Estimate of Mill Tailings Produced in the Coeur d'Alene Mining Region

Disposal Method[a]	Dates	Tailings (tons)	Metals Contained in Tailings (tons)		
			Silver	Lead	Zinc
To creeks	1884-1967	61,900,000	2,400	880,000	>720,000
To dumps	1901-1942	14,600,000	400	220,000	>320,000
Mine backfill	1949-1997	18,000,000	200	39,000	22,000
To impoundments	1928-1997	26,200,000	300	109,000	180,000
Total	1884-1997	120,700,000	3,300	1,248,000	>1,242,000

a. Long (1998) defines dumps as unsecured stockpiles of tailings. Impoundments are secured by dams or other structures. Many impoundments were built over and from older tailings dumps.

Source: Long, 1998.

riparian and riverine resources exposed to primary tailings discharges (MFG, 1992a). Downstream of Elizabeth Park, tailings were deposited in Page Pond beginning in 1926 and the CIA beginning in 1928 (MFG, 1992a).

South Fork Coeur d'Alene River Upstream of Elizabeth Park

In the South Fork drainage upstream of Elizabeth Park (excluding operations on Moon Creek, Ninemile Creek, and Canyon Creek, which are discussed separately), at least 24 mines or mine complexes produced an estimated 47 million tons of ore between 1895 and 1990 (Figure 2-3; Ridolfi, 1998). From this ore, an estimated 1.8 million tons of lead, 790,000 tons of zinc, 170,000 tons of copper, 22,000 tons of silver, 2.5 tons of gold, and 41 million tons of tailings were produced (Mitchell and Bennett, 1983; SAIC, 1993c). Table 2-2 lists the mines of the South Fork drainage upstream of Elizabeth Park, ore production, and estimated tailings production through 1990.

At least 456 adits have been identified in the South Fork drainage upstream of Elizabeth Park, excluding workings on Canyon Creek, Ninemile Creek, and Moon Creek (Hobbs et al., 1965; SAIC, 1993c; Balistrieri et al., 1998; Gearheart et al., 1999; U.S. Forest Service,[2] U.S. BLM[3]).

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2. Unpublished list of adits on U.S. Forest Service Land known to drain mine waters. Provided to Ridolfi Engineers by Jim Northrup, Coeur d'Alene National Forest, Supervisor's Office, Coeur d'Alene, ID. December 1999.

3. Unpublished field survey information provided to Ridolfi Engineers by L. Eno, U.S. BLM, Coeur d'Alene District Office, Coeur d'Alene, ID. 1997.

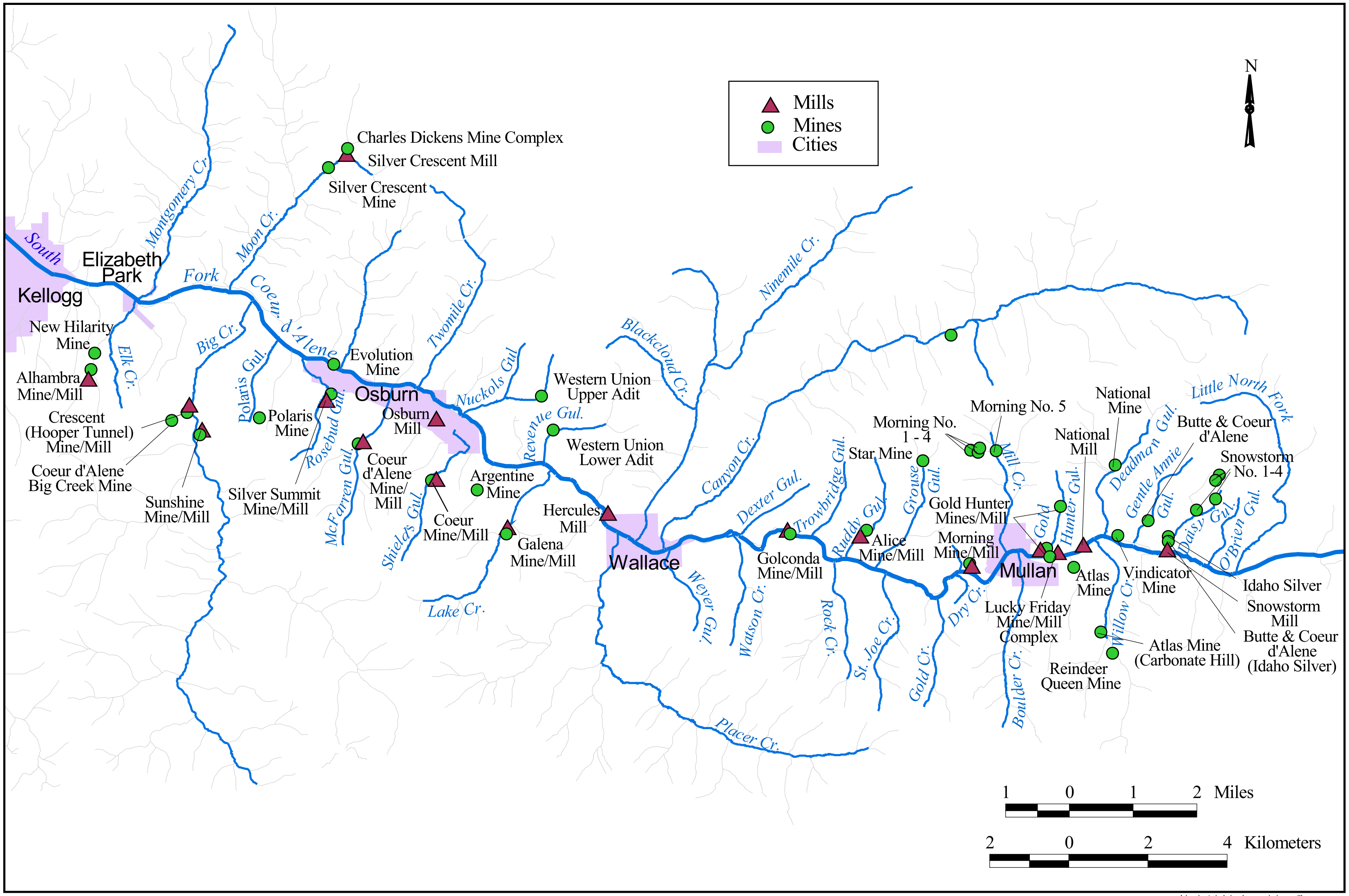

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Figure 2-3. Major mines and mills in the South Fork Coeur d'Alene River basin upstream of Elizabeth Park.
Source: U.S. BLM, 1998.

Table 2-2
South Fork Coeur d'Alene River Mine Production Upstream of Elizabeth Park

Mine	Production Years	Ore Produced (tons)	Mill[a]	Estimated Tailings Produced[b] (tons)
Upstream of Canyon Creek				
Alice	1909-1926	49,419	Alice	45,861
Atlas	1930-1970	6,936	Gold Hunter	6,351
Butte & Coeur d'Alene (Idaho Silver)	1926	35		NA
Golconda	1926-1967	339,228	Golconda	274,299
Gold Hunter	1901-1949	3,260,750	Gold Hunter	3,065,496
Lucky Friday	1938-1990	5,674,668	Lucky Friday, Golconda	4,485,010
Morning	1895-1953	14,136,333	Morning	11,163,230
National	1914-1922	170,008	National	164,316
Reindeer Queen	1910-1916	147		116
Snowstorm	1901-1943	826,580	Snowstorm	706,612
Vindicator	1922-1938	28		NA
Total		***24,464,132***		***19,911,291***
Elizabeth Park to Canyon Creek				
Alhambra	1917-1918	2,200	Crescent	2,059
Argentine	1921-1923	401		393
Big Creek Silver (part of Crescent)	1913-1935	16,847	Crescent	15,608
Coeur d'Alene (Mineral Point)	1919-1952	440,779	Coeur d'Alene (Mineral Point), Hercules (Wallace)	430,984
Coeur (originally Mineral Point)	1969-1990	2,251,910	Coeur	2,195,612
Crescent	1924-1990	962,252	Crescent, Polaris/Silver Summit, Bunker Hill Complex	NA
Evolution	1908-1948	10,474		10,342
Galena	1922-1990	5,895,490	Galena	5,682,193
New Hilarity	1944-1946	879		768
Polaris	1916-1943	320,783	Polaris/Silver Summit	308,203
Rainbow	1958	7,582		7,377

Table 2-2 (cont.)
South Fork Coeur d'Alene River Mine Production Upstream of Elizabeth Park

Mine	Production Years	Ore Produced (tons)	Mill[a]	Estimated Tailings Produced[b] (tons)
Silver Summit (Con Silver)	1948-1982	827,617	Polaris/Silver Summit	795,161
Sunshine	1904-1990	11,453,874	Sunshine	11,004,701
Western Union	1920-1948	11,173		7,838
Total		***22,202,261***		***20,461,239***
Grand Total		***46,666,393***		***40,372,530***

a. Blank cells indicate that most likely there was no mill located on site, and ores were probably shipped elsewhere for milling. No records were found identifying the mill to which the ores were shipped.
b. Estimated tailings produced by each mine were not necessarily disposed within the reach where the ores were mined.
NA = No information available.

Sources: Gage, 1941; Gross, 1982; Mitchell and Bennett, 1983; SAIC, 1993a, 1993b, 1993c; Bennett, unpublished, as cited in Ridolfi, 1998; Quivick, 1999.

Unconfined waste rock piles are found near most, if not all, adits and shafts. At least 56 adits in the South Fork Coeur d'Alene River basin upstream of Elizabeth Park have documented drainage (SAIC, 1993c; U.S. BLM, 1997; USFS, 1997; both as cited in Ridolfi, 1998; Balistrieri et al., 1998; Gearheart et al., 1999).

At least 14 mills operated in the South Fork drainage upstream of Elizabeth Park, excluding mills on Canyon Creek, Ninemile Creek, and Moon Creek (Figure 2-3). Table 2-2 identifies the mills used to process ore from mines in the area. Before 1969, tailings were dumped directly to adjacent streams. Historical discharges of tailings to the South Fork Coeur d'Alene River drainage took place as far upstream as Daisy Gulch. In addition, the tributaries Deadman Gulch, Ruddy Gulch, Lake Creek, McFarren Gulch, and Big Creek, and the mouths of Daisy Gulch, Gold Hunter Gulch, and Rosebud Gulch, were exposed to releases of tailings from milling operations with no tailings containment systems (SAIC, 1993b, 1993c).

Several companies reprocessed tailings that accumulated in the upper South Fork Coeur d'Alene River floodplains. In the early part of the 20th century the Illinois Western Concentrating Company and the Northern Idaho Metals Company both constructed mills between Mullan and Wallace to re-treat tailings deposited in the bed of the South Fork. The Northern Idaho Metals Company built a settling pond between Mullan and Wallace and in the summer of 1917 impounded about 10,000 tons of tailings from the upper South Fork Coeur d'Alene River.

In 1943, Hecla began reprocessing tailings that remained in the former Osburn tailings impoundment area. Tailings were excavated and transported to either Hecla's Osburn Mill (built to re-treat tailings) or Hecla's Gem mill. By end of 1948, Hecla had treated over 3,800,000 tons of Osburn tailings (Quivik, 1999). The Osburn Mill was destroyed by fire in December 1948. In 1946, the Zanetti Brothers also began excavating tailings from the Osburn. In addition, between 1947 and 1952, several companies, including Federal Mining and Smelting Company and the Zanetti Brothers, reworked a tailings deposit near the mouth of Big Creek, reprocessing as much as 99,600 tons in 1949 (Quivik, 1999).

Beginning in the mid-1960s, approximately one-half of the tailings produced from ore mined in the Sunshine (2.4 million tons), Silver Summit (75,000 tons), Coeur (1.1 million tons), and Galena (2.7 million tons) mines were used as sandfill to back-fill underground mine workings at each of these mines (SAIC, 1993c). After 1969, at least 4.9 million tons of tailings were discharged to tailings ponds from Sunshine (1.8 million tons), Silver Summit (13,900 tons), Coeur (1.1 million tons), and Galena (2.0 million tons) mining operations (SAIC, 1993c).

South Fork Coeur d'Alene River Basin Downstream of Elizabeth Park

In the South Fork Coeur d'Alene River basin downstream of Elizabeth Park, excluding Pine Creek (discussed separately), at least 11 mines or mine complexes produced an estimated 48 million tons of ore between 1895 and 1980 (Figure 2-4; Mitchell and Bennett, 1983). From this ore, an estimated 3.2 million tons of lead, 1.4 million tons of zinc, 13,000 tons of copper, 5,000 tons of silver, and 1.4 tons of gold were recovered. Table 2-3 lists ore production through 1980 for the mines of the South Fork drainage downstream of Elizabeth Park.

At least 11 mills, a lead smelter, a zinc electrolytic refinery, and a phosphoric acid plant operated in the South Fork drainage downstream of Elizabeth Park, excluding mills on Pine Creek (Figure 2-4). Historical discharges of tailings to the South Fork Coeur d'Alene River drainage between Elizabeth Park and the North Fork confluence took place as far upstream as Kellogg. In addition, the tributaries Milo Gulch, Deadwood Gulch, Government Gulch, and Humboldt Gulch were exposed to releases of tailings from milling operations (MFG, 1992a). The first mill was constructed in 1886 at Wardner in Milo Gulch. Between 1886 and 1891, this mill processed 117,600 tons of ore and generated 101,020 tons of tailings (Dames & Moore, 1987). Between 1891 and 1909, at least four mills (Old South Mill, South Mill, West Mill, and North Mill) were constructed on the South Fork Coeur d'Alene River near Kellogg downstream of Milo Creek. These mills processed at least 43 million tons of ore and generated approximately 37 million tons of tailings between 1891 and 1981 (Dames & Moore, 1987). Between 1917 and 1981, the lead smelter processed approximately 6.8 million tons of concentrates, 570,000 tons of zinc residue, 300,000 tons of silica and lime, and 1.2 million tons of coal and coke to produce 6.6 million tons of metals, 1.6 million tons of slag, and 16.5 million tons of dust, particulate emissions, and sulfuric acid (Dames & Moore, 1987). The electrolytic zinc plant produced an estimated 3.6 million tons of metals between 1928 and 1936 from 7.3 million tons of concentrate (Dames & Moore, 1987).

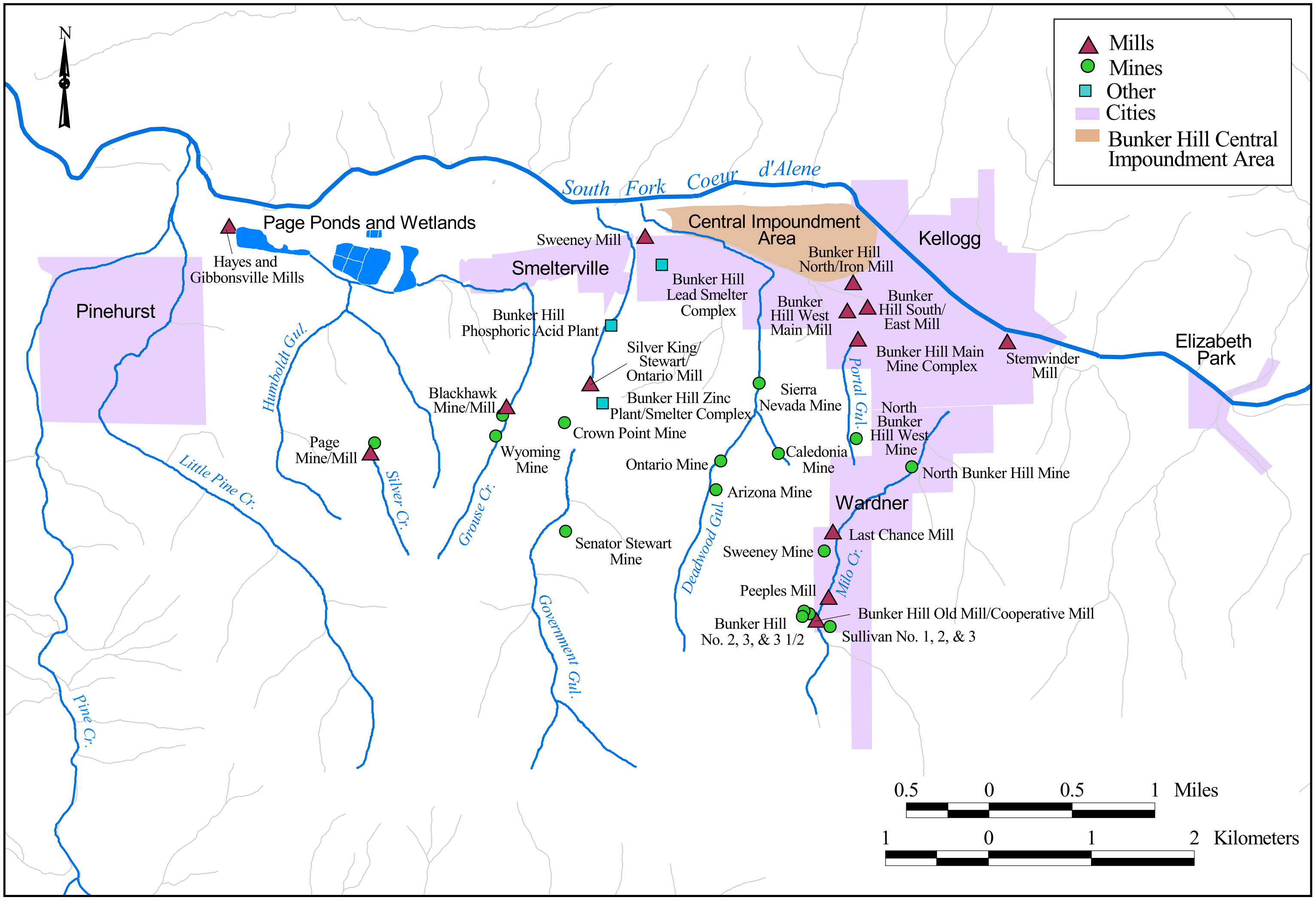

Figure 2-4. Major mines and mills in the South Fork Coeur d'Alene River basin downstream of Elizabeth Park.
Source: U.S. BLM, 1998.

Table 2-3
South Fork Coeur d'Alene River Mine Production Downstream of Elizabeth Park

Mine	Production Years	Ore Produced (tons)	Mill[a]
Arizona	1945-1946	2,321	
Blackhawk	1916-1944	214,126	Page
Bunker Hill	1887-1980	38,483,673	Sweeney, West, South
Caledonia	1909-1942	263,182	
Crown Point	1901-1940	63,098	
Last Chance	1895-1918	2,845,356	On site, Sweeney, Crescent
Ontario	1911-1917	325,502	South
Page	1916-1969	4,307,335	Page
Senator Stewart	1904-1951	1,041,814	
Sierra Nevada	1943-1947	289,450	South[b]
Wyoming	1916-1926	2,774	Page
Total		***47,838,631***	

a. Blank cells indicate that most likely there was no mill located on site, and ores were probably shipped elsewhere for milling. No records were found identifying the mill to which the ores were shipped.
b. Sierra Nevada mine ore milled at the Sierra Nevada mill not included in this production estimate.

Sources: Gross, 1982; Mitchell and Bennett, 1983; Dames & Moore, 1987.

Tailings produced before 1926 were discharged directly to adjacent streams (MFG, 1992a). In approximately 1902, a plank-and-pile dam was constructed near Pinehurst, which increased tailings deposition on Smelterville Flats (Quivik, 1999). Tailings were deposited in Page Pond beginning in 1926 and the CIA beginning in 1928 (MFG, 1992a).

Several companies reprocessed tailings deposited in the floodplain of the South Fork Coeur d'Alene River basin downstream of Elizabeth Park. Between 1904 and 1909, Safford & Safford and the Shoshone Concentrating Company reprocessed tailings on Milo Creek from the creek bed and from the Last Chance Mill, respectively (Quivik, 1999). Mullan Milling reprocessed the Ontario dump at the mouth of Government Gulch. The Ontario dump was estimated to hold 150,000 tons of tailings (Quivik, 1999). Between 1916 and 1929, the Hayes Company re-treated tailings from behind the Pine Creek dam (on the South Fork Coeur d'Alene River near Pine Creek), until the profitable supply was exhausted (Quivik, 1999).

Canyon Creek

In the Canyon Creek drainage, at least 21 mines and mining complexes produced an estimated 36 million tons of ore between 1887 and 1990 (Mitchell and Bennett, 1983; SAIC, 1993c). From this ore, an estimated 2.6 million tons of lead, 1.2 million tons of zinc, 9,000 tons of copper, 5,000 tons of silver, 1 ton of gold, and 27 million tons of tailings were produced (Mitchell and Bennett, 1983; SAIC, 1993c). Table 2-4 lists mines of the Canyon Creek drainage that recorded ore production, the documented ore production for each, and estimated tailings production through 1990.

Table 2-4
Canyon Creek Mine Production

Mine	Production Years	Ore Produced (tons)	Mill[a]	Estimated Tailings Produced[b] (tons)
Ajax	1922-1951	6,235	Bunker Hill Complex	5,020
Ambergris[c]	1919-1934	16,786		14,074
Anchor Group	1937-1951	2,589		2,104
Benton	1955-1956	625		517
Black Bear Fraction	1927-1973	19,727	Amy-Matchless	17,035
Canyon Silver-Formosa	1931-1938/ 1966-1974	24,246	Onsite	20,250
Fairview and Wide West	1945-1950	57,186		50,853
Greenhill-Cleveland	1902-1918	791,447		580,641
Hecla	1898-1944	7,686,967	Hecla, Gem, Standard, Marsh/Blackcloud, Union	6,700,193
Helena-Frisco (Black Bear, Frisco, Gem)	1897-1967	2,676,379	Helena-Frisco, Black Bear, Frisco, Gem	2,144,173
Hercules	1901-1965	3,519,592	Hercules, Hercules (Wallace), Tiger-Poorman, Sherman	2,259,849
Hummingbird	1926-1931	33,449	Hercules (Wallace)	26,125
Marsh	1908-1925	128,805	Marsh/Blackcloud	111,160
Sherman	1927-1972	661,071	Sherman, Hercules (Wallace)	545,387
Sisters	1920-1929	472		68
Standard-Mammoth	1887-1965	3,763,893	Standard-Mammoth	3,232,270
Stanley	1906-1942	1,459		1,443
Star/Morning	1925-1990	12,303,035	Star/Morning, Bunker Hill Complex, Hercules (Wallace), Hecla	9,164,183

Table 2-4 (cont.)
Canyon Creek Mine Production

Mine	Production Years	Ore Produced (tons)	Mill[a]	Estimated Tailings Produced[b] (tons)
Tamarack-Custer[c]	1905-1977	1,973,630	Tamarack-Custer, Hercules (Wallace), Frisco	1,640,484
Tiger-Poorman	1901-1961	1,128,793	Tiger-Poorman, Hercules (Wallace)	915,535
Union	<1905	5,168	Union, Standard, Mammoth	4,225
Total		***34,801,554***		***27,435,589***

a. Blank cells indicate that there was most likely no mill located on site, and ores were probably shipped elsewhere for milling. No records were found identifying the mill to which the ores were shipped.
b. Estimated tailings produced by each mine were not necessarily disposed within the reach where the ores were mined.
c. Mines located in Ninemile Creek drainage, but majority of production was extracted through Canyon Creek drainage (Ridolfi, 1998; SAIC, 1993a). Approximately 30% of the total ore extracted from Tamarack-Custer was extracted through Ninemile Creek between 1912 and 1922, and is included on Table 2-5.

Sources: Mitchell and Bennett, 1983; Fahey, 1990; SAIC, 1993a, 1993b, 1993c; Mitchell, 1996; Bennett, unpublished as cited in Ridolfi, 1998.

At least 138 adits have been identified in the Canyon Creek drainage (Hobbs et al., 1965; Gearheart et al., 1999). Approximately 47 of the adits and the two shafts are entryways to mines known to have produced ore. Waste rock piles are found near most of the adits and shafts. Waste rock from several mines, including the Hecla, the Star, and the Tiger-Poorman, may have been removed for use as construction or fill material (Fahey, 1978; Ridolfi, 1998).Twenty-four adits in the Canyon Creek drainage have documented drainage (Gearheart et al., 1999).

At least 13 mills operated in the Canyon Creek drainage. The locations of the major mills are shown in Figure 2-5. Before 1965, all mills in Canyon Creek released tailings to the stream. Historical releases of tailings to the drainage took place as far upstream as the mill at the Hercules No. 4 adit on Gorge Gulch.

In the early 1900s, small operations reprocessed tailings from the Standard, Gem, Frisco, and upper Mace tailings dumps (Quivik, 1999). The Small Leasing Company was the largest tailings reprocessor in Canyon Creek, re-treating upwards of 500,000 tons of tailings from Canyon Creek deposits between 1938 and 1949, using the Formosa, Golconda, and Hercules mills (Figures 2-3 and 2-5; Quivik, 1999).

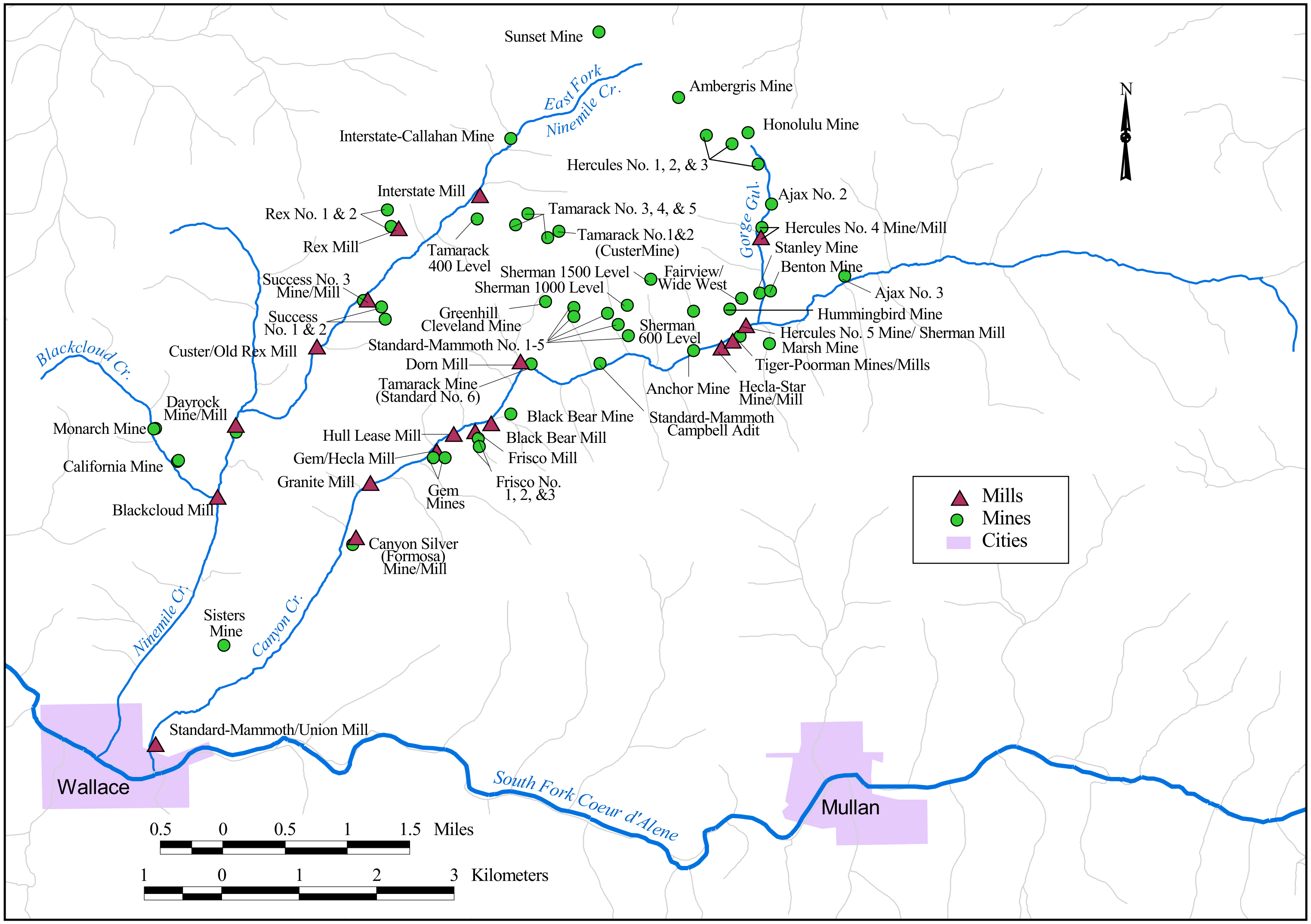

Figure 2-5. Major mines and mills in the Canyon Creek and Ninemile Creek basins.
Source: U.S. BLM, 1998.

Approximately 50% (2.8 million tons) of the tailings generated by ore from the Star/Morning mine were used as sandfill between 1959 and 1990. In 1965, the Star/Morning Mine tailings ponds 1 and 2 were built in the Canyon Creek floodplain. Between 1970 and 1979, four additional ponds were constructed. The ponds received tailings until 1990 from the Star Mine and later from the Star Phoenix Mine for a total of approximately 3.4 million tons (SAIC, 1993b).

Ninemile Creek

In the Ninemile Creek drainage, eight mines are known to have produced nearly 5 million tons of ore between 1902 and 1977 (Figure 2-5; Mitchell and Bennett, 1983). From this ore, an estimated 330,000 tons of lead, 300,000 tons of zinc, 1,800 tons of copper, 600 tons of silver, 0.17 tons of gold, and 4 million tons of tailings were produced (Mitchell and Bennett, 1983; SAIC, 1993c). Some of the ore mined in the Ninemile Creek drainage was extracted and milled in either the Beaver Creek drainage or the Canyon Creek drainage. Table 2-5 lists the mines of the Ninemile Creek drainage, ore production, and estimated tailings production through 1977.

Table 2-5
Ninemile Creek Mine Production

Mine	Production Years	Ore Produced (tons)	Mill	Estimated Tailings Produced[a] (tons)
California	1902-1925	49,079	Blackcloud/Marsh	41,945
Dayrock	1924-1974	1,276,488	Dayrock, Hercules (Wallace)	1,121,575
Interstate-Callahan[b]	1906-1977	1,423,619	Interstate-Callahan, Galena	1,039,087
Monarch	1904-1942	58,840	Blackcloud/Marsh	52,053
Rex	1905-1949	154,441	Rex, Old Rex (16 to 1)	134,813
Success (Granite)	1905-1952	789,704	Success, Granite	665,798
Sunset[b]	1913-1976	355,032	Golconda	302,863
Tamarack-Custer[c]	1912-1922	845,842	Old Rex (16 to 1), Frisco	703,065
Total		***4,953,045***		***4,061,199***

a. Estimated tailings produced by each mine were not necessarily disposed of within the reach where the ores were mined.
b. Majority of production extracted through Beaver Creek drainage in the 1940s (Ridolfi, 1998).
c. Mine located in Ninemile Creek drainage, but approximately 70% of production was extracted through Canyon Creek drainage and is therefore included in Table 2-4.

Sources: Mitchell and Bennett, 1983; SAIC, 1993c; Ridolfi, 1998.

At least 67 adits have been identified in the Ninemile Creek drainage; most are located in the East Fork of Ninemile Creek (Hobbs et al., 1965; Gearheart et al., 1999). Sixteen of the adits are entryways to mines known to have produced ore. Waste rock piles are probably associated with all of the adits and shafts. At least 12 adits in the Ninemile Creek basin have documented drainage (Gearheart et al., 1999).

At least seven milling facilities operated in the Ninemile Creek basin (Figure 2-5). Before 1965, all mills in Canyon Creek released tailings to the stream. Historical discharges of tailings to the drainage took place at least as far upstream as the Interstate-Callahan mill. Some tailings discharged into Ninemile Creek were later re-treated to extract valuable minerals. In 1916, Interstate-Callahan began re-treating 200,000 to 250,000 tons of tailings it had collected in an impoundment, and the Spokane Metals Recovery Company re-treated tailings from several operations on the East Fork of Ninemile Creek in 1918 (Quivik, 1999). In 1936, the Galena Mill on Lake Creek (Figure 2-3) treated 13,000 tons of lead zinc ore from waste dumps of the Interstate-Callahan mine (Quivik, 1999). During World War II, deposits from the Interstate-Callahan and Rex tailings dumps were re-treated by Callahan Consolidated and the Zanetti Brothers (Quivik, 1999).

Between 1950 and 1974, approximately 400,000 tons of tailings produced by the Dayrock Mine were returned to the mine as sandfill. After 1969, approximately 100,000 tons of tailings from the Dayrock Mine were placed in a tailings pond (SAIC, 1993c).

Moon Creek

In the Moon Creek drainage, eight mines are known to have operated, but most of the recorded ore production was from the Charles Dickens Mine and the Silver Crescent Mine on the East Fork of Moon Creek. The two properties were consolidated in 1937 as the Silver Crescent (SAIC, 1993b). Between 1920 and 1930, the Charles Dickens Mine produced 4,604 tons of ore, yielding 370 tons of lead, 40 tons of zinc, 16 tons of copper, 16,022 ounces of silver, 31 ounces of gold, and 3,803 tons of tailings (Figure 2-3; Table 2-6).

At least six adits and three shafts have been identified in the Moon Creek basin (IGS, 1997). Three of the adits are associated with the Charles Dickens Mine. Adit drainage has been documented in three adits in the basin (USBM, 1995).

The Charles Dickens Mill processed ores from the Charles Dickens Mine, the Silver Dollar Mining Company at Terror Gulch, and Western Union Mine, and also processed custom ores (USBM, 1995). The mill also reprocessed tailings from the Osburn dump. Mill tailings from the Charles Dickens Mill were slurried across the creek and deposited in an area adjacent to the creek and downstream from the mill site. A large tailings impoundment remains (USBM, 1995). A large tailings impoundment recently has been relocated into an on-site repository.

Table 2-6
Moon Creek Mine Production

Mine	Production Years	Ore Produced (tons)	Mill	Estimated Tailings Produced[a] (tons)
Charles Dickens/Silver Crescent	1902-1930	4,604	Charles Dickens	3,803
Total		***4,604***		***3,803***

a. Estimated tailings produced by each mine were not necessarily disposed of within the reach where the ores were mined.

Sources: Mitchell and Bennett, 1983; SAIC, 1993c.

Pine Creek

In the Pine Creek drainage, an estimated 50 mines, nine mills, and 500 patented and unpatented claims operated between 1884 and 1980 (CCJM, 1995). Ore production for mines in the Pine Creek drainage is estimated at 3.2 million tons of ore (Mitchell and Bennett, 1983; Mitchell, 1996) (Figure 2-6; Table 2-7). An estimated 102,000 tons of lead, 210,000 tons of zinc, 900 tons of copper, 140 tons of silver, and 2.5 million tons of tailings were produced (Mitchell and Bennett, 1983; SAIC, 1993c; Mitchell, 1996).

At least 76 adits have been identified in the Pine Creek drainage (Gearheart et al., 1999). Waste rock piles are associated with most of the adits and shafts. The total volume of many of the waste rock dumps has been estimated at over 1.4 million cubic yards (CCJM, 1995; McNary et al., 1995; Mitchell, 1996; Gearheart et al., 1999). At least 22 named adits in the Pine Creek basin have drainage (CCJM, 1995; McNary et al., 1995).

Figure 2-6 identifies the eight major mills that are known to have operated in the Pine Creek drainage. Historical discharges of tailings to the drainage took place as far upstream as the Constitution mill on the East Fork Pine Creek. Other tributaries in the Pine Creek basin that have received tailings from milling operations include Highland Creek, Denver Creek, and Nabob Creek. There is little record of re-treatment of tailings from the banks and bed of Pine Creek (Quivik, 1999).

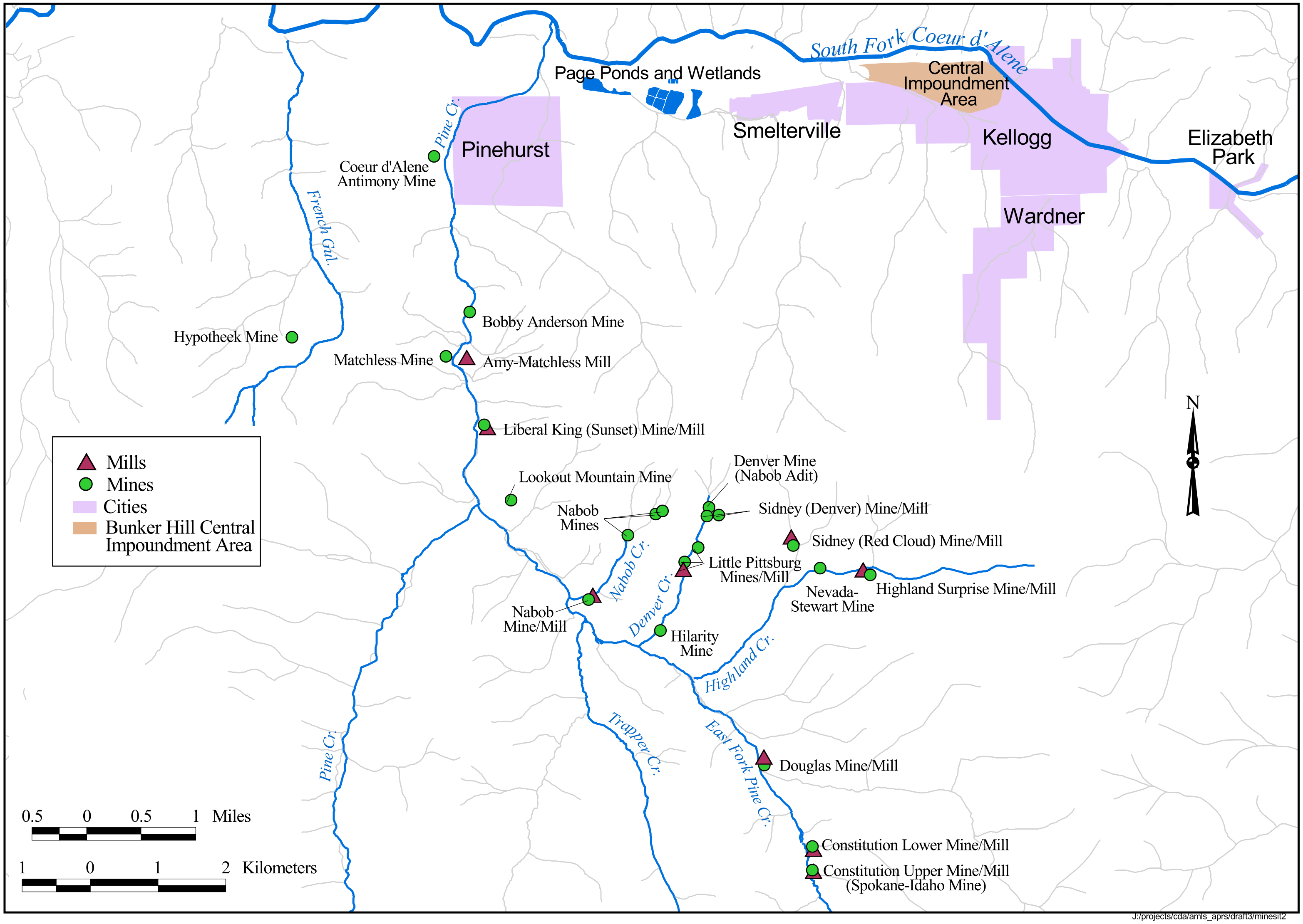

Figure 2-6. Major mines and mills in the Pine Creek basin.
Source: U.S. BLM, 1998.

Table 2-7
Pine Creek Mine Production

Mine	Production Years	Ore Produced (tons)	Mill[a]	Estimated Tailings Produced[b] (tons)
Amy-Matchless	1912-1956	4,569	Amy-Matchless	4,359
Bobby Anderson	1927-1951	523		432
Constitution (Spokane-Idaho)	1915-1968	667,326	Constitution, Amy-Matchless	538,249
Denver	1916-1944	13,000	Bunker Hill Complex, Sullivan, Sidney	8,220
Douglas	1916-1972	167,162	Douglas, Great Falls, Constitution	138,440
Highland Surprise	1904-1971	518,706	Highland Surprise	332,847
Hilarity	1926-1952	3,330		3,103
Hypotheek	1913-1954	88,702	Hypotheek	80,579
Liberal King (Sunset)	1937-1963	256,437	Liberal King (Sunset)	220,006
Little Pittsburgh	1916-1955	320,674	Little Pittsburgh, Great Falls, Nabob	275,624
Lookout Mountain	1922-1952	1,595	Charles Dickens, Liberal King (Sunset), Amy-Matchless	1,149
Nabob	1907-1977	134,069	Nabob, Amy-Matchless	111,759
Sidney (Red Cloud)	1921-1967	1,071,197	Sidney, Galena, Sweeney, Star/Morning, Bunker Hill Complex	816,733
Total[c]		***3,247,290***		***2,531,500***

a. Blank cells indicate that most likely there was no mill located on site, and ores were probably shipped elsewhere for milling. No records were found identifying the mill to which the ores were shipped.
b. Estimated tailings produced by each mine were not necessarily disposed within the reach where the ores were mined.
c. No production records available for the Coeur d'Alene Antimony Mine or the Nevada-Stewart Mine.

Sources: Jones, 1919; Mitchell and Bennett, 1983; SAIC, 1993c; CCJM, 1995; McNary et al., 1995; Mitchell, 1996.

2.3.2 Historical Smelter Emissions

In the early decades of mining in the basin, concentrated ore from the Coeur d'Alene mining region was shipped out of the basin for smelting. Smelting operations in the basin began in 1917 at the Bunker Hill smelter (Bennett, 1982; Casner, 1991). Smelting of sulfide ores produces emissions containing sulfur dioxide and particulate matter consisting of varying amounts of metals and metalloids, depending on the mineralogy of the ore (MFG, 1992a). Smelting of the predominantly galena (PbS) Bunker Hill ores and sulfide ores from other mines resulted in releases of arsenic, cadmium, copper, lead, antimony, selenium, and zinc, among other trace elements, and sulfurous compounds to the atmosphere (Bennett, 1982; CDM et al., 1986). The main sources of hazardous substance emissions were the lead smelter stack and fugitive emissions from the processing and storage areas (CDM et al., 1986). Smelter emissions from the stacks were transported in the air throughout the Coeur d'Alene River valley. Particulates transported in the emissions plume were deposited on the hillsides and valley floor surrounding the smelter (MFG, 1992a).

The smelter emissions content varied over the 63 years of operation, changing with production rates, smelting technology, and emissions control efforts. For most of the operating period, the Bunker Hill smelting complex had few controls on emissions. Table 2-8 presents a brief chronology of construction and technological modifications during the operating history of the smelter complex (Bennett, 1982; Murray, 1982; CDM et al., 1986). Early technological additions to enhance metal recovery, such as the Cottrell electrostatic precipitators installed in 1925 to recover metals from flue dust (Bennett, 1982), probably reduced particulate emissions compared to earlier years. Addition of the sulfuric acid plant in 1954 reduced sulfur dioxide emissions (CDM et al., 1986). Emissions controls were first added to the lead smelter in 1969, when a new baghouse, ventilation system, and scrubbers were installed (Bennett, 1982). In 1970, a new updraft sintering[4] plant and associated sulfuric acid plant replaced the older ore roasting machine (Bennett, 1982; CDM et al., 1986). With addition of the new sintering process, sulfur dioxide emissions were reportedly reduced by 90% (Bennett, 1982). In 1975, scrubbers were installed in the sintering stack, reducing lead smelter main stack emissions by a reported 90% (Bennett, 1982). In 1977, tall stacks (>600 feet) were added to both the zinc and lead smelters in an attempt to disperse contaminants. The stacks reduced ambient air concentrations in the Coeur d'Alene River valley (Bennett, 1982; CDM et al., 1986).

4. Sintering reduced the amount of sulfur in the ore and prepared the lead feed mixture for the blast furnace. Sulfur dioxide and other gases emitted were cleaned in the baghouse and mist precipitator and sent to the sulfuric acid plant. Waste gases from sintering were treated in the baghouse and exhausted through a stack. Sinter is an agglomeration of materials, including oxidized concentrates. Sinter and coke were fed to the blast furnace. Reducing gases and heat were used to produce molten metallic lead and slag. Exhaust gases from the blast furnace were filtered in the main baghouse and discharged from the main stack.

Table 2-8
Chronology of Bunker Hill Smelter Complex Construction and Technological Modifications

1917	Bunker Hill lead smelter began operation. Capacity: 1,000 tons per day (tpd).
1918	Lead smelter enlarged; fourth blast furnace added.
1925	Cottrell electrostatic precipitators added to recover metal-bearing dust from the flue.
1928	Electrolytic zinc plant began operation.
1929	Capacity of lead smelter doubled.
1936	New blast furnace installed; largest lead producing furnace in the United States.
1937	Zinc plant enlarged to 120 tpd.
1941	New plant to recover zinc from lead furnace slag constructed.
1943	Zinc slag fuming plant added to extract zinc from slag.
1945	Electrolytic cadmium plant constructed to extracted cadmium from smelter by-products.
1948	Zinc plant enlarged to 160 tpd.
1952-53	New crushing and grinding equipment added; new charge precipitation and bedding (ore preparation) plant; new pelletizing plant. Increased smelter capacity.
1954	Sulfuric acid plant added to zinc plant.
1957	New blast furnace installed.
1958	New stack built at smelter.
1960	Phosphoric acid plant and fertilizer plant constructed.
1964	Fire destroyed precipitation plant and baghouse.
1966	New furnace feed system added. Lead smelter capacity increased to 100,000 tpd.
1967	Zinc plant enlarged to 310 tpd.
1968	Second sulfuric acid plant added to zinc plant.
1969	New baghouse, ventilation system, and vent with scrubbers added to lead smelter.
1970	New sintering plant and sulfuric acid plant replaced the ore roasting operation.
1972	Blast furnace extended to accommodate increased production.
1973	Fire destroyed parts of main baghouse. Study of lead smelter stack and fugitive emissions conducted.
1974	Baghouse repaired.
1975	Scrubbers installed in the sintering plant.
1977	A 610 foot stack built at zinc plant; 715 foot stack built at lead smelter.
1978	Electrolytic silver refinery constructed.
1981	Smelter complex closed.

Sources: Bennett, 1982; Murray, 1982; CDM et al., 1986.

Between 1917 and 1963, the lead smelter processed 4.3 million tons of concentrate and 323,000 tons of zinc residue to produce 2.9 million tons of lead and 311,000 tons of zinc (Dames & Moore, 1987). No emissions data are available for the years between 1917 and 1955. However, from 1955 to 1964, average emissions of lead from the main lead smelter stack were estimated to be 9.2 tons per month (IDHW, 1976, as cited by Ragaini et al., 1977).

Plant production rates increased in the late 1960s and early 1970s with the addition of a new furnace feed system, enlargement of the zinc plant, replacement of the older downdraft ore roasting operation by an updraft sintering process, and extension of the blast furnace (Bennett, 1982; CDM et al., 1986). Stack emission rates for lead measured by the Bunker Hill Co. and Gulf Resources and Chemical Company (who purchased the smelter complex in 1968) increased in the late 1960s and early 1970s from historical levels of approximately 10 tons per month to approximately 15 tons per month (CDM et al., 1986). The enlargement of the blast furnace in 1972 increased lead emissions from the main stack to approximately 20 tons per month (measured by Gulf Resources and Chemical Company, reported in CDM et al., 1986). The Shoshone Lead Health Project (IDHW, 1976, as cited by Ragaini et al., 1977) estimated that emissions between 1965 and 1973 averaged 11.7 metric tons per month.

In 1973, two of seven baghouse filter units at the lead smelter main stack were destroyed in a fire (CDM et al., 1986). A third unit was shut down for routine maintenance and remained inoperable for about six months (CDM et al., 1986). The baghouse was repaired in 1974, but in the interim, emissions control was severely reduced. Total particulate emissions of approximately 15 to 160 tons per month containing 50 to 70% lead were reported from the lead smelter main stack through November 1974; in February and March 1974, monthly total particulate emissions were approximately 150 tons (TerraGraphics, 1990). Between January and September 1974, more than 4,000 pounds (2 tons) of arsenic, 70,000 pounds (35 tons) of cadmium, 700,000 pounds (350 tons) of lead, 5,000 pounds (2.5 tons) of mercury, and 123,000 pounds (61.5 tons) of zinc were released from the stack (CDM et al., 1986). The increased emissions caused a distinct increase in atmospheric lead concentrations. The effect of the increase was immediately apparent as epidemic lead poisoning among area children (IDHW, 1976, as cited by Ragaini et al., 1977). A public health study conducted in 1974 identified smelter emissions as the major source of contamination and excess absorption in children (IDHW, 1976, as cited by Ragaini et al., 1977; TerraGraphics, 1990).

After the construction of the tall stacks at the zinc plant and lead smelter in 1977, quarterly average ambient air lead concentrations measured at the Kellogg Medical Center, Silver King School, Smelterville City Hall, Kellogg City Hall, Pinehurst School, and Osburn Radio Station decreased. The decrease in ambient air concentrations was partially caused by release of emissions at greater height for longer-distance dispersal, but also partially caused by the increased draft of the taller stacks (MFG, 1992a). Gaseous and particulate wastes that previously were not captured in the draft had escaped as fugitive emissions and contributed to the greatly elevated concentrations measured at sampling stations near the smelter complex. The increased draft allowed capture of more of the process wastes (CDM et al., 1986). Following smelter closure in late 1981, airborne lead concentrations decreased by a factor of 10.

Using emissions data collected by the Bunker Hill Co. and Gulf Resources and Chemical Co. data on emissions from the lead smelter main stack, CDM et al. (1986) estimated arsenic, cadmium, lead, mercury, and zinc emissions from the lead smelter main stack from 1965 through 1981. More than 70,000 pounds of arsenic (35 tons), 570,000 pounds of cadmium (280 tons), 6,000,000 pounds of lead (3,000 tons), 29,000 pounds of mercury (15 tons), and 860,000 pounds of zinc (430 tons) were emitted between 1965 and 1981. The estimates were based on lead smelter main stack data only, and do not include fugitive emissions, which were estimated to total more than stack emissions (CDM et al., 1986).

Emissions data collected during the period of smelter operation and ambient air concentrations data collected during and after the period of smelter operation confirm that the smelters were a source of hazardous substances to the Coeur d'Alene River environment (Figure 2-7). Additional sampling of environmental media during the 1970s by the Bunker Hill Co. and during the 1980s as part of the remedial investigation and feasibility studies (TerraGraphics, 1990) confirmed that soil resources of the Coeur d'Alene River basin (in addition to humans; JEG et al., 1989) were exposed to the hazardous substances and that the smelter complex was the source of the hazardous substances.

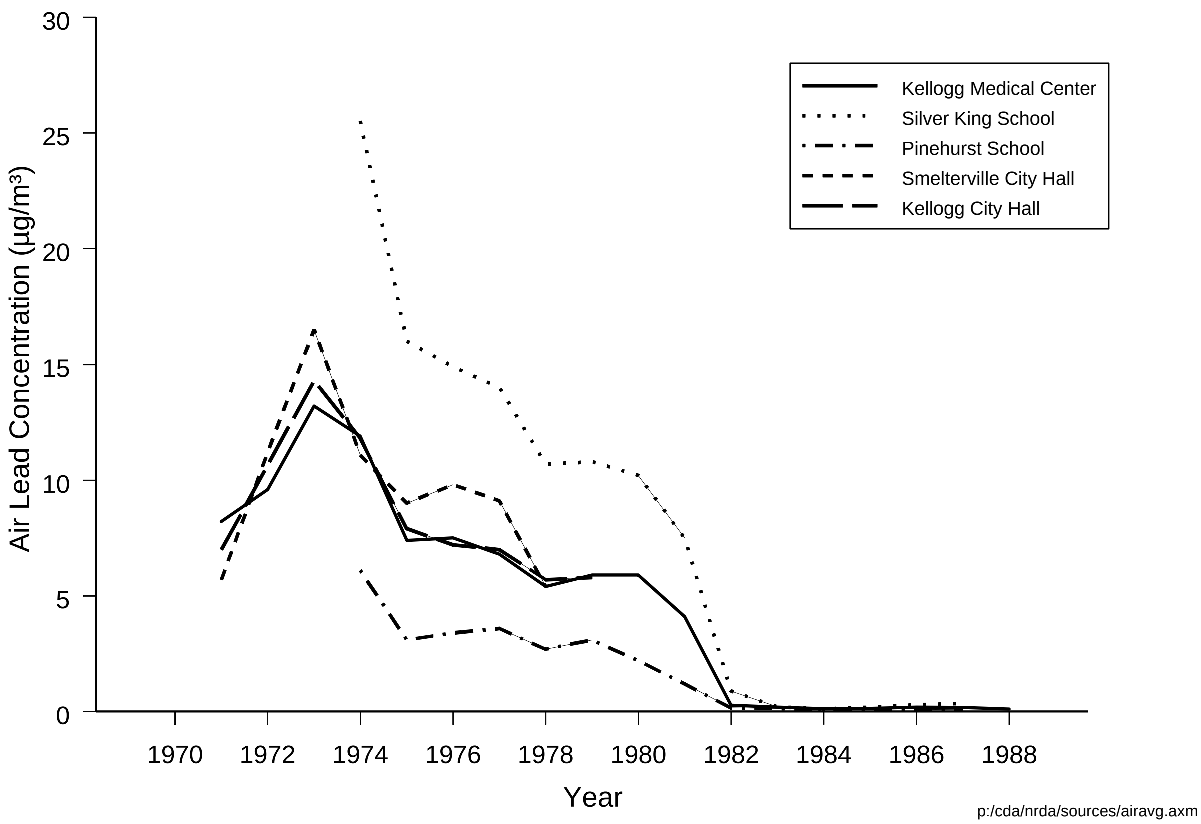

Figure 2-7. Ambient air concentrations of lead (mean annual) measured in the populated areas of the Bunker Hill Superfund site.
Data source: U.S. EPA (1989) as cited in TerraGraphics (1990).

2.4 ONGOING RELEASE MECHANISMS

Releases from source materials are ongoing. Source materials include abandoned tailings dumps and former tailings impoundments; mixed tailings and alluvium deposited in floodplains, stream beds, lake beds, and fill areas; waste rock piles; adit and seep drainage; and soils historically contaminated by smelter emissions.

Mechanisms of releases from waste rock and tailings dumps include water and wind erosion and leaching by acid water. Mechanisms of releases from tailings and mixed tailings and alluvium in the floodplain, beds, and banks include remobilization by seasonal high water, bank sloughing, and entrainment of bed sediments and inundated floodplain sediments in surface water. In addition, seasonal changes in redox chemistry cause releases of soluble metals from floodplain tailings deposits to groundwater and surface water.

Waste rock may contain elevated concentrations of hazardous substances that may be released to the environment by wind or water erosion or leaching. Some of the waste rock in the basin contains pyrite (FeS_2) or other sulfide minerals, which, upon weathering, release acid that drains from the dumps and may leach metals from the waste rock. In addition, groundwater flowing through underground mine workings may oxidize exposed pyrite and form acid mine drainage. Where surface water or groundwater contacts sulfide minerals in an oxidizing environment, such as in underground mine workings, surface waste rock piles, and floodplain tailings deposits, acid mine drainage and metal-bearing leachate may form. Where this occurs, the materials generating the acidic metal-bearing leachate continue to serve as sources of hazardous substances (Balistrieri et al., 1998).

Soils near the former Bunker Hill smelter remain devegetated and contain elevated concentrations of hazardous substances deposited from smelter emissions (Brown et al., 1998). Erosion of these soils to surface waters is an ongoing source of hazardous substances (MFG, 1992a).

This section describes the principal sources of hazardous substances in the basin, which are:

- historical releases from mines and mills, particularly tailings disposal, and re-releases from tailings mixed in bed, bank, and floodplain sediments
- waste rock dumps associated with both producing and nonproducing mines
- metal-bearing leachate draining from adits, waste rock dumps, and tailings dumps
- historical smelter emissions.

2.4.1 Tailings and Mixed Tailings, Waste Rock, and Alluvium/Soils/Sediments

Tailings historically were released by numerous mills to flowing surface waters and floodplains of the Coeur d'Alene River basin and allowed to wash downstream. An estimated 61.7 to 64.5 million tons of tailings were released to surface waters of the Coeur d'Alene River basin (Long, 1998; SAIC, 1993c). Tailings discharged to creeks and the South Fork Coeur d'Alene River from 1886 through 1968 were transported downstream by natural fluvial processes. Through natural processes the tailings became mixed with native alluvium, deposited on the floodplain and in the bed and banks of streams and lakes, remobilized by seasonal high water and floods, and redeposited. Uncontained tailings deposits and mixed tailings and alluvium remain throughout the South Fork (Figure 2-8) and mainstem Coeur d'Alene River basin and now constitute an ongoing source of hazardous substance releases throughout the basin. Tailings and mixed tailings and alluvium contain elevated concentrations of hazardous substances, are subject to erosion, leaching, and transport via surface and groundwater, and constitute an ongoing source of hazardous substances to surface water, groundwater, soils, and biota.

This section summarizes information on historical releases from mills of the Coeur d'Alene River basin, locations of former tailings impoundments, and areas where residual tailings and mixed tailings and alluvium have come to be located in floodplain, bed, and bank deposits. More detailed descriptions are presented in Ridolfi (1998), Bull (1999), Gearheart et al. (1999), and Quivik (1999). In addition, ongoing work by the U.S. EPA and its subcontractors CH2M Hill and URS Greiner Woodward Clyde will provide additional data on waste types, locations, and volumes.

Waste rock dumps consist of material extracted to reach the ore but discarded before the ore beneficiation process. Waste rock dumps are associated with most of the producing and nonproducing mines in the basin and are typically located near mine adits and shafts (Figure 2-9). Waste rock piles throughout the upper Coeur d'Alene River basin are subject to surface erosion and leaching. The U.S. Geological Survey (Hobbs et al., 1965), U.S. DOI Bureau of Land Management (McNary et al., 1995; mine site inventory mapping), USDA Forest Service (USFS, 1997, as cited in Ridolfi, 1998), SAIC (1993c), Idaho Geological Society (IGS, 1997), U.S. Bureau of Mines (USBM, 1995), and others have identified at least 670 adits and 22 shafts, and waste rock dumps are associated with most of them. Volumes of waste rock have been estimated for the Moon Creek drainage (USBM, 1995), Pine Creek drainage (CCJM, 1995; D. Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication), and the South Fork Coeur d'Alene River basin (Gearheart et al., 1999). U.S. EPA is currently conducting studies to further characterize waste volumes and concentrations of hazardous substances in source areas as part of the Coeur d'Alene Basinwide Remedial Investigation. In addition, waste rock and tailings removals by U.S. BLM are currently in progress in the Pine Creek drainage.

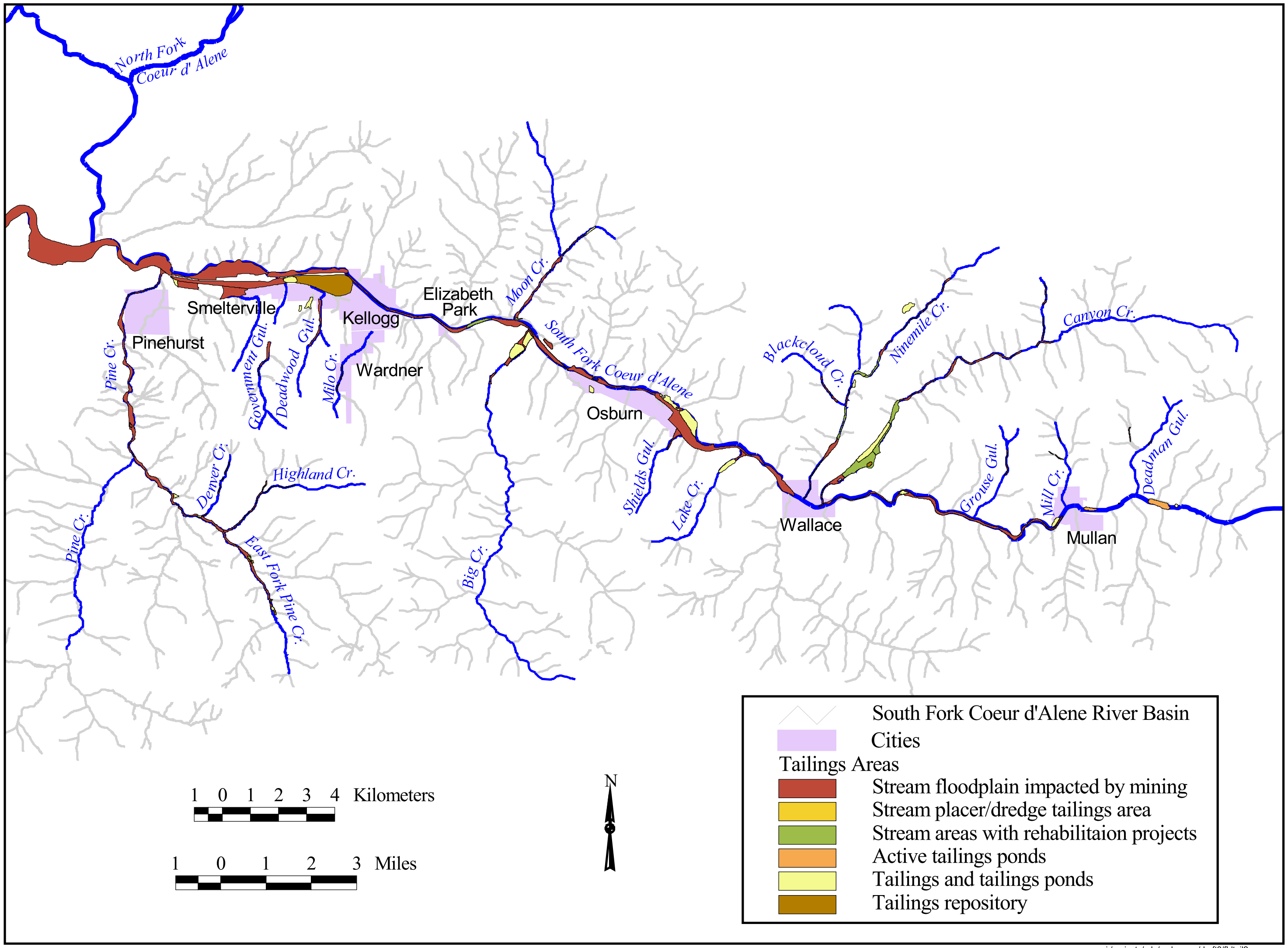

Figure 2-8. Estimated tailings distribution in South Fork Coeur d'Alene River basin.
Source: U.S. BLM, 1999.

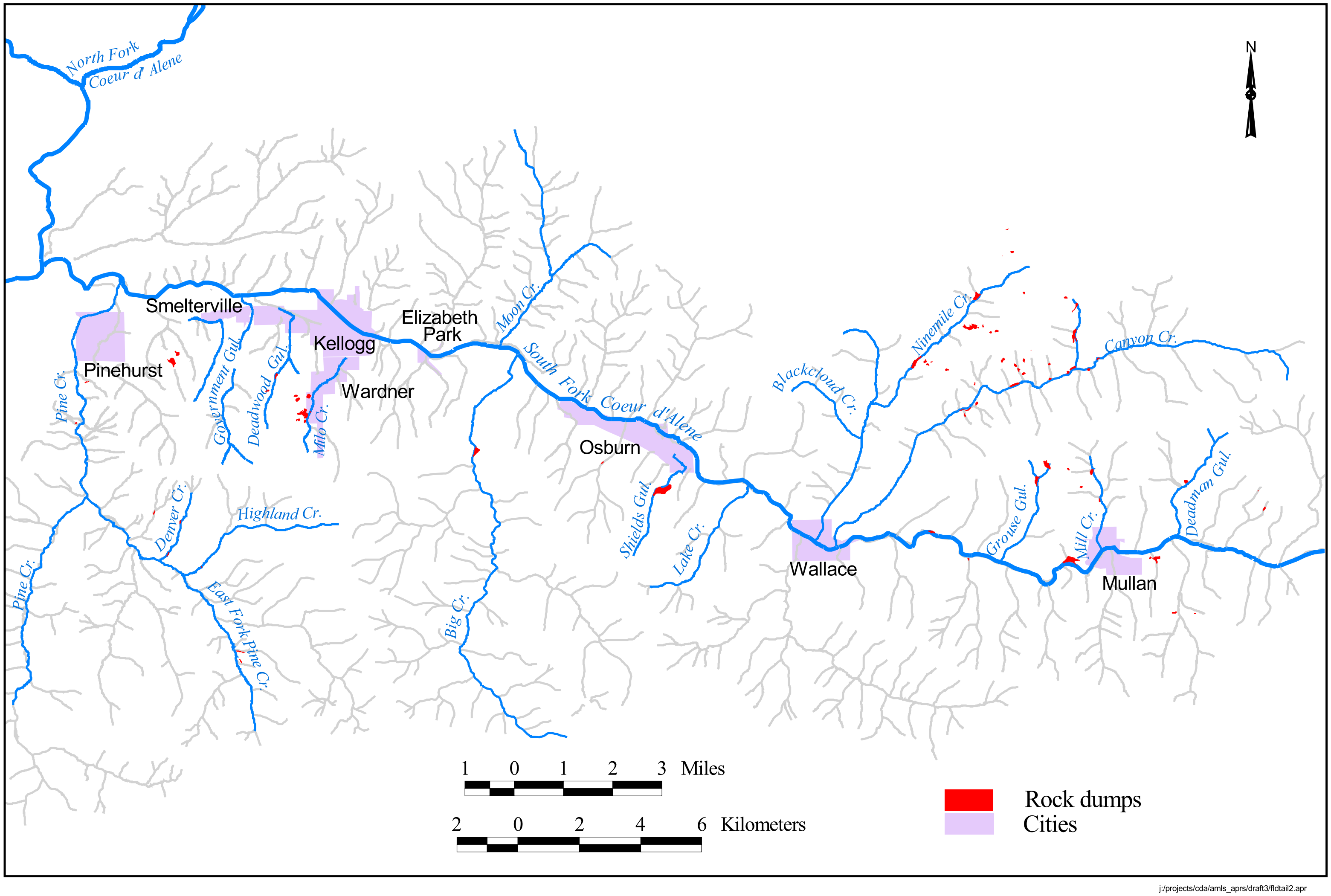

Figure 2-9. Estimated major waste rock distribution in South Fork Coeur d'Alene River basin.
Source: U.S. BLM, 1999.

South Fork Coeur d’Alene River Upstream of Elizabeth Park

The mill located farthest upstream in the basin was the Snowstorm Mill, at the mouth of Daisy Gulch (Figure 2-3). Residual tailings may be present in the floodplains and bed of the South Fork Coeur d’Alene River from there downstream to Mullan (Ridolfi, 1998). At the Lucky Friday Mine, tailings ponds constructed in and after 1969 across the river from the mouth of Gentle Annie Gulch, near Gold Hunter Gulch, and near Mullan may have been built over tailings previously deposited in the floodplain (Ridolfi, 1998). Between Mullan and Wallace, residual tailings from mills within the reach plus wastes from mills upstream of the reach remain. The uncontained tailings pond at the Golconda Mill, located in the South Fork floodplain, may also have been constructed over previously deposited tailings.

Downstream of Wallace, residual tailings are known to be present in the floodplain. An estimated 1.9 to 4.6 million cubic yards of tailings and tailings-contaminated sediments are present in the banks, beds, and floodplains of the South Fork Coeur d’Alene River basin, upstream of Elizabeth Park (Gearheart et al., 1999). An estimated 7.3 to 7.7 million cubic yards are contained in tailings piles and impoundments, including the Daisy Gulch tailings ponds, the Lucky Friday mine active and inactive tailings ponds, tailings at the National millsite, the Golconda tailings, the Osburn tailings ponds, the Sunshine Tailings ponds, the Silver Crescent tailings, and the tailings near Osburn. An estimated 230,000 to 1.2 million cubic yards of tailings remain at former millsites in the upper South Fork Coeur d’Alene basin (Gearheart et al., 1999).

Gearheart et al. (1999) estimated that there are at least 3.2 million cubic yards of waste rock covering 58 acres of the South Fork Coeur d’Alene River basin upstream of Elizabeth Park (excluding Canyon and Ninemile creeks). Waste rock piles at the Caladay Mine in Daly Gulch, the Coeur d’Alene Mine in McFarren Gulch, the Morning # 6 adit near Mullan, and the Rock Creek mine in Rock Creek are located in the creek (SAIC, 1993c; D. Fortier, U.S. BLM, pers. com., December 1999). At each of these sites, the creek flows through a culvert under the waste rock, and at the Coeur d’Alene Mine, water exiting the culvert flows along the toe of the waste rock (SAIC, 1993c). At the Golconda Mine, waste rock was placed in the floodplain of the South Fork Coeur d’Alene River, and is subject to erosion during high flows (SAIC, 1993a; 1993c).

Concentrations of metals have been measured in tailings and floodplains at several locations in the South Fork Coeur d’Alene River basin upstream of Elizabeth Park (Table 2-9). Concentrations were greatest in tailings samples collected near Wallace. Concentrations up to 169 mg cadmium/kg, 58,000 mg lead/kg, and 28,000 mg zinc/kg were measured (Ecology and Environment, 1995). Copper concentrations in sampled tailings impoundments ranged from 198 to 560 mg/kg (Gross, 1982). Arsenic concentrations in sampled tailings impoundments ranged from 30.8 to 1,200 mg/kg (Ecology and Environment, 1995).

Table 2-9
Mean (minimum-maximum) Concentrations of Metals in South Fork Coeur d'Alene River Basin Tailings, Sediments, and Soils Upstream of Elizabeth Park

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Big Creek	Soil	1[a]	—	300	320
Elk Creek Pond	Soil	1[b]	0.4	8,520	1,860
	Sediment	1[b]	16.8	5,720	5,400
Elizabeth Park (upstream)	Soil	1[b]	56.6	40,800	9,470
Evolution	Tailings	2[c]	11.8 (2.45-21.2)	2,630 (420-4,840)	1,146 (151-2,140)
	Soil	1[c]	90	31,000	14,500
	Sediment	3[c]	84 (30-112)	16,583 (5,240-35,300)	9,317 (4,850-16,700)
Galena	Tailings	16[d]	<0.5 (<0.5-2.13)	308 (94-2,750)	47 (22-78)
Gene Day Park	Soil	6[c]	3.9 (0.7-6.3)	347 (175-558)	423 (151-1,050)
	Sediment	2[c]	14.8 (8.3-21.3)	614 (369-858)	515 (314-716)
Golconda	Soil	1[e]	100	45,800	20,700
	Tailings	2[e]	1.8 (1.0-2.6)	639 (353-924)	158 (28-287)
Lucky Friday	Tailings	6[d]	17.7 (9-39)	4,800 (1,500-14,000)	2,333 (1,500-4,500)
Mullan	Sediment	4[f]	1.4 (0.1)	203 (16)	827 (478)
		8[g]	1.3 (0.5-3.7)	202 (50-596)	200 (54-568)
Osburn	Soil	1[h]	160	56,800	22,000
	Soil	1[h]	—	890	804
	Sediment	1[b]	22.2	7,030	3,280
		4-5[i]	9.7 (6.2)	3,580 (1,275)	2,865 (1,594)
Silver Summit	Tailings	3[d]	2.3 (1.8-2.6)	157 (130-180)	63 (<50-73)
Silverton	Tailings	5[c]	65.9 (22.7-90.2)	29,180 (17,200-44,400)	9,516 (5,310-11,700)
	Sediment	1[c]	34.2	9,640	5,770
South Fork CdA Floodplains between Elizabeth Park and Wallace	Soil	13[j]	28.7 (6.3-52.5)	10,191 (1,300-25,600)	4,091 (1,420-8,570)

Table 2-9 (cont.)
Mean (minimum-maximum) Concentrations of Metals in South Fork Coeur d'Alene River Basin Tailings, Sediments, and Soils Upstream of Elizabeth Park

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Wallace	Tailings	2[c]	108 (48.6-169)	54,350 (50,700-58,000)	17,330 (6,660-28,000)
	Sediment	5[c]	14.0 (7.2-19.4)	2,281 (893-3,020)	6,206 (22-17,900)
		4-5[i]	4.8 (1.9)	1,333 (557)	3,273 (1,993)
	Soil	1[a]	—	2,200	3,000

a. Soils collected from surface (Ragaini et al., 1977).
b. Sediments collected from stream channel; soils collected from floodplain banks (Ridolfi, 1991).
c. Ecology and Environment, 1995.
d. Gross, 1982.
e. Tailings collected from impoundment and soil collected from the South Fork Coeur d'Alene River bank (Hudson, 1998).
f. Sediments collected from the South Fork CdA River. Values in parentheses are standard error of the mean; minimum and maximum values were not provided (Farag et al., 1998).
g. Sediments collected from the South Fork CdA River (Reece et al., 1978).
h. Value reported is maximum value measured in the floodplain at Osburn Flats (MFG, 1996, as cited in Ridolfi, 1998).
i. Sediments collected from the South Fork CdA River. Values in parentheses are standard deviations (Woodward et al., 1997).
j. Hagler Bailly Consulting, 1995.

South Fork Coeur d'Alene River Downstream of Elizabeth Park

An estimated 24.6 million cubic yards of tailings are contained in the CIA, and an estimated 2.1 million cubic yards of tailings are contained in Page Pond (Gearheart et al., 1999) (Figure 2-4). Tailings from mills upstream and within the reach have been mixed with alluvium and are present in the floodplains at depths of up to 10 feet (MFG, 1992a). Tailings deposition throughout Smelterville Flats was promoted by the plank-and-pile dam and associated settling pond constructed at Pinehurst Narrows (MFG, 1992a; Quivik, 1999). An estimated 1.7 to 7.8 million cubic yards of tailings and tailings-contaminated sediment remain in the beds, banks, and historical floodplains of the South Fork Coeur d'Alene River downstream of Elizabeth Park and in the Page swamps (Gearheart et al., 1999). An estimated 7,900 to 39,000 cubic yards of tailings remain near former millsites (Gearheart et al., 1999).

An estimated 1.1 million cubic yards of waste rock covering 21 acres remain in the South Fork Coeur d'Alene River basin downstream of Elizabeth Park (Gearheart et al., 1999). The largest waste rock dumps are located in Silver Creek (260,000 yd^3), Deadwood Gulch (250,000 yd^3), and Milo Gulch (200,000 yd^3) (MFG, 1992a).

Concentrations of metals have been measured in tailings at several locations in the South Fork Coeur d'Alene River basin downstream of Elizabeth Park (Table 2-10). Maximum concentrations were measured in CIA pond sludge (5,680 mg cadmium/kg; 237,000 mg zinc/kg) and in CIA jig tailings (56,100 mg lead/kg) (MFG, 1992a). Concentrations of arsenic were measured up to 504 mg/kg at Smelterville flats, 202 mg/kg in Page Pond, and 692 mg/kg in the CIA (MFG, 1992a). Concentrations measured in sediments ranged from 0.6 to 140 mg cadmium/kg, 82 to 39,300 mg lead/kg, and 118 to 22,000 mg zinc/kg.

Concentrations of hazardous substances in samples of waste rock from the Bunker Hill Mine dumps up to 45.7 mg/kg cadmium (Silver Creek), 19,400 mg/kg lead (Magnet Gulch), and 8,070 mg/kg zinc were measured (Silver Creek) (MFG, 1992a). Arsenic concentrations up to 3,080 mg/kg were measured at a waste rock dump in the Little Pine Creek drainage (MFG, 1992a).

Soil sampling conducted as part of the Bunker Hill Superfund Site Remedial Investigation on the unpopulated hillsides surrounding the Bunker Hill smelter complex showed that the most elevated soil concentrations of hazardous substances were nearest the smelter complex, but contaminant concentrations did not consistently decrease with distance for all metals (MFG, 1992a). Concentrations measured in hillside soils ranged from 7.8 to 245 mg cadmium/kg, 82 to 13,700 mg lead/kg, and 310 to 16,100 mg zinc/kg.

Mainstem Coeur d'Alene River, Lateral Lakes, and Coeur d'Alene Lake

Tailings discharged to the South Fork Coeur d'Alene River have been transported by natural fluvial processes downstream to the mainstem Coeur d'Alene River and lateral lakes area, and into Coeur d'Alene Lake. Waste materials released from numerous sources were commingled, mixed with native alluvium, and, during seasonal high water, deposited in the floodplains of the Coeur d'Alene River, and on the beds and banks of the river, the lateral lakes, and Coeur d'Alene Lake.

Horowitz et al. (1993) estimated that 75 million metric tons (82.7 million tons) of sediments enriched in trace elements have been transported the length of the Coeur d'Alene River and deposited on the bed of Coeur d'Alene Lake. Sediment sampling in the river bed has indicated elevated concentrations of metals in the river bed to depths ranging up to 23 feet near Cataldo (URSG and CH2M Hill, 1998). Gearheart et al. (1999) estimated volumes of tailings-contaminated sediment containing greater than 1,000 ppm lead in the mainstem Coeur d'Alene River channel (21.4 million cubic yards), the banks and levees (1.5 million cubic yards), the floodplain (25.7 million cubic yards), palustrine wetlands (5.9 million cubic yards), and in lateral lake beds (6 million cubic yards). They estimated the volume of tailings-contaminated sediment in Coeur d'Alene Lake to be 43.8 million cubic yards. These contaminated sediments are a secondary source of hazardous substances to groundwater, surface water, and biological resources of the lower Coeur d'Alene River basin.

Table 2-10
Mean (minimum-maximum) Concentrations of Metals in South Fork Coeur d'Alene River Basin Tailings, Sediments, and Soils Downstream of Elizabeth Park

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Bunker Creek	Sediment	2[a]	34 (26-42)	1,000 (500-1,500)	9,250 (2,500-16,000)
Bunker Hill Complex	Soil	117[b]	19.0 (1.0-181)	1,606 (15.9-15,600)	1,028 (160-16,100)
CIA	Tailings (flotation)	NA[a]	(6.1-40.0)	(353-7,760)	(624-7,990)
	Tailings (jig)	NA[a]	(11.9-135)	(258-56,100)	(540-24,700)
	Sludge	1[a]	5,680	2,670	237,000
	Soil	9[a]	40.4 (NA)	4,513 (NA)	10,500 (NA)
Government Gulch	Sediment	2[a]	41 (18-63)	1,950 (1,900-2,000)	3,150 (2,500-3,800)
Grouse Creek	Sediment	2[a]	5.6 (5.2-6.0)	783 (475-1,090)	636 (619-652)
Kellogg	Sediment	32[c]	36.3 (27.0-43.3)	4,797 (1,670-11,400)	3,912 (2,080-7,550)
		4-5[d]	4.7 (1.2)	2,692 (978)	961 (189)
	Soil	16[e]	12.9 (0.5-87.0)	2,766 (72-21,000)	1,400 (87-9,200)
		5[f]	59.7 (32-82)	3,174 (170-6,700)	2,174 (200-5,700)
	Tailings	1[f]	37	7,900	7,500
		39[g]	—	3,592 (600-6,300)	4,262 (2,000-13,000)
Page Pond	Tailings	3[a]	38.7 (NA)	4,350 (NA)	4,260 (NA)
	Soil	12[h]	38.7 (21.0-48.0)	4,350 (2,560-6,550)	4,260 (2,950-6,120)
Page Swamp	Soil	18[i]	—	9,350 (182-26,800)	—
Pinehurst	Sediment	4[j]	83.0 (24.9)	4,757 (295)	8,130 (2,538)
		8[k]	38.3 (0.6-140)	8,162 (82-39,300)	5,151 (118-22,000)
		4-5[d]	60 (63)	5,400 (1,069)	5,048 (3,389)
	Soil	1[f]	18	1,000	940
Sewage Treatment Plant	Soil	16[h]	69.3 (35.0-121)	19,800 (11,600-32,700)	8,120 (4,510-12,000)
Shoshone County Airport	Soil	24[h]	49.0 (18.4-133)	15,500 (11,100-28,200)	6,050 (2,860-13,100)
	Soil	12[h]	27.8 (21.0-36.0)	5,340 (3,970-6,310)	2,910 (2,070-4,560)

Table 2-10 (cont.)
Mean (minimum-maximum) Concentrations of Metals in South Fork Coeur d'Alene River Basin Tailings, Sediments, and Soils Downstream of Elizabeth Park

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Smelter Complex	Soil (material)	47[a]	6,711 (10-127,000)	107,323 (1,210-416,000)	80,557 (593-432,000)
	Soil (residual material)	116[a]	1,391 (2.6-19,900)	39,138 (104-399,000)	32,448 (123-329,000)
	Soil (hillside)	47[a]	39.3 (7.8-245)	3,023 (81.9-13,700)	2,195 (310-16,100)
	Soil (subsurface)	151[a]	237 (<0.4-8,930)	26,090 (<5-651,000)	7,674 (46-77,100)
Smelterville	Soil	16[l]	50.2 (18.1-95.7)	14,190 (3,860-22,100)	6,650 (2,130-14,200)
		3[f]	82.7 (25-140)	6,233 (3,2007,900)	6,057 (870-13,000)
	Sediment	3[m]	27.2 (18.6-43.0)	62,500 (55,000-69,500)	10,233 (8,800-12,700)
	Tailings	6[a]	81.7 (3.3-312)	18,444 (42-48,200)	8,892 (180-33,500)
		2[f]	26	1,995 (290-3,700)	17,700 (3,200-29,000)
South Fork CdA River Mouth	Sediment	1[m]	64	1,100	4,700

a. MFG, 1992a.
b. Soils collected from 0 to 12 inches around the Bunker Hill complex area (Dames & Moore, 1990).
c. Sediments collected from the South Fork Coeur d'Alene River (Reece et al., 1978).
d. Sediments collected from the South Fork Coeur d'Alene River. Values in parentheses are standard deviations (Woodward et al., 1997).
e. Soils collected from river bank and floodplain areas (Horowitz, 1995).
f. Ragaini et al., 1977.
g. Tailings collected from surface, 5 ft, and 10 ft levels from a "classical tailings pile" approximately 4 miles west of Kellogg (Galbraith, 1971).
h. Soils collected from fugitive dust source barren areas (CH2M Hill, 1989).
i. Soils collected from 0-6 inches in West and East Page Swamp (Mullins and Burch, 1993).
j. Sediments collected from the South Fork CdA River. Values in parentheses are standard error of the mean; minimum and maximum values were not provided (Farag et al., 1998).
k. Ecology and Environment, 1995.
l. Soils collected from South Fork CdA River floodplain (Hagler Bailly Consulting, 1995).
m. Sediments collected from river bank (USGS, unpublished).[5]

5. Unpublished sampling data collected in August 1989 and June 1991 by USGS, Water Resources Division, Doraville, GA.

Table 2-11 presents example concentrations of hazardous substances measured in floodplain, lake bed, and river bed and bank sediments of the lower Coeur d'Alene River basin. Concentrations of hazardous substances up to 202 mg cadmium/kg were measured in soil collected near Rose Lake, 37,400 mg lead/kg in Killarney Lake sediments; and 34,150 mg zinc/kg in Killarney Lake sediments (USGS, unpublished;[6] Bender, 1991; Horowitz, 1995; URSG and CH2M Hill, 1998).

In addition to natural fluvial transport and deposition, tailings have been dredged from the river bed and impounded in the floodplain of the mainstem Coeur d'Alene River. In the early 1930s, the Mine Owners Association installed a dredge system to excavate tailings from the Coeur d'Alene River near Cataldo (Casner, 1991). Tailings were dredged from the river channel and piped to a disposal area at Mission Flats. Dikes made of dredged tailings were constructed around the tailings to form an impoundment for tailings deposition and drying. By 1951, the dredge spoils covered over 2,000 acres to a depth of as much as 25 to 30 feet (Casner, 1991). Dredging continued into the 1960s. An estimated 34.5 million tons of mixed alluvium and tailings were excavated between 1933 and 1967 (SVNRT, 1998, as cited in Ridolfi 1998). In the mid-1960s, the Idaho Department of Transportation purchased more than 1 million tons of dredge spoils to use in constructing the I-90 road bed (Casner, 1991). Table 2-11 presents ranges of concentrations measured in dredge spoils at Cataldo Mission Flats. Concentrations of lead in Mission Flats ranged up to 13,100 mg/kg and zinc ranged up to 16,000 mg/kg (Table 2-11; Galbraith et al., 1972).

Tailings were also used in constructing portions of the Union Pacific Railroad in 1887. The rail corridor generally follows the Coeur d'Alene River and includes 35 river and creek crossings. It also crosses portions of Coeur d'Alene Lake, Harrison Marsh, Anderson Lake, Black Lake, Cave Lake, Medicine Lake, Lane Marsh, Black Rock Slough, and Bull Run Lake (MFG, 1996; Ridolfi, 1998). The rail embankments and ballast material were constructed of tailings and other mine waste products (MFG, 1996). The Union Pacific Railroad is now discontinued (MFG, 1996).

Subsequent flooding has damaged the ballast and washed contaminated materials into the floodplain.[6] The rail corridor has served as a source of hazardous substances to surface water, groundwater, sediment, and biological resources of the lower Coeur d'Alene River basin. In addition, the railroad corridor in the lower basin has been contaminated in places by deposition of river-transported tailings during high flow.

6. Unpublished data collected by NRDA field personnel during field investigations in March 1997. As cited in Ridolfi, 1998. Available from Ridolfi Engineers, Seattle, WA.

Table 2-11
Mean (minimum-maximum) Metals Concentrations in Tailings, Sediments, and Soils in Lower Coeur d'Alene River Basin

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Anderson Lake	Sediment	24[a]	11.6 (0.3-53.9)	1,105 (20-3,860)	1,244 (73-6,520)
		3[b]	48 (42-56)	2,650 (1,750-3,350)	2,983 (2,150-3,550)
		1[c]	9.7	2,492	2,180
Bare Marsh	Sediment	25[a]	10.0 (0.8-46.0)	1,433 (71-7,020)	1,166 (64-6,180)
	Soil	1[d]	13.0	2,100	—
Black Lake	Soil	39[e]	11.5 (0.5-48.0)	2,280 (32-11,000)	1,463 (80-7,300)
	Sediment	24[a]	10.2 (1.5-33.0)	1,075 (174-4,720)	935 (185-2,760)
		4[b]	21.8 (11-29)	1,935 (490-4,700)	2,250 (1,750-2,600)
Black Rock Slough	Sediment	24[a]	17.9 (0.3-39.3)	3,447 (63-7,630)	2,272 (49-6,620)
Blessing Slough	Sediment	24[a]	19.7 (0.1-46.9)	3,801 (36-9,190)	1,584 (49-3,530)
		3[f]	—	3,499 (3,223-3,996)	—
	Soil	2[d]	7.8 (4.5-11.0)	720 (560-880)	—
Blue Lake	Sediment	24[a]	24.0 (1.5-56.5)	3,445 (31-7,860)	2,435 (97-4,460)
		4[b]	45.5 (25-83)	2,988 (950-4,200)	3,788 (2,000-6,800)
		3[f]	—	2,576 (2,447-2,688)	—
Bull Run Lake	Sediment	24[a]	21.3 (9.0-46.1)	5,060 (1,070-15,400)	2,834 (1,260-5,720)
Campbell Marsh	Sediment	25[a]	21.9 (2.7-37.4)	4,674 (312-8,890)	2,381 (239-4,330)
	Soil	13[d]	16.2 (3.2-29.0)	2,582 (26-7,500)	—
Cataldo	Soil	32[e]	8.6 (0.5-21.0)	1,817 (54-4,900)	1,189 (80-6,200)
		9[g]	22.2 (4.8-33.1)	3,742 (182-5,720)	2,361 (370-4,270)
		26[h]	18.0 (0.1-158)	3,204 (15-9,600)	2,037 (22-6,830)
	Sediment	4[i]	14.5 (2.4)	2,390 (138)	2,543 (108)
		12[j]	16.7 (7.4-22.6)	3,352 (2,610-4,180)	3,069 (1,960-3,860)
		1[c]	4.8	2,310	1,350
		4[k]	10.5 (8.4-12.9)	2,800 (2,000-3,800)	10,075 (6,500-19,000)
		33[h]	16.9 (0.02-75.3)	1,942 (12-4,640)	1,755 (44-3,780)
Cataldo Boat Ramp	Soil	1[l]	18.5	6,030	5,510
	Sediment	1[l]	3.5	1,380	13,700

Table 2-11 (cont.)
Mean (minimum-maximum) Metals Concentrations in Tailings, Sediments, and Soils in Lower Coeur d'Alene River Basin

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Cataldo Mission	Soil	1[l]	6.9	1,110	1,580
	Tailings (0-1 feet)	6[m]	—	4,217 (2,800-5,500)	3,183 (2,400-4,000)
	Tailings (2-3.5 feet)	42[m]	—	5,069 (300-13,100)	4,229 (400-16,000)
	Tailings (4-6.5 feet)	17[m]	—	626 (50-4,300)	741 (200-3,100)
	Tailings (7-11.5 feet)	10[m]	—	128 (50-500)	380 (300-600)
Cataldo Slough	Sediment	18[a]	25.5 (0.7-67.8)	2,365 (83-5,650)	2,797 (132-11,700)
Cave Lake	Sediment	22[a]	10.2 (0.9-28.1)	1,391 (36-7,490)	1,043 (48-4,450)
		3[b]	36 (29-45)	2,950 (2,300-3,850)	2,950 (2,750-3,300)
		6[h]	16.2 (0.2-39.1)	3,088 (12-9,360)	1,974 (40-5,280)
CdA River	Soil	44[n]	11.3 (0.3-31.8)	2,223 (20-8,030)	1,234 (55-8,850)
		49°	3.7 (0.5-23.8)	241 (18-1,565)	202 (39-865)
	Sediment	10[p]	—	1,997 (587-4,460)	—
		3[f]	—	2,853 (2,447-3,489)	—
		9[d]	—	2,521 (1,775-3,475)	—
CdA River Delta	Sediment	107[q]	43 (16-75)	3,700 (3,000-6,300)	3,800 (3,200-4,700)
		9[j]	33.2 (5.8-50.7)	3,374 (2,460-4,320)	3,007 (2,250-3,480)
		2[c]	25.5 (8-43)	3,929 (3,700-4,158)	3,740 (3,680-3,800)
		7[r]	—	—	3,103 (635-6,760)
CdA River near Black Lake	Sediment	4[i]	27.0 (2.7)	3,850 (442)	4,475 (474)
		4[k]	53.8 (21-145)	6,123 (3,310-12,700)	4,470 (3,070-7,350)
		28[h]	21.3 (0.02-70.6)	5,842 (18.4-35,600)	3,564 (50-10,700)
	Soil	18[h]	4.6 (0.02-17.3)	1,188 (6-6,530)	628 (31-2,730)
CdA River near Blue Lake	Sediment	7[k]	40 (19-107)	4,420 (2,150-6,870)	4,568 (3,040-5,580)
CdA River near Killarney Lake	Sediment	4[i]	24.8 (4.2)	2,175 (293)	3,290 (333)
	Soil	25[h]	6.7 (0.1-24.0)	1,949 (7-9,910)	1,064 (17-4,590)

Table 2-11 (cont.)
Mean (minimum-maximum) Metals Concentrations in Tailings, Sediments, and Soils in Lower Coeur d'Alene River Basin

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
CdA River near Rose Lake	Sediment	4[i]	33.0 (2.7)	6,810 (1,469)	6,790 (858)
		1[c]	7.2	3,870	7,300
CdA River near Thompson Lake	Sediment	2[j]	17.4 (16.5-18.0)	3,677 (2,710-4,740)	3,245 (1,730-6,650)
		1[c]	8.3	3,992	4,220
		5[k]	90 (9-208)	14,492 (4,880-28,600)	7,024 (3,400-11,830)
		3[f]	—	3,177 (2,281-4,405)	—
Dudley	Soil	9[g]	32.2 (19.7-56.6)	4,462 (2,010-6,870)	3,038 (1,830-5,430)
		10[h]	4.0 (0.1-9.2)	767 (20-2,810)	491 (86-1,230)
Harrison	Soils	5[e]	5.5 (0.5-18.0)	1,423 (140-3,500)	734 (150-2,200)
		21[h]	16.0 (0.03-72.1)	2,846 (21-17,500)	2,204 (45-10,700)
	Sediment	4[i]	25.5 (1.9)	3,363 (267)	3,895 (276)
		5[k]	4.7 (<0.5-10)	2,016 (42-5,280)	965 (111-2,270)
		28[h]	18.7 (0.03-79.5)	4,544 (11-19,900)	2,938 (48-11,500)
Harrison Marsh	Sediment	13[a]	38.1 (19.7-63.3)	4,129 (1,540-7,000)	3,959 (2,870-5,170)
Harrison Slough	Sediment	24[a]	32.3 (11.6-96.4)	4,515 (3,030-8,660)	3,425 (1,700-7,040)
Hidden Marsh	Sediment	19[a]	20.5 (0.8-77.3)	2,763 (72-6,340)	1,493 (95-2,920)
Killarney Lake	Sediment	23[a]	36.1 (11.1-76.2)	5,002 (1,890-9,680)	3,550 (1,020-5,860)
		3[b]	78.3 (50-130)	3,700 (2,550-4,600)	4,483 (4,000-5,200)
		90[s]	42.5 (<1-146)	4,893 (<2-37,400)	6,587 (100-34,150)
		3[f]	—	4,522 (3,207-5,502)	—
		10[h]	25.0 (0.02-55.8)	3,886 (48-12,800)	3,504 (134-8,710)
	Soil	7[g]	17.8 (0.2-36.3)	4,704 (434-11,600)	2,442 (589-3,980)
CdA Lake	Sediment (surface)	150[t]	62 (<0.5-157)	1,900 (14-7,700)	3,600 (63-9,100)
	Sediment (core)	12[t]	25 (<0.1-137)	3,200 (12-27,500)	2,400 (59-14,000)
CdA Lake Northwest Shore	Sediment (lower)	9[u]	0.7 (0.2-1.8)	34.9 (4.1-123)	363.6 (118-756)
	Sediment (upper)	9[u]	0.6 (0.2-1.5)	59.7 (10.2-326)	289.3 (54.5-542)
CdA Lake-North	Sediment	5[c]	7.4 (6.6-8.2)	3,315 (1,146-5,732)	4,466 (2,740-5,360)
		15[q]	—	—	3,723 (588-7,320)
CdA Lake-South	Sediment	1[c]	9.9	367	1,310
Lane	Soil	26[e]	16.0 (0.8-34.0)	2,886 (70-5,100)	2,030 (125-5,100)

Table 2-11 (cont.)
Mean (minimum-maximum) Metals Concentrations
in Tailings, Sediments, and Soils in Lower Coeur d'Alene River Basin

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Lane Marsh	Sediment	24[a]	16.5 (3.0-31.6)	3,442 (338-7,550)	1,821 (374-3,890)
		3[d]	8.5 (6.0-12.0)	2,067 (1,200-3,100)	—
Medicine Lake	Sediment	24[a]	23.8 (3.4-80.6)	3,187 (228-19,900)	2,349 (397-10,400)
		2[b]	37 (30-44)	2,825 (2,650-3,000)	2,750 (2,550-2,950)
		9[h]	27.9 (0.2-83.3)	5,755 (30-25,800)	3,835 (130-12,500)
Medimont	Sediment	28[h]	24.1 (0.1-114.0)	5,507 (17-32,900)	3,885 (45-15,400)
	Soil	30[e]	8.7 (0.5-31.0)	1,641 (29-4,900)	1,342 (75-5,100)
		1[l]	105	19,200	7,400
		24[h]	5.8 (0.05-23.8)	2,218 (18-14,500)	1,149 (30-4,510)
Mission Slough	Sediment	13[a]	22.7 (4.0-45.3)	2,928 (501-5,110)	2,258 (456-4,530)
Moffit Slough	Sediment	24[a]	14.9 (0.5-44.1)	2,851 (32-16,200)	1,665 (43-6,030)
	Soil	5[d]	17.0 (6.1-38.0)	3,022 (210-5,400)	—
Orling Slough	Sediment	24[a]	14.2 (4.8-23.1)	4,207 (426-9,680)	1,679 (723-2,410)
Porter Slough	Sediment	24[a]	14.0 (0.6-31.0)	2,621 (88-8,230)	1,526 (63-3,960)
Rose Lake	Soil	37[e]	13.7 (0.5-202.0)	1,624 (47-6,600)	1,294 (93-6,800)
		10[d]	—	2,890 (249-8,655)	—
	Sediment	20[a]	18.6 (1.2-38.6)	3,227 (32-8,870)	2,188 (56-6,090)
		3[b]	10.3 (2-15)	1,817 (100-3200)	1,413 (240-2,100)
		9[h]	0.4 (0.02-2.4)	120 (17-350)	201 (69-385)
Strobl Marsh	Sediment	24[a]	26.1 (6.8-58.8)	5,826 (3,970-11,100)	3,012 (815-5,520)
		4[d]	11.3 (2.8-22.0)	1,860 (130-4,400)	—
Swan Lake	Sediment	18[a]	32.4 (2.7-72.0)	3,965 (213-8,350)	3,258 (241-5,780)
		4[b]	31.8 (19-57)	3,263 (1,800-3,900)	3,025 (1,900-4,650)
		3[f]	—	3,814 (3,305-4,145)	—
Thompson Lake	Sediment	24[a]	27.2 (1.7-85.2)	3,723 (324-8,880)	3,009 (163-7,330)
		2[b]	27 (23-31)	3,150 (2,600-3,700)	2,950 (2,900-3,000)
		1[c]	8.9	3,386	2,560
	Soil	1[g]	8.5	2,730	1,075
		8[d]	—	3,133 (34-6,570)	—
		3[d]	12.3 (9.8-14.0)	1,863 (990-2,300)	—
Thompson Marsh	Sediment	24[a]	7.6 (0.3-19.9)	1,812 (99.4-12,200)	878 (83-2,450)

Table 2-11 (cont.)
Mean (minimum-maximum) Metals Concentrations in Tailings, Sediments, and Soils in Lower Coeur d'Alene River Basin

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)

a. Sediments collected from lacustrine and palustrine areas (Campbell et al., 1999).
b. Sediments collected from 1 to 9 m in lake inlets and open water (Bauer, 1974; data also presented in Rabe and Bauer, 1977, and Funk et al., 1975).
c. Hornig et al., 1988 (wet weight measurement).
d. Neufeld, 1987.
e. Soils collected from river bank and floodplain areas (Horowitz, 1995).
f. Krieger, 1990.
g. Soil samples collected from islands and river bank (Roy F. Weston, 1989).
h. Soils collected from floodplains and sediments collected from Coeur d'Alene River and lateral lakes (URSG and CH2M Hill, 1998).
i. Sediments collected from the Coeur d'Alene River. Values in parentheses are standard error of the mean; minimum and maximum values were not provided (Farag et al., 1998).
j. Sediments collected from the Coeur d'Alene River (Reece et al., 1978).
k. Sediment samples collected from river bank (USGS, unpublished[7]).
i. Sediments collected from stream channel; soils collected from floodplain banks (Ridolfi, 1991).
m. Tailings core samples collected from Cataldo Mission Flats area (Galbraith, 1971; Galbraith et al., 1972).
n. Soils collected from floodplain areas (Hagler Bailly Consulting, 1995).
o. Soils collected at 0-5 cm in Kootenai County (Keely, 1979).
p. Audet, 1997.
q. Sediments collected from the river delta area (Maxfield et al., 1974).
r. Sediments collected from Coeur d'Alene Lake between 2 and >20 m (Winner, 1972).
s. Sediments collected from three locations in Killarney Lake (Bender, 1991).
t. Horowitz et al., 1992, 1993, 1995.
u. Sediments collected from littoral/water interface and 1m above the water level (Cernera et al., 1998).

Concentrations of metals measured in the discontinued railroad right of ways (ROW) are presented in Tables 2-12 and 2-13. Table 2-12 presents cadmium, lead, and zinc concentrations in samples collected from the zero to 18 in. depth from locations in both the lower and upper basins (U.S. EPA, 1999). Samples were collected from the mainline and from sidings (where the track divides to allow for loading/unloading or passing). Samples were also collected from the ROW to the north and south of the tracks. Cadmium concentrations north and south of the mainline ranged from 0.5 to 99.4 mg/kg, lead concentrations ranged from 151 to 33,700 mg/kg, and zinc concentrations ranged from 114 to 15,300 mg/kg. Table 2-13 presents lead concentrations in samples collected from the 0 to 6, 6 to 12, and 12 to 18 in. depths at locations along the railroad within the Bunker Hill Superfund Site.

7. Unpublished sampling data collected in August 1989 and June 1991 by USGS, Water Resources Division, Doraville, GA.

Table 2-12
Concentrations of Cadmium, Lead, and Zinc (mg/kg) in Railroad Right of Way[a]

Location	Mile	Cadmium		Lead		Zinc	
		Mainline	Siding	Mainline	Siding	Mainline	Siding
Springston Siding #1	33.5	22.6	9.4	14,400	7,500	3,090	1,560
~0.5 miles east of Medimont	42	18.6	—	4,390	—	1,890	—
Dudley Siding	52	26.1	17.6	8,060	4,100	3,640	2,080
~1 mile east of Cataldo	58.5	34.1	—	11,500	—	5,540	—
~0.75 miles west of Enaville	62	30.9	—	8350	—	4,700	—
Siding west of Enaville	62.5	30.6	17.1	7,050	6,160	4,730	2,580
Sunshine Mine siding at Shont	72.8	190	82.4	58,800	36,700	8,4700	8,680
Silverton area east of Osburn	78	102	—	30,400	—	13,800	—
Morning Mine area	5	68.3	—	17,100	—	11,500	—

a. Samples were collected from the surface to 18 inches.

Source: U.S. EPA, 1999.

Table 2-13
Concentrations of Lead (mg/kg) Collected from Railroad Right of Way within the Bunker Hill Superfund Site

Sample Location	Sample Size	Sample Depth		
		0-6 in.	6-12 in.	12-18 in.
Eastern Site Boundary to Elizabeth Park	3	1,470-28,200	1,410-25,900	1,590-17,900
Elizabeth Park to Ross Ranch	42	1,150-56,000	560-52,900	408-67,400
Ross Ranch to Kellogg Depot	47	3,450-64,300	2,540-42,900	3,350-70,500
Kellogg Depot to Silver Mountain	39	690-80,800	3,170-64,900	1,320-55,000
Silver Mountain to Smelterville	78	867-84,600	1,850-81,600	1,560-67,500
Smelterville to Page Swamp	73	800-30,200	730-37,100	488-37,500
Page Swamp to Pine Creek	108	628-47,200	1,290-57,700	986-89,800
Pine Creek to South Fork Coeur d'Alene River	33	500-19,200	120-23,000	95-23,700
South Fork Coeur d'Alene River to Western Site Boundary	37	251-15,600	56-26,200	58-36,700

Source: MFG, 1996.

Canyon Creek

In the Canyon Creek drainage, the largest unconfined deposits of jig and flotation tailings and mixed tailings and alluvium are in the lower reaches where the creek gradient diminishes and the valley widens (Figure 2-8). The lower reach of the creek was impounded in the early part of the twentieth century to settle tailings, and more than 400,000 cubic yards (230,000 cubic yards tailings; 134,000 cubic yards reworked tailings and alluvium; 45,000 cubic yards railroad embankment; 13,000 cubic yards Formosa slimes) of tailings and alluvium accumulated (U.S. EPA, 1995). Approximately 532,300 cubic yards of mixed tailings and alluvium have been moved from the lower Canyon Creek floodplain to a repository near the southeastern edge of the floodplain in the Woodland Park area (SVNRT, 1998, as cited in Ridolfi, 1998 and in Gearheart et al., 1999). As a result of former tailings disposal practices, residual jig and flotation tailings are present in the floodplain upstream of the former impoundment area as well. In addition to unconfined tailings deposits in the drainage, the Star Mine tailings ponds are located in the Canyon Creek floodplain upstream of Woodland Park. The six ponds received tailings from 1965 to 1990. The ponds cover 62 acres and are estimated to hold 3.4 million tons of tailings (2.1 million cubic yards) (SAIC 1993a; 1993b; Gearheart et al., 1999).

An estimated 139 acres of floodplain have been remediated, but an estimated 83 acres of contaminated floodplain remain (Gearheart et al., 1999). The volume of tailings-contaminated floodplain materials remaining in the Canyon Creek and Gorge Gulch floodplains, beds, and banks is estimated to be between 134,000 and 669,000 cubic yards (Gearheart et al., 1999). An estimated 39,000 to 166,000 cubic yards of tailings-contaminated material remains near former millsites (Gearheart et al., 1999).

Waste rock is believed to be located near all adits and shafts in the basin. Gearheart et al. (1999) estimated that waste rock dumps in the Canyon Creek drainage contain 3.1 million cubic yards of waste rock and cover 75 acres. Waste rock piles at the Ajax Mine, the Hercules Mine (No. 4 adit in Gorge Gulch), the Gertie Mine, and the Tamarack-Custer #7 (also called the Standard #6) are subject to erosion by the creek (SAIC, 1993a; MFG, 1994). The waste rock pile at the Hercules No. 3 adit in Gorge Gulch is located in the creek, and the creek flows through it (Ridolfi, 1998).

Concentrations of cadmium, lead, and zinc in samples collected during the early 1990s site characterization of lower Canyon Creek are presented in Table 2-14. Concentrations of metals in tailings and alluvium were reported for three reaches: (1) the Formosa reach, from the upstream end of the Star Tailings Ponds to approximately 1,000 feet upstream of the Canyon Silver-Formosa Mine; (2) the Upper Ponds reach, from Star Tailings Ponds No. 1 to No. 4; and (3) the Woodland Park reach, from the downstream end of the Star Tailings Pond No. 2 to the old tailings dam, approximately 1,200 feet downstream of Star Tailings Pond No. 6 (U.S. EPA, 1995).

Table 2-14
Mean (minimum-maximum) Concentrations of Metals in Tailings, Sediments, and Soils in the Canyon Creek Basin

Reach	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Canyon Creek	Soils	6[a]	22.6 (4.9-44.8)	18,293 (5,460-42,200)	3,838 (590-7,450)
		18[b]	—	16,389 (500-38,000)	6,133 (500-44,000)
	Sediment	4[c]	49.3 (6.5)	9,187 (522)	8,543 (931)
		13[b]	—	3,053 (400-63,000)	2,100 (1,100-3,300)
Formosa	Railroad embankment	14[d]	54 (9.2-142)	20,599 (352-43,600)	4,013 (387-13,100)
	Reworked tailings/ alluvium	3[d]	38 (24.4-45.2)	12,633 (11,200-14,600)	2,863 (2,090-4,360)
	Alluvium	6[d]	26 (8.4-60)	2,284 (240-7,720)	606 (258-1,440)
	Tailings	6[d]	464 (9.6-1,850)	45,183 (15,300-83,600)	13,906 (876-55,200)
Frisco	Soil	1[e]	40.5	76,300	7,040
	Tailings	NA[f]	—	(2,420-93,200)	(467-46,400)
Tamarack	Tailings	1[g]	53.6	54,800	8,650
	Soil	1[g]	345	47,200	53,200
	Sediment	3[g]	58.9 (21.3-105)	11,040 (3,990-22,600)	11,163 (6,090-15,800)
Upper Pond	Railroad embankment	6[d]	41 (15.6-94)	51,117 (900-137,000)	5,381 (576-13,900)
	Tailings	2[d]	66 (27.2-104)	25,950 (22,500-29,400)	7,410 (3,620-11,200)
	Alluvium	1[d]	15.6	235	672

Table 2-14 (cont.)
Mean (minimum-maximum) Concentrations of Metals in Tailings, Sediments, and Soils in the Canyon Creek Basin

Reach	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Woodland Park	Reworked tailings/ alluvium	14[d]	29 (7.2-72.2)	16,194 (7,720-40,400)	5,380 (225-16,000)
	Jig tailings	14[d]	52 (<2-214)	78,986 (20,600-243,000)	7,139 (46.8-28,300)
	Railroad embankment	9[d]	162 (3.2-860)	34,810 (109-123,000)	17,352 (157-95,200)
	Alluvium	58[d]	55 (<2.0-1,320)	4,661 (159-20,800)	2,404 (52.4-10,400)
	Tailings	46[d]	54 (4-518)	47,750 (5,120-136,000)	7,784 (876-74,600)
	Soil	2[e]	19.2 (8.4-30)	68,200 (64,900-71,500)	5,255 (3,290-7,220)
	Sediment	1[e]	456	26,200	26,300

a. Soils collected from the floodplain (Hagler Bailly Consulting, 1995).
b. Soils and sediments collected from Canyon Creek valley bottom (Galbraith, 1971).
c. Sediments collected from stream channel (Farag et al., 1998; values in parentheses are standard error of the mean; minimum and maximum values were not provided).
d. U.S. EPA, 1995.
e. Sediments collected from stream channel; soils collected from floodplain banks (Ridolfi, 1991).
f. SVNRT, 1996, as cited in Ridolfi, 1998.
g. Ecology and Environment, 1995.

Concentrations of metals in tailings and alluvium ranged from <2 to 1,850 mg cadmium/kg, 159 to 243,000 mg lead/kg, and 46.8 to 74,600 mg zinc/kg (Table 2-14; U.S. EPA, 1995). Concentrations of metals measured in the discontinued railroad embankment ranged from 3.2 to 860 mg cadmium/kg, 109 to 137,000 mg lead/kg, and 157 to 95,200 mg zinc/kg (Table 2-14; U.S. EPA, 1995). Concentrations of metals in soils and sediments ranged from 4.9 to 456 mg cadmium/kg, 500 to 76,300 mg lead/kg, and 500 to 53,200 mg zinc/kg. Some of this material has recently been moved to a repository.

Ninemile Creek

Tailings deposits in the Ninemile Creek drainage include a large mixed-jig and flotation tailings pile at the Interstate-Callahan Mill (66,000 to 80,000 cubic yards), a tailings pond at the Rex Mill (84,000 cubic yards, plus an additional 9,000 cubic yards near the mill site), and a tailings pile at the Success Mill (200,000 cubic yards, plus an additional 200 to 1,700 cubic yards near the millsite) (Figures 2-5 and 2-8) (SAIC, 1993a, 1993b; Gearheart et al., 1999).

The tailings pile at the Interstate-Callahan Mill was historically in direct contact with Ninemile Creek. In 1992 and 1993, the Hecla Mining Company attempted to isolate the tailings from the creek, but zinc loadings still increase through the reach in which the mill site is located (Ridolfi, 1998). Surface water collects seasonally on the pond, infiltrates, and discharges from a seep at the toe of the tailings dam (Ridolfi, 1998). The waste rock and tailings pile at the Success Mill also were historically in contact with the creek and were actively eroding. In 1993, the U.S. EPA conducted a reclamation project to isolate the tailings from the creek (Ridolfi, 1998).

On the mainstem of Ninemile Creek, tailings discharged from the Dayrock Mill probably remain in the floodplain near the mill (Gross, 1982), and tailings produced at the mill at Blackcloud may also be present (Ridolfi, 1998). Volume estimates for these tailings deposits are 11,000 cubic yards (Dayrock) and 7,000 cubic yards (Blackcloud). The Dayrock impoundment is estimated to contain 134,000 to 269,000 cubic yards of tailings (Gearheart et al., 1999).

In addition to these discrete tailings deposits, historical tailings disposal to the creek and erosion of tailings in contact with the creek have distributed hazardous substances throughout the East Fork and mainstem of Ninemile Creek. In 1994, the Silver Valley Natural Resource Trustees, Idaho Division of Environmental Quality, U.S. DOI Bureau of Land Management, and Hecla Mining Company removed some of the mixed tailings and alluvium from the lower East Fork of Ninemile Creek, but an estimated 195,000 cubic yards of mixed tailings and alluvium remain in the floodplain elsewhere in the drainage (Gearheart et al., 1999).

Measured concentrations of cadmium in floodplain materials range from 0.2 to 106.5 mg/kg, lead from 3,840 to 100,000 mg/kg, and zinc from 390 to 19,700 mg/kg (Table 2-15). Copper concentrations in the Interstate-Callahan tailings impoundment ranged from 40 to 168 mg/kg (Gross, 1982). Gearheart et al. (1999) estimated that waste rock dumps in the Ninemile Creek drainage contain 2.5 million cubic yards of waste rock and cover approximately 53 acres.

Table 2-15
Mean (minimum-maximum) Concentrations of Metals in Ninemile Creek Basin Tailings, Sediments, and Soils

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
East Fork Ninemile Creek	Soils	NA[a]	—	(14,700-100,000)	(963-3,230)
Ninemile Creek	Soils	5[b]	8.8 (0.2-12.7)	27,280 (14,500-59,600)	2,580 (1,540-3,720)
		NA[a]	—	(12,600-72,000)	(1,050-10,600)
	Sediment	4[c]	106.5 (33.3)	4,503 (25)	19,700 (4,699)
Interstate-Callahan	Tailings	3[d]	3.8 (2.1-6.9)	5,703 (3,840-7,070)	980 (390-1,400)
Success	Tailings	1[e]	10.9	8,010	2,430

a. Values reported for ranges of concentrations from soil test pits (SVNRT, 1994, as cited in Ridolfi, 1998).
b. Soils collected from the floodplain (Hagler Bailly Consulting, 1995).
c. Sediments collected from stream channel (Farag et al., 1998; values in parentheses are standard error of the mean; minimum and maximum values were not provided).
d. Gross, 1982.
e. Ecology and Environment, 1993, as cited in Ridolfi, 1998.

Moon Creek

In the Moon Creek drainage, south of the former Charles Dickens Mill and in the Moon Creek floodplain (Figures 2-3 and 2-8), an estimated 40,000 to 42,600 cubic yards of tailings remain, covering approximately 5 acres (Gross, 1982; USBM, 1995; Ridolfi, 1996, as cited in Ridolfi, 1998). Moon Creek bisects the tailings and is in direct contact with them throughout the length of the tailings impoundment. Soils surrounding the mill comprise 6 to 8 feet of jig tailings, waste rock, wood, and other debris mixed with alluvium (Ridolfi, 1998). Mine wastes have been transported from the Silver Crescent and Charles Dickens mine sites throughout the floodplain and the channel of the East Fork and possibly the main stem of Moon Creek.[8]

Concentrations of metals in the Silver Crescent Mill and Charles Dickens Mine Complex tailings range from 0.5 to 120 mg cadmium/kg, 2 to 47,300 mg lead/kg, and 1 to 17,000 mg zinc/kg (Table 2-16). In Moon Creek tailings, copper ranged from 1 to 840 mg/kg, antimony ranged from 5 to 330 mg/kg, arsenic ranged from 5 to 1,300 mg/kg, and mercury ranged from 0.016 to 19 mg/kg (Gross, 1982; USBM, 1995).

8. Unpublished data collected by NRDA field personnel during field investigations in October 1996. As cited in Ridolfi, 1998. Available from Ridolfi Engineers, Seattle, WA.

Table 2-16
Mean (minimum-maximum) Concentrations of Metals in Moon Creek Basin Tailings, Sediments, and Soils

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Charles Dickens/ Silver Crescent	Tailings	312[a]	23.1 (0.5-120)	5,657 (2-47,300)	4,217 (1-17,000)
		6[b]	42.6 (5.2-91.3)	14,967 (1,080-29,180)	4,088 (1,710-8,050)

a. USBM, 1995.
b. Gross, 1982.

Pine Creek

Tailings deposits in the Pine Creek drainage include dumps associated with the Constitution Mill, the Little Pittsburgh (Mascot) Mill, the Nabob Mill, the Liberal King (Sunset) Mill, the Douglas Mill, and the Amy Matchless Mill (Figures 2-6 and 2-8).

Tailings associated with the Amy Matchless and Liberal King mines, and tailings believed to be associated with the Little Pittsburgh Mill at the mouth of Denver Creek, were removed by U.S. BLM in 1996 and 1997 (CCJM, 1998). These tailings, totaling about 23,075 cubic yards, were initially moved to a temporary storage area (TSA) near the upper Constitution Mill (CCJM, 1998). In 1998, they were removed to the CIA (Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication, June, 2000). In 1998, another 420 cubic yards were removed from the Amy Matchless site to the CIA, completing the planned U.S. BLM removals from the site (D. Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication, June, 2000).

Approximately 4,800 to 9,000 cubic yards of tailings were estimated to remain below the Liberal King (Sunset) Mill (Gross, 1982; CCJM, 1995). The floodplain tailings were removed by the U.S. BLM in 1997 (CCJM, 1998). Approximately 8,700 cubic yards of tailings and 660 cubic yards of the alluvium beneath the tailings were removed to the TSA. In 1998, approximately 20 cubic yards of tailings material were removed directly to the CIA (D. Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication, June, 2000). In 1999, U.S. BLM removed approximately 1,800 cubic yards of tailings material from the rock dump and hillsides near and below the mill, to the CIA (D. Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication, June, 2000).

An impoundment in the East Fork of Pine Creek near the confluence with Denver Creek was estimated to contain approximately 1,000 to 1,880 cubic yards of tailings believed to have been discharged from the Little Pittsburg Mill (Gross, 1982; CCJM, 1995; McNary et al., 1995). In 1996, that estimate was revised to 7,900 cubic yards. Of that amount, 5,200 cubic yards (4,300 cubic yards of tailings and 660 cubic yards of alluvium) were located on public lands and were moved to the TSA in 1996 and 1997 (CCJM, 1998; D. Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication, June, 2000).

An estimated 31,000 to 46,000 cubic yards of tailings are located at the Douglas Mine site (Gross, 1982; McNary et al., 1995). The U.S. EPA removed 24,762 cubic yards of tailings from near the road in 1996 and covered them in 1997 (U.S. EPA, 1998). In 1998, U.S. BLM removed tailings and mill wastes from mill areas at the Liberal King (99 cubic yards), the Upper Constitution (361 cubic yards), and the Red Cloud/Sidney (688 cubic yards) (D. Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication, June, 2000).

Tailings associated with other sites in the Pine Creek drainage have not been removed. Approximately 40,000 to 45,000 cubic yards of tailings remain near the Nabob Mill (CCJM, 1995; McNary et al., 1995; Gearheart et al., 1999). In 1995, the mine operator seeded and placed soil cover materials over the tailings, but success of the revegetation is limited (CCJM, 1998). At the Constitution Mine site, two tailing dumps are estimated to contain 25,900 and 35,900 cubic yards (Gross, 1982; CCJM, 1995; McNary et al., 1995); these tailings have not been removed (CCJM, 1998). According to Gross (1982), tailing ponds at the Constitution site could be eroded by surface streams and wind. Gearheart et al. (1999) estimated that the total volume of tailings remaining in piles and impoundments is 79,700 cubic yards, and the total volume of tailings remaining at 10 former mines and millsites is 29,000 to 126,000 cubic yards.

Other smaller tailing deposits exist throughout the basin, and many tailing deposits are near or in contact with streams in the Pine Creek basin (McNary et al., 1995). In addition to the discrete tailings deposits, the discharge of tailings to the Pine Creek drainage has resulted in the distribution of tailings and mixed tailings and alluvium throughout reaches of the East Fork and mainstem Pine Creek, and tributaries to the East Fork (Highland, Denver, Red Cloud, and Nabob creeks), downstream of mills. An estimated 346,000 to 1.4 million cubic yards of tailings-contaminated materials may remain in the beds and banks of Pine Creek, East Fork Pine Creek, Highland Creek, Red Cloud Creek, and Denver Creek (Gearheart et al., 1999). In 1999, U.S. BLM removed the major discrete tailings deposits from public lands in Highland Creek. Approximately 8,100 cubic yards of tailings were removed and placed on the CIA (D. Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication, June, 2000).

More than 1.4 million cubic yards of waste rock are associated with the producing and nonproducing mines in the Pine Creek basin (CCJM, 1995; McNary et al., 1995; Gearheart et al., 1999). The largest waste rock dumps inventoried are associated with the Sidney (95,000 yd^3 on Denver Creek, plus a 2 acre dump of undetermined volume in Red Cloud Creek), Lookout Mountain (50,000 yd^3), Nabob (48,000 yd^3), Highland Surprise (45,000-85,000 yd^3), Douglas (35,000 yd^3), Crystalite (25,000 yd^3), and Constitution (21,000 yd^3) mines (CCJM, 1995; McNary et al., 1995). Smaller waste rock piles are associated with the Blue Eagle Group (1,000 yd^3), Little Pittsburg (1,000 2,000 yd^3), Nevada Stewart (1,000 yd^3), Silver Hill (700 yd^3), and Sullivan (600 yd^3) (CCJM, 1995; McNary et al., 1995). The waste rock dumps are typically located near mine adits and shafts.

Other waste rock sources are near or in direct contact with streams in the basin (McNary et al., 1995). At the Crystalite claim at the Nabob Mine, an ore bin at the south end of the waste dump has been undercut by Nabob Creek. At the Little Pittsburg Mine, surface structures are within the active channel of Denver Creek and one adit is flooded and filled with stream sediment. Mascot Mining recently regraded the Hilarity Mine rock dumps in Denver Creek (D. Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication, June, 2000). High flows in Highland Creek have eroded the base of a Highland Surprise mine dump. Dry Creek flows through a waste dump associated with the Blue Eagle Group. A small tributary to the East Fork Pine Creek erodes at least three of the waste dumps associated with the Pine Claim (SAIC, 1993a; CCJM, 1995; McNary et al., 1995). In winter 1999 and spring 2000, U.S. BLM regraded the Sidney rock dump and reconstructed Red Cloud Creek to reduce erosion of the rock dump to the stream (D. Fortier, U.S. BLM Coeur d'Alene Field Office, personal communication, June, 2000).

Table 2-17 lists concentrations of metals measured in waste rock dumps in the Pine Creek basin. Cadmium concentrations ranged from <1 mg/kg at most sites to 140 mg/kg at the Douglas mine site. Lead ranged from 13 mg/kg at the Blue Eagle Group to 53,300 mg/kg at the Crystalite claim. Zinc ranged from 16 mg/kg at the Blue Eagle Group to 46,400 mg/kg at the Crystalite claim. Ranges of other contaminant concentrations measured in waste rock dumps include those for antimony (<10-160 mg/kg), arsenic (<10-3,400 mg/kg), copper (<10-580 mg/kg), and mercury (<0.01-20.6 mg/kg) (McNary et al., 1995).

Table 2-17
Mean (minimum-maximum) Concentrations of Metals in Pine Creek Basin Tailings, Sediments, and Soils

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Amy-Matchless	Tailings	6[a]	31.2 (<0.1-122)	4,266 (973-8,260)	5,569 (660-16,900)
		7[b]	87.5 (0.22-392)	1,948 (63.3-4,790)	10,604 (137-23,700)
	Sediment	2[a]	1.4 (1.1-1.7)	524 (310-738)	393 (270-516)
		1[c]	<1.0	285	352
		3[b]	1.7 (1.1-2.4)	310 (299-324)	362 (279-427)
	Soil	1[a]	4.0	825	1,030
Blue Eagle Group	Waste rock	2[c]	<1	15 (13-17)	31 (16-45)
Bobby Anderson	Sediment	1[c]	<1	237	310
Constitution	Tailings	26[c]	33.0 (4-112)	4,487 (85-11,900)	8,495 (870-29,800)
		3[a]	16.7 (9.5-30.7)	2,740 (1,300-4,930)	5,410 (3,460-8,990)
		6[d]	15.8 (9.8-22.9)	3,618 (1,130-5,910)	4,312 (2,270-6,850)
	Sediment	4[a]	9.2 (<1-18.2)	3,517 (9-5,510)	3,498 (22-6,930)
		3[c]	9.9 (1.6-19.1)	3,503 (1,110-4,710)	3,232 (807-5,020)
	Waste rock	2[c]	4 (<1-7)	512 (314-710)	790 (340-1,240)
Crystalite Claim	Waste rock	5[c]	34 (<1-110)	24,780 (6,300-53,300)	12,958 (690-46,400)

Table 2-17 (cont.)
Mean (minimum-maximum) Concentrations of Metals in Pine Creek Basin Tailings, Sediments, and Soils

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Denver	Tailings	2[c]	21.5 (17-26)	3,800 (2,700-4,900)	3,350 (2,400-4,300)
		3[a]	11.6 (<0.1-34.7)	3,242 (847-4,710)	6,073 (408-16,800)
	Sediment	6[a]	3.7 (<1-15.5)	1,188 (426-3,260)	1,199 (770-2,610)
Douglas	Tailings	21[c]	16.8 (<1-66)	2,666 (120-5,300)	4,935 (280-11,900)
		3[d]	16.6 (9.5-21.7)	1,953 (1,090-2,570)	4,643 (3,040-7,340)
	Sediment	2[c]	1.3 (<1-1.6)	419 (376-462)	550 (468-632)
	Waste rock	7[c]	28 (<1-140)	7,574 (620-33,800)	11,131 (220-59,700)
Douglas/Sherman	Waste rock	2[c]	<1	841 (82-1,600)	155 (120-190)
Fourth of July	Sediment	1[c]	<1	269	511
Highland Surprise	Sediment	5[a]	7.2 (<1-13.7)	2,564 (72-6,680)	2,284 (161-3,790)
		1[c]	20.9	3,690	5,730
	Waste rock	25[c]	20 (<1-95)	5,343 (59-51,900)	6,920 (110-34,100)
Hilarity	Sediment	3[c]	5.5 (3.1-6.4)	1,500 (621-1,930)	2,180 (1,470-2,430)
Liberal King	Tailings	3[a]	14.5 (<0.1-43.3)	1,251 (331-2,880)	784 (113-1,460)
	Sediment	2[a]	1.4 (1.1-1.7)	258 (211-304)	364 (357-370)
		1[c]	<1	246	469
	Soil	5[a]	2.0 (<1-3.0)	1,353 (140-4,320)	405 (65-657)
Little Pittsburg	Sediment	1[c]	10.7	4,850	4,595
	Waste rock	5[c]	25 (<1-66)	4,778 (190-11,800)	7,271 (57-17,800)
Lookout Mountain	Sediment	1[c]	2.7	476	957
	Waste rock	7[c]	<1	2,825 (76-9,300)	86 (41-180)
Lynch Gulch	Waste rock	1[c]	<1	65	26
Nabob	Tailings	56[c]	33.9 (<1-400)	5,777 (590-61,700)	4,446 (110-74,300)
		2[a]	45.6 (8.5-82.6)	7,325 (6,960-7,690)	2,890 (1,370-4,410)
	Sediment	4[a]	4.6 (<1-10.1)	628 (241-1,190)	1,116 (596-1,780)
	Soil	4[a]	1.0 (<1-1.3)	1,412 (183-2,790)	579 (254-894)
	Waste rock	3[c]	4.3 (<1-7.0)	16,633 (1,800-28,800)	1,587 (260-2,600)
Nevada Stewart	Sediment	1[c]	10.1	2,460	4,370
	Waste rock	3[c]	<1 (<1-1)	6,400 (1,000-11,800)	230 (130-420)
Owl Prospect	Sediment	1[c]	<1	53	180
Pine Creek	Sediment	4[e]	2.3 (0.8)	264 (79)	469 (139)
Sidney	Sediment	3[a]	8.8 (<1-14.4)	1,151 (192-1,940)	1,976 (388-3,580)
		1[c]	15.9	3,780	5,170
	Waste rock	16[c]	15 (<1-40)	2,781 (37-11,000)	4,341 (74-11,800)
Silver Hill	Waste rock	1[c]	<1	43	54

Table 2-17 (cont.)
Mean (minimum-maximum) Concentrations of Metals in Pine Creek Basin Tailings, Sediments, and Soils

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Star Antimony	Sediment	2[c]	4.7 (3.1-6.2)	833 (774-891)	2,100 (1,610-2,590)
Sullivan	Waste rock	2[c]	<1	84 (17-150)	154 (58-250)

a. CCJM, 1995.
b. Ecology and Environment, 1995.
c. McNary et al., 1995.
d. Gross, 1982.
e. Farag et al., 1998 (values in parentheses are standard error of the mean; minimum and maximum values were not provided).

Concentrations of metals in Pine Creek basin tailings have been measured at the Nabob, Denver, Douglas, Constitution, Liberal King, and Amy-Matchless operations (Table 2-17). Concentrations of cadmium (400 mg/kg), lead (61,700 mg/kg), and zinc (74,300 mg/kg) were greatest at the Nabob site (Table 2-17). In Pine Creek tailings, copper ranged from below detection to 4,940 mg/kg, antimony ranged from <10 to 920 mg/kg, arsenic ranged from <10 to 1,400 mg/kg, mercury ranged from 0.024 to 45.5 mg/kg, nickel ranged from below detection to 47.3 mg/kg, and silver ranged from 0.27 to 56.1 mg/kg (Gross, 1982; CCJM, 1995; Ecology and Environment, 1995; McNary et al., 1995).

Concentrations of metals in soils and sediments ranged from <0.01 to 20.9 mg cadmium/kg, 9 to 6,680 mg lead/kg, and 22 to 6,930 mg zinc/kg.

2.4.2 Summary of Tailings and Mixed Tailings, Waste Rock, and Alluvium/Soils/ Sediments

- At least 44 former mills historically produced an estimated 110 to 120 million tons of tailings; an estimated 103 million tons of tailings were discharged to creeks, unsecured dumps, and impoundments; and an estimated 75 million metric tons (82.7 million tons) of trace-element enriched sediments have been deposited in the bed of Coeur d'Alene Lake.

- Disposal practices included direct disposal to surface waters, disposal on floodplains, and impoundment of tailings in the floodplains.

- Tailings and mixed tailings and alluvium (soils and sediments) contain elevated concentrations of hazardous substances. Concentrations measured in tailings, soils, and sediment samples collected throughout the basin by numerous investigators over many years indicate that the contamination is pervasive in the basin, concentrations of hazardous substances are consistently elevated, and the concentrations are sufficiently elevated that these materials serve as sources of releases of hazardous substances.

- The hazardous substances released from the many sources in the Coeur d'Alene River basin are inextricably commingled in the environment. Transport and mixing via natural fluvial processes resulted in downstream movement of hazardous substances, and deposition of inextricably commingled wastes in sediments in floodplains, beds, and banks throughout the Coeur d'Alene River basin.

- Waste rock dumps are known or believed to be associated with most adits and shafts.

- Waste rock dumps may contain elevated concentrations of hazardous substances, may be acid generating, and may serve as sources of hazardous substances to surface water, groundwater, soil, and biological resources.

2.4.3 Drainage from Adits and Seeps

In the South Fork Coeur d'Alene River basin, mining activities resulted in many miles of underground workings, interconnecting mines, interconnecting drainages, and connectivity at multiple levels. Some of the underground workings have been backfilled with tailings. Shafts, adits, and underground workings expose minerals in the remaining ore and backfilled tailings to oxygen and groundwater, which can form acid mine drainage, or metal-laden leachate. Discharge of mine drainage containing elevated concentrations of metals is an ongoing source of hazardous substances to surface waters. At least 115 adits are known to discharge mine drainage in the South Fork Coeur d'Alene River basin (Gearheart et al., 1999).

Seeps, which are surface expressions of groundwater, are commonly found at the bases of waste rock piles and along creek banks, including banks covered by tailings and mixed tailings and alluvium. Seeps typically result from infiltration of rainfall, snowmelt, or mine drainage. Releases from seeps typically flow to streams. Seep water emerging from waste rock, tailings, or mixed tailings and alluvium deposits often contains greatly elevated concentrations of hazardous substances leached from waste deposits.

The following sections present evidence of hazardous substance releases from underground mine workings as adit discharge, and from seeps emerging from waste deposits.

South Fork Coeur d'Alene River Upstream of Elizabeth Park

Fifty-six adits in the South Fork drainage upstream of Elizabeth Park, excluding the Canyon Creek, Ninemile Creek, and Moon Creek drainages, are known to discharge mine drainage (Gearheart et al., 1999). Available water quality data from Osburn Flats seeps and four adits, the

Snowstorm No. 3, the Morning No. 5, the Morning No. 6, and the Silver Dollar, are presented in Table 2-18.

Table 2-18
Concentrations of Dissolved Hazardous Substances in Adit and Seep Discharge, South Fork Coeur d'Alene River Basin Upstream of Elizabeth Park

Site	Type	Date	Flow (cfs)	pH	Cond. (µS/cm)	Hard. (mg/L)	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)
Crescent Mine (Hooper Tunnel)	Adit	Aug. 1996[a]	0.04	6.64	501	278	0.91	3.8	142
		Jun. 1997[a]	0.08	7.15	377	192	1.3	27	238
Morning No. 5	Adit	Aug. 1996[a]	0.06	7.03	381	220	0.59	0.67	401
		Jun. 1997[a]	0.09	7.57	363	196	45	4.1	4,270
Morning No. 6	Adit	May 1991[b]	0.60	8.26	980	—	0.7	<3	<20
		Oct. 1991[c]	0.92	7.74	1481	—	0.4	<1	<12
Osburn Flats	Seep	Mar. 1997[d]	—	—	—	—	—	—	8,370
		Jun. 1997[a]	0.06	6.62	201	99	38	1.8	4,720
Silver Dollar	Adit	Aug. 1996[a]	0.01	7.63	370	234	0.02	0.45	11
		Jun. 1997[a]	0.02	7.72	374	240	0.02	0.05	19
Snowstorm No. 3	Adit	Jun. 1997[a]	12.00	6.97	26	11.3	0.04	0.2	13
Sunshine	Outfall	May 1991[b]	3.50	6.16	44	—	2.1	<3	<20
		Oct. 1991[c]	4.02	7.26	14.22	—	1.6	<1	240

a. Balistrieri et al., 1998.
b. MFG, 1991.
c. MFG, 1992b.
d. SVNRT, 1997, as cited in Ridolfi, 1998.

The Snowstorm No. 3 discharges to Daisy Gulch, which drains to the South Fork Coeur d'Alene River. Ores from the Snowstorm Mine contained mainly copper, and drainage from the adit contains elevated concentrations of copper (Balistrieri et al., 1998; copper data not shown in Table 2-18). The Morning No. 5 drains to Mill Creek, which flows to the South Fork Coeur d'Alene River. The Morning Mine ore was rich in lead and zinc, and drainage from the Morning No. 5 adit contains elevated concentrations of lead and zinc (Balistrieri et al., 1998). Drainage from the Morning No. 6 flows through a biological treatment system that retains metals to some degree and then discharges into the South Fork (SAIC, 1993b). The data presented in Table 2-18 confirm that adits are a source of hazardous substances released from underground mine workings in the South Fork Coeur d'Alene River basin.

Seeps from waste rock piles and tailings and mixed tailings and alluvium are known to occur along the South Fork Coeur d'Alene River upstream of Elizabeth Park. Information regarding seep locations, discharge, and water quality is limited. Table 2-18 presents seep water quality data collected from the Osburn Flats tailings deposits in March and June 1997 (SVNRT, 1997, as cited in Ridolfi, 1998; Balistrieri et al., 1998). These data confirm that the Osborn Flats seeps are a source of hazardous substances to the South Fork Coeur d'Alene River.

South Fork Coeur d'Alene River Downstream of Elizabeth Park

Seeps from waste rock piles and tailings and mixed tailings and alluvium are known to occur along the South Fork Coeur d'Alene River downstream of Elizabeth Park. Information regarding adit and seep locations, discharge, and water quality is limited. Table 2-19 presents seep water quality data collected from two seeps near the CIA and from the Kellogg Tunnel discharge, which is treated at the Central Treatment Plant near the CIA before discharging to the South Fork Coeur d'Alene River (MFG, 1992a).

Table 2-19
Concentrations of Dissolved Hazardous Substances in Adit and Seep Discharge, South Fork Coeur d'Alene River Basin Downstream of Elizabeth Park

Site	Type	Date	Flow (cfs)	pH	Cond. (µS)	Hard. (mg/L)	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)
CIA Tailings Pond	Seep	— [a]				—	<4-9	<5-25	4,940-25,700
	Seep (upper)	Nov. 1996[b]	0.11	5.69	783	400	33	123	20,150
	Seep (lower)	Nov. 1996[b]	1.71	6.05	639	338	32	35	10,080
Kellogg Tunnel[b]	Adit	Jun. 1997[b]	1.5-3.12	2.72	4,140	1,432	1,570	825	615,000

a. MFG, 1992a.
b. Balistrieri et al., 1998 (concentrations before water is treated).

Canyon Creek

In the Canyon Creek drainage, 24 adits discharge mine waters to surface water (Gearheart et al., 1999); others may also discharge. Water quality data for six of the more well-sampled adits are presented in Table 2-20; additional adit water quality data are presented in Gearheart et al. (1999).

Table 2-20
Concentrations of Dissolved Hazardous Substances in Adit and Seep Discharge, Canyon Creek Drainage

Site	Type	Date	Flow (cfs)	pH	Cond. (µS/cm)	Hard. (mg/L)	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)
Black Bear	Adit	Nov. 1997[a]	1.13	—	—	45	0.5	2.2	89
Canyon Silver-Formosa	Adit	May 1998[a]	—	—	—	249	0.3	1.5	206
Hercules No. 5	Adit	May 1991[b]	2.8	6.21	219	—	64	308	6,550
		Oct. 1991[c]	0.79	7.88	260	—	0.3	<1	<12
		Aug. 1996[d]	2.6	7.75	221	130	0.65	0.54	103
		Jun. 1997[d]	3.0	7.58	220	118	32	223	2,510
		Nov. 1997[a]	1.4	7.86	—	111	3.2	2.1	277
		May 1998[a]	1.9	7.27	—	112	26	81.9	2,120
Hidden Treasure	Adit	May 1998[a]	1.44	6.97	—	81	1.5	0.2	363
Tamarack No. 7	Adit	May 1991[b]	3.2	7.01	168	—	5.1	<3	1,720
		Oct. 1991[c]	1.6	6.84	207	—	1.4	<1	501
		Aug. 1996[d]	—	7.51	205	115	2	0.1	632
		Jun. 1997[d]	2.0	7.50	216	122	16	0.2	2,800
		Nov. 1997[a]	0.01	—	—	113	1.3	0.1	586
		May 1998[a]	—	7.11	—	121	16.6	<0.5	2,790
Gem No. 3	Adit	May 1991[b]	0.2	6.95	405	—	9.1	3	17,150
		Oct. 1991[c]	0.25	6.76	382	—	7.5	<1	14,100
		Aug. 1996[d]	—	6.98	376	178	9.6	0.1	16,300
		Jun. 1997[d]	1.0	7.10	375	185	17	0.7	18,030
		May 1998[a]	0.6	6.93	—	163	10.8	<0.5	13,200
Railroad Track	Spring	May 1994[e]	—				179	1,031	27,200
Star Phoenix	Outfall	May 1991[b]	1.10	—	—	—	5.6	14	1,420
		Oct. 1991[c]	0.94	6.96	180	—	6.4	11	1,160

a. CH2M Hill and URSGWC, 1998.
b. MFG, 1991.
c. MFG, 1992b.
d. Balistrieri et al., 1998.
e. U.S. EPA, 1995.

The Hercules No. 5, Tamarack No. 7, and Gem No. 3 are the most well characterized adits in the Canyon Creek Basin (MFG, 1991, 1992b; Balistrieri et al., 1998; CH2M Hill and URSGWC, 1998). The Hercules No. 5 drains the Hercules and Hummingbird underground workings, and possibly the Union and the Sherman workings as well (SAIC, 1993c). Approximately 25% of the Hercules No. 5 adit discharge enters Gorge Gulch directly, and approximately 75% of the flow infiltrates the waste rock pile and discharges to Gorge Gulch as seepage (SAIC, 1993a). The Tamarack No. 7 drains the Tamarack-Custer, the Standard-Mammoth, and most likely the

Greenhill-Cleveland underground workings (SAIC, 1993c; Ridolfi, 1998). Discharge flows to Canyon Creek through a pipe (Ecology and Environment, 1995). The Gem No. 3 drains the Gem, Black Bear, and Frisco (Helena-Frisco) workings (SAIC, 1993c; Ridolfi, 1998). Discharge from the Gem No. 3 also flows to Canyon Creek through a pipe (SAIC, 1993a).

Concentrations in Hercules No. 5 and Tamarack No. 7 water are substantially more elevated during high flow than during low flow at each adit, most likely because an increased volume of groundwater is in contact then with mine workings. Concentrations in adit discharge from the Gem No. 3 are consistently elevated during both low flow and high flow. The data presented in Table 2-20 confirm these adits as sources of hazardous substances during both high flow and low flow.

At least seven seeps from waste rock piles have been identified in the Canyon Creek drainage. Among the seven are seeps associated with waste rock piles at the Hercules No. 3 and No. 5 adits, the Star Mine Tailings ponds, and the Woodland Park floodplain. Additional seeps may exist.

Concentrations of total zinc measured in seeps from the lower Canyon Creek floodplain in October 1991, September 1993, and May 1994 range from 29,867 µg/L to 35,400 µg/L (MFG, 1992b; Houck and Mink, 1994; U.S. EPA, 1995). In October 1991, MFG (1992b) measured dissolved zinc at 3,830 µg/L. Concentrations of total and dissolved cadmium measured in a seep from the lower Canyon Creek floodplain in October 1991 were 396 µg/L and 390 µg/L, and concentrations of total and dissolved lead were 1,590 µg/L and 1,480 µg/L. Concentrations of total zinc measured in seeps from the Star Tailings Ponds NPDES-permitted discharge in 1991 ranged from 1,230 µg/L during low flow to 1,360 µg/L during high flow (MFG, 1991, 1992b). In May 1998, total and dissolved concentrations of zinc measured in seeps from the Star Tailings Ponds were 9,720 µg/L and 9,370 µg/L, respectively (CH2M Hill and URSGWC, 1998).

These concentrations confirm that seep discharge from tailings and mixed tailings and alluvium are sources of hazardous substances to Canyon Creek.

Ninemile Creek

In the Ninemile Creek drainage, 12 adits are known to discharge mine water to surface water (Gearheart et al., 1999). Other draining adits may exist. Water quality data are available for four draining adits: the Interstate No. 4, the Rex No. 2, the Success No. 3, and the Sunset (Table 2-21).

The Interstate No. 4 drainage flows from the adit through a waste rock pile, and discharges to the East Fork of Ninemile Creek as seepage (SAIC, 1993b). The drainage from the Rex No. 2 discharges to a tributary gulch via a culvert and decant pond on the tailings pond surface (SAIC, 1993b). The gulch discharges to the East Fork of Ninemile Creek. Historically, drainage from the Success No. 3 infiltrated the tailings pile and entered the creek as seepage (SAIC, 1993b). Since 1993, adit drainage has been diverted around the tailings pile and enters the creek upstream and downstream of the tailings pile (IDEQ, 1994, as cited in Ridolfi, 1998).

Table 2-21
Concentrations of Dissolved Hazardous Substances in Adit Discharge, Ninemile Creek

Site	Type	Date	Flow (cfs)	pH	Cond. (µS/cm)	Hard. (mg/L)	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)
Interstate-Callahan	Adit (No. 4)	Oct. 1991[a]	—	—	—	—	0.3	<0.1	73
		Aug. 1996[b]	0.07	7.33	204	110	0.14	0.03	39
		Jun. 1997[b]	0.14	7.50	158	88	0.04	0.05	26
		Nov. 1997[c]	0.04	—	—	112	0.06	0.14	25
		May 1998[c]	0.03	7.44	—	86	0.04	0.11	8
	Seep	Nov. 1996[b]	0.002	4.8	679	144	650	225	172,000
		Jun. 1997[b]	0.007	4.6	674	121	680	386	179,500
Rex	Adit (No. 2)	Aug. 1996[b]	0.01	7.10	150	70	5.5	42	1,210
		Jun. 1997[b]	0.02	7.29	119	50	11	197	2,350
		Nov. 1997[c]	0.03	—	—	67	6.2	45	1,350
		May 1998[c]	0.01	6.63	—	51	12	110	2,550
	Seep	Nov. 1996[b]	0.02	6.17	368	163	36	5.3	13,100
		Jun. 1997[b]	0.06	6.66	450	185	8.8	0.72	20,750
Success	Adit (No. 3)	Aug. 1996[b]	0.01	6.89	578	256	280	2.8	50,700
		Jun. 1997[b]	0.04	7.34	538	239	357	44	57,400
		May 1998[c]	0.01	6.37	—	231	376	7	73,500
	Seep (upper)	Nov. 1996[b]	0.01	4.85	157	43	117	215	20,200
		Jun. 1997[b]	0.003	7.13	56	15	26	112	3,760
	Seep (lower)	Nov. 1996[b]	0.002	6.11	184	55	140	930	24,200
		Jun. 1997[b]	0.04	6.29	120	34	82	515	13,600
Sunset	Adit	Nov. 1997[c]	—	—	—	50	150	93	24,300

a. MFG, 1992b.
b. Balistrieri et al., 1998. Cd, Pb, and Zn concentrations in August 1996 Interstate No. 4 samples are the mean of duplicate samples. Cd, Pb, and Zn concentrations in June 1997 Success No. 3 samples are the mean of triplicate samples.
c. CH2M Hill and URSGWC, 1998.

Five seeps from tailings and waste rock dumps have been identified in the Ninemile Creek watershed. Seeps have been identified emerging from Interstate-Callahan waste rock, Interstate-Callahan tailings, Tamarack waste rock, Rex tailings, and Success tailings. Other seeps may exist.

Table 2-21 presents high and low flow concentrations of hazardous substances measured in seep discharge at four locations. Each of the four seeps discharges substantial concentrations of cadmium, lead, and zinc to the East Fork of Ninemile Creek. In particular, concentrations of dissolved zinc in seep discharge from the Interstate-Callahan tailings exceed 170,000 µg/L and are relatively constant during high flow and low flow (Table 2-21). The total zinc load from the Interstate-Callahan tailings seeps to the East Fork of Ninemile Creek is estimated to range from 0.93 lb/day to 8.6 lb/day.

The concentrations presented in Table 2-21 confirm that adit discharge and seep discharge from tailings are sources of hazardous substances to Ninemile Creek.

Moon Creek

In the Moon Creek drainage, three adits — the Silver Crescent adit and two Charles Dickens Mine adits — drain to surface water resources. Two seeps believed to drain the Charles Dickens Mine and contaminated soil and jig tailings from the Charles Dickens Mine emerge from the bank of the East Fork of Moon Creek. Dissolved metals concentrations measured in seep and adit discharge in the Moon Creek basin range from 0.21 to 224 µg cadmium/L, 0.7 to 500 µg lead/L, and 46 to 28,854 µg zinc/L (Table 2-22; USBM, 1995). Maximum concentrations of metals measured in tailings pore water were 864 µg cadmium/L, 2,400 µg lead/L, and 175,000 µg zinc/L (Table 2-22; USBM, 1995).

Table 2-22
Concentrations of Dissolved Hazardous Substances in Moon Creek Basin Seep and Adit Discharge

Site	Type	Date	Flow (cfs)	pH	Cond. (µS/cm)	Hard. (mg/L)	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)
Charles Dickens/ Silver Crescent	Seep (road)	Jan. 1993	—	6.75	—	47.3	1.88	1.6	973
		Mar. 1993	—	6.79	—	34.7	3.45	3.6	793
	Seep (confluence)	Apr. 1993	—	3.67	—	192.8	224	318	28,854
		May 1993	—	3.11	—	164.0	179	389	27,800
		Jun. 1993	—	3.29	—	144.3	136	500	20,130
		Aug. 1993	—	3.05	—	93.2	77	300	1,110
		Oct. 1993	—	2.86	—	115.8	68	300	9,020
		Dec. 1993	—	3.29	—	79.0	58.7	220	7,700
	Seep (tailings)	Mar. 1993	—	4.60	—	70.0	19.8	64.0	5,220
	Adit	Mar. 1993	—	7.57	—	271.8	0.21	0.7	46
	Pore water (tailings)[a]	Jun. 1993	—	—	—	592	805	1,490	104,980
		Jul. 1993	—	5.1-6.5	1804	610	775	1,675	91,640
		Aug. 1993	—	4.6-6.0	1,805	597	953	1,690	97,600

a. Mean of four samples.

Source: USBM, 1995.

Pine Creek

Of the more than 50 known adits associated with producing and nonproducing mines in the Pine Creek basin, at least 22 are known to drain to surface water resources water (Gearheart et al., 1999). Table 2-23 presents concentrations of the hazardous substances cadmium, lead, and zinc measured in draining adits, seeps, and springs in the Pine Creek basin. Dissolved metal concentrations measured in seep and adit discharge on the Pine Creek basin range from below detection to 423 µg cadmium/L, below detection to 2,560 µg lead/L, and below detection to 167,000 µg zinc/L.

Table 2-23
Concentrations of Dissolved Hazardous Substances in Pine Creek Basin Adit, Seep, and Spring Discharge

Site	Type	Date	Flow (cfs)	pH	Cond. (µS/cm)	Hard. (mg/L)	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)
Amy-Matchless	Adit	Jul. 1994[a]	—	7.2	520	247	<0.3	<1.0	90
		Nov. 1997[b]	0.001	—	—	270	0.5	0.1	349
		May 1998[b]	0.01	6.7	—	325	0.2	<0.5	192
Constitution	Adit	Jun. 1993[c]	—	—	—	31	ND	6.87	406
		Aug. 1993[c]	—	6.8	80	45	3.7	8.63	1,030
		Jul. 1994[a]	—	7.6	243	45	3.1	15.9	606
		Nov. 1997[b]	0.10	—	—	15	0.9	3.9	214
		May 1998[b]	0.06	7.1	—	9.6	<0.4	2.9	116
	Seep	Jul. 1994[a]	—	6.5	60	23	3.6	3.0	1,300
	Spring	Jul. 1994[a]	—	6.3	28	12	<0.3	67.9	111
Denver	Seep	Jul. 1994[a]	—	6.8	127	40	12.0	8.6	3,690
	Spring	Jun. 1993[c]	—	7.9	310	126	ND	ND	ND
		Aug. 1993[c]	—	7.6	260	126	ND	—	24
Highland Surprise	Adit	Jun. 1993[c]	—	7.5	510	—	9.0	11.1	5,790
		Aug. 1993[c]	—	7.5	380	219	ND	ND	2,650
		Jul. 1994[a]	—	7.6	379	193	2.9	4.2	1,690
		Nov. 1997[b]	0.04	—	—	197	0.83	0.17	1,250
		May 1998[b]	0.04	7.8	—	196	0.6	<0.1	2,010
	Seep	Jun. 1993[c]	—	7.5	150	49	ND	—	521
		Aug. 1993[c]	—	8.4	400	217	2.5	1.9	2,070
		Jul. 1994[a]	—	6.8	223	86	37.1	57	12,500
	Spring	Jun. 1993[c]	—	7.1	210	74	32.7	39.8	12,900
		Aug. 1993[c]	—	7.5	230	106	36.1	344	14,100
Hilarity	Adit	Jun. 1993[c]	—	7.4	360	157	6.9	4.89	5,290
		Aug. 1993[c]	—	8.0	430	215	—	—	—
	Seep	Jun. 1993[c]	—	—	—	79.4	21.2	104	8,910
		Aug. 1993[c]	—	6.2	130	57.2	12	7.3	5,130
	Spring	Jun. 1993[c]	—	7.3	40	10.9	ND	1.7	8.8
		Aug. 1993[c]	—	8.0	20	7.1	ND	ND	92.9

Table 2-23 (cont.)
Concentrations of Dissolved Hazardous Substances in Pine Creek Basin Adit, Seep, and Spring Discharge

Site	Type	Date	Flow (cfs)	pH	Cond. (µS/cm)	Hard. (mg/L)	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)
Liberal King	Adit	Jul. 1994[a]	—	8.7	720	357	<0.3	<1.0	73
		Nov. 1997[b]	0.01	—	—	335	0.1	0.9	37
		May 1998[b]	0.002	8.0	—	319	0.1	<0.5	39
	Seep	Jul. 1994[a]	—	6.9	703	340	6.6	2.4	1,430
Little Pittsburg	Adit (upper)	Jun. 1993[c]	—	3.9	620	128	92.7	686	22,100
		Aug. 1993[c]	—	3.3	1,220	472	226	2,560	73,600
		May 1998[b]	0.0004	3.4	—	250	187	2,150	62,300
	Adit (lower)	Jun. 1993[c]	—	7.2	760	449	161	2.5	63,300
		Aug. 1993[c]	—	7.4	800	444	—	—	—
		Nov. 1997[b]	0.005	—	—	178	24.7	1.0	13,300
		May 1998[b]	0.007	6.7	—	271	107	0.4	63,600
	Seep	Jun. 1993[c]	—	7.7	40	11.4	ND	5.14	198
		Aug. 1993[c]	—	6.8	50	22.6	2.7	—	918
	Spring 1	Jun. 1993[c]	—	6.6	60	20.4	ND	1.5	777
		Aug. 1993[c]	—	7.3	110	49.5	8.1	ND	3,380
	Spring 2	Jun. 1993[c]	—	6.5	560	229	ND	11.7	1,010
		Aug. 1993[c]	—	6.3	390	188	—	—	1,030
Lookout Mountain	Adit	Jun. 1993[c]	—	7.8	470	176	ND	ND	39
		Aug. 1993[c]	—	7.2	345	180	ND	ND	61
		Nov. 1997[b]	0.03	—	—	182	1.4	0.4	57
		May 1998[b]	0.03	8.3	—	172	0.8	<0.8	39
	Seep	Jun. 1993[c]	—	8.0	230	80.8	ND	1.6	17
		Aug. 1993[c]	—	7.7	290	—	ND	ND	28.3
	Spring	Jun. 1993[c]	—	7.1	140	65.9	ND	ND	6.5
		Aug. 1993[c]	—	7.0	240	—	ND	ND	6.5
Lynch-Nabob	Adit	Nov. 1997[b]	0.001	—	—	128	30.5	640	11,100
Lynch-Pine	Adit	Jun. 1993[c]	—	4.8	210	105	67.9	1,020	15,200
		Aug. 1993[c]	—	6.0	340	149	61.8	822	16,300
Nabob	Adit	Jun. 1993[c]	—	7.7	840	433	14	ND	7,190
		Aug. 1993[c]	—	8.3	570	305	ND	1.5	683
		Jul. 1994[a]	—	8.8	541	298	5.6	119	3,530
		Nov. 1997[b]	0.07	—	—	597	7.4	0.1	10,100
		May 1998[b]	0.06	7.3	—	535	8.0	<0.2	8,310
Nevada-Stewart	Adit	Jun. 1993[c]	—	6.8	1,030	485	ND	5.73	10,100
		Aug. 1993[c]	—	6.9	930	653	1.0	1.4	9,950
		Nov. 1997[b]	0.11	—	—	508	0.44	0.31	10,700
		May 1998[b]	0.04	7.4	—	470	<0.5	<1.1	8,720
	Spring	Jun. 1993[c]	—	7.1	430	168	4.1	3.1	3,640
		Aug. 1993[c]	—	7.1	310	154	3.2	1.3	2,760

**Table 2-23 (cont.)
Concentrations of Dissolved Hazardous Substances
in Pine Creek Basin Adit, Seep, and Spring Discharge**

Site	Type	Date	Flow (cfs)	pH	Cond. (µS/cm)	Hard. (mg/L)	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)
Owl Prospect	Adit	Jun. 1993[c]	—	6.9	280	168	ND	9.63	470
		Aug. 1993[c]	—	7.0	250	129	ND	7.93	389
Sidney	Adit (Red Cloud)	Jun. 1993[c]	—	7.1	920	465	423	349	167,000
		Aug. 1993[c]	—	7.9	340	170	24.3	16.9	8,450
		Nov. 1997[b]	0.003	—	—	155	10.8	19.3	4,850
		May 1998[b]	0.01	7.1	—	224	135	20	<9
	Adit (Sidney)	Jun. 1993[c]	—	7.3	80	25	11.0	93.8	3,540
		Aug. 1993[c]	—	6.5	580	313	46.6	7.43	26,200
		Jul. 1994[a]	—	8.2	340	160	19.0	22.6	5,110
S F Fraction	Adit	Jun. 1993[c]	—	7.7	120	50.3	ND	7.9	14

a. CCJM, 1995.
b. CH2M Hill and URSGWC, 1998.
c. McNary et al., 1995.

ND: not detected.

2.5 SUMMARY

Information presented in this chapter confirms that hazardous substances have been and continue to be released from sources related to historical mining, milling, and smelting in the Coeur d’Alene River basin. The data presented in this chapter are not an exhaustive compilation of source areas and concentrations. Characterization of source areas and of the dynamics of releases is ongoing in the Coeur d’Alene River basin. However, the data presented in this chapter reflect the consistent finding that mining and mineral processing sources are the primary sources of hazardous substances to resources of the basin.

The types of materials containing elevated concentrations of hazardous substances (surface water, adit and seep drainage, tailings, soils, and sediments) and the location of materials that contain elevated concentrations (i.e., associated with or downgradient of mining operations) are consistent with the conclusion that wastes released from mining and mineral processing operations were the original sources of hazardous substance releases in the basin. The consistently elevated concentrations of hazardous substances in floodplain soils and sediments throughout the basin confirm that the floodplains, beds, and banks where hazardous substances have come to be located now are ongoing sources of hazardous substances.

In summary, the data presented in this chapter confirm that hazardous substances in wastes from mining and mineral processing operations are released from numerous source areas in the Coeur d'Alene River basin. The areas include adits, seeps, and waste rock and tailings dumps, contaminated upland soils that are eroded and remobilized by wind and water, and tailings and mixed tailings and alluvium that are distributed throughout the floodplains of the Coeur d'Alene River basin.

While sources such as certain adits, waste rock piles, and confined tailings dumps remain relatively discrete sources, tailings historically discharged to creeks, transported by surface waters, and deposited in floodplain, bed, or bank sediments have become intermixed and commingled. Tailings and mixed tailings and alluvium released from a single source have been differentially transported, mixed, deposited, and reworked by flooding and seasonal high water. As a result of the mobilization, remobilization, and mixing of releases from numerous sources, and sorting by energy and gravity in the transport by surface water pathways, tailings have lost the original geochemical identities or ratios of elements that might have characterized the waste upon release from the mill. Moreover, since many of the mills processed ores from numerous mines, even confined tailings dumps may not contain deposits of distinguishable source. Similarly, upland soils historically contaminated by smelter emissions, fugitive dust emissions, waste storage, or windblown tailings also become a part of the inextricably commingled waste released to the South Fork Coeur d'Alene River. Erosion and release to surface water have resulted in mixing and commingling with sediments and tailings from upstream sources.

Many of the adits that currently discharge water are draining the interconnected workings of numerous mines. Where one adit drains a series of interconnected mines, the source of metals contained in the drainage, or of the acid that leaches the ore remaining in the underground workings, cannot be traced. In such cases, the original source of much of the hazardous substances discharged in mine drainage cannot be apportioned among mines. Once mine drainage discharges to surface waters or infiltrates shallow groundwater, it becomes mixed with surface or groundwater. As with the mixing of tailings, discharges from numerous adits, seeps, and groundwater in contaminated floodplain deposits become mixed and inseparable in the surface water resource.

Releases from sources located throughout the basin are ongoing. Contaminated groundwater continues to be released from adits, seeps continue to discharge leachate from waste rock dumps and tailings deposits, and contaminated materials in the floodplains and uplands continue to be eroded and released to surface water. Tailings and mixed tailings in the floodplains, beds, and banks are continually reworked by natural processes, resuspended, and redeposited. During high flows, hazardous substances in floodplain, bed, and bank sediments are re-released to the surface water column, transported, and redeposited. Natural fluvial and hydraulic processes that would, absent the release of hazardous substances from mining and mineral processing operations, function to maintain the structure and function of the Coeur d'Alene River basin watershed and aquatic and riparian ecosystems, instead function as pathways of hazardous substance transport and re-release.

Ongoing releases of hazardous substances from point and diffuse sources occur throughout the basin. Releases occur at spatial and temporal scales ranging from periodic releases of hazardous substances by movements of large amounts of sediments during seasonal high water, to episodic small-scale erosive events, to steady discharge of metal leachate from adits. Releases occur from near the headwaters of the South Fork Coeur d'Alene River, including numerous tributaries, throughout the length of the South Fork and mainstem Coeur d'Alene river valleys, and in Coeur d'Alene Lake.

Finally, releases from the sources described are mobile in the environment. Releases from sources to pathway resources result in the transport of hazardous substances and the exposure of natural resource. Transport and exposure pathways are described in Chapter 3.

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Next

CHAPTER 3
TRANSPORT AND EXPOSURE PATHWAYS

3.1 INTRODUCTION

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

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

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

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

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

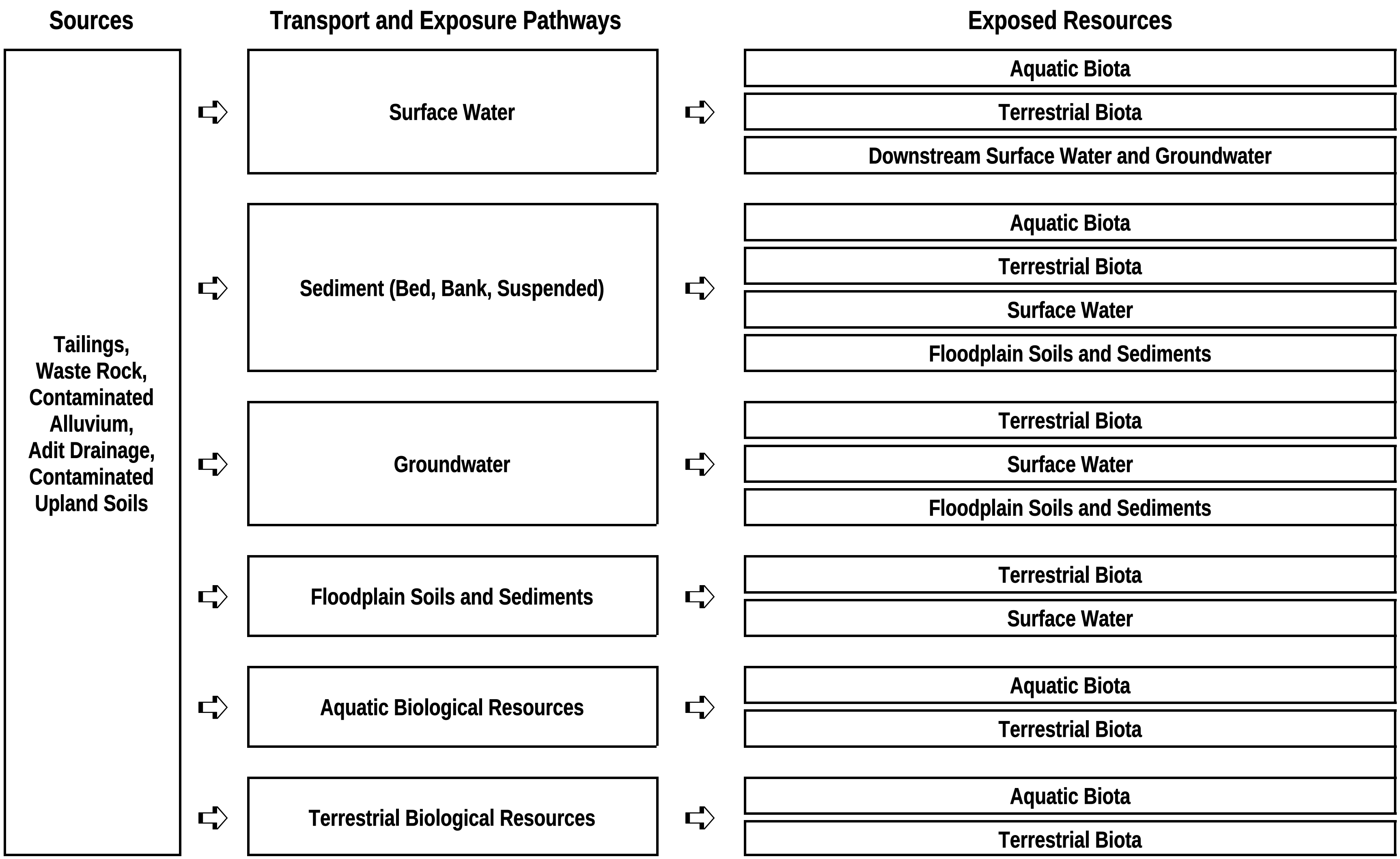

Figure 3-1. Overview of transport and exposure pathways.

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

And:

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

And:

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

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

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

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

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

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

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

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

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

- surface water and groundwater interactions along the river channel

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

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

The information presented in this chapter demonstrates the following:

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

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

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

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

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

3.2 DATA SOURCES

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

Table 3-1
Transport and Exposure Pathway Data Sources

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

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

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

3.3 SURFACE WATER

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

3.3.1 Surface Water Exposure to Hazardous Substance Releases

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

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

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

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

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

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

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

3.3.2 Mobility and Transport of Hazardous Substances in Surface Water

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

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

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

Source: Beckwith et al., 1997.

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

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

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

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

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

Source: Beckwith, 1996.

3.3.3 Surface Water Is Exposed to Hazardous Substances

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

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

3.3.4 Resources Exposed to Surface Water

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

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

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

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

a. For data sources, see Chapter 4.

u — undetected at the reported concentration.

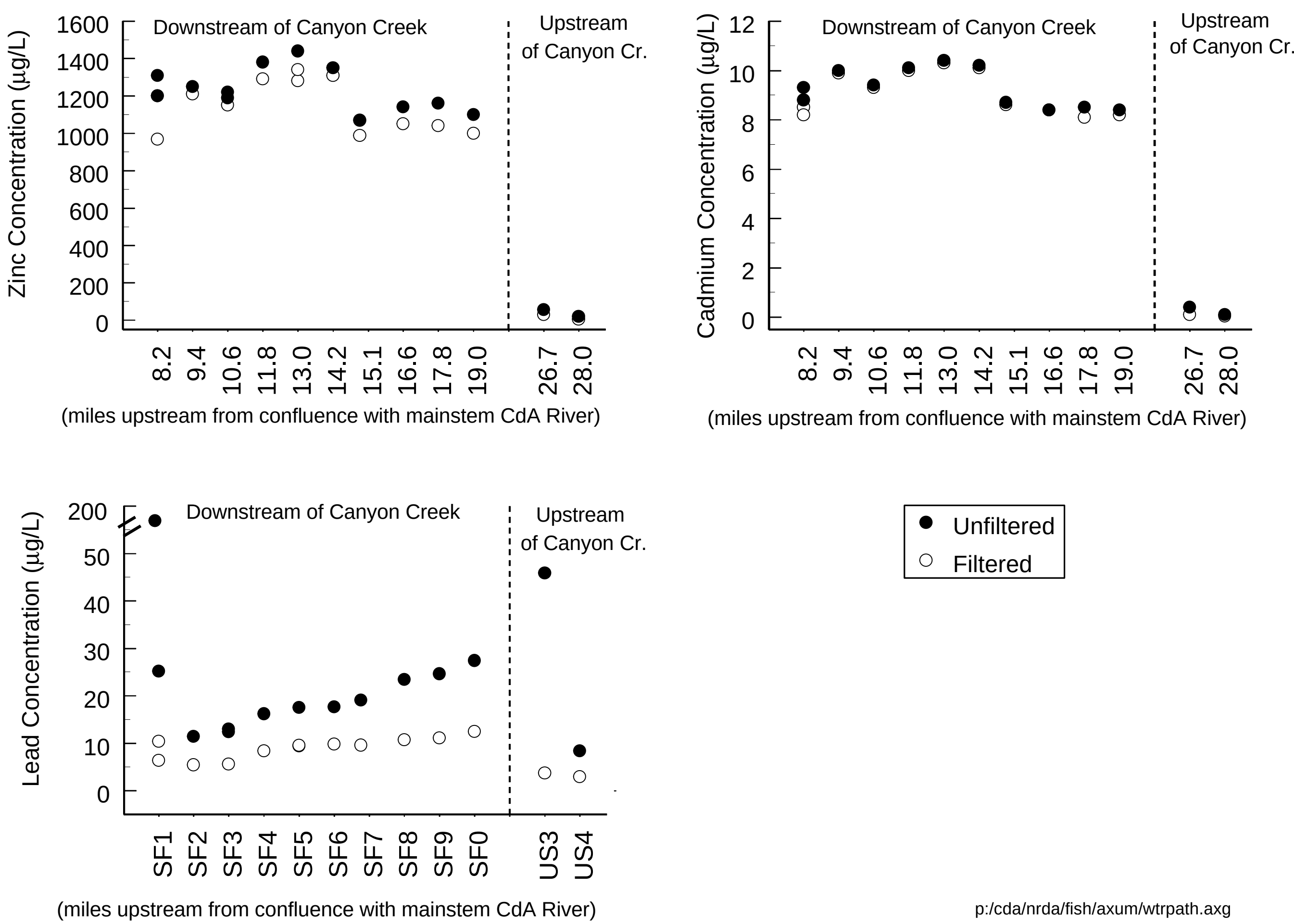

Figure 3-2. Concentrations of the hazardous substances cadmium, lead, and zinc measured in filtered and unfiltered water samples collected from the South Fork Coeur d'Alene River in Fall, 1998 (low flow).
Source: Stratus Consulting, 1999.

Surface Water/Groundwater

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

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

Floodplain Soils and Sediments

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

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

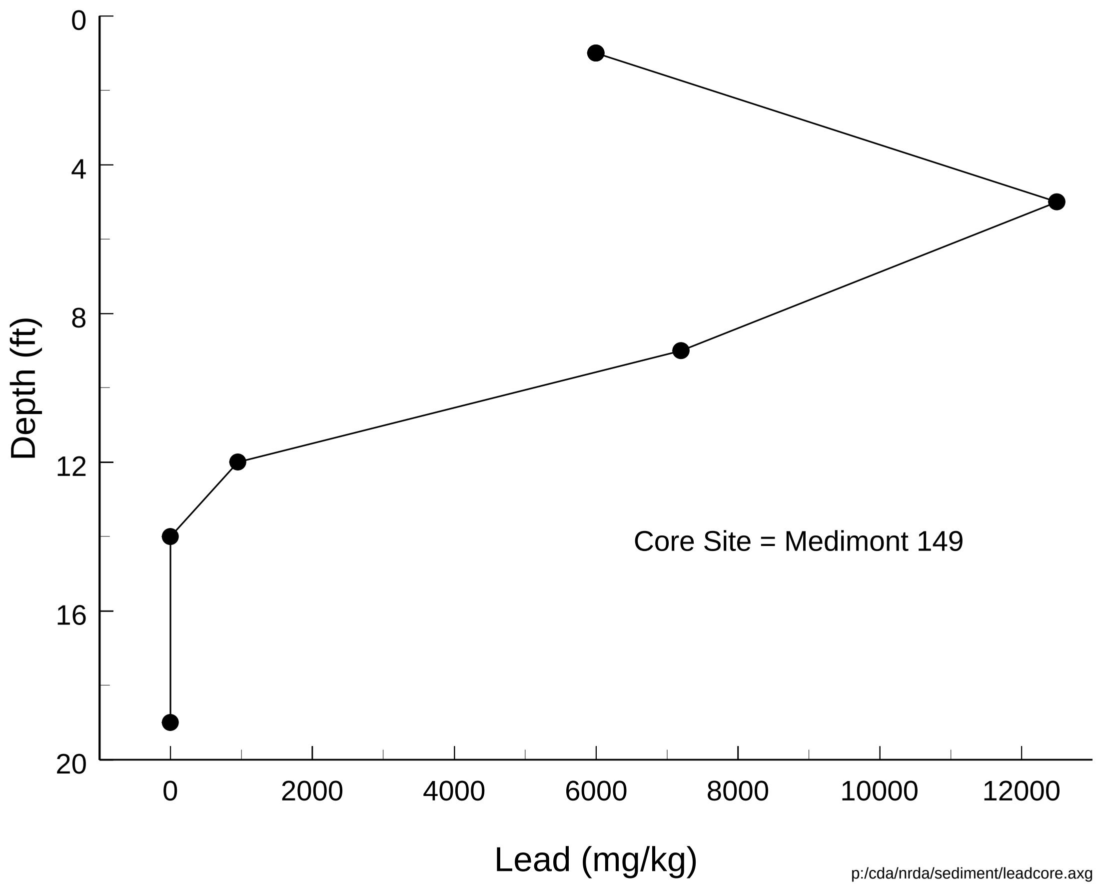

Figure 3-3. Lead concentrations at depth in a sediment core collected near Medimont.
Source: URSG and CH2M Hill, 1998**.**

Aquatic Biological Resources

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

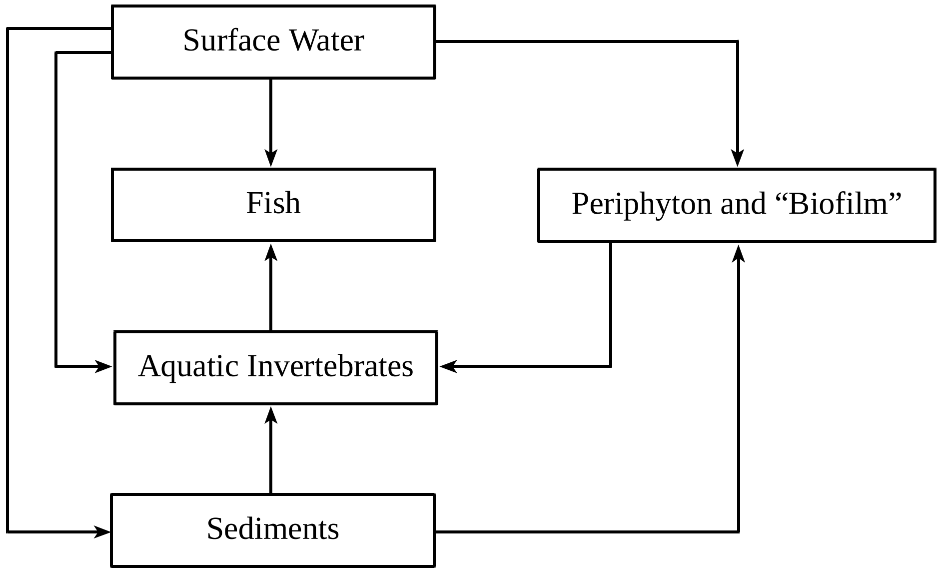

Figure 3-4. Surface water and sediment pathways to aquatic biological resources. Also illustrated are foodchain exposure pathways that result from surface water and sediment pathways.

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

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

Source: Farag et al., 1998.

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

Terrestrial Biological Resources

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

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

3.4 SEDIMENTS

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

3.4.1 Sediment Exposure to Hazardous Substance Releases

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

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

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

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

3.4.2 Resources Exposed to Sediments

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

Terrestrial Biota

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

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

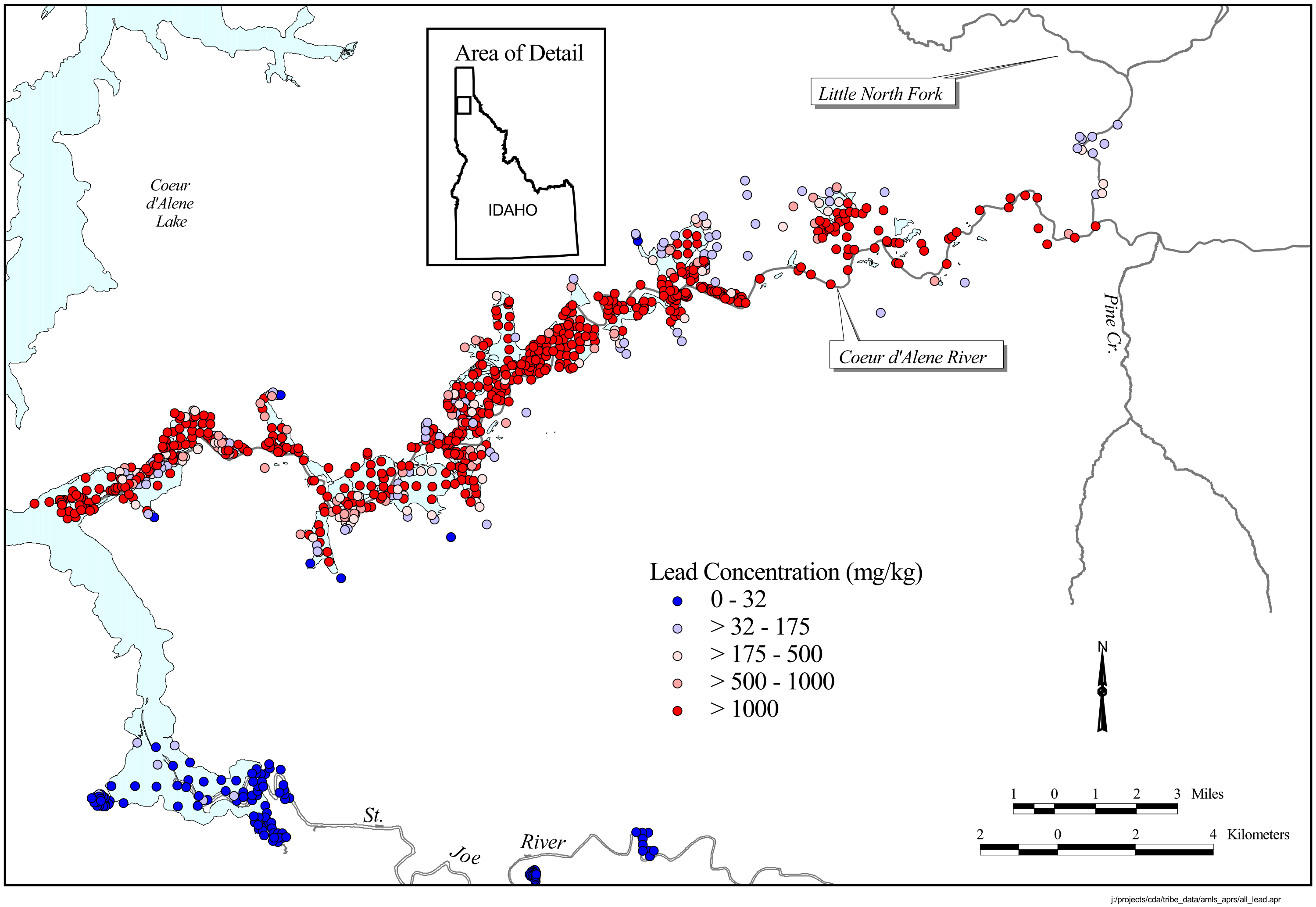

Figure 3-5. Distribution of lead concentrations in surface bed, bank, and floodplain sediments of the lower Coeur d'Alene River basin. See Chapter 5 for a description of data sources.

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

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

Aquatic Biota

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

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

3.5 GROUNDWATER

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

3.5.1 Groundwater Exposure to Hazardous Substance Releases

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

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

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

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

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

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

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

3.5.2 Groundwater Is Exposed to Hazardous Substances

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

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

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

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

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

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

3.5.3 Resources Exposed to Groundwater

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

3.6 SOILS

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

3.6.1 Soils Exposure to Hazardous Substance Releases

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

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

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

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

3.6.2 Mobility and Transport of Hazardous Substances in Soils

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

3.6.3 Soils Are Exposed to Hazardous Substances

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

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

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

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

3.7 BIOLOGICAL PATHWAYS

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

- aquatic benthic invertebrates and fish contain elevated concentrations of metals and serve as a pathway to fish and other organisms that consume them (Farag et al., 1998)
- forage and prey items of waterfowl (e.g., vegetation, water potatoes), shore birds (e.g., invertebrates), and birds of prey (e.g., fish, small mammals, waterfowl) contain elevated concentrations of metals and serve as a pathway to the wildlife that consume them (Audet, 1997; Audet et al., 1999a and 1999b; Campbell et al., 1999b).

3.8 CONCLUSIONS

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

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

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

The information presented in this chapter demonstrates the following:

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

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

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

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

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

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Next

CHAPTER 4
SURFACE WATER RESOURCES

4.1 INTRODUCTION

This chapter presents the determination of injuries to surface waters of the Coeur d'Alene River basin. Surface water resources include surface water and suspended, bed, and bank sediments [43 CFR 11.14 (pp)]. The injury determination presented in this chapter focuses on surface water and suspended sediments only. Bed, bank, and floodplain sediments are considered in the following chapter.

Surface water resources of the Coeur d'Alene River basin have been injured as a result of releases of hazardous substances — particularly cadmium, lead, and zinc — from mining and mineral processing operations in the basin. The information presented in this chapter demonstrates the following:

- Sufficient concentrations of hazardous substances exist in pathway resources now, and have in the past, to expose surface water resources to hazardous substances.

- Sufficient concentrations of hazardous substances exist in surface water resources now, and have in the past, to exceed federal, state, and tribal water quality criteria developed for protection of aquatic life. Therefore, surface water resources are injured.

- Exceedences of federal water quality criteria, and therefore, surface water injuries, have been documented from the upper reaches of the South Fork Coeur d'Alene River (downstream of Daisy Gulch), through the mainstem Coeur d'Alene River and Coeur d'Alene Lake, to at least the USGS gauge station at Post Falls Dam on the Spokane River. Surface waters of the mainstem Coeur d'Alene River from the North Fork Coeur d'Alene River confluence to Coeur d'Alene Lake are injured, surface waters of the lateral lakes are injured, and surface waters of Coeur d'Alene Lake are injured.

- Exceedences of federal water quality criteria have also been documented in tributaries of the South Fork Coeur d'Alene River, including Canyon Creek from approximately Burke to the mouth and Gorge Gulch downstream of the Hercules No. 3 adit; the East Fork and mainstem Ninemile Creek from the Interstate-Callahan Mine to the mouth; Grouse Gulch from the Star Mine waste rock dumps to the mouth; Moon Creek from the Charles Dickens Mine/Mill to the mouth; Milo Creek from the Sullivan Adits to the mouth; Portal Gulch downstream of the North Bunker Hill West Mine; Deadwood Gulch/Bunker Creek downstream of the Ontario Mill; Government Gulch from the Senator Stewart Mine to the mouth; East Fork and mainstem Pine Creek from the Constitution Upper Mill to the mouth; Highland Creek from the Highland Surprise Mine/Mill and the Sidney (Red Cloud) Mine/Mill to the mouth; Denver Creek from the Denver Mine to the mouth; and Nabob Creek from the Nabob Mill to the mouth.

- Concentrations of hazardous substances in surface water resources downstream of releases are high enough that surface water serves as a pathway of injury to downstream surface waters.

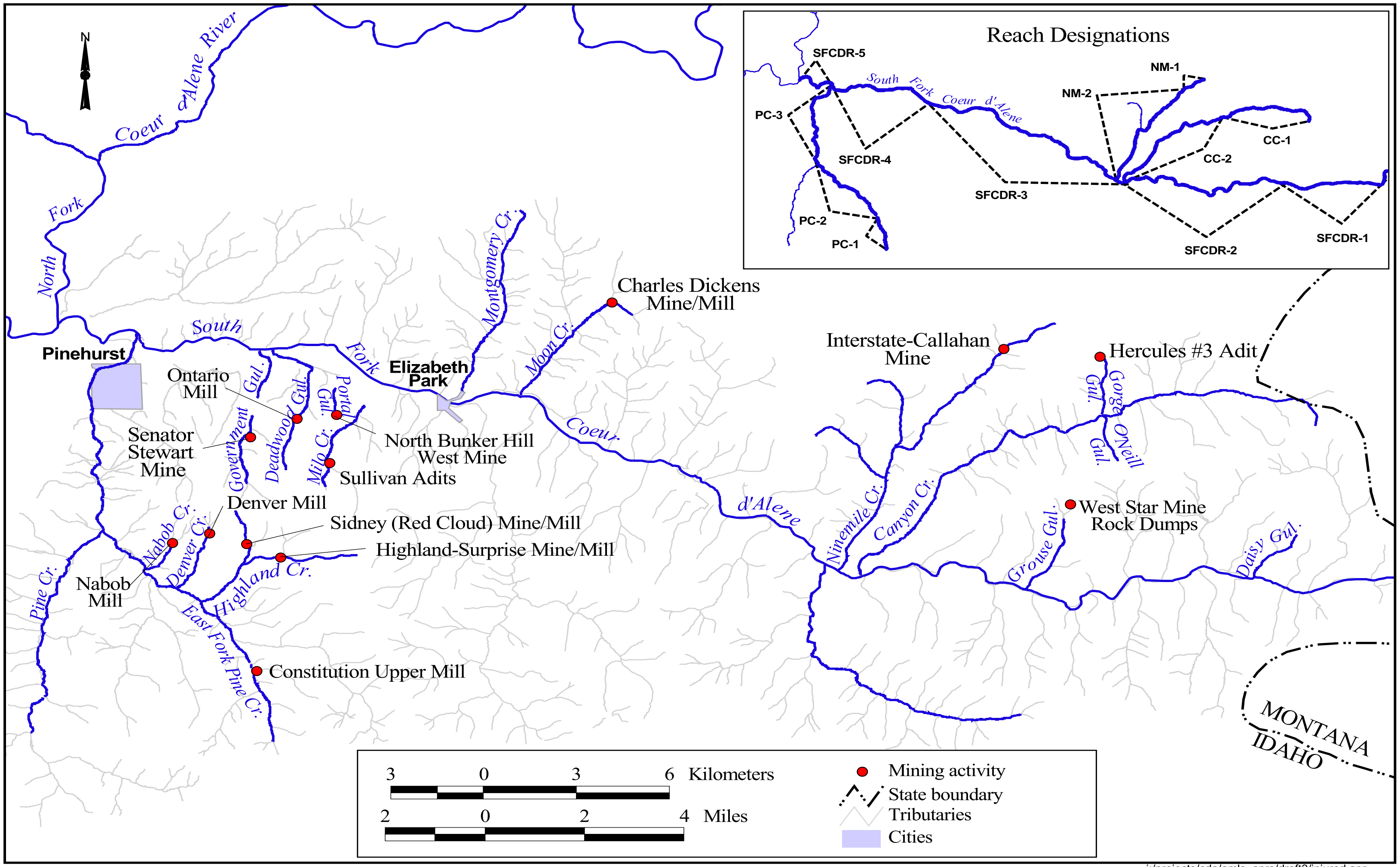
- Concentrations of hazardous substances in surface water resources of Coeur d'Alene Lake are sufficient to cause adverse effects to phytoplankton

- Concentrations of hazardous substances in surface water resources are sufficient to cause injury to aquatic biological resources (Chapter 7, Fish Resources), and to serve as a pathway of injury to wildlife (Chapter 6, Wildlife Resources) and to aquatic biological resources (Chapter 7, Fish Resources; and Chapter 8, Benthic Macroinvertebrates).

4.2 SURFACE WATER RESOURCES ASSESSED

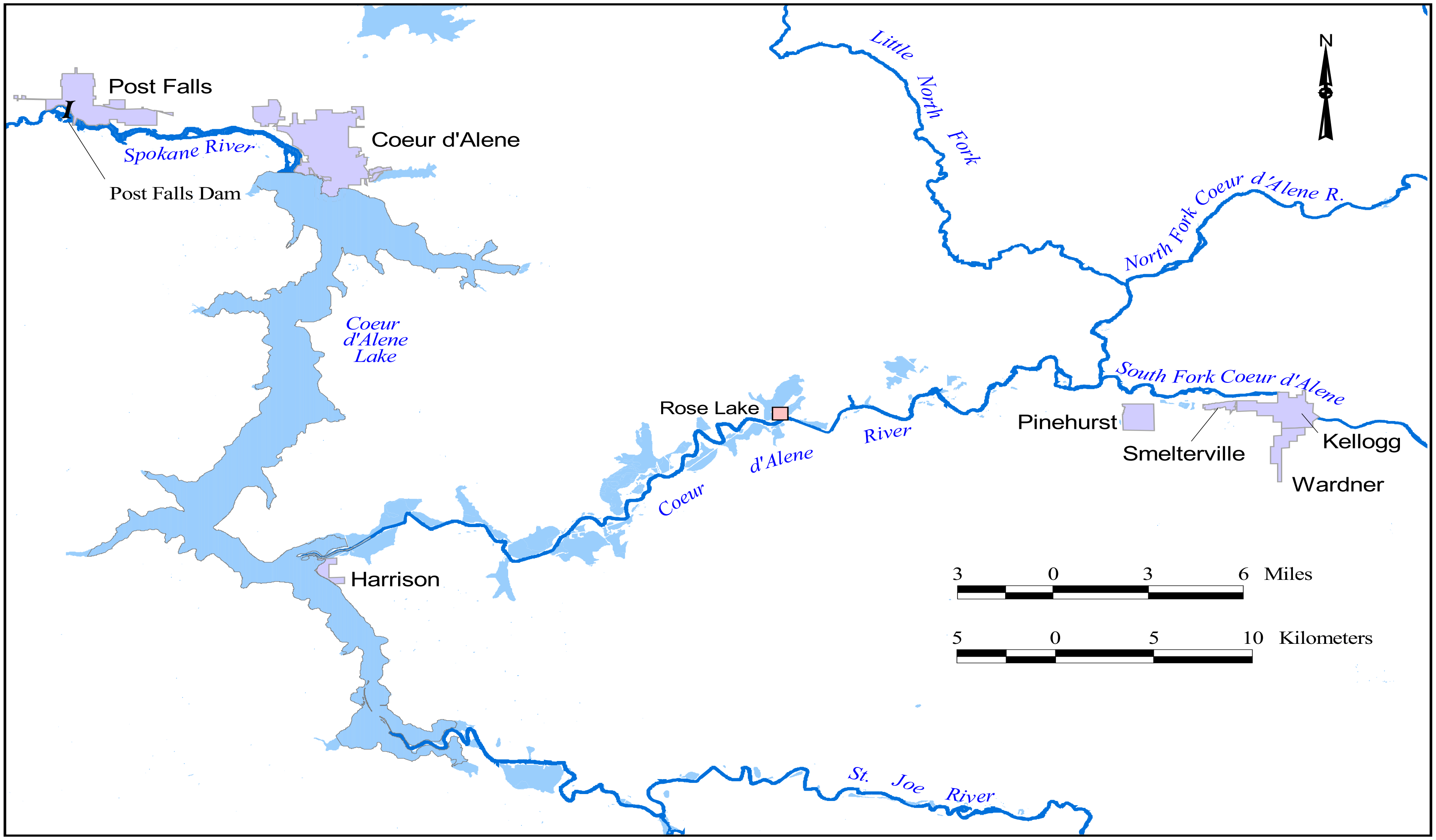
The Coeur d'Alene River basin extends west from the Idaho-Montana border and includes the North Fork Coeur d'Alene River, South Fork Coeur d'Alene River, and mainstem Coeur d'Alene River watersheds, and Coeur d'Alene Lake (Figures 4-1 and 4-2). In the upper part of the basin, the South Fork Coeur d'Alene River and its tributaries drain approximately 304 square miles (USHUD, 1979). The valleys are narrow; floodplains are less than 1 mile wide. The South Fork Coeur d'Alene River downstream of Wallace is relatively shallow and swift flowing, with a gradient of about 30 feet per mile. The larger tributaries to the South Fork Coeur d'Alene River include Canyon Creek, Ninemile Creek, Placer Creek, Big Creek, Moon Creek, Montgomery Creek, and Pine Creek.

The South Fork Coeur d'Alene River and North Fork Coeur d'Alene River meet near Enaville, Idaho. The North Fork Coeur d'Alene River and its tributaries drain approximately 897 square miles (USHUD, 1979). Tributaries to the North Fork include Shoshone Creek, Prichard Creek, Beaver Creek, and the Little North Fork.



j:/projects/cda/amls_aprs/draft3/injured.apr

Figure 4-1. South Fork Coeur d'Alene River and tributaries. Mines and mills specifically discussed in the text are shown. Inset shows South Fork Coeur d'Alene River reach designations used in the assessment of injury to surface water resources described in this chapter. See Section 4.4.6 for reach descriptions.



j:/projects/cda/amls_aprs/draft3/surfwtr.apr

Figure 4-2. Coeur d’Alene River basin and vicinity, showing the North Fork Coeur d’Alene River, South Fork Coeur d’Alene River, mainstem Coeur d’Alene River, Coeur d’Alene Lake, the upper Spokane River, and the St. Joe River.

The mainstem Coeur d'Alene River area extends from the confluence of the North and South Fork Coeur d'Alene rivers southwest to Coeur d'Alene Lake near Harrison, Idaho. Downstream of the North and South Fork Coeur d'Alene River confluence, the floodplain of the Coeur d'Alene River broadens, averaging 2 to 3 miles. The channel gradient is about 1 foot per mile, and the river is both deeper and slower moving than it is upstream. Many lakes and wetlands border the mainstem channel. The floodplain, lakes, and wetland areas of the lower basin are collectively known as the lateral lakes. The lateral lakes include thousands of acres of marshy wetlands (Bookstrom et al., 1999). The lakes vary from 85 to 640 acres, with a maximum depth of about 50 feet. The Coeur d'Alene River drains approximately 1,475 square miles (USGS, 1997).

Coeur d'Alene Lake is a large natural lake fed mainly by the Coeur d'Alene River and the St. Joe River. The drainage area of Coeur d'Alene Lake is approximately 3,440 square miles (Woods and Beckwith, 1997). Coeur d'Alene Lake discharges to the Spokane River at the north end of the lake. Lake elevation is controlled by the Post Falls Dam on the Spokane River near the Idaho-Washington state line. The normal full pool elevation for the Coeur d'Alene Lake is 2,128 feet msl (WWPC, 1996). At this elevation, the lake's surface area is approximately 50 square miles, mean depth is about 72 feet, and maximum depth is about 209 feet (CLCC, 1996). Operation of the Post Falls Dam also affects the surface water elevation and hydraulics of the lower segments of the mainstem Coeur d'Alene River and lateral lakes.

4.3 INJURY DEFINITIONS

Injury to a surface water resource results from the release of a hazardous substance if one or more of the following changes in the physical or chemical quality of the resource is measured:

- Concentrations and duration of substances in excess of applicable water quality criteria established by section 304(a)(1) of the CWA (Clean Water Act), or by other federal or state laws or regulations that establish such criteria, in surface water that before the discharge or release met the criteria and is a committed use, as that phrase is used in this part, as a habitat for aquatic life, water supply, or recreation [43 CFR § 11.62(b)(1)(iii)].

- Concentrations of substances on bed, bank, or shoreline sediments sufficient to have caused injury as defined . . . to groundwater, air, geologic, or biological resources, when exposed to surface water, suspended sediments, or bed, bank, or shoreline sediments [43 CFR § 11.62(b)(1)(v)].

In this chapter, data confirming exceedences of water quality criteria and concentrations in surface water sufficient that surface water serves as a pathway of injury to downstream surface water resources are presented. In addition, data confirming that surface water causes injury to aquatic biological resources (specifically, phytoplankton) are discussed. Subsequent chapters present data confirming that surface water serves as a pathway of injury to other resources.

4.3.1 Applicable Water Quality Criteria

Applicable water quality criteria include:

- national water quality criteria developed pursuant to section 304(a)(1) of the Clean Water Act
- Coeur d'Alene Tribal water quality criteria
- federal water quality criteria promulgated for the State of Idaho under the National Toxics Rule (NTR), as revised
- State of Idaho water quality criteria.

In accordance with requirements of section 304(a)(1) of the Clean Water Act, the U.S. EPA develops, publishes, and periodically revises national recommended water quality criteria that are generally applicable to the waters of the United States. The criteria address risks to both human health and aquatic life. For the metals addressed in this report, the most stringent 304(a)(1) criteria that apply to waters of the Coeur d'Alene River basin are criteria designed to protect aquatic life. These criteria are generally referred to as aquatic life criteria (ALC).

Federal ALC for metals were originally expressed as total recoverable metal concentrations. The use of total recoverable concentrations was considered to be the simplest, most conservative approach for application to a large number of water bodies of varying water quality. In 1993, based on further scientific review and comment, the U.S. EPA revised its policy on metal criteria. U.S. EPA now recommends the use of dissolved metal concentrations for establishing compliance with ALC, because dissolved metal concentrations more closely approximate the bioavailable fraction of metal in the water column (58 Federal Register 32131, June 8, 1993). The most recent modifications of and corrections to the ALC are contained in U.S. EPA (1999), and it is these criteria that were used to assess injury to surface water in the Coeur d'Alene basin.

In 1992, the U.S. EPA promulgated the NTR, which applied federal water quality criteria to a number of states, including Idaho, that had failed to fully comply with CWA requirements to develop adequately protective criteria for priority toxic pollutants. On February 5, 1993, the NTR criteria became the legally enforceable water quality standards in Idaho for all purposes and programs under the Clean Water Act. Based on the change in U.S. EPA policy for applying metals criteria, the NTR aquatic life criteria for 11 metals, including cadmium, lead, and zinc, were revised in 1995 to express the criteria as dissolved concentrations rather than total recoverable concentrations (60 Federal Register 22228, May 4, 1995). As of April 12, 2000, U.S. EPA withdrew Idaho from the NTR for all aquatic life criteria because the state adopted criteria that are identical to the federal criteria (65 Federal Register 19659, April 12, 2000).

The Coeur d'Alene Tribe has adopted water quality standards for the surface waters of the Coeur d'Alene Reservation. Aquatic life criteria in the tribal standards are based on NTR criteria, and the equations for calculating aquatic life criteria for cadmium, lead, and zinc are identical to those in the NTR. However, if hardness values are below 25 mg/l as $CaCO_3$, the Tribe uses the actual hardness, whereas a hardness of 25 mg/l would be used under the NTR and for section 304(a)(1) of the Clean Water Act (see following section).

For lead, the state criteria, the current recommended 304(a)(1) criteria, the NTR criteria, and the tribal criteria are identical. For cadmium and zinc, the current recommended 304(a)(1) criteria and the identical state criteria are slightly less stringent than the NTR criteria. Therefore, any exceedences of the state criteria are also exceedences of the federal criteria, the NTR criteria, and the tribal criteria.

4.3.2 Calculation of ALC

The toxicity of cadmium, lead, and zinc to aquatic species varies with water hardness. Water hardness is measured as the amount of calcium and magnesium present and is expressed as milligrams of calcium carbonate ($CaCO_3$) per liter. Cadmium, lead, and zinc are more toxic at low hardness values than at high hardness values, and the equations used to calculate freshwater ALC for these metals incorporate water hardness.

The ALC for cadmium, lead, and zinc are expressed in terms of a criterion maximum concentration (acute criterion) and a criterion continuous concentration (chronic criterion). The acute criterion is an estimate of the highest concentration of a substance in surface water to which an aquatic community can be exposed briefly without an unacceptable effect. The chronic criterion is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without an unacceptable effect (63 Federal Register 68364, December 10, 1998).

The acute and chronic criteria are each one of three components that constitute an ALC (U.S. EPA, 1987). The other two parts are the averaging period and the frequency of allowable exceedence. For cadmium, lead, and zinc, the acute averaging period is 1 hour, the chronic averaging period is 4 days, and the frequency of allowable exceedence for both chronic and acute criteria is no more than once every 3 years. For example, the chronic ALC for cadmium at a hardness value of 25 mg/L is a 4-day average concentration of 0.80 µg/L not to be exceeded more than once every three years.

The equations developed by U.S. EPA to calculate freshwater total recoverable metals criteria (µg/L) are:

$$\text{acute criteria} = e^{\left[m_A\left[\ln(\text{hardness})\right]+b_A\right]}$$
$$\text{chronic criteria} = e^{\left[m_C\left[\ln(\text{hardness})\right]+b_C\right]}.$$

The values for the variables m and b for these equations for cadmium, lead, and zinc are presented in Table 4-1.

Table 4-1
Variables m and b for Acute and Chronic ALC

Metal	Acute Criteria		Chronic Criteria	
	m_A	b_A	m_C	b_C
Cadmium	1.128	-3.6867	0.7852	-2.715
Lead	1.273	-1.460	1.273	-4.705
Zinc	0.8473	0.884	0.8473	0.884

The dissolved metals criteria are derived by multiplying the total recoverable metal acute and chronic criteria by a conversion factor. The conversion factors for cadmium and lead are themselves hardness dependent (Table 4-2).

Table 4-2
Equations Used to Convert the Total Acute (CMC) and Chronic (CCC) Criteria to Dissolved Criteria

Metal	CMC Conversion Factor	CCC Conversion Factor
Cadmium	1.136672-[ln(hardness)(0.041838)]	1.101672-[ln(hardness)(0.041838)]
Lead	1.46203-[ln(hardness)(0.145712)]	1. 46203-[ln(hardness)(0.145712)]
Zinc	0.978	0.986
Source: 63 Federal Register 68364, December 10, 1998.		

The equations are applicable for hardness values within the range of 25 to 400 mg/L $CaCO_3$ [40 CFR § 131.36 (c)(4)(i)]. In the past, the U.S. EPA generally recommended that 25 mg/L as $CaCO_3$ be used as a default hardness value in deriving aquatic life criteria for metals when the actual hardness value is below 25 mg/L. However, use of this approach results in criteria that may not be fully protective (62 Federal Register 42175, August 5, 1997). The U.S. EPA now recommends that, for waters with a hardness value less than 25 mg/L, the criteria should be calculated using the actual ambient hardness of the surface water. The Coeur d'Alene Tribal aquatic life criteria for metals are derived based on actual hardness values in surface waters, and the resulting criteria are more stringent than NTR criteria at low hardness values (i.e., below 25 mg/L).

For this assessment, where hardness was less than 25 mg/L, a value of 25 mg/L was used to calculate the ALC. Using this approach, any exceedences of the current recommended 304(a)(1) criteria are also exceedences of the Tribal criteria. No values greater than 400 mg/L were found in the data. Table 4-3 compares current national recommended 304(a)(1) criteria, NTR criteria for the State of Idaho, and Coeur d'Alene Tribal criteria for dissolved cadmium, lead, and zinc at hardness values of 15, 50, and 100 mg/L as $CaCO_3$. The criteria for a hardness of 15 mg/L for the 304(a)(1) Clean Water Act and the NTR are the same as for a hardness of 25 mg/L. At a hardness of 15 mg/L, the Tribe's criteria are lower. Hardness values of 15 mg/L and lower are common in the upper South Fork, upper Ninemile Creek, upper Canyon Creek, and many other streams in the Coeur d'Alene basin (see Section 4.5.2).

Table 4-3
Comparison of Current 304(a)(1) ALC, National Toxics Rule ALC, and Coeur d'Alene Tribal Water Quality Standards

Water Quality Criteria	Hardness = 15 mg/L			Hardness = 50 mg/L			Hardness = 100 mg/L		
	Cd (µg/l)	Pb (µg/l)	Zn (µg/l)	Cd (µg/l)	Pb (µg/l)	Zn (µg/l)	Cd (µg/l)	Pb (µg/l)	Zn (µg/l)
Acute Criteria									
Current Federal 304(a)(1) Criteria; State Criteria	0.95	13.9	36.2	2.01	30.1	65.1	4.27	64.5	117
National Toxics Rule Criteria for Idaho	0.82	13.9	35.4	1.74	30.1	63.6	3.70	64.5	114
Coeur d'Alene Tribal Water Quality Standards	0.47	7.8	23.0	1.74	30.1	63.6	3.70	64.5	114
Chronic Criteria									
Current Federal 304(a)(1) Criteria; State Criteria	0.80	0.54	36.5	1.34	1.18	65.7	2.24	2.52	118
National Toxics Rule Criteria for Idaho	0.37	0.54	32.2	0.62	1.18	58.1	1.03	2.52	104
Coeur d'Alene Tribal Water Quality Standards	0.26	0.30	20.9	0.62	1.18	58.1	1.03	2.52	104

4.3.3 Committed Use Determination

To determine injury, concentrations of hazardous substances are compared to ALC in surface waters with "committed uses" of habitat for aquatic life, water supply, or recreation. A committed use means either a current public use or a planned public use of a natural resource for which there is a documented legal, administrative, budgetary, or financial commitment established before the release of a hazardous substance is detected [43 CFR § 11.14(h)]. The most stringent criterion values or standards apply when surface water is used for more than one committed use [43 CFR §11.62(b)(iii)].

For cadmium, lead, and zinc, the chronic ALC are the most stringent criteria or standards that apply to surface waters of the Coeur d'Alene River basin. The ALC promulgated in the NTR for the State of Idaho apply to all surface waters whose designated uses include cold water biota, warm water biota, and salmonid spawning [40 CFR § 131.36(d)(13)]. Federal ALC are generally applicable to all waters of the United States.

The State of Idaho has classified all surface waters in the Coeur d'Alene River basin for the protection of cold water biota, except the South Fork Coeur d'Alene River downstream of Daisy Gulch, and Canyon Creek and Shields Gulch downstream of mining operations. All surface waters that the state has not specifically classified must support all designated uses, including aquatic life uses.

On July 31, 1997, the U.S. EPA promulgated federal water quality standards for Idaho. The standards added the cold water biota use designation to Canyon Creek downstream of mining operations, to the South Fork Coeur d'Alene River from Daisy Gulch to the mouth, and to Shields Gulch downstream of mining operations. In its final rule, the U.S. EPA indicated that "information and data obtained from the Idaho Division of Environmental Quality support cold water biota as an existing use for the South Fork Coeur d'Alene River." In designating uses for the surface waters, the U.S. EPA also relied on the rebuttable presumption implicit in the Clean Water Act and U.S. EPA's regulations at 40 CFR part 131, that in the absence of data to the contrary, "fishable" uses are attainable (62 Federal Register, 42175, July 31, 1997).

Based on state use designations and those added under federal law which apply to state waters, all surface waters within the Coeur d'Alene River basin are currently designated for the protection and support of cold water biota.

4.4 COMPILATION AND ANALYSIS OF EXISTING DATA

To evaluate injury to surface water, existing data were compiled, screened for data quality, and compared to acute and chronic ALC (Ridolfi, 1995, 1999). Sources of data included the U.S. EPA's Storage and Retrieval of U.S. Waterways Parametric Data (STORET) database, data collected for the Bunker Hill RI/FS and the Coeur d'Alene Basinwide RI/FS by U.S. EPA and its contractors, and data collected by the Idaho Division of Environmental Quality (IDEQ), the U.S. Geological Survey (USGS), the U.S. Bureau of Land Management (U.S. BLM), and the Silver Valley Natural Resource Trustees (SVNRT). The data compiled include hardness and both total recoverable and dissolved concentrations of cadmium, lead, and zinc.

Data retained for use in the injury determination are data obtained from sources that used methods and quality assurance/quality control (QA/QC) protocols that are generally accepted or have been scientifically verified and documented [43 CFR § 11.64(b)]. Data sources used in the injury assessment are summarized in the following sections.

4.4.1 U.S. EPA Data

STORET. STORET is a repository of surface water data collected by U.S. EPA and other federal and state agencies. STORET data used in the injury assessment were collected by or for U.S. EPA and Idaho Department of Health and Welfare (IDHW). Most of the STORET data used in the injury assessment are associated with a long-term U.S. EPA monitoring program in the basin (Hornig et al., 1988) and the Bunker Hill RI/FS (Dames & Moore, 1990). Samples taken as a part of these two programs were collected and analyzed according to standard, accepted U.S. EPA methods and QA/QC protocols.

Coeur d'Alene Basinwide RI/FS data. U.S. EPA has collected surface water quality data as part of the Coeur d'Alene Basinwide RI/FS, primarily in the South Fork Coeur d'Alene River drainage basin (data collection and analysis was ongoing at the time of the preparation of this document). Surface water data, mostly collected during fall 1997 and spring 1998, were available for use in this injury assessment. In addition, samples collected from Coeur d'Alene Lake in 1999 were available. The samples were collected and analyzed according to current standard, accepted U.S. EPA methods and QA/QC protocols.

Bunker Hill RI/FS data. Surface water quality data were collected in 1986 and 1987 at eight stations on the South Fork Coeur d'Alene River for the Bunker Hill RI/FS (Dames & Moore, 1990). Most of the data for these stations were retrieved from STORET. Additional data were compiled from Dames & Moore (1990). The samples were collected and analyzed according to standard, accepted U.S. EPA methods and QA/QC protocols.

4.4.2 IDEQ Data

The IDEQ collected surface water quality data as part of a trace elements monitoring program in the South Fork Coeur d'Alene River drainage (Harvey, 1993). Samples were collected approximately monthly during the 1994, 1995, and 1996 water years. In addition, IDEQ collected water quality data as part of an investigation of point and nonpoint sources of heavy metals to the South Fork Coeur d'Alene River upstream of Canyon Creek (Hartz, 1993). Samples associated with these two programs were collected and analyzed using IDEQ-specified methods and accepted QA/QC protocols.

4.4.3 USGS Data

USGS has collected water quality data, including metal concentrations, in the Coeur d'Alene River basin since the 1960s. Most of the water quality samples were collected in conjunction with water flow measurements at gauging stations. USGS gauging stations have variable periods of records, and some of the older stations are no longer monitored. Data for stations included within the Coeur d'Alene River basin are maintained in the district database by the Idaho District. Most of the USGS data used in the injury assessment were acquired from the district database. In addition, data from recent district water year books were compiled for use in the injury assessment. Samples were collected and analyzed according to standard USGS-specified methods and QA/QC protocols.

4.4.4 U.S. BLM Data

Surface water quality data for the mainstem Coeur d'Alene River and Pine Creek were obtained from the U.S. BLM Coeur d'Alene Office. Data for the mainstem Coeur d'Alene River were obtained as part of a river water quality monitoring program (1991 through 1993) and a draft Preliminary Assessment/Site Investigation conducted during 1992 for U.S. BLM by IDEQ (U.S. BLM, undated). Data for Pine Creek were available in a draft preliminary assessment report (CCJM, 1994). Samples associated with these programs were collected and analyzed using standard, acceptable IDEQ and U.S. BLM-specified methods and QA/QC protocols.

4.4.5 Silver Valley Natural Resource Trustee Data

Surface water quality data were obtained for the Silver Valley Natural Resource Trustees during a 1991 water quality study of the South Fork Coeur d'Alene River and its tributaries (MFG, 1991, 1992). Samples were collected once in the spring (May 1991) and once in the fall (October 1991). Samples were collected and analyzed according to standard, accepted U.S. EPA methods and QA/QC protocols.

4.4.6 Data Analysis

The DOI NRDA regulations stipulate that surface water samples used in assessing injuries meet a specific acceptance criterion:

- The acceptance criterion for injury to the surface water resource is the measurement of concentrations of . . . a hazardous substance in two samples from the resource. The samples must be one of the following types: (A) Two water samples from different locations, separated by a straight-line distance of not less than 100 feet; . . . or (D) Two water samples from the same location collected at different times [43 CFR § 11.62(b)(2)(i)].

The water quality data compiled for the injury determination include numerous stations throughout the Coeur d'Alene River basin. Many of these stations have been sampled repeatedly during different seasons and under a variety of flow conditions. The data used to assess injury meet the acceptance criterion.

Water quality data from the sources identified above were compiled by reach (Table 4-4 and Figures 4-1 and 4-2). For many tributaries to the South Fork Coeur d'Alene River (e.g., Portal Gulch, Moon Creek, Big Creek), surface water data exist only for stations near the mouths of the tributaries. For a number of the tributaries assessed for injury in Table 4-4, no reaches were assigned. In these cases, surface water sampling location identifications were used instead of reach abbreviations. Data from individual reaches and data from the mouths of certain tributaries were compared to federal water quality criteria for determination of injury.

4.5 INJURY DETERMINATION EVALUATION

4.5.1 Pathway Determination

Hazardous substances have been and continue to be transported from mining and mineral processing sources to surface water resources. Pathways of hazardous substances to surface water include groundwater, surface water, and sediments. Resources that serve as a pathway of injury to surface water are, themselves, injured [43 CFR 11.62 (b)(v) and (c)(iv)].

Groundwater. The determination of groundwater as a pathway for contamination of surface water is described in general terms because of the lack of comprehensive data on aquifer properties and groundwater hazardous substance concentrations in the Coeur d'Alene River basin. Groundwater upgradient of surface water resources can be a pathway for transport of heavy metals from mining and mineral processing-related sources to surface water. Mine waters that discharge from adits can transport heavy metals to surface water resources. Groundwater and surface runoff interacting with waste rock can dissolve and transport heavy metals to surface waters. Groundwater and surface runoff interacting with both upland tailings piles and mixed tailings and alluvium in floodplains can also dissolve and transport heavy metals to surface water resources.

Table 4-4
Surface Waters Assessed for Injury in the Coeur d'Alene Basin

Reach Abbreviation/ Location ID	Reach Description	Period of Record[a]
South Fork Coeur d'Alene River		
SFCDR-1	Headwaters to Daisy Gulch	1968-1998
SFCDR-2	Daisy Gulch to Canyon Creek	1971-1995
Tributaries		
SF 223, 317, 318, 319	Grouse Gulch downstream of Star Mine waste rock dumps	1997-1998
SFCDR-3	Canyon Creek to Milo Creek	1971-1998
Tributaries		
CC-1	Headwaters to O'Neill Gulch	1979-1998
CC-2	O'Neill Gulch to mouth	1971-1998
CC 392	Gorge Gulch downstream of Hercules No. 3 adit	1991, 1998
NM-1	Headwaters upstream of Interstate-Callahan Mine[b]	1991-1998
NM-2	Interstate-Callahan Mine to mouth	1971-1998
SFCDR-4	Milo Creek to Pine Creek	1967-1998
Tributaries		
MC 262	Moon Creek downstream of Charles Dickens Mine/Mill	1991-1998
SF 183, 184, 186, 187	Milo Creek downstream of Sullivan adits	1997-1998
SF 104	Portal Creek downstream of North Bunker Hill West Mine	1997
SF 100, 101, 102, 103	Deadwood Gulch/Bunker Creek downstream of Ontario Mill	1997-1998
SF 110	Government Gulch downstream of Senator Stewart Mine	1997-1998
PC-1	East Fork Pine Creek upstream of Constitution Upper Mill[c]	1993-1998
PC-2	Constitution Mine downstream to mouth of East Fork	1993-1998
PC-3	Mainstem Pine Creek from mouth to EF confluence	1972-1998
PC 307, 322, 323	Highland Creek downstream of Highland Surprise Mine/Mill	1993-1998
PC 308, 324	Denver Creek downstream of Denver Mine	1993-1998
PC 310, 326	Nabob Creek downstream of Nabob Mill	1997-1998
SFCDR-5	Pine Creek to North Fork Coeur d'Alene River	1966-1986
Lower Coeur d'Alene River		
CDR-1	Confluence of North and South Forks to Cataldo	1968-1997
CDR-2	Cataldo to Rose Lake	1968-1997
CDR-3	Rose Lake to Harrison	1966-1998
Coeur d'Alene Lake		
CDAL	Coeur d'Alene Lake	1971-1999

a. The period of record is the range of years in which water quality samples were collected and analyzed, and is not continuous for any reach. The period of record used in this injury assessment extends through 1998.
b. Also includes several samples from tributaries to the East Fork of Ninemile Creek downstream of the Interstate-Callahan Mine, which are unexposed to mine wastes.
c. Also includes several samples from tributaries to Pine Creek downstream of the Constitution Upper Mill, which are unexposed to mine wastes.

CC: Canyon Creek; NM: Ninemile Creek; MC: Moon Creek; PC: Pine Creek.

The groundwater system in the South Fork Coeur d'Alene River basin west of Kellogg is divided into three hydrostratigraphic units: an upper alluvial zone, a middle lacustrine confining zone, and a lower alluvial zone (Dames & Moore, 1991). The upper zone consists of mixed jig and flotation tailings and alluvium underlain by natural alluvium, and reaches thicknesses of 30-40 feet in eastern Smelterville Flats. The alluvium consists of silty to clay sand and gravel with lenses of sand and gravel. Thicknesses of mixed tailings and alluvium are greatest (more than 7 feet) near the CIA and in central Smelterville Flats.

The middle confining zone, which consists of lacustrine silts and clays, retards vertical groundwater flow between the upper and lower zones (Dames & Moore, 1991). The confining zone is believed to end beneath Kellogg between the mouths of Milo and Portal gulches (Dames & Moore, 1991). Thicknesses range from 0 feet near Kellogg to over 50 feet near Smelterville Flats. The composition of the lower zone is similar to the alluvium in the upper zone. The lower zone alluvium is deposited on bedrock of the Belt Supergroup rock. Unlike the upper zones, the lower zone is thickest (>50 feet) near Kellogg and thins westward. East of Kellogg, there is no confining zone, and the upper and lower alluvial units merge into one, unconfined alluvial unit (Dames & Moore, 1991).

Upper zone groundwater flow is largely unconfined, although seasonal and local confinement may occur where overlying tailings are fine grained and in contact with the water table. The saturated thickness of the upper zone ranges from approximately 3 to 40 feet, thickening to the west near the central and western areas of Smelterville (Dames & Moore, 1991). During seasonal high water conditions, the bottom portion of the tailings deposits may become locally saturated (Dames & Moore, 1991). Groundwater elevations in the upper zone fluctuate seasonally and are recharged by precipitation and snowmelt. Groundwater levels are highest in the spring during periods of increased snowmelt and precipitation, and lowest during winter and early spring when precipitation is lowest and snow is not melting (Dames & Moore, 1991).

Groundwater flow in the upper zone is predominantly east to west, with north-south flow near losing and gaining reaches of the South Fork Coeur d'Alene River and near mouths of tributary gulches (Dames & Moore, 1991). Gaining and losing reaches are believed to be associated with variations in valley width. Where the valley widens, the water table falls below the river channel bed surface, and the channel loses water to the upper zone. Where the valley constricts, upper zone groundwater discharges to the river.

Hydraulic conductivity was measured in each of the three groundwater flow zones. Hydraulic conductivity was highest in the upper zone, ranging from 500-10,790 ft/day, and lowest in the confining zone, ranging from 0.00028-0.028 ft/day (Dames & Moore, 1991). Hydraulic conductivity in the lower alluvial aquifer ranged from 100-1,910 ft/day. Transmissivity ranged from 10,002-216,852 ft^2/day in the upper zone and 3,220-80,000 ft^2/day in the lower zone (Dames & Moore, 1991).

In losing sections of stream, surface water can be a pathway to shallow alluvial groundwater. Conversely, in gaining sections of stream, groundwater can be a pathway for contamination of surface water. Surface water/groundwater interactions are evident in gaining and losing sections of the river as seasonal and perennial seeps, and during seasonal flooding and subsequent receding of floodwaters. In losing stream reaches where the valley floor widens, such as in lower Canyon Creek and at Osburn Flats on the South Fork Coeur d'Alene River, water leaves the stream channel and enters the floodplain aquifer (Dames & Moore, 1991). Where the valley constricts, groundwater discharges back to the stream (Dames & Moore, 1991). Hazardous substances leached from the floodplain tailings deposits in these wider reaches of the valley are transferred to the stream with the returning groundwater.

Streams may lose water to groundwater during high flow, and gain water from groundwater during low flow. For example, in the lower Coeur d'Alene River basin, after seasonal flooding and saturation of wetland sediments, groundwater stored in the sediments slowly drains to the river and lakes as the water table lowers during the drier months, and hazardous substances leached from the mixed tailings and alluvium are transferred back to surface waters.

Gaining and losing reaches between Elizabeth Park and Pinehurst on the South Fork Coeur d'Alene River were measured in September 1987 (Dames & Moore, 1991). Between Elizabeth Park and Milo Gulch, the South Fork gained 4.1 ft^3/s. Between Milo Gulch and Deadwood Gulch, the South Fork lost 8.6 ft^3/s. This reach includes the eastern half of the CIA. From the middle of the CIA to Government Gulch, the South Fork gained 3.9 ft^3/s. This indicates that while mill discharge was being applied to the CIA, drainage from at least half of the CIA was being transported to the South Fork. From Smelterville to the Page Ponds, the South Fork lost 2.6 ft^3/s; from the Page Ponds to downstream of Pine Creek, it gained 11.8 ft^3/s. Although the locations of gaining and losing sections of stream probably vary seasonally, the alternating gaining and losing sections in this part of the South Fork indicate that exchange between alluvial groundwater and stream water is extensive and that contaminated groundwater and surface water each are a pathway for contamination of the other.

Metal loadings to Ninemile Creek, Canyon Creek, and the South Fork Coeur d'Alene River confirm that groundwater discharges hazardous substances to surface water. For example, groundwater discharge in Canyon Creek accounts for the majority of zinc (200-300 lb/day) gained in the stream (Box et al., 1997). Near Osburn Flats, groundwater discharges approximately 100-150 lbs of zinc/day to the South Fork, and in western Smelterville Flats, groundwater discharges to surface water between 300 and 600 lbs of zinc/day (Box et al., 1997).

Concentrations of dissolved cadmium, lead, and zinc in groundwater samples collected in Osburn Flats on the South Fork Coeur d'Alene River (Table 4-5) and in lower Canyon Creek (Table 4-6) are presented below. Both areas contain extensive floodplain tailings deposits that are sources of groundwater contamination. The concentrations of dissolved cadmium and zinc in Osburn Flats groundwater are well above acute ALC values, and concentrations of dissolved lead are well above chronic ALC values. As noted above, groundwater in this area discharges to the South Fork in gaining reaches and serves as a pathway for contamination of surface water.

Table 4-5
Dissolved Metals Concentrations in Groundwater from Osburn Flats, South Fork Coeur d'Alene River

Sample ID	Cadmium (µg/L)	Zinc (µg/L)	Lead (µg/L)
GW-TP-4-16-D	139	20,700	23
GW-TP-4-17-T	492	56,300	48
GW-TP-4-18-T	231	26,000	57
Data source: Silver Valley Natural Resource Trustees, 1997, as cited in Ridolfi, 1998.			

Concentrations of metals in the shallow alluvial groundwater in lower Canyon Creek are also extremely elevated. Mean concentrations were 33,900 µg/L of zinc, 260 µg/L of cadmium, and 1,450 µg/L of lead (Houck and Mink, 1994). Houck and Mink concluded that "a significant portion of these metals discharge to the lower portion of Canyon Creek from the ground water system." Table 4-6 presents dissolved zinc concentrations in groundwater in lower Canyon Creek. These data confirm that groundwater concentrations of zinc are extremely elevated in lower Canyon Creek. Where groundwater discharges to the stream, groundwater serves as a pathway for contamination of surface water in the Canyon Creek drainage.

Groundwater draining these and other areas in the South Fork Coeur d'Alene River basin may account for as much as 80% of the dissolved metal loading to the South Fork (Box et al., 1997). In addition to the discharge of contaminated groundwater to streams in floodplains, seepage from adits can contaminate downgradient surface water. Numerous adits and seeps in the South Fork Coeur d'Alene River watershed discharge groundwater directly to surface water resources. The discharge associated with many of these seeps and adits contains heavy metals in concentrations that exceed federal water quality criteria (Tables 2-18 through 2-23, Chapter 2).

Table 4-6
Dissolved Zinc Concentrations in Groundwater,
Lower Canyon Creek, April 1993 and April 1997

Well	Dissolved Zinc (mg/L)			
	Mean	Minimum	Maximum	Number of Samples
WP-1	51.4	22.3	93.4	8
WP-2	17.9	10.6	27.2	7
WP-3	23.2	19.4	28.3	6
WP-4	20.8	17.0	24.1	7
WP-5	16.7	2.6	31.8	6
T-2	21.8	3.9	50.0	7
T-3	29.7	20.9	38.9	6
T-4	58.1	17.3	145	7
T-5	26.4	6.5	44.7	7
T-6	36.0	28.5	43.4	2
T-7	19.2	5.1	46.8	7
CM-1	0.83	0.18	1.6	5
CM-2	9.9	6.5	14.6	3
CM-3	48.3	23.8	79.6	5
CM-4	98.7	37.9	172	6
CM-5	48.1	14.9	89.5	5
CM-6	55.7	14.1	116	5
CM-7	21.1	5.2	39.2	5
CM-8	12.0	5.5	15.6	5
CM-9	5.2	0.85	10.2	5
CM-10	42.7	27.9	54.6	5
CM-11	42.4	15.1	105	5
CM-12	15.7	7.0	27.3	5

Data for wells with more than one measurement are shown.

Data source: MFG, 1998.

Surface Water and Sediments. Surface water carries heavy metals from mining and mineral processing-related sources to downstream surface water resources, including suspended sediments. Surface runoff erodes tailings accumulations and waste rock piles, transporting heavy metals into streams. Surface water remobilizes previously released tailings that are mixed with alluvium in stream beds, banks, and floodplains and transports heavy metal-bearing particulates to downstream surface water resources. Hydrologic processes associated with sediment transport in streams are discussed in Chapter 5.

Data collected in the Coeur d'Alene River basin demonstrate that surface water serves as a pathway to downstream surface water and sediments. Metal loadings data for the South Fork Coeur d'Alene River demonstrate ongoing releases from sources and transport of metals in surface water, resulting in increased metal loads to the river downstream (Ridolfi, 1998). Zinc loads in the South Fork generally increase from the Canyon and Ninemile Creek confluences with the South Fork to the North Fork confluence, with greater loadings and greater variability during high flow than during low flow (Figure 4-3). In both Canyon Creek (Figure 4-4) and Ninemile Creek (Figure 4-5), zinc loads increase with distance downstream of mining-related operations. As in the South Fork, loadings and variability during high flow are greater than during low flow.

The spatial distribution of metals concentrations in Coeur d'Alene Lake bottom sediments also indicates that the Coeur d'Alene River is a source of metals to lake sediments. Sediments near and downgradient of the mouth of the Coeur d'Alene River are enriched in zinc by up to 118 times relative to sediments from the south end of the lake (Table 4-7; see also Chapter 5). The south end of the lake receives surface water primarily from the St. Joe River.

4.5.2 Exceedences of Applicable Water Quality Criteria

In the following sections, measured dissolved concentrations are compared to ALC to determine if stream reaches or locations are injured [43 CFR §11.62 (b)(iii)]. The determination that surface water met the ALC before the release of hazardous substances is presented in Chapter 10.

Analytical detection limits for cadmium, lead, and zinc decreased during the past three decades (the period for which there are surface water data), as laboratory techniques and instrumentation improved. Detection limits for cadmium and lead associated with older data sets frequently exceed acute and chronic criteria, so concentrations near and lower than the criteria were not quantifiable. In some cases, analytical detection limits associated with newer data sets also exceed the criteria, particularly in low hardness waters where the criteria concentrations are also very low. For sample results that were below the detection limit, the detection limit value was compared to the applicable water quality criteria. If the detection limit was greater than the applicable water quality criteria, the result was eliminated from the data set since it is unknown whether the true concentration was greater or less than the criteria.

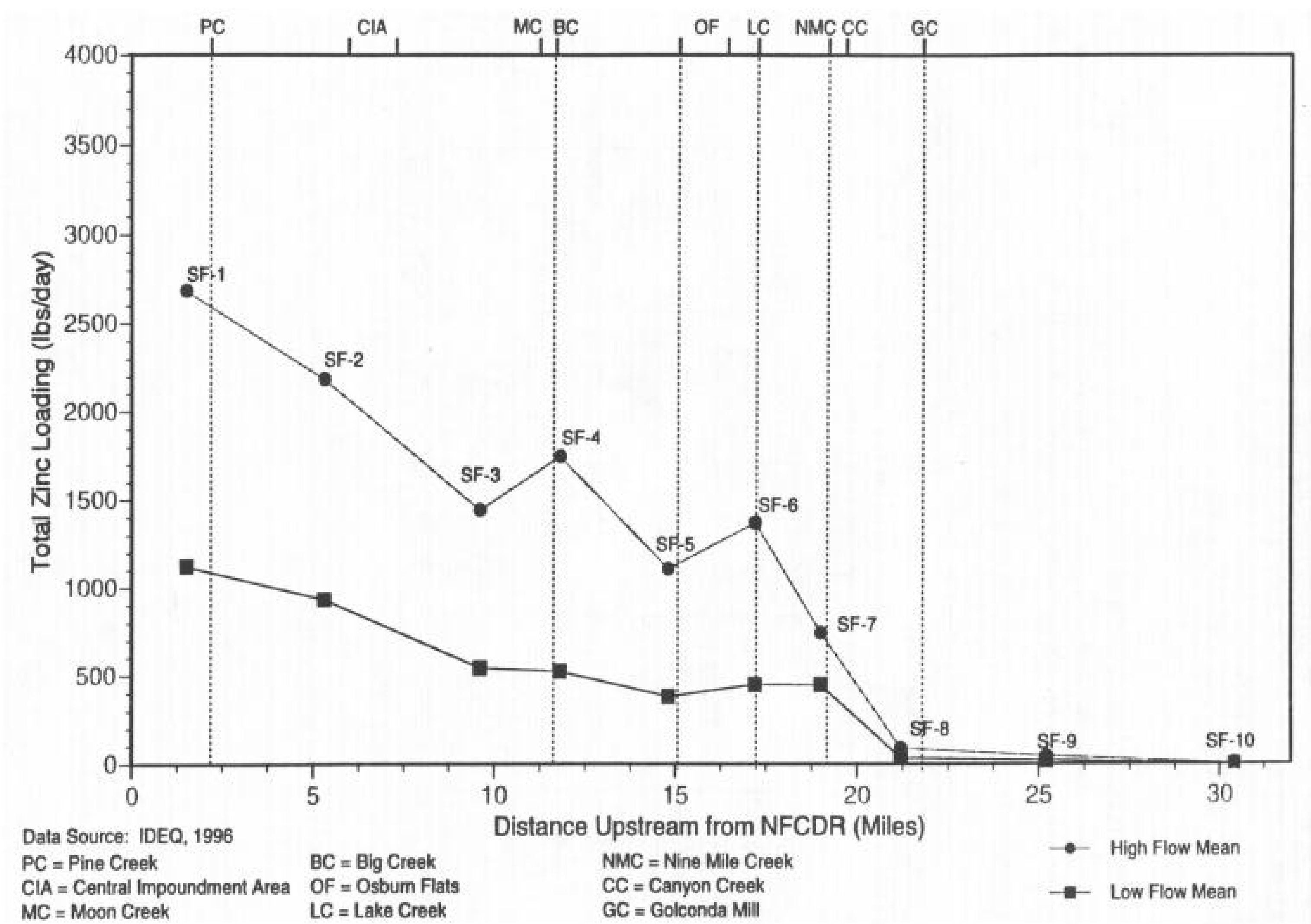


Figure 4-3. Total zinc loading, South Fork Coeur d'Alene River, 1994 water year.
Source: Ridolfi, 1999.

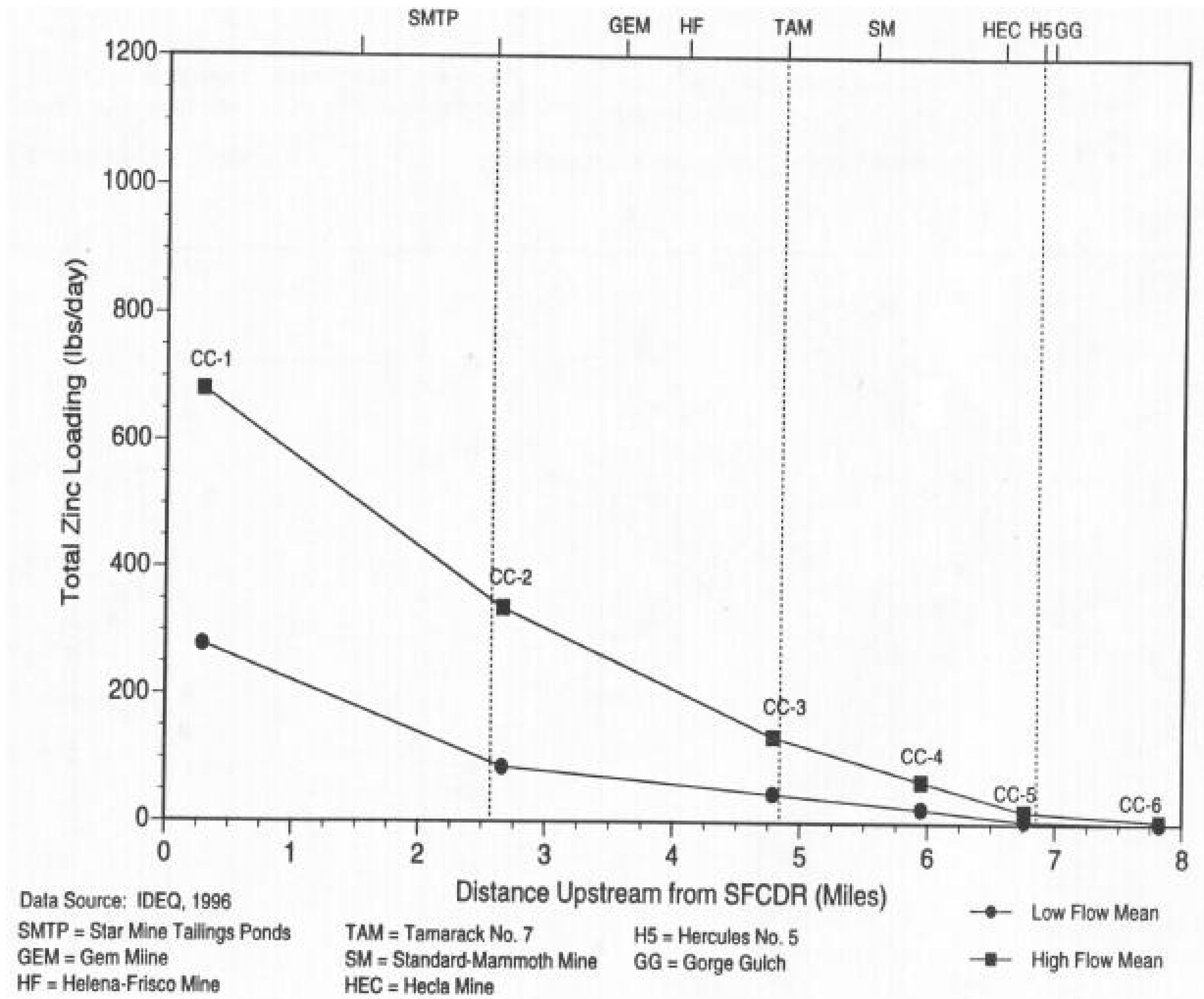


Figure 4-4. Total zinc loading, Canyon Creek, 1994 water year.
Source: Ridolfi, 1999.

For data sets that included both total and dissolved metal concentrations, the data were screened for dissolved concentrations that exceed total concentrations. Any sample for which the dissolved measurement exceeded the total measurement by more than 20% RPD (relative percent difference) was dropped from the data set, unless the dissolved concentration was less than or equal to the ALC. Overall, relatively few data pairs exceed the >20% RPD criterion.

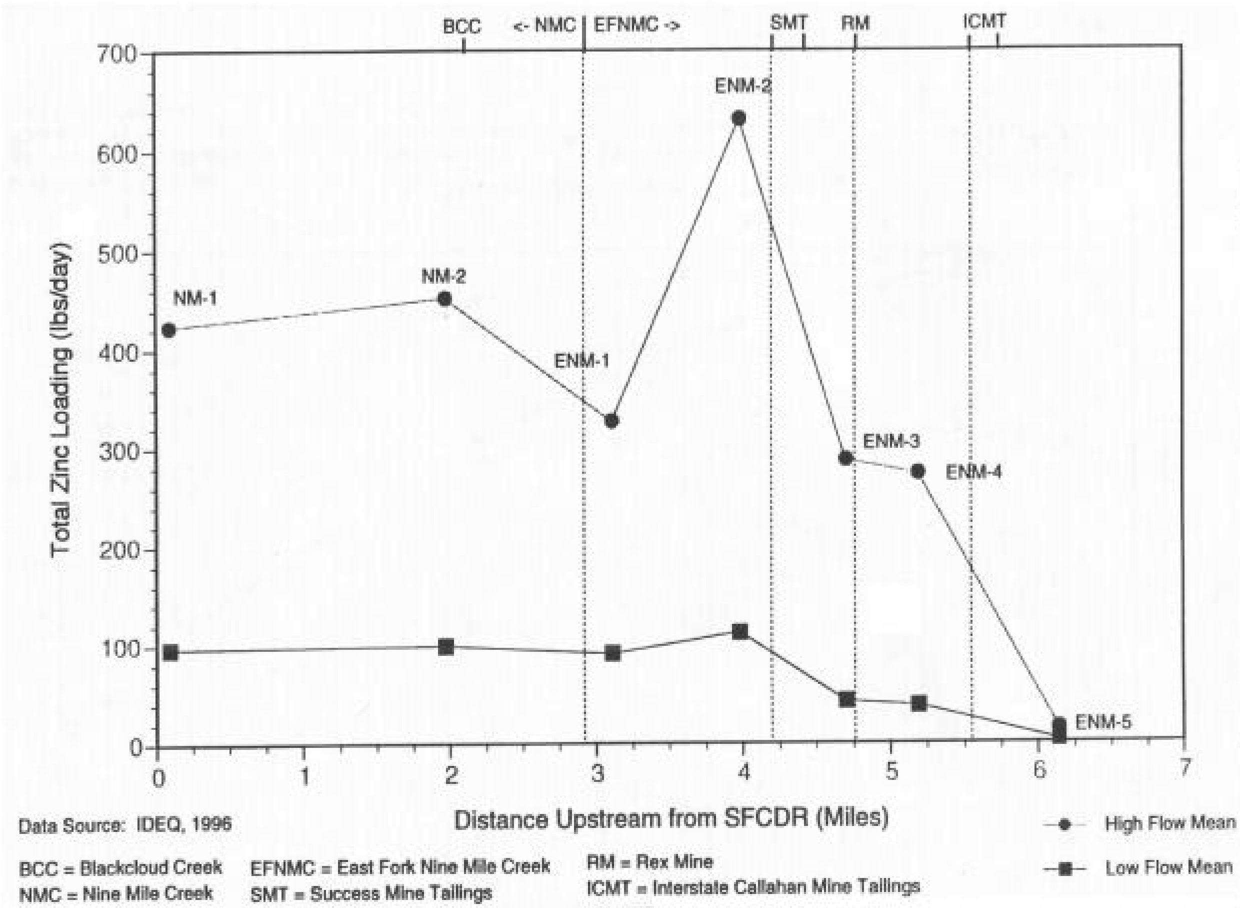


Figure 4-5. Total zinc loading. Ninemile Creek, 1994 water year.
Source: Ridolfi, 1999.

Acute ALC. Acute ALC are 1-hour average concentrations that are not to be exceeded more than once in a 3-year period (U.S. EPA, 1987). The recommended exceedence frequency of 3 years is the U.S. EPA's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to a contaminant exceeds the criterion. A stressed system (e.g., one in which several sources contribute pollutants in a small area) probably requires more time for recovery (U.S. EPA, 1987).

Table 4-7
Minimum, Maximum, Mean, and Median Hazardous Substance Concentrations in Surface and Subsurface Sediments from Coeur d'Alene Lake Near and Downgradient of the Coeur d'Alene River Delta

Element	Surface/ Core Sample[a]	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)	Median (mg/kg)	Unenriched Median[b] (mg/kg)	Enrichment Factor[c]
Arsenic	S	2.4	660	151	120	4.7	26
	C	3.5	845	103	30	12	2.5
Cadmium	S	<0.5	157	62	56	2.8	20
	C	<0.1	137	25	26	0.3	87
Copper	S	9	215	72	70	25	2.8
	C	20	650	91	60	30	2.0
Lead	S	14	7,700	1,900	1,800	24	75
	C	12	27,500	3,200	1,250	33	38
Zinc	S	63	9,100	3,600	3,500	110	32
	C	59	14,000	2,400	2,100	118	18

a. S: surface samples (n = 150); C: subsurface core samples (n = 189).
b. Data from south end of Coeur d'Alene Lake.
c. Enrichment factor = median/unenriched median.

Data source: Horowitz et al., 1995.

Tables 4-8 through 4-10 and Figure 4-6a and b and Figure 4-7a, b, and c summarize acute ALC exceedences. Tables 4-8 through 4-10 and Figure 4-7a, b, and c show acute ALC exceedences for cadmium, lead, and zinc for the South Fork Coeur d'Alene River and tributaries, the mainstem Coeur d'Alene River and Coeur d'Alene Lake for the entire period of record (see Table 4-4). Information in the tables is for the entire reach noted. Figures 4-6a and b show individual locations in the South Fork Coeur d'Alene River basin where one or more acute ALC values were exceeded from 1991 to 1998. Some locations without latitude and longitude designations were not plotted on Figure 4-6. For samples without hardness values, average hardness values from Tables 4-8 through 4-10 were used. Where there was a range of hardness values (e.g., for Highland Creek), the average hardness value was calculated and used. The results characterize acute exceedences of cadmium, lead, and zinc over the seven year period from 1991 to 1998. These figures show the preponderance of acute ALC exceedences in surface waters downstream of mining disturbance. Figures 4-7a, b, and c show the data distribution for cadmium, lead, and zinc relative to mean acute and chronic ALC for each reach of the Coeur d'Alene River, South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, Pine Creek, and Coeur d'Alene Lake.

Table 4-8
Acute Criteria for Cadmium — Summary of Exceedences

Stream or Water Body	Reach/ Location ID[a]	Measured Hardness (mg/L as $CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Range	ALC Values[b] (µg/L) Range	No. Exceed	No. Used	(%)	Measured Concentration/ ALC[c] Range
South Fork	SFCDR-1	10.3-40.0 (24.6)	0.25	0.01 U-2.50	0.95-1.58	2 /	38	(5)	0.01-2.33
	SFCDR-2	14.8-96.0 (41.0)	0.80	0.04 U-6.00	0.95 -4.08	9 /	117	(8)	0.03-4.22
	SFCDR-3	22.1-146 (52.5)	7.40	0.20-18.00	0.95-6.42	241 /	253	(95)	0.07-8.10
	SFCDR-4	27.0-270 (102)	10.2	1.20-220.00	1.03-12.5	92 /	97	(95)	0.26-48.2
	SFCDR-5	24.2-271 (89.2)	9.00	1.00 U-390	0.95 -12.5	105 /	111	(95)	0.12-103
South Fork Tributaries									
Grouse Gulch	SF-223	27.0-48.0 (37.5)	8.29	8.20-8.37	1.03-1.92	2 /	2	(100)	4.35-7.95
Moon Creek	MC-262	26.0-60.0 (34.4)	0.70	0.40-1.80	0.99-1.58	1 /	15	(7)	0.32-1.41
Milo Creek	SF-183	71.7[d]	11.4	10.0-24.1	2.97[h]	3 /	3	(100)	3.36-8.11
Portal Creek	SF-104	71.7[d]	3.00	3.00 U	2.97[h]	0 /	1	(0)	1.01
Deadwood Gulch	SF-100-103	71.7[d]	83.9	3.00 U-736	2.97[h]	9 /	12	(75)	1.01-248
Government Gulch	SF-110	71.7[d]	184	40.8-306	2.97[h]	4 /	4	(100)	13.7-103
Canyon Creek	CC-1	2.00-56.0 (13.5)	0.25U	0.04 U-1.00	0.95-2.27	1 /	42[i]	(2)	0.04-1.06
	CC-2	5.00-90.0 (32.9)	5.00	0.25-408	0.95-3.80	295 /	357	(836)	0.19-303
Gorge Gulch	CC-392	17.3[e]	1.30	0.30-.90	0.95[h]	2 /	3	(67)	0.32-2.01
Ninemile Creek	NM-1	5.49-139 (61.1)	0.20	0.04 U-0.46	0.95-6.10	0 /	13	(0)	0.01-0.21
	NM-2	4.36-96.0 (35.8)	23.0	0.20 U-90.00	0.95-4.08	246 /	261	(94)	0.21-62.0
Pine Creek	PC-1	5.43-25.0 (9.86)	0.04	0.01 U-0.20 U	0.95	0 /	8	(0)	0.01-0.21
	PC-2	8.00-48.0 (20.9)	1.30	0.38-10.0	0.95-1.92	4 /	7	(57)	0.40-10.6
	PC-3	3.0-76.0 (14.1)	0.27	0.04-4.00	0.95-3.17	4 /	58	(7)	0.04-4.22

Table 4-8 (cont.)
Acute Criteria for Cadmium — Summary of Exceedences

Stream or Water Body	Reach/ Location ID[a]	Measured Hardness (mg/L as $CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Measured Concentration (µg/L) Range	ALC Values (µg/L) Range	No. Exceed	No. Used	(%)	Measured Concentration/ ALC[c] Range
Pine Creek Tributaries									
Highland Creek	PC-307	23.8-52.2[f] (38.7)	2.50	1.60-3.50	0.95-2.11	34 /	34	(100)	1.05-2.58
Denver Creek	PC-308	25.9-72.0[g] (44.3)	11.00	7.30-18.30	0.98-2.99	1 /	3	(100)	4.08-10.2
Nabob Creek	PC-310, 326	24.6-233 (173)	4.59	3.00-4.78	0.95-10.6	1 /	3	(33)	0.45-3.17
Coeur d'Alene River	CDR-1	11.9-160 (42.7)	2.80	1.00-120	0.95-7.09	33 /	7	(89)	0.43-66.5
	CDR-2	9.00-137 (46.0)	18.0	1.00-122	0.95-6.00	42 /	45	(93)	1.06-66.0
	CDR-3	12.7-49.8 (28.3)	2.00	0.94-19.0	0.95-2.00	8 /	11	(73)	0.99-16.9
Coeur d'Alene Lake	CDAL	7-76.0 (22.1)	1.00	0.07-2.00	0.95-3.17	21 /	100[i]	(21)	0.07-2.11

a. See Table 4-4 for reach definitions.
b. For values below the detection limit, the detection limit was used to calculate the median.
c. Values below 1 indicate the ALC was not exceeded; values greater than 1 indicate the magnitude of exceedence. If the measured concentration was below detection, the detection limit was divided by the ALC value.
d. Used average hardness for SF 270 in South Fork (n = 15).
e. Used one hardness measurement (17.3) for other two samples with no measured hardness.
f. Used average of existing hardness values (18/34 samples) for samples with no measured hardness.
g. Used average of existing hardness values (16/30 samples) for samples with no measured hardness.
h. Criterion value using noted hardness.
i. Extremely high undetected values not used in calculations.

U = below detection.

Table 4-9
Acute Criteria for Lead — Summary of Exceedences

Stream or Water Body	Reach[a]	Measured Hardness (mg/L $CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Measured Concentration (µg/L) Range	ALC Values[b] (µg/L) Range	No. Exceed / No. Used	(%)	Measured Concentration/ ALC[c] Range
South Fork	SFCDR-1	10.3-40.0 (24.6)	1.50	0.10 U-5.00	13.9-23.5	0 / 37	(0)	0.01-0.36
	SFCDR-2	14.8-96.0 (41.0)	3.00	0.32-45.0	13.9-61.8	1 / 127	(1)	0.02-2.97
	SFCDR-3	22.1-146 (52.5)	10.0	2.00-45.0	13.9-97.3	7 / 267	(3)	0.02-1.35
	SFCDR-4	27.0-270 (102)	10.0	1.00 U-185	15.1-186.8	9 / 110	(8)	0.01-11.3
	SFCDR-5	24.2-271 (89.2)	7.00	0.80 U-420	13.9-187.3	9 / 128	(7)	0.01-27.5
South Fork Tributaries								
Grouse Gulch	SF-223	27.0-48.0 (37.5)	7.82	6.40-9.23	15.2-28.8	0 / 2	(0)	0.32-0.42
Moon Creek	MC-262	26.0-60.0 (34.4)	1.50	0.23-6.00	14.5-36.9	0 / 33	(0)	0.01-0.14
Milo Creek	SF-183	71.7[d]	507	380-533	44.9[h]	4 / 4	(100)	8.47-11.9
Portal Creek	SF-104	71.7[d]	22.0	4.00-25.9	44.9[h]	0 / 3	(0)	0.09-0.58
Deadwood Gulch	SF-100-103	71.7[d]	11.9	1.50 U-191	44.9[h]	2 / 17	(12)	0.03-4.26
Government Gulch	SF-110	71.7[d]	4.80	1.50 U-21.0	44.9[h]	0 / 4	(0)	0.03-0.47
Canyon Creek	CC-1	2.00-56.0 (13.5)	1.50	0.12-3.00	13.9-34.2	0 / 43[i]	(0)	0.01-0.22
	CC-2	5.00-90.0 (32.9)	15.1	1.50 U-578	13.9-57.6	125 / 370	(34)	0.08-28.9
Gorge Gulch	CC-392	17.3[e]	4.00	3.00 U-11.7	13.9[h]	0 / 3	(0)	0.22-0.84
Ninemile Creek	NM-1	5.49-139 (61.1)	0.60	0.10 U-3.95	13.9-92.4	0 / 13	(0)	0.01-0.09
	NM-2	4.36-96.0 (35.8)	44.0	0.20 U-378	13.9-61.8	169 / 263	(64)	0.01-17.5
Pine Creek	PC-1	5.43-25.0 (9.86)	0.10	0.10 U-0.50 U	13.9	0 / 7	(0)	0.01-0.04
	PC-2	8.00-48.0 (20.9)	0.95	0.61-30.9	13.9-28.8	1 / 7	(14)	0.04-2.23
	PC-3	3.0-76.0 (14.1)	1.50	0.20-20.0	13.9-47.8	1 / 63	(2)	0.01-1.44

Table 4-9 (cont.)
Acute Criteria for Lead — Summary of Exceedences

Stream or Water Body	Reach[a]	Measured Hardness (mg/L $CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Measured Concentration (µg/L) Range	ALC Values[b] (µg/L) Range	No. Exceed	No. Used	(%)	Measured Concentration/ ALC[c] Range
Pine Creek Tributaries									
Highland Creek	PC-307	23.8-52.2[f] (38.7)	1.50	1.2-4.00	13.9-31.6	0	31	(0)	0.05-0.19
Denver Creek	PC-308	25.9-72.0[g] (44.3)	5.00	1.50 U-14.4	14.4-45.1	0	29	(0)	0.06-0.45
Nabob Creek	PC-310, 326	24.6-233 (173)	16.2	5.70-16.3	13.9-160	0	3	(0)	0.10-0.41
Coeur d'Alene River	CDR-1	11.9-160 (42.7)	5.00	1.00-24.0	13.9-107	1	38	(3)	0.02-1.73
	CDR-2	9.00-137 (46.0)	24.0	1.60-770	13.9-90.8	56	104	(54)	0.09-27.8
	CDR-3	12.7-49.8 (28.3)	7.35	1.00-100	13.9-30.0	1	12	(8)	0.03-7.20
Coeur d'Alene Lake	CDAL	7-76.0 (22.1)	5.00	0.02-12.0	13.9-47.8	0	101	(0)	0.001-0.86

a. See Table 4-4 for reach definitions.
b. For values below the detection limit, the detection limit was used to calculate the median.
c. Values below 1 indicate the ALC was not exceeded; values greater than 1 indicate the magnitude of exceedence. If the measured concentration was below detection, the detection limit was divided by the ALC value.
d. Used average hardness for SF 270 in South Fork (n = 15).
e. Used one hardness measurement (17.3) for other two samples with no measured hardness.
f. Used average of existing hardness values (18/34 samples) for samples with no measured hardness.
g. Used average of existing hardness values (16/30 samples) for samples with no measured hardness.
h. Criterion value using noted hardness.
i. Extremely high undetected values not used in calculations.

U = below detection.

Table 4-10
Acute Criteria for Zinc — Summary of Exceedences

Stream or Water Body	Reach[a]	Measured Hardness ($mg/L\ CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Measured Concentration (µg/L) Range	ALC Values[b] (µg/L) Range	No. Exceed / No. Used	(%)	Measured Concentration/ ALC[c] Range
South Fork	SFCDR-1	10.3-40.0 (24.6)	11.0	5.00 U-59.3	36.2-53.9	2 / 25	(8.00)	0.09-1.20
	SFCDR-2	14.8-96.0 (41.0)	108	1.50 U-339	36.2-113	89 / 123	(72)	0.03-5.97
	SFCDR-3	22.1-146 (52.5)	1030	269-2840	36.2-161	267 / 267	(100)	4.44-32.0
	SFCDR-4	27.0-270 (102)	2050	40.0-19000	38.6-272	109 / 110	(99)	0.28-146
	SFCDR-5	24.2-271 (89.2)	1920	3.00 U-23000	36.2-272	127 / 129	(99)	0.01-187
South Fork Tributaries								
Grouse Gulch	SF-223	27.0-48.0 (37.5)	1370	1340-1400	38.7-63.0	2 / 2	(100)	21.3-36.2
Moon Creek	MC-262	26.0-60.0 (34.4)	121	74.0-318	37.4-76.0	18 / 18	(100)	1.33-6.97
Milo Creek	SF-183	71.7[d]	2460	1560-7880	88.4[h]	4 / 4	(100)	17.7-89.1
Portal Creek	SF-104	71.7[d]	440	129-1300	88.4[h]	3 / 3	(100)	1.46-14.7
Deadwood Gulch	SF-100-103	71.7[d]	3980	322-10000	88.4[h]	12 / 12	(100)	3.64-113
Government Gulch	SF-110	71.7[d]	6130	1400-10500	88.4[h]	4 / 4	(100)	15.8-119
Canyon Creek	CC-1	2.00-56.0 (13.5)	16.0	0.30-42.0	36.2-71.7	2 / 45	(44)	0.01-1.16
	CC-2	5.00-90.0 (32.9)	787	29.3-9463	36.2-107	370 / 373	(99)	0.81-199
Gorge Gulch	CC-392	17.3[e]	54.0	12.0 U-172	36.2	2 / 3	(67)	0.33-4.75
Ninemile Creek	NM-1	5.49-139 (61.1)	14.0	4.70-77.0	36.2-155	0 / 12	(0)	0.03-0.86
	NM-2	4.36-96.0 (35.8)	3540	10.0 U-12400	36.2-113	260 / 262	(99)	0.28-246
Pine Creek	PC-1	5.43-25.0 (9.86)	4.70	1.90 U-10.0 U	36.2	0 / 7	(0)	0.05-0.28
	PC-2	8.00-48.0 (20.9)	484	107-3920	36.2-62.9	8 / 8	(100)	2.96-108
	PC-3	3.0-76.0 (14.1)	99.0	20.0 U-402	36.2-92.9	57 / 60	(95)	0.55-11.1

Table 4-10 (cont.)
Acute Criteria for Zinc — Summary of Exceedences

Stream or Water Body	Reach[a]	Measured Hardness ($mg/L\ CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Measured Concentration (µg/L) Range	ALC Values[b] (µg/L) Range	No. Exceed / No. Used	(%)	Measured Concentration/ ALC[c] Range
Pine Creek Tributaries								
Highland Creek	PC-307	23.8-52.2[f] (38.7)	949	577-1370	36.2-67.6	34 / 34	(100)	11.1-23.8
Denver Creek	PC-308	25.9-72.0[g] (44.3)	4150	2850-7410	37.3-88.7	30 / 30	(100)	47.9-125
Nabob Creek	PC-310, 326	24.6-233 (173)	3420	728-3430	36.2-240	3 / 3	(100)	14.3-20.1
Coeur d'Alene River	CDR-1	11.9-160 (42.7)	468	20.0-3300	36.2-175	37 / 38	(97)	0.55-55.1
	CDR-2	9.00-137 (46.0)	1600	69.0-13200	36.2-153	109 / 109	(100)	1.91-164
	CDR-3	12.7-49.8 (28.3)	346	122-1820	36.2-64.9	12 / 12	(100)	3.37-44.1
Coeur d'Alene Lake	CDAL	7-76.0 (22.1)	100	2.17-190	36.2-92.9	121 / 128	(95)	0.06-4.14

a. See Table 4-4 for reach definitions.
b. For values below the detection limit, the detection limit was used to calculate the median.
c. Values below 1 indicate the ALC was not exceeded; values greater than 1 indicate the magnitude of exceedence. If the measured concentration was below detection, the detection limit was divided by the ALC value.
d. Used average hardness for SF 270 in South Fork (n = 15).
e. Used one hardness measurement (17.3) for other two samples with no measured hardness.
f. Used average of existing hardness values (18/34 samples) for samples with no measured hardness.
g. Used average of existing hardness values (16/30 samples) for samples with no measured hardness.
h. Criterion value using noted hardness.

U = below detection.

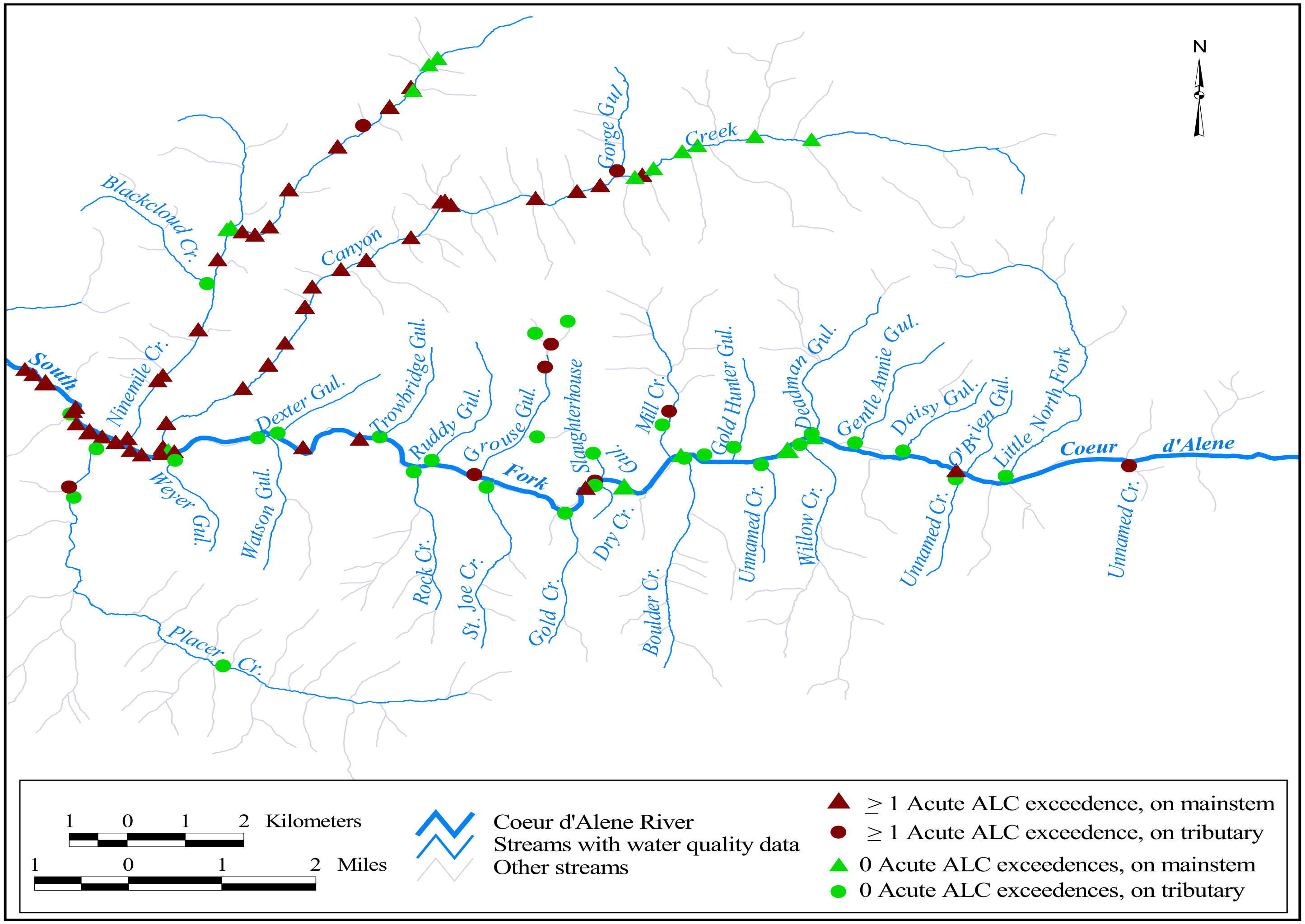


Figure 4-6a. Locations of one or more acute ALC exceedence from 1991 to 1998, South Fork Coeur d'Alene River basin, eastern section. Triangles designate samples collected from mainstem South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek sites. Circles designate samples collected from tributaries to each of those mainstems.

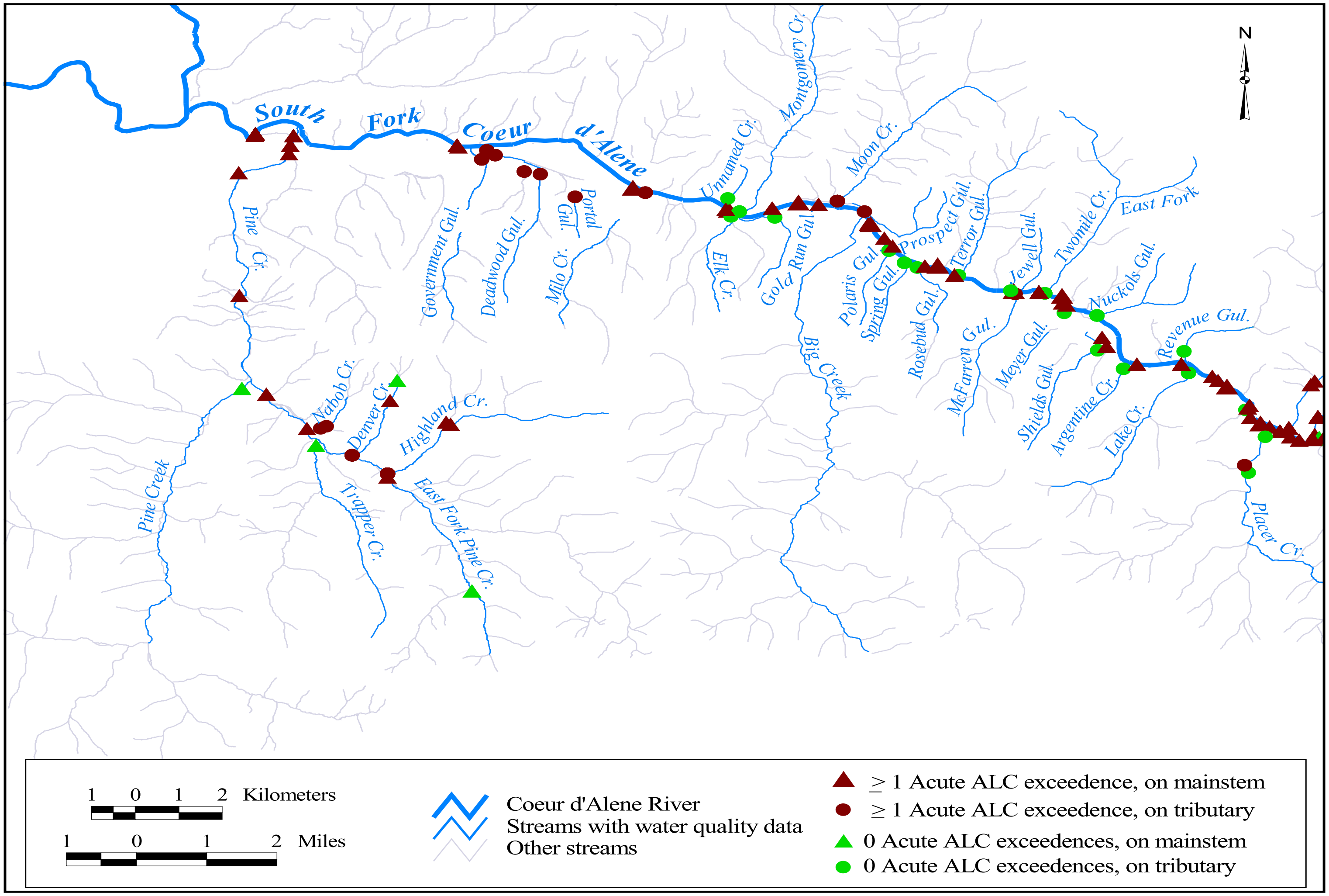


Figure 4-6b. Locations of one or more acute ALC exceedence from 1991 to 1998, South Fork Coeur d'Alene River basin, western section. Triangles designate samples collected from mainstem South Fork Coeur d'Alene River and Pine Creek sites. Circles designate samples collected from tributaries to each of those mainstems.

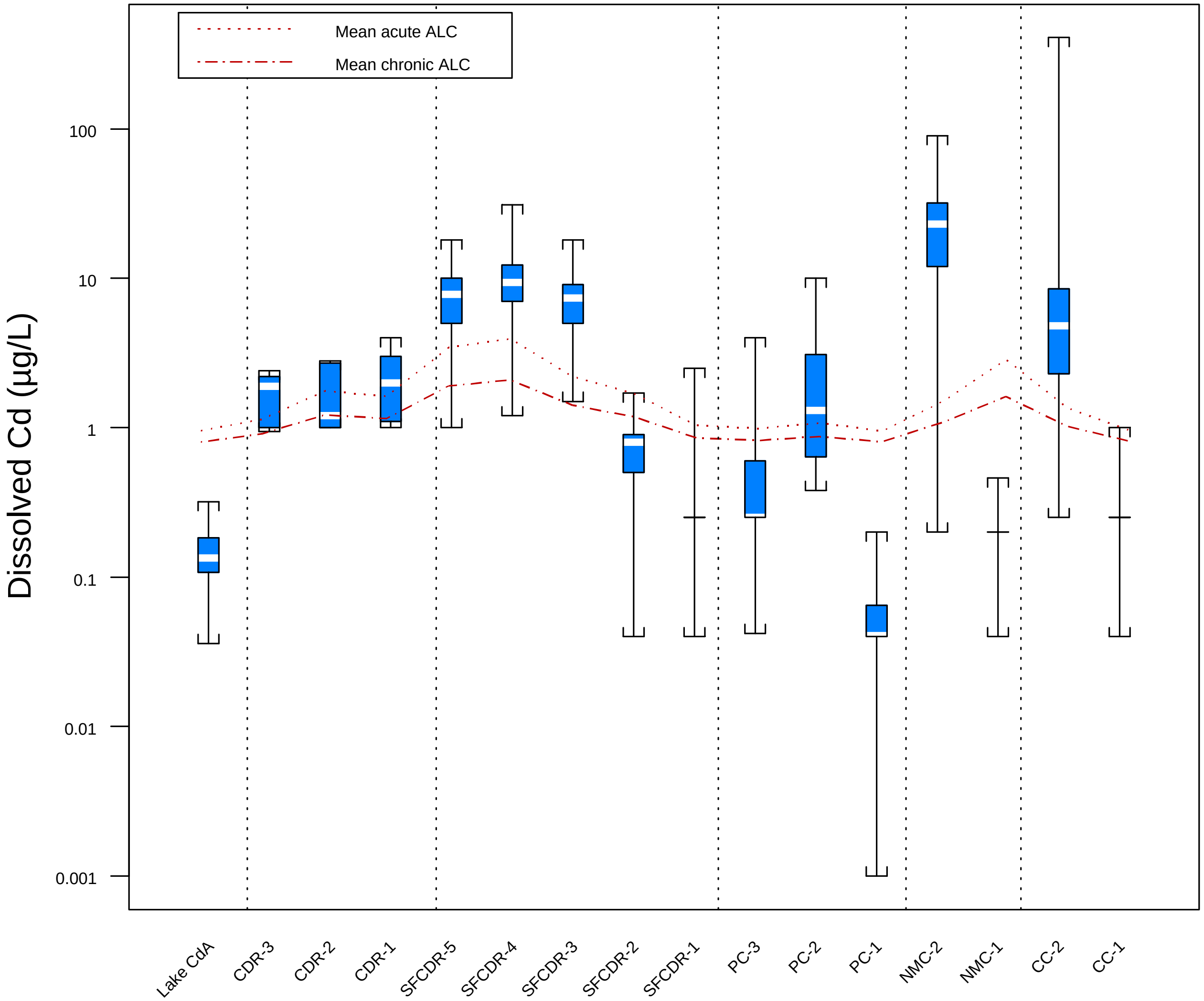


Figure 4-7a. Distribution of cadmium concentrations measured between 1991 and 1999 in reaches of the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, Pine Creek, the mainstem Coeur d'Alene River, and Coeur d'Alene Lake. Box plots show the median (white line in box), interquartile range (box ends), and data range (box whiskers). Dotted and dashed lines are the mean acute and chronic ALC in each reach.

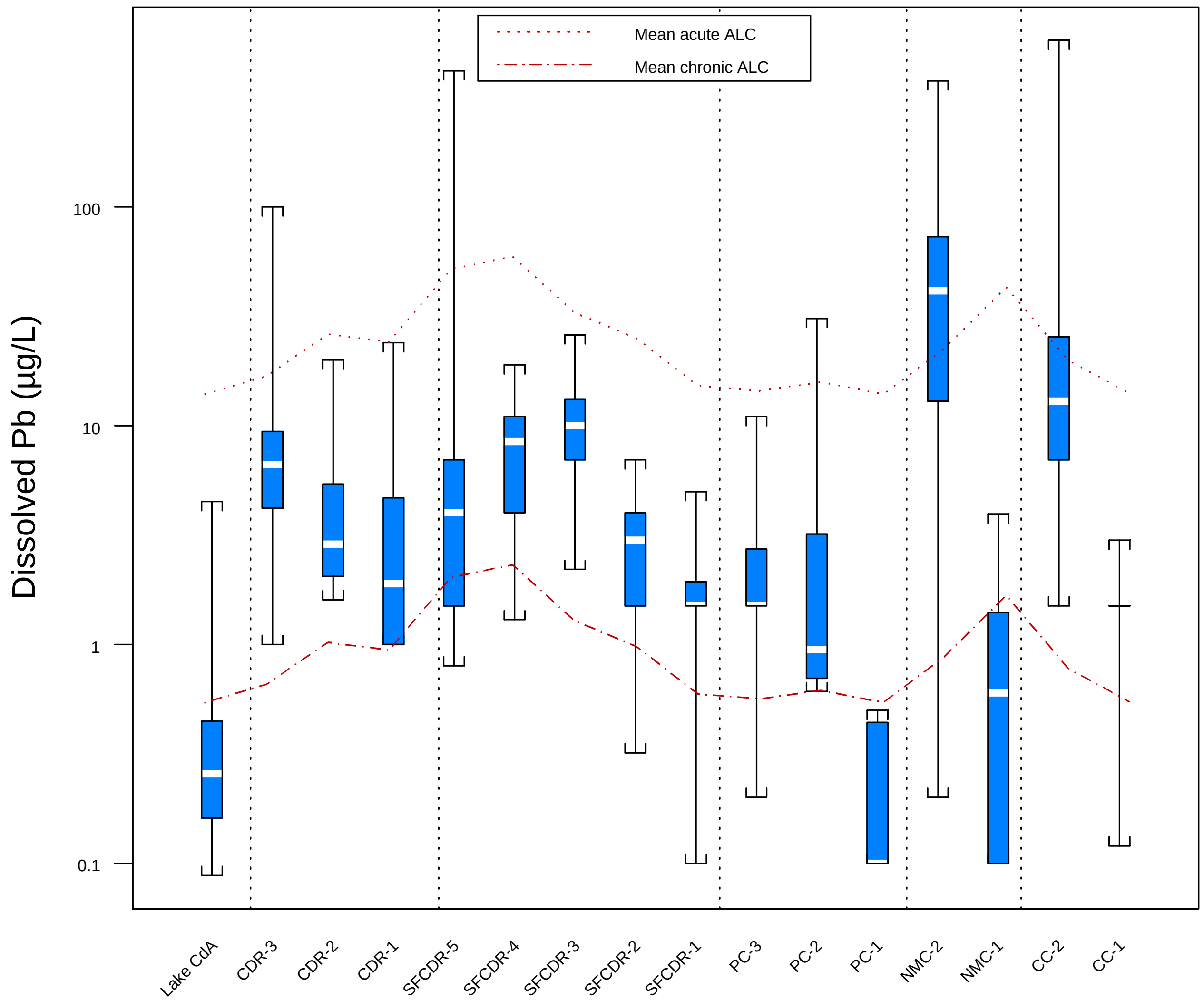


Figure 4-7b. Distribution of lead concentrations measured between 1991 and 1999 in reaches of the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, Pine Creek, the mainstem Coeur d'Alene River, and Coeur d'Alene Lake. Box plots show the median (white line in box), interquartile range (box ends), and data range (box whiskers). Dotted and dashed lines are the mean acute and chronic ALC in each reach.

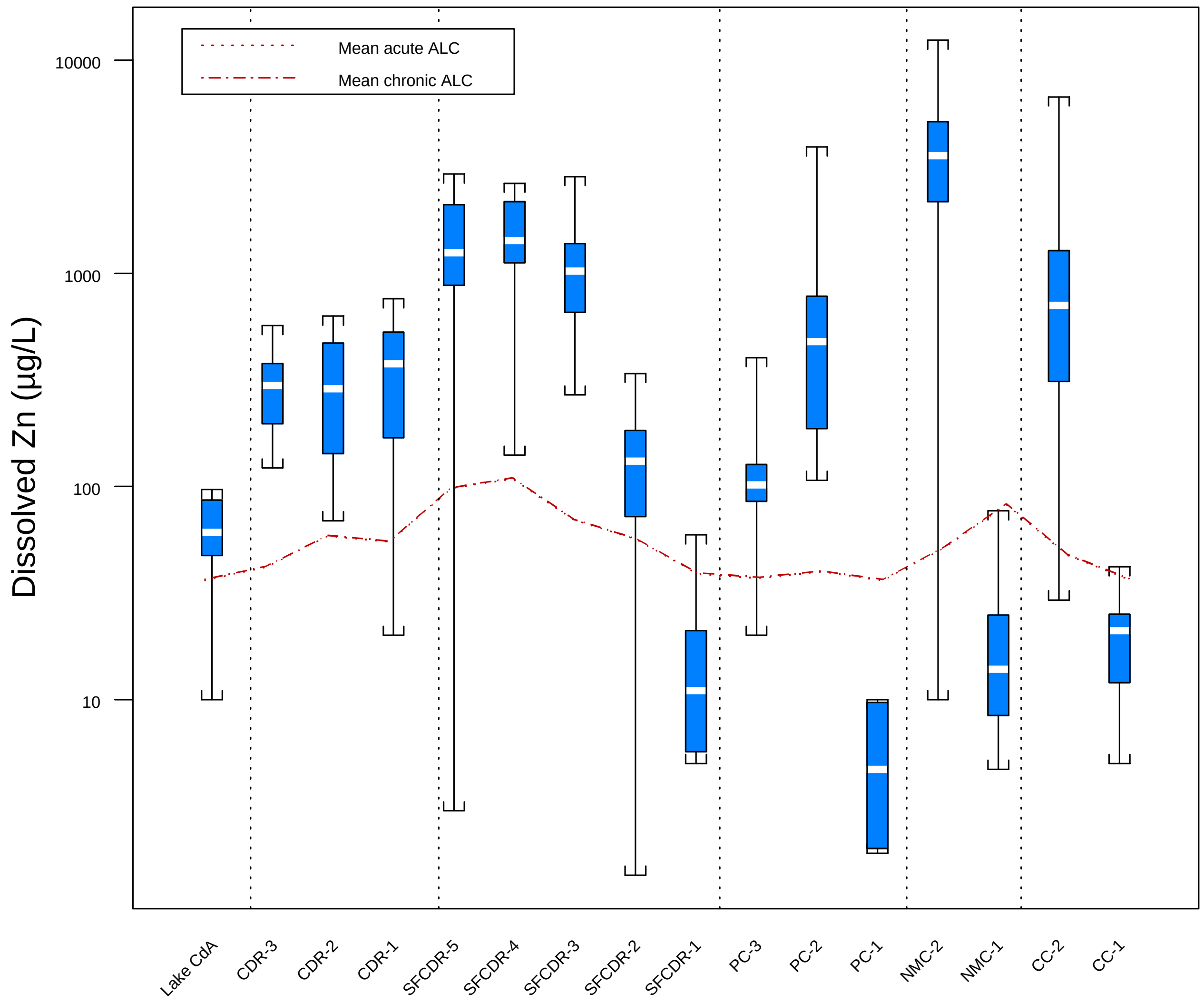


Figure 4-7c. Distribution of zinc concentrations measured between 1991 and 1999 in reaches of the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, Pine Creek, the mainstem Coeur d'Alene River, and Coeur d'Alene Lake. Box plots show the median (white line in box), interquartile range (box ends), and data range (box whiskers). Dashed line is the mean chronic; dotted line (mean acute ALC) overlays it.

Acute ALC have been exceeded repeatedly in the South Fork Coeur d'Alene River downstream of Larson and Daisy Gulch (Reach SFCDR-2), in Canyon Creek downstream of O'Neill Gulch, in Ninemile Creek downstream of the Interstate Callahan Mine, in Pine Creek downstream of the Constitution Mine, in the mainstem Coeur d'Alene River, and in Coeur d'Alene Lake. Exceedences of acute cadmium and zinc criteria have also occurred in the South Fork Coeur d'Alene River upstream of Daisy Gulch (Reach SFCDR-1) and in Canyon Creek upstream of O'Neill Gulch (Reach CC-1), but such exceedences are infrequent relative to the downstream reaches, and the magnitude of the exceedences in these reaches is much lower than in downstream reaches. These upstream reaches and the upper reaches of Ninemile Creek (Reach NM-1) and Pine Creek (Reach PC-1) are upstream of major mining and mineral processing activity.

In addition to acute ALC exceedences in the reaches identified above, acute ALC have been exceeded repeatedly in smaller tributaries in the South Fork basin, including Grouse Gulch, Gorge Gulch, Moon Creek, Milo Creek, Portal Creek, Deadwood Gulch/Bunker Creek, Government Gulch, Highland Creek, Denver Creek, and Nabob Creek (Tables 4-8 through 4-10 and Figures 4-6a and b). Acute ALC values were exceeded in these tributaries during both low flow and high flow conditions. Acute lead and zinc ALC exceedences have also been documented in the lateral lakes, including Killarney Lake, Killarney wetland, and Thompson Lake.

Chronic ALC. Chronic ALC are four-day average concentrations that are not to be exceeded more than once in a 3-year period (U.S. EPA, 1987). Chronic ALC were developed to protect aquatic life from long-term exposures to contaminants and are lower concentrations than acute ALC. Chronic ALC exceedences were evaluated using measured concentrations of dissolved metals in grab samples collected over an approximately 30-year period. For zinc, chronic and acute ALC values are very similar. Therefore, most waters that exceed chronic ALC values for zinc also exceed acute ALC zinc values.

Tables 4-11 through 4-13 summarize chronic ALC exceedences for all data compiled for the assessed reaches. Chronic ALC were exceeded repeatedly in the South Fork Coeur d'Alene River downstream of Larson and Daisy Gulch, in Canyon Creek downstream of O'Neill Gulch, in Ninemile Creek downstream of the Interstate Callahan Mine, and in Pine Creek downstream of the Constitution Mine. Chronic criteria have also been exceeded repeatedly in the mainstem Coeur d'Alene River and in Coeur d'Alene Lake. Exceedences of chronic cadmium, zinc, and particularly lead criteria have also occurred in the South Fork Coeur d'Alene River upstream of Daisy Gulch, in Canyon Creek upstream of O'Neill Gulch, in Ninemile Creek upstream of the Interstate Callahan Mine (lead only), and in East Fork Pine Creek upstream of Constitution Mine (lead only), but exceedences in these upstream reaches are infrequent relative to the downstream reaches, and the magnitude of the exceedences in the upstream reaches is much lower than that in downstream reaches.

Table 4-11
Chronic Criteria for Cadmium — Summary of Exceedences

Stream or Water Body	Reach[a]	Measured Hardness (mg/L $CaCO_3$) Range (mean)	Measured Concentration (µg/L)		ALC Values[b] (µg/L) Range	No. Exceed	No. Used	(%)	Measured Concentration/ ALC[c] Range
			Median[b]	Range					
South Fork	SFCDR-1	10.3-40.0 (24.6)	0.25	0.01 U-2.50	0.80-1.14	2	38	(5)	0.01-2.87
	SFCDR-2	14.8-96.0 (41.0)	0.80	0.04 U-6.00	0.80-2.17	18	117	(15)	0.04-5.05
	SFCDR-3	22.1-146 (52.5)	7.40	0.20-18.00	0.80-2.96	251	253	(99)	0.12-12.5
	SFCDR-4	27.0-270 (102)	10.2	1.20-220.00	0.85-4.66	92	97	(95)	0.51-93.8
	SFCDR-5	24.2-271 (89.2)	9.00	1.00 U-390	0.80-4.67	109	111	(98)	0.28-189
South Fork Tributaries									
Grouse Gulch	SF-223	27.0-48.0 (37.5)	8.29	8.20-8.37	0.85-1.30	2	2	(100)	6.44-9.65
Moon Creek	MC-262	26.0-60.0 (34.4)	0.70	0.40-1.80	0.83-1.53	4	49	(8)	0.44-1.83
Milo Creek	SF-183	71.7[d]	11.4	10.0-24.1	1.75[h]	3	3	(100)	5.71-13.8
Portal Creek	SF-104	71.7[d]	3.00	3.00 U	1.75[h]	0	1	(0)	1.71
Deadwood Gulch	SF-100-103	71.7[d]	83.9	3.00 U-736	1.75[h]	9	12	(75)	1.71-421
Government Gulch	SF-110	71.7[d]	184	40.8-306	1.75[h]	4	4	(100)	23.3-175
Canyon Creek	CC-1	2.00-56.0 (13.5)	0.25U	0.04 U-1.00	0.80-1.46	1	42[i]	(2)	0.05-1.25
	CC-2	5.00-90.0 (32.9)	5.00	0.25-408	0.80-2.07	299	357	(84)	0.25-400
Gorge Gulch	CC-392	17.3[e]	1.30	0.30-1.90	0.80	2	3	(67)	0.37-2.37
Ninemile Creek	NM-1	5.49-139 (61.1)	0.20	0.04 U-0.46	0.80-2.86	0	13	(0)	0.01-0.25
	NM-2	4.36-96.0 (35.8)	23.0	0.20 U-90.00	0.80-2.17	250	261	(96)	0.25-83.9
Pine Creek	PC-1	5.43-25.0 (9.86)	0.04	0.01 U-0.20 U	0.80	0	8	(0)	0.01-0.25
	PC-2	8.00-48.0 (20.9)	1.30	0.38-10.0	0.80-1.30	4	7	(57)	0.47-12.5
	PC-3	3.0-76.0 (14.1)	0.27	0.04-4.00	0.80-1.83	5	58	(9)	0.05-4.99

Table 4-11 (cont.)
Chronic Criteria for Cadmium — Summary of Exceedences

Stream or Water Body	Reach[a]	Measured Hardness (mg/L $CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Range	ALC Values[b] (µg/L) Range	No. Exceed / No. Used	(%)	Measured Concentration/ ALC[c] Range
Pine Creek Tributaries								
Highland Creek	PC-307	23.8-52.2[f] (38.7)	2.50	1.60-3.50	0.80-1.38	34 / 34	(100)	1.44-3.32
Denver Creek	PC-308	25.9-72.0[g] (44.3)	11.00	7.30-18.30	0.82-1.76	34 / 34	(100)	5.90-14.6
Nabob Creek	PC-310, 326	24.6-233 (173)	4.59	3.00-4.78	0.80-4.17	3 / 3	(100)	1.10-3.74
Coeur d'Alene River	CDR-1	11.9-160 (42.7)	2.80	1.00-120	0.80-3.17	33 / 37	(89)	0.68-96.4
	CDR-2	9.00-137 (46.0)	18.0	1.00-122	0.80-2.82	42 / 45	(93)	1.25-96.4
	CDR-3	12.7-49.8 (28.3)	2.00	0.94-19.0	0.80-1.34	9 / 11	(82)	1.17-21.1
Coeur d'Alene Lake	CDAL	7-76.0 (22.1)	1.00	0.07-2.00	0.80-1.83	21 / 100[i]	(21)	0.09-2.49

a. See Table 4-4 for reach definitions.
b. For values below the detection limit, the detection limit was used to calculate the median.
c. Values below 1 indicate the ALC was not exceeded; values greater than 1 indicate the magnitude of exceedence. If the measured concentration was below detection, the detection limit was divided by the ALC value.
d. Used average hardness for SF 270 in South Fork (n = 15).
e. Used one hardness measurement (17.3) for other two samples with no measured hardness.
f. Used average of existing hardness values (18/34 samples) for samples with no measured hardness.
g. Used average of existing hardness values (16/30 samples) for samples with no measured hardness.
h. Criterion value using noted hardness.
i. Extremely high undetected values not used in calculations.

U = below detection.

Table 4-12
Chronic Criteria for Lead — Summary of Exceedences

Stream or Water Body	Reach[a]	Measured Hardness ($mg/L\ CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Measured Concentration (µg/L) Range	ALC Values[b] (µg/L) Range	No. Exceed / No. Used	(%)	Measured Concentration/ ALC[c] Range
South Fork	SFCDR-1	10.3-40.0 (24.6)	1.50	0.10 U-5.00	0.54-0.92	8 / 37	(22)	0.15-9.24
	SFCDR-2	14.8-96.0 (41.0)	3.00	0.32-45.0	0.54-2.41	71 / 127	(56)	0.59-76.3
	SFCDR-3	22.1-146 (52.5)	10.0	2.00-45.0	0.54-3.79	255 / 267	(96)	0.53-34.6
	SFCDR-4	27.0-270 (102)	10.0	1.00 U-185	0.59-7.28	83 / 110	(76)	0.18-289
	SFCDR-5	24.2-271 (89.2)	7.00	0.80 U-420	0.54-7.30	89 / 128	(70)	0.20-706
South Fork Tributaries								
Grouse Gulch	SF-223	27.0-48.0 (37.5)	7.82	6.40-9.23	0.59-1.12	2 / 2	(100)	8.22-10.8
Moon Creek	MC-262	26.0-60.0 (34.4)	1.50	0.23-6.00	0.57-1.44	2 / 33	(6)	0.29-3.50
Milo Creek	SF-183	71.7[d]	507	380-533	1.75[h]	4 / 4	(100)	217-305
Portal Creek	SF-104	71.7[d]	22.0	4.00-25.9	1.75[h]	3 / 3	(100)	2.29-14.8
Deadwood Gulch	SF-100-103	71.7[d]	11.9	1.50 U-191	1.75[h]	10 / 17	(59)	0.86-109
Government Gulch	SF-110	71.7[d]	4.80	1.50 U-21.0	1.75[h]	2 / 4	(50)	0.86-12.0
Canyon Creek	CC-1	2.00-56.0 (13.5)	1.50	0.12-3.0	0.54-1.33	7 / 43[i]	(16)	0.22-5.55
	CC-2	5.00-90.0 (32.9)	15.1	1.50 U-578	0.54-2.24	328 / 370	(89)	1.93-742
Gorge Gulch	CC-392	17.3[e]	4.00	3.00 U-11.7	0.54	2 / 3	(67)	5.55-21.6
Ninemile Creek	NM-1	5.49-139 (61.1)	0.60	0.10 U-3.95	0.54-3.60	4 / 13	(31)	0.03-2.40
	NM-2	4.36-96.0 (35.8)	44.0	0.20 U-378	0.54-2.41	245 / 263	(93)	0.37-450
Pine Creek	PC-1	5.43-25.0 (9.86)	0.10	0.10 U-0.50 U	0.54	0 / 7	(0)	0.18-0.92
	PC-2	8.00-48.0 (20.9)	0.95	0.61-30.9	0.54-1.12	7 / 7	(100)	1.13-57.1
	PC-3	3.0-76.0 (14.1)	1.50	0.20-20.0	0.54-1.86	15 / 63	(24)	0.37-37.0

Table 4-12 (cont.)
Chronic Criteria for Lead — Summary of Exceedences

Stream or Water Body	Reach	Measured Hardness (mg/L $CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[a]	Measured Concentration (µg/L) Range	ALC Values[a] (µg/L) Range	No. Exceed / No. Used	(%)	Measured Concentration/ ALC[b] Range
Pine Creek Tributaries								
Highland Creek	PC-307	23.8-52.2[f] (38.7)	1.50	1.2-4.00	0.54-1.23	15 / 31	(48)	1.34-4.88
Denver Creek	PC-308	25.9-72.0[g] (44.3)	5.00	1.50 U-14.4	0.56-1.76	28 / 29	(97)	1.44-11.5
Nabob Creek	PC-310, 326	24.6-233 (173)	16.2	5.70-16.3	0.54-6.22	3 / 3	(100)	2.60-10.5
Coeur d'Alene River	CDR-1	11.9-160 (42.7)	5.00	1.00-24.0	0.54-4.18	25 / 38	(66)	0.64-44.4
	CDR-2	9.00-137 (46.0)	24.0	1.60-770	0.54-3.54	98 / 104	(94)	2.20-714
	CDR-3	12.7-49.8 (28.3)	7.35	1.00-100	0.54-1.17	10 / 12	(83)	0.86-185
Coeur d'Alene Lake	CDAL	7-76.0 (22.6)	5.00	0.02-12.0	0.54-1.86	16 / 101	(16)	0.04-22.2

a. See Table 4-4 for reach definitions.
b. For values below the detection limit, the detection limit was used to calculate the median.
c. Values below 1 indicate the ALC was not exceeded; values greater than 1 indicate the magnitude of exceedence. If the measured concentration was below detection, the detection limit was divided by the ALC value.
d. Used average hardness for SF 270 in South Fork (n = 15).
e. Used one hardness measurement (17.3) for other two samples with no measured hardness.
f. Used average of existing hardness values (18/34 samples) for samples with no measured hardness.
g. Used average of existing hardness values (16/30 samples) for samples with no measured hardness.
h. Criterion value using noted hardness.
i. Extremely high undetected values not used in calculations.

U = below detection.

Table 4-13
Chronic Criteria for Zinc — Summary of Exceedences

Stream or Water Body	Reach[a]	Measured Hardness ($mg/L\ CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Measured Concentration (µg/L) Range	ALC Values[b] (µg/L) Range	No. Exceed / No. Used	(%)	Measured Concentration/ ALC[c] Range
South Fork	SFCDR-1	10.3-40.0 (24.6)	11.0	5.00 U-59.3	36.5-54.4	2 / 25	(8)	0.09-1.19
	SFCDR-2	14.8-96.0 (41.0)	108	1.50 U-339	36.5-114	89 / 123	(72)	0.03-5.92
	SFCDR-3	22.1-146 (52.5)	1030	269-2840	36.5-163	267 / 267	(100)	4.41-31.8
	SFCDR-4	27.0-270 (102)	2050	40.0-19000	38.9-274	109 / 110	(99)	0.28-144
	SFCDR-5	24.2-271 (89.2)	1920	3.00 U-23000	36.5-275	127 / 129	(99)	0.01-185
South Fork Tributaries								
Grouse Gulch	SF-223	27.0-48.0 (37.5)	1370	1340-1400	39.0-63.5	2 / 2	(100)	21.1-35.9
Moon Creek	MC-262	26.0-60.0 (34.4)	121	74.0-318	37.7-76.6	18 / 18	(100)	1.32-6.92
Milo Creek	SF-183	71.7[d]	2460	1560-7880	89.1[h]	4 / 4	(100)	17.5-88.4
Portal Creek	SF-104	71.7[d]	440	129-1300	89.1[h]	3 / 3	(100)	1.45-14.6
Deadwood Gulch	SF-100-103	71.7[d]	3980	322-10000	89.1[h]	12 / 12	(100)	3.61-112
Government Gulch	SF-110	71.7[d]	6130	1400-10500	89.1[h]	4 / 4	(100)	15.7-118
Canyon Creek	CC-1	2.00-56.0 (13.5)	16.0	0.30-42.0	36.5-72.3	2 / 45	(4)	0.01-1.15
	CC-2	5.00-90.0 (32.9)	787	29.3-9463	36.5-108.1	370 / 373	(99)	0.80-197
Gorge Gulch	CC-392	17.3[e]	54.0	12.0 U-172	36.5	2 / 3	(67)	0.33-4.71
Ninemile Creek	NM-1	5.49-139 (61.1)	14.0	4.70-77.0	36.5-156	0 / 12	(0)	0.03-0.85
	NM-2	4.36-96.0 (35.8)	3540	10.0 U-12400	36.5-114	260 / 262	(99)	0.27-244
Pine Creek	PC-1	5.43-25.0 (9.86)	4.70	1.90 U-10.0 U	36.5	0 / 7	(0)	0.05-0.27
	PC-2	8.00-48.0 (20.9)	484	107-3920	36.5-63.4	8 / 8	(100)	2.93-107
	PC-3	3.0-76.0 (14.1)	99.0	20.0 U-402	36.5-93.6	57 / 60	(95)	0.55-11.0

Table 4-13 (cont.)
Chronic Criteria for Zinc — Summary of Exceedences

Stream or Water Body	Reach[a]	Measured Hardness (mg/L $CaCO_3$) Range (mean)	Measured Concentration (µg/L) Median[b]	Measured Concentration (µg/L) Range	ALC Values[b] (µg/L) Range	No. Exceed / No. Used	(%)	Measured Concentration/ ALC[c] Range
Pine Creek Tributaries								
Highland Creek	PC-307	23.8-52.2[f] (38.7)	949	577-1370	36.5-68.1	34 / 34	(100)	10.9-23.6
Denver Creek	PC-308	25.9-72.0[g] (44.3)	4150	2850-7410	37.6-89.4	30 / 30	(100)	47.5-124
Nabob Creek	PC-310, 326	24.6-233 (173)	3420	728-3430	36.5-242	2 / 3	(67)	14.2-20.0
Coeur d'Alene River	CDR-1	11.9-160 (42.7)	468	20.0-3300	36.5-176	37 / 38	(97)	0.55-54.7
	CDR-2	9.00-137 (46.0)	1600	69.0-13200	36.5-154	109 / 109	(100)	1.89-163
	CDR-3	12.7-49.8 (28.3)	346	122-1820	36.5-65.4	12 / 12	(100)	3.34-43.7
Coeur d'Alene Lake	CDAL	7-76.0 (22.8)	100	2.17-190	36.5-93.6	121 / 128	(95)	0.06-4.11

a. See Table 4-4 for reach definitions.
b. For values below the detection limit, the detection limit was used to calculate the median.
c. Values below 1 indicate the ALC was not exceeded; values greater than 1 indicate the magnitude of exceedence. If the measured concentration was below detection, the detection limit was divided by the ALC value.
d. Used average hardness for SF 270 in South Fork (n = 15).
e. Used one hardness measurement (17.3) for other two samples with no measured hardness.
f. Used average of existing hardness values (18/34 samples) for samples with no measured hardness.
g. Used average of existing hardness values (16/30 samples) for samples with no measured hardness.
h. Criterion value using noted hardness.
i. Extremely high undetected values not used in calculations.

U = below detection.

In addition to chronic ALC exceedences in the reaches identified above, chronic ALC have been exceeded in Grouse Gulch, Gorge Gulch, Milo Creek, Portal Creek, Deadwood Gulch/Bunker Creek, Government Gulch, Highland Creek, Denver Creek, and Nabob Creek (Tables 4-11 through 4-13). Chronic ALC values were exceeded in these tributaries during both high and low flow conditions. Chronic lead and zinc ALC exceedences have also been documented in Killarney Lake, Killarney Wetland, and Thompson Lake.

Exceedences of ALC at Specific Locations. In the foregoing evaluation, acute and chronic ALC were summarized by the reaches designated in Table 4-4, or by individual locations for the South Fork, Canyon Creek, Pine Creek tributaries. To assess the effect of combining the data in reaches (rather than examining individual sites), results for individual sampling points in the South Fork Coeur d'Alene River were plotted for both low and high flow periods (fall 1997 and spring 1998, respectively). Sampling during fall 1997 (November 4 through November 12) and spring 1998 (May 7 through May 16) was synoptic. Figures 4-8 through 4-10 show measured dissolved metals concentrations and chronic and acute criteria values during high flow and low flow for sampling sites in all five reaches of the South Fork Coeur d'Alene River.

As seen in Figures 4-7 through 4-9, concentrations of dissolved metals are much lower upstream of Canyon Creek than downstream of Canyon Creek. In reaches upstream of Canyon Creek (SFCDR-1 and 2), concentrations of dissolved cadmium, lead, and zinc are similar during high and low flow conditions. In reaches downstream of Canyon Creek (SFCDR-3, 4, and 5), low flow metal concentrations are much higher than high flow metal concentrations. Dissolved cadmium and zinc concentrations increase with distance downstream, while dissolved lead concentrations decrease with distance downstream of the Canyon Creek confluence. The point very close to the line between SFCDR-2 and 3 during high flow is SF-398, located just upstream of the Canyon Creek confluence. This location was not sampled during low flow in 1997. The point very close to the line between SFCDR-2 and 3 during low flow in 1997 is SF-232, located just downstream of the Canyon Creek confluence. As expected, concentrations from SF-398 and SF-232 are similar to concentrations measured at other upstream and downstream locations, respectively.

In the upper South Fork reaches, dissolved cadmium concentrations did not exceed chronic or acute ALC values for cadmium during low flow in 1997 or high flow in 1998 (Figure 4-8). All concentrations downstream of Canyon Creek exceeded both chronic and acute ALC values for cadmium during both low and high flow times (Figure 4-8).

Dissolved cadmium concentrations show a monotonic increase with distance downstream that is particularly apparent in the three downstream reaches. This pattern holds during both high and low flow synoptic sampling. Dissolved cadmium concentrations are approximately three to four times higher during low flow in 1997 than in high flow in 1998.

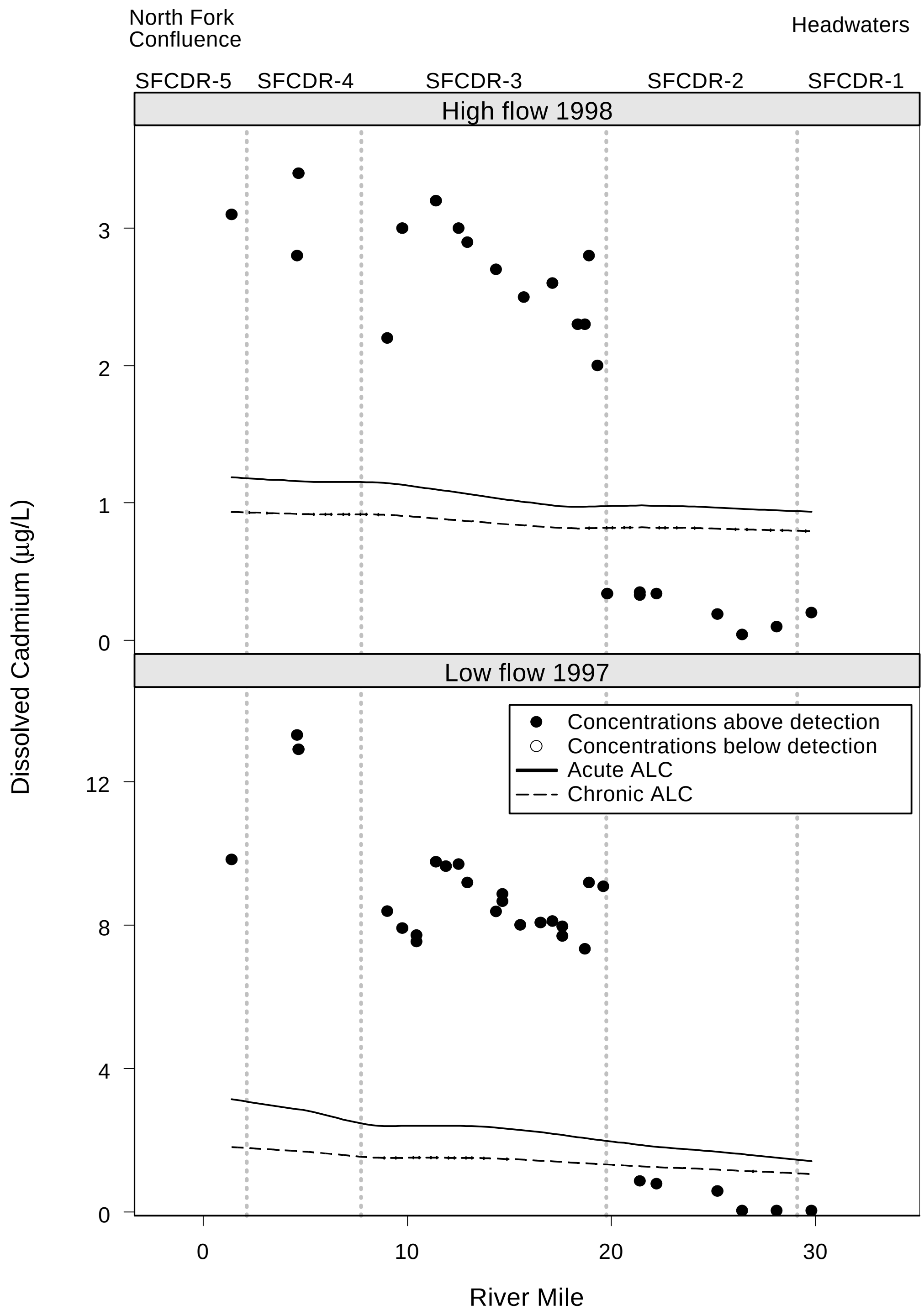


Figure 4-8. Dissolved cadmium concentrations and chronic and acute ALC values during low flow 1997 and high flow 1998 synoptic samplings.

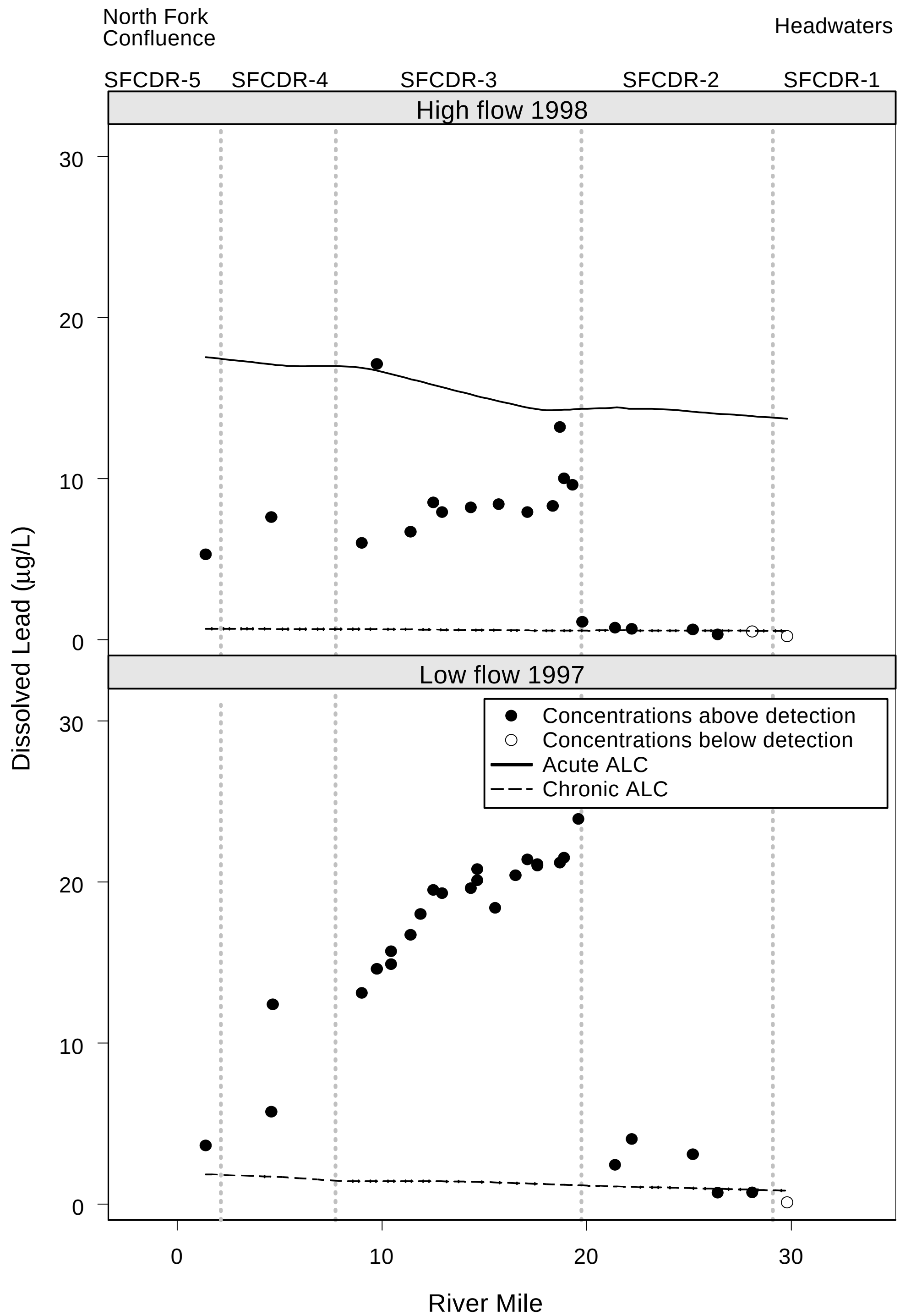


Figure 4-9. Dissolved lead concentrations and chronic and acute ALC values during low flow 1997 and high flow 1998 synoptic samplings.

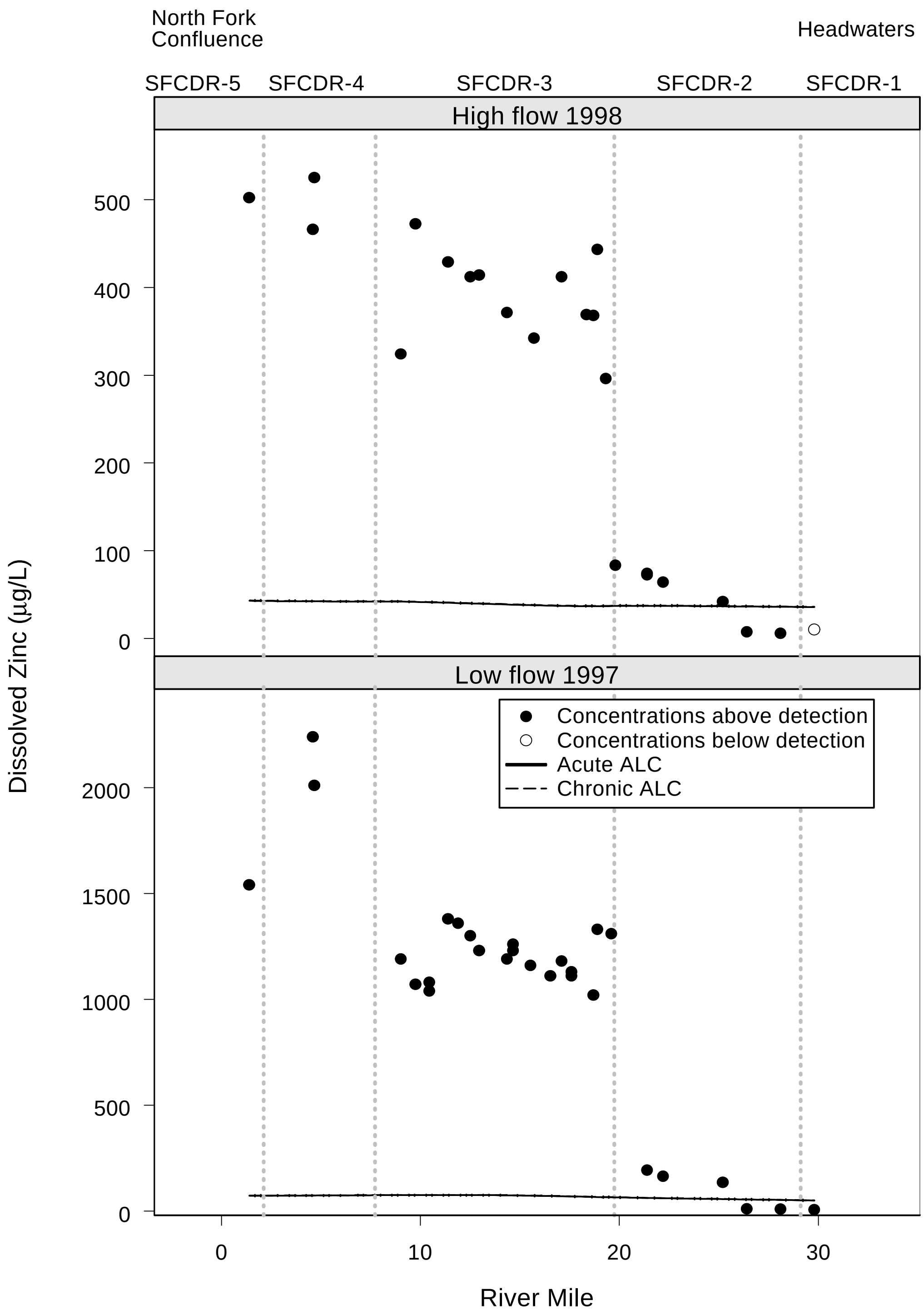


Figure 4-10. Dissolved zinc concentrations and chronic and acute ALC values during low flow 1997 and high flow 1998 synoptic samplings.

Acute ALC values for lead are much higher than chronic ALC values. Only two samples collected during high flow in 1998 exceeded the acute ALC lead value (Figure 4-9). No samples collected during low flow in 1997 exceeded the acute ALC lead value, and the acute ALC for lead is not shown in Figure 4-9. For high flow 1998 (Figure 4-9), only the three most upstream samples did not exceed the chronic ALC value for lead. All three samples are located upstream of Mullan, and two of these samples had concentrations below detection. During the low flow 1997 synoptic sampling, again, lead concentrations from the three most upstream sampling locations did not exceed the chronic ALC value for lead. For SFCDR-2, most of the concentrations exceeded chronic ALC values, but concentrations from the two most upstream sampling points did not.

Concentrations of dissolved lead increase dramatically downstream of the Canyon Creek confluence (upstream end of SFCDR-3). Unlike the profile of dissolved cadmium with distance in the South Fork Coeur d'Alene River, dissolved lead concentrations decrease monotonically with distance downstream of Canyon and Ninemile creek inputs. This pattern is apparent during both low flow 1997 and high flow 1998 synoptic samplings, with the exception of the two points in SFCDR-3 and 4 that exceed the acute ALC value for lead. This decrease with distance downstream is characteristic of a point source of contamination (in this case input from Canyon and Ninemile creeks).

Chronic and acute ALC values for zinc are nearly identical (Figure 4-10). All sampling points downstream of the Canyon Creek confluence exceeded both chronic and acute lead ALC values during both low flow in 1997 and high flow in 1998. Results for SFCDR-2 are similar to those for lead, in that the two most upstream points in the reach (upstream of Mullan) did not exceed ALC values, while all other points in the reach did. The one sampling point in SFCDR-1 did not exceed zinc ALC values during low flow or high flow.

Like dissolved cadmium concentrations, dissolved zinc concentrations show a monotonic increase with distance downstream, especially downstream of the Canyon and Ninemile creek confluences. Dissolved zinc concentrations in the South Fork Coeur d'Alene River downstream of Canyon Creek are higher than zinc ALC values by an order of magnitude or more during both high flow 1998 and low flow 1997. Concentrations in reaches SFCDR-3, 4, and 5 were approximately three to four times higher during low flow than high flow for the synoptic samplings in 1997 and 1998.

This additional analysis confirms that exceedences of acute and chronic cadmium, lead, and zinc criteria occur during both high flow and low flow conditions in all except the upper reaches of the South Fork Coeur d'Alene River, and that repeated exceedences occur at individual locations within the assessed reaches.

Both the acute and chronic ALC have been exceeded in reaches of streams in the South Fork Coeur d'Alene River basin, and at specific locations in the basin, repeatedly during the past 30 years. The duration of exposure is sufficient to trigger the ALC as well. Given the substantial magnitude of the exceedences, as well as the very high percentage of samples that exceed the ALC (Tables 4-8 through 4-13), the measured concentrations clearly meet both the 1-hour and 4-day average concentration standard. Moreover, exceedences are sufficiently frequent (approaching 100% of samples collected between 1967 and 1998) to indicate that the 3-year recovery period clearly is exceeded.

4.5.3 Surface Water as a Pathway of Injury to Other Resources

In addition to the injuries to surface water associated with exceedences of ALC, surface waters in the assessment area are injured because other natural resources have been injured as a result of exposure to contaminated surface water [43 CFR § 11.62 (b)(v)]. For example, as described in Chapter 7, fish are injured by exposure to contaminated surface waters. Chapter 8 demonstrates that benthic invertebrates also are injured as a result of exposure to contaminated surface waters (including suspended and bed sediments).

Studies conducted by the U.S. Geological Survey have also shown that zinc concentrations similar to those measured in Coeur d'Alene Lake cause toxicity (specifically, growth inhibition) in phytoplankton isolated from the lake (see Woods and Beckwith, 1997). In laboratory bioassays conducted in 1994, Kuwabara et al. (as cited in Woods and Beckwith, 1997) observed significant growth reductions in two species of Coeur d'Alene Lake phytoplankton, *Achnanthes minutissima* and *Cyclotella stelligera*, exposed to dissolved zinc concentrations of 19.6 and 39.2 µg/L.[1] Substantial growth reductions were observed even in the lower concentration (19.6 µg Zn/L); this concentrations is less than the median concentration of zinc measured in Coeur d'Alene Lake for the period 1993-1994, as reported by Woods and Beckwith (1997). These data demonstrate that exposure to zinc concentrations that commonly occur in Coeur d'Alene Lake injures phytoplankton, which form the basis of the aquatic food web. Coupled with data on toxicity to fish and invertebrates (Chapters 7 and 8), these studies confirm that surface waters are injured because concentrations of hazardous substances caused injuries to other natural resources.

1. The phytoplankton bioassays were conducted in the presence of EDTA (ethylenediaminetetraacetic acid), an artificial chelating agent designed to mimic the natural complexation of dissolved organic carbon (DOC) in Coeur d'Alene Lake water and hence simulate zinc bioavailability in the lake. However, as pointed out in the Expert Rebuttal Report of Dixon (1999), EDTA has a much higher affinity for zinc than naturally occurring DOC. As such, the bioassays would tend to underestimate the amount of bioavailable zinc in lake water thereby underestimating toxicity.

4.6 SUMMARY

The information presented in this chapter demonstrates the following:

- Sufficient concentrations of hazardous substances exist in pathway resources now, and have in the past, to expose surface water.

- Sufficient concentrations of hazardous substances exist in surface water resources now, and have in the past, to exceed federal, state, and tribal water quality criteria developed for protection of aquatic life. Therefore, surface water resources are injured.

- Methods and protocols for sampling and analysis of surface water varied over time and between agencies. The variability resulting from differences in methods may reduce overall data comparability. However, given the magnitude of ALC exceedences and the frequency of ALC exceedences over time in stream reaches downgradient of mining-related activity, it is unlikely that variability in the data set caused by differences in methods significantly affects the injury assessment results.

- Exceedences of federal water quality criteria, and therefore, surface water injuries, have been documented from the upper reaches of the South Fork Coeur d'Alene River (downstream of Daisy Gulch), through the mainstem Coeur d'Alene River and Coeur d'Alene Lake, to at least the USGS gauge station at Post Falls Dam on the Spokane River. Surface waters of the mainstem Coeur d'Alene River from the North Fork Coeur d'Alene River confluence to Coeur d'Alene Lake are injured, surface waters of the lateral lakes are injured, and surface waters of Coeur d'Alene Lake are injured.

- Exceedences of federal water quality criteria have also been documented in tributaries of the South Fork Coeur d'Alene River, including Canyon Creek from approximately Burke to the mouth and Gorge Gulch downstream of the Hercules No. 3 adit; the East Fork and mainstem Ninemile Creek from the Interstate-Callahan Mine to the mouth; Grouse Gulch from the Star Mine waste rock dumps to the mouth; Moon Creek from the Charles Dickens Mine/Mill to the mouth; Milo Creek from the Sullivan Adits to the mouth; Portal Gulch downstream of the North Bunker Hill West Mine; Deadwood Gulch/Bunker Creek downstream of the Ontario Mill; Government Gulch from the Senator Stewart Mine to the mouth; East Fork and mainstem Pine Creek from the Constitution Upper Mill to the mouth; Highland Creek from the Highland Surprise Mine/Mill and the Sidney (Red Cloud) Mine/Mill to the mouth; Denver Creek from the Denver Mine to the mouth; and Nabob Creek from the Nabob Mill to the mouth.

- Concentrations of hazardous substances in surface water resources of Coeur d'Alene Lake are sufficient to cause adverse effects to phytoplankton

- Concentrations of hazardous substances in surface water resources are sufficient to cause injury to aquatic biological resources (Chapter 7, Fish Resources), and to serve as a pathway of injury to wildlife (Chapter 6, Wildlife Resources) and to aquatic biological resources (Chapter 7, Fish Resources; and Chapter 8, Benthic Macroinvertebrates).

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Next

CHAPTER 5
SEDIMENT RESOURCES

5.1 INTRODUCTION

This chapter presents data on the sediment resources of the Coeur d'Alene River basin. Sediments are materials deposited by water and include suspended sediments in the water column, and bed, bank, and floodplain sediments. Sediment resources are defined by DOI NRDA regulations both as geologic resources [43 CFR §11.14 (s)] and as a component of surface water resources [43 CFR § 11.14 (pp)].[1] However, because sediments represent a distinct component of the ecosystem, data on sediments are discussed separately from surface water.

The information presented in this chapter supports the following conclusions:

- Metals in streambeds, banks, and floodplains are remobilized through natural hydrologic processes such as scouring, erosion, and resuspension during high water events.

- Sediments of the Coeur d'Alene River basin downstream of mining and mineral processing facilities contain substantially elevated concentrations of hazardous substances, including cadmium, lead, and zinc. Sediment contamination is pervasive in the beds, banks, and floodplains of the basin.

- Concentrations of hazardous substances in Coeur d'Alene River basin sediments exceed thresholds associated with adverse effects for benthic invertebrates. As concentrations of hazardous substances in these sediments increase, concentrations of hazardous substances in biofilm (attached algae, bacteria, and associated fine detrital material that adheres to substrates in surface waters and is a food source for higher trophic level consumers), benthic invertebrates, and fish in the basin increase. Sites with the highest concentrations of metals in water, sediment, biofilm, and benthic invertebrates were also the sites where fish populations were reduced, mortality was observed, and tissues contained elevated concentrations of metals.

- Coeur d'Alene River basin sediments containing elevated concentrations of lead and other hazardous substances are ingested by migratory waterfowl. Ingestion of contaminated sediments causes death, physiological malfunction, and physiological deformation of wildlife resources. Sufficient concentrations of hazardous substances are

1. "Surface water resources means the waters of the United States, including the sediments suspended in water or lying on the bank, bed, or shoreline . . ." [43 CFR § 11.14 (pp)].

present in sediments to cause injury to biological resources, and therefore sediments are injured [43 CFR §11.62 (b)(1)(v)].

5.2 SEDIMENT RESOURCES ASSESSED

5.2.1 Definition of Sediment Resources

Sediments are derived naturally from chemical and physical weathering of rock and from soil erosion. Mineral sediments range in size from colloidal clays to large boulders. Sediments also include organic material such as leaves and detritus from the riparian zone (known as allochthonous material) carried by surface water. Because organic matter is decomposed by aquatic organisms to smaller and smaller fractions, organic sediment spans a wide range of size classes also.

Sediments provide substrate for vegetative growth, mineral nutrients and organic material necessary for primary productivity and nutrient cycling, and physical habitat for aquatic and semi-aquatic biota, including cover, feeding, and nesting habitat. Mineral sediments are a source of essential elements for biota, and organic material in sediments provides the major energy source for benthic invertebrates, which are prey items of fish and other aquatic and terrestrial organisms. The periodic inundation of floodplains results in a significant input of nutrients in deposited sediments, which stimulates primary production in riparian and wetland communities.

5.2.2 Sediment Resources of the Coeur d'Alene River Basin

Sediment resources of the Coeur d'Alene River basin include suspended, bed, bank, and floodplain sediments of the South Fork Coeur d'Alene River and its tributaries, the mainstem Coeur d'Alene River and lateral lakes, and Coeur d'Alene Lake. The focus of this chapter is on the current condition of sediments of the lower basin, although the current condition of sediments in the lower basin has been substantially influenced by releases of hazardous substances in the upper basin (Chapter 2). Information on injuries to riparian soils/floodplain sediments in the upper basin is presented in Chapter 9, Riparian Resources.

In the lower basin, downstream of Enaville and the confluence of the South and North Fork Coeur d'Alene rivers, the mainstem Coeur d'Alene River is a meandering, low gradient, deep river. The valley opens into a broad alluvial basin, and the floodplain is wider than one mile in places. The river is bordered by lake, riparian and palustrine and lacustrine wetland habitat (Campbell et al., 1999; Figure 5-1). The lakes are connected hydraulically to the river by natural and artificial channels. The Coeur d'Alene River discharges to Coeur d'Alene Lake, which is a natural submerged riverbed lake (Horowitz et al., 1992). The level of the lake is now controlled by the Post Falls Dam, and water level varies between 2,122 and 2,128 ft.

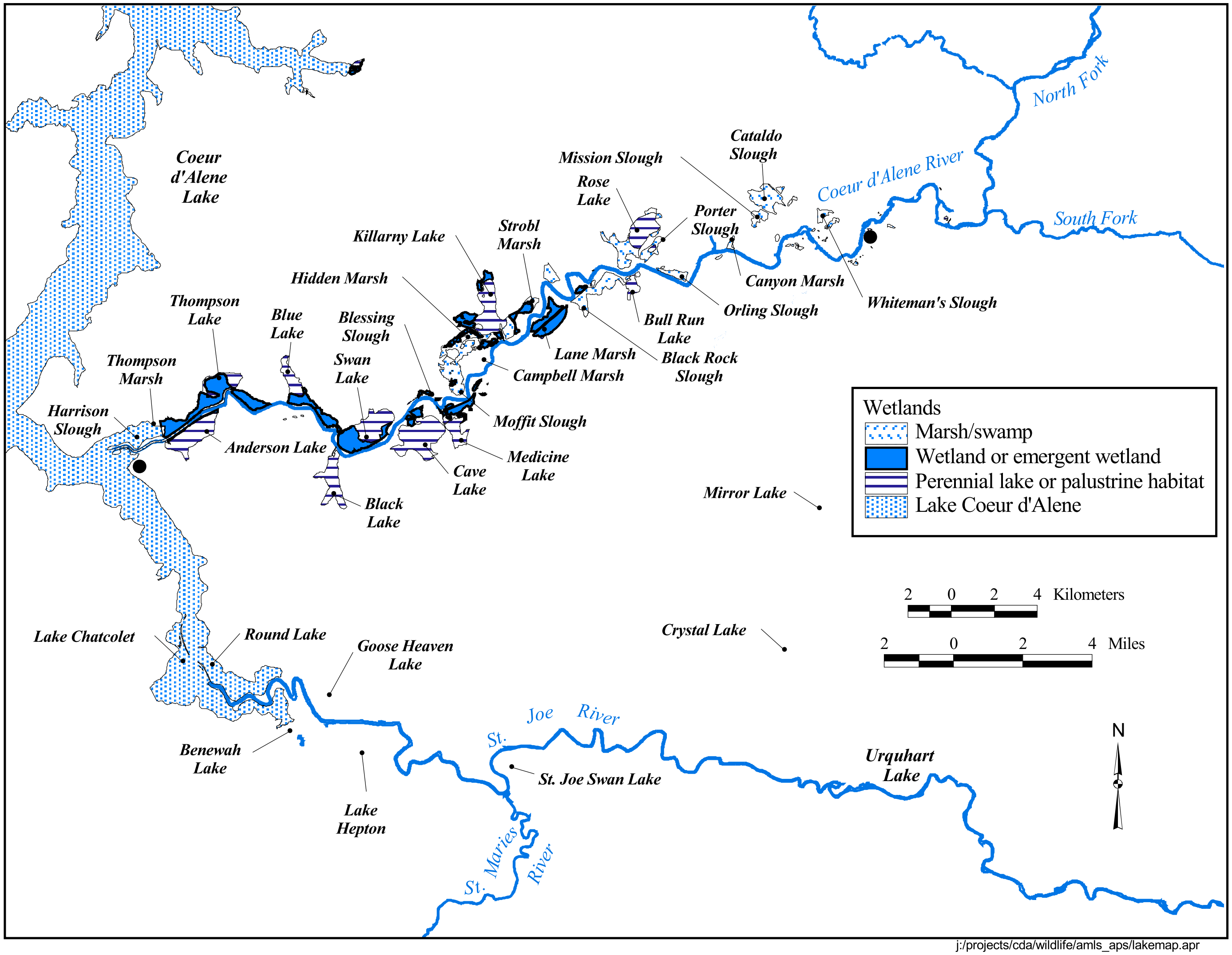


Figure 5-1. Geographic areas used to describe sources of hazardous substances in the mainstem Coeur d'Alene River and the lateral lakes area.

Bookstrom et al. (1999) mapped and described surficial hydrologic and sedimentary features of the lower Coeur d'Alene River valley. An abbreviated summary of their description, with particular reference to descriptions of the distribution of metal-enriched sediments, follows.

From the confluence of the North and South Forks of the Coeur d'Alene River to Cataldo, the channel is composite and braided. Upstream of Cataldo Flats, the channel is bordered by erosional remnants of up to four alluvial terraces, all of which are in the floodplain. High-water overflow channels and channel scars braid some of the alluvial terraces. These lead to lateral marshes and oxbow ponds, which slowly drain back to the river. The lower terraces are flooded more frequently than the upper ones and have received more metal-rich sediment; metal-enriched sediments are thickest in overflow channels and partly filled channel scars. Accumulations of metal-enriched sediments along channel scars active during the mining era are locally more than 2 m thick.

Downstream of Cataldo Flats, the river current decreases, the river bottom is sandy to muddy, and the channel contains thick deposits of metal-enriched sand. At Cataldo Landing, where the river current diminishes, a large metal-enriched sand bar nearly fills the channel. The river channel is bounded by steep banks where the river has cut into bank-wedge deposits of metal-enriched sand and silt previously deposited on the natural, premining levees. Bank wedge deposits are believed to have formed mostly before 1968. Since then, they have eroded laterally while continuing to thicken vertically. Since 1980, an estimated average of 8 cm of metal-enriched sediment has been deposited. Bank thickness of metal-enriched sediments typically ranges from 2 to 0.4 m; on levee tops, thicknesses range from about 1.4 to 0.3 m. Over-bank deposits of metal-enriched sediment extend over the tops of natural levees toward lateral flood basins. On the levees that are only flooded occasionally, metal-enriched sediments oxidize and become iron-stained. In saturated environments, the metal-enriched sediments are often in transitional to reducing conditions and are generally dark gray to black. Distributary streams and human-made canals allow transport of contaminated sediments across the floodplain.

Along straighter reaches, the river channel is partly filled with metal-enriched sediments that form a relatively flat, sandy bottom. The average thickness of metal-enriched sediments in the river channel decreases with distance downstream, from 3.5 m between Cataldo Landing and Rose Lake to 2.7 m from Rose Lake to Medicine Lake, to 2.2 m from Medicine Lake to Harrison. Point-bar deposits of metal-enriched sand are present on the inside margins of meander bends, and lateral bar deposits extend downstream from many point bars. Premining sediments are exposed only along nondepositional river bends. The palustrine wetlands of the lower basin are shallow (less than 2 m at low water) and support emergent wetland vegetation (Cowardin et al., 1979). Some are seasonally flooded, some infrequently flooded, and others perennially or persistently flooded. Where palustrine wetlands are farmed, they are artificially drained and seasonally flooded.

The palustrine wetlands of the lateral lakes include meadows, marshes, and sloughs. The metal-enriched sediments of the lateral lakes marshes are silty, muddy, and organic rich. Metal-enriched sediments in seasonally palustrine wetlands cycle between reducing and oxidizing conditions, which increases the geochemical mobility of metals in the sediments.

Lacustrine habitats of the lower basin are inland bodies of standing water that are larger than 20 acres and have maximum depths of more than 2 m at low water (Cowardin et al., 1979). Lacustrine habitats include littoral zones, where the water is less than 2 m deep at low water, and deep lake environments. The lateral lakes receive suspended metal-enriched sediments from river floodwaters that wash over levees, or via distributaries and canals. Many lateral lakes also receive nonmining sediments from tributaries to the lower river. In deep lake environments, contaminated sediments are in transitional to reducing conditions. In littoral zones, sediments may cycle between reducing and oxidizing conditions as water levels fluctuate seasonally.

Small deltaic deposits of metal-enriched sediments have formed at the mouths of distributary streams in lateral lakes. Larger deposits are present at the mouth of the Coeur d'Alene River where it enters Coeur d'Alene Lake. The deltaic deposits at the mouth of the river are moved by the river current into the lake, where they settle on the lake bed. Horowitz et al. (1995) found that eighty-five percent of Coeur d'Alene Lake contained metals-enriched lakebed sediments. They estimated that 75 million metric tons of trace-element enriched sediment have been deposited in Coeur d'Alene Lake in the last 100 to 110 years.

Anthropogenically influenced sedimentary features include metal-enriched dredge spoils at the Cataldo Mission Flats, road and railroad beds, road, railroad, and other types of cuts and embankments, ditches, canals, filled areas, dikes, levees, piers, riprap, bank liner pilings, and canals, and artificial nesting mounds created from dredged metal-contaminated sediments. The discontinued Union Pacific Railroad follows the river through the lower basin, modifying the natural flow of water to and from the river in places. Water control structures, including artificial levees, dikes, canals, ditches, ponds, and drainage pumps, influence the hydrology of the basin.

5.3 DATA SOURCES

Data from samples collected previously in the basin, from samples collected as part of the injury assessment for the NRDA, and from samples collected recently by the USGS and by the U.S. EPA for the Coeur d'Alene Basinwide RI/FS were used in the evaluation of sediment conditions. Samples collected previously in the basin include tailings core samples collected from the Cataldo Mission Flats (Galbraith, 1971; Galbraith et al., 1972; Ridolfi, 1991); sediments collected in lateral lake bed sediments and wetlands (Bauer, 1974; Funk et al., 1975; Rabe and Bauer, 1977; Neufeld, 1987; Hornig et al., 1988; Krieger, 1990; Bender, 1991); sediments collected from Coeur d'Alene Lake bed and banks (Winner, 1972; Keely, 1979; Hornig et al., 1988; Horowitz et al., 1992, 1993, 1995); and sediments collected from the river, banks, and delta (Maxfield et al., 1974; Reece et al., 1978; Roy F. Weston, 1989; USGS, 1991).

Data from the Bunker Hill Basinwide RI/FS that were used in the evaluation include data from sediment cores from the river channel, wetlands, and lake beds (URSG and CH2M Hill, 1998). Data from the USGS that were used in the evaluation include sediment core data from the bed of Coeur d'Alene Lake (Horowitz et al., 1992, 1993) and sediment transport data collected during the February 1996 flood in the Coeur d'Alene River basin (Beckwith, 1996).

Samples collected by the Trustees for the NRDA include soil and sediment samples from the floodplain (Hagler Bailly Consulting, 1995; Horowitz, 1995; see Chapter 9 of this document); sediment samples from floodplain palustrine and lacustrine wildlife habitats (Campbell et al., 1999; see Chapter 6 of this document); sediment samples from the littoral zone of the northwest shore of Coeur d'Alene Lake (Cernera et al., 1998); and sediment samples from river and creek beds (Woodward, 1997; Farag et al., 1998).

Table 5-1 (reprinted from Chapter 2, Table 2-11) summarizes concentrations of hazardous substances in sediments collected by the investigators identified above. The data presented in Table 5-1 illustrate that floodplain sediments throughout the lower Coeur d'Alene River basin contain substantially elevated concentrations of the hazardous substances cadmium, lead, and zinc.

The recent sediment sampling studies, including studies conducted as part of the NRDA, are described in more detail in the following paragraphs.

NRDA Studies

In 1993, the USGS collected sediment samples from approximately 150 sites between Smelterville and the mouth of the mainstem Coeur d'Alene River at Harrison (Horowitz, 1995). Samples were collected on a 1 km grid, with random location within each 1 km grid cell (Horowitz, 1993[2]). Samples were collected from the 0 to 2 in. and 2 to 6 in. depths. Samples were sieved to retain the <180 µm fraction, and analyzed using a complete-acid digest. Concentrations of cadmium ranged from 0.5 to 202 mg/kg; concentrations of lead ranged from 32 to 11,000 mg/kg, and concentrations of zinc ranged from 80 to 7,300 mg/kg. Mean concentrations and ranges by area are summarized in Table 5-1. Sample site locations are shown in Figure 5-2.

As part of the riparian resources injury assessment (Hagler Bailly Consulting, 1995; LeJeune and Cacela, 1999; see Chapter 9), soil samples were collected near a subset of Horowitz (1995) sampling locations. The Horowitz data were stratified by measured lead concentration level as 0-100 mg/kg lead, 100-500 mg/kg lead, 500-1,000 mg/kg lead, and >1,000 mg/kg lead.

2. Unpublished summary of field sampling procedures used by USGS in Coeur d'Alene, Idaho, Summer 1993. Provided by A.J. Horowitz, USGS, Doraville, GA.

Table 5-1
Mean (minimum-maximum) Metal Concentrations
in Tailings, Sediments, and Soils in Lower Coeur d'Alene River Basin

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Anderson Lake	Sediment	24[a]	11.6 (0.3-53.9)	1,105 (20-3,860)	1,244 (73-6,520)
		3[b]	48 (42-56)	2,650 (1,750-3,350)	2,983 (2,150-3,550)
		1[c]	9.7	2,492	2,180
Bare Marsh	Sediment	25[a]	10.0 (0.8-46.0)	1,433 (71-7,020)	1,166 (64-6,180)
	Soil	1[d]	13.0	2,100	—
Black Lake	Soil	39[e]	11.5 (0.5-48.0)	2,280 (32-11,000)	1,463 (80-7,300)
	Sediment	24[a]	10.2 (1.5-33.0)	1,075 (174-4,720)	935 (185-2,760)
		4[b]	21.8 (11-29)	1,935 (490-4,700)	2,250 (1,750-2,600)
Black Rock Slough	Sediment	24[a]	17.9 (0.3-39.3)	3,447 (63-7,630)	2,272 (49-6,620)
Blessing Slough	Sediment	24[a]	19.7 (0.1-46.9)	3,801 (36-9,190)	1,584 (49-3,530)
		3[f]	—	3,499 (3,223-3,996)	—
	Soil	2[d]	7.8 (4.5-11.0)	720 (560-880)	—
Blue Lake	Sediment	24[a]	24.0 (1.5-56.5)	3,445 (31-7,860)	2,435 (97-4,460)
		4[b]	45.5 (25-83)	2,988 (950-4,200)	3,788 (2,000-6,800)
		3[f]	—	2,576 (2,447-2,688)	—
Bull Run Lake	Sediment	24[a]	21.3 (9.0-46.1)	5,060 (1,070-15,400)	2,834 (1,260-5,720)
Campbell Marsh	Sediment	25[a]	21.9 (2.7-37.4)	4,674 (312-8,890)	2,381 (239-4,330)
	Soil	13[d]	16.2 (3.2-29.0)	2,582 (26-7,500)	—
Cataldo	Soil	32[e]	8.6 (0.5-21.0)	1,817 (54-4,900)	1,189 (80-6,200)
		9[g]	22.2 (4.8-33.1)	3,742 (182-5,720)	2,361 (370-4,270)
		26[h]	18.0 (0.1-158)	3,204 (15-9,600)	2,037 (22-6,830)
	Sediment	4[i]	14.5 (2.4)	2,390 (138)	2,543 (108)
		12[j]	16.7 (7.4-22.6)	3,352 (2,610-4,180)	3,069 (1,960-3,860)
		1[c]	4.8	2,310	1,350
		4[k]	10.5 (8.4-12.9)	2,800 (2,000-3,800)	10,075 (6,500-19,000)
		33[h]	16.9 (0.02-75.3)	1,942 (12-4,640)	1,755 (44-3,780)
Cataldo Boat Ramp	Soil	1[l]	18.5	6,030	5,510
	Sediment	1[l]	3.5	1,380	13,700
Cataldo Mission	Soil	1[l]	6.9	1,110	1,580
	Tailings (0-1 feet)	6[m]	—	4,217 (2,800-5,500)	3,183 (2,400-4,000)
Cataldo Mission	Tailings (2-3.5 feet)	42[m]	—	5,069 (300-13,100)	4,229 (400-16,000)
	Tailings (4-6.5 feet)	17[m]	—	626 (50-4,300)	741 (200-3,100)
	Tailings (7-11.5 feet)	10[m]	—	128 (50-500)	380 (300-600)
Cataldo Slough	Sediment	18[a]	25.5 (0.7-67.8)	2,365 (83-5,650)	2,797 (132-11,700)

Table 5-1 (cont.)
Mean (minimum-maximum) Metal Concentrations
in Tailings, Sediments, and Soils in Lower Coeur d'Alene River Basin

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Cave Lake	Sediment	22[a]	10.2 (0.9-28.1)	1,391 (36-7,490)	1,043 (48-4,450)
		3[b]	36 (29-45)	2,950 (2,300-3,850)	2,950 (2,750-3,300)
		6[h]	16.2 (0.2-39.1)	3,088 (12-9,360)	1,974 (40-5,280)
CdA River	Soil	44[n]	11.3 (0.3-31.8)	2,223 (20-8,030)	1,234 (55-8,850)
		49°	3.7 (0.5-23.8)	241 (18-1,565)	202 (39-865)
	Sediment	10[p]	—	1,997 (587-4,460)	—
		3[f]	—	2,853 (2,447-3,489)	—
		9[d]	—	2,521 (1,775-3,475)	—
CdA River Delta	Sediment	107[q]	43 (16-75)	3,700 (3,000-6,300)	3,800 (3,200-4,700)
		9[j]	33.2 (5.8-50.7)	3,374 (2,460-4,320)	3,007 (2,250-3,480)
		2[c]	25.5 (8-43)	3,929 (3,700-4,158)	3,740 (3,680-3,800)
		7[r]	—	—	3,103 (635-6,760)
CdA River near Black Lake	Sediment	4[i]	27.0 (2.7)	3,850 (442)	4,475 (474)
		4[k]	53.8 (21-145)	6,123 (3,310-12,700)	4,470 (3,070-7,350)
		28[h]	21.3 (0.02-70.6)	5,842 (18-35,600)	3,564 (50-10,700)
	Soil	18[h]	4.6 (0.02-17.3)	1,188 (6-6,530)	628 (31-2,730)
CdA River near Blue Lake	Sediment	7[k]	40 (19-107)	4,420 (2,150-6,870)	4,568 (3,040-5,580)
CdA River near Killarney Lake	Sediment	4[i]	24.8 (4.2)	2,175 (293)	3,290 (333)
	Soil	25[h]	6.7 (0.1-24.0)	1,949 (7-9,910)	1,064 (17-4,590)
CdA River near Rose Lake	Sediment	4[i]	33.0 (2.7)	6,810 (1,469)	6,790 (858)
		1[c]	7.2	3,870	7,300
CdA River near Thompson Lake	Sediment	2[j]	17.4 (16.5-18.0)	3,677 (2,710-4,740)	3,245 (1,730-6,650)
		1[c]	8.3	3,992	4,220
		5[k]	90 (9-208)	14,492 (4,880-28,600)	7,024 (3,400-11,830)
		3[f]	32.2 (19.7-56.6)	3,177 (2,281-4,405)	—
Dudley	Soil	9[g]	32.2 (19.7-56.6)	4,462 (2,010-6,870)	3,038 (1,830-5,430)
		10[h]	4.0 (0.1-9.2)	767 (20-2,810)	491 (86-1,230)
Harrison	Soils	5[e]	5.5 (0.5-18.0)	1,423 (140-3,500)	734 (150-2,200)
		21[h]	16.0 (0.03-72.1)	2,846 (21-17,500)	2,204 (45-10,700)
	Sediment	4[i]	25.5 (1.9)	3,363 (267)	3,895 (276)
		5[k]	4.7 (<0.5-10)	2,016 (42-5,280)	965 (111-2,270)
		28[h]	18.7 (0.03-79.5)	4,544 (11-19,900)	2,938 (48-11,500)
Harrison Marsh	Sediment	13[a]	38.1 (19.7-63.3)	4,129 (1,540-7,000)	3,959 (2,870-5,170)
Harrison Slough	Sediment	24[a]	32.3 (11.6-96.4)	4,515 (3,030-8,660)	3,425 (1,700-7,040)
Hidden Marsh	Sediment	19[a]	20.5 (0.8-77.3)	2,763 (72-6,340)	1,493 (95-2,920)

Table 5-1 (cont.)
Mean (minimum-maximum) Metal Concentrations
in Tailings, Sediments, and Soils in Lower Coeur d'Alene River Basin

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Killarney Lake	Sediment	23[a]	36.1 (11.1-76.2)	5,002 (1,890-9,680)	3,550 (1,020-5,860)
		3[b]	78.3 (50-130)	3,700 (2,550-4,600)	4,483 (4,000-5,200)
		90[s]	42.5 (<1-146)	4,893 (<2-37,400)	6,587 (100-34,150)
		3[f]	—	4,522 (3,207-5,502)	—
		10[h]	25.0 (0.02-55.8)	3,886 (48-12,800)	3,504 (134-8,710)
	Soil	7[g]	17.8 (0.2-36.3)	4,704 (434-11,600)	2,442 (589-3,980)
CdA Lake	Sediment (surface)	150[t]	62 (<0.5-157)	1,900 (14-7,700)	3,600 (63-9,100)
	Sediment (core)	12[t]	25 (<0.1-137)	3,200 (12-27,500)	2,400 (59-14,000)
CdA Lake Northwest Shore	Sediment (lower)	9[u]	0.7 (0.2-1.8)	34.9 (4-123)	363 (118-756)
	Sediment (upper)	9[u]	0.6 (0.2-1.5)	59.7 (10.2-326)	289 (55-542)
CdA Lake-North	Sediment	5[c]	7.4 (6.6-8.2)	3,315 (1,146-5,732)	4,466 (2,740-5,360)
		15[r]	—	—	3,723 (588-7,320)
CdA Lake-South	Sediment	1[c]	9.9	367	1,310
Lane	Soil	26[e]	16.0 (0.8-34.0)	2,886 (70-5,100)	2,030 (125-5,100)
Lane Marsh	Sediment	24[a]	16.5 (3.0-31.6)	3,442 (338-7,550)	1,821 (374-3,890)
		3[d]	8.5 (6.0-12.0)	2,067 (1,200-3,100)	—
Medicine Lake	Sediment	24[a]	23.8 (3.4-80.6)	3,187 (228-19,900)	2,349 (397-10,400)
		2[b]	37 (30-44)	2,825 (2,650-3,000)	2,750 (2,550-2,950)
		9[h]	27.9 (0.2-83.3)	5,755 (30-25,800)	3,835 (130-12,500)
Medimont	Sediment	28[h]	24.1 (0.1-114.0)	5,507 (17-32,900)	3,885 (45-15,400)
	Soil	30[e]	8.7 (0.5-31.0)	1,641 (29-4,900)	1,342 (75-5,100)
Medimont	Soil	1[l]	105	19,200	7,400
		24[h]	5.8 (0.05-23.8)	2,218 (18-14,500)	1,149 (30-4,510)
Mission Slough	Sediment	13[a]	22.7 (4.0-45.3)	2,928 (501-5,110)	2,258 (456-4,530)
Moffit Slough	Sediment	24[a]	14.9 (0.5-44.1)	2,851 (32-16,200)	1,665 (43-6,030)
	Soil	5[d]	17.0 (6.1-38.0)	3,022 (210-5,400)	—
Orling Slough	Sediment	24[a]	14.2 (4.8-23.1)	4,207 (426-9,680)	1,679 (723-2,410)
Porter Slough	Sediment	24[a]	14.0 (0.6-31.0)	2,621 (88-8,230)	1,526 (63-3,960)
Rose Lake	Soil	37[e]	13.7 (0.5-202.0)	1,624 (47-6,600)	1,294 (93-6,800)
		10[d]	—	2,890 (249-8,655)	—
	Sediment	20[a]	18.6 (1.2-38.6)	3,227 (32-8,870)	2,188 (56-6,090)
		3[b]	10.3 (2-15)	1,817 (100-3,200)	1,413 (240-2,100)
		9[h]	0.4 (0.02-2.4)	120 (17-350)	201 (69-385)
Strobl Marsh	Sediment	24[a]	26.1 (6.8-58.8)	5,826 (3,970-11,100)	3,012 (815-5,520)
		4[d]	11.3 (2.8-22.0)	1,860 (130-4,400)	—
Swan Lake	Sediment	18[a]	32.4 (2.7-72.0)	3,965 (213-8,350)	3,258 (241-5,780)
		4[b]	31.8 (19-57)	3,263 (1,800-3,900)	3,025 (1,900-4,650)
		3[f]	—	3,814 (3,305-4,145)	—

Table 5-1 (cont.)
Mean (minimum-maximum) Metal Concentrations in Tailings, Sediments, and Soils in Lower Coeur d'Alene River Basin

Site	Type	Sample Size	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Thompson Lake	Sediment	24[a]	27.2 (1.7-85.2)	3,723 (324-8,880)	3,009 (163-7,330)
		2[b]	27 (23-31)	3,150 (2,600-3,700)	2,950 (2,900-3,000)
		1[c]	8.9	3,386	2,560
	Soil	1[g]	8.5	2,730	1,075
		8[d]	—	3,133 (34-6,570)	—
		3[d]	12.3 (9.8-14.0)	1,863 (990-2,300)	—
Thompson Marsh	Sediment	24[a]	7.6 (0.3-19.9)	1,812 (99-12,200)	878 (83-2,450)

a. Sediments collected from lacustrine and palustrine areas (Campbell et al., 1999).
b. Sediments collected from 1 to 9 m in lake inlets and open water (Bauer, 1974; Funk et al., 1975; data also presented in Rabe and Bauer, 1977).
c. Hornig et al., 1988 (wet weight measurement).
d. Neufeld, 1987.
e. Soils collected from river bank and floodplain areas (Horowitz, 1995).
f. Krieger, 1990.
g. Soil samples collected from islands and river bank (Roy F. Weston, 1989).
h. Soils collected from floodplains and sediments collected from CdA River and lateral lakes (URSG and CH2M Hill, 1998).
i. Sediments collected from the CdA River. Values in parentheses are standard error of the mean; minimum and maximum values were not provided (Farag et al., 1998).
j. Sediments collected from the CdA river (Reece et al., 1978).
k. Sediment samples collected from river bank (USGS, 1991).
l. Sediments collected from stream channel; soils collected from floodplain banks (Ridolfi, 1991).
m. Tailings core samples collected from Cataldo Mission Flats area (Galbraith, 1971; Galbraith et al., 1972).
n. Soils collected from floodplain areas (Hagler Bailly Consulting, 1995).
o. Soils collected at 0-5 cm in Kootenai County (Keely, 1979).
p. Audet, 1997.
q. Sediments collected from the river delta area (Maxfield et al., 1974).
r. Sediments collected from CdA Lake between 2 and >20 m (Winner, 1972).
s. Sediments collected from three locations in Killarney Lake (Bender, 1991).
t. Horowitz et al., 1992, 1993, 1995.
u. Sediments collected from littoral/water interface and 1 m above the water level (Cernera et al., 1998).

Approximately 15 sites per stratum were randomly selected and sampled in an attempt to collect samples representing a wide range of metal concentrations. Complete sampling and analysis methods are described in Chapter 9. Cadmium concentrations averaged 11.3 mg/kg and ranged from below the detection limit to 31.8 mg/kg. Lead concentrations averaged 2,222 mg/kg and ranged from 19.8 to 8,030 mg/kg, and zinc concentrations averaged 1,234 mg/kg and ranged from 55 to 8,850 mg/kg. Concentrations are summarized by area in Table 5-1. Sample site locations are shown in Figure 5-2.

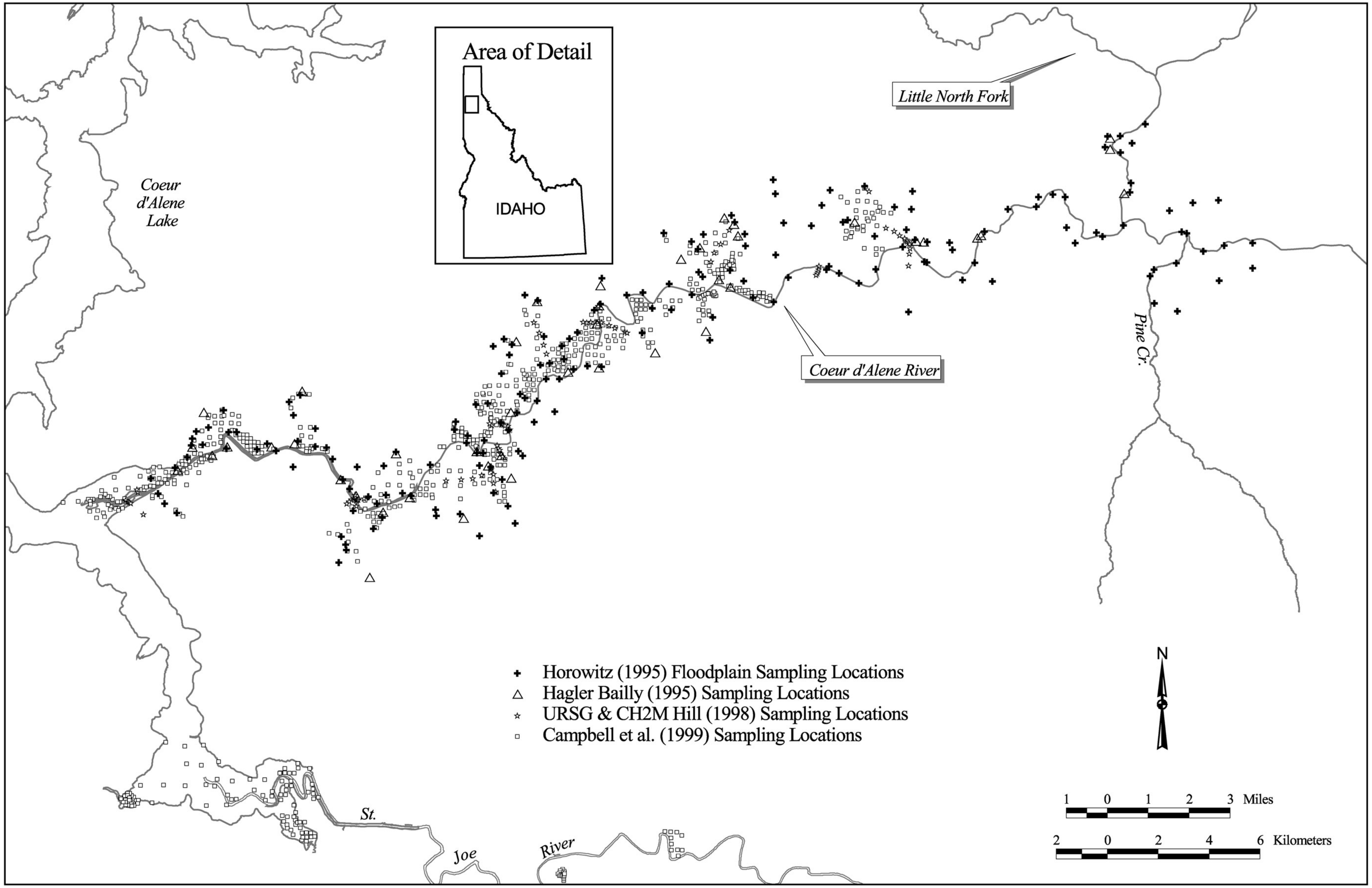


Figure 5-2. Bed, bank, and floodplain sediment sampling locations in the lower Coeur d'Alene River basin.

As part of pathway determination, sediment samples were collected from geographically and hydrologically discrete palustrine and lacustrine wildlife habitats to determine if Coeur d'Alene River basin sediment serves as a pathway of waterfowl exposure to hazardous substances. Concentrations of hazardous substances in Coeur d'Alene River basin sediments ($n = 555$) were compared to concentrations in sediments from the St. Joe River basin ($n = 126$), and concentrations of all analytes (arsenic, cadmium, iron, manganese, lead, and zinc) were greater in Coeur d'Alene River basin samples than in St. Joe River basin samples ($p < 0.0001$; Campbell et al., 1999). The data were also analyzed by comparing mean values from discrete 25 wetland units sampled in the Coeur d'Alene River basin to mean values from each of 6 discrete wetland units in the St. Joe River basin. Mean lead concentrations in all Coeur d'Alene wetland units exceeded 1,000 mg/kg; mean lead concentrations in St. Joe wetland units were all below 20 mg/kg. Mean lead concentrations in sediments from each of the Coeur d'Alene wetland units (range of 1,075 to 5,826 mg/kg) were significantly greater than mean lead concentrations in St. Joe River basin wetland units ($p < 0.0001$). Mean concentrations of cadmium, zinc, arsenic, and manganese were also significantly greater in Coeur d'Alene River basin wetland units than in St. Joe River basin units ($p < 0.0001$). Concentrations are summarized by area in Table 5-1. Sample site locations are shown in Figure 5-2.

Audet et al. (1999), examining the data in Campbell et al. (1999) and waterfowl habitat use data, found that mean concentrations of lead in sediments in waterfowl feeding areas within the wetland units sampled by Campbell et al. (1999) occasionally differed substantially from the overall mean for the wetland area. For 10 of the 25 wetland units sampled, the mean sediment lead concentration for the whole wetland unit and the mean lead concentration for the feeding area within the unit differed by more than 500 mg/kg. Examples include Stroble Marsh and Bull Run Lake, where mean lead concentrations in the feeding area exceeded mean lead concentrations in the whole wetland by 670 mg/kg and 1,662 mg/kg, respectively, and Cave Lake and Cataldo Slough, where mean lead concentrations in the whole wetland exceeded mean lead concentrations in the feeding area by 853 mg/kg and 1,068 mg/kg, respectively. Audet et al. (1999) concluded that feeding area mean concentrations are more appropriate for evaluating lead exposure than whole wetland mean concentrations. Feeding area mean concentrations are presented in Table 5-2.

As part of the characterization of the pathway of metals in water, sediments, and aquatic biota, bed sediments were collected from the Coeur d'Alene River and its tributaries, including the North Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, and Pine Creek, and the St. Joe and Spokane rivers (Farag et al., 1998). Sediment samples were collected from the South Fork Coeur d'Alene River near Mullan and Pinehurst, and from five sites along the lower Coeur d'Alene River between Cataldo and Harrison. Table 5-1 presents metals concentrations in the sediments from the lower Coeur d'Alene River sites. Concentrations of cadmium, lead, and zinc in sediments and biofilm were as much as 50 to 100 times greater in samples from assessment area sites than in samples from the North Fork and upstream South Coeur d'Alene rivers and the St. Joe River.

Table 5-2
Mean Lead Concentration in Sediment from Wetland Units and from Wildlife Feeding Areas within Each Wetland Unit of the Coeur d'Alene River Basin

Wetland Unit	Whole Wetland Unit		Feeding Area	
	n	Lead (mg/kg)	n	Lead (mg/kg)
Harrison Slough	24	4,515	14	4,597
Harrison Marsh	13	4,129	8	4,815
Thompson Marsh	24	1,812	15	1,836
Thompson Lake	24	3,723	14	4,281
Anderson Lake	24	1,105	7	408
Bare Marsh	25	1,433	16	682
Blue Lake	24	3,445	3	3,830
Black Lake	24	1,075	11	611
Swan Lake	18	3,965	7	4,003
Cave Lake	22	1,391	9	539
Medicine Lake	24	3,187	9	3,443
Blessing Slough	24	3,801	3	4,406
Moffit Slough	24	2,851	11	2,520
Campbell Marsh	25	4,674	9	4,712
Hidden Marsh	19	2,763	3	2,843
Killarney Lake	23	5,002	9	4,793
Strobl Marsh	24	5,826	7	6,497
Lane Marsh	24	3,442	15	3,077
Black Rock Slough	24	3,447	5	1,309
Bull Run Lake	24	5,060	7	6,721
Rose Lake	37	3,227	2	4,095
Porter Slough	24	2,621	11	2,596
Orling Slough	24	4,207	16	4,194
Cataldo Slough	18	2,365	6	1,297
Mission Slough	13	2,928	6	3,065

Data Sources: Audet et al., 1999; Campbell et al., 1999.

Mean concentrations of lead in samples collected near Cataldo, Rose Lake, Killarney, Black Lake, and Harrison ranged from 2,175 to 6,810 mg/kg. Mean concentrations of lead in samples collected in the North Fork Coeur d'Alene River, the St. Joe River, and in the South Fork Coeur d'Alene River near Mullan ranged from 10 to 203 mg/kg. Mean concentrations of cadmium and zinc from the same lower basin samples ranged from 14.5 to 33 mg Cd/kg and 2,543 to 6,790 mg Zn/kg. Mean concentrations of cadmium and zinc in the North Fork, St. Joe, and upper South Fork Coeur d'Alene river samples ranged from 0.2 to 1.4 mg Cd/kg and 61 to 827 mg Zn/kg. Concentrations of hazardous substances in sediments collected from Canyon and Ninemile creeks, and from the South Fork Coeur d'Alene River near Pinehurst, were greatly elevated. Cadmium concentrations at these three sites ranged from 49.3 to 106 mg/kg, lead from 4,503 to 9,187 mg/kg, and zinc from 8,130 to 19,700 mg/kg.

Sediments from the northwestern shore of Coeur d'Alene Lake were sampled to determine concentrations of hazardous substances in sediments at water level and at a location 3 feet above the water level (Cernera et al., 1998).Concentrations of cadmium ranged from below the detection limit to 1.8 mg/kg, concentrations of lead ranged from 4.1 to 326 mg/kg, and concentrations of zinc ranged from 54.5 to 756 mg/kg (Table 5-1). Concentrations of cadmium, lead, and zinc collected at the different heights above water level did not differ significantly.

USGS Studies

Data from samples collected by the USGS during the February 1996 flood indicated that the Coeur d'Alene River transported an estimated 69,000 metric tons of sediment, 720 metric tons of lead, and 180 metric tons of zinc, and 111 kg of cadmium to Coeur d'Alene Lake on a single day (February 10), the day after the peak flow (Beckwith, 1996, 1997). Concentrations of hazardous substances in the South Fork and mainstem Coeur d'Alene rivers were substantially greater than concentrations in the North Fork Coeur d'Alene River, and concentrations of hazardous substances and suspended sediment generally increased with distance downstream (Table 5-3). Comparison of concentrations in unfiltered and filtered samples collected at Cataldo, Rose Lake, and Harrison showed that during the flood, hazardous substances, including cadmium, lead, and zinc, were transported primarily as suspended sediment (>0.45 µm diameter) rather than as dissolved (<0.45 µm diameter) in the water (Beckwith, 1996). The study confirmed that contaminated sediments are mobile in the basin, and that during floods, large volumes of sediments and hazardous substances are transported through the lower Coeur d'Alene River basin.

In addition, the USGS collected surface and subsurface samples from the bed of Coeur d'Alene Lake (Horowitz et al., 1992, 1993). Surface samples (upper 2 cm) were collected at 150 locations (Figure 5-3), and subsurface samples at 12 locations. Subsurface core lengths ranged from 97.5 to 140.5 cm. The data were used to assess patterns in the spatial distribution of metals concentrations and to estimate volumes of contaminated sediments in the lake.

In surface samples, cadmium concentrations averaged 62 mg/kg and ranged from below the detection limit to 157 mg/kg. Lead concentrations averaged 1,900 mg/kg and ranged from 14 to 7,700 mg/kg, and zinc concentrations averaged 3,600 mg/kg and ranged from 63 to 9,100 mg/kg.

Table 5-3
Concentrations of Trace Metals and Suspended Sediment in Unfiltered Samples, Coeur d'Alene River Basin, February 8-10, 1996

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

Source: Beckwith, 1996.

In subsurface samples, cadmium concentrations averaged 25 mg/kg and ranged from below the detection limit to 137 mg/kg. Lead concentrations averaged 3,200 mg/kg and ranged from 12 to 27,500 mg/kg, and zinc concentrations averaged 2,400 mg/kg and ranged from 59 to 14,000 mg/kg. The cores all had generally similar features, including an upper, heavily banded (striated) section ranging in thickness from 17 to 119 cm and a lower homogeneous section.

In several of the cores, as many as 80 individual layers were identified. In most cores, a distinct metal enrichment maxima was detected at or near the base of the banded zone. Based on age-estimation of the layers, Horowitz et al. (1995) concluded that metal enrichment of lakebed sediments began between 1895 and 1910, concurrent with the onset of mining and ore-processing in the Coeur d'Alene River basin. In the underlying homogeneous zone only, structures believed to be infilled burrows and worm tubes indicated historical biological activity in the lake bed sediments.

Bunker Hill Basinwide RI/FS Study

Sediments of the lower Coeur d'Alene River basin between Cataldo and Harrison were sampled in 1997 as part of the Bunker Hill Basinwide Remedial Investigation/Feasibility Study (URSG and CH2M Hill, 1998). Cores ranging in depth up to 25 feet were collected along transects crossing the river and floodplain of the lower basin. Samples were taken from both floodplain soils and submerged sediments in the main river channel and in lateral lakes (Figure 5-2). The cores were divided into a series of samples for analysis of hazardous substances and other constituents. The data show clear evidence of a horizon of elevated concentrations of hazardous substances in the upper portion of most cores, and a lower horizon of low concentrations of

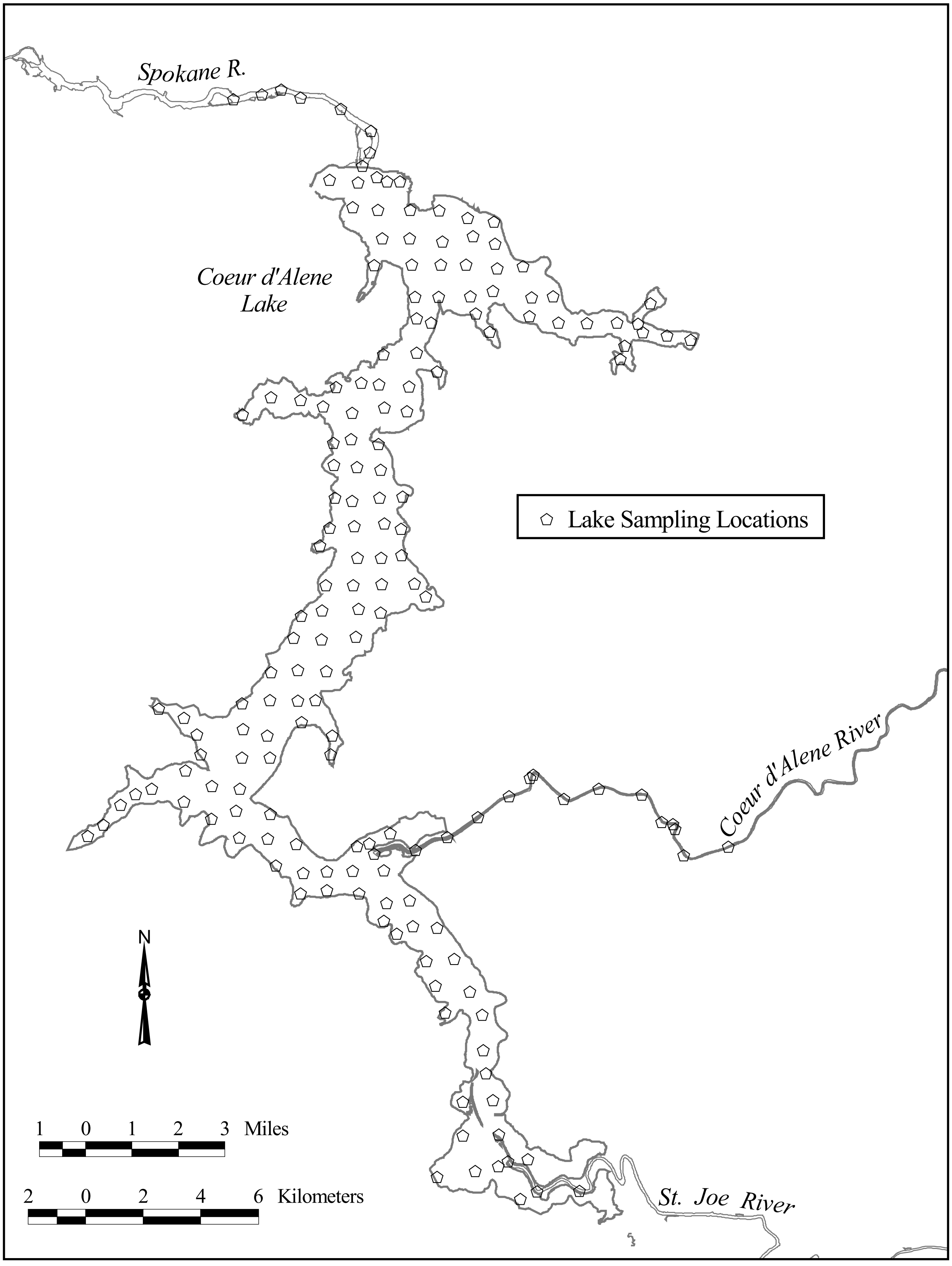


Figure 5-3. Sediment sampling locations in Coeur d'Alene Lake (Horowitz et al., 1992).

hazardous substances. Previous studies (Horowitz et al., 1993, 1995; S. Box, USGS, Spokane, WA, unpublished data) and historical accounts of tailings releases from mills, transport of tailings downstream, and deposition on floodplains, beds and banks of the lower river (Ellis, 1940; Casner, 1991; Long, 1998) indicate that the upper sediments containing elevated concentrations of hazardous substances were deposited after mining began in the basin, and that the lower sediments were deposited before mining began in the basin. An analysis of concentrations in lower pre-mining sediments is presented in Chapter 10.

5.4 DISTRIBUTION OF HAZARDOUS SUBSTANCES IN SEDIMENTS

5.4.1 Lower Basin Sediments

The distribution of hazardous substances in sediments of the lower Coeur d'Alene River basin was assessed using data from samples collected in the 1900's (Hagler Bailly Consulting, 1995; Horowitz, 1995; URSG and CH2M Hill, 1998; Campbell et al., 1999; Chapter 9). Together, these studies provide data from approximately 789 sites in the lower basin (Figure 5-4). The data in Figure 5-4 are from the sources identified in Figure 5-2. Concentrations at the majority of the sites sampled in the lateral lakes area exceed 1,000 mg/kg lead, whereas concentrations in samples from the southern end of Coeur d'Alene Lake are predominantly less than 30 mg/kg. Sediments with concentrations exceeding 1,000 mg/kg are distributed throughout the wetlands, lakes, and river channel of the lower basin (Figures 5-1 and 5-4).

5.4.2 Coeur d'Alene Lake Sediments

Horowitz et al. (1992, 1993, 1995) collected 150 surface and 12 subsurface samples from the bed of Coeur d'Alene Lake. The distribution patterns of metals in the surface sediments are consistent with the Coeur d'Alene River as the main source of contaminated sediments (Horowitz et al., 1992, 1995). Localized areas of peak concentrations reflect water velocity and movement from south to north in the lake. Some of the highest concentrations occur in and around Harrison Slough, where the velocity of the Coeur d'Alene River would be expected to decrease substantially as it enters the lake. Other sites with particularly elevated concentrations are found where the geomorphology of the lake causes changes in the current direction or velocity and where a loss of suspended sediment is likely to occur (Horowitz et al., 1992).

Figure 5-5 shows lead concentrations in surface sediments of Coeur d'Alene Lake, and the majority exceed 1,000 mg/kg. Only the southern end of the lake, which is primarily influenced by sediment inputs from the St. Joe River basin, has lead sediment concentrations below 175 mg/kg.

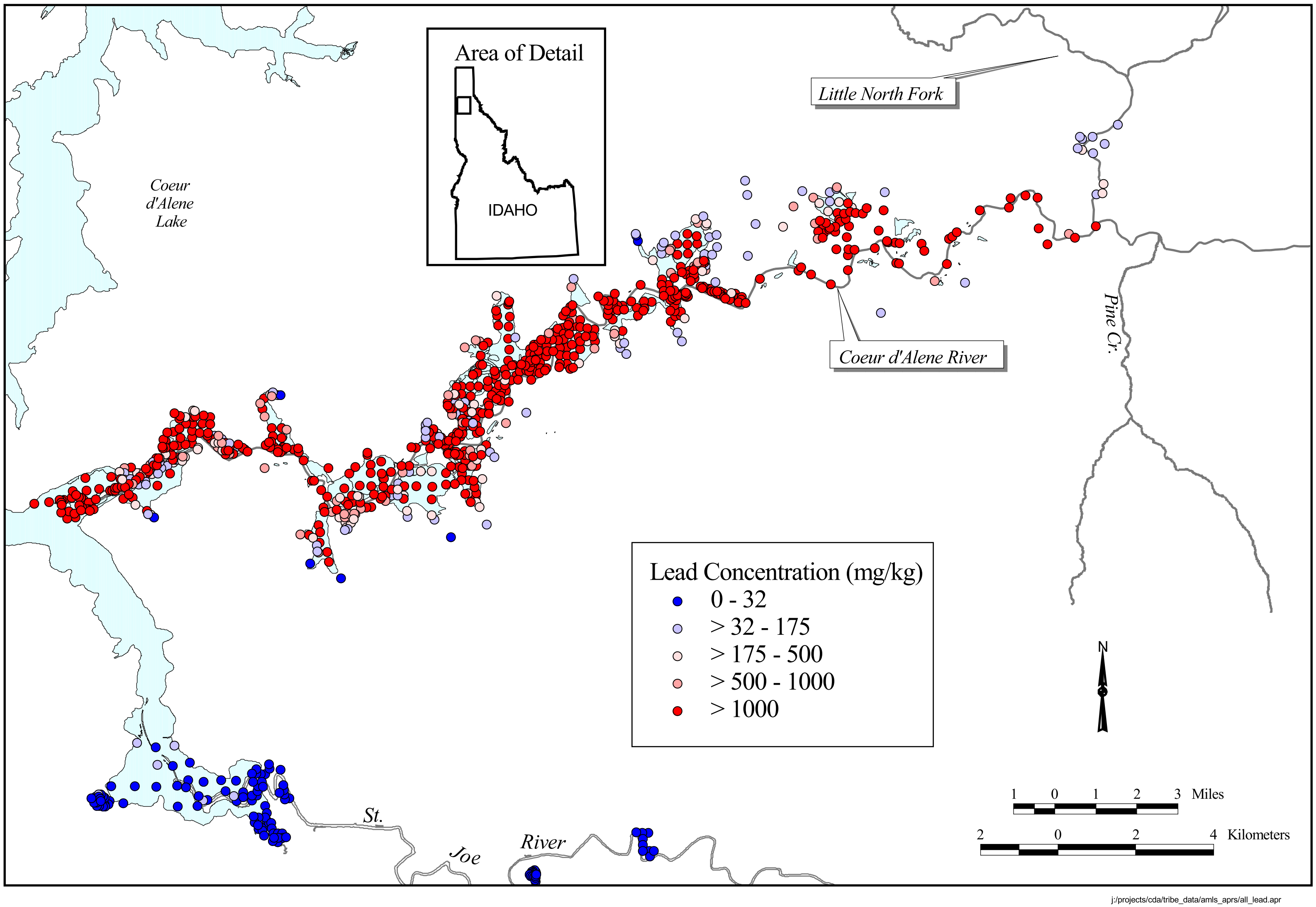
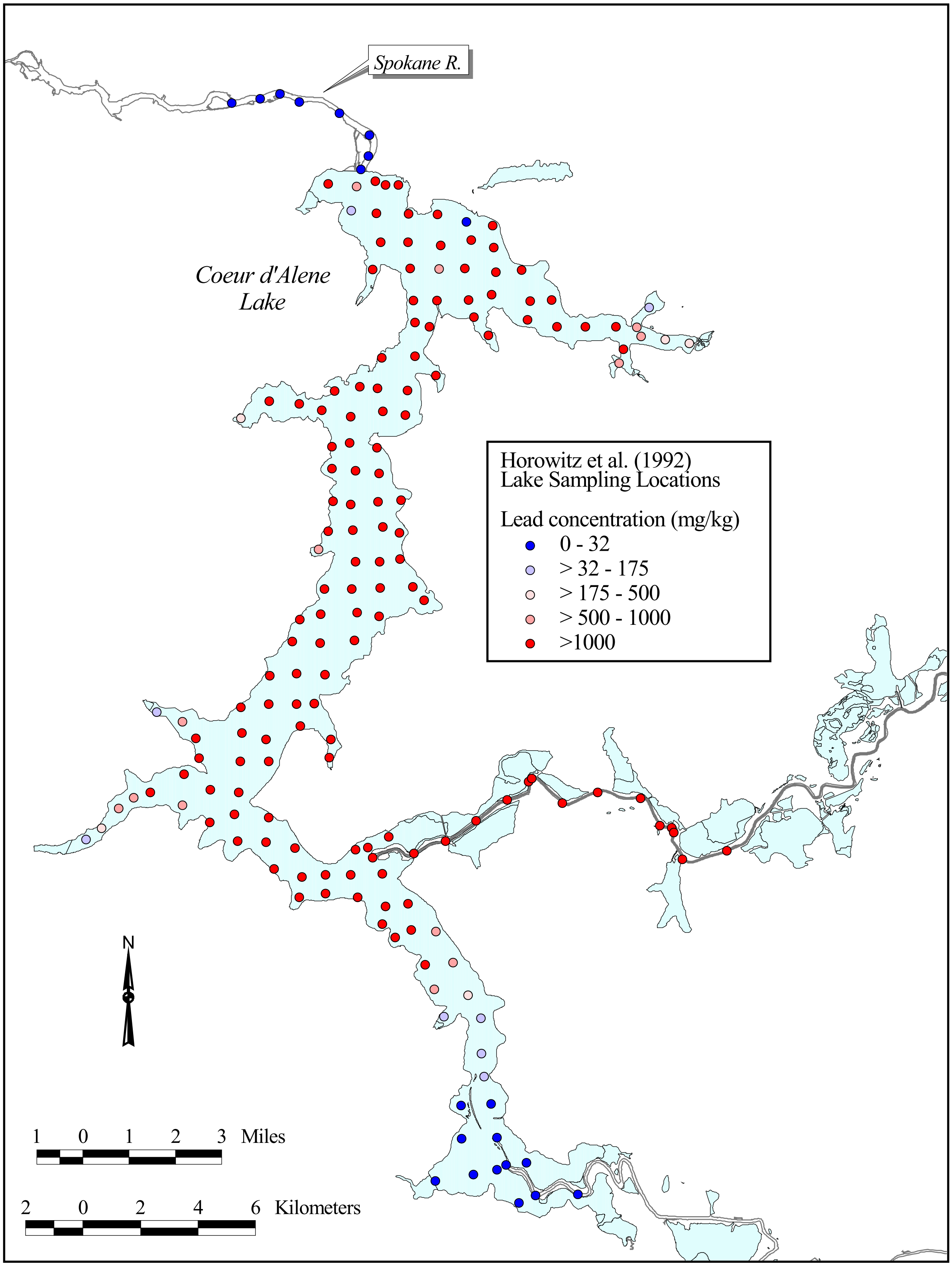


Figure 5-4. Distribution of lead concentrations in surface bed, bank, and floodplain sediments of the lower Coeur d'Alene River basin.



j:/projects/cda/tribe_data/amls_aprs/all_lead.apr

Figure 5-5. Lead concentrations in Coeur d'Alene Lake surface bed sediments.

The 12 subsurface samples were collected from the Coeur d'Alene River delta, the main stem of the lake, and the backs of several bays perpendicular to the main stem (Horowitz et al., 1993, 1995). Based on metal concentrations in the surface and subsurface sediments and the volume of sediments represented by the cores, the mass of metal-enriched sediment and the mass of each enriched element were calculated. Normal masses of trace elements were calculated by substituting median concentrations data from the lower portion of cores determined to represent premining conditions and a core from the southern end of the lake. An estimated 75 million metric tons of metal-contaminated sediments currently overlie approximately 85% of the bed of Coeur d'Alene Lake (Horowitz et al., 1993, 1995). The contaminated sediments contain an estimated 10,000 metric tons of cadmium, 468,000 metric tons of lead, and 240,000 metric tons of zinc. The mass of metals in background (unenriched) sediments was estimated to comprise less than 2% of the total metal mass for each element (Horowitz et al., 1993, 1995).

5.5 ECOLOGICAL IMPLICATIONS OF SEDIMENT CONTAMINATION

Metals accumulated in sediment can be toxic to aquatic biota, through direct contact with the sediment or through movement of the metals from the sediment into the sediment porewater or water column (Burton, 1992). However, no national sediment quality criteria have been developed to protect aquatic biota or wildlife from toxic sediments. Several groups have developed "sediment effect concentrations" that are intended to estimate sediment concentrations above which adverse effects to benthic macroinvertebrates occur. For freshwater sediments such as those in the Coeur d'Alene River system, sediment effect concentrations have been derived by the Ontario Ministry of the Environment (Persaud et al., 1993) and by researchers who have studied contaminated sediments for the U.S. EPA (Ingersoll et al., 1996). In addition, NOAA has developed sediment effect concentrations using a database that includes information from both freshwater and marine systems (Long and Morgan, 1991). These sediment effect concentrations can be compared to measured metal concentrations in the Coeur d'Alene River basin as an indication of the likelihood that the concentrations are sufficient to cause toxicity.

Sediment effect concentrations were developed by the Ontario Ministry of the Environment (Persaud et al., 1993), U.S. EPA (Ingersol et al., 1996; McDonald et al., 1999), and NOAA (Long and Morgan, 1991) from statistical analyses of datasets on the co-occurrence of sediment contamination and toxicity. Although the underlying databases and statistical analyses used by the different groups differ, the contaminant concentrations predicted to cause toxicity to benthic macroinvertebrates are similar (Table 5-4). For each of the metals shown in Table 5-4, sediment effect concentrations are within a factor of approximately 3 of each other, indicating a general consistency despite differences in underlying databases and methods. Also included in Table 5-4 are "consensus" sediment effect concentrations developed by MacDonald et al. (1999). MacDonald et al. (1999) combined the various individual sediment effect concentrations into single effect concentrations intended to reflect the information from all the separate groups. MacDonald et al. (1999) report that the consensus numbers for cadmium, lead, and zinc correctly predicted sediment toxicity in 93.7%, 89.6%, and 90.0%, respectively, of 347 samples from freshwater systems in the United States.

Table 5-4
Sediment Effect Concentrations for Freshwater Sediment

Name	Definition	Basis	Concentration (mg/kg dry wt) Cd	Pb	Zn	Reference
Severe Effects Level	"Level at which pronounced disturbance of the sediment-dwelling community can be expected"	Field data on benthic communities	10	250	820	Persaud et al., 1993
Probable Effect Level	"Concentrations that are usually or always associated with adverse biological effects"	Laboratory toxicity tests using field-collected sediment	3.2	82	540	Ingersoll et al., 1996
Effects Range-Median[a]	"Concentration above which effects were frequently or always observed or predicted among most species"	Field data on benthic communities and spiked laboratory toxicity test data	9.0	110	270	Long and Morgan, 1991
Consensus Probable Effect Concentration	"Concentrations above which harmful effects on sediment-dwelling organisms were expected to occur frequently"	Geometric mean of published effect concentrations	4.98	128	459	MacDonald et al., 1999

a. Based on data from both freshwater and marine sites.

Concentrations measured in sediments from the lower Coeur d'Alene River, Coeur d'Alene Lake, and lateral lakes area (see Table 5-1) consistently exceed all sediment effect concentrations presented in Table 5-4. In many areas of the lower Coeur d'Alene River basin, *mean* concentrations of cadmium, lead, and zinc exceed all the effect concentrations by an order of magnitude. Although the sediment effect concentrations listed in Table 5-4 may not be specific to the biotic and abiotic conditions of the Coeur d'Alene River basin, the consistency and degree of exceedence of the effect concentrations indicate a high likelihood of the sediment metal concentrations being sufficient to cause toxicity.

To investigate the site-specific exposure and toxicity of sediments to benthic invertebrates, fish, and wildlife, pathway studies were conducted by the Trustees as part of the NRDA. The pathway studies conducted by the Trustees confirm that biota of the Coeur d'Alene River basin are exposed to hazardous substances in sediments, and that exposure to hazardous substances in sediments causes injury. These pathway studies are described briefly below, and more completely in Chapters 6, 7, and 8.

Contaminated sediments in the Coeur d'Alene River serve as an exposure pathway to waterfowl of the Coeur d'Alene River basin by direct ingestion (Beyer et al., 1994, 1997, 1998). Concentrations in ingested floodplain sediments are sufficient to cause injury to wildlife, including death, physiological malfunctions, and physical deformations (Chapter 6). Contaminated sediments in the Coeur d'Alene River also serve as an exposure pathway to biofilm, benthic invertebrates, and fish of the Coeur d'Alene River basin (Woodward et al., 1997; Farag et al., 1998), and to riparian vegetation (Chapter 9). Concentrations of hazardous substances in river bed sediments, in combination with concentrations in surface water, are sufficient to cause death and physiological malfunctions in fish (Chapter 7).

Exposure of waterfowl to lead and other hazardous substances in sediments was confirmed by collection and analysis of digesta (dietary contents of the digestive system) and excreta (excretory products including feces) from wood ducks, tundra swans, Canada geese, and mallards of the lower Coeur d'Alene River basin and reference areas (Beyer et al., 1997, 1998; Audet et al., 1999). The average lead concentration (dry weight) in excreta of tundra swans was 880 mg/kg in the Coeur d'Alene River basin, and 2 mg/kg in reference areas. Lead concentration in tundra swan feces was significantly correlated ($p < 0.05$; Spearman's rho = 0.74) with the amount of sediment ingested, and fecal lead concentrations of all waterfowl were significantly correlated with lead concentrations in Coeur d'Alene River basin sediments ($r^2 = 0.83$, $p < 0.05$) (Beyer et al., 1998). Lead concentrations in the ingesta of swans from the Coeur d'Alene River basin were 140 times greater than lead concentrations in swan ingesta from the St. Joe River basin. The results of these studies (described further in Chapter 6) confirm that direct ingestion of contaminated sediment is the principal exposure pathway of lead and other hazardous substances to waterfowl in the Coeur d'Alene River basin, and that concentrations are sufficient to provide a direct pathway to wildlife resources of the Coeur d'Alene River basin. Moreover, Coeur d'Alene tundra swans, Canada geese, and mallards ingest contaminated sediments in sufficient concentrations to cause injury, including death, physiological malfunctions, and physiological deformations (Chapter 6).

Farag et al. (1998) demonstrated a link between metal concentrations in sediments and metal concentrations in biofilm in the Coeur d'Alene River basin. As concentrations of hazardous substances in sediments and biofilm increased, concentrations of hazardous substances in composite samples of invertebrates increased. In addition, concentrations of cadmium, lead, and zinc in whole perch collected from the Coeur d'Alene River were significantly greater than concentrations in perch collected from the Spokane River, where sediment and biofilm concentrations are much lower, and mean concentrations of cadmium, lead, and zinc in kidneys and gills of trout collected in the South Fork Coeur d'Alene River near Pinehurst were significantly greater than concentrations in brook trout collected from the North Fork Coeur d'Alene River.

Woodward et al. (1997) showed that Coeur d'Alene River basin sites with the highest concentrations of metals in water, sediment, biofilm, and benthic invertebrates were also the sites where fish populations were reduced, mortality was observed, and tissues contained elevated concentrations of metals. The Woodward (1997) and Farag et al. (1998) data confirm that sediments, biofilm, invertebrates, and fish are exposed to hazardous substances, and provide evidence of the sediment-invertebrate dietary exposure pathway to fish (see also Chapter 7).

In summary, contaminated sediments represent an important exposure pathway of hazardous substances to terrestrial and aquatic biota. Moreover, exposure to these contaminated sediments causes injuries to biological resources that rely on sediments as a component of their habitat.

5.6 INJURY DETERMINATION EVALUATION

5.6.1 Injuries Evaluated in the Assessment Area

Injuries to sediments were assessed in accordance with the DOI guidance for determination of injuries to surface water [43 CFR §11.62 (b)(1)] and geologic resources [43 CFR § 11.62 (e)]. Relevant definitions of injury to sediment include:

- Concentrations and duration of substances sufficient to have caused injury (. . . as defined . . .) to groundwater, air, geologic, or biological resources when exposed to . . . suspended sediments, or bed, bank, or shoreline sediments [43 CFR §11.62 (b)(1)(iv)].

- Concentrations of substances sufficient to have caused injury as defined to surface water, groundwater, air or biological resources when exposed to the substances [43 CFR § 11.62 (e)(11)].

These definitions of injury pertain to sediments as an exposure pathway of injury to other resources. To address these injury definitions, the Trustees conducted pathway and injury studies (Chapters 6, 7, and 8) to evaluate exposure and responses of biota to contaminated and reference sediment.

5.6.2 Confirmation of Exposure in Sufficient Concentrations

The data presented in Tables 5-1 and 5-2, plus additional data presented in the following chapters, confirm that sufficient concentrations of hazardous substances are present in floodplain, bed, bank, and suspended sediments to cause injury to wildlife (Chapter 6, Wildlife Resources), fish (Chapter 7, Fish Resources), and benthic invertebrates (Chapter 8, Benthic Macroinvertebrates). Sufficient concentrations are present in floodplain sediments of the upper basin to cause injury to riparian vegetation (Chapter 9, Riparian Resources).

Information presented in Chapter 6 confirms that:

- Sufficient concentrations of lead are present in sediments of the lower Coeur d'Alene River basin to cause death, physiological malfunctions, and physical deformations in waterfowl [43 CFR 11.62 (f)(4)]. Waterfowl consume sediments contaminated with lead and other hazardous substances, the lead in the sediments is bioavailable, and the lead in the sediment causes the injuries listed above.

Information presented in Chapters 7 and 8 confirms that:

- Sufficient concentrations of hazardous substances are present in sediments of the Coeur d'Alene River basin to expose benthic invertebrates and fish. Exposure to hazardous substances causes injury to fish and benthic invertebrates, including death, physiological malfunctions, and physical deformations [43 CFR 11.62 (f)(4)].

Information presented in Chapter 9 confirms that:

- Sufficient concentrations of hazardous substances are present in floodplain soils and sediments of the upper Coeur d'Alene River basin to expose riparian vegetation. Concentrations of hazardous substances are phytotoxic, and cause injury to riparian vegetation [43 CFR 11.62 (e), (f)(2)].

Based on the consistent evidence that sediments serve as a pathway of injury to biological resources of the Coeur d'Alene River basin, sediments throughout the basin are injured [43 CFR §11.62 (b)(1)(iv) and (e)(11)].

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Next

CHAPTER 6
WILDLIFE RESOURCES

This chapter describes injuries to wildlife resources of the Coeur d'Alene River basin that have resulted from exposure to hazardous metals released from mining and mineral processing operations. Section 6.1 describes the wildlife resources of the Coeur d'Alene River basin. Section 6.2 provides an overview of the toxic effects of lead on wildlife. Section 6.3 describes the injuries evaluated in the Coeur d'Alene, Section 6.4 summarizes the testing and sampling approaches, and Section 6.5 summarizes the results of the injury assessment studies. Section 6.6 presents the injury determination evaluation, Section 6.7 summarizes the conclusions of the assessment of injuries to wildlife resources, and Section 6.8 provides references cited.

6.1 DESCRIPTION OF WILDLIFE RESOURCES

The Coeur d'Alene River basin is located in the Pacific flyway for migratory waterfowl and provides important habitat for a diverse assemblage of aquatic and terrestrial wildlife species (Figure 6-1). The Coeur d'Alene River and lateral lakes area of the basin (Figure 6-2) provide abundant and diverse riparian, wetland, and lake habitats that support diverse wildlife uses, including feeding, resting, and reproduction (Figure 6-3). Historically, the riparian zones of the South Fork Coeur d'Alene River provided feeding, resting, and reproductive habitat as well. Wildlife known to inhabit or suspected to visit the lower Coeur d'Alene area include over 280 migratory and nesting bird species (Ridolfi, 1993), as well as many mammals, reptiles (e.g., snakes, turtles), and amphibians (e.g., frogs, salamanders).

Migratory birds in the Coeur d'Alene River basin include waterfowl, birds of prey, songbirds, and other neotropical species. Ducks nesting in the basin include mallards (*Anas platyrhynchos*), wood ducks (*Aix sponsa*), green-winged teal (*Anas crecca*), ring-necked ducks (*Aythya collaris*), lesser scaup (*Aythya affinis*), northern shovelers (*Anas clypeata*), ruddy ducks (*Oxyura jamaicensis*), cinnamon teal (*Anas cyanoptera*), and redheads (*Aythya americana*) (Burch et al., 1996; Audet et al., 1999c). Other waterbirds nesting in the wetland and lateral lakes area include Canada geese (*Branta canadensis*), red-necked grebes (*Podiceps grisegena*), western grebes (*Aechmophorus occidentalis*), American coots (*Fulica americana*), pied-billed grebes (*Podilymbus podiceps*), black terns (*Chlidonias niger*), common snipe (*Gallinago gallinago*), and sora (*Porzana carolina*) (Chupp and Dalke, 1964; IDFG, 1987).

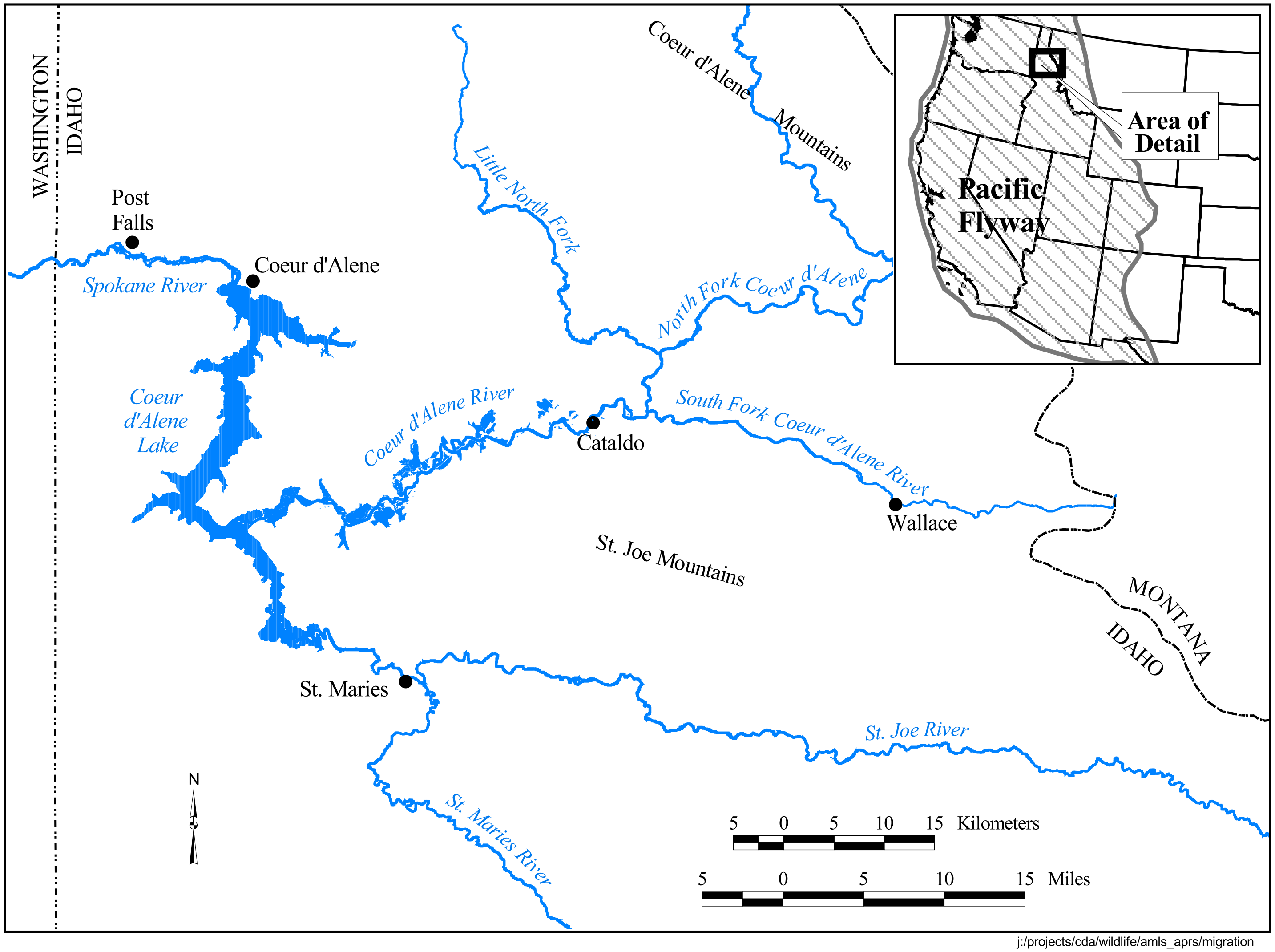


Figure 6-1. Map of the Coeur d'Alene River basin, St. Joe River basin, and surrounding areas. Inset shows area of assessment in relation to the Pacific flyway for migratory waterfowl.

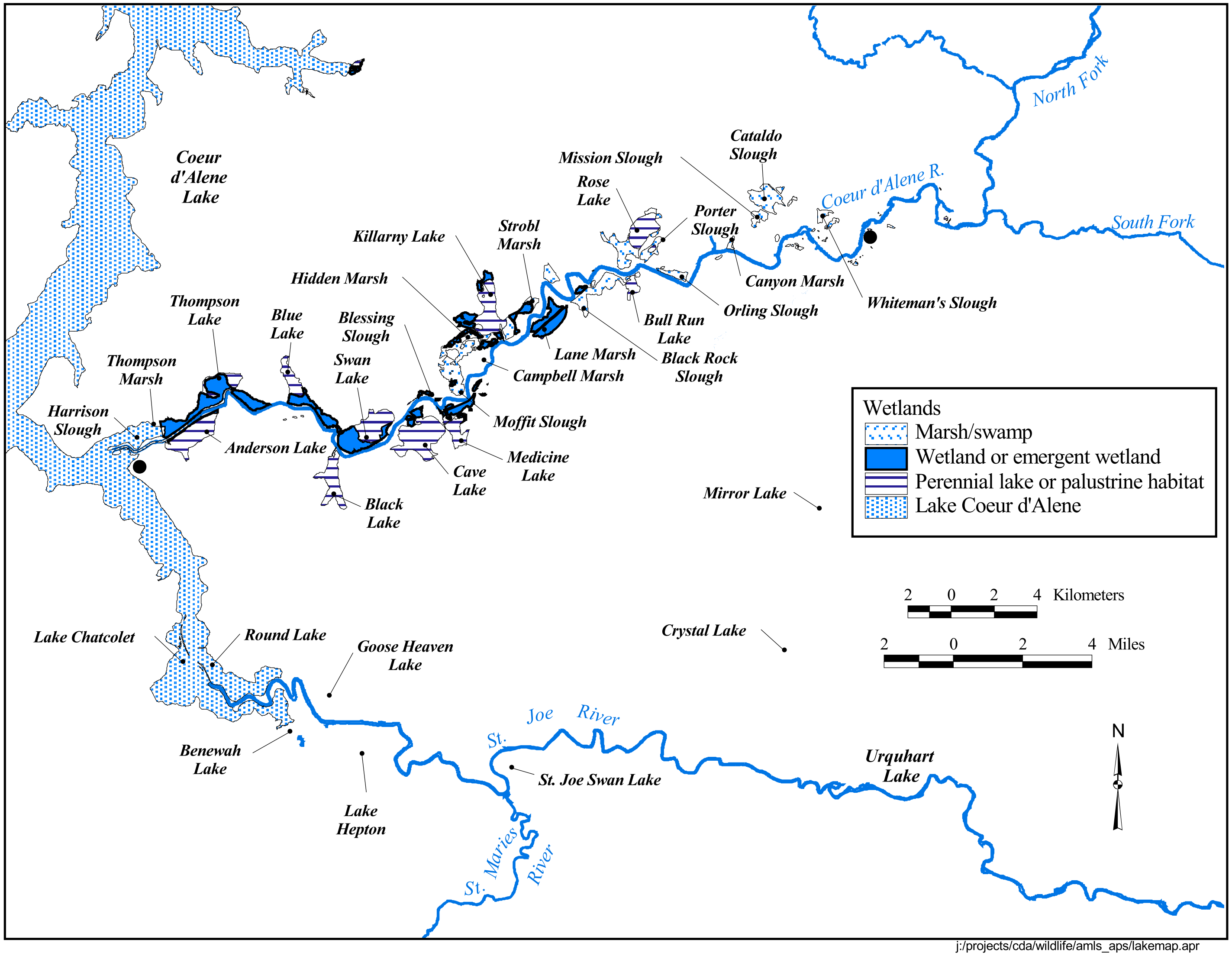


Figure 6-2. Map of the lower Coeur d'Alene basin showing the wetland and lake system adjacent to the Coeur d'Alene River (lateral lakes area).

Figure 6-3. Examples of bird usage in the Coeur d'Alene River basin. Top: tundra swans in Lane Marsh; bottom: mallards and other waterfowl in Canyon Marsh.

Waterfowl are most abundant in the Coeur d'Alene River basin during the spring migration. An estimated 270 tundra swans, 2,060 Canada geese, and 3,000 to 4,000 ducks were observed in the 1955 spring migration (Chupp and Dalke, 1964). Neufeld (1987) reported that flocks of 800 to 2,000 tundra swans and 2,000 to 10,000 Canada geese arrive in the basin during late February or early March, and remain for three to five weeks before flying to more northern breeding grounds. Blus et al. (1991) estimated a partial count of 900 tundra swans in the basin in 1987. Peak one-day waterfowl counts estimated during surveys in 1994 through 1997 were 3,758 tundra swans, 13,230 Canada geese, and 1,730 mallards (Audet et al., 1999c).

Birds of prey that inhabit the Coeur d'Alene River basin include bald eagle *(Haliaeetus leucocephalus)*, osprey *(Pandion haliaetus)*, American kestrel *(Falco sparverius)*, red-tailed hawk *(Buteo jamaicensis)*, northern harrier *(Circus cyaneus)*, sharp-shinned hawk *(Accipter striatus)*, northern goshawk *(Accipiter gentilis)*, great-horned owl *(Bubo virginianus)*, barred owl *(Strix varia)*, and western screech owl *(Otus kennicottii)*. Upland game birds such as ruffed grouse *(Bonasa umbrellus)*, California quail *(Callipepla californica)*, ring-necked pheasant *(Phasianus colchicus)*, and wild turkey *(Meleagris gallopavo)* also inhabit the floodplain and upland habitats.

Songbirds and other neotropical species that inhabit the Coeur d'Alene River basin include thrushes, sparrows, kingbirds, warblers, flycatchers, swallows, hummingbirds, and blackbirds. Amphibians present in the basin include Colombian spotted frogs *(Rana luteiventris)*, bullfrogs *(Rana catesbeiana)*, Pacific treefrogs *(Hyla regilla)*, western toads *(Bufo boreas)*, long-toed salamanders *(Ambystoma Macrodactylum)*, Giant salamanders *(Dicamptodon atterimus), and* tailed frogs *(Ascaphus truei)* (Beck et al., 1997; Howard et al., 1998).

The basin's riparian zones, wetlands, and lateral lakes also provide habitat for beaver *(Castor canadensis)*, mink *(Mustela vison)*, muskrat *(Ondatra zibethicus)*, raccoon *(Procyon lotor)*, and river otter *(Lutra canadensis)*. Larger mammals inhabiting the Coeur d'Alene River basin include black bear *(Ursus americanus)*, bobcat *(Felis rufus)*, cougar *(Felis concolor)*, coyote *(Canis latrans)*, elk *(Cervus elaphus)*, gray wolf *(Canis lupus)*, moose *(Alces alces)*, mule deer *(Odocoileus hemionus)*, and white-tailed deer *(Odocoileus virginianus)* (IDFG, 1987). Small mammals in the basin include meadow voles *(Microtus pennsylvanicus)*, shrews *(Sorex spp.)*, deer mice *(Peromyscus maniculatus)*, and others, which are hunted by birds of prey and larger mammals.

6.2 TOXIC EFFECTS OF LEAD ON WILDLIFE

Although other hazardous metals such as cadmium and zinc are present in the Coeur d'Alene River basin at elevated concentrations (see previous chapters discussing contamination in surface water and sediments) and can be toxic to wildlife, this review focuses on lead because (1) concentrations of lead in sediment and floodplain soils are extremely elevated, and (2) domestic and wildlife sicknesses and deaths in the basin have been diagnosed as lead poisoning (Chupp and Dalke, 1964; Neufeld, 1987; Blus et al., 1991; Audet et al., 1999c).

6.2.1 Literature Review

Exposure to lead can result in adverse effects to multiple tissues and organs that are critical to the viability and reproduction of wildlife (Figure 6-4). Lead affects hematological (blood), renal (kidney), muscular, behavioral, nervous, and reproductive systems (Eisler, 1988; Pain, 1996). Increasing exposure to lead typically results in an increase in the number and severity of adverse effects, from physiological malfunctions to physical deformations and eventually to death (Figure 6-5). Adverse effects of lead on wildlife include the following general categories: mortality and morbidity, disease, behavioral abnormalities, physiological malfunctions, and physical deformations (Table 6-1).

Mortality and morbidity. Clinical signs of lead poisoning in birds have been well documented in the scientific literature and include torpor; vomiting; impaction of esophagus, proventriculus, and gizzard with food leading to starvation; sloughing of gizzard; loss of coordination; accumulation of pericardial fluid; gall bladder enlargement/bile stains on gizzard lining, feces, and perianal plumage; anorexia, emaciation, and muscular atrophy; paralysis in wings and legs; loss of vision; convulsions; coma; and death (Trainer and Hunt, 1965; Venugopal and Luckey, 1978; Friend, 1987; Eisler, 1988; Franson, 1996; Pain, 1996). In general, nestlings are more sensitive than older life stages of birds, and severity of pathology increases with increasing lead exposure (Eisler, 1988).

Lead poisoning in mammals results in a similar suite of effects, including vomiting, loss of appetite, uncoordinated body movements, convulsions, stupor, coma, diarrhea, anemia, and blindness (WHO, 1995; Ma, 1996). Lead poisoning in amphibians includes sloughing of integument, sluggishness, and decreased muscle tone (Eisler, 1988). Death generally results from one or a combination of these physical and physiological impairments.

Lead can bioaccumulate in the tissues of prey organisms because it is excreted slowly, resulting in secondary poisoning of predators (Eisler, 1988).

Disease. Lead affects multiple organ systems of animals, resulting in a general decrease in health and susceptibility to disease or pathogen exposure (Eisler, 1988). Decreased host resistance to pathogens due to lead exposure has been demonstrated in laboratory tests with several species of mammals (McCabe, 1994). For example, sublethal lead exposure in mice reduced the resistance to bacterial infection by *Salmonella typhimurium* (Hemphill et al., 1971). Dietary lead (100 ppm) exposure altered immune responses of chicken, including phagocytosis and antibody titres (Hill and Oureshi, 1998). Although data are limited, lead appears to impair antibody production, reduce disease resistance, and increase mortality in animals infected with bacterial and viral agents (WHO, 1995).

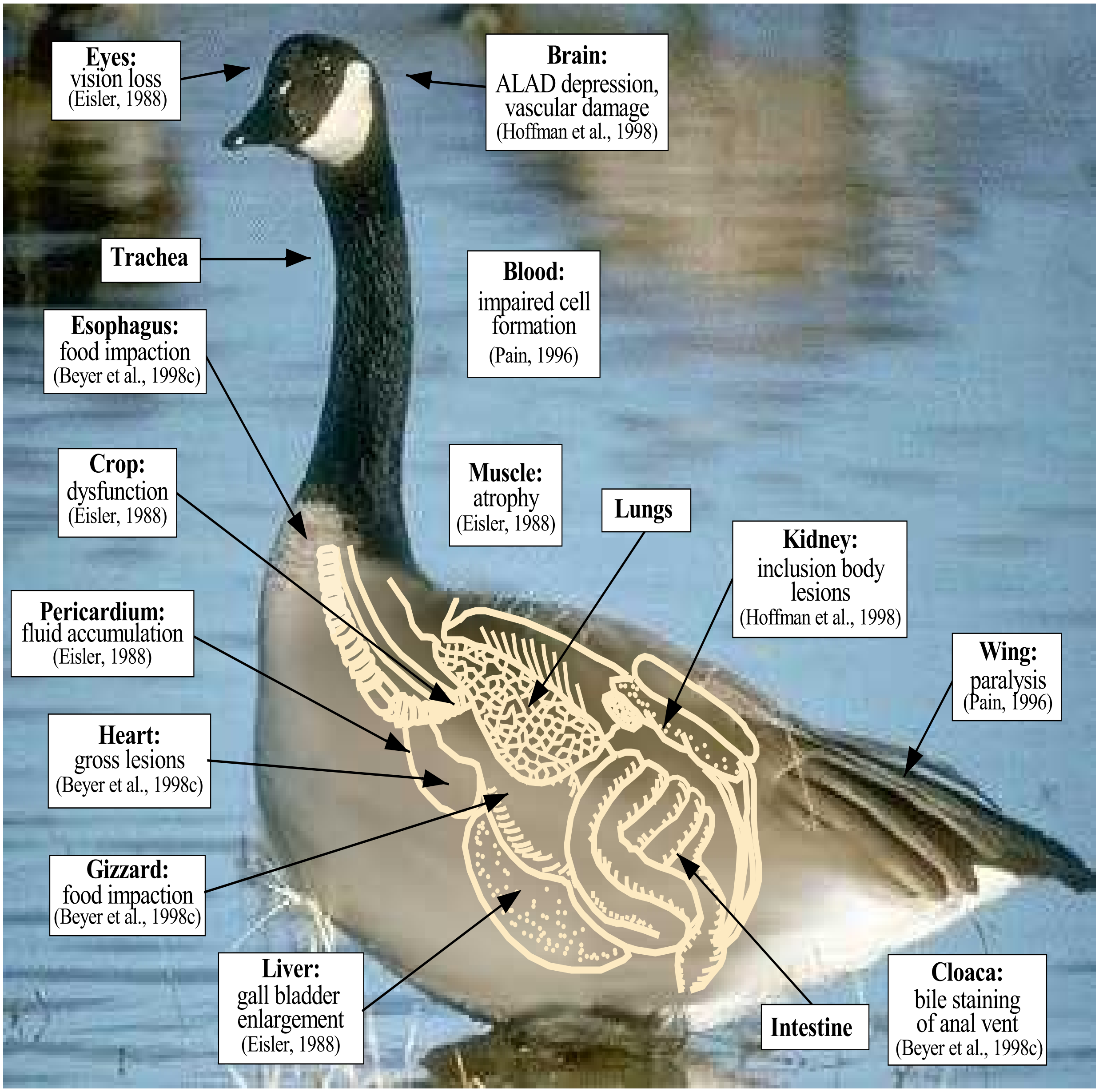


Figure 6-4. Generalized anatomy of birds showing major organs and tissues affected by lead exposure. Adapted from Hickman et al., 1974.

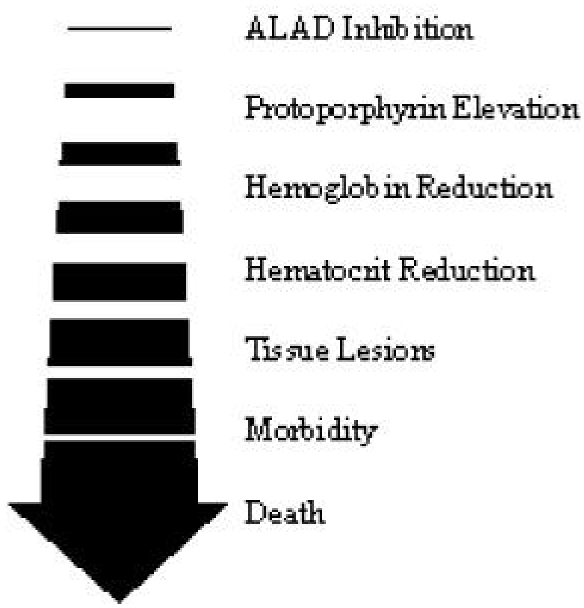


Figure 6-5. Increasing lead exposure results in an increase in the number and severity of adverse effects in wildlife from biochemical changes to death. ALAD is an enzyme involved in blood formation. Protoporphyrin, hemoglobin, and hematocrit also are components of blood that can be affected by lead.

Table 6-1
Adverse Effects of Lead on Wildlife

General Effect	Specific Effects	Information Sources
Mortality and morbidity	Torpor, vomiting, starvation, loss of coordination, paralysis in wings and legs, loss of vision, coma, death	Eisler (1988), Franson (1996), Pain (1996)
Disease	Impaired immunological responses; lower resistance to infections and pathogens	Hemphill et al. (1971), Hill and Oreshi (1998)
Behavioral abnormalities	Hyperactivity, impaired learning and memory, impaired avoidance behavior	Eisler (1988), Burger (1998)
Physiological malfunctions	Delta-aminovulinic acid dehydratase (ALAD) depression; weight loss, reproductive impairment	Dieter and Finley (1979), Hoffman et al. (1985), Eisler (1988), Pain (1996), Kelly et al. (1998)
Physical deformations	Impacted esophagus, emaciation, bile staining of gizzard lining, gall bladder enlargement, muscular atrophy; renal intranuclear inclusion bodies	Trainer and Hunt (1965), Kendall and Driver (1982), Eisler (1988), Franson (1996), Pain (1996)

Behavioral abnormalities. Lead can cause neurotoxicity and behavioral impairments in amphibians, birds, and mammals, including disruption of social behavior, hyperactivity, distractibility, impaired learning ability, and impaired predator avoidance. For example, Burger (1998) reported impaired sibling recognition in herring gulls experimentally exposed to lead. In rats, lead exposure alters development, affects specific motor skills, and can result in long-term cognitive deficits (Kuhlmann et al., 1997; Mello et al., 1998). Acutely toxic doses of lead may cause loss of coordination and paralysis. Retarded brain growth of laboratory mammals has also been reported (Eisler, 1988). Laboratory studies with mammalian species have demonstrated that lead impairs learning and memory functions in nearly all life stages of animals (WHO, 1995). Sublethal lead exposure during early development of animals produces behavioral change and deficits in learning ability that persist beyond the period of exposure (Rice, 1985; Rice and Karpinski, 1988; Ma, 1996; ATSDR, 1997; Stewart et al., 1998). Eisler (1988) concluded that lead causes neurobehavioral deficits such as learning impairment at very low blood lead levels, and at levels less than those that cause more overt signs of toxicity. The ecological importance of lead induced behavioral abnormalities may include death of wildlife caused by increased susceptibility to predation, and reduced reproductive success from altered nest building, parenting behavior, or maternal imprinting (Eisler, 1988; Lefcort et al., 1998).

Physiological malfunctions. Physiological malfunctions caused by lead exposure include hematological responses associated with inhibition of the formation of red blood cells, impairment of renal function, weight loss, and impaired reproduction.

Hematological responses are among the first measurable biochemical changes in animals exposed to lead, including inhibition of delta-aminolevulinic acid dehydratase (ALAD) activity, elevation of protoporphyrin, and reductions in hemoglobin and hematocrit levels. Increasing lead exposure leads to a cascade of biochemical changes measurable in blood, from ALAD inhibition, to protoporphyrin elevation, to reduction in hemoglobin and hematocrit, and ultimately to reduced viability of the animal from the reduced capacity to transport oxygen to the brain and other tissues (Figure 6-6).

Inhibition of blood ALAD activity after exposure to lead has been demonstrated in multiple species of wildlife (Pain, 1996). ALAD inhibition also occurs in brain, spleen, liver, kidney, and bone marrow (Hoffman et al., 1985). Anemia, or reduced hematocrit and hemoglobin resulting from inhibition of the enzymes ALAD and ferrochelatase involved in hemoglobin synthesis (Figure 6-6), may occur following a >75% inhibition of ALAD activity (Hoffman et al., 2000). ALAD inhibition by lead in mallard ducks has been associated with an increase in brain levels of the enzyme butrylcholinesterase. The increase in butrylcholinesterase may cause destruction of neural cells in the cerebellum (Dieter and Finley, 1979). Even a partial loss of cerebellum tissue is severely debilitating in waterfowl because functions critical to survival (e.g., visual, auditory, motor, and reflex responses) are integrated in this region of the brain (Dieter and Finley, 1979).

Lead exposure impairs kidney function by accumulating in the proximal convoluted tubule cells of the renal cortex in mammals, resulting in waste product (urea and uric acid) accumulation in the blood (Quarterman, 1986).

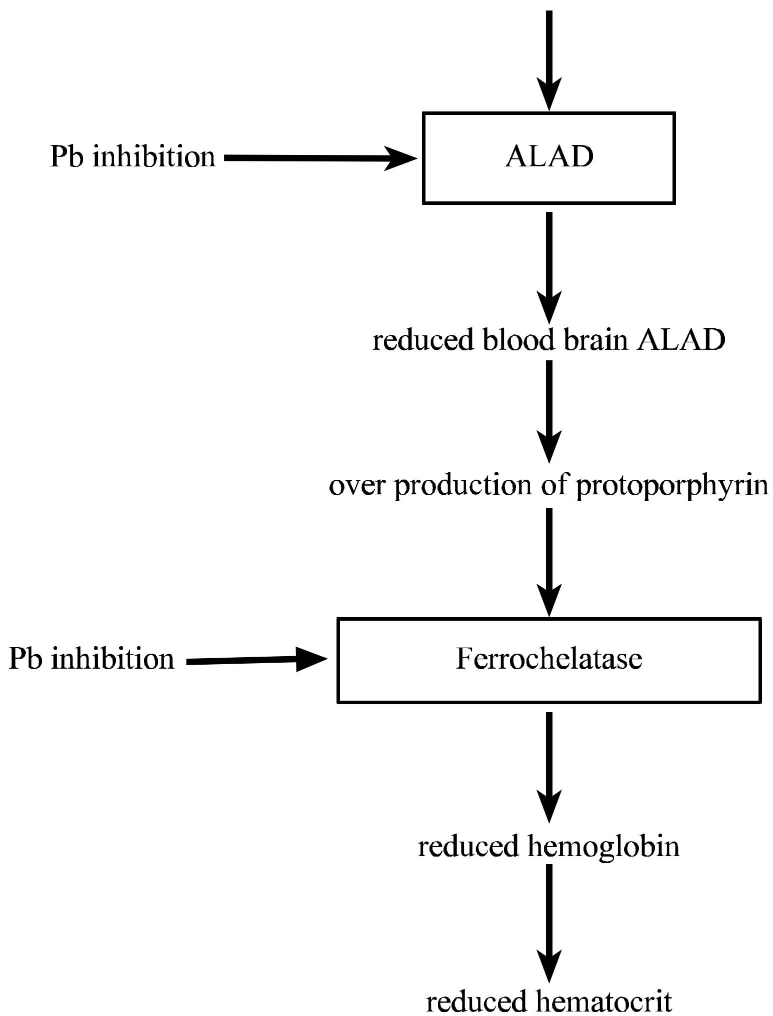


Figure 6-6. Biochemical pathway showing lead effects on blood formation.

The growth and development of animals also can be impaired following toxic exposure to lead. Emaciation is a common effect observed in lead poisoned waterfowl (Beyer et al., 1998c). Altered growth can affect the viability and reproductive success of birds (O'Connor, 1984), and delayed development may preclude metamorphosis of amphibians living in temporary water bodies (Lefcort et al., 1998).

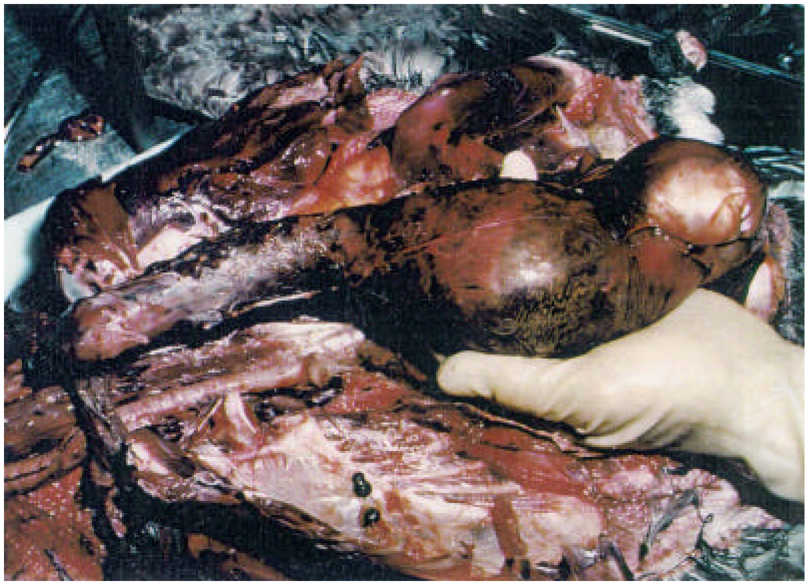
Lead can impair wildlife reproduction at very low dietary exposures. For example, Edens et al. (1976) observed reduced egg production in Japanese quail *(Coturnix coturnix)* at dietary concentrations of lead between 1 and 100 ppm.

Physical deformations. Physical deformations include both external signs and gross pathological lesions of lead poisoning (Wetmore, 1919; Trainer and Hunt, 1965; Cook and Trainer, 1966; Bagley et al., 1967; Karstad, 1971; Sileo et al., 1973; Clemens et al., 1975; Wobeser, 1981; Pain, 1992; Locke and Thomas, 1996).

Physical deformations of lead-poisoned waterfowl include impaction of the esophagus, proventriculus, or gizzard with food (Figure 6-7), leading to starvation, emaciation, and atrophy of skeletal muscles and viscera. Lead exposure causes roughening or sloughing of the lining of the gizzard, gall bladder engorgement, and regurgitating and bile staining of the gizzard lining, feces, and the perianal plumage. Excessive pericardial fluid may accumulate, and the heart may develop white streaks that are presumed to be necrotic tissue and are associated with abnormal heart function. Tissues in general may appear pale, suggesting anemia, and the subcutaneous tissues of the submandibular area may become edemic.

Lead causes histological deformations such as interstitial fibrosis, edema, formation of acid-fast renal intranuclear inclusion bodies (RIIBs; Figure 6-8), and hemosiderosis in the liver and kidney. RIIBs, which are diagnostic of lead poisoning, are kidney lesions containing a lead-protein complex in the cell nucleus (L. Sileo, USGS-BRD, National Wildlife Health Center, pers. com., December 10, 1999). RIIBs can be seen under a microscope when treated with an acid-fast stain. Pathogens may cause other kinds of inclusion bodies in cells, but they do not react with the acid-fast stain (Locke et al., 1966). Hemosiderosis is the presence of excessive amounts of the iron-containing pigment hemosiderin (Figure 6-8). Hemosiderin results from the metabolic breakdown of hemoglobin from red blood cells (L. Sileo, USGS-BRD, National Wildlife Health Center, pers. com., December 10, 1999). Lead also causes blood vessel damage in the brain, nerve cell and ganglia damage, and demyelinating lesions (loss of nerve cell sheath) (Eisler, 1988).

Lead concentrations associated with toxicity. According to the scientific literature, blood concentrations greater than 0.5 ppm and liver concentrations of 6 to 15 ppm (wet weight) have been associated with clinical poisoning in birds, including overt signs of poisoning such as muscle wasting, weakness, anemia, and incoordination (Table 6-2). Clinical poisoning in mammals occurs at similar tissue levels as in birds. For example, Ma (1996) suggested that clinical poisoning in mammalian species occurs at blood lead levels of greater than 0.35 ppm to greater than 0.6 ppm, which is within the range of blood levels causing clinical poisoning in birds (0.5 to >5 ppm; Table 6-2). Liver lead concentrations of greater than 10 ppm wet weight are often associated with clinical signs of lead poisoning (Zook et al., 1972; Osweiler et al., 1978; Ma, 1996), although signs of lead poisoning have occurred at lower liver lead concentrations (Clarke, 1973; Osweiler et al., 1978; Ma, 1996). Kidney lead concentrations greater than 27 ppm wet weight also are associated with clinical signs of lead poisoning (Ma, 1996). Liver lead concentrations greater than 3 ppm wet weight and kidney lead concentrations greater than 7.5 ppm wet weight are considered diagnostic for lead poisoning in wild mammals (Ma, 1996). These lead concentrations are also within the range reported for birds (6 to 20 ppm; Table 6-2). Blood concentrations greater than 1 ppm and liver concentrations greater than 15 ppm are associated with death and morbidity in birds (Table 6-2).



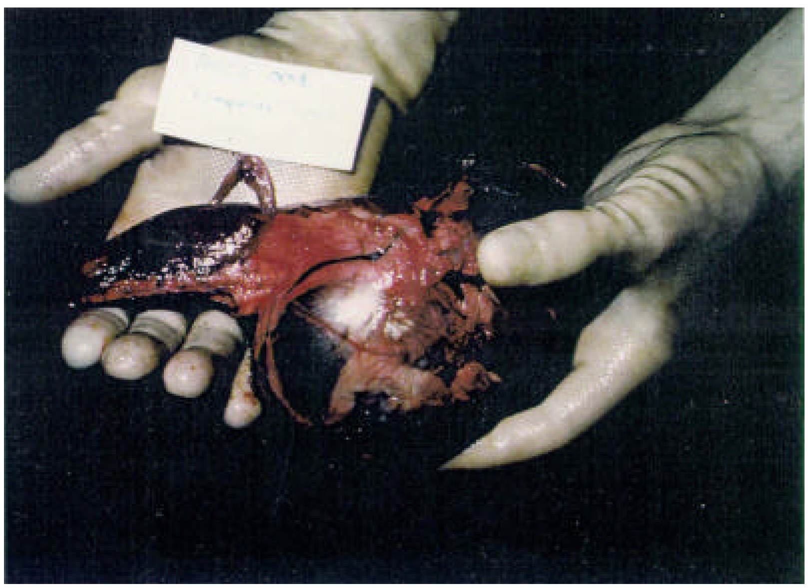


Figure 6-7. Top: Distended esophagus and proventriculus of a lead-poisoned Canada goose from the Coeur d'Alene Basin, ID. The proventriculus (in the gloved hand) is abnormally packed with food. Liver lead: 15.02 ppm. Photo date: April 15, 1997. **Bottom: Normal esophagus and proventriculus of a trumpeter swan from Wisconsin.** Cause of death unknown. Liver lead: below detection. Photo date: December 9, 1998. Source: L. Sileo, USGS, National Wildlife Health Center.

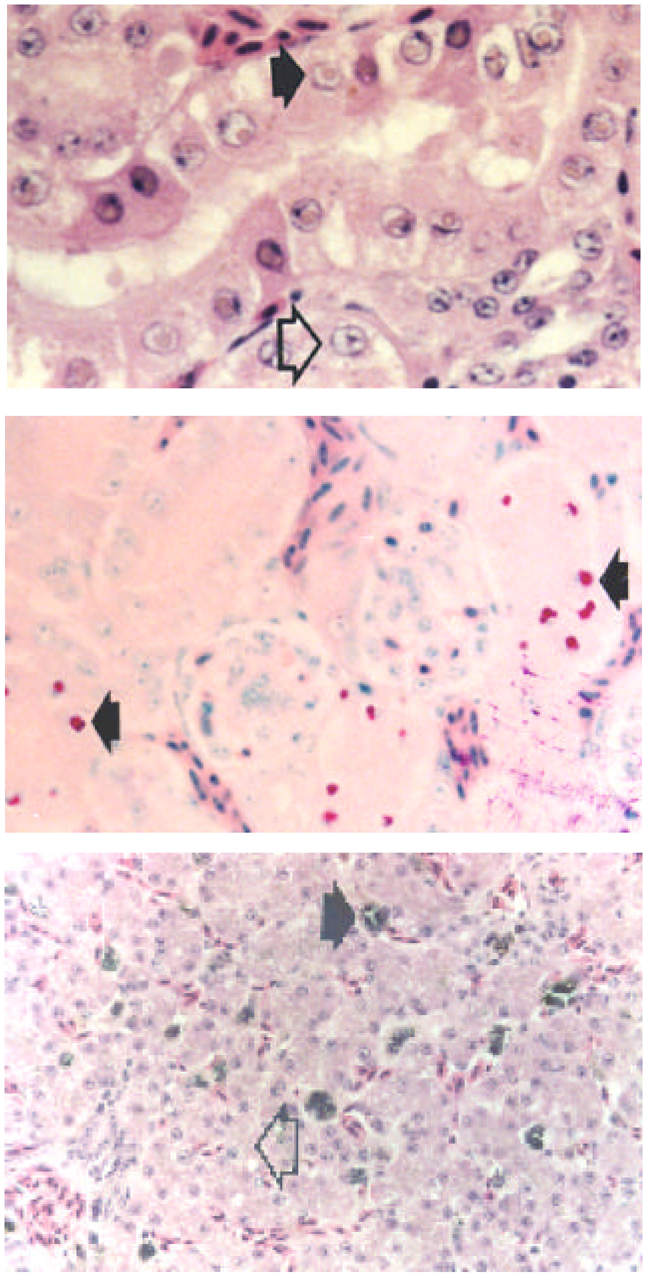


Figure 6-8. Histological deformations. Top: Microscopic section of a kidney (hematoxylin/eosin stained) from a mute swan (*Cygnus olor*) experimentally fed Coeur d'Alene River sediment (Day et al., 1998). Open arrow marks normal nuclei and closed arrow marks renal intranuclear inclusion body (RIIB). Middle: Microscopic section of kidney (acid fast stain) from a mallard duck experimentally fed Coeur d'Alene sediment (Heinz et al., 1999); closed arrows mark RIIBs. Bottom: Liver from mute swan (hematoxylin/eosin stained) experimentally fed sediment from the Coeur d'Alene River (Day et al., 1998). The prominent, irregular, dark masses (closed arrow) are deposits of hemosiderin. In many other liver cells are tiny brown granules (open arrow) that are also hemosiderin deposits. Hemosiderin is present in normal livers, but deposits this prominent are abnormal.
Source: L. Sileo, USGS, National Wildlife Health Center.

Table 6-2
Lead Concentrations (ppm, wet weight) in Bird Tissues Associated with Toxicity

Tissue	Poisoning Category	Waterfowl (Pain, 1996)	Birds of Prey (Franson, 1996)	Doves, Pigeons (Franson, 1996)	Quail, Pheasant (Franson, 1996)
Blood	No effects	< 0.2	< 0.2	< 0.2	< 0.2
	Subclinical[a]	0.2 to 0.5	0.2 to 1.5	0.2 to 2.5	0.2 to 3
	Clinical/toxic[b]	0.5 to 1	> 1	> 2	> 5
	Severe clinical/death[c]	1	> 5	> 10	> 10
Liver	No effects	< 2	< 2	< 2	< 2
	Subclinical	2 to 6	2 to 4	2 to 6	2 to 6
	Clinical/toxic	6 to 15	> 3	> 6	> 6
	Severe clinical/death	> 15	> 5	> 20	> 15
Kidney[d]	No effects	-	< 2	< 2	< 2
	Subclinical	-	2 to 5	2 to 20	2 to 20
	Clinical/toxic	-	> 3	> 15	> 15
	Severe clinical/death	-	> 5	> 40	> 50

a. Physiological effects (e.g., ALAD depression) without overt signs of poisoning.
b. Overt signs of poisoning, including muscle wasting, weakness, anemia, incoordination.
c. Mortality and morbidity.
d. Kidney: birds of prey; doves, pigeons; quail, pheasant.

Reproduction is impaired at dietary levels between 1 and 100 ppm lead in sensitive bird and mammal species (Eisler, 1988). For example, Edens et al. (1976) observed reduced egg production in Japanese quail *(Coturnix coturnix)* at dietary concentrations between 1 and 1,000 ppm lead. Pattee (1984) observed no effect on reproduction of American kestrels at dietary concentrations of 10 and 50 ppm. Lowest observed adverse effect level (LOAEL)[1]-based toxicity benchmarks for lead proposed by Sample et al. (1996) ranged from 9.4 to 1,182 ppm in diet for bird and mammal species.

1. LOAEL-based toxicity benchmarks represent lead-ingestion thresholds at which adverse effects are likely to become evident (Sample et al., 1996).

6.2.2 Data Collected Previously in the Assessment Area

There have been numerous reports of the environmental contamination, exposure, and adverse effects of metals on wildlife resources of the Coeur d'Alene River basin (Table 6-3).

Table 6-3
Chronology of Documentation of Exposure and Effects of Hazardous Substances in Coeur d'Alene Wildlife[a]

Observation Year	Species	Observations	Information Source
1924-1956	Waterfowl[b]	Exposure, deaths	Chupp and Dalke (1964)
1924-1986	Waterfowl	Exposure, deaths, lesions	Neufeld (1987)
1931	Tundra swan	Deaths	Bureau of Biological Survey (1931)
1955	Waterfowl, birds of prey	Deaths; eagle predation	Chupp (1956)
1971	Waterfowl	Deaths	Bruner (1971)[f]
1974	Tundra swan	Deaths	Benson et al. (1976)
1975	Mice, vegetation	Exposure	Herman et al. (1975)
1981-1983	Mammals[c]	Exposure	Blus et al. (1987)
1982-1989	Waterfowl, mammals, vegetation	Exposure, deaths	Krieger (1990)
1982	Waterfowl	Exposure, lesions	Stroud (1982)
1986-1987	Mink	Exposure	Blus and Henny (1990)
1986-1987	Wood duck	Exposure, sublethal effects	Blus et al. (1993)
1986-1987	Osprey	Exposure, sublethal effects	Henny et al. (1991)
1986-1987	Birds of prey,[d] mammals	Exposure	Henny et al. (1994)
1987	Waterfowl, songbirds[e]	Exposure, sublethal effects	Blus et al. (1995)
1987-1989	Tundra swan	Exposure, deaths, lesions	Blus et al. (1991)
1993	Waterfowl	Exposure, sublethal effects	Mullins and Burch (1993)
1994-1995	Aquatic biota, mallard duck	Exposure, sublethal effects	Burch et al. (1996)
1994-1995	Tundra swan	Exposure, deaths, lesions	Blus et al. (1999)
1994-1995	Mammals	Exposure	Szumski (1999)
1997	Waterfowl	Exposure	Audet et al. (1999a)

a. Adapted from Audet, 1997, which provides complete documentation.
b. Multiple waterfowl species (e.g., tundra swans, mallards).
c. Multiple mammal species (e.g., mink, deer mice, muskrat).
d. Multiple birds of prey species (e.g., American kestrel, red-tailed hawk, western screech owl).
e. Multiple songbird species (e.g., tree swallow, American robin).
f. Waterfowl Mortality on the Lower Coeur d'Alene River. Idaho Department of Fish and Game. Unpublished Report. 16 pp.

Note: Supplemental studies conducted by the Trustees between 1992 and 1997 provide additional documentation of exposure, deaths, lesions, and sublethal effects (summarized in Section 6.5).

Migratory Bird Exposure and Effects

Waterfowl deaths in the Coeur d'Alene River basin have been reported since 1924, and bird carcasses collected from the basin consistently have shown evidence of lead exposure and lesions indicative of lead poisoning (e.g., Chupp and Dalke, 1964; Neufeld, 1987). Waterfowl deaths in the basin have been investigated and reported by various agencies and university researchers, including the Bureau of Biological Survey (1931); Idaho Department of Health and Welfare (Benson et al., 1976); Idaho Department of Fish and Game (Bruner, 1971; Neufeld, 1987); U.S. Bureau of Sport Fisheries and Wildlife (Chupp and Dalke, 1964); U.S. DOI Bureau of Land Management, Washington State University, and University of Idaho (Krieger, 1990); and the U.S. Fish and Wildlife Service (Blus et al., 1991; Audet et al., 1999c).

In 1948, about 100 of an estimated 400-600 swans died in the basin, despite attempts by wildlife biologists to disperse them from the area (Chupp and Dalke, 1964). In 1954 and 1955, Chupp and Dalke (1964) recorded dead waterfowl in the Coeur d'Alene River basin, including tundra swans, Canada geese, eight species of duck, and American coots. They concluded that the dead tundra swans they examined had died from lead poisoning and that the source of the lead was the river sediments laden with mine waste that coated the aquatic vegetation eaten by the waterfowl. Chupp and Dalke (1964) suggested that waterfowl mortality increased in the Coeur d'Alene River basin when weather conditions caused migrating birds to stay longer in the area.

In 1974, Benson et al. (1976) found 13 lead-poisoned tundra swans at Mission Slough and concluded that their exposure and death resulted from ingestion of lead-contaminated vegetation. Five of six waterfowl carcasses from the Coeur d'Alene River basin examined by Stroud (1982) were diagnosed as lead poisoned without ingested lead shot. An estimated 200 tundra swans (17%) of a group of 1,200 died in the basin in 1982 (Krieger, 1990). The swans examined were diagnosed with lead poisoning based on emaciation, engorged gall bladder, impacted proventriculus and gizzard, empty gastrointestinal tracts with bile, and toxic levels of lead in tissues (Krieger, 1990). Thirty-two dead tundra swans diagnosed as lead poisoned were collected from the basin between 1987 and 1989 (Blus et al., 1991). Neufeld (1987) reported swan mortality throughout the Coeur d'Alene River Wildlife Management Area (lower Coeur d'Alene River basin) associated with the deposition of contaminated sediment on vegetation by high water just before the spring waterfowl migration.

Blus et al. (1995) measured highly elevated lead concentrations in blood and livers of American robins from the Coeur d'Alene River basin, compared to concentrations in American robins from reference areas. Liver lead concentrations were slightly elevated in tree swallows *(Tachycineta bicolor)*. Blus et al. (1995) found that lead had accumulated to potentially toxic levels in nestling robins (maximum concentrations of 0.87 μg/g in blood and 5.6 μg/g in liver) and mallards (maximum concentrations of 10.2 μg/g in blood and 2.8 μg/g in liver).

Studies of the physiological effects of lead on birds of prey in the Coeur d'Alene River basin (1986-1987) indicated that despite the fact that raptors in the basin are less exposed to lead than waterfowl, some still exhibit reductions in ALAD activity greater than 50% (Henny et al., 1991; Henny et al., 1994). Adult and nestling osprey *(Pandion haliaetus)* along the Coeur d'Alene River had elevated blood lead concentrations and exhibited greater than 50% reduction in ALAD activity compared to osprey from reference areas (Henny et al., 1991). In addition, ALAD activity was reduced by 35% in nestling northern harriers *(Circus cyaneus)*, by 55% in nestling American kestrels *(Falco sparverius)*, and by 81% in adult American kestrels of the Coeur d'Alene River basin (Henny et al., 1994).

In 1995, Burch et al. (1996) reported blood lead concentrations ranging from 0.29 to 1.37 ppm (mean 0.85 ppm) in mallard ducks from the Page Pond wetlands (Bunker Hill Superfund Site). Blood lead concentrations in mallards collected in 1997 from the Page Pond Wastewater Treatment Plant ranged from 0.67 to 10 ppm (mean 2.68 ppm) (Audet et al., 1999a). Audet et al. (1999a) found that the mean blood lead concentration in adult mallard ducks (3.7 ppm) was twice that of hatch year mallards (1.73 ppm). Blood lead concentrations in mallard ducks collected in 1997 from the Page Ponds Wastewater Treatment Plant area were significantly greater ($p = 0.0095$) than blood lead concentrations at the same site in 1995 (mean 0.846 ppm, range 0.29 to 1.37 ppm) (Audet et al., 1999a).

Mammal Exposure and Effects

Studies of lead concentration in wild mammals of the Coeur d'Alene River basin have shown elevated concentrations of lead in tissues and ingesta of muskrats, mink, raccoons, beaver, deer, voles (*Microtus* spp.), and deer mice (Blus et al., 1987; Blus and Henny, 1990; Audet, 1997; Szumski, 1999).

Liver and kidney lead concentrations in mink collected from the lateral lakes of the Coeur d'Alene River basin were elevated relative to concentrations in mink from reference sites (Blus et al., 1987; Blus and Henny, 1990; Szumski, 1999). Liver lead concentrations in lower Coeur d'Alene River basin mink were significantly greater ($p < 0.05$) than concentrations in mink collected from the North Fork Coeur d'Alene River and from Washington. Liver lead concentrations averaged 4.1 and 3.2 ppm wet weight in 1981-82 and 1986-1987, respectively, and ranged up to 34 ppm wet weight, which was the highest liver lead concentration ever recorded in a mink (Blus et al., 1987; Blus and Henny, 1990). Liver lead concentrations were positively correlated with lead concentrations of stomach contents, which ranged up to 51 ppm. Blus and Henny (1990) concluded that lead concentrations in mink in the Coeur d'Alene River basin were sufficient to cause adverse effects.

Tissue concentration data indicated no decrease in exposure to lead of mink between 1981 and 1987 ($p > 0.05$) (Blus et al., 1987; Blus and Henny, 1990), and mean liver lead concentrations in juvenile mink collected from the lateral lakes in 1994 and 1995 (Szumski, 1999) and adult mink collected in 1996 (National Wildlife Health Center Necropsy Report #WM96CO83, USGS-BRD, Madison, WI) (2.1 ppm wet weight) were only slightly lower than the 1980s averages.

Mean lead concentrations in mink livers from the Coeur d'Alene River basin (2 to 4 ppm wet weight) were much greater than mean concentrations reported in mink from state-wide surveys in Virginia (0.05 ppm wet weight; Ogle et al., 1985) and New York (0.27 ppm wet weight; Foley et al., 1991), and across Ontario (0.10 to 0.35 ppm wet weight; Wren et al., 1988), including areas affected by mining and smelting. Lead concentrations in Coeur d'Alene River mink were also much greater than concentrations measured in mink collected downstream of a copper mining and smelting region in Montana (mean 0.26 ppm wet weight; Szumski, 1998).

Geometric mean lead concentrations in the livers of muskrat collected from the Coeur d'Alene River basin (n = 72) ranged from 0.2 ppm wet weight to 1.5 ppm wet weight (Blus et al., 1987; Krieger, 1990; Audet, 1997; Szumski, 1999). The maximum liver lead concentration (16.3 ppm wet weight) was reported in a muskrat collected during the 1994-1995 trapping season from the lateral lakes area (Szumski, 1999). Lead concentrations in muskrat tissues reported by both Blus et al. (1987) and Szumski (1999) greatly exceeded concentrations in muskrats collected at reference sites on the Big Hole River in Montana (mean liver lead 0.04 ppm wet weight).

Mean liver lead concentrations in Coeur d'Alene River muskrats (1.13 ppm wet weight) were also much greater than concentrations in livers of muskrats collected in the Missouri lead mining district (0.69 ppm wet weight; Niethammer et al., 1985), areas of Pennsylvania (0.002 to 0.15 ppm wet weight; Everett and Anthony, 1976), and near an ore smelter in Manitoba (0.16 ppm wet weight; Radvanyi and Shaw, 1981), but were lower than concentrations reported in muskrats from a tidal marsh in Pennsylvania receiving industrial and municipal wastes (3.7 to 5.3 ppm wet weight; Erickson and Lindzey, 1983).

Beaver collected from the Coeur d'Alene River as part of a reconnaissance study that preceded injury studies (Audet, 1997) had a mean liver lead concentration of 1.32 ppm wet weight, which is similar to liver lead concentrations in muskrats from the same area (Szumski, 1999). The mean liver lead in Coeur d'Alene River beaver was also similar to concentrations reported in beaver collected near a metal smelter in Ontario (2.7 ppm wet weight; Hillis and Parker, 1993).

Liver lead concentrations means were also elevated in Coeur d'Alene River basin raccoons (1.10 ppm wet weight) compared to concentrations in reference raccoons from an undisturbed area in Montana (0.07 ppm wet weight; Szumski, 1999).

Deer kidneys collected in 1987 and 1988 near the former Bunker Hill smelters and along the South Fork Coeur d'Alene River contained significantly elevated ($p < 0.05$) lead (1.7 ppm wet weight) compared to deer from reference areas (1.08 ppm wet weight; Dames & Moore, 1990).

Herman et al. (1975) evaluated whole body metal concentrations and species abundance and diversity of small mammals with distance from the smelters near Kellogg. Lead concentrations in deer mice collected near the smelters were greatly elevated relative to concentrations in deer mice from reference sites to the north and south of the smelters. In mice collected within 5 miles of the smelters, geometric mean concentrations of whole body lead ranged from 7.3 to 332.5 ppm wet weight. Geometric mean lead concentration in reference mice was <5 ppm wet weight. Small mammal diversity increased with distance from the smelters; this was attributed to the adverse effects of metals on plant diversity.

Deer mice and voles collected near tailings ponds in the Kellogg area in 1982 and 1983 (shortly after the closure of the smelters) contained greatly elevated whole body, kidney, and liver concentrations of lead (Blus et al., 1987). Whole body lead concentrations in deer mice averaged 55.3 ppm wet weight (geometric mean) and in voles, 54.7 ppm wet weight (geometric mean). Deer mice and voles collected along the South Fork and mainstem Coeur d'Alene rivers between Kellogg and Thompson Lake in 1986 also contained greatly elevated whole body lead concentrations (geometric mean >40 ppm wet weight in deer mice; Henny et al., 1994). Concentrations declined with distance downstream from Kellogg, but even as far as 40 km and 60 km downstream from the smelter, concentrations in whole body deer mice still averaged 22.8 ppm wet weight and 19 ppm wet weight, respectively.

Whole body and kidney lead concentrations were also significantly elevated in deer mice collected in 1988 near the smelter and in the Kellogg area relative to mice collected from a reference area ($p < 0.01$; Dames & Moore, 1990). Kidneys in several mice collected near the smelter evidenced renal pathologies consistent with damage produced by lead and cadmium, but no intranuclear inclusion bodies were observed.

Audet (1997) measured whole body lead concentrations in voles collected in 1992 from Kellogg and from Killarney Lake. Mean lead concentrations (13.7 ppm wet weight) were significantly greater ($p < 0.0001$) than lead concentrations in voles from the St. Joe River (0.36 ppm wet weight). Mean concentrations of liver lead (1.43 ppm wet weight) were also greater in deer mice collected from the Coeur d'Alene River than in deer mice collected from the St. Joe River (0.25 ppm wet weight).

Mean whole body concentrations of lead in deer mice collected from several sites in the vicinity of the smelters at Kellogg ranged from 7.3 to 111.5 ppm wet weight (Herman et al., 1975; Dames & Moore, 1990; Henny et al., 1994) and were 8 to 124 times concentrations reported for deer mice from an unmined area in Wisconsin (<0.1 to 0.9 ppm wet weight; Smith and Rongstad, 1981). Mean whole body concentrations of lead in voles collected from the Coeur d'Alene River basin (2.6 to 54.7 ppm wet weight; Blus et al., 1987; Henny et al., 1994; Audet, 1997) were 4 to 78 times concentrations reported for voles from an unmined area in Wisconsin (0.45 to 0.7 ppm wet weight; Smith and Rongstad, 1981). While lead concentrations in the Kellogg area apparently have declined, they still remain greatly elevated.

Amphibian Exposure and Effects

Tadpoles collected from East Page Swamp (Bunker Hill Superfund Site) contained 271 ppm (dry weight) of lead, which is substantially greater than lead concentrations in tadpoles from uncontaminated sites (e.g., 14 to 23 ppm dry weight; Mullins and Burch, 1993). Lefcort et al. (1998) and Lefcort et al. (1999) observed reduced survival, reduced growth and altered development (delayed metamorphosis), and behavioral abnormalities (altered predator avoidance and competitive interactions) in amphibians (spotted frog *Rana luteiventris* tadpoles) exposed to stream bank soil from the Coeur d'Alene River basin.

6.3 INJURIES EVALUATED IN THE ASSESSMENT AREA

Injuries to wildlife resources in the Coeur d'Alene River basin were assessed in accordance with the DOI guidance for determination of injury to biological resources [43 CFR § 11.62 (f)(4)]. The following injury categories were evaluated: death [43 CFR § 11.62 (f)(4)(i)], physiological malfunctions [43 CFR § 11.62 (f)(4)(v)], and physical deformation [43 CFR § 11.62 (f)(4)(vi)]. These injuries were selected for assessment because existing information indicated that lead was the cause of observed bird mortalities in the basin and that lead had caused physiological malfunctions such as ALAD inhibition, and because lead is known to cause these types of adverse effects in wildlife, as discussed in Section 6.2.1.

Assessment of associated injuries to the supporting ecosystem (surface water, sediments, riparian resources) is described in separate chapters of this report.

Injury Category: Death

The following injury definitions apply:

- Injury has occurred when a significant increase in the frequency or number of dead or dying birds can be measured in a population sample from the assessment area as compared to a population sample from a control area [43 CFR § 11.62 (f)(4)(i)(C)].

To address this injury definition, the number and frequency of dead and dying birds were determined during field investigations in both the lower Coeur d'Alene River basin and reference areas. Field investigations included waterfowl and mortality surveys and laboratory diagnosis of the cause of wildlife deaths.

- Injury has occurred when 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)].

Toxicity tests were conducted under controlled laboratory conditions. The response of birds exposed to Coeur d'Alene River basin sediments was compared to the response of birds exposed to reference area sediment.

Injury Category: Physiological Malfunctions

The following injury definition applies:

- Injury has occurred when the activity level of whole blood ALAD in a sample from the population of a given species at an assessment area is significantly less than mean values for a population at a control area, and ALAD depression of at least 50% can be measured [43 CFR § 11.62 (f)(4)(v)(C)].

  Blood ALAD activity in waterfowl, birds of prey, and songbirds in the Coeur d'Alene and reference areas was quantified. Controlled laboratory studies were conducted to determine the relationship between waterfowl ingestion of Coeur d'Alene sediment, lead exposure, and ALAD depression.

Additional physiological malfunctions assessed included parameters indicative of impaired blood formation (protoporphyrin elevation, hemoglobin suppression, and hematocrit reduction) and weight loss.

- ***Protoporphyrin elevation.*** This chemical becomes elevated in blood following lead exposure because lead inhibits the enzyme ferrochelatase (also known as heme synthetase) (Figure 6-6). Normally ferrochelatase converts protoporphyrin to heme, which is a step in the biochemical pathway to formation of hemoglobin. In the presence of lead, the ferrochelatase enzyme is inhibited, the conversion of protoporphyrin is reduced, and protoporphyrin levels in blood become elevated.

- ***Hemoglobin suppression.*** Hemoglobin is the component of blood that carries and transfers oxygen to the cells of animals. Lead exposure decreases hemoglobin levels through the blockage of the biochemical pathway producing heme (Figure 6-6). Inhibition of the enzyme ferrochelatase reduces the amount of heme available for conversion to hemoglobin, eventually causing anemia.

- ***Hematocrit reduction.*** Hematocrit is an index of the red blood cell content of blood, and is measured by determining the packed cell volume (primarily red blood cells) of a blood sample. Lead exposure causes a decrease in hematocrit (Figure 6-6). Hematocrit reduction lowers the oxygen carrying capacity of blood, which can result in anemia and tissue hypoxia.

Blood levels of protoporphyrin, hemoglobin, and hematocrit were quantified in multiple species of wildlife collected from the Coeur d'Alene River basin and reference areas, including waterfowl, songbirds, and birds of prey. In addition, controlled laboratory studies were conducted to determine the relationship between waterfowl ingestion of Coeur d'Alene sediment, lead exposure, and changes in these blood parameters.

- ***Weight loss.*** Changes in body weight of waterfowl exposed to Coeur d'Alene River basin sediment in controlled laboratory studies were assessed because loss of body weight can affect the viability and reproductive success of birds (O'Connor, 1984). In addition, the growth of juvenile bald eagles in a field investigation was assessed by comparing the increase in body weight of eaglets from nests in the Coeur d'Alene River basin to a reference area nest.

Although not specifically identified as injury categories in the DOI regulations at [43 CFR § 11.62 (f)(4)] (with the exception of ALAD inhibition), the physiological malfunction responses described above satisfy the four acceptance criteria for injury outlined at [43 CFR § 11.62(f)(2)(i-iv)]. Specifically, the measured biological responses are:

- ***Often the result of exposure to hazardous substances, as shown in scientific studies.*** Numerous studies have shown that parameters related to blood formation are altered by lead exposure, and that lead exposure causes elevation of protoporphyrin, hemoglobin suppression, and hematocrit reduction (Eisler, 1988; Pain, 1996; Kelly et al., 1998). Numerous scientific studies have demonstrated that changes in body weight (e.g., emaciation) are caused by lead exposure in both laboratory and field studies (Eisler, 1988; Franson, 1996; Pain, 1996). These biological responses are known to be the result of lead exposure and to increase in severity with increase in lead exposure.

- ***Caused in free-ranging organisms by exposure to hazardous substances.*** Numerous field investigations have demonstrated blood protoporphyrin elevation, hemoglobin suppression, and hematocrit reduction in wildlife populations exposed to lead (Eisler, 1988; Pain, 1996). Numerous studies have demonstrated that changes in body weight are caused by lead exposure in both the laboratory and the field (Eisler, 1988; Franson, 1996; Pain, 1996).

- ***Found in controlled laboratory experiments by exposure to hazardous substances.*** Numerous controlled laboratory studies have shown that parameters related to blood formation are altered by lead exposure, including elevation of protoporphyrin, hemoglobin suppression, and hematocrit reduction (Eisler, 1988; Pain, 1996). Growth impairment and weight loss have also been observed in controlled laboratory feeding studies with lead (e.g., Edens et al., 1976; WHO, 1995).

- ***Demonstrated by routine measurements that are practical to perform and produce scientifically valid results.*** The procedures used to collect and analyze protoporphyrin, hemoglobin, and hematocrit are standard methods that have been used for years by wildlife biologists and toxicologists (see citations in proceeding paragraphs). Growth measurements, quantified as change in the weight or length of specific body parts or the whole animal, are also routine and simple procedures used in ecology and toxicology. For both laboratory tests and field investigations, written protocols, standard procedures, and quality assurance plans were used, instruments were calibrated before use and regularly during use, and quality assurance/quality control procedures were followed.

Injury Category: Physical Deformation

The following injury definition applies:

- A statistically significant difference can be measured in the frequency of tissue or cellular lesions when comparing samples from populations of wildlife species from the assessment area and a control area [43 CFR § 11.62 (f)(4)(vi)].

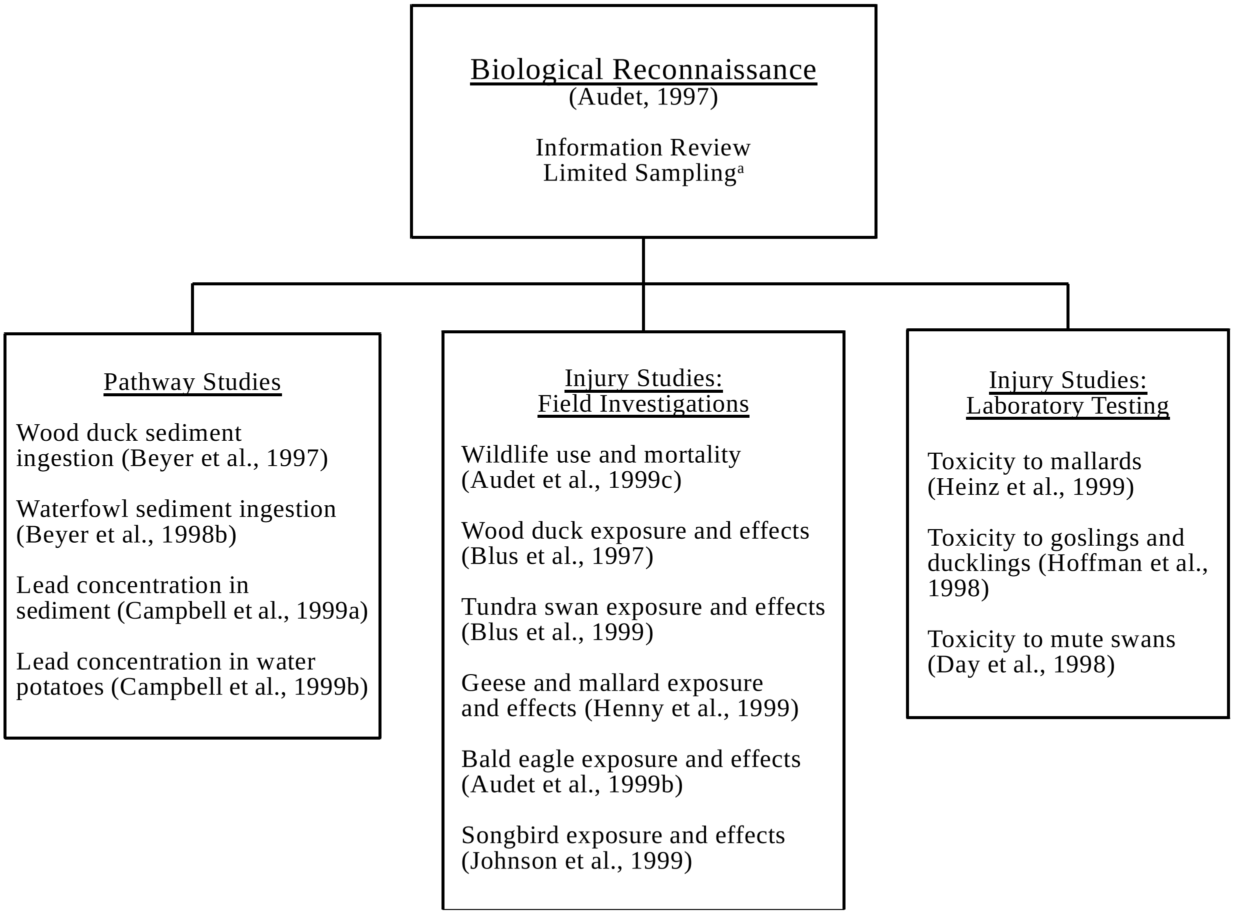
The assessment of physical deformations included quantifying differences between the frequency of gross and histopathological lesions in waterfowl populations in the Coeur d'Alene River basin and their frequency in reference areas, and between laboratory treatment groups exposed to Coeur d'Alene River basin sediment and reference area sediment. Gross lesions assessed included emaciation, abnormal bile, bile staining, and impactions of the upper gastrointestinal tract. Histopathological lesions assessed included hepatic and renal hemosiderosis, myocardial necrosis, arterial fibrinoid necrosis, and RIIBs. These gross and histopathological lesions are characteristic of lead exposure and are routinely assessed during necropsy and diagnostic examination of carcasses by trained pathologists to determine the cause of death.

6.4 INJURY DETERMINATION: TESTING AND SAMPLING APPROACHES

The injury assessment for wildlife resources in the Coeur d'Alene River basin began with an initial biological reconnaissance investigation. This investigation included a comprehensive review of existing data on the exposure and effects of metals in the Coeur d'Alene River basin and limited field sampling to determine food web exposure, to facilitate the design of pathway and injury studies, sampling methods, and quality control procedures, and to identify reference areas. The results of the biological reconnaissance investigation were used to design subsequent injury evaluation studies that focused on pathway determination and injury determination studies, as described below (Figure 6-9).

6.4.1 Pathway Studies

Pathway studies were conducted to determine the route and magnitude of exposure of biological resources to hazardous substances [43 CFR § 11.63] and to determine whether sufficient concentrations of hazardous substances were present in sediment, forage, and wildlife prey items to cause injury to biological resources [43 CFR § 11.63 (a)(2)]. Comparisons were performed to determine whether exposure of wildlife to hazardous substances in the Coeur d'Alene River basin differed from exposure of wildlife to hazardous substances at reference locations. The pathway studies characterized (1) routes of hazardous substance exposure from sediment, forage, and prey items to wildlife and (2) the degree of exposure of wildlife in the basin to pathway resources.



a. Component of pathway studies.

Figure 6-9. Flow diagram of wildlife injury assessment studies.

Pathway studies included the following (Table 6-4):

- ***Characterization of hazardous substance concentrations in sediments in areas used by wildlife.*** Surface sediments from multiple wetland and lake locations in the lower Coeur d'Alene River basin and reference areas known to be used by wildlife were collected and analyzed for hazardous substance concentrations. Details of the study are presented in:

    - Metal Contamination of Palustrine and Lacustrine Habitats in the Coeur d'Alene River basin, Idaho (Campbell et al., 1999a). Waterfowl use of the Coeur d'Alene River basin wetland habitats is documented in Audet et al. (1999c).

Table 6-4
Pathway and Injury Studies (field investigations, laboratory experiments) for Wildlife Resources Performed in the Coeur d'Alene River Basin and Reference Areas

Study Focus (study number[a])	Study Date	Measurement Objectives	Reference Area	Study Authors
Pathway Studies				
Biological reconnaissance (B1; B2)	1992-1993	Literature review; metal exposure, contamination	SJ[b]	Audet (1997)
Wood ducks (B1)	1992	Sediment ingestion by wood ducks	SJ	Beyer et al. (1997)
Water potato contamination (B1)	1994	Metal contamination in tubers[d]	SJ	Campbell et al. (1999b)
Tundra swans, Canada geese, mallard ducks (B1)	1994-1996	Sediment ingestion by waterfowl	SJ; MWMA[c]	Beyer et al. (1998b)
Sediment contamination (B1)	1995	Metal contamination in wetland/lateral lake sediments	SJ	Campbell et al. (1999a)
Injury Studies: Field Investigations				
Waterfowl; other species (B3)	1992-1997	Lead exposure; mortality/morbidity; gross/histopathological lesions; habitat use	SJ	Audet et al. (1999c)
Wood ducks (B3)	1992, 1995	Lead exposure; blood parameters	SJ	Blus et al. (1997)
Canada geese; mallards (B3)	1994-1995	Metal exposure; blood parameters; pathology	SJ; MWMA; Snake River; TNWR[e]	Henny et al. (1999)
Tundra swans (B3)	1994-1995	Metal exposure; blood parameters; pathology	MNWR[f]; KNWR[g]	Blus et al. (1999)
Bald eagles (B3)	1994	Lead exposure; metal contamination in prey; blood parameters; chick growth	MWMA	Audet et al. (1999b)
Song sparrows; American robins (B3)	1995	Lead exposure; blood parameters	SJ; Little North Fork River CdA	Johnson et al. (1999)

Table 6-4 (cont.)
Pathway and Injury Studies (field investigations, laboratory experiments) for Wildlife Resources Performed in the Coeur d'Alene River Basin and Reference Areas

Study Focus (study number[a])	Study Date	Measurement Objectives	Reference Area	Study Authors
Injury Studies: Laboratory Experiments				
Mallards (B3)	1994, 1995[h]	Toxicity of ingested sediment	SJ	Heinz et al. (1999)
Canada geese; mallards (B3)	1995[h]	Toxicity of ingested sediment	SJ	Hoffman et al. (1998)
Mute swans (B3)	1995[h]	Toxicity of ingested sediment	SJ	Day et al. (1998)

a. Refers to study identification number provided in NRDA Assessment Plan (Natural Resources Trustees, 1993).
b. SJ: St. Joe River basin, including the St. Maries River and adjacent wetlands and lakes.
c. MWMA: McArthur Wildlife Management Area (northern ID).
d. *Sagittaria* spp., a major food source of waterfowl and a traditional subsistence item for Coeur d'Alene tribal members.
e. TNWR: Turnbull National Wildlife Refuge (eastern WA).
f. MNWR: Malheur National Wildlife Refuge (central OR).
g. KNWR: Lower Klamath National Wildlife Refuge (southern OR).
h. Dates sediment samples were collected for use in laboratory feeding studies.

- ***Quantification of sediment ingestion by waterfowl.*** Sediment ingestion by waterfowl was quantified by collecting and analyzing fecal samples and the contents of the digestive system from representative species, including wood ducks, tundra swans, Canada geese, and mallard ducks from the lower Coeur d'Alene River basin and reference areas. Details are presented in:

  - The Role of Sediment Ingestion in Exposing Wood Ducks to Lead (Beyer et al., 1997)

  - Lead Exposure of Waterfowl Ingesting Coeur d'Alene River Basin Sediments (Beyer et al., 1998b).

- ***Metal contamination in the forage, prey items, and tissues of wildlife.*** Forage and prey items of waterfowl (e.g., vegetation, invertebrates) and birds of prey (e.g., fish, small mammals, waterfowl), and tissues and fecal samples from wildlife, were collected in both the Coeur d'Alene River basin and reference areas and analyzed for metal concentrations. Details are presented in:

  - Coeur d'Alene Basin Natural Resource Damage Assessment Biological Reconnaissance Investigation (Audet, 1997).

- ***Metal contamination of vegetation.*** Metal concentrations were measured in tubers of *Sagittaria latifolia* and *S. cuneata* (water potatoes) collected from the lower Coeur d'Alene River basin and the St. Joe River basin reference area. Water potatoes are an important food item of waterfowl and a traditional food of the Coeur d'Alene tribe. Metal concentrations in whole tubers (including skin and adhering sediment) were compared to metal concentrations in tubers with skin and adhering sediment removed. Details are presented in:

  - Heavy Metal Concentrations in *Sagittaria* spp. Tubers (Water Potato) in the Coeur d'Alene Basin (Campbell et al., 1999b).

Results of the pathway studies are discussed in Section 6.5. Full reports are provided in Volume II of this report: Studies Conducted as Part of the Injury Assessment.

6.4.2 Injury Studies

Supplemental injury studies were conducted to assess the biological responses of lead-exposed birds of the Coeur d'Alene River basin and to evaluate whether a relationship exists between the degree of sediment exposure and the frequency and degree of biological responses in waterfowl. Injury studies included field investigations of hazardous substances exposure and effects in waterfowl, bald eagles, and songbirds, as well as controlled laboratory toxicity tests designed to evaluate the toxicity of ingested sediment to waterfowl.

Results of individual injury studies are summarized in Section 6.5. Full reports are provided on discs 2 and 3 of this report.

Injury studies included the following (Table 6-4):

- ***Waterfowl habitat use and diagnostic evaluation of the causes of waterfowl deaths.*** Waterfowl surveys were conducted to determine areas of use and major types of activities (feeding and comfort). Carcass searches were conducted, and dead and dying waterfowl were collected and submitted for necropsy and diagnostic evaluation. Necropsy and diagnostic evaluation included gross and histopathological examination of lesions, inspection for disease and lead artefacts, analysis of lead concentrations in tissues and ingesta, and determination of causes of deaths. In addition, food items in ingesta were identified. The number, frequency, and causes of waterfowl mortality and morbidity were determined. Details are presented in:

  - Wildlife Use and Mortality Investigation in the Coeur d'Alene Basin 1992-1997 (Audet et al., 1999c).

- ***Lead exposure and effects in waterfowl.*** Concentrations of metals in blood and other tissues, hematological responses (changes in blood ALAD activity and in levels of blood protoporphyrin, hemoglobin, and hematocrit), and physical deformations (gross and histopathological lesions) in representative waterfowl species from the Coeur d'Alene River basin and reference areas were measured and compared. Results were also compared to available historical information on lead exposure and effects in the Coeur d'Alene River basin. Details are presented in:

  - Persistence of High Blood Lead Concentrations and Associated Effects in Wood Ducks Captured near a Mining and Smelting Complex in Northern Idaho (Blus et al., 1999)

  - Field Evaluation of Lead Effects on Canada Geese and Mallards in the Coeur d'Alene River Basin, Idaho (Henny et al., 1999)

  - Persistence of High Blood Lead Concentrations and Associated Effects in Tundra Swans Captured near a Mining and Smelting Complex in Northern Idaho (Blus et al., 1999).

- ***Lead exposure and effects in bald eagles.*** Lead residues in blood and prey items, hematological responses (blood ALAD activity, hemoglobin, hematocrit), and growth were measured in young bald eagles from the Coeur d'Alene River basin and reference areas. Dead bald eagles from northern Idaho and eastern Washington were necropsied to determine causes of death. Details are presented in:

  - Lead Exposure of Bald Eagles and Prey Items in Northern Idaho and Eastern Washington (Audet et al., 1999b).

- ***Lead exposure and effects in songbirds.*** Lead residues in liver and hematological responses (changes in blood ALAD activity and hematocrit levels) were measured in song sparrows and American robins from the lower Coeur d'Alene River basin and reference areas. Details are presented in:

  - Lead Exposure in Passerines Inhabiting Lead-Contaminated Floodplains in the Coeur d'Alene River basin, Idaho (Johnson et al., 1999).

- ***Toxicity of lead-contaminated sediment to waterfowl.*** Controlled laboratory tests were conducted to assess the toxicity of ingested sediment from the Coeur d'Alene River basin to representative waterfowl species (mallards, Canada geese, mute swans), relative to the toxicity of ingested sediment from the St. Joe River basin. Biological responses evaluated included death, physiological malfunctions (e.g., changes in blood parameters, body weight), and physical deformations (gross and histological lesions). Relationships between the degree of sediment ingestion and biological responses of waterfowl were quantified. Details are presented in:

  - Toxicity of Lead-Contaminated Sediment to Mallards (Heinz et al., 1999)

  - Toxicity of Lead-Contaminated Sediment to Canada Goose Goslings and Mallard Ducklings (Hoffman et al., 1998)

  - Toxicity of Lead-Contaminated Sediment to Mute Swans (Day et al., 1998).

The biological responses selected for measurement in the injury studies are known to be responsive to lead exposure, have been used previously in scientific studies, are practical to perform, and produce scientifically valid results [43 CFR § 11.62(f)(2)(iv)]. The studies were conducted according to the quality assurance guidelines specified in the NRDA Quality Assurance Plan (USFWS, 1995).

6.4.3 Reference Areas

For each injury and pathway study, one or more reference areas appropriate for comparison to the study endpoints were selected (Table 6-4). For each of the studies, data from the reference areas were collected using methods comparable to the methods used in the Coeur d'Alene River basin [43 CFR § 11.72 (d)(5)]. Reference areas are described below and shown in Figure 6-10.

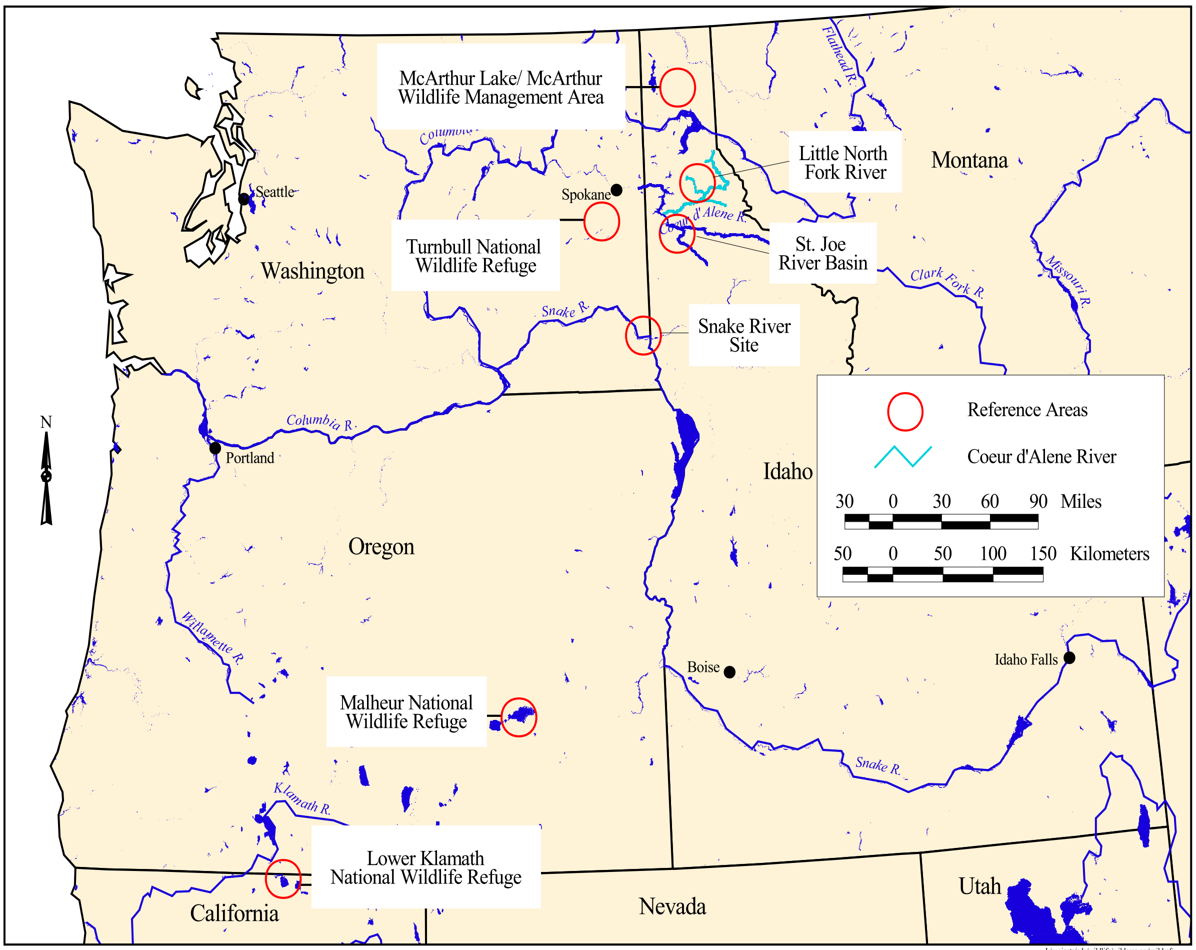


Figure 6-10. Locations of reference areas used in the Trustees' injury assessment studies.

St. Joe River basin. The St. Joe River basin is the drainage basin to the south of the Coeur d'Alene River basin. The St. Joe River basin includes the St. Joe River, the St. Maries River, and adjacent wetlands and lakes, including the southern Coeur d'Alene Lake (Figure 6-2). The basin was used as a reference area for the majority of wildlife pathway and injury studies for the following reasons:

- Absence of known releases of hazardous substance related to mining activities, including lead.

- Similarity of climate and seasonal environmental variability, and major vegetation types.

- General morphological and geographical similarity to the Coeur d'Alene River basin. The St. Joe River flows from the Montana/Idaho border, through the St. Joe Mountains, and discharges to Coeur d'Alene Lake at the southern end of the lake. The St. Joe River basin and Coeur d'Alene River basin have generally similar headwater geology, ranges in elevations and stream gradients, and stream flow rates.

- Similar wildlife species assemblages. The St. Joe River basin is on the same migration corridor (part of the Pacific flyway) as the Coeur d'Alene River basin, and thus provides similar migration routes and timing. For example, northward migrating waterfowl typically first stop in the St. Joe River basin before arriving in the Coeur d'Alene River basin.

- Similar types of wildlife habitats. The St. Joe River basin contains lacustrine, palustrine, and riparian habitats. Habitat abundance and diversity are lower in the St. Joe River basin than in the Coeur d'Alene River basin. Data collected as part of the injury assessment confirmed that habitat use by waterfowl (average number of waterfowl feeding per survey) is similar in the St. Joe River and Coeur d'Alene River basins, although the average feeding use per acre is slightly higher in the St. Joe River basin (Audet et al., 1999c).

- Similar wildlife management activities, including hunting activity. The exposure of wildlife to lead shot and other lead artifacts in the St. Joe River basin was expected to be similar to the exposure in the Coeur d'Alene River basin because management activities and hunting access are generally similar.

Data collected from the St. Joe River basin included (1) wildlife kill investigation data, including carcass counts for comparison of the frequency of wildlife kills and collection of carcasses for evaluation of the causes of mortality; (2) necropsy data to identify the frequency and severity of physical deformations and causes of death in the St. Joe River basin; (3) blood samples for comparison of endpoints related to physiological malfunctions such as inhibition of ALAD activity, and measurements of levels of protoporphyrin, hemoglobin, and hematocrit; (4) fecal samples for evaluation of the degree of exposure of reference organisms to dietary sediment; (5) hazardous substance concentrations in wildlife blood and tissues; and (6) hazardous substance concentrations in pathway items, including water potato and sediment.

Several other reference areas were selected and sampled because of one or more of the following: (1) similarity of waterfowl species that occur in the Coeur d'Alene River basin, (2) proximity to the Coeur d'Alene River basin, (3) location within the same migratory pathway (Pacific flyway), (4) expected low concentrations of hazardous substances because of absence of known mining related activities, and (5) expected similar exposure of hazardous substances from other sources (e.g., automobile emissions, lead artifacts).

McArthur Wildlife Management Area (MWMA). The MWMA, an approximately 310 ha area that includes McArthur Lake, is located approximately 115 km north of the Coeur d'Alene River basin in northern Idaho and includes habitat similar to habitat of the Coeur d'Alene River basin (Beyer et al., 1998b). The MWMA was a reference area for sediment ingestion studies (Beyer et al., 1998b) and exposure and effects studies (Henny et al., 1999). Data collected included (1) fecal samples for the determination of hazardous substances exposure to waterfowl; (2) blood samples for comparison of endpoints related to physiological malfunctions (inhibition of ALAD activity, and levels of protoporphyrin, hemoglobin, and hematocrit); (3) blood, liver, and kidney samples for comparison of hazardous substances exposure; and (4) physical deformation data to identify the frequency and severity of lesions in reference areas.

McArthur Lake was the reference area for the bald eagle study. Audet et al. (1999b) evaluated 20 potential nest locations in Kootenai, Bonner, and Boundary counties, Idaho, and ultimately selected McArthur as the reference area. Selection criteria included (1) presence of eaglets 45-55 days old, (2) nest accessibility, and (3) ability to collect data without harming either field personnel or eagles. Data collected included (1) blood samples for comparison of endpoints related to physiological malfunctions (inhibition of ALAD activity, levels of hemoglobin and hematocrit, growth); (2) blood samples for comparison of hazardous substances exposure; and (3) body weight data.

Malheur National Wildlife Refuge (MNWR) and Lower Klamath National Wildlife Refuge (KNWR). The MNWR (central Oregon) and KNWR (southern Oregon) were used as reference for studies of lead exposure and effects in tundra swans (Blus et al., 1999). Rationale for selecting these reference areas included (1) presence of the same species of birds; (2) similarity of hunting access and wildlife management activities, and thus similar exposure to lead shot; (3) same general region of Pacific flyway, and thus similar arrival and departure times at breeding grounds and wintering areas, and similar migration routes; (4) absence of known releases of hazardous substances related to mining activities, including lead; and (5) locations south of the Coeur d'Alene River basin, so birds had not recently been in the Coeur d'Alene River basin. Data collected included blood samples for comparison of endpoints related to physiological malfunctions (inhibition of ALAD activity, levels of hemoglobin and hematocrit); and blood and liver samples for comparison of hazardous substances exposure.

Turnbull National Wildlife Refuge (TNWR) and Snake River site. The TNWR, near the Coeur d'Alene River basin in eastern Washington state, and the Snake River site, south of the Coeur d'Alene River basin near Lewiston, Idaho, were used as reference areas for the field evaluation of lead effects on Canada geese and mallards (Henny et al., 1999). Henny et al. collected data for mallards from the TNWR, St. Joe River basin, and MWMA reference areas and for Canada geese from the Snake River reference area. Rationale for selecting these reference areas included (1) presence of the same species of birds; (2) similar hunting access, so similar exposure to lead shot; (3) same general region of Pacific flyway, thus similar arrival and departure times at breeding grounds and wintering areas and migration routes; and (4) absence of known releases of hazardous substance related to mining activities, including lead. Data collected included

(1) blood samples for comparison of endpoints related to physiological malfunctions (inhibition of ALAD activity, and levels of protoporphyrin, hemoglobin, and hematocrit); (2) blood, liver, and kidney samples for comparison of hazardous substances exposure; and (3) physical deformation data to identify the frequency and severity of lesions in reference areas.

Little North Fork Coeur d'Alene River. The Little North Fork Coeur d'Alene River is a tributary to the North Fork of the Coeur d'Alene River and is not exposed to mining related contamination. The Little North Fork Coeur d'Alene River and the St. Joe River basin were used as reference areas for the field investigation of exposure and effects on songbirds (Johnson et al., 1999). Selection criteria included (1) similar wildlife management activities (lands owned and managed by the Idaho Department of Fish and Game); (2) location on public or private land accessible by vehicle; (3) proximity to the Coeur d'Alene River basin; (4) similar habitat for the target species (e.g., riparian areas or near wetlands or lakes; and (5) presence of the target species. Data collected from the Little North Fork Coeur d'Alene River included (1) blood samples for comparison of endpoints related to physiological malfunctions (inhibition of ALAD activity, and hematocrit levels); and (2) liver samples for comparison of hazardous substances exposure.

6.5 INJURY ASSESSMENT STUDIES: RESULTS

This section presents the results of the pathway studies in Section 6.5.1. The injury study results are presented according to field investigations (Section 6.5.2), and laboratory toxicity tests (Section 6.5.3), with conclusions in Section 6.5.4.

6.5.1 Pathway Studies

Metal Concentrations in Sediments in Wildlife Use Areas

Concentrations of hazardous substances in sediments from Coeur d'Alene River basin areas used by wildlife were compared to concentrations in sediments from St. Joe River basin areas used by wildlife (Campbell et al., 1999a). Mean lead concentrations in Coeur d'Alene River basin sediments (1,075 to 5,826 ppm) were significantly ($p < 0.001$) greater than lead concentrations in reference area sediments (all reference area averages less than 20 ppm; Campbell et al., 1999a) (Figure 6-11). Zinc, cadmium, and arsenic concentrations were also significantly greater in Coeur d'Alene River basin sediments ($p < 0.001$); concentrations ranged from 2 to 100 times greater in Coeur d'Alene River basin sediments.

The results confirm that sediment in habitats used by wildlife of the Coeur d'Alene River basin is contaminated with lead and other metals and that concentrations of hazardous substances are substantially elevated relative to reference areas (Campbell et al., 1999a). These results are consistent with historical data showing that concentrations of lead are elevated in Coeur d'Alene River basin sediments.

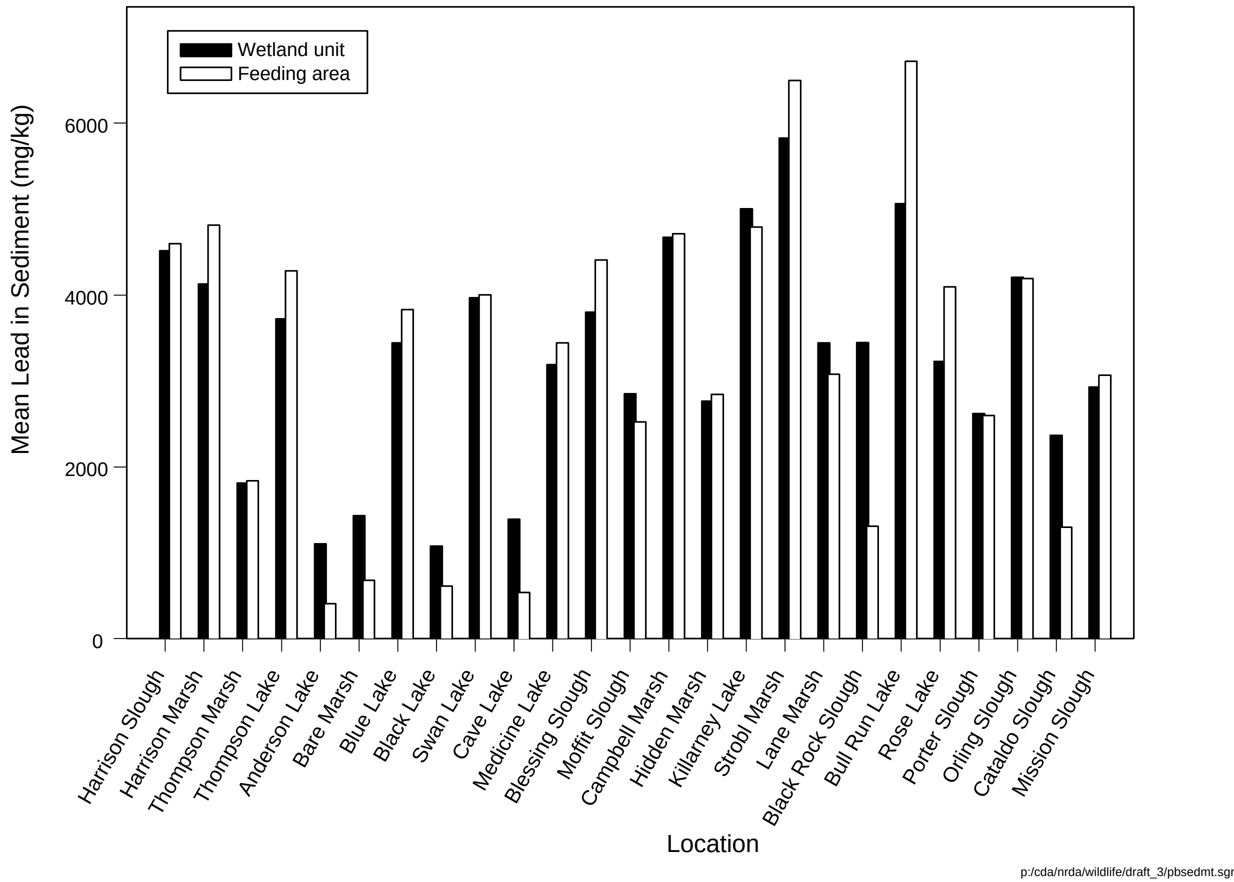


Figure 6-11. Lead concentrations in sediments of Coeur d'Alene lacustrine and palustrine habitats. Mean lead concentrations in sediment from reference area wetland units and feeding areas were 17.07 and 16.04 mg/kg, respectively.
Sources: Audet et al., 1999c; Campbell et al., 1999a.

The concentrations of lead and other hazardous substances in Coeur d'Alene River basin sediments are sufficient to provide a direct pathway to the wildlife resources of the Coeur d'Alene [43 CFR § 11.63(e)] through direct sediment ingestion [see Beyer (1997) and Beyer et al. (1998b)].

Sediment Ingestion by Waterfowl

Sediment ingestion by waterfowl was quantified to determine the degree of exposure of wildlife to sediment and to lead in sediment. Digesta (dietary contents of the digestive system) and excreta (excretory products, including feces) from representative species, including wood ducks (Beyer et al., 1997), tundra swans, Canada geese, and mallard ducks (Beyer et al., 1998b) from the Coeur d'Alene River basin and reference areas, were collected and analyzed.

Wood ducks. Since wood ducks feed on the water surface and, in the Coeur d'Alene River basin, ingest less than 2% sediment in their diet (Beyer et al., 1997), they were studied as a species representative of waterfowl expected to be less exposed to metal contaminated sediments than species that feed on wetland or lakebed surfaces. Results of digesta analyses confirmed that Coeur d'Alene River basin wood duck digesta contains elevated concentrations of lead (mean of 32 ppm) relative to digesta of wood ducks from reference areas (8 ppm). Lead concentrations in wood duck digesta were correlated with lead concentrations in the sediment in areas where the ducks feed, and most of the lead in digesta came from ingested sediment rather than from plant material (Beyer et al., 1997). The results of the wood duck study demonstrate that the contaminated sediments of the Coeur d'Alene River basin can serve as an important pathway of hazardous substances exposure even in waterfowl that have low rates of sediment ingestion.

Tundra swans, Canada geese, mallards. Analysis of the excreta of tundra swans, Canada geese, and mallard ducks from the Coeur d'Alene River basin confirmed that these species ingest large amounts of sediment and that sediment is the primary source of the lead ingested by these species (Beyer et al., 1998b). Sediment ingestion rates were determined by the relationship between the acid insoluble ash content of feces (i.e., the "mineral" component), food digestibility, and the sediment content of diets (Beyer et al., 1994). Estimated average sediment ingestion rates for both Canada geese and tundra swans were 9%, and for mallards, approximately 5% (Beyer et al., 1998b). The ninetieth percentile for sediment ingestion of tundra swans was estimated to be 22% sediment in the diet (i.e., an estimated 90% of tundra swans ingest 22% or less sediment, and 10% of tundra swans ingest more than 22%).

The average lead concentration (dry weight) in the excreta of tundra swans was 880 ppm in the Coeur d'Alene River basin and 2 ppm in reference areas (Figure 6-12). In the Coeur d'Alene River basin, lead concentrations in excreta up to 3,900 ppm (Canada goose) and 3,300 ppm (tundra swan) were found, whereas in the reference areas maximum values measured in excreta

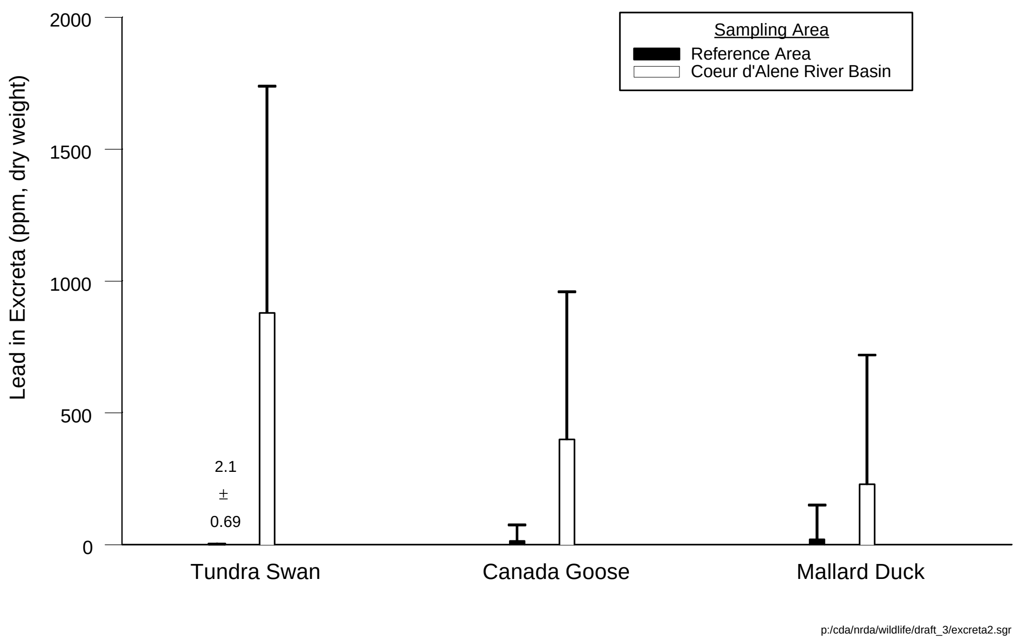


Figure 6-12. Mean (plus standard deviation) lead concentrations in the excreta of tundra swans, Canada geese, and mallard ducks from the Coeur d'Alene River basin and reference areas.
Source: Beyer et al., 1998b.

were 930 ppm (Canada goose) and 3.1 ppm (tundra swan). The average concentration of lead in mallard duck excreta was 230 ppm in the Coeur d'Alene River basin compared to 21 ppm in reference areas. The degree of elevation in lead concentrations in Canada goose, tundra swan, and mallard duck excreta demonstrates substantially elevated dietary exposure of waterfowl in the Coeur d'Alene River basin (Figure 6-12).

Lead concentrations in tundra swan feces were significantly correlated ($p < 0.05$; Spearman's rho = 0.74) with the amount of sediment ingested (Beyer et al., 1994), demonstrating that ingestion of the contaminated sediment was the source of the lead in the waterfowl (Beyer et al., 1998b). Fecal lead concentrations of all waterfowl were also significantly correlated ($p < 0.05$; $r^2 = 0.83$) with lead concentrations in sediment in the Coeur d'Alene River basin (Beyer et al., 1998b). Feces with very low lead concentrations had correspondingly low acid-insoluble ash content, which demonstrates that the primary source of the lead in the waterfowl was lead in sediment rather than lead in ingested plant material (Beyer et al., 1998b).

The results confirm that direct ingestion of contaminated Coeur d’Alene sediment is the principal exposure pathway of waterfowl to lead and other hazardous substances in the Coeur d’Alene River basin (Beyer et al., 1998b).

Metal Contamination of Vegetation

Aquatic vegetation from waterfowl use areas in the Coeur d’Alene and St. Joe river basins was collected to determine if Coeur d’Alene River basin vegetation serves as a pathway of waterfowl exposure to hazardous substances (Audet, 1997; Campbell et al., 1999b). Important components of waterfowl diets, including tubers of *Sagittaria* spp. and horsetail (*Equisetum fluviatile*), were analyzed for lead and other metals. The large, starchy tubers of *Sagittaria* spp. (water potatoes) are found throughout the Coeur d’Alene and the St. Joe river basins and are a food source for waterfowl and a traditional food of the Coeur d’Alene Tribe. Metal concentrations in whole tubers (with skin and adhering sediment) were compared to tubers with the skin and adhering sediment removed. Concentrations in Coeur d’Alene River basin tubers were compared to concentrations in St. Joe River basin tubers.

Mean lead concentrations in *Equisetum* and other aquatic vegetation that are consumed by waterfowl in the Coeur d’Alene River basin ranged from 13.78 ppm in arrowhead (*Sagittaria* spp.) to 60.29 ppm in coontail *(Ceratophyllum demersum)* (Figure 6-13) (Audet, 1997; Campbell et al., 1999b). The mean lead concentration in Coeur d’Alene River basin whole tubers (with skin and adhering sediment; 30 ppm) was significantly greater than both the mean lead concentration in whole tubers from the St. Joe River basin (0.3 ppm; $p < 0.05$) and the mean lead concentration in Coeur d’Alene River basin tubers with the skin and adhering sediment removed (0.4 ppm lead; $p = 0.185$). The results indicate that lead contamination of Coeur d’Alene River basin tubers is associated with the outside surface of the tuber, and that hazardous substances contaminate forage of Coeur d’Alene River basin wildlife.

The elevated concentrations of lead in *Equisetum*, water potatoes, and other vegetation from the Coeur d’Alene River basin are sufficient to provide a direct pathway to waterfowl.

Metal Contamination in the Wildlife Food Web

Reconnaissance sampling was conducted to assess the extent of exposure of Coeur d’Alene River basin wildlife to hazardous substances by the food chain (Audet, 1997). The reconnaissance sampling and analysis revealed exposure of dietary items of birds of prey, including small mammals (deer mouse and meadow vole), aquatic species (brown bullhead, yellow perch, and tench), and avian species (tundra swan and Canada goose); dietary items of fish (aquatic invertebrates) (Figure 6-14); and dietary items of dabbling and diving ducks (aquatic vegetation species, to lead and other heavy metals. Samples of some species were collected from the St. Joe River basin for comparison to the Coeur d’Alene River basin samples. Metals concentrations for all sample matrices collected from the St. Joe River basin were consistently low (Figure 6-14).

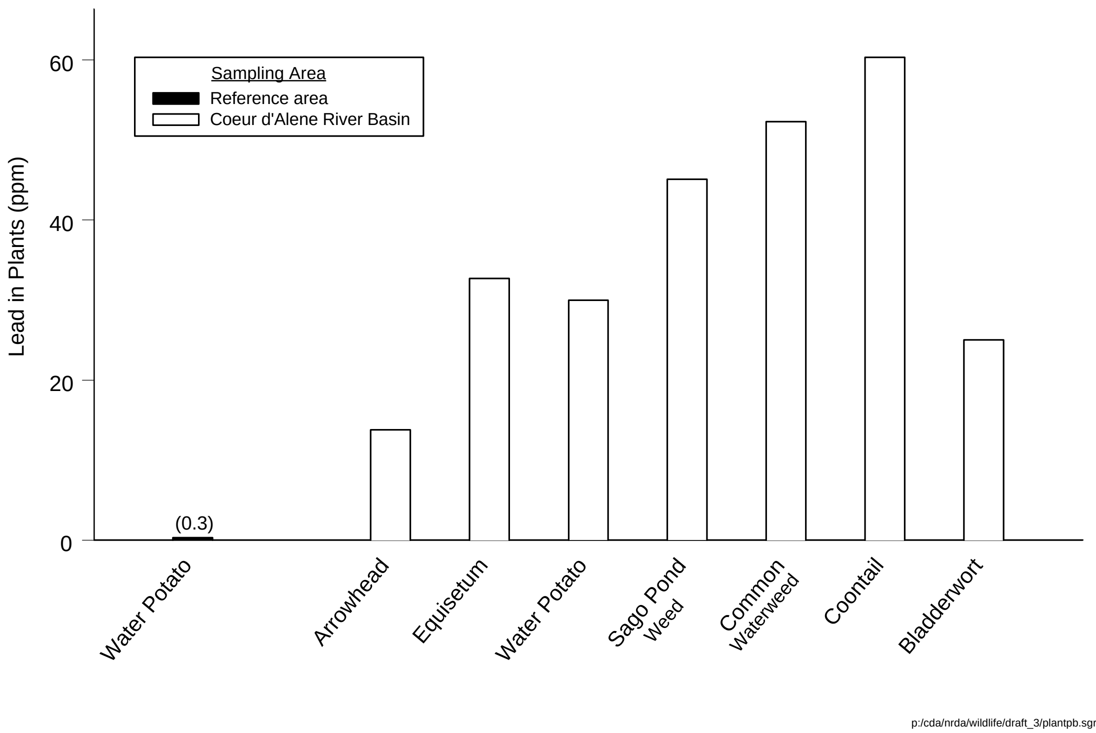


Figure 6-13. Mean lead contaminations in aquatic vegetation (ppm, wet weight; with skin and adhering sediment) consumed by waterfowl from the Coeur d'Alene and reference areas.
Sources: Audet, 1997; Campbell et al., 1999b.

Comparison of the reconnaissance sampling results to previous sampling results in the Coeur d'Alene River basin revealed little change in lead concentrations in various matrices with time. No evidence of attenuation of exposure from 1982 to 1992 for mammals (Figure 6-15), fish, or waterfowl was detected. Livers of deer mice and mink also exceeded the 7.5 ppm threshold for lead poisonings in mammals proposed by Ma (1996).

The results of this study show that multiple components of the Coeur d'Alene River basin food web are contaminated with lead. Lead concentrations are elevated in important forage and prey items of Coeur d'Alene River basin wildlife, including aquatic vegetation, fish, small mammals, and waterfowl. Contamination of the biological resources of the Coeur d'Alene River basin by hazardous substances is pervasive and sufficient to provide a food chain pathway to Coeur d'Alene wildlife resources.

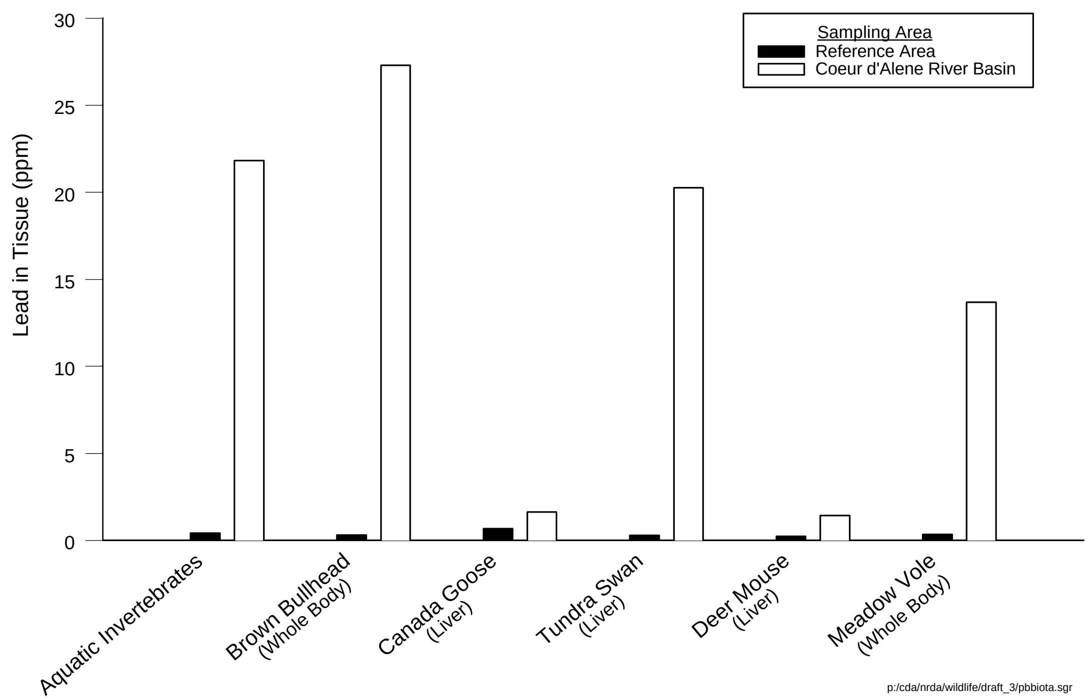


Figure 6-14. Mean lead concentrations in food web resources of the Coeur d'Alene River basin and the St. Joe River basin reference areas.
Source: Audet, 1997.

Pathway Study Conclusions

The results of the pathway studies demonstrate that Coeur d'Alene River basin sediments are contaminated with lead and other hazardous substances and that concentrations of these substances in sediments are substantially elevated relative to concentrations in St. Joe River basin sediments. Waterfowl in the Coeur d'Alene River basin are directly exposed to lead and other hazardous substances by ingestion of contaminated sediments during foraging activities.

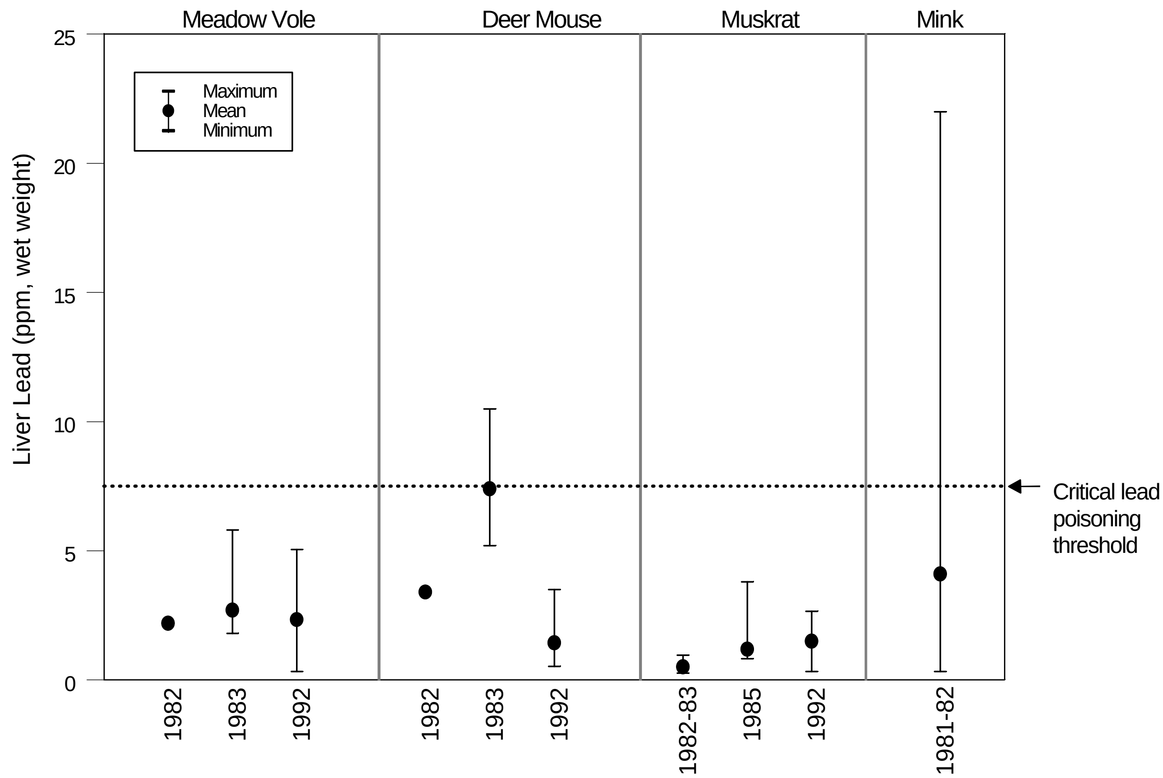


Figure 6-15. Mean lead concentrations in the tissues of Coeur d'Alene River basin wildlife collected in 1982, 1983, 1985, and 1992. Critical lead poisoning threshold of 7.5 ppm for mammals based on Ma (1996). Sources: Blus et al., 1987; Krieger, 1990; Ma, 1996; Audet, 1997.

Waterfowl, songbird, invertebrate, fish, small mammal, and aquatic vegetation tissues contain elevated concentrations of lead and provide a food chain exposure pathway to wildlife predators. Contamination of the sediment and biological resources of the Coeur d'Alene River basin by hazardous substances is pervasive and sufficient to provide both direct and indirect pathways to Coeur d'Alene River basin wildlife resources.

6.5.2 Injury Field Studies

Field investigations included determination of waterfowl habitat use and diagnosis of the causes of waterfowl deaths; evaluation of the persistence of elevated lead exposure and effects in waterfowl; and evaluation of lead exposure and effects in bald eagles and songbirds. Laboratory studies involved exposing representative species of waterfowl to sediment from either the Coeur d'Alene River basin or reference areas. The laboratory experiments included determination of the bioavailability and toxicity of contaminated sediment to mallards, Canada geese, and mute swans (a surrogate test species for tundra swans).

The biological responses investigated included death, physiological malfunctions, and physical deformations. As noted previously, the specific responses measured, which meet the acceptance criteria of the DOI regulations, are characteristic of lead exposure and effects.

Waterfowl Habitat Use and Causes of Waterfowl Deaths

Surveys were performed in the lower Coeur d'Alene area and the St. Joe River basin reference area to quantitatively evaluate waterfowl habitat use (1995 to 1997) and to determine the causes of waterfowl deaths (1992 to 1997). Areas used by wildlife were characterized by the type of use (i.e., feeding, resting) (Audet et al., 1999c), and searches for dead and dying wildlife were conducted. Recovered carcasses were submitted for necropsy examination to determine the cause of death. Diagnostic veterinary procedures included evaluation of gross and histopathological lesions, inspection for disease and lead artifacts (such as lead shot), and analysis of lead residues in tissues and ingesta.

Waterfowl surveys indicated that migratory birds, specifically tundra swans and mallard ducks, stop in the St. Joe River basin before stopping in the Coeur d'Alene River basin during their northward migration in the spring (Figure 6-1) (Audet et al., 1999c). From 1995 through 1997, tundra swan peak counts were similar in the Coeur d'Alene River basin and in the St. Joe River basin. Canada goose peak counts were 2 to 6 times higher in the Coeur d'Alene River basin, and mallard abundance, basin preference, and seasonal use varied greatly year to year (Audet, 1999c). There was no significant difference ($p > 0.05$) between waterfowl feeding use or feeding use per acre in the lower Coeur d'Alene River basin and the St. Joe River basin. However, there was a significantly greater number and frequency of dead and dying birds found in the Coeur d'Alene River basin ($p < 0.0001$) (Audet et al., 1999c).

During the 1992 to 1997 surveys, 682 animals, including 29 species of birds and 6 species of mammals, were found dead or sick in the Coeur d'Alene River basin (Audet et al., 1999c). In contrast, only 40 animals (9 species of birds, 2 species of mammals) were found dead or sick in the St. Joe River basin during the same period (Table 6-5). Animals found dead or sick included waterfowl (e.g., tundra swans, Canada geese, mallards, wood ducks), songbirds (e.g., American robin, swallows), birds of prey (e.g., bald eagles, osprey, red-tailed hawk), amphibians and reptiles (e.g., frogs and turtles), meadow vole, muskrat, mink, and beaver (Audet et al., 1999c).

Table 6-5
Animals Found Dead or Sick in the Coeur d'Alene and St. Joe River Basins, 1992-1997
[total # found (# submitted for necropsy examination)]

Species	1992	1993	1994	1995	1996	1997	Total
Coeur d'Alene River Basin							
Tundra swan	11 (11)	43 (37)	12 (5)	25 (18)	28 (19)	170 (112)	289 (202)
Canada goose	1 (1)	3 (2)	14 (3)	22 (7)	45 (16)	93 (26)	178 (55)
Mallard	1 (1)	-	14 (4)	4 (0)	10 (4)	26 (4)	55 (13)
Unknown	-	-	6 (0)	8 (0)	4 (0)	6 (0)	24 (0)
Wood duck	1 (1)	-	2 (1)	4 (0)	7 (2)	4 (2)	18 (6)
American coot	-	-	3 (3)	1 (0)	3 (1)	10 (0)	17 (4)
Muskrat	-	-	5 (5)	1 (0)	7 (4)	3 (2)	16 (11)
Violet-green swallow	2 (2)	1 (0)	-	5 (2)	2 (2)	-	10 (6)
Northern pintail	-	-	1 (0)	1 (0)	6 (1)	2 (0)	10 (1)
Barn swallow	-	5 (0)	-	3 (2)	-	-	8 (2)
Great blue heron	-	-	2 (0)	-	4 (0)	1 (0)	7 (0)
Meadow vole	2 (2)	-	1 (1)	1 (1)	1 (1)	1 (1)	6 (6)
Green-winged teal	-	-	1 (1)	2 (0)	1 (0)	1 (0)	5 (1)
Western painted turtle	-	-	1 (0)	2 (0)	-	1 (0)	4 (0)
American wigeon	-	-	-	1 (1)	2 (2)	-	3 (3)
Common goldeneye	-	-	-	-	1 (0)	2 (1)	3 (1)
Gull spp.	-	-	1 (0)	-	1 (0)	-	2 (0)
Beaver	-	-	2 (0)	-	-	-	2 (0)
Common merganser	-	-	-	-	-	2 (1)	2 (1)
American robin	-	1 (1)	1 (0)	-	-	-	2 (1)
Osprey	-	-	-	-	2 (0)	-	2 (0)
Bull frog	-	-	-	1 (0)	1 (0)	-	2 (0)
Redhead	-	1 (1)	-	-	-	1 (0)	2 (1)
Dark-eyed junco	-	-	-	1 (1)	-	-	1 (1)
Coyote	-	1 (0)	-	-	-	-	1 (0)
Common snipe	-	-	1 (1)	-	-	-	1 (1)
Grebe spp.	-	-	-	1 (0)	-	-	1 (0)
Wild turkey	-	-	-	-	-	1 (1)	1 (1)
Northern flicker	-	-	1 (1)	-	-	-	1 (1)
Canvasback	-	-	1 (1)	-	-	-	1 (1)

Table 6-5 (cont.)
Animals Found Dead or Sick in the Coeur d'Alene and St. Joe River Basins, 1992-1997
[total # found (# submitted for necropsy examination)]

Species	1992	1993	1994	1995	1996	1997	Total
Coeur d'Alene River Basin (cont.)							
Red-tailed hawk	-	-	-	-	1 (0)	-	1 (0)
Shrew spp.	-	-	-	1 (1)	-	-	1 (1)
Sora rail	-	-	-	1 (0)	-	-	1 (0)
Trumpeter swan	-	-	1 (1)	-	-	-	1 (1)
Bald eagle	-	1 (1)	-	-	-	-	1 (1)
Mink	-	-	-	-	1 (1)	-	1 (1)
Swainson thrush	1 (1)	-	-	-	-	-	1 (1)
American crow	-	-	1 (1)	-	-	-	1 (1)
CdA River Basin Total	**19 (19)**	**56 (42)**	**71 (28)**	**85 (33)**	**127 (53)**	**324 (150)**	**682 (325)**
St. Joe River Basin							
Canada goose	-	1 (1)	2 (1)	5 (4)	5 (3)	1 (0)	14 (9)
Tundra swan	-	2 (2)	1 (0)	-	1 (1)	4 (1)	8 (4)
Muskrat	-	-	-	3 (1)	1 (1)	-	4 (2)
Unknown	-	-	2 (0)	1 (0)	-	-	3 (0)
Mallard	-	-	-	-	-	2 (0)	2 (0)
Unidentified ducklings	-	-	2 (2)	-		-	2 (2)
Bald eagle	-	-	-	1 (0)	-	-	1 (0)
Bufflehead	-	-	-	-	-	1 (0)	1 (0)
Beaver	-	-	-	-	-	1 (0)	1 (0)
Varied thrush	-	-	-	-	-	-	1 (1)
Gull spp.	-	-	1 (1)	-	1 (1)	-	1 (1)
American robin	-	-	1 (0)	-	-	-	1 (0)
Redhead	-	-	-	-	1 (1)	-	1 (1)
St. Joe River Basin Total	**-**	**3 (3)**	**9 (4)**	**10 (5)**	**9 (7)**	**9 (1)**	**40 (20)**

The actual number of dead and sick animals in the Coeur d'Alene basin is greater than the number of animals observed during the surveys. Only a fraction of animal carcasses can actually be detected in the wild because all areas are not surveyed, sick and moribund animals are reclusive and/or immobile, and carcasses may be scavenged by predators or hidden in vegetation. Detection rate studies in the Coeur d'Alene River basin showed that 0% to 57% of carcasses were found by field observers (Audet et al., 1999c).

During the 1992 to 1997 surveys, 325 animal carcasses from the Coeur d'Alene River basin and 20 from the St. Joe River basin were necropsied to determine the cause of sickness or death. Fourteen of the Coeur d'Alene River basin carcasses and one of the St. Joe River basin carcasses were badly decomposed or scavenged and were unsuitable for reliable diagnosis; statistics are based on 311 Coeur d'Alene River basin and 19 St. Joe River basin carcasses (Audet et al., 1999c).

Lead poisoning was the single greatest cause of sickness or death of wildlife from the Coeur d'Alene River basin (80%, Figure 6-16), and 92% of the lead poisoned animals had not ingested lead artifacts (e.g., lead shot or fishing sinkers) (Figures 6-16 and 6-17). Nine species of waterfowl were documented with lead poisoning without the presence of lead artefacts (Figure 6-7). In contrast, 47% of the 19 carcasses necropsied from the St. Joe River basin were diagnosed as lead poisoned, and 78% of them (7 of 9) had ingested lead artifacts. Ingested lead artifacts were present in only 8.4% of the lead-poisoned birds examined from the Coeur d'Alene basin compared to 87.5% of lead poisoned birds from the St. Joe River basin. The carcass survey data show that swan mortality is significantly greater in the Coeur d'Alene River basin than in the St. Joe River basin ($p < 0.0001$), and that mortality rates are approximately 7 times greater in the Coeur d'Alene River basin. These data indicate that wildlife mortality rates are elevated in the Coeur d'Alene River basin, that the principal cause of wildlife deaths is lead poisoning, and that lead poisoning does not result from the ingestion of lead artifacts.

Information summarized by Audet et al. (1999c) shows that the frequency of lead poisoning without the presence of lead artifacts as a cause of mortality to tundra swans relative to other causes of death is substantially greater in the Coeur d'Alene River basin than in either the United States as a whole or in the Pacific flyway (Figure 6-18). Lead poisoning accounts for 22% to 29% of tundra swan mortalities nationwide, as well as in the Pacific flyway (Figure 6-18). These percentages include lead poisoning caused by ingestion of lead artifacts. Mortality rates and causes of death in the St. Joe River basin are similar to other waterfowl areas that experience lead poisoning because of ingestion of lead artifacts. In contrast, 96% of the tundra swan mortality in the Coeur d'Alene River basin is caused by lead poisoning without the presence of ingestion lead artifacts (Figure 6-18).

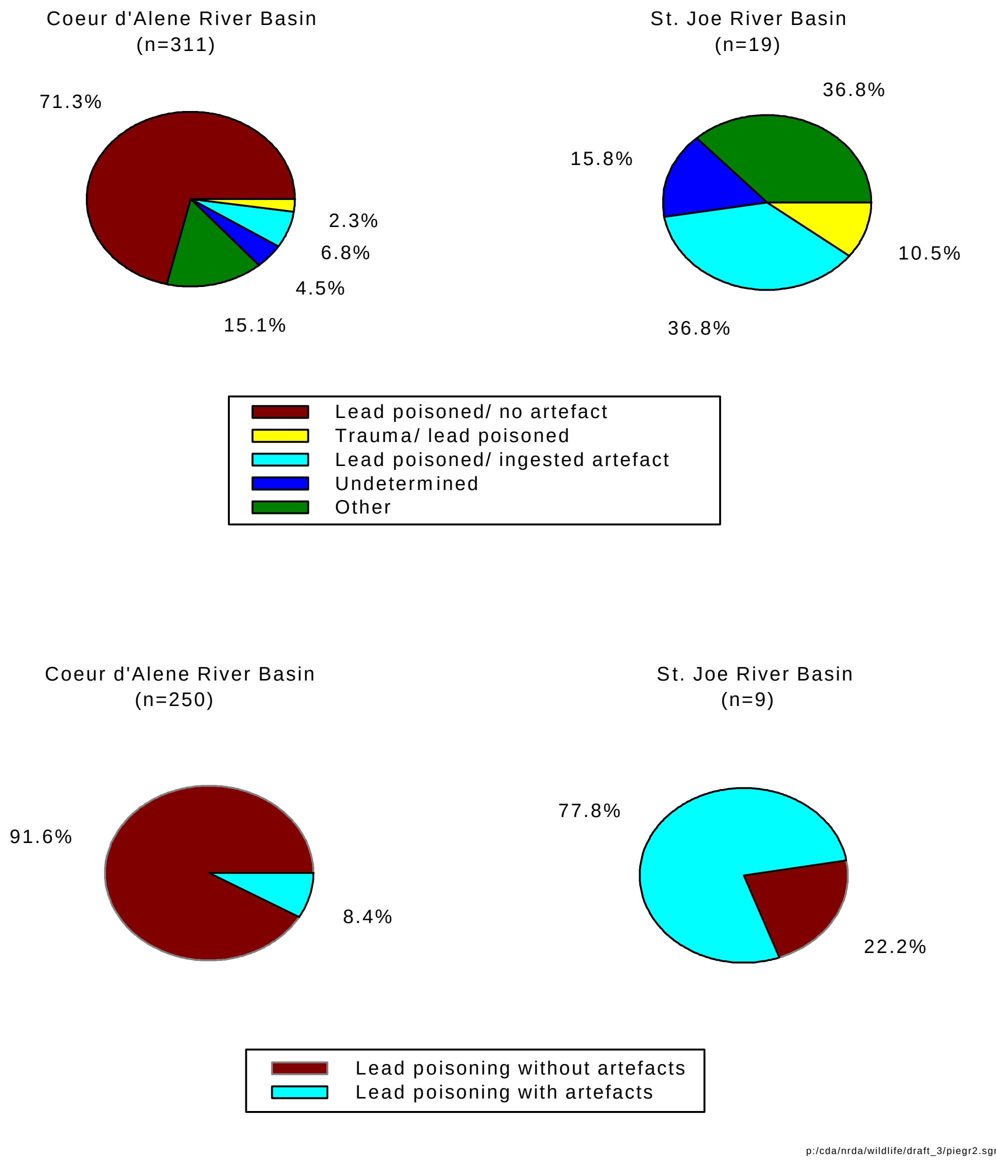


Figure 6-16. Pie charts showing causes of waterfowl deaths in the Coeur d'Alene River basin and St. Joe River basin. Top: percentage occurrence for all causes of mortality in birds submitted for necropsy; n refers to total number of dead birds found and submitted for diagnosis. Bottom: percentage occurrence of lead artifacts in birds diagnosed as lead poisoned.
Source: Audet et al., 1999b.

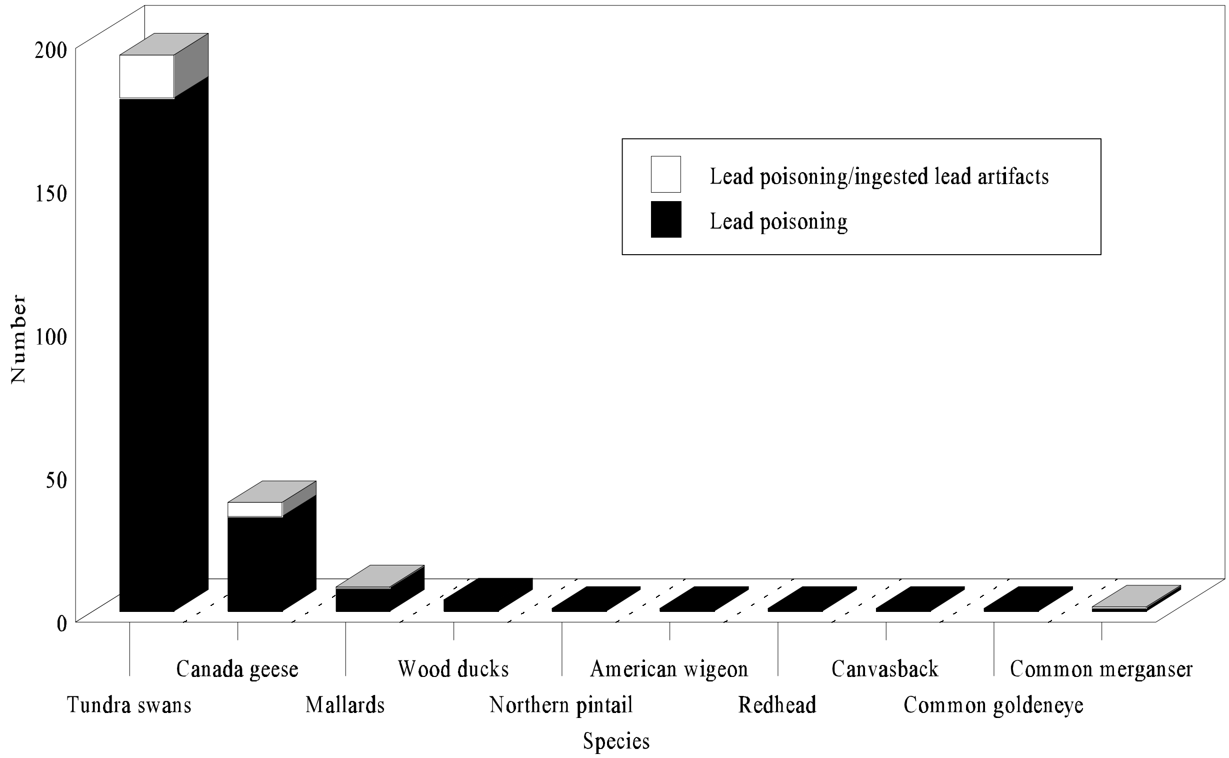


Figure 6-17. Species of waterfowl diagnosed as lead poisoned with and without lead artifacts during the 1992-1997 survey period. n = 194 for tundra swans, 38 for Canada geese, 8 for mallards, and 1 for all others. Source: Audet et al., 1999b.

The high concentrations of lead in Coeur d'Alene River basin sediments (Campbell et al., 1999a), the high rates of sediment ingestion by waterfowl (Beyer et al., 1998b), and the elevated mortality caused by lead poisoning without lead artifact ingestion (Audet et al., 1999c) all indicate that the primary source of the lead in Coeur d'Alene River basin waterfowl is ingested sediments containing lead (Audet et al., 1999c).

Altogether, from 1992 to 1997, sick and dying waterfowl diagnosed as lead poisoned without the presence of lead artifacts were found in 78% of the Coeur d'Alene River basin waterfowl habitat surveyed. Physical deformations (gross and histopathological lesions characteristic of lead poisoning) were observed in 97% of the lead-poisoned birds. Waterfowl carcasses found in the Coeur d'Alene River basin in 1997 represented the largest documented waterfowl kill in the basin since 1953 (Audet et al., 1999c). The mortality survey data indicate that waterfowl deaths occur throughout the lower Coeur d'Alene area and in areas including the South Fork Coeur d'Alene River floodplain, that poisoning occurs in multiple species, and that mortality rates have not declined from historical levels.

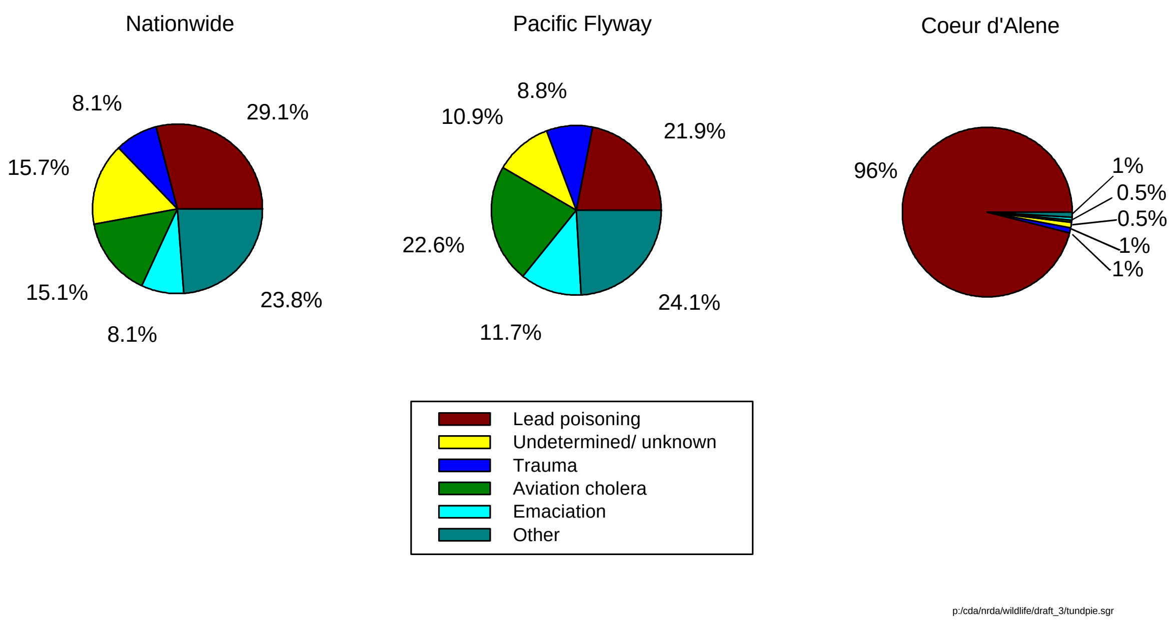


Figure 6-18. Comparison of causes of tundra swan death in the Coeur d'Alene (1992 to 1996), Pacific flyway (1980 to 1993), and nationwide (1981 to 1988).
Source: Audet et al., 1999c.

Lead Exposure and Effects in Waterfowl

Wood ducks, tundra swans, mallard ducks, and Canada geese were captured from the Coeur d'Alene River basin and reference areas to evaluate the degree and sublethal effects of lead exposure (Blus et al., 1997; Blus et al., 1999; Henny et al., 1999). These species were selected to represent migratory waterfowl species of the Coeur d'Alene River basin, and to represent a variety of foraging and feeding strategies used by waterfowl that inhabit the Coeur d'Alene River basin. Lead concentrations in blood and other tissues were measured, and hematological responses (e.g., ALAD activity, hematocrit, and hemoglobin) were quantified.

Wood ducks. Lead exposure (blood lead concentration) and hematological responses (changes in blood ALAD activity, hemoglobin, hematocrit) in wood ducks captured in 1986-1987, 1992, and 1995 from the Coeur d'Alene River basin were compared to lead exposure and hematological data from wood ducks captured in the same years from reference areas north of the Coeur d'Alene River basin (1986-1987) and the St. Joe River basin (1992 and 1995) (Blus et al., 1997).

Exposure of wood ducks collected in 1995 in the Coeur d'Alene River basin to lead was significantly greater (mean blood lead 2 ppm; range 0.63 to 4.5 ppm) than exposure of wood ducks in 1986-1987 ($p = 0.024$; mean blood lead 1.2 ppm; range below detection to 9.0 ppm). Blood lead concentrations in wood ducks collected from the Coeur d'Alene River basin in 1986-1987 and 1995 were significantly greater than blood lead concentrations in wood ducks from the St. Joe River basin ($p < 0.001$; all years combined). Eighty percent of wood ducks in the Coeur d'Alene River basin had a blood lead concentration greater than 0.25 ppm, compared to 6% in the reference area (Blus et al., 1997). Wood ducks from the Coeur d'Alene River basin exhibited physiological impairments in all years sampled, including significant reductions in ALAD activity ($p < 0.0001$), hemoglobin ($p < 0.0002$), and hematocrit ($p < 0.0001$) relative to reference area wood ducks (Figure 6-19). ALAD activity and hemoglobin reductions were significantly correlated with lead residues in blood ($p < 0.001$; ALAD $r^2 = 0.26$; hemoglobin $r^2 = 0.18$). ALAD activity was inhibited by 85 to 96% in Coeur d'Alene wood ducks. Blood lead concentrations and ALAD inhibition measured in wood ducks in 1995 and ALAD inhibition in 1992 were greater than concentrations and ALAD inhibition measured in wood ducks in 1986 and 1987 (Blus et al., 1993). These data indicate that there has been no decrease in lead exposure and effects in wood ducks from the Coeur d'Alene River basin for at least 10 years (1986-1995) (Figure 6-19) (Blus et al., 1997).

These results confirm that even bird species whose exposure to hazardous substances in the Coeur d'Alene River basin is limited by their feeding habits (e.g., water surface feeders) exhibit evidence of significantly greater lead exposure and physiological impairments than reference area birds (Blus et al., 1997).

Tundra swans. Lead exposure (lead concentrations in blood and liver) and hematological responses (changes in blood ALAD activity, hemoglobin, and hematocrit) in moribund and apparently healthy tundra swans captured in 1994-1995 from the Coeur d'Alene River basin were compared to lead exposure and hematological data from tundra swans captured in 1994-1995 in reference areas. Comparisons were also made to data from moribund and apparently healthy swans captured in 1987 from the Coeur d'Alene River basin (Blus et al., 1999). Reference areas included the Malheur National Wildlife Refuge (central Oregon) and the Lower Klamath National Wildlife Refuge (southern Oregon).

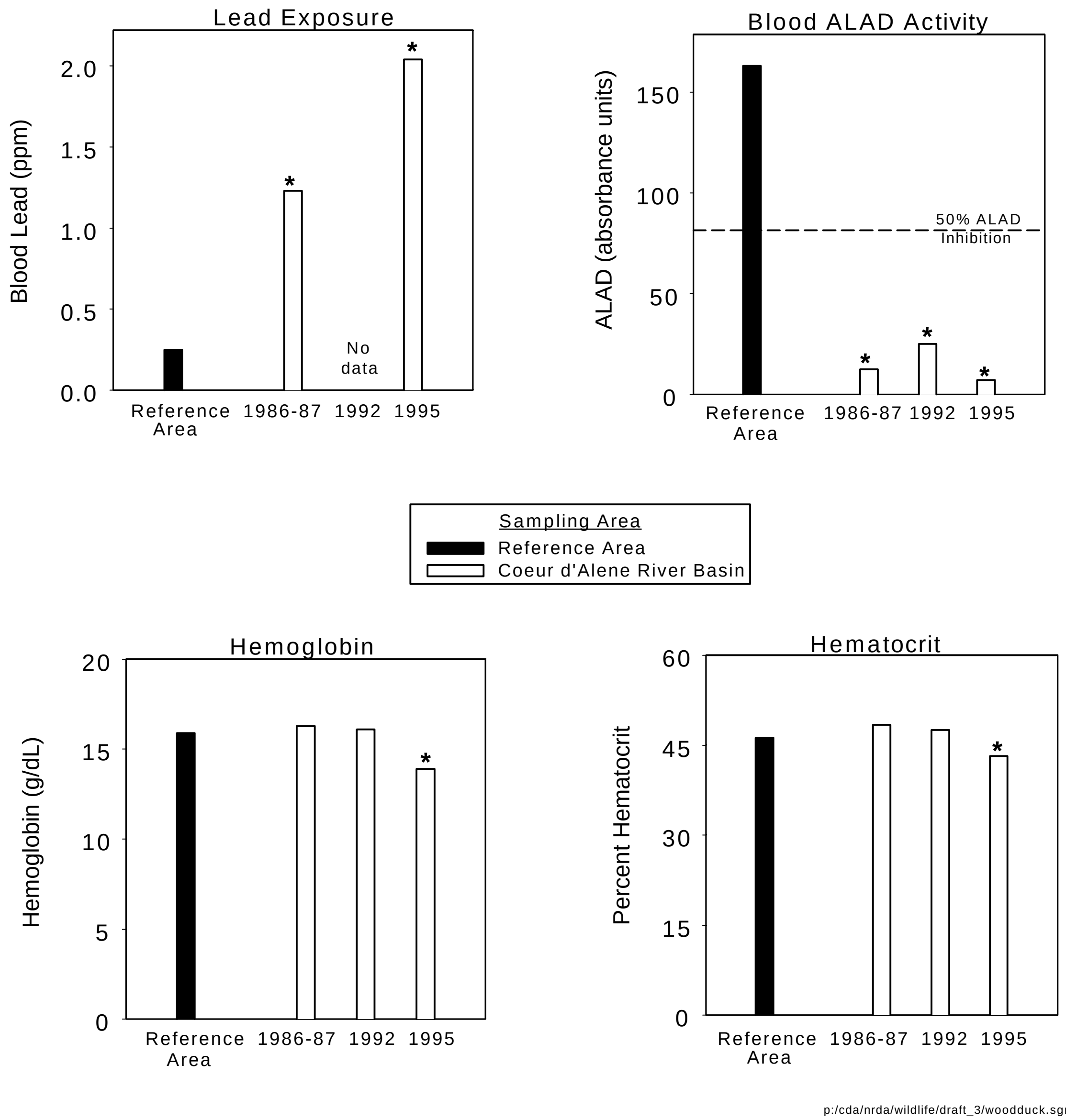


Figure 6-19. Comparison of lead exposure and effects in Coeur d'Alene River basin wood ducks over time. Reference area values are combined data for 1986 to 1995. An asterisk (*) indicates a significant difference ($p < 0.05$) between the Coeur d'Alene and reference areas. Dashed line in top right panel shows 50% ALAD inhibition level relative to reference levels. Lead exposure and ALAD activity data are geometric means.
Source: Blus et al., 1997.

Lead exposure of moribund tundra swans captured in 1994-1995 was significantly greater in the Coeur d'Alene River basin (mean blood lead of 3.3 ppm; range of 0.5 to 6.2 ppm) than in reference areas (0.11 ppm; range 0.02 to 28 ppm) ($p < 0.0001$) (Blus et al., 1999). Mean blood lead concentration of apparently healthy birds captured in the Coeur d'Alene River basin (mean 1.8 ppm, range 1.2 to 3.8 ppm) was also significantly greater than the reference mean. Excluding two extreme values that may have been related to lead shot (3 and 28 ppm), mean blood lead concentration in reference area birds was 0.08 ppm (Blus et al., 1999).

Moribund tundra swans from the Coeur d'Alene River basin exhibited physiological impairments, including statistically significant reductions in ALAD activity and hemoglobin compared to swans from reference areas. ALAD was inhibited by 93% in Coeur d'Alene tundra swans, and ALAD activity was significantly negatively correlated with the concentrations of lead in swan blood ($p < 0.001$; $r^2 = 0.75$). Hemoglobin and hematocrit levels were also significantly negatively correlated with blood levels, but appeared to show a threshold response. Hemoglobin concentrations and percent hematocrit were both relatively constant at blood lead concentrations between 0.01 and 1 ppm and declined at blood lead concentrations greater than 2 ppm lead (Blus et al., 1999).

The persistence of elevated exposure and continuing effects on swans was evaluated by comparing current data (1994 and 1995) to data collected in 1987 (Blus et al., 1991). Lead poisoning was the cause of death of 14 of 15 moribund swans collected in the Coeur d'Alene River basin in 1994-1995, and of all of 4 moribund swans collected in 1987 (Blus et al., 1991; Blus et al., 1999). Necropsy results confirmed that liver lead concentrations of the 18 lead poisoned swans ranged from 6.4 to 40 µg/g, and that all 18 swans showed signs of emaciation. Only one of the 18 lead poisoned swans contained ingested lead shot in the gizzard. There was no significant difference in liver lead concentrations between swans captured in 1994-1995 and swans captured in 1987.

Comparisons of blood and liver lead concentrations and blood parameters responsive to lead exposure indicated no reduction in lead exposure or physiological malfunctions in tundra swans from the Coeur d'Alene River basin between 1987 and 1995 (Figure 6-20) (Blus et al., 1999). Liver lead concentrations measured in lead poisoned swans in 1994-1995 by Blus et al. (1999; range of 9 to 34) were similar to liver residues in tundra swans measured in 1974 (Benson et al., 1976; range of 7 to 43 ppm; 1 of 13 birds had ingested lead shot).

These results indicate that tundra swans in the Coeur d'Alene River basin contain elevated tissue concentrations of lead, that they experience both lethal and sublethal effects characteristic of lead exposure, that most lead poisoning occurs without the presence of ingested lead artifacts, and that exposure has not diminished during the past 20 years.

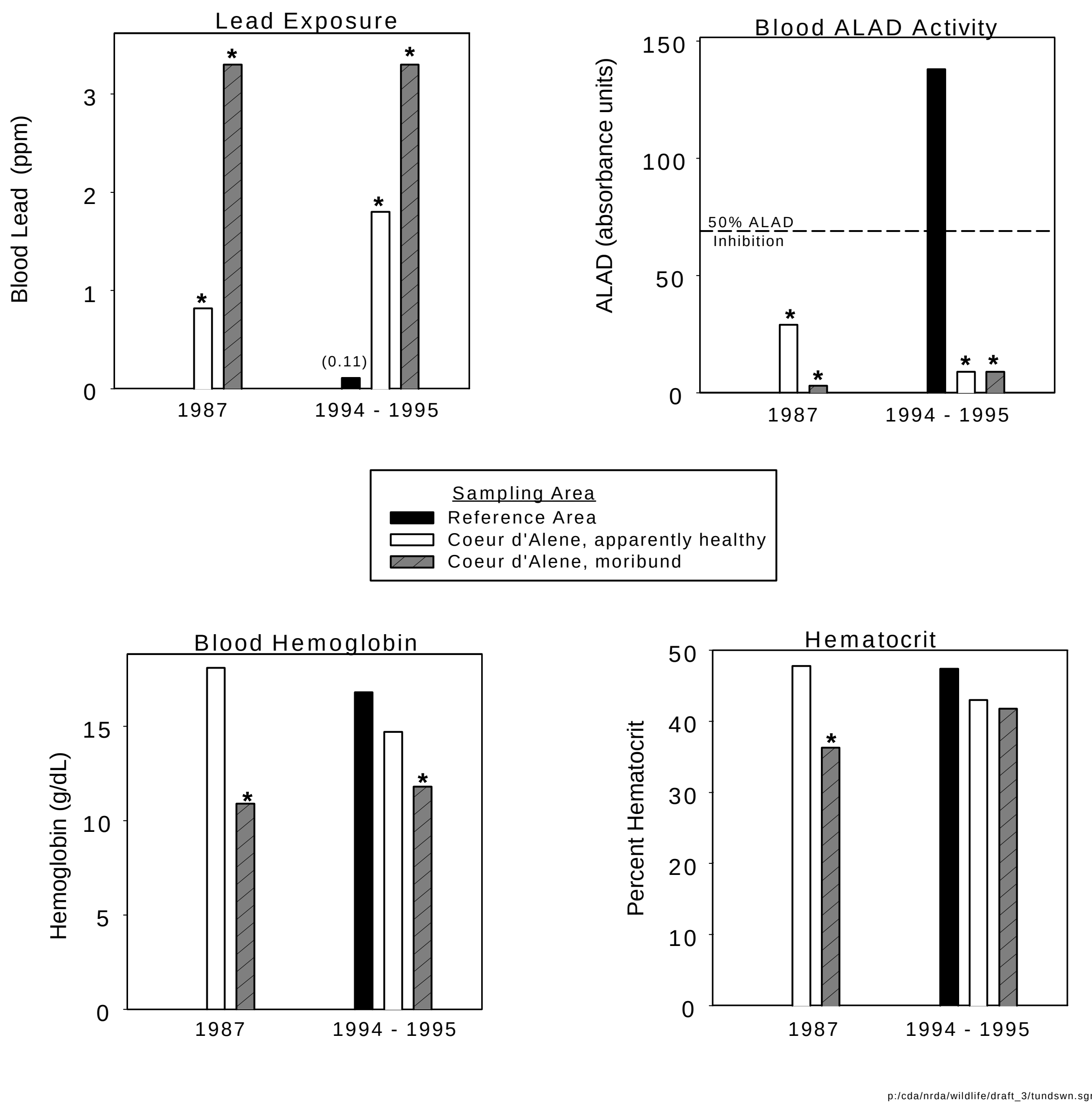


Figure 6-20. Comparison of lead exposure and effects in Coeur d'Alene River basin tundra swans over time. Reference area values are combined data for 1994 and 1995. Figure legends designate birds observed to be apparently healthy (not impaired) and sick (impaired). An asterisk (*) indicates a significant difference ($p < 0.05$) between the Coeur d'Alene and reference areas. Dashed line in the top right panel shows 50% ALAD inhibition level relative to reference levels. Lead exposure and ALAD activity data are geometric means.
Source: Blus et al., 1997.

Canada geese. Lead exposure (lead concentrations in blood, liver, and kidney) and hematological responses (changes in blood ALAD activity, protoporphyrin, hemoglobin, hematocrit) in adult and young Canada geese (goslings) from the Coeur d'Alene River basin were compared to lead exposure and hematological data from the Canada geese adults and goslings from reference areas (Henny et al., 1999). Reference areas included McArthur Wildlife Management Area (northern Idaho), a Snake River location (near Lewiston, Idaho), and the St. Joe River basin.

Lead exposure in goslings from the Coeur d'Alene area (mean blood lead 0.28 ppm; range 0.12 to 1.2 ppm) was significantly greater than in reference area goslings of comparable body mass (0.01 ppm; range <0.001 to 0.15; $p < 0.0001$) (Henny et al., 1999). Lead exposure was also significantly greater in adults from the Coeur d'Alene River basin (0.41 ppm; range 0.26 to 1.3) than in reference area adults (0.02 ppm; range 0.002 to 0.14) ($p < 0.01$). Coeur d'Alene River basin adults and goslings exhibited physiological impairments, including 65 to 86% inhibition of blood ALAD activity ($p < 0.0001$), 132 to 1523% elevation of blood protoporphyrin, and 3 to 12% reduction in hemoglobin and hematocrit relative to reference geese (Figure 6-21) (Henny et al., 1999).

In general, Coeur d'Alene goslings and adult life stages of Canada geese exhibited similar lead exposure and effects. These results indicate that both young and adult life stages of Canada geese in the Coeur d'Alene River basin contain elevated tissue concentrations of lead and that they experience effects characteristic of lead exposure.

Mallard ducks. Lead exposure (lead concentrations in blood, liver, and kidney), hematological responses (changes in blood ALAD activity, protoporphyrin, hemoglobin, hematocrit), and physical deformations (gross and histological lesions) in adult and young (hatch year; HY) mallard ducks from the Coeur d'Alene River basin were compared to lead exposure and hematological data from birds from reference areas (Henny et al., 1999). Reference areas included McArthur Wildlife Management Area (northern Idaho), Turnbull National Wildlife Refuge (eastern Washington), and the St. Joe River basin.

Lead exposure was significantly greater in Coeur d'Alene HY mallard ducks (mean blood lead 0.98 ppm; range 0.25 to 6.6 ppm) than in reference area HY mallard ducks (0.02 ppm; range of 0.007 to 0.51) ($p < 0.001$) (Figure 6-22) (Henny et al., 1999). Lead exposure was also significantly greater in adult mallard ducks from the Coeur d'Alene River basin (1.8 ppm; range 0.19 to 17.4 ppm) than in reference area adults (0.03 ppm; range 0.004 to 0.81; $p < 0.001$). Three of the 22 mallards (14%) euthanized from the Coeur d'Alene River basin contained ingested lead shot.

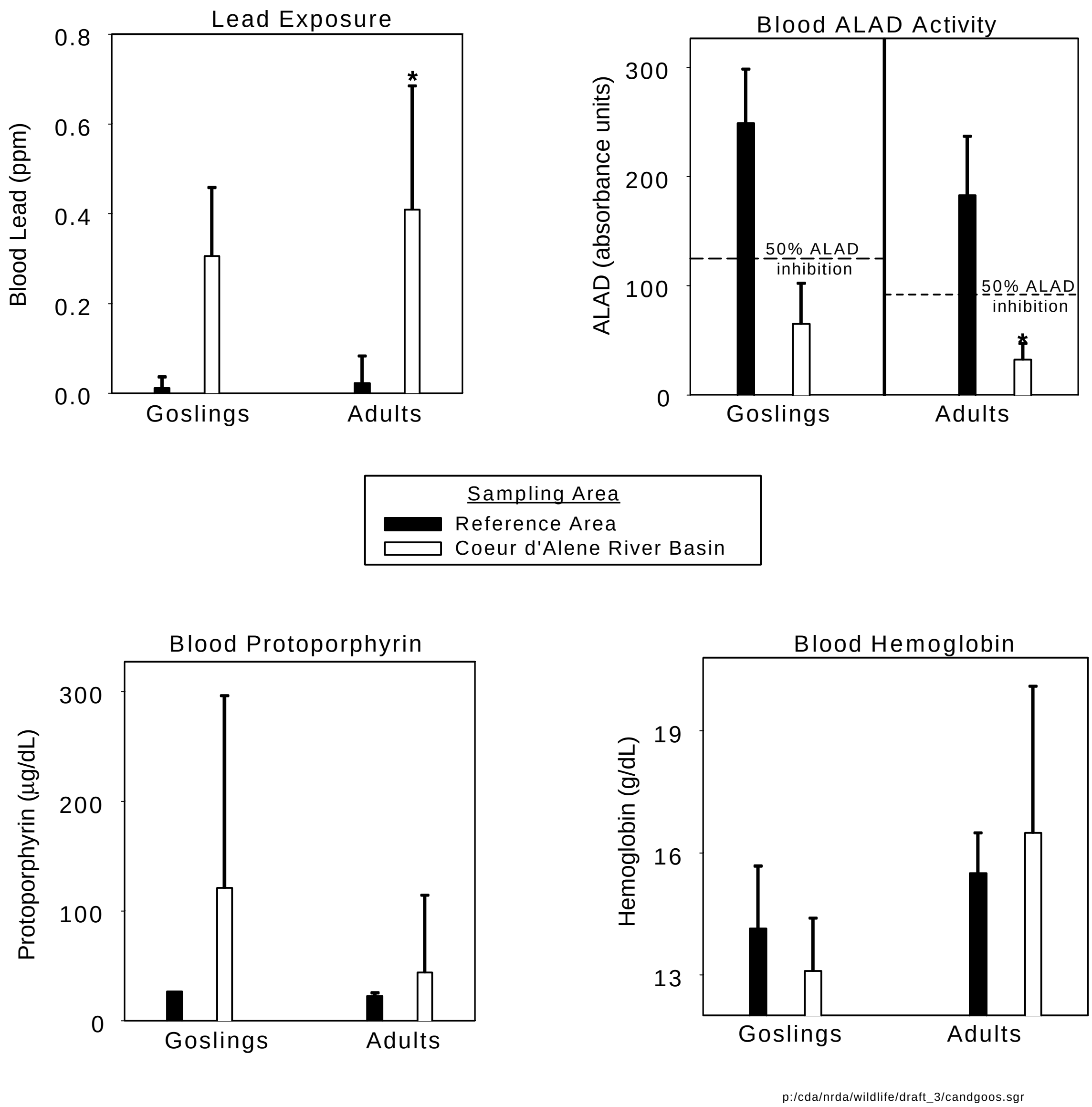


Figure 6-21. Comparison of lead exposure and effects in Canada geese goslings and adults from the Coeur d'Alene River basin and reference areas. An asterisk (*) indicates a significant difference ($p < 0.05$) between the Coeur d'Alene and reference areas. Dashed lines in top right panel show 50% ALAD inhibition level relative to reference levels.
Source: Henny et al., 1999.

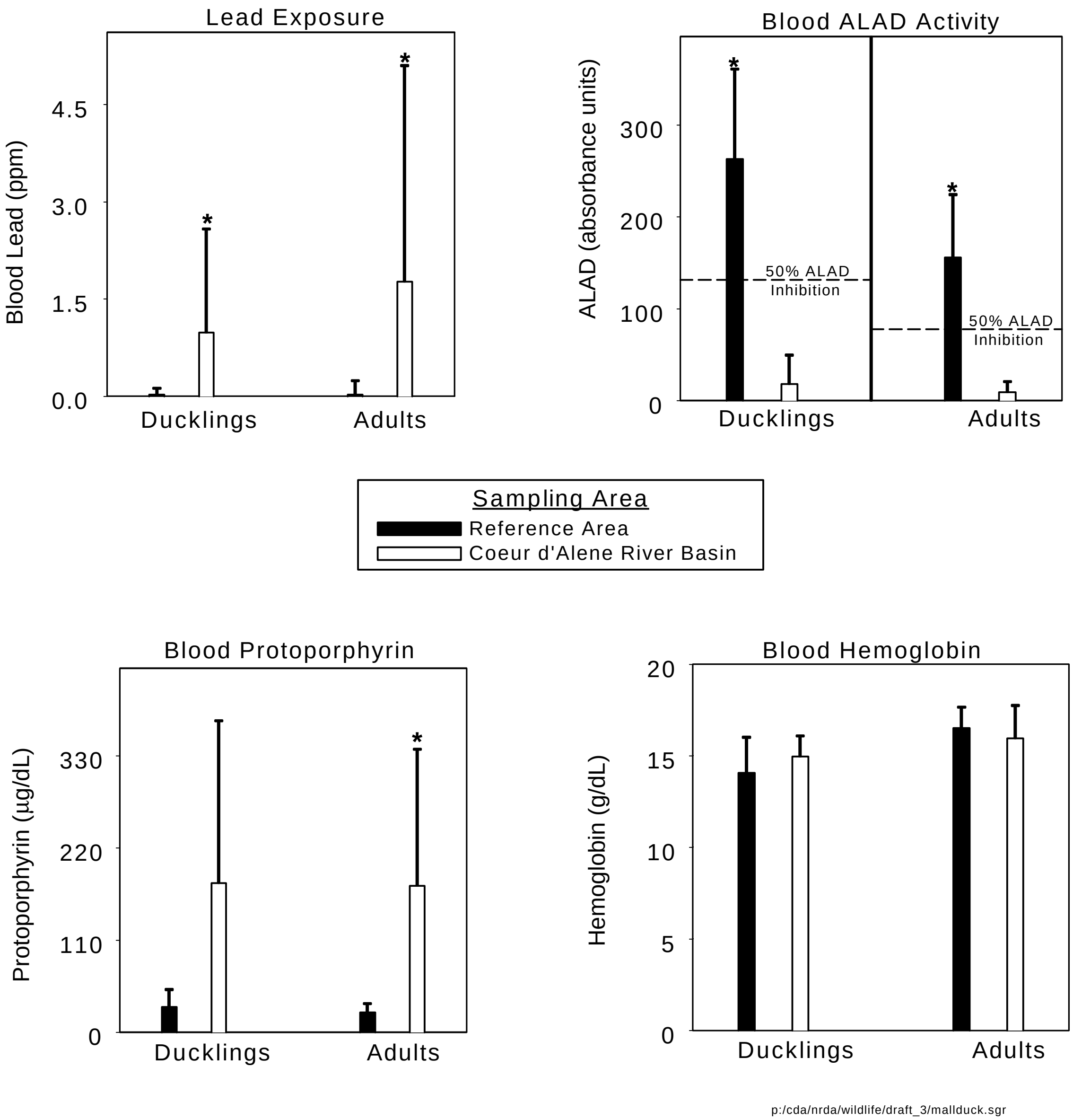


Figure 6-22. Comparison of lead exposure and effects in hatch year mallards and adults from the Coeur d'Alene and reference areas. An asterisk (*) indicates a significant difference ($p < 0.05$) between the Coeur d'Alene and reference areas. Dashed lines in top right panel show 50% ALAD inhibition level relative to reference levels. Source: Henny et al., 1999.

Ninety-four percent of the Coeur d'Alene River basin HY mallard ducks exhibited greater than 50% ALAD inhibition. Ninety percent of Coeur d'Alene River basin adults exhibited significant ALAD inhibition relative to reference adult mallard ducks ($p < 0.0001$), and all showed greater than 50% ALAD inhibition. Protoporphyrin concentrations were significantly elevated in Coeur d'Alene HY mallard ducks and in adult mallard ducks compared to birds from reference areas ($p < 0.0004$ for HY, $p < 0.002$ for adults). In Coeur d'Alene River basin HY mallard ducks, protoporphyrin was elevated by approximately 590%, and in adults, by approximately 740%.

The majority of the young and adult mallard ducks captured from the Coeur d'Alene River basin also exhibited physiological deformations related to lead exposure, including poor body condition, hepatic hemosiderosis, and renal necrosis (Henny et al., 1999). In general, lead exposure and effects were similar in mallard duckling and adult life stages.

The study results indicate that young and adult mallard ducks from the Coeur d'Alene River basin contain elevated tissue concentrations of lead, that they experience physiological effects characteristic of lead exposure, and that lead poisoning typically occurs without the presence of ingested lead artifacts.

Lead Exposure and Effects in Bald Eagles

To evaluate lead exposure and effects on bald eagles in the Coeur d'Alene River basin, blood samples were collected from young bald eagles and hematological parameters (blood ALAD activity, hemoglobin and hematocrit levels) and growth were measured. Blood samples and growth data were collected from eagles in nests in the Coeur d'Alene River basin and at McArthur Lake, MWMA (Audet et al., 1999b). Food chain exposure was evaluated by measuring lead concentrations in eagle prey items, including muskrats *(Ondatra zibethicus)*, brown bullheads (*Ameriurus nebulosus*), and other fish species collected from the Coeur d'Alene and St. Joe river basins, and by measuring lead concentrations in lead-poisoned waterfowl (without ingested lead shot) from the Coeur d'Alene River basin (Audet, 1997; Audet et al., 1999b).

Blood lead levels were higher in Coeur d'Alene River basin eaglets (0.03 to 0.18 ppm) than in reference eaglets (0.01, 0.02 ppm) (Audet et al., 1999b). Blood protoporphyrin and hemoglobin were similar in Coeur d'Alene River basin and reference area eaglets. ALAD was inhibited by 35 to 65% in Coeur d'Alene River basin eaglets. The average weight of Coeur d'Alene eaglets was lower than the average weight of reference area eaglets of similar age. For both blood and growth measurements, sample sizes were small, so statistics were not provided.

Prey items of eagles in the Coeur d'Alene River basin were contaminated with lead (Figure 6-14). For example, lead concentrations were significantly greater in brown bullheads from the Coeur d'Alene River basin (range 3.8 to 122 ppm) than in brown bullheads from the St. Joe River basin (range <0.1 to 2.9 ppm) ($p < 0.0001$). Lead concentrations in tissues of lead-poisoned waterfowl prey items from the Coeur d'Alene area were elevated and ranged from 1.64 to 38.0 ppm in liver and from <0.09 to 0.76 ppm in muscle (Audet, 1997).

For comparison, dead bald eagles from northern Idaho and eastern Washington were necropsied to determine causes of death. Lead poisoning without the presence of ingested lead shot was the most common diagnosis of dead bald eagles collected in northern Idaho/eastern Washington. Of the 13 carcasses documented, 10 were suitable for necropsy. Six of the 10 carcasses necropsied, including 2 of the 4 carcasses collected from the Spokane River basin (which includes the Coeur d'Alene River basin), were lead-poisoned without ingested lead shot (Audet et al., 1999b).

The results of the blood parameter and growth comparisons and the food chain exposure studies indicate that bald eagles of the Coeur d'Alene River basin are exposed to elevated concentrations of lead in prey items, have elevated blood lead concentrations, and have reduced blood ALAD activity. Four types of lead exposure were considered possible: ingestion of lead shot embedded in the tissues of waterfowl prey; ingestion of lead sinkers in fish; ingestion of lead in offal; and ingestion of lead in sediments, either directly or in prey (Audet et al., 1999b). Lead poisoning without ingested artifacts was documented as a cause of bald eagle death in northern Idaho and eastern Washington.

Lead Exposure and Effects in Songbirds

Biological reconnaissance sampling conducted in 1992 indicated that floodplain songbirds in the Coeur d'Alene River basin were exposed to elevated concentrations of lead (Audet, 1997). Songbirds, which feed on insects, worms, and other invertebrates, are exposed to lead in the Coeur d'Alene River basin by routes other than ingestion of lead artifacts and incidental consumption of soil while feeding. To evaluate lead exposure (liver lead) and effects (changes in blood ALAD activity and hematocrit) in songbirds, song sparrows and American robins were sampled in 1995 in the floodplain of the lower Coeur d'Alene River basin and in reference areas (Johnson et al., 1999). Reference areas included the North Fork Coeur d'Alene River and the St. Joe River basin.

Liver lead concentrations were significantly greater in song sparrows collected from the lower Coeur d'Alene River basin than in sparrows from reference areas (mean 1.9 ppm versus 0.10 ppm, $p = 0.0079$; Johnson et al., 1999). Blood ALAD activity in song sparrows and robins from the Coeur d'Alene River basin was significantly inhibited relative to ALAD activity in reference birds ($p = 0.004$). Inhibition of blood ALAD activity averaged 51% in Coeur d'Alene

River basin song sparrows and 75% in robins. ALAD activity was inhibited by greater than 50% in 43% of Coeur d'Alene River basin song sparrows and in 84% of Coeur d'Alene River basin robins (Johnson et al., 1999).

These data indicate that songbirds inhabiting the floodplain of the Coeur d'Alene River basin are exposed to elevated lead concentrations and exhibit physiological malfunctions from lead exposure.

6.5.3 Injury Laboratory Studies

In addition to the field studies described above, the Trustees performed a series of controlled laboratory feeding experiments to examine the relationship between ingestion of lead-contaminated Coeur d'Alene River basin sediments and lead exposure and effects. In each experiment, sediments from the Coeur d'Alene River basin were mixed with waterfowl feed (to simulate naturally occurring sediment ingestion) and fed to representative species of waterfowl, including mallards, Canada geese, and mute swans (a surrogate for tundra swans) (Table 6-6). Measurement endpoints included death, physiological malfunctions (e.g., changes in blood parameters, body weight), and physical deformations (gross and histological lesions).

Table 6-6
Experimental Design of Laboratory Studies[a]

Test Species	Life Stage	Exposure (% sediment)	Food Matrix Tested	Duration (weeks)	Study Authors
Mallard duck	Subadult	Ingested dose: 3% to 20% (Experiment 1)	Commercial diet (pelletized)	5 to 10	Heinz et al. (1999)
		Ingested dose: 14%, 17% (Experiment 3)	Commercial diet (mash) or ground corn diet	15	
	Juvenile	Nominal exposure: 12%, 24%	Commercial diet (mash) or 2/3 ground corn/commercial diet (mash)	6	Hoffman et al. (1998)
Canada goose	Juvenile	Nominal exposure: 12% to 48%	Commercial diet (mash)		
Mute swan	Juvenile	Nominal exposure: 12%, 24%	Commercial diet (pelletized) or ground rice diet (pelletized)	7	Day et al. (1998)

a. Measurements: ALAD, blood lead, hematocrit, hemoglobin, metals in kidney and liver, protoporphyrin, survival, tissue lesions, body weight, lead in feces (Heinz et al. and Day et al. only), and blood enzymes (Hoffman et al. and Day et al. only).

The controlled laboratory experiments enabled investigators to (1) expose animals in a controlled setting to field collected sediments in the absence of lead shot; (2) alter the type of diet mixed with the sediment to investigate food matrix effects; and (3) expose animals to increasing concentrations of lead in sediment to evaluate exposure or dose-response relationships. Although laboratory studies allow for precise testing of dietary exposure conditions, they may result in an underestimate of the actual toxicity of lead contaminated sediments since laboratory studies are generally conducted under less stressful conditions than animals encounter in the wild (e.g, absence of food limitations, predators, temperature extremes).

Waterfowl were exposed to laboratory diets prepared with sediment from either the Coeur d'Alene River basin (average 3,700 ppm lead, range 3,400-4,000 ppm) or the St. Joe River basin reference area (8 ppm lead, range 6.3-9.7 ppm). All sediments were sieved (1 mm) to remove lead artifacts (Heinz et al., 1999). Lead exposure concentrations in the laboratory diets were produced by mixing sediments with feed. For example, the commercial and corn diets prepared from 24% Coeur d'Alene River basin sediment in the Heinz et al. (1999) study contained 950 and 870 ppm lead, respectively.

Nominal exposure levels (expressed as the percent sediment in bird feed) were selected based on the amount of sediment that waterfowl ingest in the field (Beyer et al., 1998b). The highest exposure levels were selected to approximate the upper ninetieth percentile of sediment ingestion of tundra swans in the Coeur d'Alene River basin, or 22% sediment ingestion (Beyer et al., 1998b). Fecal samples were collected in the laboratory studies by Heinz et al. (1999) and Day et al. (1998) to allow comparison to sediment content and lead concentrations measured in fecal samples collected in the field.

Feeding experiments were conducted with either a nutritionally complete commercial waterfowl feed or less nutritious diets containing corn (mallard and Canada goose studies) or rice (swan study) that are more representative of natural diets in the field. The different diets were used to evaluate the effect of the food matrix (pelleted or mash diets; commercial, corn, or rice diets) on the bioavailability of sediment lead to waterfowl. In the wild, waterfowl may ingest a diversity of food items that are less nutritious than commercial diets (Day et al., 1998). Less nutritious diets (e.g., low in calcium) have been shown to increase lead accumulation in birds (e.g., Scheuhammer, 1996).

Toxicity of Sediments to Subadult Mallard Ducks

To evaluate relationships between ingestion of lead-contaminated sediment and biological responses, subadult mallard ducks (20 to 30 weeks old) were fed either Coeur d'Alene sediment or reference area sediment in a commercial duck feed or in a nutritionally deficient ground corn diet (Heinz et al., 1999). Dietary mixtures with Coeur d'Alene sediment contained from 3 to 24%

sediment. The 24% sediment diet contained 870 to 950 ppm lead. The dietary mixture with reference sediment contained 24% sediment and approximately 3 ppm lead. Measurement endpoints included lead and zinc concentrations in blood, kidney, and liver; survival; physiological malfunctions (weight loss, changes in blood ALAD activity and protoporphyrin, hemoglobin, and hematocrit levels); and physical deformities (gross and histopathological lesions). The results are expressed as the ingested dose of sediment (% in diet), estimated from analysis of fecal samples using the same procedures used to estimate mallard duck sediment ingestion in the field.

Experimental dietary groups of mallard ducks fed increasing percentages of Coeur d'Alene sediment in a commercial diet showed corresponding increases in lead exposure (lead concentrations in blood and liver) in the absence of lead shot (Figure 6-23). In comparison, ducks that consumed reference area sediment exhibited minimal lead exposure (Figure 6-23). The positive relationship between Coeur d'Alene River basin sediment ingestion and blood and liver lead concentrations demonstrate that lead in Coeur d'Alene River basin sediment is bioavailable to waterfowl.

With the pelletized commercial diet (Experiment 1 of Heinz et al., 1999), nominal exposures (% sediment in feed) were nearly identical to the estimated ingested doses (% ingested). Mallards fed pellets containing 3, 6, 12, and 24% Coeur d'Alene sediment actually ingested an estimated average of 3.2, 6.5, 11, and 19% sediment (Heinz et al., 1999). Mallards fed the ground corn diet ingested less sediment than mallards fed the pelletized commercial diet. Mallards fed the mash commercial diet consumed the least amount of sediment, possibly because of sorting by the ducks. For example, mallards fed 24% sediment in the pelletized commercial diet (Experiment 1 of Heinz et al., 1999) ingested 27% sediment and mallards fed 24% sediment in the mash commercial diet (Experiment 2 of Heinz et al., 1999) ingested only 11% sediment. Lead concentrations in feces of mallards exposed to Coeur d'Alene sediments in the laboratory tests (means of 284 to 1660 ppm) were within the range measured in the field by Beyer et al. (1998b) (2.3 to 3,600 ppm; mean of 230; median of 98 ppm).

Even low levels of Coeur d'Alene River basin sediment ingestion (average of 3.2%) caused physiological malfunctions, including depression of ALAD activity greater than 50% and elevation of blood protoporphyrin (Figure 6-23; Heinz et al., 1999). Higher sediment ingestion rates resulted in increasing effects, including significant reductions in hemoglobin levels (Figure 6-23). Mallards that ingested an average of 19% Coeur d'Alene River basin sediment in the commercial diet exhibited physical deformations, including atrophy of the breast muscles, green staining of the feathers around the vent, viscous bile, green staining of the gizzard lining, and RIIBs (Figure 6-24). One of 10 mallards from the 19% Coeur d'Alene River basin sediment ingestion group died. Necropsy observations of atrophied breast muscles and green stained gizzard lining confirmed that the cause of death was lead poisoning (Heinz et al., 1999).

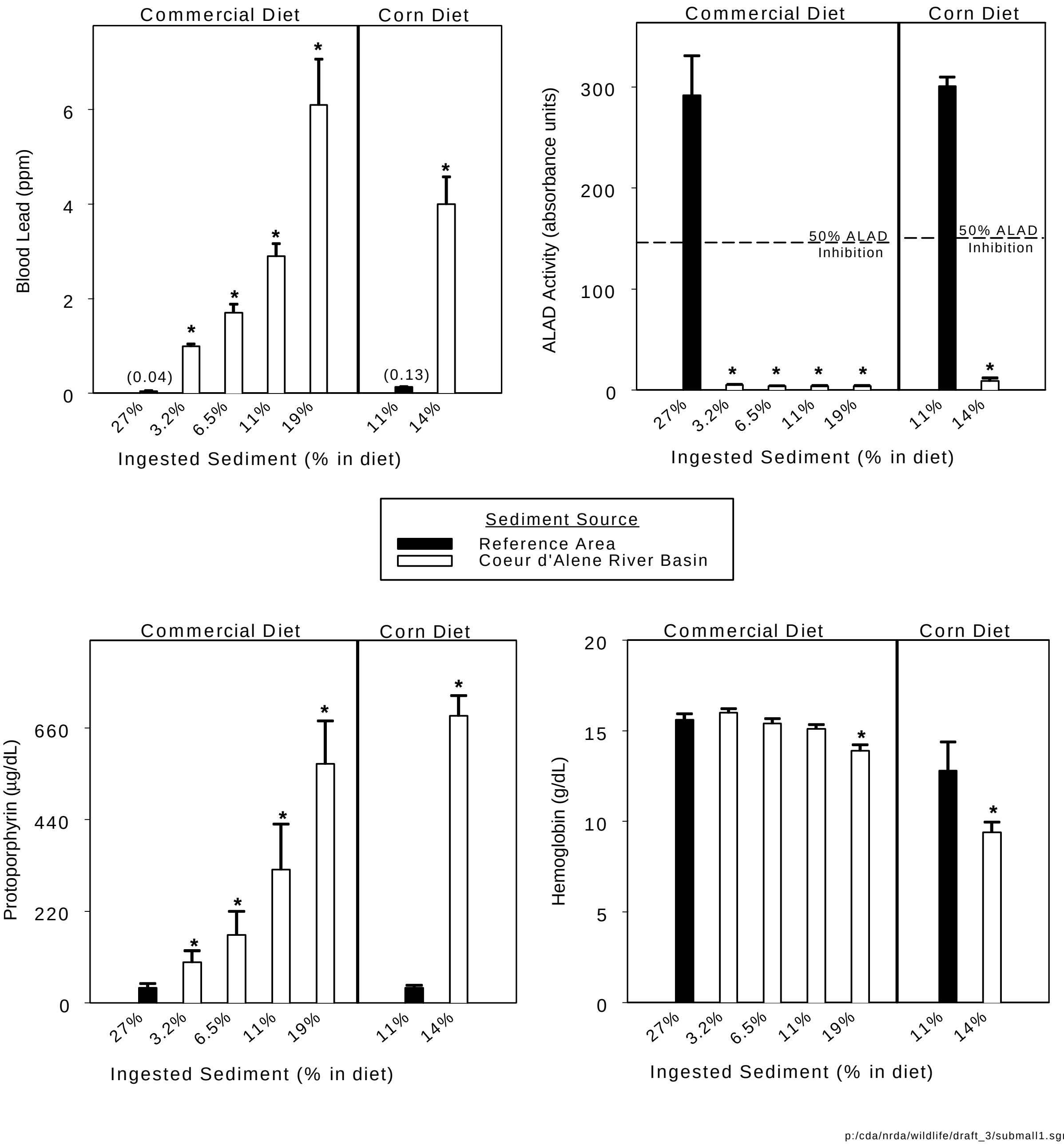


Figure 6-23. Blood liver lead residues (top left), blood ALAD activity (top right), blood protoporphyrin levels (bottom left), and blood hemoglobin levels (bottom right) of subadult mallard ducks ingesting sediment from the Coeur d'Alene River basin or the reference area. Birds were provided sediment mixed in either a commercial diet or a ground corn diet. An asterisk (*) indicates a significant difference ($p < 0.05$) in lead concentrations in birds ingesting Coeur d'Alene sediment compared to birds on the same diet ingesting reference sediment.
Source: Heinz et al., 1999; Experiments I and III.

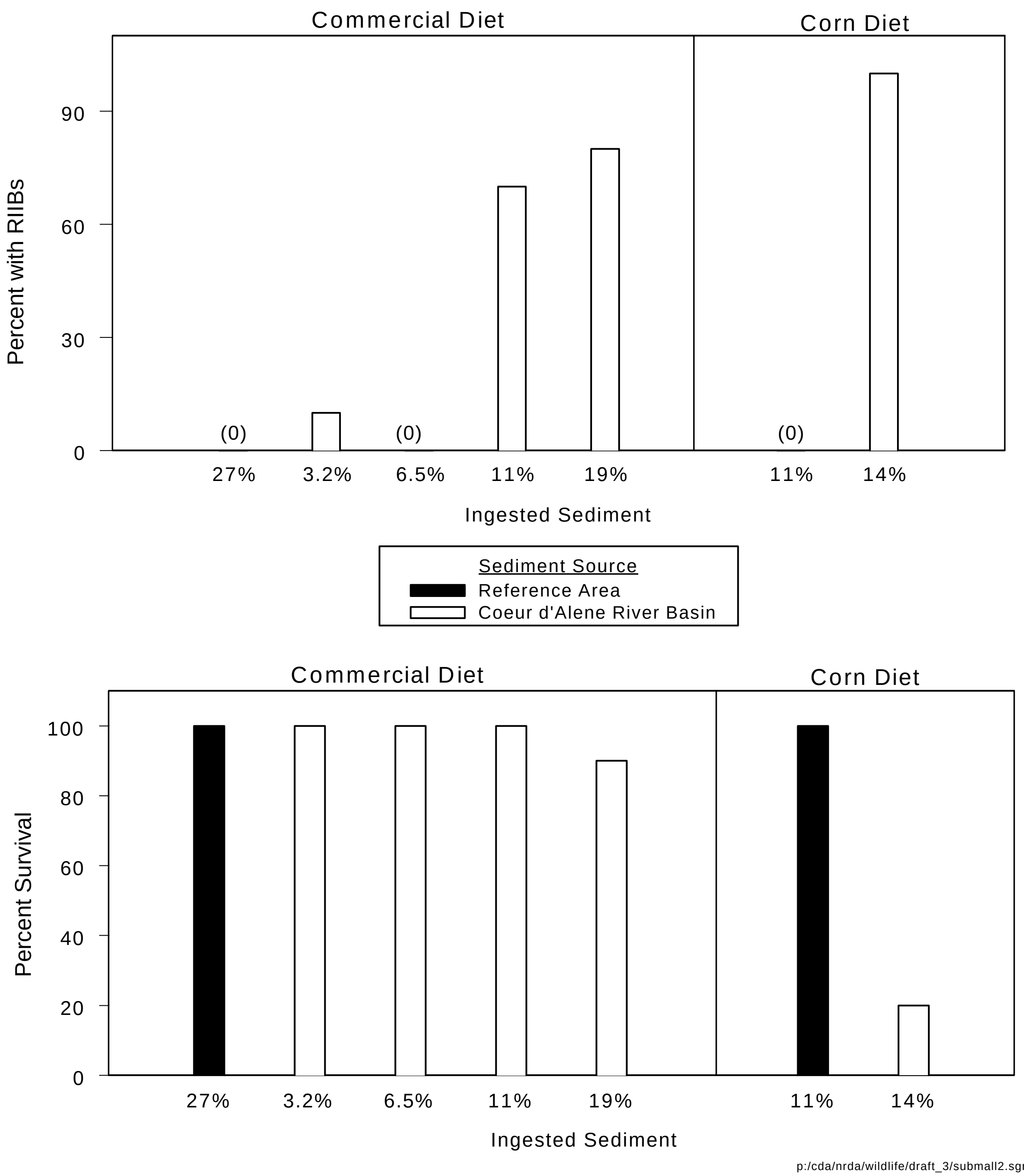


Figure 6-24. Comparison of the frequency of renal intranuclear inclusion bodies (RIIBs) (top panel) and survival (bottom panel) in subadult mallard ducks ingesting sediment from the Coeur d'Alene River basin or the reference area. Birds were provided sediment mixed in either a commercial diet or a ground corn diet. Source: Heinz et al., 1999; Experiments I and III.

When birds were fed a nutritionally deficient ground corn diet, the effects of ingestion of Coeur d'Alene River basin sediment relative to ingestion of reference area sediment were more severe (Figures 6-23 and 6-24; Heinz et al., 1999). In addition to significant changes in blood and liver lead concentrations, ALAD activity, protoporphyrin, and hemoglobin levels, mallards that ingested an average of 14% Coeur d'Alene sediment showed a 27% reduction in body weight relative to birds fed the corn diet and reference area sediment. Blood ALAD activity was depressed by 97% relative to reference birds (Figure 6-23). All birds ingesting Coeur d'Alene River basin sediment on the corn diet had physical deformations, including emaciation and RIIBs (Figure 6-24; Heinz et al., 1999). Four of the five birds (80%) ingesting the corn diet with 14% Coeur d'Alene sediment died from lead poisoning during the 15 week exposure period (Figure 6-24).

The feeding experiments show that lead in Coeur d'Alene River basin sediments is bioavailable to mallard ducks, that lead poisoning results from exposure to Coeur d'Alene River basin sediments in the absence of lead shot, and that the number and severity of effects increase as sediment ingestion increases. Effects observed in the feeding experiments were similar to responses observed during field investigations, including hematological changes, physical deformations, and death. The degree of lead exposure and the number and severity of effects were greater in mallards fed a nutritionally deficient corn diet more similar to field conditions than in those fed a nutritionally complete commercial diet.

Toxicity of Sediments to Goslings and Ducklings

The relationship between ingestion of lead-contaminated sediment and biological responses was also evaluated in laboratory experiments with Canada goslings and mallard ducklings (Hoffman et al., 1998). Birds were fed either Coeur d'Alene River basin sediment or reference area sediment in a commercial duck feed. Mallard ducklings were also fed a less nutritious corn/commercial diet mixture. Dietary mixtures with Coeur d'Alene sediment contained from 12 to 48% reference area sediment. The 48% reference sediment diet contained an estimated 1656 ppm lead. The dietary mixture with reference sediment contained 24 and 48% sediment. The 48% sediment diet contained approximately 5.5 ppm lead. Measurement endpoints included lead and zinc concentrations in blood, kidney, and liver; survival; physiological malfunctions (loss of body weight; changes in blood ALAD activity, and protoporphyrin, hemoglobin, and hematocrit levels; changes in blood and liver biochemical parameters); and physical deformations (gross and histopathological lesions). The results are expressed as a nominal exposure (% sediment in feed provided to the birds) rather than the actual dose ingested because the amount of sediment actually consumed was not measured. All birds were fed mash diets (both commercial and corn diets), so actual sediment ingestion may have been less than the nominal exposure concentration based on the results of Heinz et al. (1999) that were previously presented.

With a commercial diet, the lowest experimental exposure to Coeur d'Alene River basin sediment (12%) resulted in elevated tissue concentrations of lead and physiological malfunctions in both goslings and ducklings, including significant elevation of blood protoporphyrin levels and depression of ALAD activity greater than 50% ($p \leq 0.05$; Figures 6-23 and 6-25; Hoffman et al., 1998). Higher sediment exposure levels resulted in an increase in lead concentrations in tissues and greater frequency and degree of physiological malfunctions characteristic of lead exposure, including significant reductions in hemoglobin concentrations, changes in blood and liver biochemical parameters, and weight loss ($p \leq 0.05$; Figures 6-23, 6-24, and 6-25). Both the goslings and the ducklings exposed to Coeur d'Alene River basin sediment exhibited physical deformations, including RIIBs in ducklings (Figure 6-24). Twenty-two percent of the goslings in the highest exposure group (48% Coeur d'Alene River basin sediment) died (Hoffman et al., 1998).

With the less nutritionally complete diet containing corn (two-thirds mixture of ground corn and commercial diet), the effects of ingestion of Coeur d'Alene River basin sediment were generally more severe (Figures 6-26 and 6-27; Hoffman et al., 1998). In addition to showing significant changes in ALAD activity (96% depression) and protoporphyrin levels ($p \leq 0.05$), the ducklings exposed to 24% Coeur d'Alene River basin sediment in the corn diet showed a 20% reduction in body weight relative to control birds fed the corn diet with added reference area sediment. Ducklings ingesting Coeur d'Alene River basin sediment in the corn diet also demonstrated physical deformations, including both RIIBs and brain lesions (Figure 6-27; Hoffman et al., 1998).

Weight loss in both goslings and ducklings occurred at levels of Coeur d'Alene River basin sediment exposure that caused other physiological impairments such as reductions in hemoglobin levels. For example, in the commercial diet treatments, significant reductions in the tarsus length of goslings were observed in birds fed a diet containing 48% sediment, and reductions in the brain weight of ducklings were observed in birds fed a diet containing 24% sediment ($p \leq 0.05$). These results suggest that growth of waterfowl in the Coeur d'Alene River basin may be impaired as physiological impairments occur. Reduced growth in birds is associated with reduced viability and impaired reproduction in field populations (O'Connor, 1984; Harris et al., 1993).

The relative bioavailability of lead in Coeur d'Alene River basin sediment was evaluated by comparing tissue concentrations and effects in ducklings exposed to diets containing Coeur d'Alene River basin sediments to tissue concentrations and effects in ducklings fed reference area sediment mixed with a form of lead known to be biologically available (lead acetate).

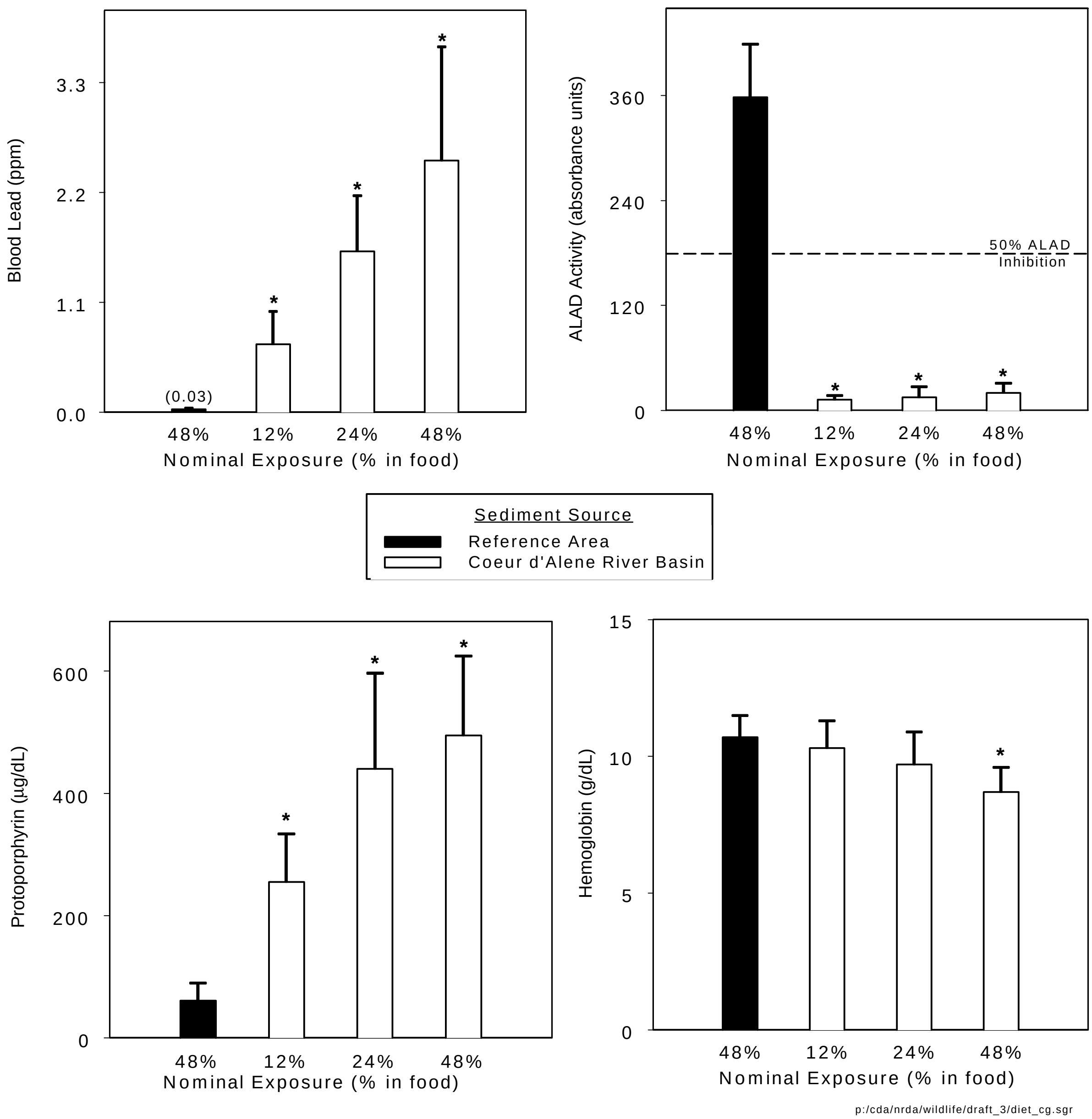


Figure 6-25. Blood lead (top left) and blood ALAD activity (top right), blood protoporphyrin levels (bottom left), and blood hemoglobin levels (bottom right) in Canada goslings exposed to sediment from the Coeur d'Alene River basin or the reference area. Birds were provided sediment mixed in a commercial diet. An asterisk (*) indicates a significant difference ($p < 0.05$) in birds ingesting Coeur d'Alene sediment compared to birds ingesting reference sediment. Blood lead and ALAD values are geometric means. All other values are arithmetic means.
Source: Hoffman et al., 1998.

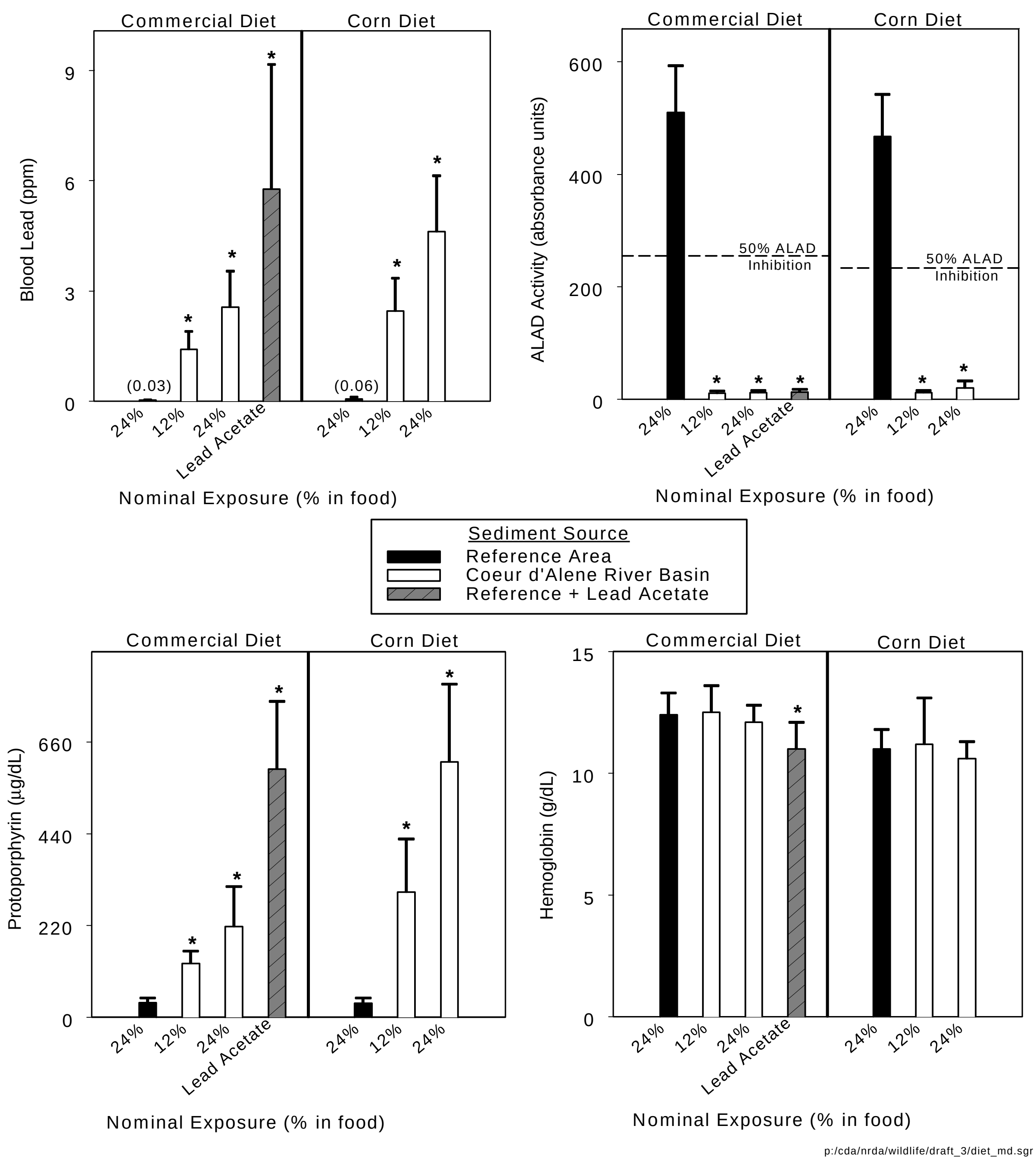


Figure 6-26. Blood lead residues (top left), blood ALAD activity (top right), blood protoporphyrin levels (bottom left), and blood hemoglobin levels (bottom right) in mallard ducklings exposed to sediment from the Coeur d'Alene River basin, the reference area, or to reference sediment spiked with lead acetate (commercial product). Birds were provided sediment mixed in either a commercial diet or a diet containing both corn and commercial feed. An asterisk (*) indicates a significant difference ($p < 0.05$) in birds ingesting Coeur d'Alene sediment compared to birds on the same diet ingesting reference sediment. Blood lead and ALAD values are geometric means. All other values are arithmetic means.
Source: Hoffman et al., 1998.

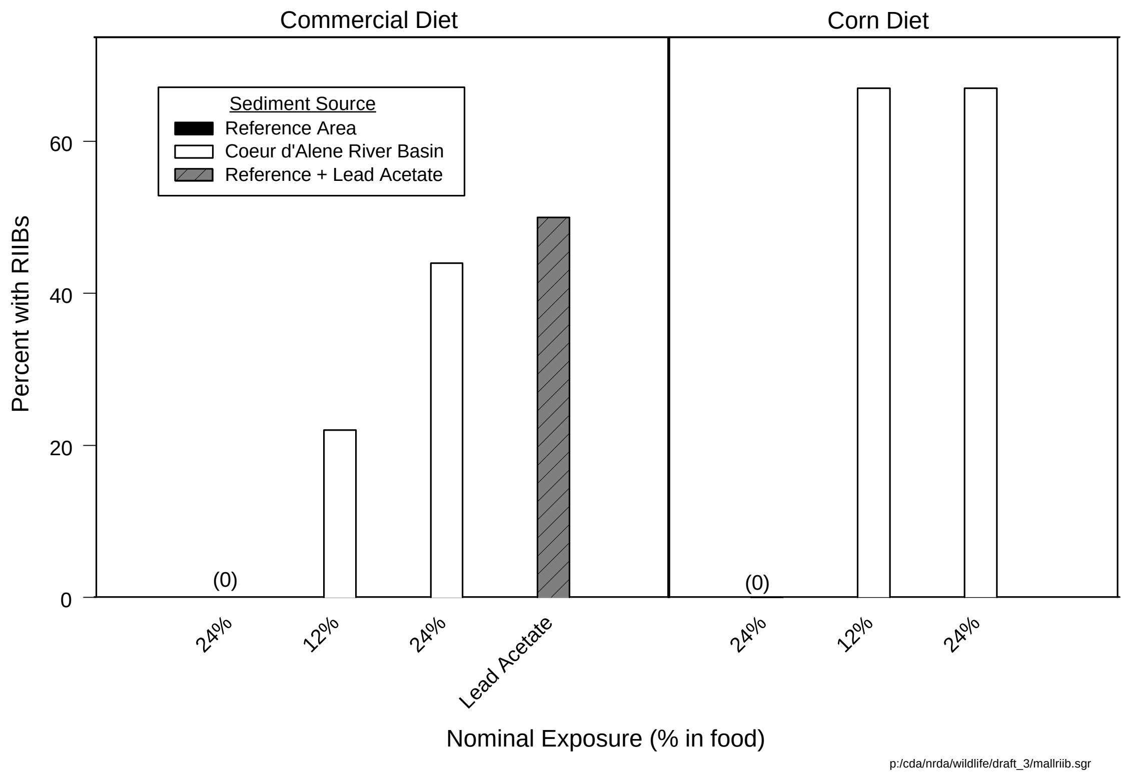


Figure 6-27. Renal intranuclear inclusion bodies (RIIBs) in mallard ducklings exposed to sediment from the Coeur d'Alene River basin, the reference area, or to reference sediment spiked with lead acetate (commercial product). Birds were provided sediment mixed in either a commercial diet or a diet containing corn and a commercial feed.
Source: Hoffman et al., 1998.

Lead acetate is a commercially produced form of lead that has been used in other laboratory toxicity studies (Eisler, 1988). The effects of lead acetate exposure on ducklings were generally similar to effects in mallards fed Coeur d'Alene River basin sediment mixed in the corn diet (Figures 6-26 and 6-27). For example, both treatment groups exhibited a similar degree of physiological malfunctions (20 to 21% reduction in weight relative to reference birds; 17- to 18-fold increase in protoporphyrin levels; greater than 95% depression of ALAD activity; Hoffman et al., 1998). The results demonstrate that lead acetate is more bioavailable than lead in Coeur d'Alene River basin sediment (as measured by tissue lead concentrations), but the types and degree of biological responses caused by both forms of lead are similar.

The feeding experiments show that lead in Coeur d'Alene River basin sediments is bioavailable to both young Canada geese and mallard ducks, that lead poisoning results from exposure to Coeur d'Alene River basin sediments in the absence of lead shot, and that the number and severity of effects increase as sediment ingestion increases. Lead exposure and effects were generally similar in the young of Canada geese and mallards. For example, goslings and ducklings exposed to 12% Coeur d'Alene sediment (commercial diet) had similar mean blood lead concentrations (1 ppm), inhibition of ALAD activity (>95%), and elevation of protoporphyrin (400% increase). Effects observed in the feeding experiments were similar to responses observed during field investigations, including hematological changes and physical deformations. The degree of lead exposure and the number and severity of effects were greater in mallards fed a less nutritious diet containing corn than in those fed a nutritionally complete commercial diet.

Toxicity of Sediments to Juvenile Mute Swans

The relationship between ingestion of lead-contaminated sediment and biological responses of young of mute swans was evaluated by Day et al. (1998). Mute swans were used as a surrogate for tundra swans because of (1) similar size, (2) similar feeding preferences in aquatic habitats, and (3) the availability of a source of swans not previously exposed to lead. Birds were fed either sediment from the Coeur d'Alene River basin or sediment from a reference area in a commercial diet or a less nutritious rice diet. Dietary mixtures with Coeur d'Alene River basin sediment contained 12 or 24% sediment. The 24% sediment diet contained an estimated 700 to 850 ppm lead. The dietary mixture with reference sediment contained 24% sediment and approximately 4.4 to 5.8 ppm lead.

The nutritional value of the rice diet was more comparable to the preferred diet of swans in the wild (water potato tubers and wild rice) than was the commercial diet. For example, the commercial diet contained 16% protein, 20,600 ppm calcium, and 10,000 ppm phosphorus, whereas the cultivated rice used by Day et al. (1998) contained 7.1% protein, 260 ppm calcium, and 3,000 phosphorus, water potatoes contain 3.2% protein, 380 ppm calcium, and 6,100 ppm phosphorus, and wild rice contains 7.5% protein, 160 ppm calcium, and 3,100 ppm phosphorous.

Measurement endpoints included lead and zinc residues in blood, brain, and liver; survival; physiological malfunctions (weight loss, changes in blood ALAD activity, and protoporphyrin, hemoglobin, and hematocrit levels; changes in plasma and brain biochemical parameters); and physical deformations (gross and histopathological lesions). The results are expressed as a nominal exposure (% sediment in feed provided to the birds), which approximates actual ingestion rates since pelletized feeds were used.

Sediment exposure levels for mute swans (12% and 24% sediment) were selected to be similar to sediment ingestion rates determined for wild tundra swans from the Coeur d'Alene River basin (mean of 9%; 90th percentile of 22%; n = 86, Beyer et al., 1998b). Lead concentrations in feces of swans exposed in the laboratory (1,200 to 2,000 ppm; Day et al., 1998) were within the range of lead in feces measured in the Coeur d'Alene River basin (6 to 3,300 ppm; Beyer et al., 1998b). The overlap indicates that levels of ingestion and exposure to contaminated sediment in the laboratory studies were similar to exposure of wild birds.

Exposure to 12% Coeur d'Alene River basin sediment in the commercial diet caused increased concentrations of lead in tissues and physiological malfunctions, including significant elevation of blood protoporphyrin and depression of ALAD activity greater than 50% ($p \leq 0.05$; Figures 6-28 and 6-29; Day et al., 1998). Exposure to 24% Coeur d'Alene River basin sediment in the commercial diet resulted in more severe effects, including significant reductions in hemoglobin concentrations and hematocrit levels ($p \leq 0.05$; Figures 6-28 and 6-29). In addition, all swans exposed to 24% Coeur d'Alene River basin sediment exhibited physical deformations, including RIIBs (Figure 6-29; Day et al., 1998).

The effects of exposure to Coeur d'Alene River basin sediment were more severe in swans fed the rice diet than in those fed the commercial diet (Figures 6-28 and 6-29). In addition to significant changes in ALAD activity (96% inhibition) and protoporphyrin, hemoglobin, and hematocrit levels ($p \leq 0.05$), swans fed the rice diet containing 24% Coeur d'Alene River basin were significantly smaller (32% lower body weight than birds fed the rice diet and reference area sediment; $p \leq 0.05$) (Figure 6-29). Swans that ingested Coeur d'Alene River basin sediment with the rice diet were ataxic (exhibited loss of equilibrium) and lethargic and had physical deformations, including emaciation and RIIBs (Day et al., 1998).

The feeding experiments show that lead in Coeur d'Alene River basin sediments is bioavailable to swans, that lead poisoning results from exposure to Coeur d'Alene River basin sediments in the absence of lead shot, and that the number and severity of effects increase as sediment ingestion increases. Effects observed in the feeding experiments were similar to responses observed during field investigations, including hematological changes and physical deformations. The degree of lead exposure and the number and severity of effects were greater in swans fed a more environmentally comparable rice diet than in those fed a nutritionally complete commercial diet.

6.5.4 Injury Study Conclusions

The results of controlled laboratory feeding studies demonstrate that lead in Coeur d'Alene River basin sediments is bioavailable to multiple species of migratory birds, that lead poisoning results from exposure to Coeur d'Alene River basin sediments in the absence of lead shot, and that the number and severity of effects increase as ingestion of lead-contaminated sediment increases. These relationships are observed in representative life stages and species of migratory birds, including young and subadult mallards, young Canada geese, and juvenile mute swans. The effects observed in the laboratory were similar to responses observed in multiple species of migratory birds in the wild in the Coeur d'Alene River basin, including hematological changes, physical deformations, and death. The degree of lead exposure and the number and severity of effects were greater in waterfowl fed less nutritionally complete diets that are representative of natural diets in the field.

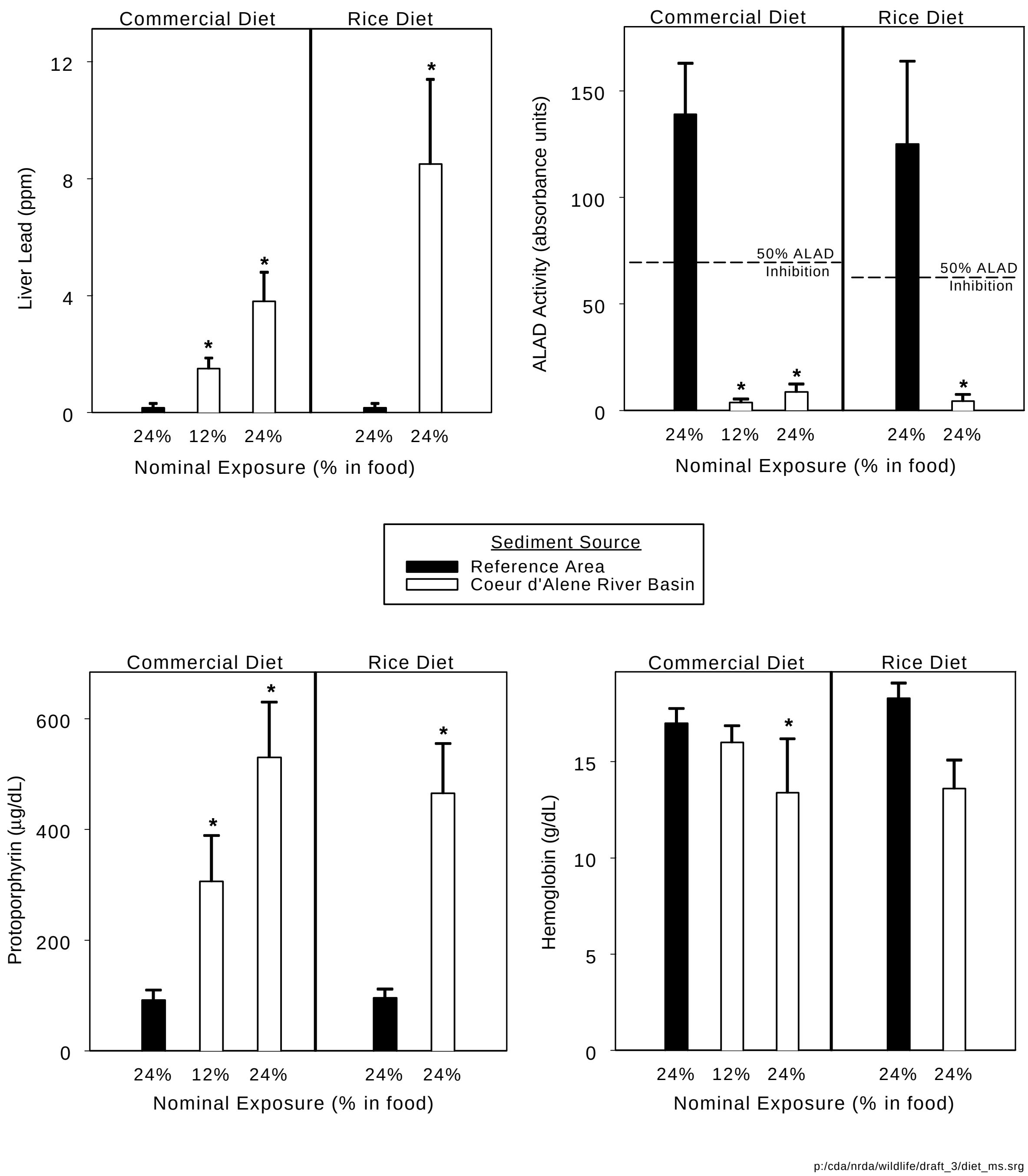


Figure 6-28. Blood and liver lead residues (top left), blood ALAD activity (top right), blood protoporphyrin levels (bottom left), and hemoglobin levels (bottom right) in mute swans exposed to sediment from the Coeur d'Alene River basin or the reference area. Birds were provided sediment mixed in either a commercial diet or a rice diet. An asterisk (*) indicates a significant difference ($p < 0.05$) in birds ingesting Coeur d'Alene sediment compared to birds on the same diet ingesting reference sediment.
Source: Day et al., 1998.

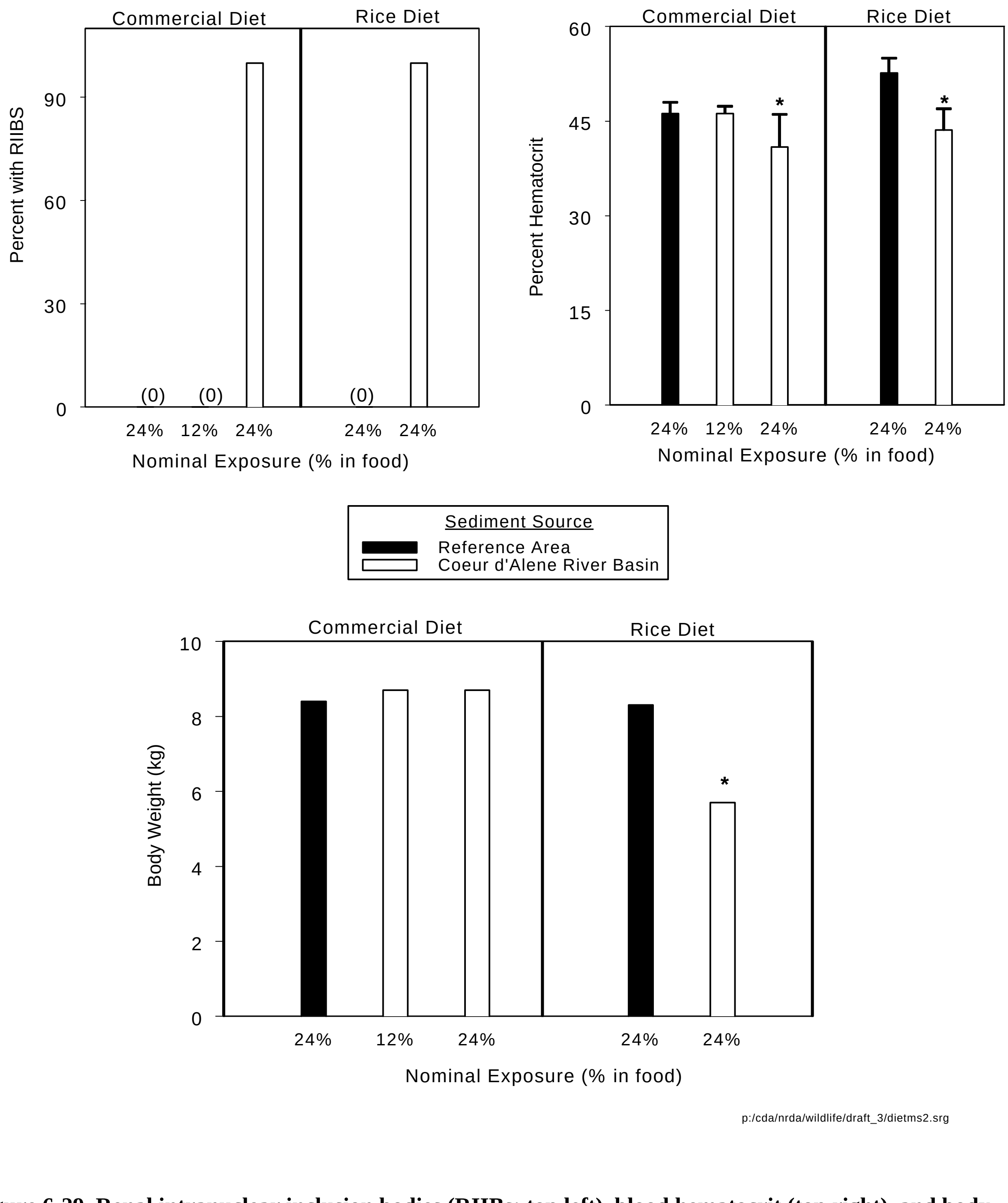


Figure 6-29. Renal intranuclear inclusion bodies (RIIBs; top left), blood hematocrit (top right), and body weight (bottom left) in mute swans exposed to sediment from the Coeur d'Alene River basin or the reference area. Birds were provided sediment mixed in either a commercial diet or a rice diet. An asterisk (*) indicates a significant difference ($p < 0.05$) in birds ingesting Coeur d'Alene sediment compared to birds on the same diet ingesting reference sediment.
Source: Day et al., 1998.

6.6 INJURY DETERMINATION EVALUATION

The results of the Trustees' studies and other existing data from the Coeur d'Alene River basin demonstrate the following:

- ***Wildlife resources in the Coeur d'Alene are exposed to elevated concentrations of lead.*** Types of biota confirmed to contain elevated concentrations of lead include:

  - aquatic vegetation, including waterfowl forage such as water potatoes
  - aquatic biota, including invertebrates, amphibians, and fish
  - small mammals, including meadow voles and deer mice
  - larger mammals, including muskrat, beaver, mink, and deer
  - birds of prey, including bald eagles, osprey, kestrel, and prey items
  - floodplain songbirds, including song sparrows and American robins
  - waterfowl, including wood ducks, Canada geese, mallards, and tundra swans.

  Exposure was confirmed by the extremely high concentrations of lead in Coeur d'Alene River basin sediments (e.g., 500 to 20,000 ppm), sediment ingestion by wildlife, bioaccumulation of lead in the blood and tissues of multiple species of wildlife, and documentation of biological responses in multiple species of Coeur d'Alene River basin wildlife that are characteristic of lead exposure.

- ***Wildlife exposure occurs as a result of ingestion of contaminated sediments and from consumption of lead-contaminated food items.*** Lead exposure in migratory birds has been found to increase with increasing sediment ingestion rates and increasing sediment contamination with lead.

- ***Multiple adverse effects caused by lead exposure have been observed in Coeur d'Alene wildlife in the field.*** The biological responses observed in Coeur d'Alene wildlife include:

  - death, in numerous species of migratory birds

  - physiological malfunctions, including changes in parameters related to impaired blood formation in migratory birds

  - physical deformations, including gross and histopathological lesions in multiple tissues of migratory birds

  - lead and cadmium concentrations in tissues of multiple species of mammal that exceed concentrations associated with clinical signs of metal poisoning

  - reduced survival, reduced growth, delayed development, and behavioral abnormalities of amphibians.

- ***Controlled laboratory studies have confirmed that the lead contained in Coeur d'Alene River basin sediments is bioavailable and causes the adverse effects observed in the field.*** The number and severity of adverse effects was found to increase with increasing lead exposure.

6.6.1 Pathway Determination

The purpose of pathway determination is to identify the route or media by which hazardous substances have been transported from sources to the wildlife resources of the Coeur d'Alene River basin [43 CFR § 11.63(dd)].

Pathways were determined by demonstrating that sufficient concentrations exist in pathway resources now, and have existed in the past, to carry hazardous substances to Coeur d'Alene River basin wildlife and their supporting habitats [43 CFR § 11.63 (a) (2)]. The critical pathways for wildlife exposure in the Coeur d'Alene River basin are sediment and dietary (food chain) pathways.

Sediment Pathway

The sediment exposure pathway involves exposure to hazardous substances through ingestion of contaminated sediment, followed by absorption in the gastrointestinal tract during digestion of food items [43 CFR § 11.63(b) and (e)]. Sediment was found to be the principal pathway of lead exposure to migratory birds in the Coeur d'Alene, as evidenced by the following:

- ***Sediments are contaminated with lead.*** The sediments in the floodplains, beds, and banks of the lower Coeur d'Alene River basin contain extremely elevated lead concentrations. For example, lead concentrations in surface sediments in wetlands of the lower Coeur d'Alene area range as high as 19,900 ppm (i.e., nearly 2% of sediment by weight is lead) (Campbell et al., 1999a). Additional information documenting the extent of sediment contamination is presented in Chapter 5, Sediment Resources, and Chapter 10, Injury Quantification.

- ***Wildlife ingest sediment.*** Sediment ingestion can be substantial for many wildlife species (Beyer et al., 1994). Many migratory birds species ingest sediment while feeding on roots, tubers, and submergent and emergent vegetation. In addition, birds may deliberately ingest sediment to aid digestion.

  On average, Canada geese and tundra swans ingest an estimated 9% sediment in diet, and an estimated 10% of tundra swans ingest more than 22% sediment in diet (Beyer et al., 1998b). Moreover, the contaminated sediments of the Coeur d'Alene River basin serve as an important pathway of hazardous substances exposure even in surface-feeding waterfowl such as wood ducks that have low rates of sediment ingestion (Beyer et al., 1997). Consistent with observations of the sediment pathway in the Coeur d'Alene River basin, Nelson et al. (1998) reported that lead exposure in filter-feeding waterbirds in Lake Nakuru, Kenya, occurred predominately through ingestion of lead-contaminated suspended solids.

- ***Sediment lead is bioavailable.*** Controlled laboratory experiments with mallards (ducklings and subadults), Canada geese (goslings), and mute swans (juveniles) have demonstrated that the lead in the sediment from the lower Coeur d'Alene River basin is bioavailable to migratory birds (Day et al., 1998; Hoffman et al., 1998; Heinz et al., 1999). Lead residues in the blood, liver, and kidney tissues of these species increased with increasing sediment exposure. Biological responses sensitive to and diagnostic of lead exposure also increased with increasing sediment exposure.

Food Chain Pathway

The food chain pathway [43 CFR § 11.63(f)] involves contact with hazardous substances through consumption of contaminated food. Hazardous substances in sediments are accumulated in plants, invertebrates, fish, mammals, and birds, which are consumed by other species of birds and mammals in the Coeur d'Alene River basin. Food chain exposure is an important pathway for lead and other metals in the Coeur d'Alene River basin, as evidenced by the following:

- ***Sediment lead contaminates vegetation.*** Lead contamination of vegetation in the Coeur d'Alene River basin is caused by sediments adhering to the surface of plants (Campbell et al., 1999b). Waterfowl are exposed to high lead concentrations when feeding on vegetation that holds contaminated sediment on leaf surfaces or when they consume vegetative parts that are partially buried in the sediment (Beyer et al., 1998b). Waterfowl may also ingest some lead incorporated in plant tissues, independent of adhering sediment.

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

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

6.6.2 Injury Determination

Wildlife injuries resulting from exposure to lead that were specifically evaluated included:

- death [43 CFR § 11.62 (f)(4)(i)
- physiological malfunctions [43 CFR § 11.62 (f)(4)(v)]
- physical deformations [43 CFR § 11.62 (f)(4)(vi)].

Other types of injuries, such as behavioral abnormalities [43 CFR § 11.62 (f)(4)(iii)] and disease [43 CFR § 11.62 (f)(4)(ii)], were not evaluated explicitly for wildlife resources but can be caused by lead exposure (Section 6.3). Behavioral abnormalities have been observed in the field in the Coeur d'Alene River basin and in wildlife exposed to Coeur d'Alene River basin sediment and soil in controlled laboratory studies. Douglas-Stroebel (1997) reported altered activity levels in mallards fed Coeur d'Alene sediment, and Lefcort et al. (1998) observed altered predator avoidance and competitive interactions in amphibians exposed to Coeur d'Alene River basin sediment/bank soil. Nevertheless, because of the relatively large amount of available and relevant data, injury determination focused on death, physiological malfunctions, and physical deformations.

Death [43 CFR § 11.62 (f)(4)(i)]

Wildlife in the Coeur d'Alene River basin have died from exposure to lead. Death from lead poisoning has been documented in both field investigations and controlled laboratory studies in which waterfowl were fed diets containing lead-contaminated sediment.

Wildlife kill investigations. The wildlife kill investigations confirmed that the number and frequency of dead and dying birds in the Coeur d'Alene River basin are significantly greater than the number and frequency in the St. Joe River basin [43 CFR § 11.62 (f)(4)(i)(C)]. Of the carcasses collected in the Coeur d'Alene River basin, 71% were diagnosed as lead poisoned without lead artifacts, and 78% of the areas of the Coeur d'Alene River basin that were investigated contained dead or dying waterfowl diagnosed with lead poisoning without the presence of lead artifacts. In comparison, 19% of waterfowl diagnosed as lead poisoned from the St. Joe River basin contained no ingested lead artifacts. The results of wildlife kill investigations demonstrate death injuries to wildlife in the Coeur d'Alene River basin as defined by the DOI regulations.

Laboratory toxicity testing. Laboratory toxicity testing demonstrated that ingestion of lead-contaminated sediments from the Coeur d'Alene River basin causes waterfowl deaths [43 CFR § 11.62 (f)(4)(i)(E)]. A greater number of deaths occurred within treatments groups that ingested Coeur d'Alene River basin sediments than within treatment groups that ingested reference sediment. The laboratory experiments were conducted using standard test methods, and waterfowl were exposed to the same substances to which wild populations are exposed [43 CFR § 11.62 (f)(4)(i)(E)]. The results of laboratory toxicity testing demonstrate death injuries to wildlife in the Coeur d'Alene River basin as defined by the DOI regulations.

Physiological Malfunctions [43 CFR § 11.62 (f)(4)(v)]

Physiological malfunctions in migratory birds caused by lead were documented in field investigations and in controlled laboratory studies in which waterfowl were fed diets containing lead-contaminated sediment. Physiological malfunctions related to lead exposure include ALAD inhibition, other physiological and biochemical changes, and reduced growth.

ALAD inhibition. Injury has occurred when the activity level of whole blood ALAD in a sample from the population of a given species at an assessment area is significantly less than mean values for a population at a control area, and ALAD depression of at least 50% can be measured [43 CFR § 11.62 (f)(4)(v)(C)].

Field studies confirm that ALAD inhibition in birds from the Coeur d'Alene River basin is prevalent, that ALAD activity in birds of many species from the Coeur d'Alene River basin is significantly inhibited relative to reference bird populations, and that for many species, ALAD inhibition relative to reference populations exceeds 50% [43 CFR § 11.62 (f)(4)(v)(D)]. Relative to reference populations, ALAD activity is significantly reduced in Coeur d'Alene wood ducks, tundra swans, Canada geese goslings and adults, mallard juveniles and adults, osprey juveniles and adults, kestrel juveniles and adults, American robins, and song sparrows. Injury studies confirmed that ALAD activity in Coeur d'Alene wood ducks was inhibited by 85 to 96%; in Coeur d'Alene tundra swans, by 93%; in Coeur d'Alene Canada geese goslings and adults, by >50%; in Coeur d'Alene juvenile and adult mallards, by >50%; in Coeur d'Alene American robins and song sparrows, by >50%; and in Coeur d'Alene bald eagle chicks, by 35% to 65%. Previous studies the basin confirmed that in Coeur d'Alene juvenile and adult osprey, ALAD activity was inhibited by >52% (Henny et al., 1991), and in Coeur d'Alene juvenile and adult kestrels, by >55% and > 81%, respectively (Henny et al., 1994). Injury studies confirmed that ALAD activity was inversely correlated with lead concentration in the blood of wood ducks and tundra swans, and ALAD activity in song sparrows was inversely correlated with soil lead concentrations (i.e., increasing inhibition with increasing sediment/soil contamination).

Laboratory injury studies confirmed that ingestion of lead-contaminated sediment causes ALAD inhibition in waterfowl species representative of the Coeur d'Alene River basin waterfowl that exhibited ALAD inhibition in the field. ALAD inhibition greater than 50% was demonstrated for multiple species of waterfowl in controlled laboratory experiments in which test species ingested sediment collected from the lower Coeur d'Alene River basin. ALAD activity was lower in all subadult mallards that ingested lead-contaminated sediments (3% to 19% sediment ingestion) than in control birds. ALAD inhibition >90% was observed in Canada geese goslings and mallard ducklings at all doses of contaminated sediment (12% to 48% sediment exposure; actual dose not measured). ALAD activity was inhibited by >95% in mute swans at all exposure levels (12% to 24% Coeur d'Alene sediment in feed; both commercial and rice diets).

The laboratory results confirm the field results and explain the cause of the ALAD inhibition. Significant ALAD inhibition observed in both field investigations and controlled laboratory experiments demonstrates injury to wildlife in the Coeur d'Alene as defined by the DOI regulations [43 CFR § 11.62 (f)(4)(v)(D)].

Responses associated with impaired blood formation. Other physiological malfunctions caused by hazardous substances that satisfy the acceptance criteria for biological responses [43 CFR § 11.62(f)(2)(i-iv)], including increases in protoporphyrin and decreases in hemoglobin and hematocrit, were demonstrated in field and laboratory studies.

- ***Protoporphyrin.*** Protoporphyrin concentrations increase in blood following lead exposure because of inhibition of the enzyme ferrochelatase, which is involved in hemoglobin formation. Field investigations results confirmed that protoporphyrin levels in multiple species of Coeur d'Alene River basin migratory birds are significantly elevated relative to levels in birds from reference areas. In controlled laboratory experiments, protoporphyrin was significantly greater in waterfowl fed lead-contaminated sediment than in waterfowl fed reference sediment. Protoporphyrin levels increased in proportion to the percentage of lead-contaminated sediments in the diet.

- ***Hemoglobin.*** This biochemical is the component of blood that carries and transfers oxygen to the cells of animals. Lead exposure decreases hemoglobin levels through the blockage of the biochemical pathway producing heme. In field studies, hemoglobin levels of wood ducks and tundra swans were inversely correlated with blood lead concentrations, indicating that increased lead exposure results in decreased hemoglobin. Hemoglobin was significantly lower in multiple species of Coeur d'Alene waterfowl, including tundra swans and wood ducks, relative to birds in reference areas. In controlled laboratory tests, hemoglobin was significantly reduced in mallards, Canada geese, and mute swans fed Coeur d'Alene River basin sediment.

- ***Hematocrit.*** Hematocrit is an index of the red blood cell content of blood and is measured by determining the packed cell volume (primarily red blood cells) of a blood sample. Lead exposure causes a decrease in hematocrit via inhibition of the early steps of red blood cell formation. In field studies, hematocrit levels of wood ducks and tundra swans were inversely correlated with blood lead concentrations, indicating that increased lead exposure results in decreased hematocrit. Hematocrit was significantly reduced in waterfowl from the Coeur d'Alene River basin and in waterfowl fed lead-contaminated Coeur d'Alene River basin sediment.

Loss of body weight. Weight loss, a physiological malfunction caused by hazardous substances that satisfies the acceptance criteria for biological responses [43 CFR § 11.62(f)(2)(i-iv)], was demonstrated in controlled laboratory studies. The body weights of mallard ducks, Canada geese, and mute swans fed Coeur d'Alene River basin sediments were 20 to 30% lower than the weights of waterfowl fed diets containing reference area sediment. Loss of body weight occurred at exposure levels similar to those causing hemoglobin and hematocrit reductions.

The ecological significance of changes in blood parameters and weight loss is reduced viability of wildlife caused by impaired blood formation and other physiological malfunctions. The results of field investigations and controlled laboratory experiments demonstrate physiological malfunction injuries to wildlife in the Coeur d'Alene River basin as defined by the DOI regulations [43 CFR § 11.62(f)(4)(v)].

Physical Deformation [43 CFR § 11.62 (f)(4)(vi)]

Physical deformations caused by lead were demonstrated in both field investigations and controlled laboratory studies. Physical deformations caused by lead exposure include internal gross and histological lesions.

Gross lesions. Gross lesions caused by lead exposure include emaciation, atrophy of breast muscles, abnormal bile, bile staining, and impactions of the upper gastrointestinal tract. These lesions were observed in Coeur d'Alene River basin waterfowl and in waterfowl that ingested Coeur d'Alene River basin sediments in controlled laboratory experiments.

Histopathological lesions. Histopathological lesions caused by lead exposure include hepatic and renal hemosiderosis, myocardial necrosis, arterial fibrinoid necrosis, and RIIBs. RIIBs, which are lesions diagnostic of lead exposure, were observed in Coeur d'Alene River basin waterfowl and in waterfowl ingesting Coeur d'Alene sediments in controlled laboratory experiments. Additionally, mallard ducklings ingesting Coeur d'Alene sediment exhibited brain lesions (myelin swelling of the brain and nerve fiber degeneration) (Hoffman et al., 1998). Ducklings ingesting reference area sediment did not exhibit these lesions.

6.6.3 Summary of the Injury Determination Evaluation

- ***Sufficient concentrations of hazardous substances exist in pathway resources to expose wildlife resources.*** The source of hazardous substance exposure to wildlife is releases of lead and other metals from mining and mineral processing activities. Hazardous substances are transported from the South Fork Coeur d'Alene River basin in surface water, soil, and sediment to the lower Coeur d'Alene River basin.

Hazardous substance concentrations in pathway resources are sufficient to expose wildlife via ingestion of contaminated sediment and forage and prey items. Concentrations of cadmium and lead in tissues of wildlife from the Coeur d'Alene River basin greatly exceed concentrations in tissues of wildlife from reference areas. Exposure to lead artifacts is not the principal pathway of lead exposure to waterfowl in the Coeur d'Alene River basin.

- ***Exposure of wildlife species in the Coeur d'Alene River basin to hazardous substances causes injury.*** The results of field investigations and controlled laboratory experiments demonstrate that death, physiological malfunctions, and physical deformation injuries to wildlife of the Coeur d'Alene River basin result from dietary exposure to hazardous substances. Injuries have occurred and continue to occur as a result of exposure to lead and other hazardous substances in Coeur d'Alene River basin sediments, wildlife forage items, and prey items. In addition, sediments, vegetation, and biota are injured, as defined by the DOI regulations [e.g., 43 CFR § 11.62(b)(i)(v)], because they serve as pathways of injury to other aquatic biological resources.

  Birds in the Coeur d'Alene River basin that ingest sediment, forage, or prey contaminated with lead (tundra swans, Canada geese, mallard ducks, wood ducks, northern pintails, American wigeons, redhead ducks, canvasback ducks, osprey, American kestrels, American robins, song sparrows and eagles) and mammals that ingest sediment or prey contaminated with lead (mice, voles, and mink) are injured by exposure to lead. The number of dead and dying swans and geese diagnosed as lead poisoned (without the presence of lead artifacts; normalized for population sizes) was significantly greater in the Coeur d'Alene River basin than in reference areas. Field studies confirm that ALAD inhibition in birds from the Coeur d'Alene River basin is prevalent, that ALAD activity in birds from the Coeur d'Alene River basin is significantly inhibited relative to reference bird populations, and that ALAD inhibition relative to reference populations exceeds 50%. The frequency of gross and histopathological lesions diagnostic of lead poisoning was substantially greater in carcasses collected from the Coeur d'Alene River basin than in carcasses collected from reference areas.

  Controlled laboratory experiments confirmed that birds die after ingesting sediments from the Coeur d'Alene River basin. Laboratory studies confirmed that ingestion of Coeur d'Alene sediment causes ALAD inhibition in waterfowl representative of wild species that exhibit ALAD inhibition in the Coeur d'Alene River basin. The laboratory results confirm the field results and confirm the cause of the ALAD inhibition. Other physiological malfunctions also occur in wildlife ingesting Coeur d'Alene sediment, including weight loss and changes in blood parameters associated with blood formation (e.g., protoporphyrin, hemoglobin, hematocrit). Laboratory feeding studies confirmed that birds fed lead-contaminated sediments developed gross and histopathological lesions characteristic of lead poisoning.

> Laboratory studies have determined that there is a dose-response relationship between the magnitude of exposure to Coeur d'Alene River basin sediment and physiological malfunctions such as biochemical changes in migratory birds. The injury assessment studies demonstrated a causal relationship between increasing sediment ingestion by multiple species of waterfowl and 1) elevation of protoporphyrin levels in blood and 2) reduction in hemoglobin and hematocrit levels. Exposure of amphibians to floodplain sediment from the Coeur d'Alene River basin causes death, physiological malfunctions (impaired development and growth), and behavioral abnormalities.
>
> Field and laboratory studies have demonstrated that there is a dose-response relationship between lead in sediments and the injuries described above. Ingestion of lead-contaminated sediments is the most plausible pathway and cause of the injuries to waterfowl in the basin. Deaths and sublethal injuries cannot be explained by other agents, including lead artifacts (e.g., shot or sinkers), disease (e.g., aspergillosis, avian cholera), or other factors (e.g., trauma).

The above conclusions all indicate the presence of multiple and pervasive injuries to the wildlife resources of the Coeur d'Alene River basin caused by hazardous substance releases associated with mining related activities. Contaminated sediments are the source of lead exposure to wildlife and serve as either direct (sediment ingestion) or indirect (food web contamination) exposure pathways. The injuries are caused by lead-contaminated sediment; thus the supporting habitat for wildlife in the basin, which serves as an exposure pathway, is injured.

6.6.4 Consideration of Lead Artifacts as Cause of Lead Poisoning

Outside of the Coeur d'Alene River basin, the principal source of lead exposure to wildlife is lead shot, lead bullet fragments, and lead sinkers (lead artifacts) ingested by or embedded in the tissues of game animals (Anderson and Havera, 1985; Sanderson and Bellrose, 1986; Beyer et al., 1998c; Wayland and Bollinger, 1999). Beyer et al. (1998c) examined data describing over 1,000 dead and dying waterfowl from hunting areas throughout the United States and found that 29% contained at least one lead shot in the gizzard, and 94% of the waterfowl with ingested lead shot were diagnosed as lead poisoned. Lead shot was detected in 23.5% of trumpeter and tundra swans found dead and dying in western Washington between 1986 and 1992 (Lagerquist et al., 1994). Lead shot accounted for about 20% of the known deaths of trumpeter swans in Idaho, Montana, and Wyoming (survey years 1976 to 1987; Blus et al., 1989). These data indicate that over the last 20 to 25 years, 20 to 24% of the waterfowl carcasses examined in the United States contained ingested lead artifacts, and lead poisoning is the major cause of death of dead and dying waterfowl that contain ingested lead shot.

Overall, the incidence of ingestion of lead artifacts by waterfowl in Coeur d'Alene River basin is similar to the incidence of ingestion in other hunting areas in the United States. During the 1984-1985 hunting season, 29% of the duck carcasses collected in the Coeur d'Alene River basin contained ingested lead shot, and during the 1985-1986 hunting season, 25% of the duck carcasses collected in the Coeur d'Alene River basin had ingested lead shot (Shipley, 1985 and Krieger 1986, as cited in Neufeld, 1987). Casteel et al. (1991) reported that in 1987, 23 of 70 (33%) mallard ducks collected from the Coeur d'Alene River basin had ingested lead shot. Use of lead shot for waterfowl hunting in the Coeur d'Alene River basin was prohibited in 1986, and thus the percentage of waterfowl examined that contain lead artifacts may be declining. For example, during each year of the 1990 to 1997 waterfowl hunting seasons, 4 to 14% of the waterfowl gizzards examined from the Coeur d'Alene River Wildlife Management Area contained lead shot (IDFG, 1993, and unpublished reports; Audet et al., 1999c), and 15% of dead waterfowl collected from the Coeur d'Alene and St. Joe river basins in 1987 contained ingested lead shot (Blus et al., 1995).

In contrast to patterns in other areas of the United States, the lead-poisoned waterfowl of the Coeur d'Alene River basin contain a relatively low incidence of ingested lead artifacts. In 1974, 13 dead tundra swans collected in the Coeur d'Alene area were diagnosed as lead poisoned based on liver lead concentrations, but only one of the 13 (8%) contained lead shot (Benson et al., 1976). Only 13% of 32 lead-poisoned swans (1987-1989 collections) examined by Blus et al. (1991) contained lead artifacts, whereas 95% of lead poisoned tundra swans outside of the Coeur d'Alene area contain lead artifacts (Blus et al., 1991). Audet et al. (1999c) reported that only 12.5% of mallards diagnosed with lead poisoning in the Coeur d'Alene River basin contained lead shot. These data indicate that only 8 to 13% of Coeur d'Alene waterfowl diagnosed with lead poisoning contain lead shot. In contrast, 78% of lead poisoned birds collected from the St. Joe River basin between 1992 and 1997 contained lead artifacts (Audet et al., 1999c).

The frequency of lead poisoning of waterfowl is substantially elevated in the Coeur d'Alene River basin (96% of deaths) compared to the frequency of lead poisoning deaths reported for the Pacific flyway (23%) and nationwide (29%; Figure 6-18; Audet et al., 1999c). However, in contrast to most other areas in the United States, the principal pathway of lead exposure to wildlife in the Coeur d'Alene area is not ingestion of lead artifacts. Ingested lead artifacts were observed in only 8.4% of lead poisoned birds from the Coeur d'Alene area between 1992 and 1997 (Audet et al., 1999b). The incidence of lead artifact ingestion in the Coeur d'Alene River basin is similar to or possibly lower than in the Pacific flyway and nationwide, and, therefore, lead artifact ingestion in the Coeur d'Alene River basin does not provide an explanation for the elevated rate of lead poisoning mortality there.

Finally, the controlled laboratory studies documented adverse effects similar to effects observed in the field (death, ALAD inhibition, changes in other blood parameters, presence of lesions). The studies were performed by sieving Coeur d'Alene sediments to remove lead shot or other artifacts. Therefore, the laboratory studies provide additional evidence that injuries to Coeur d'Alene wildlife are not caused by artifacts. Overall, the evidence indicates that injuries are caused by exposure to hazardous substances released from mining and mineral processing activities.

6.6.5 Causation Evaluation

Injuries to wildlife result from exposure to lead-contaminated sediments, forage, and prey items in the Coeur d'Alene River basin. Injuries resulting from exposure to lead are demonstrated by the following:

- ***Wildlife are exposed to lead.*** The Coeur d'Alene River basin ecosystem is contaminated with lead, and wildlife in it ingest lead in sediment, forage, and prey items. Lead concentrations in these pathway resources are sufficient to expose wildlife to injurious levels of lead. Multiple species of wildlife, wildlife forage, and wildlife prey in the Coeur d'Alene area, including invertebrates, fish, amphibians, songbirds, waterfowl, birds of prey, and small and large mammals, have elevated tissue lead concentrations.

- ***Lead is known to cause the same biological responses observed in Coeur d'Alene wildlife.*** Multiple scientific studies of amphibians, birds, and mammals have shown that lead causes death, increased disease susceptibility, behavioral abnormalities, physiological malfunctions, and physical deformations. These same effects have been observed in field investigations of Coeur d'Alene wildlife and in wildlife exposed to Coeur d'Alene sediment in the laboratory.

- ***Lead exposure exceeds toxicity thresholds.*** Concentrations of lead in the tissues of Coeur d'Alene wildlife are greater than the toxicity thresholds recommended by Pain (1996) for waterfowl, and Ma (1996) for mammals (Table 6-7). Lead residues in both blood and liver tissues of Coeur d'Alene River basin waterfowl exceed both clinical and severe poisoning thresholds (Table 6-7). Clinical poisoning (e.g., physiological malfunctions) thresholds are exceeded in songbirds and mammals. The threshold values in Table 6-7 are consistent with field observations in the Coeur d'Alene River basin, where extensive waterfowl deaths have been observed (severe poisoning), physiological malfunctions are observed in songbirds (clinical poisoning), and ALAD inhibition is observed in eagles (subclinical poisoning).

- ***Lead exposure and effects are spatially consistent.*** Lead exposure, sediment contamination, and biological responses are significantly correlated in multiple species of wildlife (i.e., lead exposure and effects increase in proportion to sediment and soil contamination levels). Species with high sediment ingestion rates (i.e., tundra swans) exhibit the most adverse effects (death). Waterfowl feeding in areas with the highest lead concentrations in sediment have the highest lead exposure.

Table 6-7
Comparison of Tissue-Residue Toxicity Values for Lead with Lead Residues in Coeur d'Alene River Basin Wildlife

Parameter	Blood Lead				Liver Lead (ppm, wet wt.)				
	Waterfowl		Bald Eagles		Waterfowl		Songbirds		Mammals
Toxicity Value	0.5-1 ppm[a]	>1 ppm[a]	1-5 ppm[b]	>5 ppm[b]	6-15 ppm[a]	>15 ppm[a]	5-8 ppm[c]	>8 ppm[d]	>7.5 ppm wet wt.[e]
Effect	Clinical poisoning	Severe poisoning	Clinical poisoning	Severe poisoning	Clinical poisoning	Severe poisoning	Clinical poisoning	Severe poisoning	Clinical poisoning
Exceeded in CdA Wildlife Tissues	✓	✓	No	No	✓	✓	✓	✓	✓
Data Source	1, 2, 3	1, 2, 3	4	4	1, 5	1, 5	5	5	5, 6, 7

Toxicity values: a. Pain, 1996 b. Franson, 1996 c. Friend, 1987 d. Blus et al., 1995 e. Ma, 1996.

Data source: 1. Blus et al., 1999 2. Henny et al., 1999 3. Blus et al., 1997 4. Audet et al., 1999b 5. Audet et al., 1997 6. Kreiger, 1990 7. Blus et al., 1987.

- ***Lead exposure causes injury.*** Controlled laboratory experiments demonstrate that increasing lead exposure results in an increase in biological responses, from biochemical alterations, to physical deformations, to death. Waterfowl ingesting lead contaminated sediment from the Coeur d'Alene River basin exhibit injuries from lead, whereas waterfowl ingesting reference area sediment do not. The laboratory experiments enabled elimination of lead artifacts — as well as other factors such as trauma, predation, etc. — as a possible cause of the lead poisoning.

- ***Evaluation of alternatives.*** Necropsy reports of pathologists from the U.S. Fish and Wildlife Service National Wildlife Health Center have identified lead as the principal cause of death of waterfowl in the Coeur d'Alene River basin. Deaths and sublethal injuries cannot be explained by other agents, including lead artifacts (e.g., shot or sinkers), disease (e.g., aspergillosis, avian cholera), or other factors (e.g., trauma). Lead poisoning was the greatest single cause of sickness or death (80%) of Coeur d'Alene wildlife, and 92% of those lead-poisoned animals had no ingested lead artifacts (e.g., lead shot or fishing sinkers). In contrast, 47% of the carcasses necropsied from the St. Joe River basin reference area were diagnosed as lead poisoned, and 78% of those contained lead artifacts (Audet et al., 1999c).

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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

		Number of Fish Captured				Density (fish/m^2)			
Site	**Date**	**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.

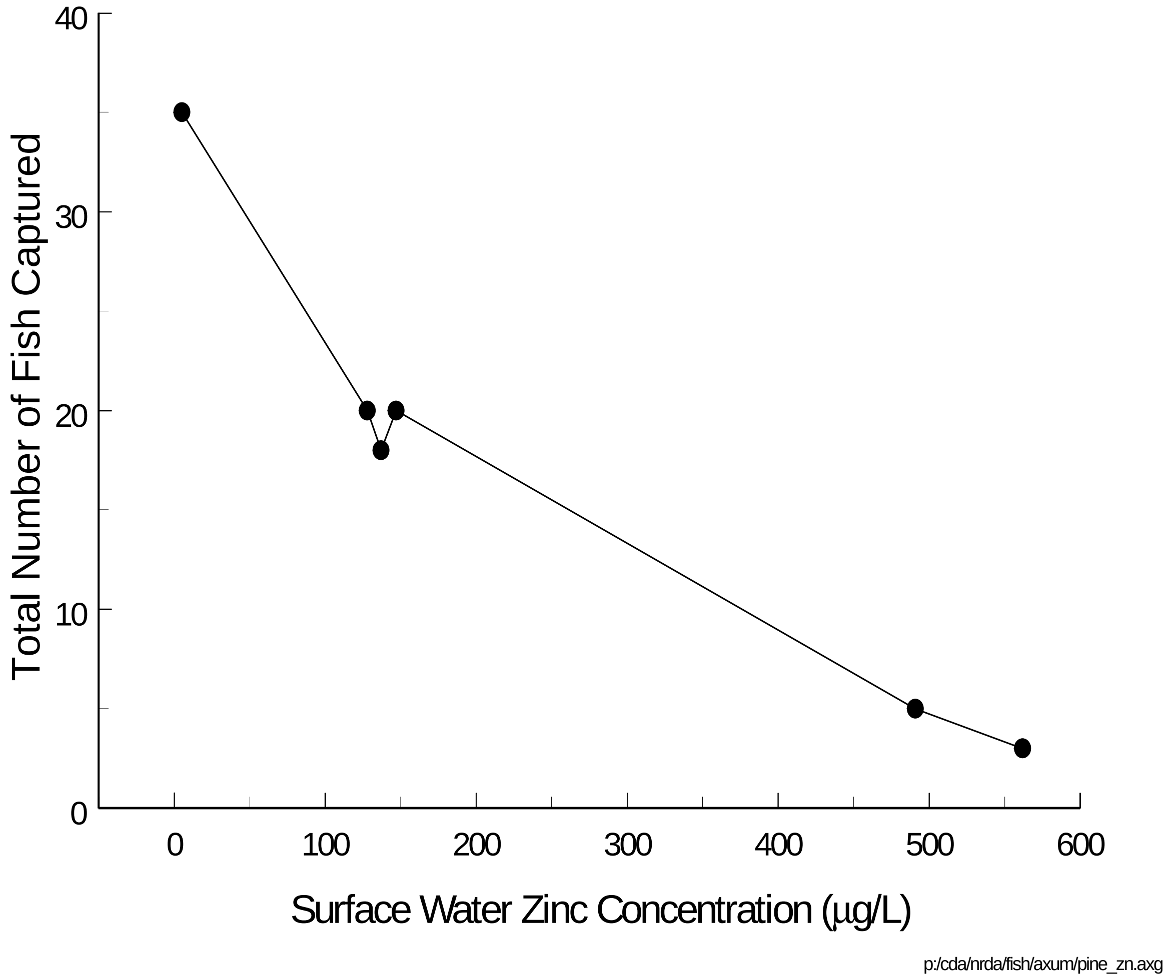

Figure 7-1. Concentration-response relationship of total fish numbers and measured zinc concentrations in surface water.
Source: McNary et al., 1995.

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.

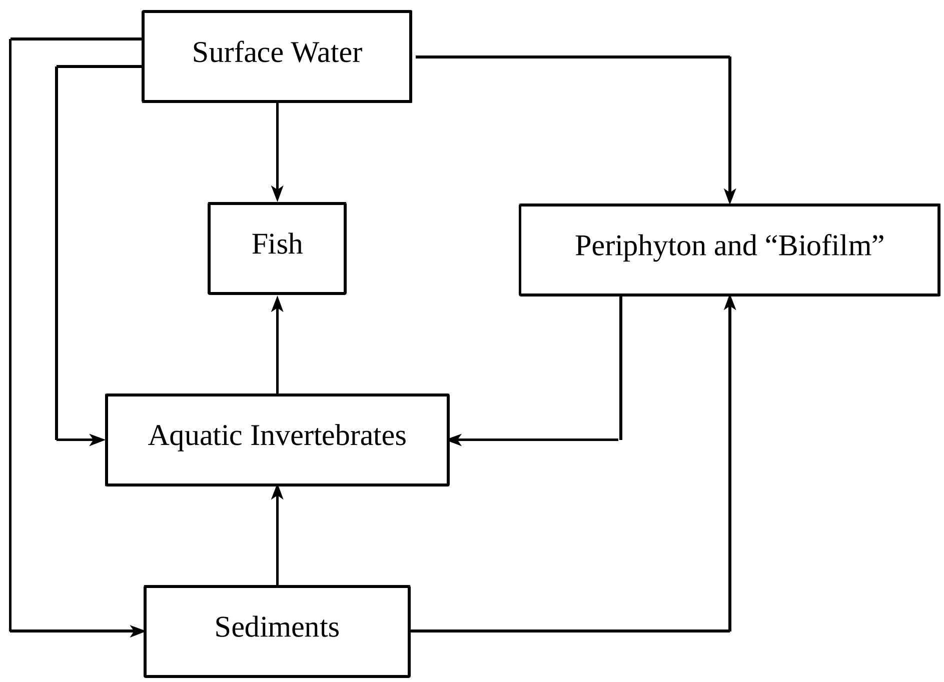

Figure 7-2. Conceptual diagram of exposure pathways to fish.

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

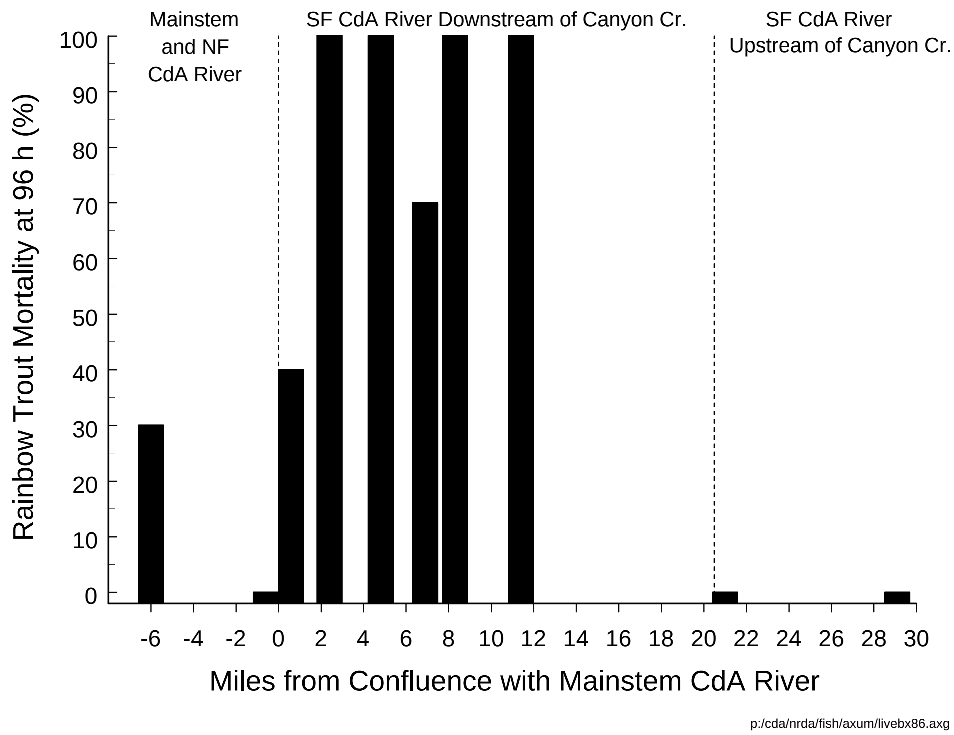

Figure 7-3. Rainbow trout mortality (96-hour) in livebox tests conducted by the U.S. EPA in September 1986. Source: Hornig et al., 1988.

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.

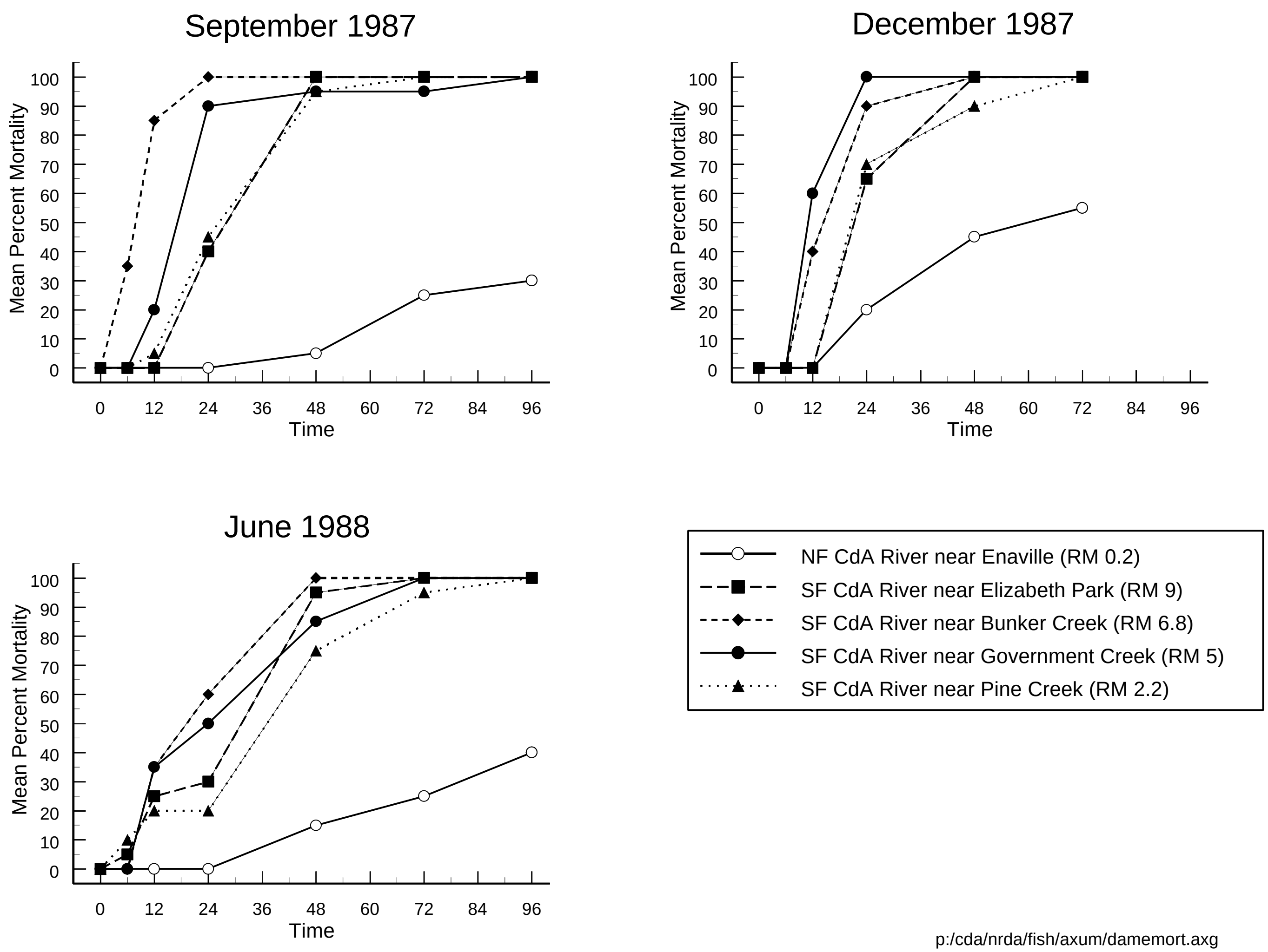

Figure 7-4. Rainbow trout mortality in livebox tests conducted by Dames & Moore (1989) as part of the Bunker Hill RI/FS.

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.

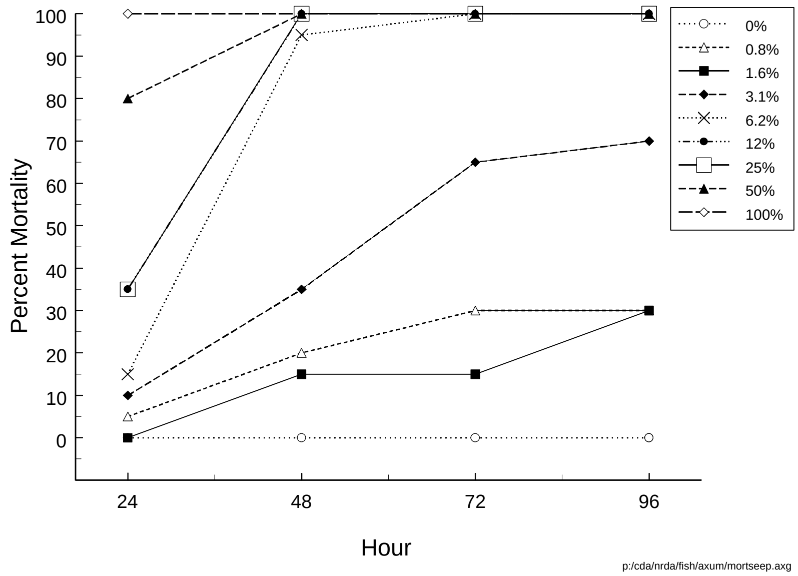

Figure 7-5. Cutthroat trout mortality in acute toxicity tests conducted by the U.S. EPA in August 1986 with Bunker Hill central impoundment area seep water.
Source: Hornig et al., 1988.

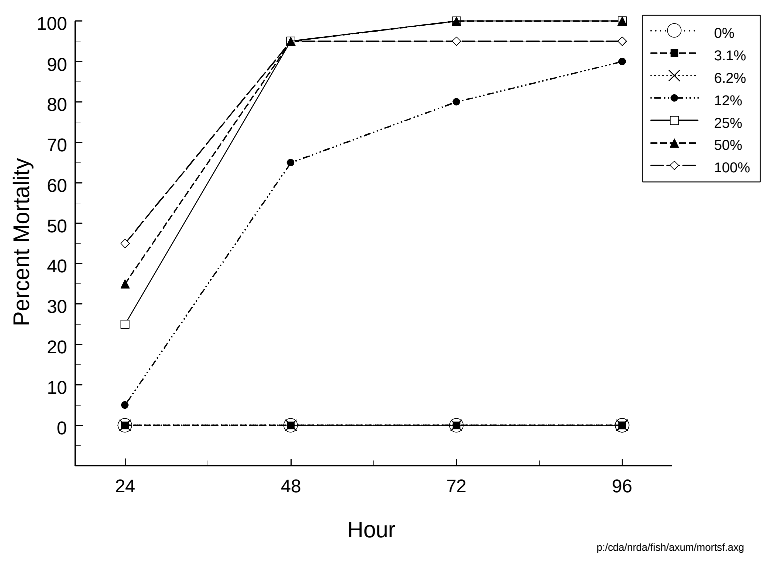

Figure 7-6. Cutthroat trout mortality in acute toxicity tests conducted by the U.S. EPA in September 1986 with South Fork Coeur d'Alene River water collected upstream of Pine Creek.
Source: Hornig et al., 1988.

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.

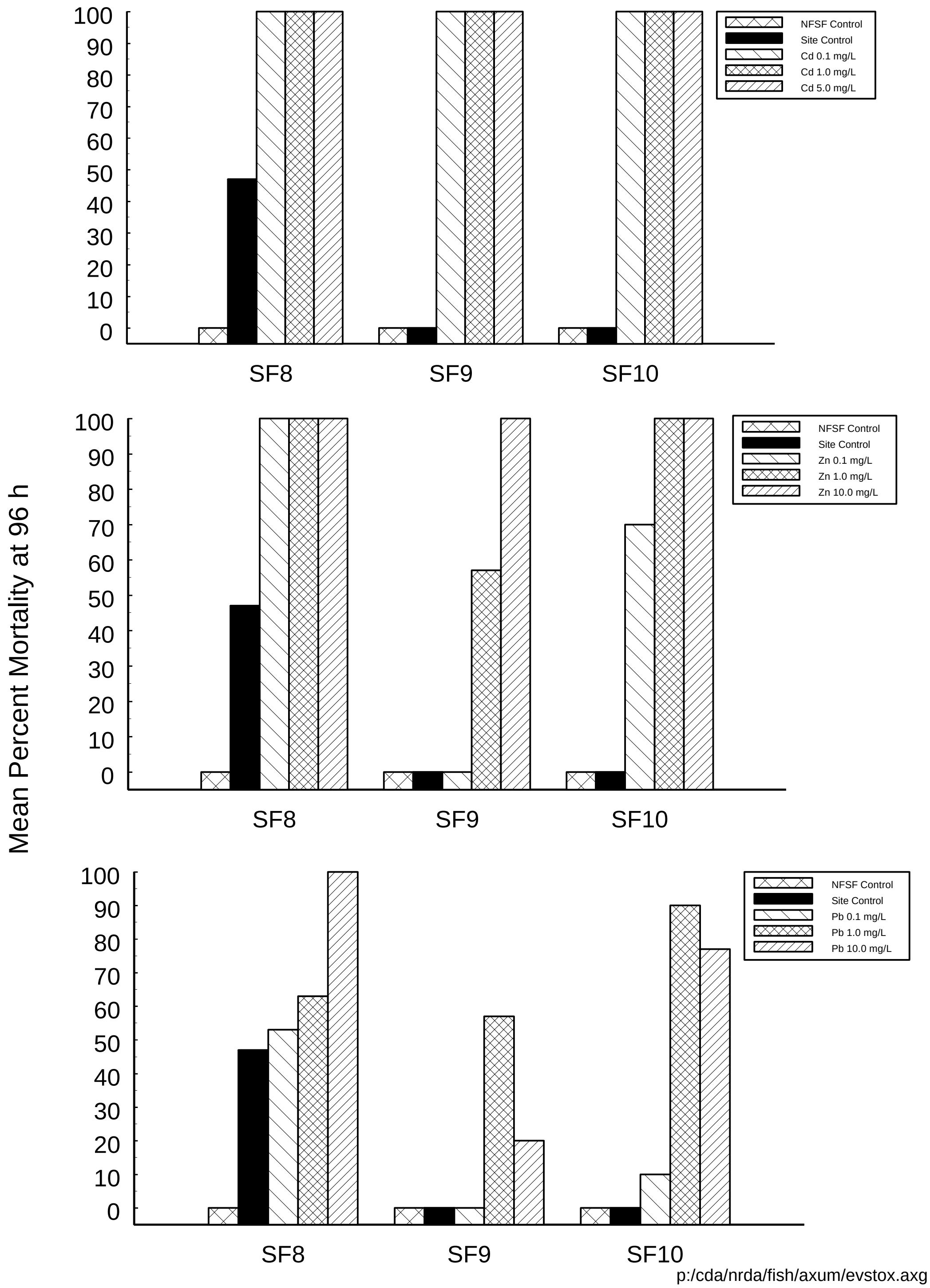

Figure 7-7. Hatchery rainbow trout mortality (96 hours) in acute toxicity tests conducted by EVS with South Fork Coeur d'Alene River water.
Source: EVS, 1996b.

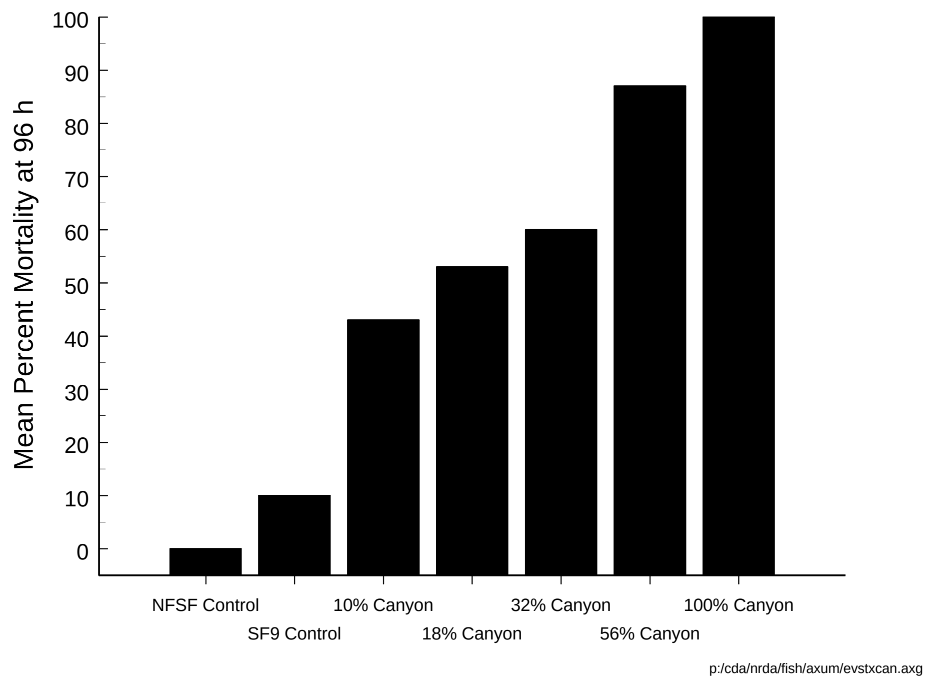

Figure 7-8. Hatchery rainbow trout mortality (96 hours) in acute toxicity tests conducted by EVS with dilutions of Canyon Creek water.
Source: EVS, 1996b.

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.

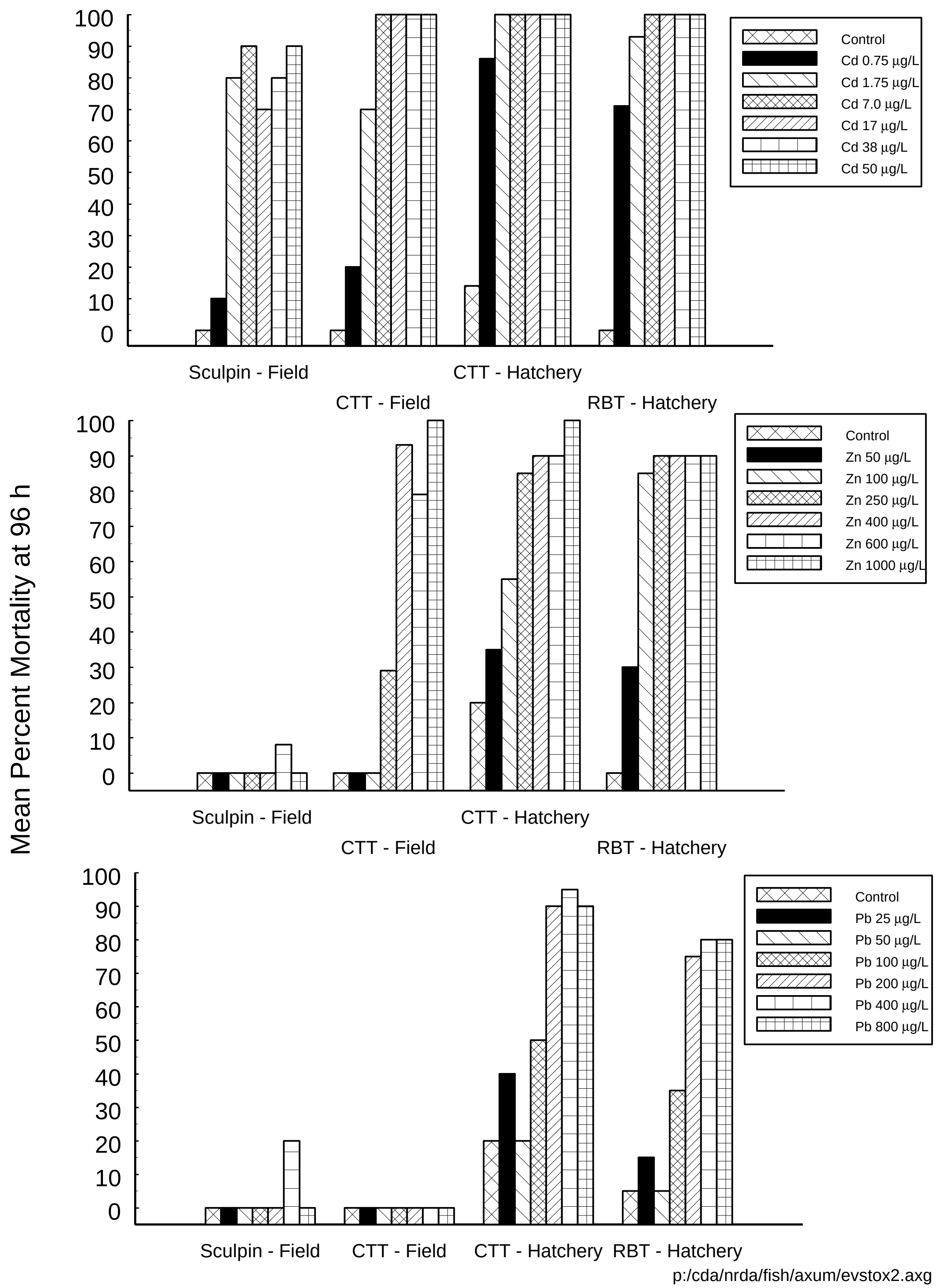

Figure 7-9. Mortality in acute toxicity tests conducted by EVS with Little North Fork of the South Fork Coeur d'Alene River water using field collected sculpin and cutthroat trout (CTT) and hatchery reared cutthroat and rainbow trout (RBT).
Source: EVS, 1996c.

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 $\geq$ 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.

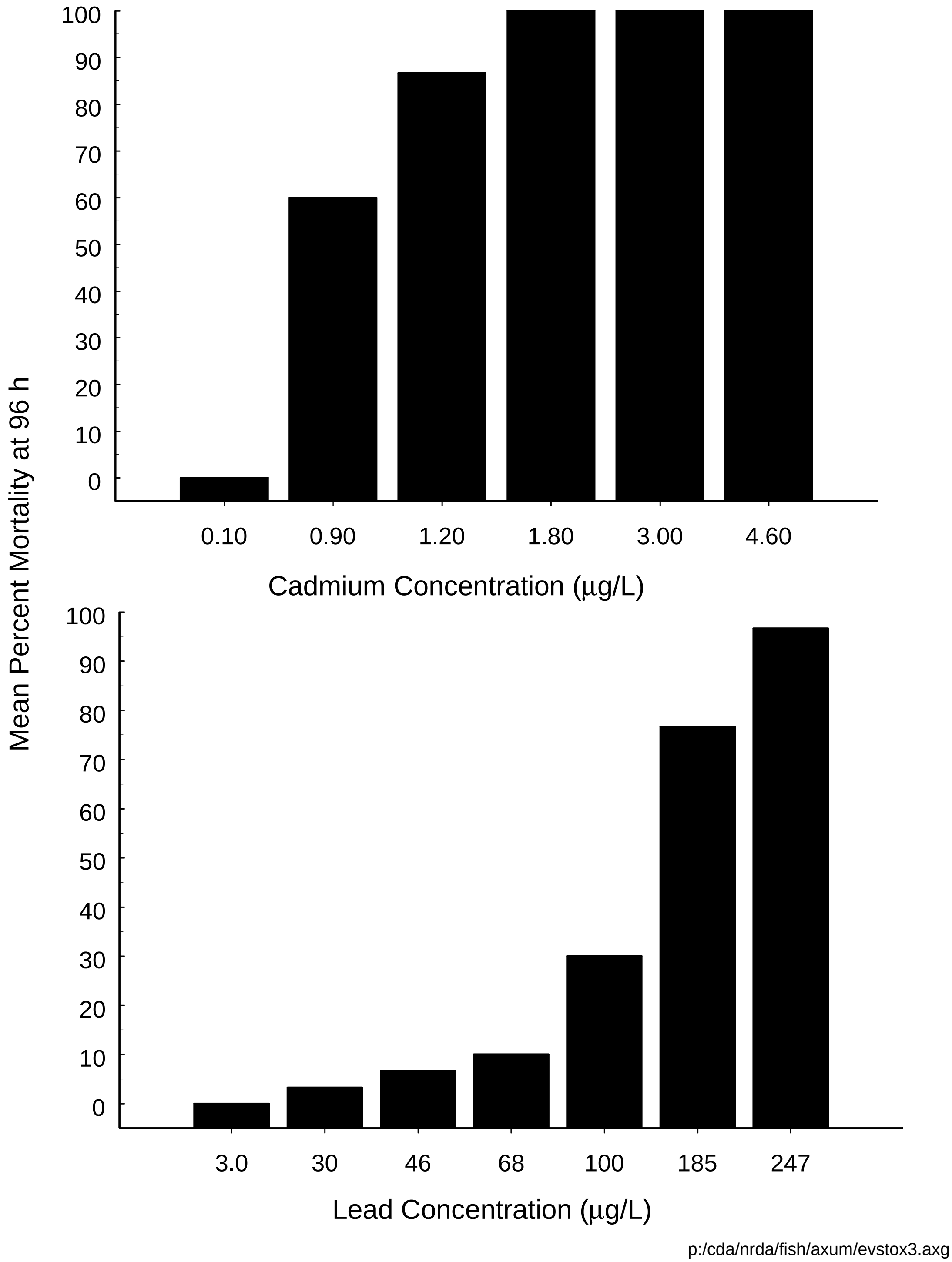

Figure 7-10. Hatchery rainbow trout mortality in acute toxicity tests conducted by EVS with Little North Fork of the South Fork Coeur d'Alene River water. Control data not reported.
Source: EVS, 1997b.

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 LC50[b] (µg/L)	Rainbow Trout LC20[a] (µg/L)	Bull Trout LC50 (µg/L)	Bull Trout 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).

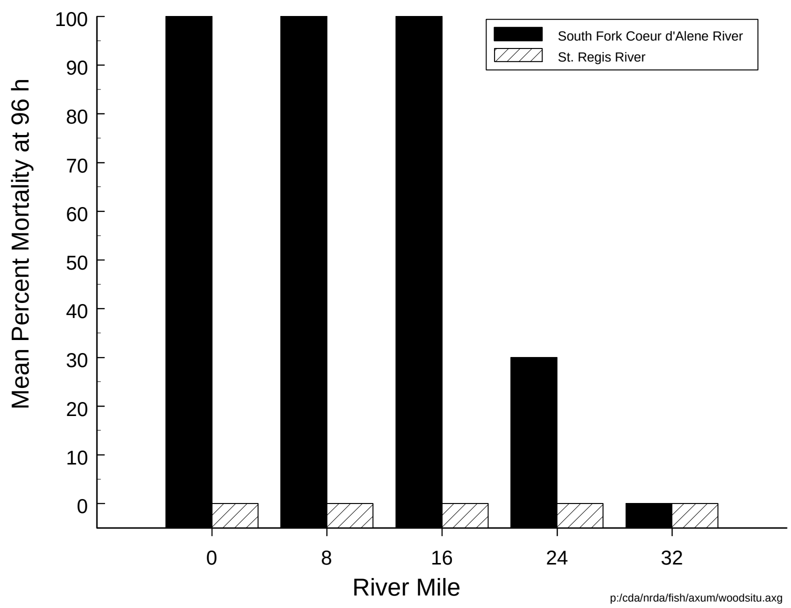

Figure 7-11. Cutthroat trout mortality (96-hour) in *in situ* tests conducted at paired locations in the South Fork Coeur d'Alene River and the St. Regis River.
Source: Woodward et al., 1997b.

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.

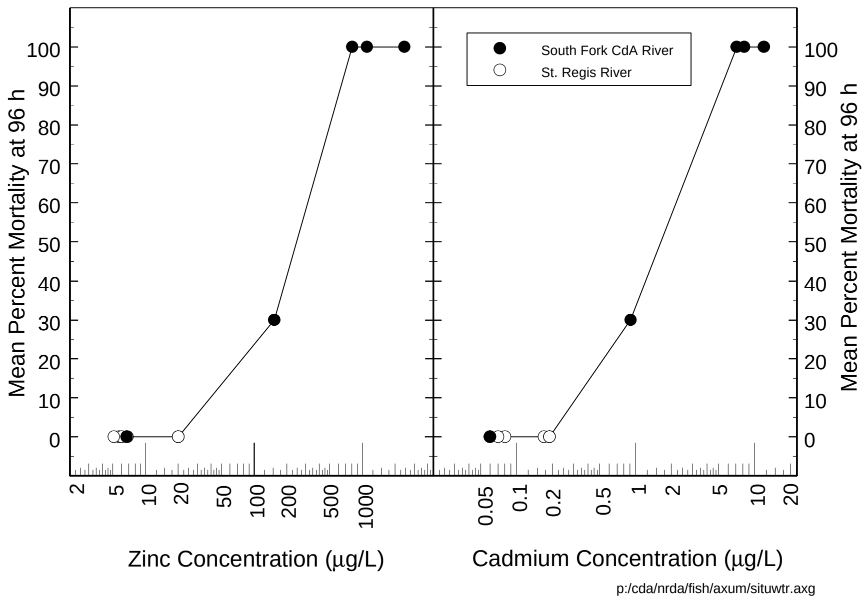

Figure 7-12. Relationship between measured concentrations of cadmium and zinc and cutthroat trout mortality in *in situ* bioassays at locations in the South Fork Coeur d'Alene and St. Regis rivers.
Source: Woodward et al., 1997b.

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.

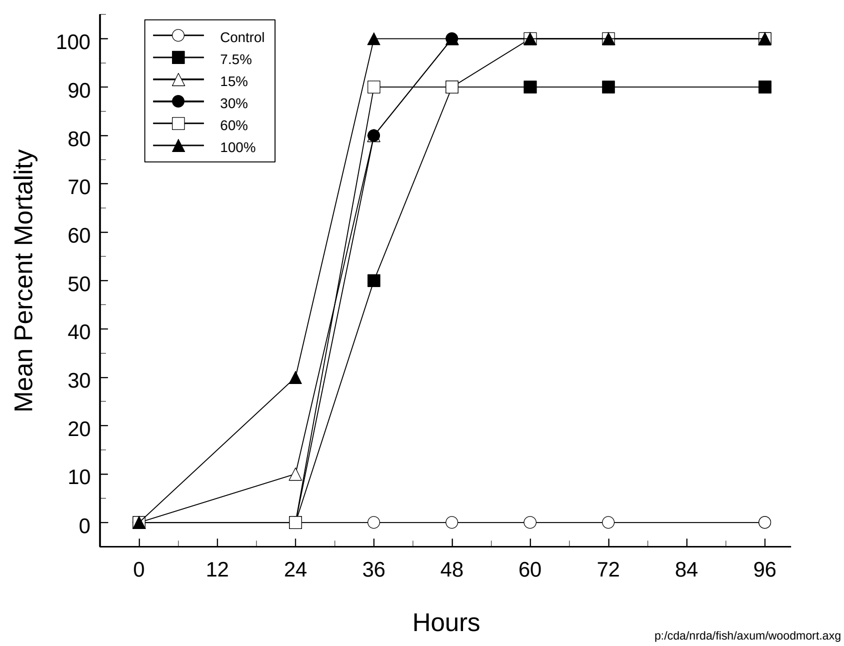

Figure 7-13. Cumulative mortality (96 hours) in cutthroat trout exposed to serial dilutions of South Fork Coeur d'Alene River water.
Source: Woodward et al., 1995a.

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.

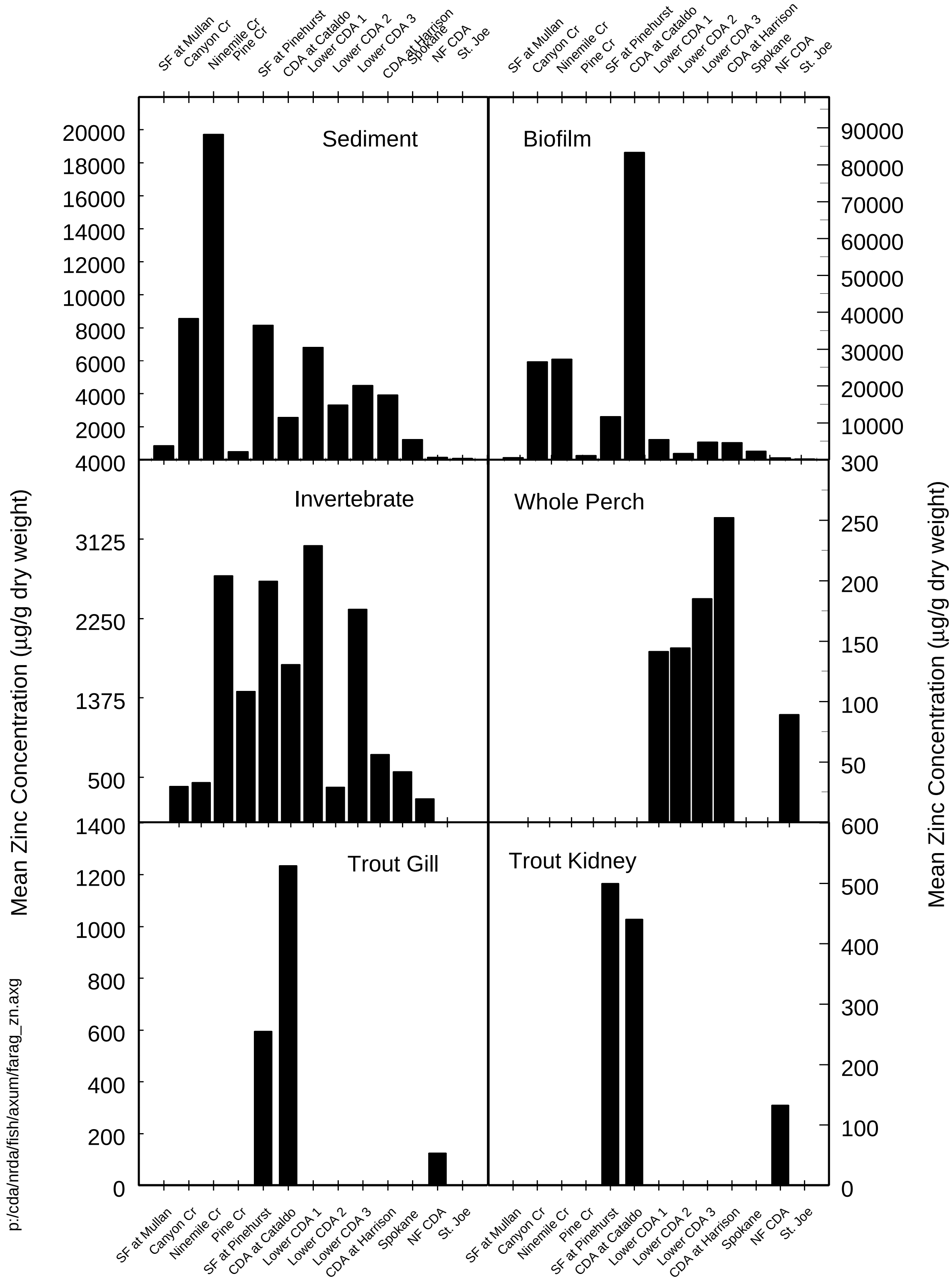

Figure 7-14a. Concentrations of zinc in sediments, biofilm, benthic macroinvertebrates, and fish.
Source: Farag et al., 1998a.

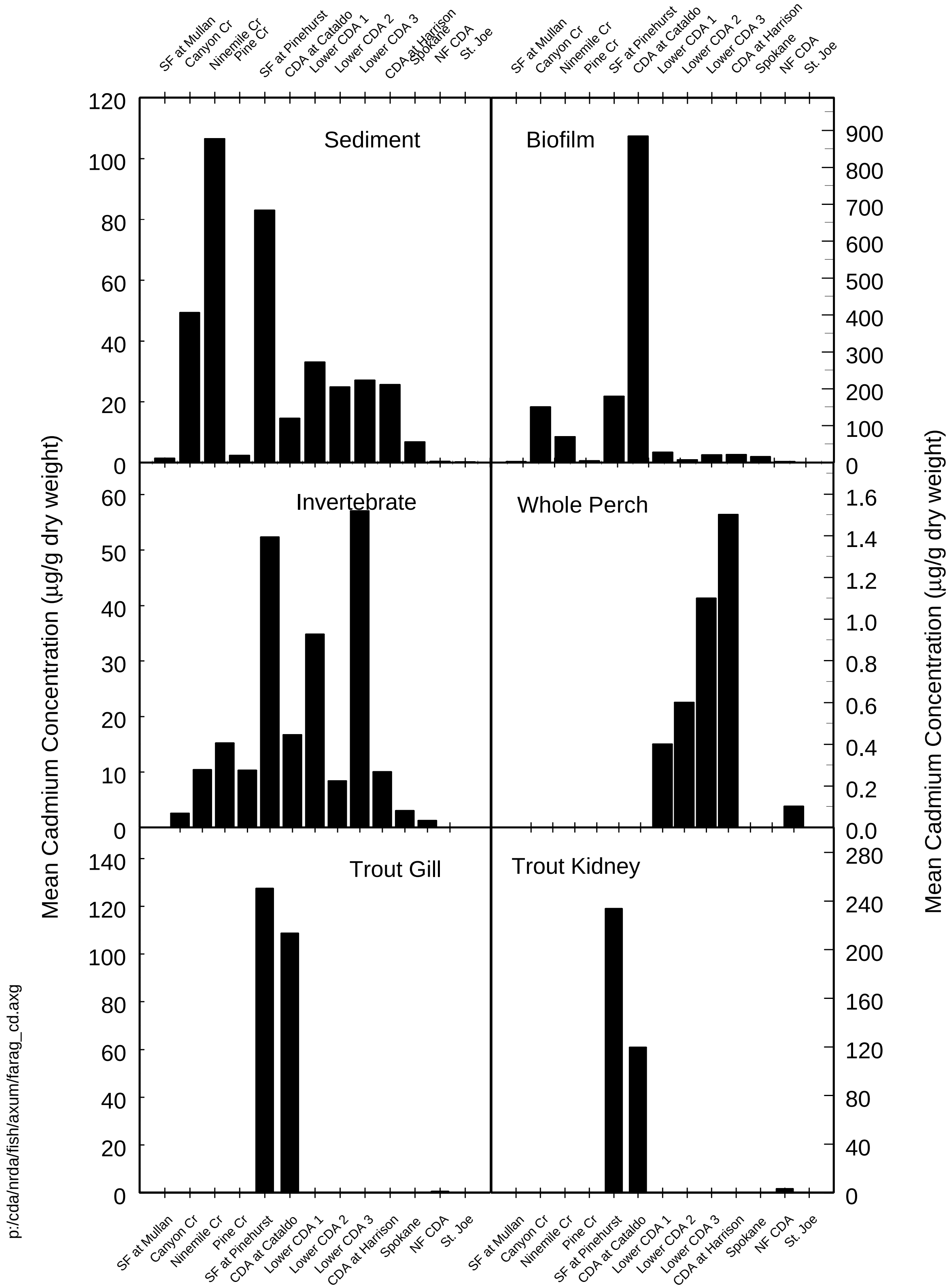

Figure 7-14b. Concentrations of cadmium in sediments, biofilm, benthic macroinvertebrates, and fish.
Source: Farag et al., 1998a.

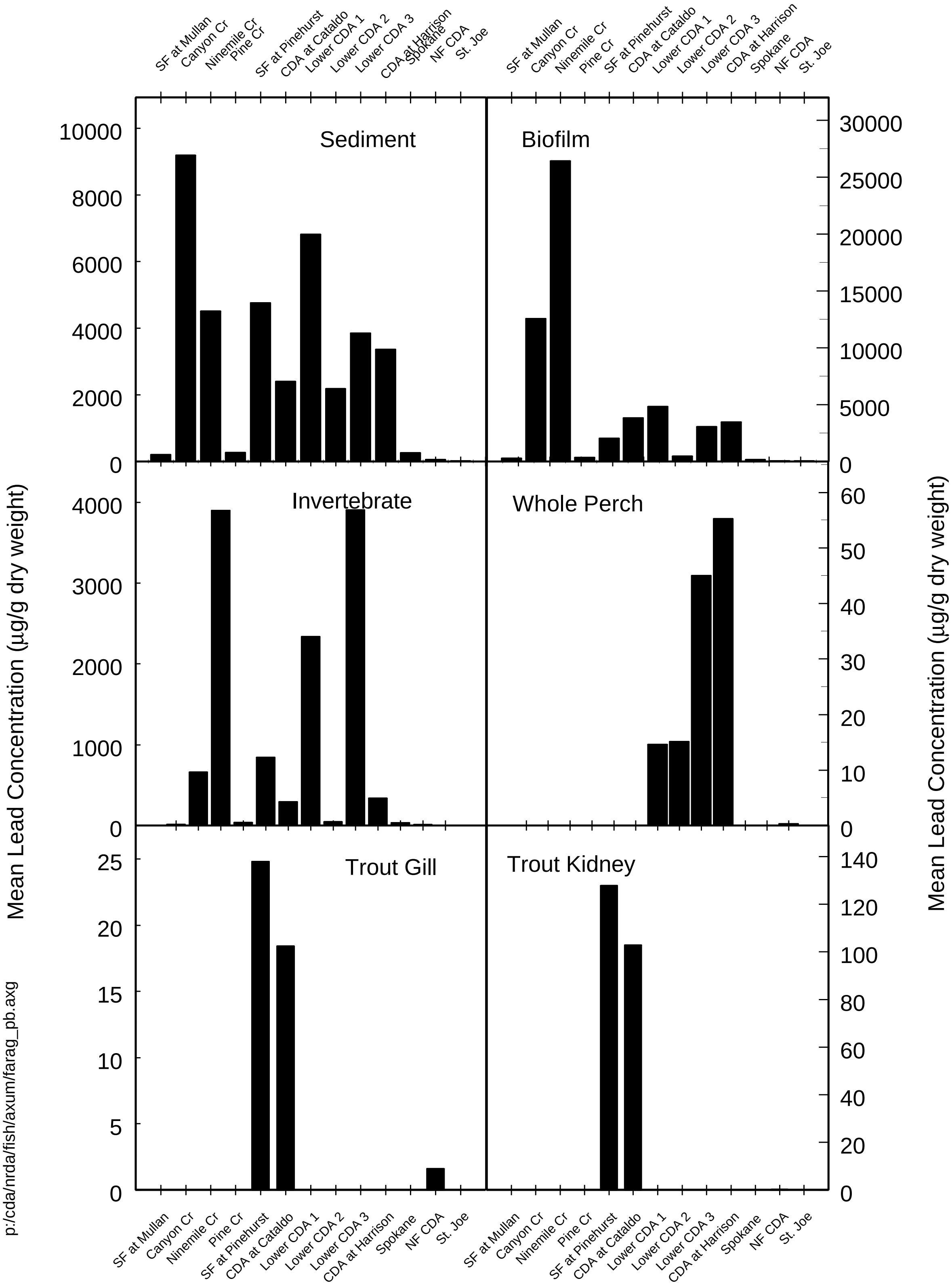

Figure 7-14c. Concentrations of lead in sediments, biofilm, benthic macroinvertebrates, and fish.
Source: Farag et al., 1998a.

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).

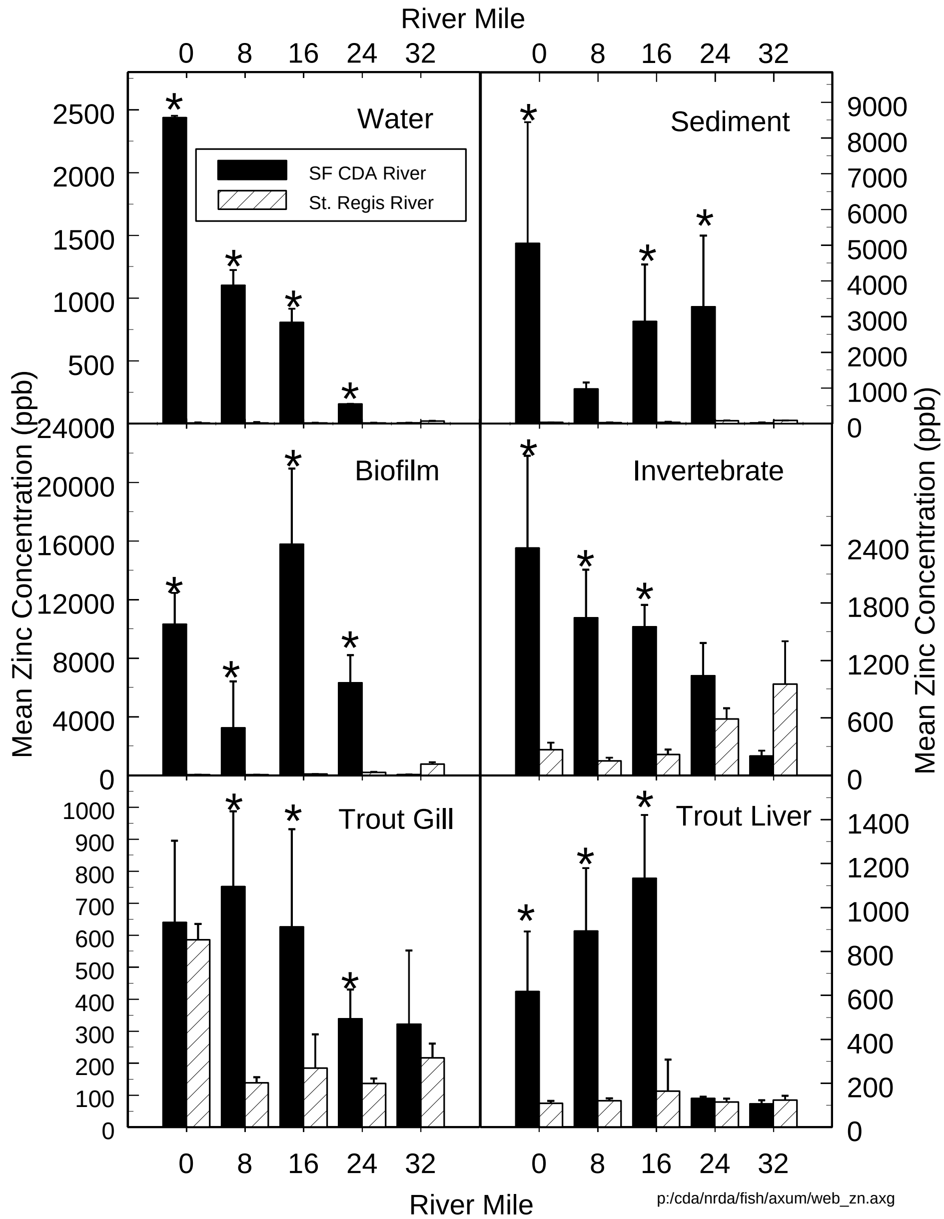

Figure 7-15a. Mean concentrations (standard deviation) of zinc in the South Fork Coeur d'Alene River food web. An asterisk indicates that concentrations are significantly greater than in the paired reference site. Source: Woodward et al., 1997b.

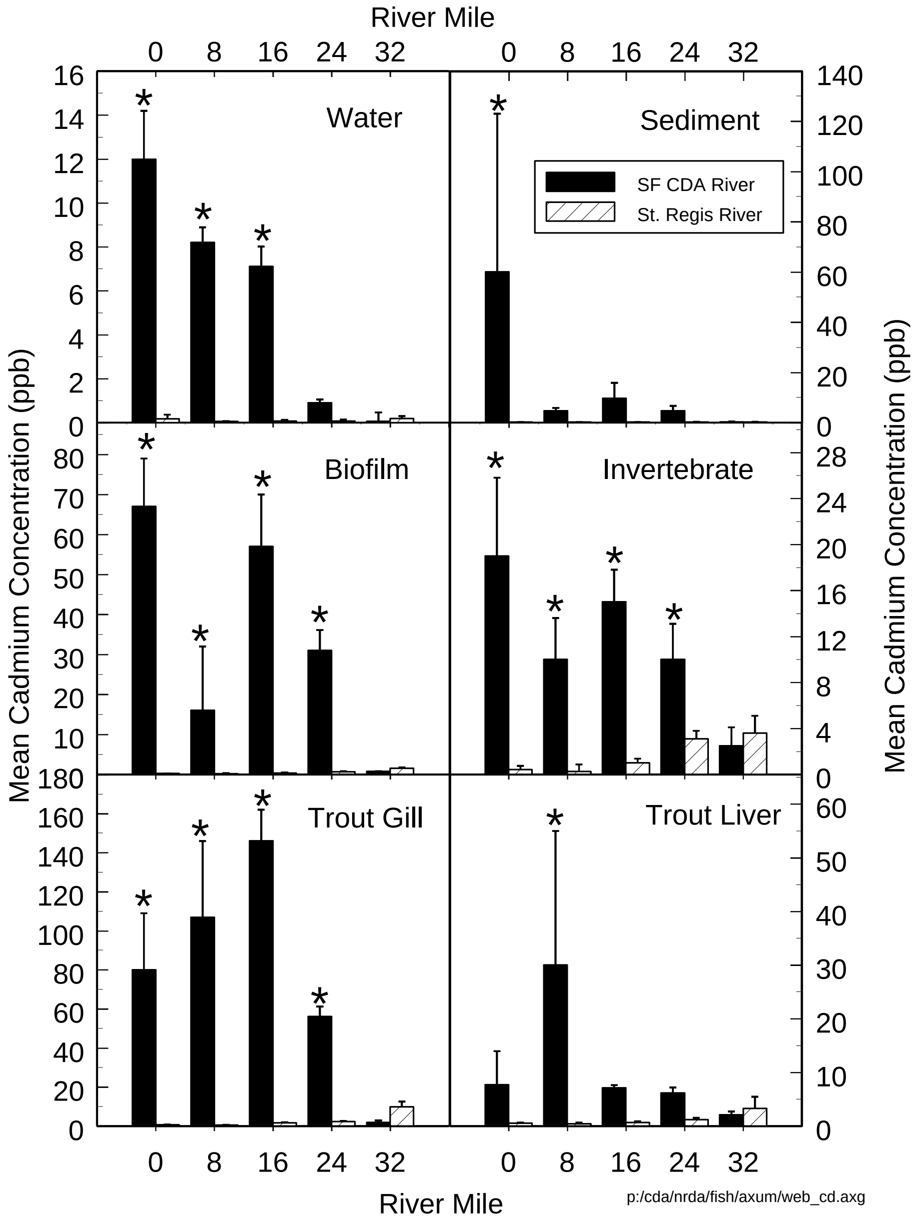

Figure 7-15b. Mean concentrations (standard deviation) of cadmium in the South Fork Coeur d'Alene River food web. An asterisk indicates that concentrations are significantly greater than in the paired reference site. Source: Woodward et al., 1997b.

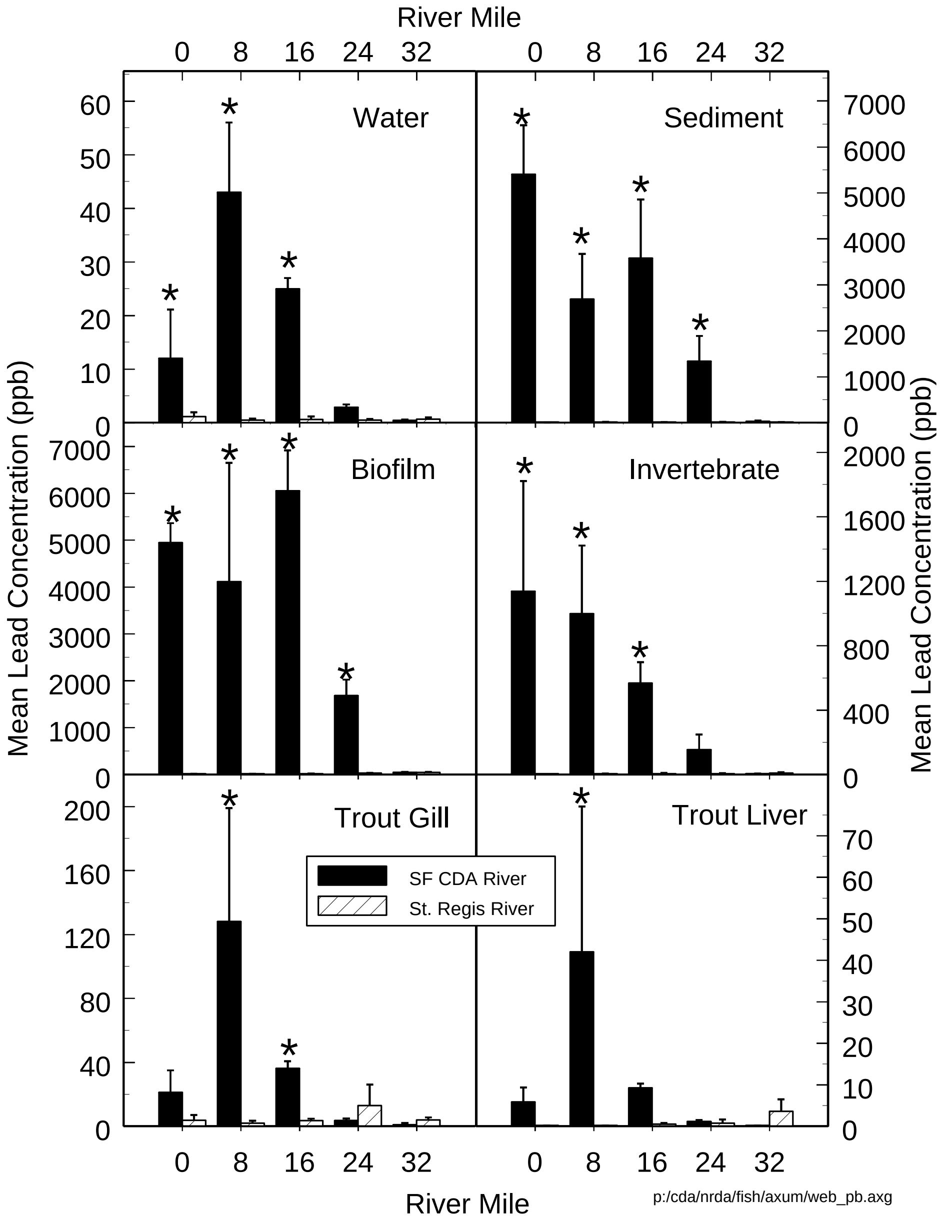

Figure 7-15c. Mean concentrations (standard deviation) of lead in the South Fork Coeur d'Alene River food web. An asterisk indicates that concentrations are significantly greater than in the paired reference site.
Source: Woodward et al., 1997b.

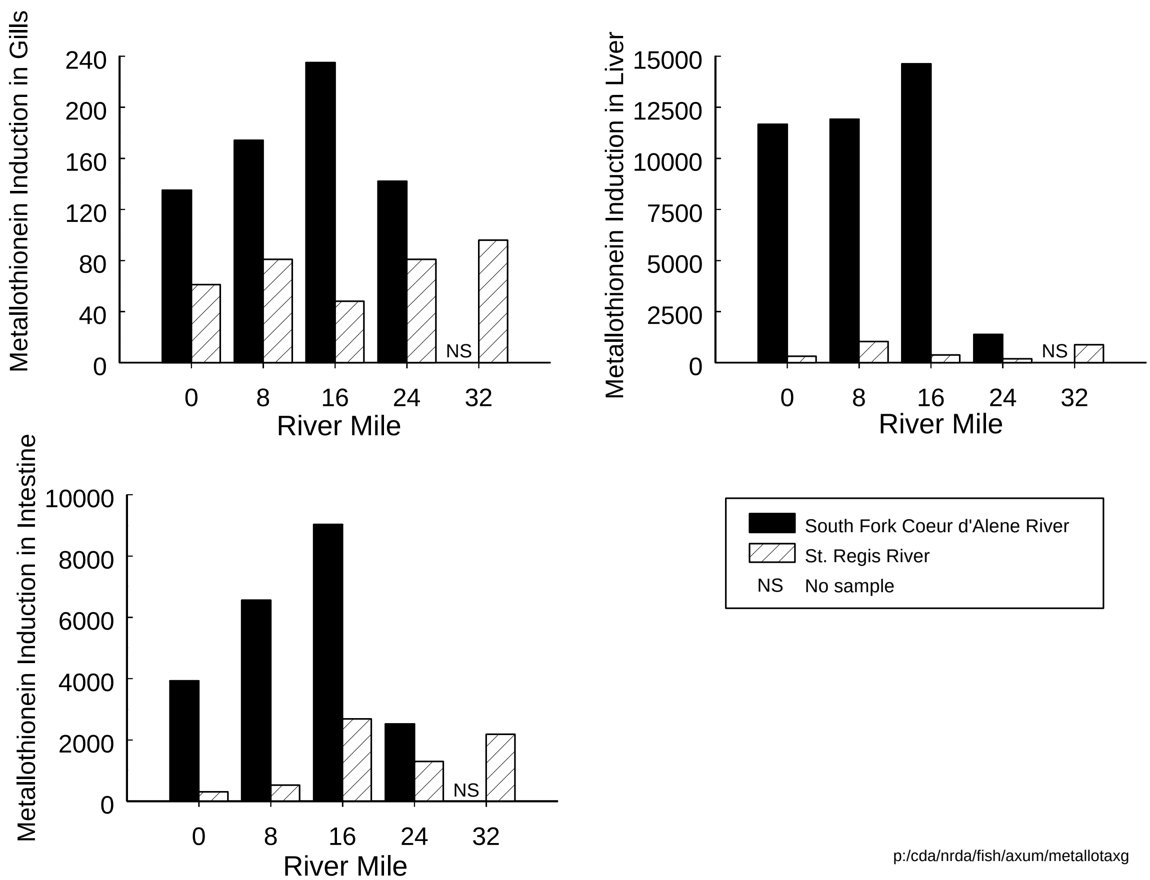

Figure 7-16. Metallothionein induction in fish tissues.
Source: Woodward et al., 1997b.

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).

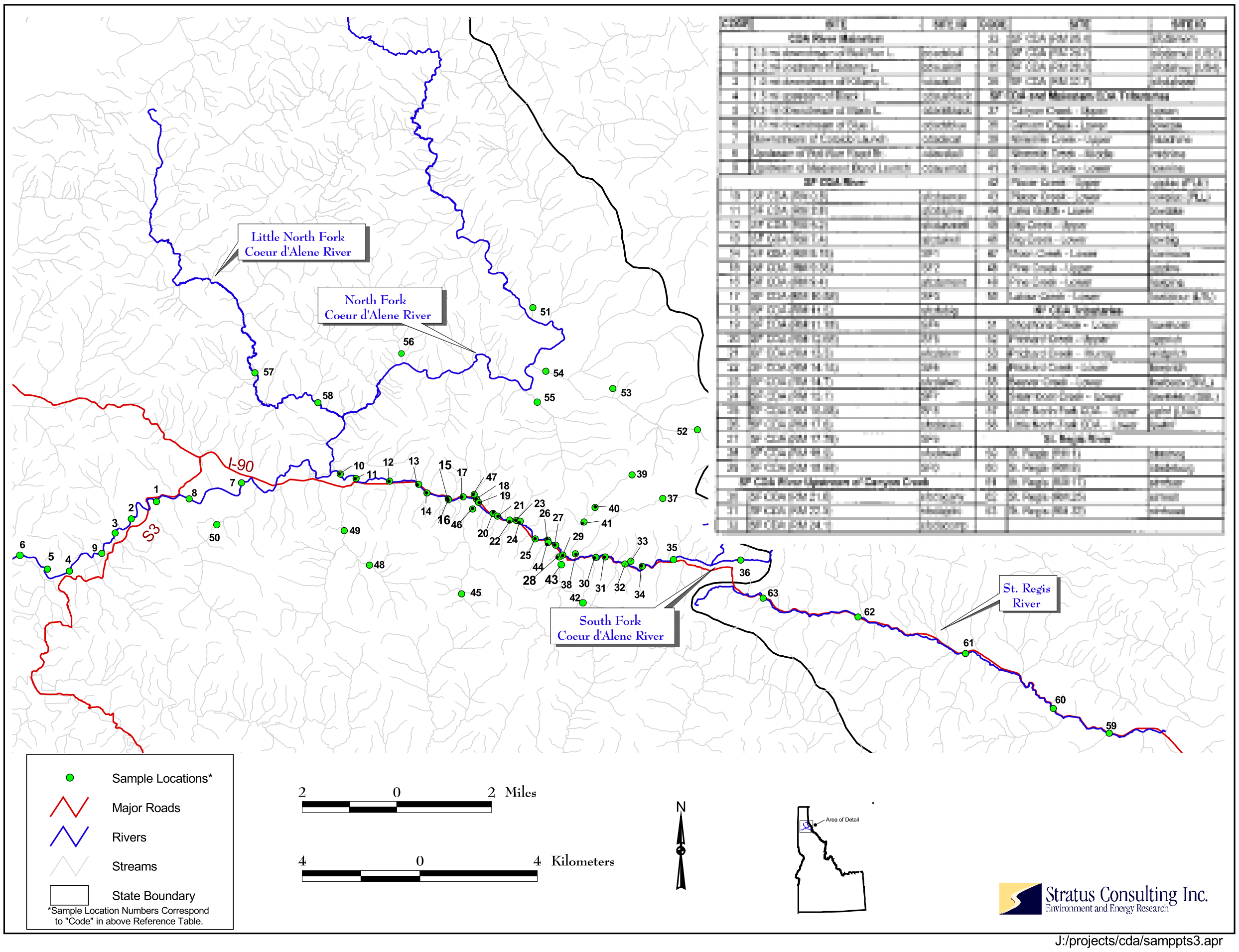

Figure 7-17. Fish population monitoring locations.

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 lower 32 km	 0.87 0.45	 0.64 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

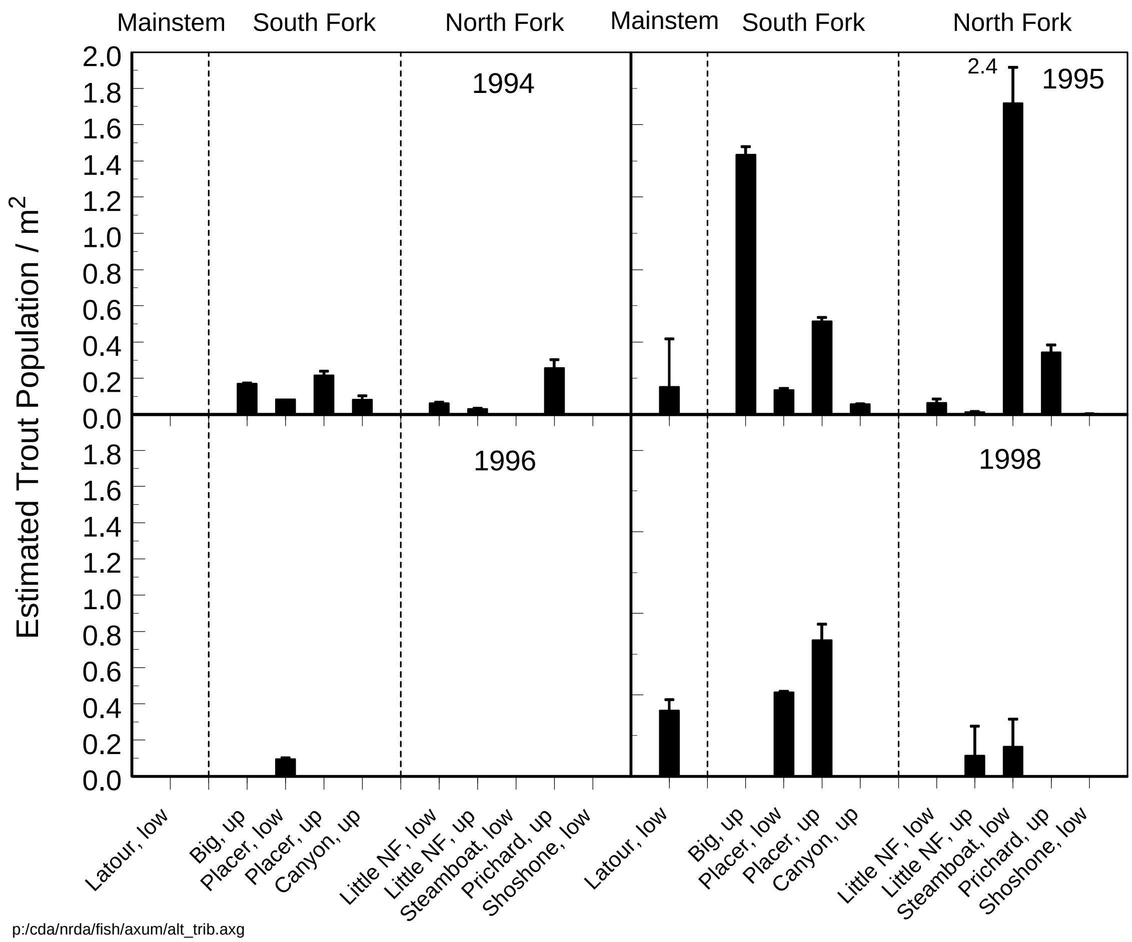

Figure 7-18a. Estimated trout populations from tributary surveys conducted by MPD between 1994 and 1998.
Note: No bar indicates site not sampled.
Sources: R2 Resource Consultants, 1995a, 1996c, 1997; Stratus Consulting, 1999a, 1999b.

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.

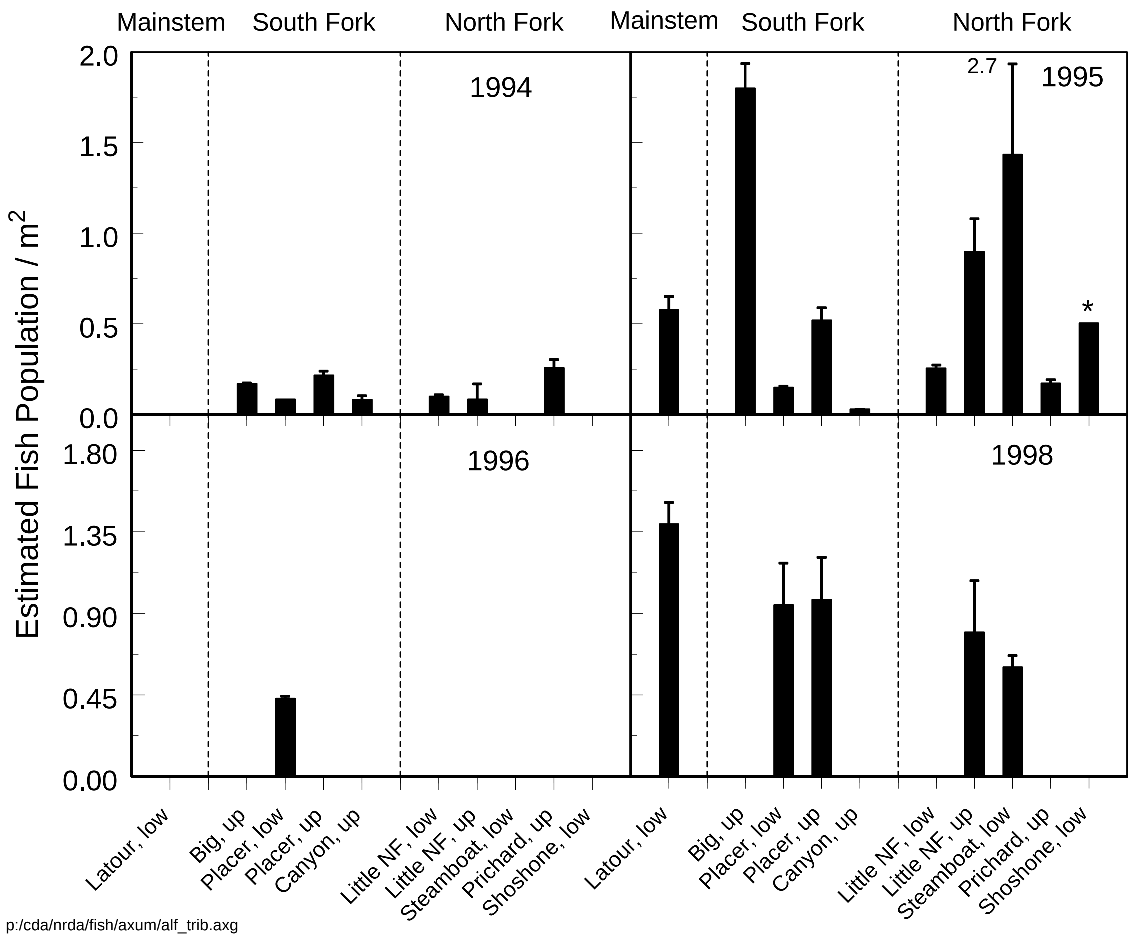

Figure 7-18b. Estimated fish populations from tributary surveys conducted by MPD between 1994 and 1998.
Note: 1994 estimates do not include sculpin. No bar indicates site not sampled.
Sources: R2 Resource Consultants, 1995a, 1996, 1997; Stratus Consulting, 1999a, 1999b.

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: Trout	Number of Fish Captured: Sculpin	Number of Fish Captured: Other[f]	Estimated Population Density[g] ($\#/m^2$): Trout	Estimated Population Density[g] ($\#/m^2$): Total Fish	Estimated Population Density[g] ($\#/m^2$): 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	—	0.062
			8/13/96	Recapture		6	98 (15)[g]	6	52 (14)[g]			
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.

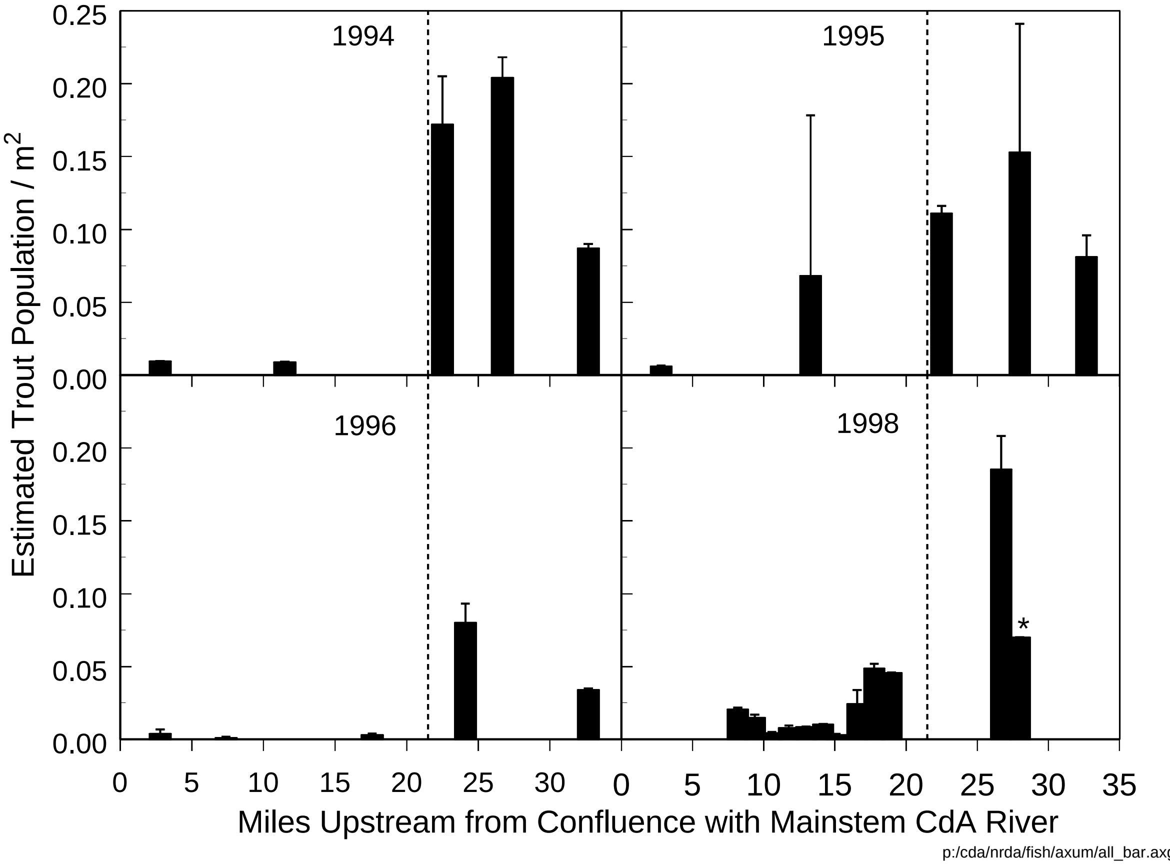

Figure 7-19a. Estimated trout populations in the South Fork Coeur d'Alene River from MPD and mark/recapture data. Note: Vertical dashed line indicates where Canyon Creek enters the South Fork Coeur d'Alene River.
Sources: R2 Resource Consultants, 1995a, 1996, 1997; Reiser et al., 1999; Stratus Consulting,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

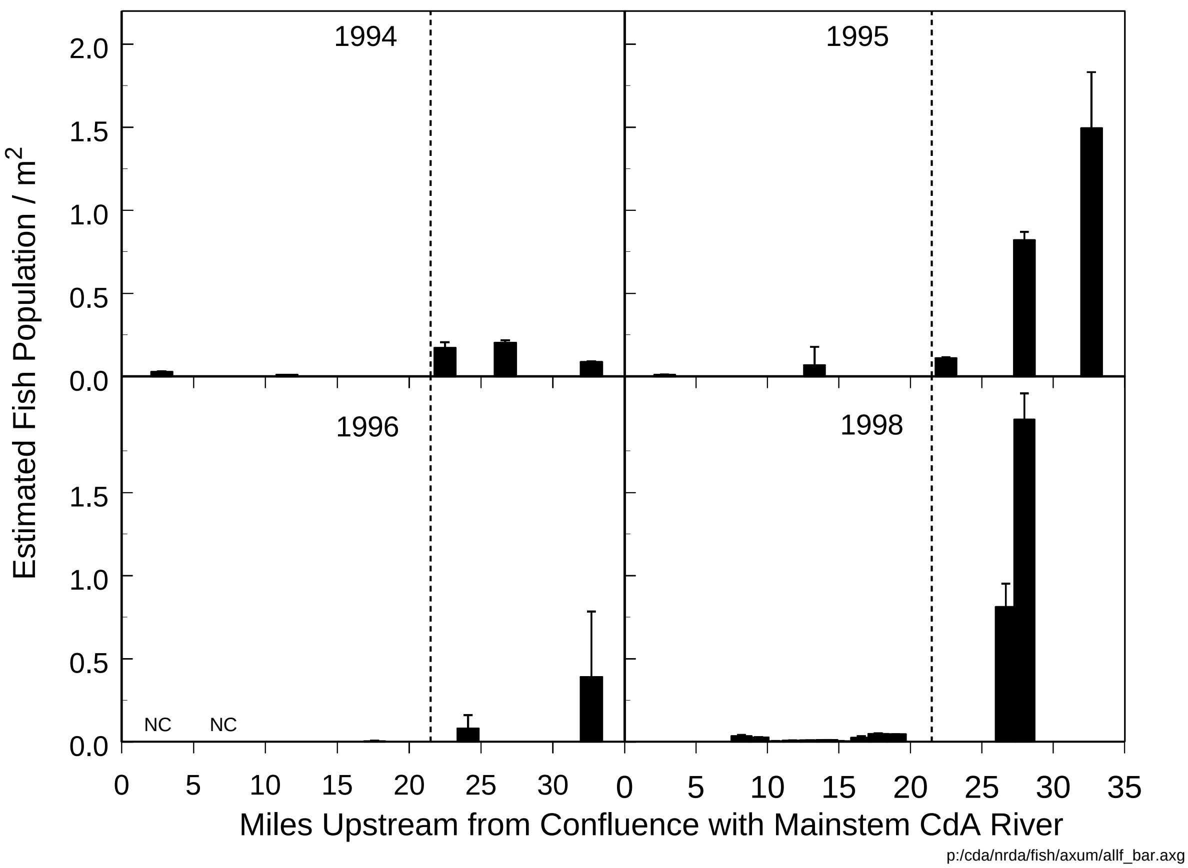

Figure 7-19b. Estimated total fish populations in the South Fork Coeur d'Alene River from MPD and mark/recapture data. Note: Vertical dashed line indicates where Canyon Creek enters the South Fork Coeur d'Alene River. NC = total fish population estimates were not calculated for mark/recapture data. 1994 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).

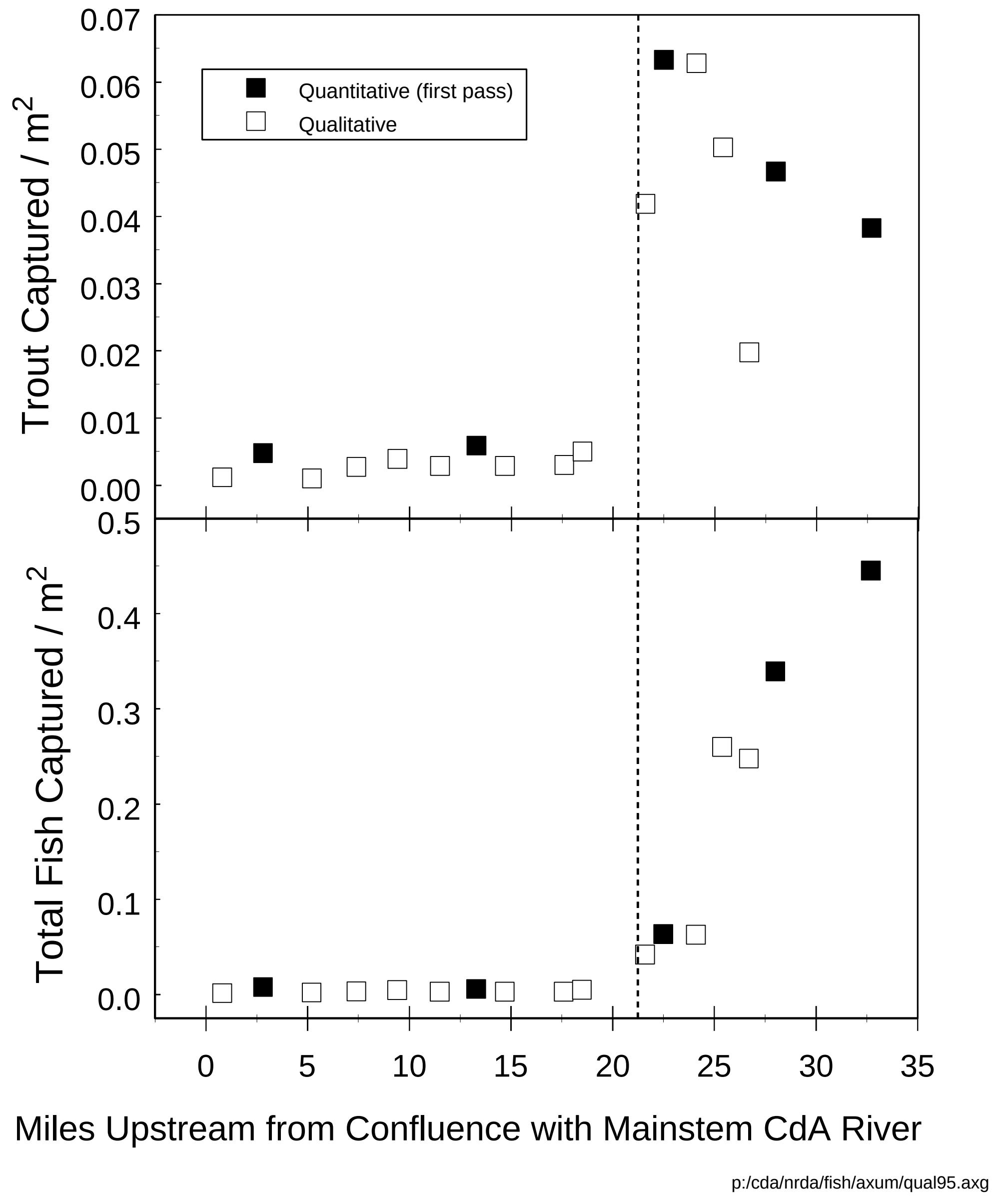

Figure 7-20. Trout (top panel) and all fish combined (bottom panel) collected in the South Fork Coeur d'Alene River during 1995 qualitative (open symbols) and first pass MPD (solid symbols).
Source: R2 Resource Consultants, 1996.

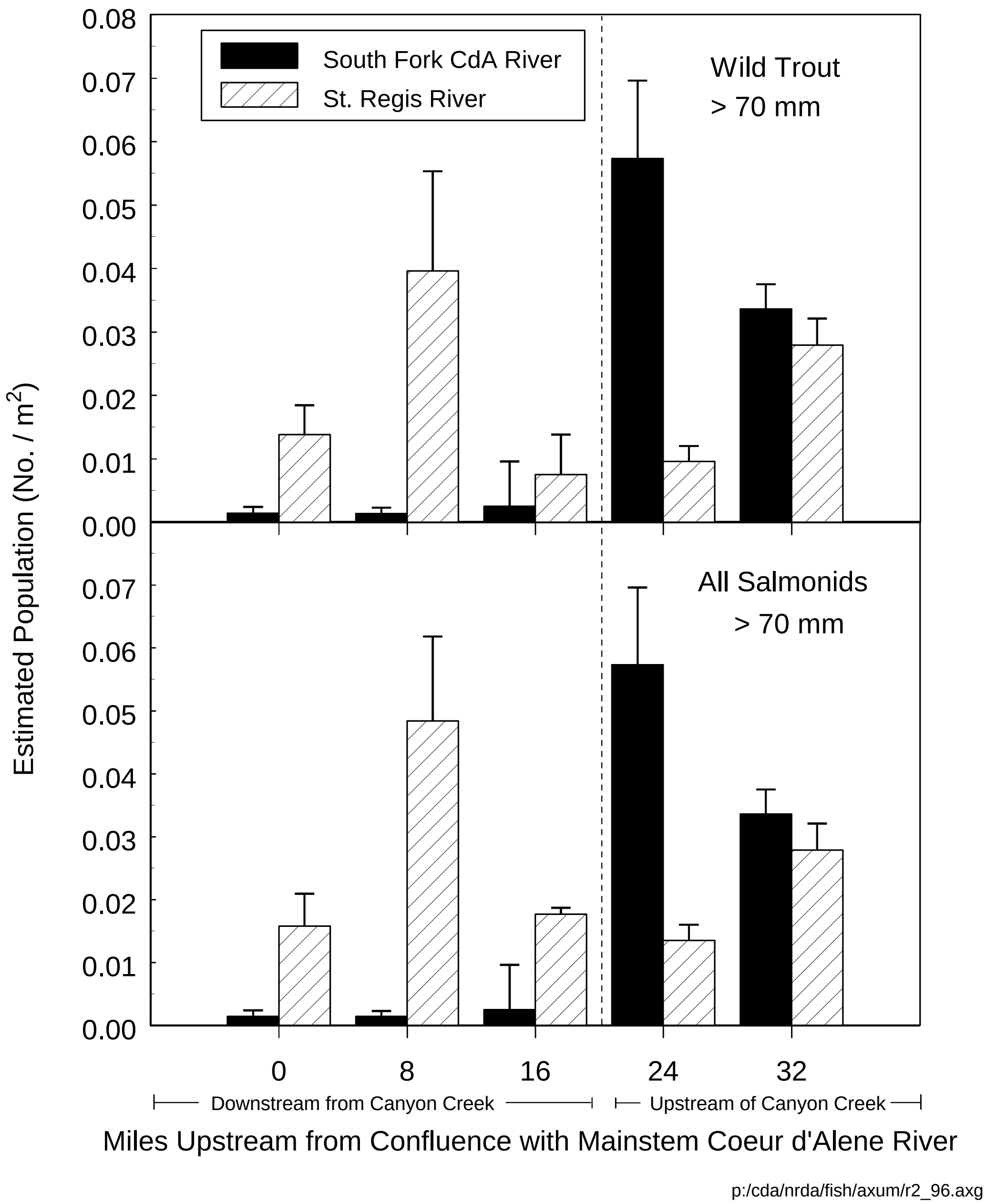

Figure 7-21. Estimated wild trout and all salmonid populations.
Source: Reiser et al., 1999.

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.

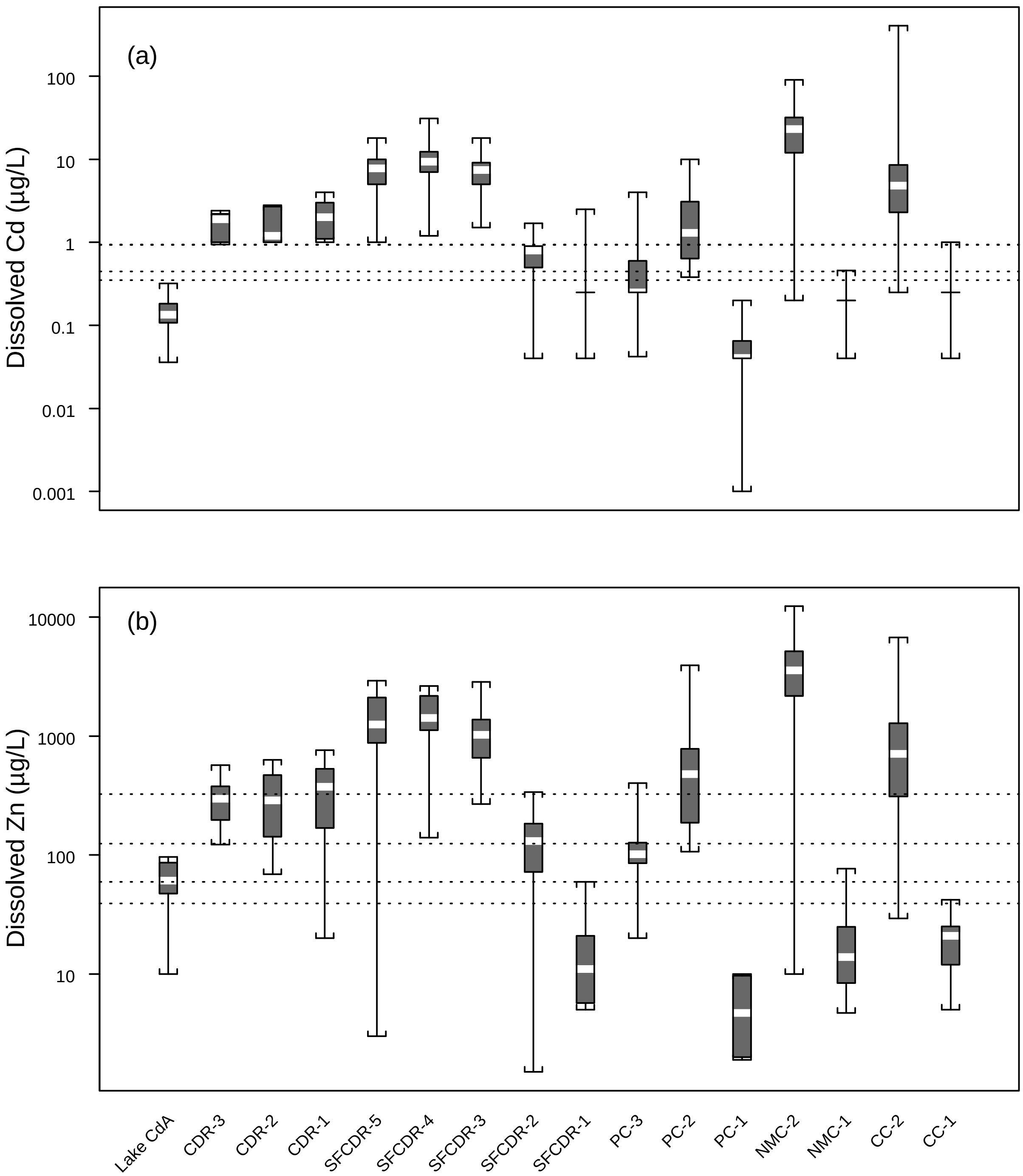

Figure 7-22a. Comparison of dissolved cadmium and zinc concentrations in surface water (1991-1999) and adverse effects concentrations from site-relevant bioassays. Horizontal dashed lines are LC50 values for bull trout (0.94 µg Cd/L and 59.4 µg Zn/L) (Hansen et al., 1999a), rainbow trout (0.445 µg Cd/L 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.

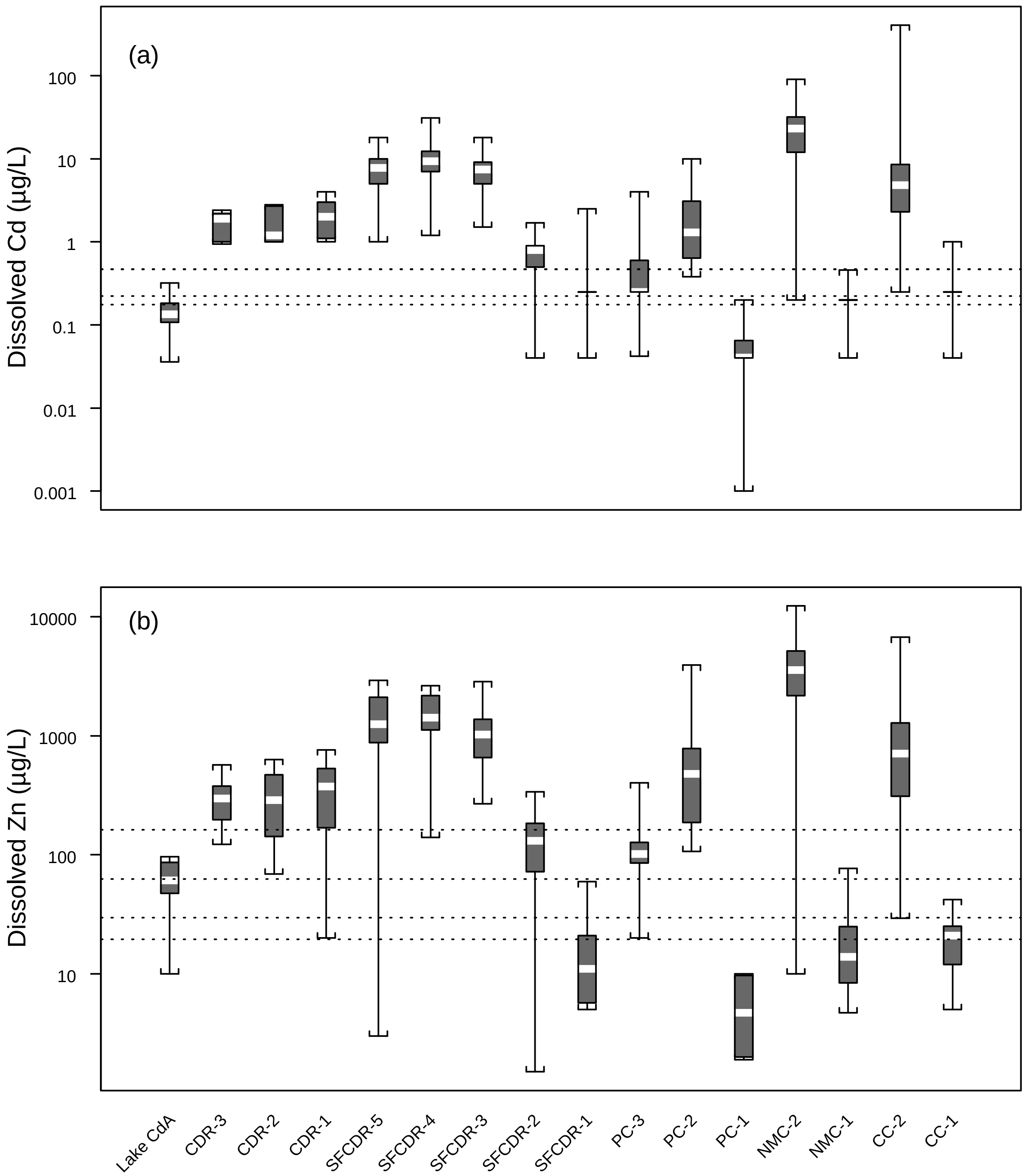

Figure 7-22b. Comparison of dissolved cadmium and zinc concentrations in surface water (1991-1999) and adverse effects concentrations from site-relevant bioassays. Horizontal dashed lines represent one-half the LC50 values identified in Figure 7-22a for bull trout (Hansen et al., 1999a), rainbow trout (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.

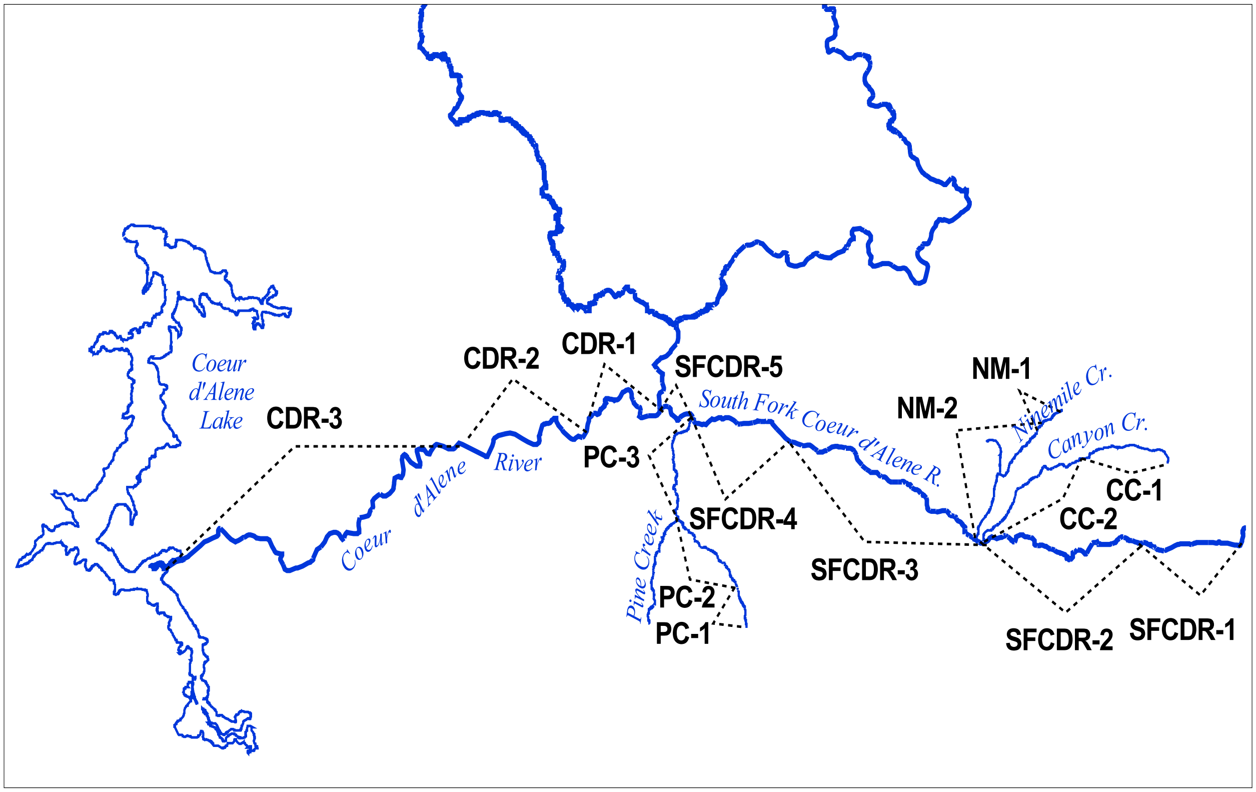

Figure 7-23. Stream reaches referenced in Figure 7-22a and b. See Table 4-4 for descriptions of the reaches.

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.

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CHAPTER 8
BENTHIC MACROINVERTEBRATES

8.1 INTRODUCTION

This chapter presents the determination of injury to benthic macroinvertebrate resources of the Coeur d'Alene basin, focusing on the South Fork Coeur d'Alene River, the Coeur d'Alene River, and tributaries to the South Fork Coeur d'Alene and Coeur d'Alene rivers. Information is also presented on the benthic macroinvertebrate community of Coeur d'Alene Lake. Benthic macroinvertebrates are invertebrates that live on stream or lake bottoms. Many are the larval stages of insects that emerge from the stream as flying or terrestrial adults. They are essential to decomposition and nutrient cycling in aquatic systems, and are a primary food source for fish, including trout (Stolz and Schnell, 1991). Healthy aquatic systems of Rocky Mountain montane rivers typically support complex and diverse macroinvertebrate communities that include mayflies, stoneflies, caddisflies, and craneflies. They fill various food web roles, including herbivorous shredders and scrapers that consume algae and biofilm that grows on stream bottoms, filterers and gatherers that consume detritus, and carnivorous engulfers that consume other invertebrates (Merritt and Cummins, 1984).

Benthic macroinvertebrate resources have been injured in the South Fork Coeur d'Alene, the Coeur d'Alene River, Coeur d'Alene Lake, Canyon Creek, and Ninemile Creek, as well as other stream/river reaches affected by releases of hazardous substances from mining and mineral processing operations. Specifically, the information presented in this chapter demonstrates the following:

- Benthic macroinvertebrates in the South Fork Coeur d'Alene, the Coeur d'Alene River, Coeur d'Alene Lake, Canyon Creek, and Ninemile Creek, as well as other tributary reaches, are exposed to elevated concentrations of cadmium, lead, and zinc in surface water, sediment, and biofilm.

- The metal concentrations to which benthic macroinvertebrates of the South Fork Coeur d'Alene, the Coeur d'Alene River, Coeur d'Alene Lake, Canyon Creek, and Ninemile Creek are exposed are well above concentrations shown to cause toxicity.

- Toxicity tests using water and sediment demonstrate that surface water and sediment downstream of mining activity are toxic to invertebrates under controlled laboratory conditions.

- Benthic macroinvertebrate communities in the South Fork Coeur d'Alene, Canyon Creek, Ninemile Creek, and other stream/river reaches are adversely affected by metals. Specifically, metal-sensitive species are largely absent from the invertebrate communities of these waterways downstream of mining activity. Historical data also demonstrate that the invertebrate communities in the mainstem Coeur d'Alene River and Coeur d'Alene Lake have been adversely affected in the past. Recent data on the communities in these areas are not available to confirm that the effects are continuing, but hazardous substance concentrations in surface water and sediment of the Coeur d'Alene River and Lake remain elevated. In addition, chironomid mouthpart deformities resulting from metals exposure may be ongoing in the South Fork and mainstem Coeur d'Alene rivers.

- The adverse effects on the invertebrate community have been occurring since at least the 1930s. Reductions in metals concentrations over time have resulted in an improvement in the benthic macroinvertebrate community, but the communities of the South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek remain adversely affected.

8.2 BACKGROUND: EFFECTS OF HAZARDOUS METALS ON BENTHIC MACROINVERTEBRATES

8.2.1 Exposure Pathways

Benthic macroinvertebrates can be exposed to hazardous metals in surface water, sediment, sediment pore water, and food items (Figure 8-1). Metals in surface water or sediment pore water can be assimilated through direct uptake across the gill surface and other external body parts (Dodge and Theis, 1979; Hare et al., 1991).

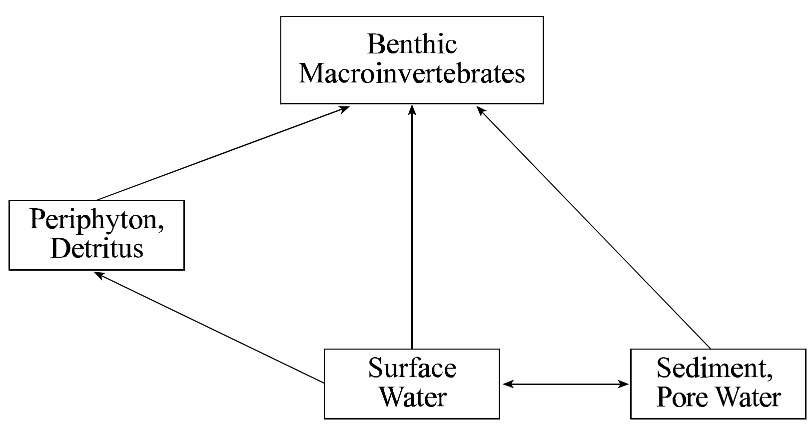

Figure 8-1. Pathways of metal exposure for benthic macroinvertebrates in the Coeur d'Alene River basin.

Benthic macroinvertebrates also can be exposed to metals via ingestion of contaminated food items. Invertebrates consume a variety of food items, including algae, periphyton, detritus, and other invertebrates (Merritt and Cummins, 1984). Several studies have documented that in riverine systems contaminated with metals from mining activities, invertebrate food items can become highly contaminated with metals (Kiffney and Clements, 1993; Lipton et al., 1995; Beltman et al., 1999). Benthic macroinvertebrates can also incidentally ingest contaminated sediment during feeding. The assimilation of metals ingested by invertebrates has been well documented (Burrows and Whitton, 1983; Smock, 1983; Gower and Darlington, 1990; Hare et al., 1991). Therefore, ingestion of contaminated food items and sediment is another mechanism by which benthic macroinvertebrates are exposed to metals.

8.2.2 Adverse Effects on Viability

Benthic macroinvertebrates have been used extensively to monitor the effects of metals contamination on aquatic systems. Benthic macroinvertebrates demonstrate individual level responses (e.g., mortality, reduced growth, reduced reproductive fitness) as well as community level responses (e.g., reduced density, reduced species richness, community shift to more tolerant species) to metals. Attributes that make benthic macroinvertebrates useful for evaluating ecological effects of hazardous substances include the following: (1) they are in intimate contact with sediments; (2) they exhibit a wide range of sensitivity to metals; (3) they occupy limited home ranges; (4) they are integral components of the aquatic food chain; (5) they integrate exposure conditions over their life spans, typically several months to a few years; and (6) they are relatively easy to monitor (Winner, 1972; Wiederholm, 1984; U.S. EPA, 1989; Voshell et al., 1989; Burton, 1992; Cairns and Pratt, 1993).

Metals have been shown to be toxic to benthic macroinvertebrates in laboratory toxicity tests (U.S. EPA, 1992), artificial laboratory streams (Selby et al., 1985; Clements et al., 1988, 1989, 1992; Kiffney and Clements, 1994), natural streams experimentally dosed with metals (Winner et al., 1975, 1980; Leland et al., 1989), and streams or rivers receiving metal pollution (Clements et al., 1992; Beltman et al., 1999).

Community level responses often are used to evaluate the effects of metals on benthic macroinvertebrates (Clements, 1991). Where metals concentrations are sufficiently high, benthic invertebrates may be entirely absent or their abundance greatly reduced (Clements, 1991). Where metals concentrations do not entirely eliminate the community, however, measures of taxa richness (e.g., total number of species present) or abundance of metals-sensitive taxa provide the most sensitive and reliable measure of community level effects (Barbour et al., 1992; Clements and Kiffney, 1995; Carlisle and Clements, 1999). Invertebrate taxa richness is reduced by exposure to metals, as metal-sensitive species are eliminated. For example, many mayfly species are sensitive to metals contamination (Warnick and Bell, 1969), and a reduction in the number of mayfly species present is an effective and reliable measure of metals impacts on benthic macroinvertebrate communities (Ramusino et al., 1981; Specht et al., 1984; Van Hassel and

Gaulke, 1986; Clements, 1991; Clements et al., 1992; Kiffney and Clements, 1994). Metal-exposed communities with reduced taxa richness thus are dominated by metal-tolerant species, fundamentally altering the community structure.

In contrast to community taxa richness or the presence of metals-tolerant species, other metrics such as total invertebrate density (or total abundance) provide a much less sensitive and reliable measure of metal effects on benthic macroinvertebrate communities (except in areas of extremely high metal concentrations). Some investigators have proposed using total invertebrate abundance in the determination of metal effects on benthic communities (e.g., Ginn, 1999). However, studies of invertebrate communities downstream of mining sites in the western United States have shown that total abundance is a poor measure of metals effects. For example, in the Arkansas River in Colorado, Clements (1994) found that at locations downstream of a mine site, metal-sensitive invertebrates were replaced with metal-tolerant ones in response to zinc exposure, and as a result there was no correlation between total abundance and zinc concentrations. Similar results have been reported for Panther Creek, Idaho (Beltman et al., 1999), and Eagle River, Colorado (Kiffney and Clements, 1994), downstream of mine pollution, where metals caused substantial shifts in the benthic community composition but not in the total number of invertebrates present. Carlisle and Clements (1999) conducted a detailed comparison of the reliability and sensitivity of different benthic macroinvertebrate community metrics as indicators of metal effects and concluded that total abundance is a poor metric for detecting metal effects. In contrast, measures of taxa richness and the presence of metal-sensitive taxa were found to be the most reliable and consistent metrics.

8.3 TOXICOLOGICAL DATA

Several toxicity studies have been conducted in which invertebrates have been exposed to water or sediment from the Coeur d’Alene River basin either in the field or under controlled laboratory conditions. The studies are summarized in Table 8-1 and described in detail below. In addition, a study has been conducted on the mouthpart deformity rates in invertebrates from the assessment area.

A small scale, 16-day *in situ* test with benthic macroinvertebrates was initiated by Rabe and Biggam (1990). Invertebrates collected from the South Fork Coeur d’Alene River upstream of Mullan and from the North Fork Coeur d’Alene River were placed in vials in the South Fork Coeur d’Alene River and Canyon Creek downstream of mining. Invertebrates were also placed in the South Fork Coeur d’Alene River upstream of Mullan and in the North Fork Coeur d’Alene River as reference sites. Twelve individual invertebrates were placed at each location. Mortality varied across locations; however, the authors concluded that because of the small sample size, differences in survival across sites could not be determined.

Table 8-1
Summary of Invertebrate Toxicity Studies Conducted Using Coeur d'Alene Basin Water or Sediment

Study	Year of Study	Media Tested	Location Tested	Reference Location	Test Organism	Summary of Results
Rabe and Biggam (1990)	Not specified	Surface water	South Fork Coeur d'Alene Canyon Creek	South Fork Coeur d'Alene (upstream) North Fork Coeur d'Alene	Invertebrates collected from reference areas	Small sample sizes make results difficult to interpret.
Hornig et al. (1988)	1986	Surface water	South Fork Coeur d'Alene Coeur d'Alene River	South Fork Coeur d'Alene (upstream) North Fork Coeur d'Alene	Waterflea (*Ceriodaphnia dubia*)	100% mortality in water collected from all locations downstream of mining activity. Less than 10% mortality in reference site water.
		Sediment	Coeur d'Alene River Coeur d'Alene Lake	Chatcolet Lake	Waterflea (*Daphnia magna*); amphipod (*Hyallela azteca*)	Hyallela had higher mortality in Coeur d'Alene River sediments than in reference; Daphnia had unusually high reference mortality.
Dames & Moore (1989)	1987-1988	Surface water	South Fork Coeur d'Alene	North Fork Coeur d'Alene	Waterflea (*Ceriodaphnia dubia*)	100% mortality in South Fork Coeur d'Alene water. Low mortality in North Fork Coeur d'Alene water.

In 1986, bioassays were conducted with the waterflea *Ceriodaphnia dubia* at the U.S. EPA Environmental Research Laboratory in Duluth, Minnesota (Hornig et al., 1988). Organisms were exposed to water collected from seven locations on the South Fork Coeur d'Alene River between the mouth and Canyon Creek and the mainstem Coeur d'Alene River near Cataldo. Organisms were also exposed to reference water collected from the North Fork Coeur d'Alene River near Enaville and the South Fork Coeur d'Alene River upstream of Mullan. Exposures of invertebrates to water collected from the South Fork Coeur d'Alene and mainstem Coeur d'Alene rivers downstream of mining activity (i.e., between Cataldo and Canyon Creek) resulted in 100% mortality (Table 8-2). Dilution tests showed that as little as 10% South Fork Coeur d'Alene water mixed with clean water caused an increase in mortality relative to reference water. Mortality was less than 10% in site reference water.

Table 8-2
Results of Site Water Invertebrate Toxicity Tests by Hornig et al. (1988)

Site	River Mile[a]	Ceriodaphnia Survival (%)	Mean Young Produced (#)
North Fork Coeur d'Alene at Enaville (reference)	0.6	95	25.8
South Fork Coeur d'Alene above Mullan (reference)	29.1	90	23.1
Mainstem Coeur d'Alene at Cataldo	6.0	0	0
South Fork Coeur d'Alene at mouth	0.0	0	0
South Fork Coeur d'Alene above Pine Creek	2.4	0	0
South Fork Coeur d'Alene below Smelterville	4.8	0	0
South Fork Coeur d'Alene at Bunker Avenue	6.9	0	0
South Fork Coeur d'Alene above Kellogg	8.3	0	0
South Fork Coeur d'Alene above Big Creek	11.4	0	0
South Fork Coeur d'Alene above Canyon Creek	21.0	0	0

a. Number of miles from the North Fork and South Fork Coeur d'Alene confluence.

Source: Hornig et al., 1988.

Hornig et al. (1988) also conducted sediment toxicity tests with the macroinvertebrates *Daphnia magna* and *Hyalella azteca* in 1986. Organisms were exposed to sediment collected from five locations on the mainstem Coeur d'Alene River and Coeur d'Alene Lake and from a single location designated by the study authors as a reference location (Chatcolet Lake). Table 8-3 presents the metal concentrations and organism survival rates for sediment from each location.

Table 8-3
Results of Site Sediment Invertebrate Toxicity Tests by Hornig et al. (1988)

Site	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)	Mean Survival[a]	
				Daphnia	Hyallela
Chatcolet Lake (reference)	0.6	10	77	33%	88%
Coeur d'Alene River near Rose Lake	7.2	3,870	7,300	73%	65%
Coeur d'Alene River near Blue Lake	8.3	3,992	4,220	27%	37%
Coeur d'Alene Lake near Coeur d'Alene River delta	8.0	4,158	3,680	63%	80%
Coeur d'Alene Lake near Conkling Point	9.9	367	1,310	70%	93%
Coeur d'Alene Lake near Rockford Bay	7.7	2,136	3,620	87%	77%

a. Mean of three replicates of 10 organisms (Daphnia) or 20 organisms (Hyallela).

Source: Hornig et al., 1988.

Although statistical tests were not conducted, the data in Table 8-3 indicate that Hyallela exposed to sediment from the Coeur d'Alene River near Blue Lake had lower mean survival (37%) than those exposed to reference sediment (88%). Low survival was observed in the Daphnia exposed to the reference sediment (33%), making comparisons with Coeur d'Alene River results difficult.

Dames & Moore (1989) exposed the waterflea *Ceriodaphnia dubia* to water collected from four sites on the South Fork Coeur d'Alene River and one site on the North Fork Coeur d'Alene River (used as a reference site). Water was collected on three different dates in 1987 and 1988, representing low flow conditions, transient high flow, and late spring runoff. Results are expressed as LC50s, which are the percentages of site water that were calculated to cause mortality to 50% of the exposed organisms. Table 8-4 shows that from 0.1% to 6.1% of South Fork Coeur d'Alene River water diluted with clean water resulted in mortality to 50% of the exposed organisms. In contrast, limited mortality was observed for invertebrates exposed to water from the North Fork Coeur d'Alene River. Metal concentrations measured in the South Fork Coeur d'Alene River water to which invertebrates were exposed were many times higher than concentrations in North Fork Coeur d'Alene River water (Table 8-4). For example, dissolved zinc ranged from 1,230 to 3,000 µg/L in South Fork Coeur d'Alene River water compared with 9.4 to 30 µg/L in North Fork Coeur d'Alene River water. Therefore, the higher mortality of invertebrates exposed to South Fork Coeur d'Alene River water is associated with elevated metal concentrations.

Table 8-4
Results of Site Water Invertebrate Toxicity Tests by Dames & Moore (1989)

Site	Date	Hardness (mg/L)	Dissolved Metal Concentration: Cadmium (µg/L)	Lead (µg/L)	Zinc (µg/L)	LC50[a] (as % of site water)
North Fork Coeur d'Alene near Enaville (reference)	Sept. 1987	18	<2	31[b]	9.4	>100.0
	Dec. 1987	17.4	<4	<5	<20	>100.0
	June 1988	17.1	<4	<5	30	>100.0
South Fork Coeur d'Alene near Elizabeth Park (RM 9)	Sept. 1987	84	12	21	1,800	2.0
	Dec. 1987	80	6	13	2,190	6.1
	June 1988	67	10	<5	1,230	5.1
South Fork Coeur d'Alene near Bunker Creek (RM 6.8)	Sept. 1987	104	10	<19	2,200	0.1
	Dec. 1987	88.7	7	25	2,760	1.9
	June 1988	74.4	10	<5	1,490	3.7
South Fork Coeur d'Alene near Government Creek (RM 5)	Sept. 1987	168	11	<19	2,400	0.1
	Dec. 1987	141	7	<25	3,000	1.9
	June 1988	78.5	13	9	1,710	1.7
South Fork Coeur d'Alene near Pine Creek (RM 2.2)	Sept. 1987	120	8	<19	2,100	3.9
	Dec. 1987	121	6	18	2,780	5.6
	June 1988	73.8	9	<5	1,480	1.9

a. Represents the percentage of the site water that, when mixed with clean water, causes lethality to 50% of the test organisms.
b. Potential residual lead contamination on ICP torch (Dames & Moore, 1989; p. 18).

RM — river mile from the confluence of the South and North Fork Coeur d'Alene rivers.

Thornberg (1995) and Martinez (1998) both found a significantly higher incidence of mouthpart deformities in chironomid larvae from sites in the South Fork Coeur d'Alene River at Smelterville and in the mainstem Coeur d'Alene River than at sites upstream of mining related contamination. Rates of mouthpart deformity were positively correlated with metals concentrations in sediment at the collection sites, but were not related to metal concentrations in the chironomids (Martinez, 1998). In subsequent laboratory experiments, Martinez (2000) observed significantly greater rates of mouthpart deformities in populations exposed to lead or zinc than in the control population, and the incidence of mouthpart deformities increased with exposure duration. No clear dose response relationship between exposure concentration and deformity rate was observed, however. Martinez (2000) also found that the increase in the rate of mouthpart deformities induced by lead exposure persisted in the progeny of the exposed population, which suggests that lead exposure is mutagenic.

8.4 BENTHIC MACROINVERTEBRATE COMMUNITY DATA

This section presents and discusses data on the benthic macroinvertebrate community structure of the South Fork Coeur d'Alene and Coeur d'Alene rivers, their tributaries, and Coeur d'Alene Lake, focusing on two measures of metal effects on benthic communities: total taxa richness (i.e., the total number of benthic invertebrate taxa present) and mayfly species richness (i.e., the number of mayfly species present). These community measures are highlighted because they are proven, reliable indicators of metal effects on benthic communities (see Section 8.2.2). Exposure to metals causes a loss of metal-sensitive taxa from the community, resulting in a decrease in total taxa richness and a decrease in the number of mayfly taxa, which are among the metal-sensitive taxa.

8.4.1 Historical Data

The historical benthic macroinvertebrate community studies that have been conducted in the Coeur d'Alene River basin are summarized in Table 8-5. In general, these studies show that no or very few invertebrates were present in the South Fork Coeur d'Alene and Coeur d'Alene rivers until the early 1970s, soon after construction of tailings ponds reduced direct discharge of tailings to the system. The invertebrate community continued to improve slightly through the early 1980s following the reductions in metal loadings, but the community remained severely affected. Only a few metal-tolerant species were able to survive, and metal-sensitive taxa (such as mayflies) were largely absent. Surveys in the South Fork Coeur d'Alene and Coeur d'Alene rivers through the early 1990s have continued to show a community characteristic of an aquatic ecosystem impacted by metals, with metal-sensitive taxa largely absent.

South Fork Coeur d'Alene and Coeur d'Alene Rivers

Ellis (1940) was the first to report on the condition of benthic macroinvertebrates in the Coeur d'Alene River basin. In a 1932 survey of biological resources, he observed that the mainstem Coeur d'Alene River between the mouth and the confluence of the North Fork and South Fork Coeur d'Alene rivers, and the South Fork Coeur d'Alene River from its confluence with the North Fork to a point upstream of Wallace, were essentially devoid of aquatic biota, including benthic macroinvertebrates (Ellis, 1940). Benthic organisms were found only in the immediate areas where clean tributaries entered the contaminated rivers. Upstream of Wallace, benthic invertebrate communities included abundant caddisfly larvae (Trichoptera), stonefly larvae (Plecoptera), and mayfly nymphs (Ephemeroptera) and appeared unaffected by mining related disturbances (Ellis, 1940). Ellis attributed the absence of aquatic biota in the South Fork and mainstem Coeur d'Alene rivers to the turbidity and adverse effects on habitat caused by tailings and to acute zinc toxicity.

Table 8-5
Summary of Historical Invertebrate Community Studies

Study	Sampling Dates	Assessment Area Sampled	Reference Area Sampled[a]	Summary of Results
Ellis (1940)	1932	South Fork Coeur d'Alene River Mainstem Coeur d'Alene River Coeur d'Alene Lake Various tributaries	South Fork Coeur d'Alene River upstream of Mullan St. Joseph River	Areas downstream of mining "practically devoid of bottom fauna." Healthy, diverse communities at reference sites.
Wilson (1952) and Olson (1963)	Early 1950s and 1960s	South Fork Coeur d'Alene River Mainstem Coeur d'Alene River	None specified	"Virtually no benthic invertebrates."
Savage and Rabe (1973)	1968-1971	South Fork Coeur d'Alene River (three sites) Mainstem Coeur d'Alene River (one site)	North Fork Coeur d'Alene River South Fork Coeur d'Alene River upstream of Mullan	Reduced taxa richness and density at all assessment area sites.
Stokes and Ralston (1972)	1969-1970	South Fork Coeur d'Alene River (four sites) Mainstem Coeur d'Alene River (one site)	North Fork Coeur d'Alene River South Fork Coeur d'Alene River upstream of Mullan	Reduced taxa richness and density at all assessment area sites.
Funk et al. (1975)	1973	South Fork Coeur d'Alene River (one site) Mainstem Coeur d'Alene River (two sites)	North Fork Coeur d'Alene River	Reduced taxa richness and density at all assessment area sites.
Hornig et al. (1988)	1986	South Fork Coeur d'Alene River (five sites) Mainstem Coeur d'Alene River (one site)	North Fork Coeur d'Alene River South Fork Coeur d'Alene River upstream of Mullan	Reduced taxa richness at most South Fork Coeur d'Alene River sites.
Dames & Moore (1989)	1987	South Fork Coeur d'Alene River (four sites)	North Fork Coeur d'Alene River	Reduced taxa richness at all assessment area sites.

Table 8-5 (cont.)
Summary of Historical Invertebrate Community Studies

Study	Sampling Dates	Assessment Area Sampled	Reference Area Sampled[a]	Summary of Results
Hoiland (1992); Hoiland et al. (1994)	1987-1989, 1991	South Fork Coeur d'Alene River (three sites; two sites, 1991 only) Mainstem Coeur d'Alene River (one site) Ninemile Creek (three sites, 1991 only) Canyon Creek (three sites, 1991 only)	North Fork Coeur d'Alene River South Fork Coeur d'Alene River upstream of Mullan Canyon Creek upstream of Burke (1991 only)	Reduced taxa richness at all assessment area sites.
Clark (1992)	1992	South Fork Coeur d'Alene River (four sites) Mainstem Coeur d'Alene River (two sites)	South Fork Coeur d'Alene River upstream of Canyon Creek	Reduced taxa richness at South Fork Coeur d'Alene River sites.
U.S. Bureau of Mines (1995)	1993	Moon Creek (2 sites)	Moon Creek upstream of mine (one site)	Reduced taxa richness at both assessment area sites.
McNary et al. (1995)	1993 or 1994	Pine Creek basin (15 sites)	East Fork Pine Creek and Highland Creek upstream of mining activity	Reduced taxa richness at some assessment area sites.
Winner (1972)	1971-1972	Coeur d'Alene Lake	Lake Chatcolet and Round Lake	Difference in communities between assessment area and reference sites.
Skille et al. (1983)	1981-1982	Mainstem Coeur d'Alene River (two sites) Coeur d'Alene Lake (one site downgradient of Coeur d'Alene River mouth)	St. Joe River Coeur d'Alene Lake (four sites upgradient of Coeur d'Alene River mouth)	Reduced total abundance and biomass.
Ruud (1996)	1995	Coeur d'Alene Lake	Priest Lake Lake Chatcolet	Differences in communities between assessment area and reference sites.

a. As designated by study authors.

Tailings settling ponds in the basin installed in 1968 reduced tailings loads to the system (Savage and Rabe, 1973). Mink et al. (1971, as cited in Savage and Rabe, 1973) reported a significant reduction in suspended solids after the installation of settling ponds, but little change in metals concentrations in surface water. In late 1968, a single metals-tolerant taxon, midge fly larvae (Chironomids), had established in the South Fork Coeur d'Alene River (Savage, 1970). By late 1970 and in 1973, additional metals-tolerant taxa, including the mayfly *Baetis tricaudatus* and other stonefly, caddisfly, and beetle species, were found in the South Fork Coeur d'Alene River downstream of Wallace and on the mainstem Coeur d'Alene River near Cataldo (Figure 8-2) (Stokes and Ralston, 1972; Savage and Rabe, 1973; Funk et al., 1975). Nevertheless, the total number of taxa in the impacted areas of the South Fork Coeur d'Alene and mainstem Coeur d'Alene rivers remained low. For example, Savage and Rabe (1973) reported finding 25 to 32 invertebrate taxa in the North Fork Coeur d'Alene River and 19 taxa in the South Fork Coeur d'Alene River upstream of Mullan, compared with 2 to 4 invertebrate taxa at South Fork Coeur d'Alene and mainstem Coeur d'Alene river locations downstream of Canyon Creek (Figure 8-2). Water chemistry samples collected during the same time confirm the high metals exposure in the South Fork Coeur d'Alene River downstream of Mullan and in the mainstem Coeur d'Alene River compared with upstream and reference areas (Mink et al., 1971, as cited in Savage and Rabe, 1973).

Direct discharges of metals to the lower South Fork Coeur d'Alene River declined in the 1970s (Hornig et al., 1988). Between the 1970s and 1986, taxa richness increased in the South Fork Coeur d'Alene River downstream of Wallace and in the mainstem near Cataldo (Hornig et al., 1988). Although chironomid species remained dominant, increases in the numbers of species and relative abundance of other invertebrates were reported. Despite the improvement, metal-sensitive taxa remained absent from the South Fork Coeur d'Alene and mainstem Coeur d'Alene rivers, and the community was dominated by metal-tolerant midge fly larvae (Hornig et al., 1988). In 1981-1982, Skille et al. (1983) found almost complete absence of benthic invertebrates in the lower six miles of the mainstem Coeur d'Alene River. Mean invertebrate density in the Coeur d'Alene River ranged from 0 to 56 organisms/m^2, compared to averages of 397 to 1,600 organisms/m^2 in the lower St. Joe River (taxa richness was not reported).

Dames & Moore (1989) conducted benthic macroinvertebrate community surveys at two different flow periods in 1987-1988 in the South Fork Coeur d'Alene and North Fork Coeur d'Alene rivers. All sites sampled had similar substrate composition (dominated by cobble and gravel), riffle and thalweg depths, stream velocity, and stream width. Taxa richness results (Figure 8-3) show that fewer taxa were found in the South Fork Coeur d'Alene River sites (average of 10 to 16) than in the North Fork Coeur d'Alene River site (average of 27). The lowest number of taxa were measured in the South Fork near Bunker Creek (Figure 8-3).

Water quality data collection and site water toxicity tests conducted by Dames & Moore (1989) from the same locations during the same period (described in detail in Section 8.3) confirm that water at these sites had highly elevated metal concentrations and was toxic to invertebrates.

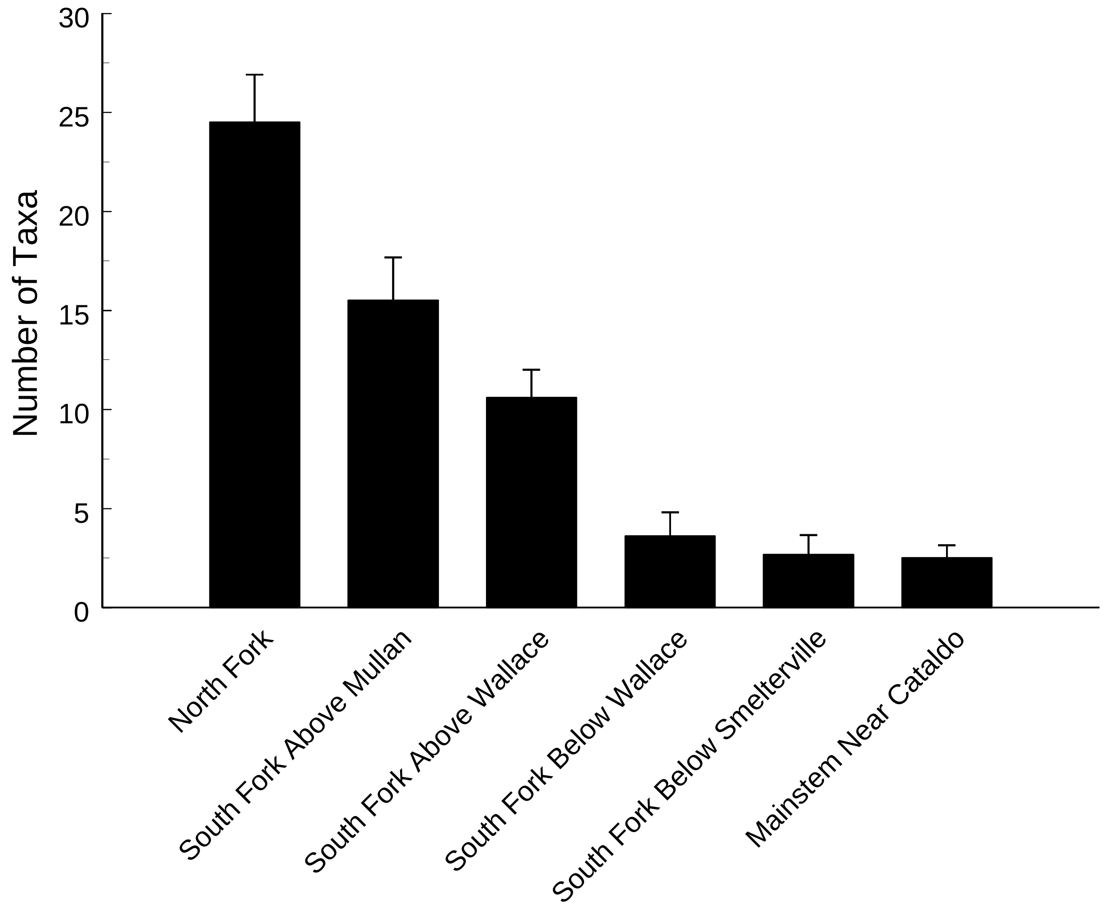

Figure 8-2. Invertebrate taxa richness (categorized to species level) in North Fork Coeur d'Alene, South Fork Coeur d'Alene, and Coeur d'Alene rivers in 1968-1970. Bars are means, vertical lines are means plus one standard error.
Source: Data from Savage and Rabe (1973) and Stokes and Ralston (1972).

Hoiland (1992), Clark (1992, as cited in Hartz, 1993), and Hoiland et al. (1994) report on invertebrate community studies conducted in the late 1980s and early 1990s (through 1992). Their results are similar to the studies conducted in the mid-1980s, with taxa richness reduced in the South Fork Coeur d'Alene and mainstem Coeur d'Alene rivers compared to the North Fork Coeur d'Alene River. Metal-sensitive species were absent or reduced in areas downstream of mining activity. Measurements of dissolved metals in surface water again confirmed the presence of higher metal concentrations at the South Fork Coeur d'Alene and mainstem Coeur d'Alene river sites compared to reference areas (Hoiland and Rabe, 1992). These studies confirm that no or little improvement occurred in the invertebrate communities from the mid-1980s through the early 1990s.

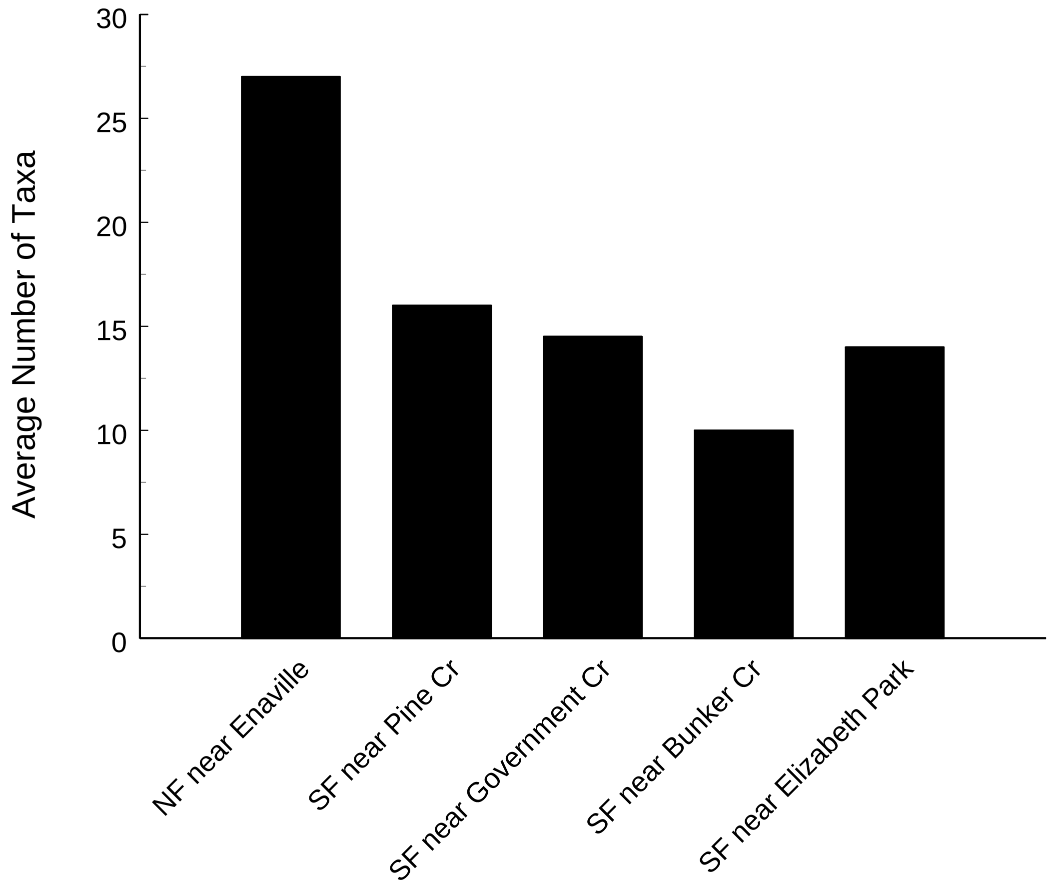

Figure 8-3. Invertebrate taxa richness (categorized to species level) in the South Fork Coeur d'Alene River and North Fork Coeur d'Alene River in 1987.
Source: Data from Dames & Moore, 1989.

Tributaries

Several studies have also been conducted on tributaries to the South Fork Coeur d'Alene and Coeur d'Alene rivers impacted by mining activity. Hoiland (1992) compared benthic invertebrate communities in Canyon and Ninemile creeks downstream of mining activities with the community in Canyon Creek upstream of mining. He found reduced taxa richness, loss of metal-sensitive species, and dominance by metal-tolerant species downstream of mining activities. Zinc concentrations were 20 to 320 µg/L at locations used as reference sites, compared with 1,490 to 5,290 µg/L at locations downstream of mining activity.

Benthic macroinvertebrate populations in Moon Creek upstream and downstream of mining activity were surveyed in 1993 by the U.S. Bureau of Mines (1995). Habitat quality parameters (e.g., embeddedness, diversity, canopy cover, substrate, habitat composition) were similar at all sites. The number of taxa (families) ranged from 17 at the site upstream of the mine to 5 downstream of the mine. Metal concentrations were much higher downstream of the mine (e.g., 477 µg/L Zn) than upstream (2.2 µg/L).

A similar study was conducted by the U.S. Bureau of Mines on the Pine Creek watershed (McNary et al., 1995). This study had similar results, with higher metal concentrations, reduced taxa richness, and loss of metal-sensitive taxa in areas downstream of mining activity compared with upstream.

Coeur d'Alene Lake

Studies of benthic macroinvertebrate communities of Coeur d'Alene Lake include Winner (1972), Skille et al. (1983), and Ruud (1996). Winner (1972) observed strong dominance by chironomids (comprising 51 to 75% of the total number of benthic macroinvertebrates) and oligochaetes (comprising 26 to 49% of the total number of benthic macroinvertebrates) in benthic macroinvertebrate communities of Coeur d'Alene Lake. Species of the subfamily Chironominae (dominated by *Microspectra* spp. and *Chironimus* spp.) comprised the majority (73%) of the Chironomids. Based on one density estimate per site at four sites, Winner (1972) reported no relationship between sediment zinc concentrations and the distribution of chironomids or oligochates. However, the small sample size did not allow statistical analysis of the data.

Skille et al. (1983) sampled benthic macroinvertebrates in Lake Coeur d'Alene to the north (downgradient) and to the south (upgradient) of the mouth of the Coeur d'Alene River. Invertebrate density was greatest at sites upgradient of the Coeur d'Alene River mouth and lowest at the site downgradient of the river mouth.

Horowitz et al. (1995) observed burrow and worm tubes indicative of biological activity in the deeper, pre-mining sediment layers of cores taken from Coeur d'Alene Lake. In sediments deposited after mining began (i.e., sediments with elevated metals concentrations), they observed a complete absence of structures of biological origin. They suggested three potential causes for the elimination of the sediment fauna, all related to increased mining activity in the basin: high turbidity caused by increased concentrations of suspended sediments in the lake, increased sedimentation, and direct metals toxicity. They concluded that the disappearance of at least part of the benthic macroinvertebrate community was related to mine waste disposal.

Ruud (1996) detected significant differences in the dominant taxa of profundal communities (20 m to 40 m depths) and sublittoral communities (5 m to 10 m depths) between Coeur d'Alene Lake and in Priest Lake, Idaho, an oligotrophic lake of similar size, flow, and parent geology. Profundal communities of Priest Lake were dominated by chironominae (*Microspectra* spp. and *Chironomus* spp.) and sphaeriinae, whereas Coeur d'Alene Lake profundal communities were dominated by nematophora, tricladidae, and oligochaetae. Sublittoral communities in Priest Lake were dominated by chironominea and tanypodinae, whereas Coeur d'Alene Lake sublittoral communities were dominated by amphipoda, isopoda, tanypodinae, and oligochaetae. Ruud (1996) reported a positive correlation between zinc concentrations in water and total abundance, total biomass, taxa richness, and mean diversity, as well as between lead concentrations in water and total abundance and total biomass. Ruud did not measure sediment metal concentrations, however, and thus did not explore relationships between sediment concentrations and invertebrate measures.

The available data suggest that benthic macroinvertebrate communities in Coeur d'Alene Lake are significantly different from communities in lakes with no metal enrichment and that deposition of mining related wastes has adversely affected the benthic macroinvertebrate community. Concentrations in lake bed sediments greatly exceed toxicity thresholds (Figure 5-5 and Table 5-4, Chapter 5). The reduced density of invertebrates downgradient of the Coeur d'Alene River mouth relative to densities upgradient and the differences in the Coeur d'Alene Lake community relative to reference areas are consistent with the conclusion that metals in sediments are adversely affecting the invertebrate community.

Summary

In summary, historical studies of benthic macroinvertebrate communities in the Coeur d'Alene River basin show the following:

- Measurements of surface water metal concentrations confirm that the invertebrate communities downstream of mining activity are exposed to greatly elevated concentrations of metals.

- Before the late 1960s, invertebrates were virtually absent from the South Fork Coeur d'Alene and Coeur d'Alene rivers downstream of mining activity, compared with diverse communities upstream. Biological activity in Coeur d'Alene Lake sediment appears to have ceased with the onset of releases of mining-related wastes into the lake.

- The construction of tailings retention ponds in the late 1960s and other reductions in direct mine waste discharges in the 1970s resulted in an improvement in the benthic macroinvertebrate communities in areas downstream of mining activity. However, communities of the South Fork Coeur d'Alene River and its tributaries, the mainstem Coeur d'Alene River, and Coeur d'Alene Lake remained characteristic of metals-impacted systems, with reductions in abundance, taxa richness, and metal-sensitive taxa. Community effects continued in the South Fork Coeur d'Alene River and its tributaries at least through the early 1990s.

8.4.2 Supplemental Trustee Study

In 1996 the Trustees conducted a supplemental invertebrate community survey in the Coeur d'Alene River basin. The objective of the study was to supplement the existing historical data on invertebrate communities with more recent data and with data from tributaries for which historical data are not available.

The 1996 macroinvertebrate sampling was conducted at 25 sites, including 2 sites on the South Fork Coeur d'Alene River upstream of Canyon Creek; 3 sites on the South Fork Coeur d'Alene downstream of Canyon Creek; 15 South Fork, North Fork, and mainstem Coeur d'Alene River tributaries; and 5 sites on the St. Regis River (R2 Resource Consultants, 1997; Woodward et al., 1997). The sampling locations were selected to achieve consistency between sites with respect to habitat type and hydraulic parameters (Woodward et al., 1997). Invertebrate sampling was conducted by placing three artificial habitat substrates at each location from July 10-12, 1996, to August 20-24, 1996. The samplers were then removed, placed in glass jars, and stored in 70% ethanol for preservation. At the laboratory, samples were sorted and identified to the genus level. Habitat and water quality measurements were also made at the invertebrate sampling locations.

For the South Fork Coeur d'Alene River sites downstream of Canyon Creek, two types of reference sites were sampled: (1) sites on the South Fork Coeur d'Alene River upstream of Canyon Creek (two locations), and (2) sites on the St. Regis River (five locations). For the Canyon and Ninemile Creek sites downstream of mining activity, reference sites include one location on Canyon Creek upstream of mining activity, and six locations on other tributaries in the basin that are relatively unaffected by mining.

Benthic community survey results are shown in Figure 8-4 for the South Fork Coeur d'Alene River and reference areas for the South Fork Coeur d'Alene River. Mean total taxa richness at the three South Fork Coeur d'Alene River stations downstream of mining activity was 7.3, 8.7, and 10.0. In contrast, taxa richness at the two South Fork Coeur d'Alene River locations upstream of mining activity was 14.0 and 17.5, indicating a reduction in taxa richness downstream of mining activity. Mean mayfly taxa richness at the three downstream South Fork Coeur d'Alene River stations was 0.7, 1.3, and 1.3, compared with 3.0 and 5.5 at the upstream South Fork Coeur d'Alene River locations. These data indicate that both total taxa richness and mayfly taxa richness were reduced in the South Fork Coeur d'Alene River downstream of mining activity.

Figure 8-5 shows the percent of the sampled invertebrates that are mayflies (order Ephemeroptera) within the South Fork of the Coeur d'Alene River. As discussed previously, most mayflies are relatively sensitive to metal pollution, and decreases in mayflies are indicative of metals effects on the benthic macroinvertebrate community. The figure shows that the percent of mayflies decreases with distance downstream in the South Fork Coeur d'Alene River, from a mean of 30.8% at the most upstream location to 0.4% at the most downstream location (R2 Resource Consultants, 1997). In contrast, the percent of mayflies in the St. Regis River is relatively constant with distance downstream (R2 Resource Consultants, 1997), indicating that

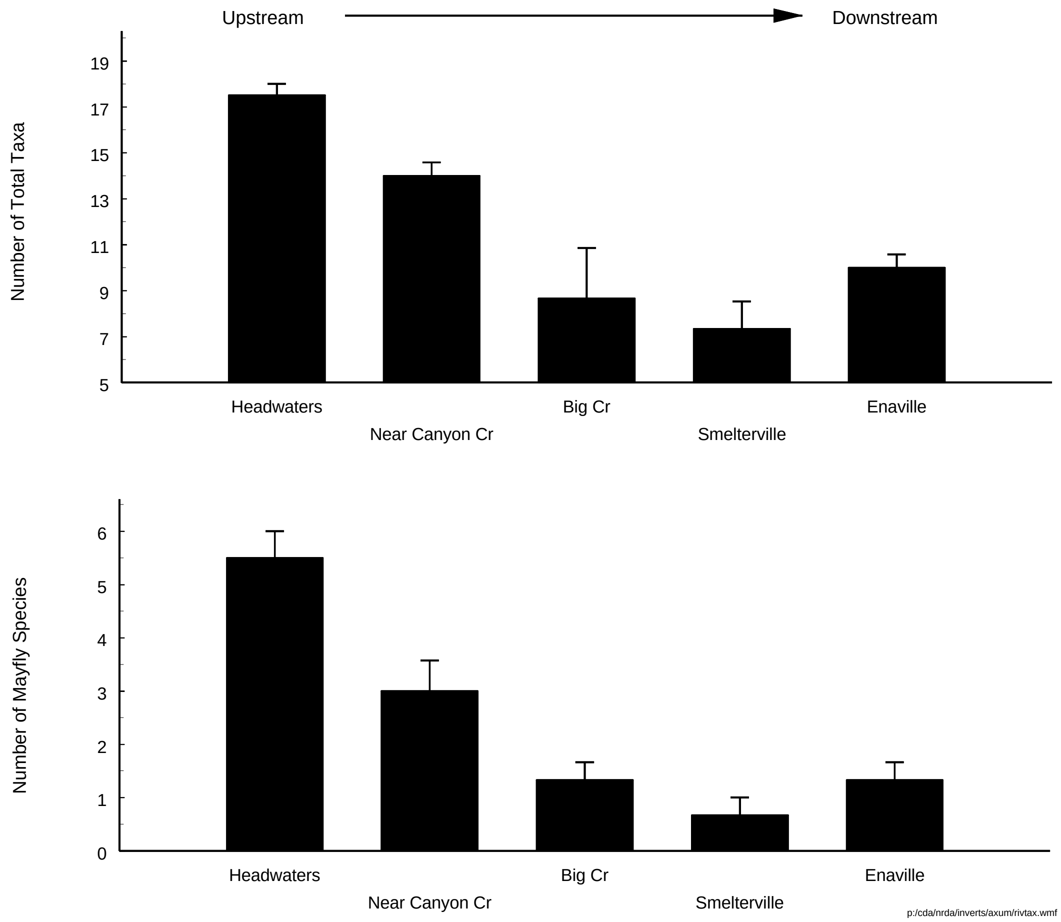

Figure 8-4. Total taxa richness (top panel) and mayfly taxa richness (bottom panel) measured in 1996 in the South Fork Coeur d'Alene River. Bars are means, vertical lines are means plus one standard error. Source: Data from R2 Resource Consultants (1997) and Woodward et al. (1997).

absent mining impacts, percent of mayflies should also remain relatively constant with distance downstream in the South Fork Coeur d'Alene River. The loss of mayflies in the South Fork Coeur d'Alene River corresponds with an increase in diptera larvae, particularly midges (chironomidae) and blackflies (simuliidae) (R2 Resource Consultants, 1997), many species of which are relatively tolerant of metals (McGuire, 1999). Thus the observed shift in the benthic macroinvertebrate community from metals-sensitive taxa to metals-tolerant taxa from upstream areas to downstream areas is consistent with metals causing the community change.

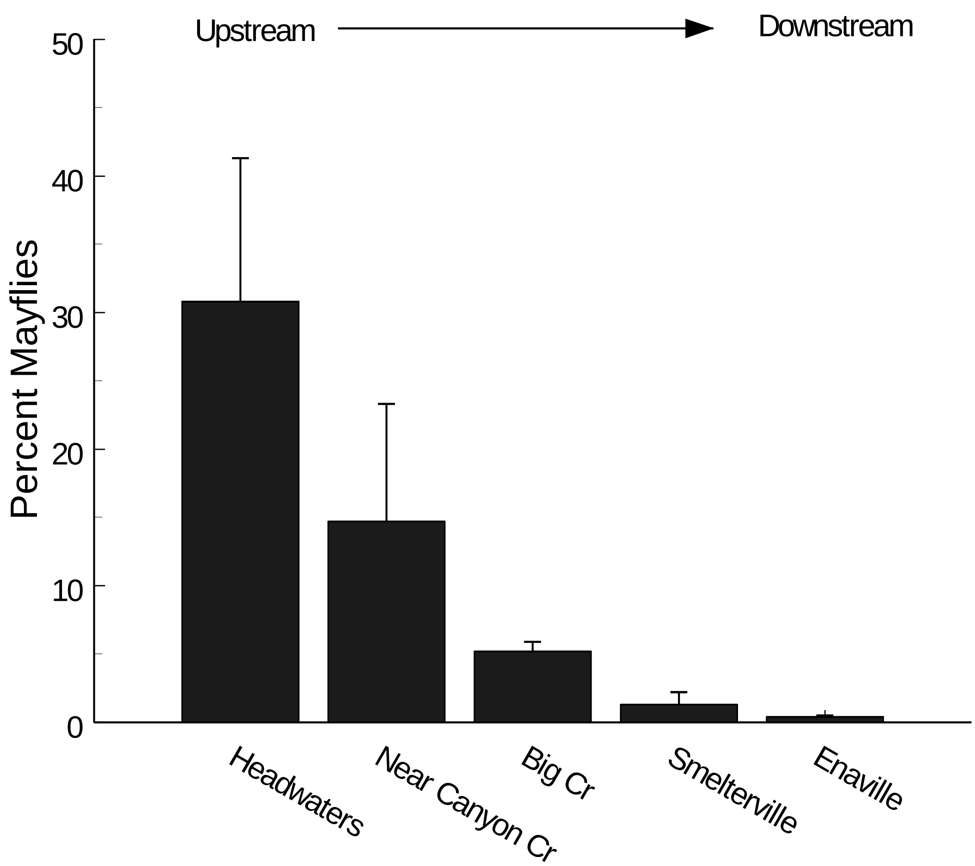

Figure 8-5. Percent mayflies in 1996 in the South Fork Coeur d'Alene River. Bars are means, vertical lines are means plus one standard error.
Source: Data from R2 Resource Consultants (1997) and Woodward et al. (1997).

Figure 8-6 shows the community composition results for Canyon and Ninemile creeks and their reference sites. As in the South Fork Coeur d'Alene River, total taxa richness and mayfly taxa richness are lower in Canyon and Ninemile creeks downstream of mining activity compared with upstream Canyon Creek and with other tributary reference sites. The reduction is greater for mayfly taxa richness, with Canyon and Ninemile creeks downstream sites having 0.33, 1.33, and 1.33 mean mayfly species present, compared with 4.0 at the upstream Canyon Creek site and 3.0 to 4.7 at other reference tributary sites. The communities in Ninemile Creek and downstream Canyon Creek are dominated by metals-tolerant species. Therefore, these data demonstrate that the invertebrate communities in Canyon and Ninemile creeks downstream of mining activity are adversely affected compared with reference areas.

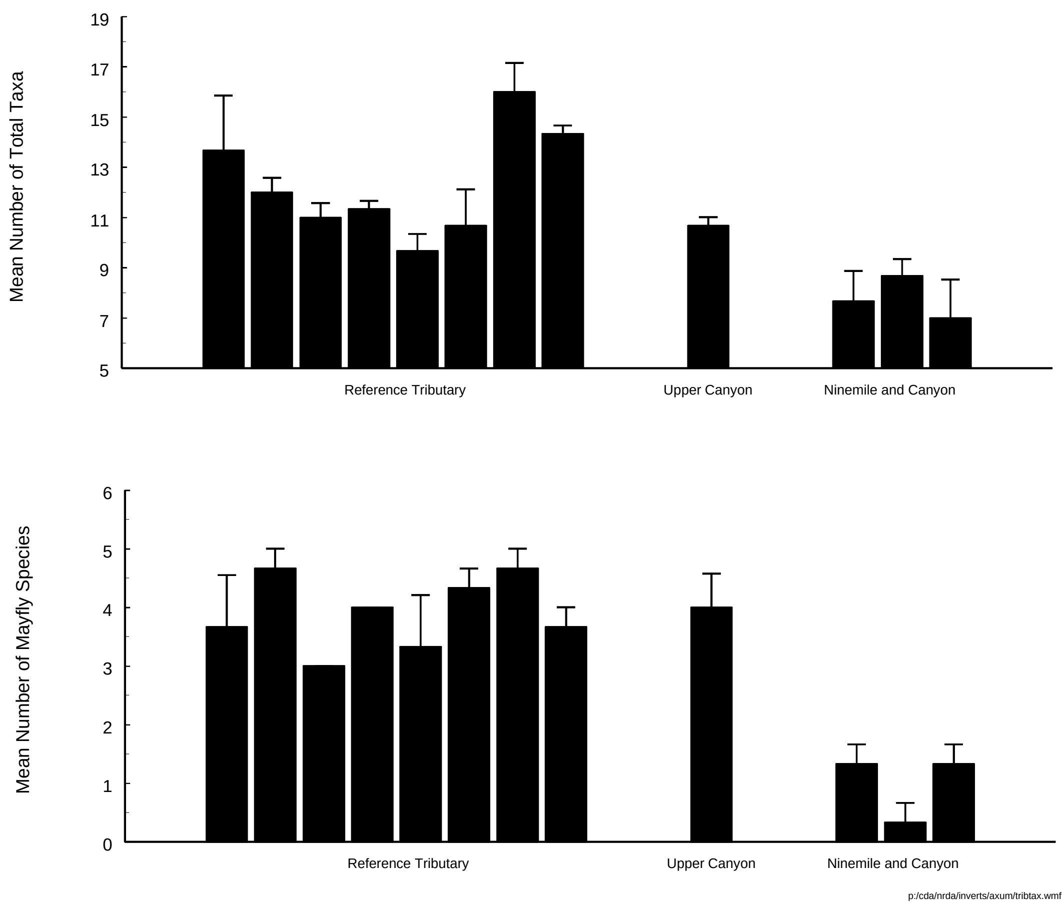

Figure 8-6. Total taxa richness (top panel) and mayfly taxa richness (bottom panel) measured in 1996 in Canyon and Ninemile creeks and in reference areas. Bars are means, vertical lines are means plus one standard error.
Source: Data from R2 Resource Consultants (1997) and Woodward et al. (1997).

Figure 8-7 shows mean total taxa richness and mayfly species richness plotted against dissolved zinc concentrations for all sites sampled. Figure 8-6 shows that at all locations with dissolved zinc greater than approximately 300 µg/L, total taxa richness does not exceed 10. At sites with lower zinc concentrations, taxa richness ranges up to approximately 18. A similar but more pronounced pattern is evident with mayfly taxa richness and dissolved zinc. Mean mayfly taxa richness at all sites with greater than 1,000 µg/L Zn is less than 1.5. Mean mayfly species richness is between 2.0 and 6.5 for sites with zinc concentrations of less than approximately 500 µg/L zinc. These data show that the observed adverse effects on the benthic macroinvertebrate communities are associated with elevated concentrations of hazardous metals.

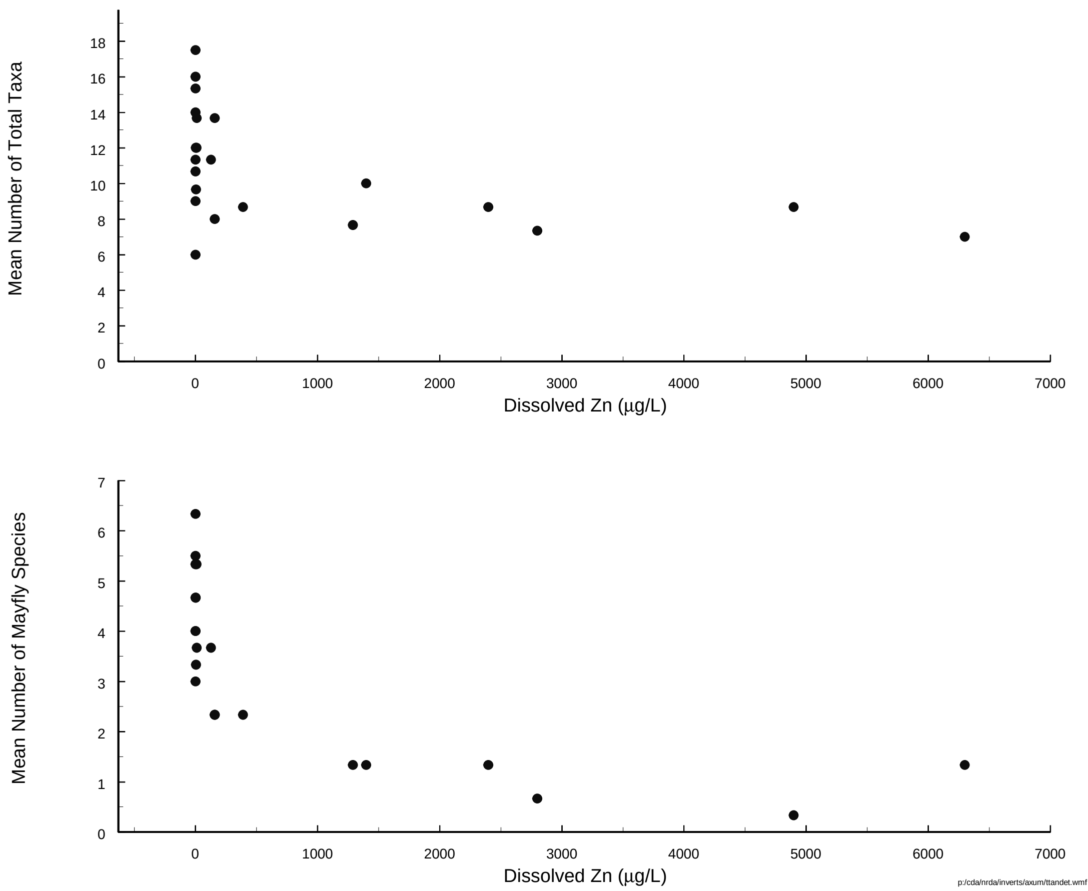

Figure 8-7. Dissolved zinc versus total taxa richness (top panel) and mayfly taxa richness (bottom panel), all 1996 sampling sites combined.
Source: Data from R2 Resource Consultants (1997) and Woodward et al. (1997).

8.4.3 Summary of Community Studies

No or very few invertebrates were present in the South Fork Coeur d'Alene and Coeur d'Alene rivers until the early 1970s, soon after construction of tailings ponds reduced direct discharge of tailings to the system. The invertebrate community of Coeur d'Alene Lake was also historically depauperate. The invertebrate community improved slightly through the early 1980s following the reductions in metal loadings, but the community in the South Fork Coeur d'Alene and Coeur d'Alene rivers remained severely affected. Only a few metal-tolerant species were able to survive, and metal-sensitive species (such as mayflies) were largely absent. Surveys in the South Fork Coeur d'Alene and Coeur d'Alene rivers through the early 1990s have continued to show a community characteristic of an aquatic ecosystem impacted by metals, with metal-sensitive taxa absent or reduced in number.

The results of a supplemental study by the Trustees in 1996 are consistent with the historical data. The benthic macroinvertebrate communities in the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, and the mainstem Coeur d'Alene River downstream of mining activity are reduced in total taxa richness and mayfly species richness compared with reference areas. Reductions in these community structure measures are consistent with adverse effects from metal toxicity. Dissolved zinc concentrations measured during the supplemental study show that effects on the benthic macroinvertebrate community are associated with elevated concentrations of zinc.

8.5 INJURY DETERMINATION

This section presents the determination of injury for benthic macroinvertebrates in the Coeur d'Alene River basin. The injury definitions for which injuries were tested and the lines of evidence available for evaluation of injuries are discussed, and alternative causes of adverse effects to benthic macroinvertebrates are evaluated. Finally, the regulatory determination of injury is presented.

8.5.1 Injury Definitions

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

- death [43 CFR § 11.62 (f)(4)(i)]
- behavioral avoidance [43 CFR § 11.62 (f)(4)(iii)(B)]
- physical deformation [43 CFR § 11.62 (f)(4)(vi)(A)].

Death and behavioral avoidance are manifested as changes in the benthic macroinvertebrate community structure. Studies have shown that the community structure response to metals toxicity can involve both mortality and invertebrate avoidance. Invertebrate avoidance occurs primarily as an increase in invertebrate drift (Brittain and Eikeland, 1988).

8.5.2 Lines of Evidence

Comparison of Toxicity Thresholds with Surface Water and Sediment Data

As discussed in Chapter 7, the U.S. EPA has developed aquatic life criteria (ALC) for the protection of aquatic biota (Stephen et al., 1985). The analysis presented in Chapter 7 demonstrates that ALC exceedences are observed throughout the Coeur d'Alene River basin downstream of mining activity. The frequency of exceedences and the magnitude of the exceedences provide evidence of the likelihood of adverse toxic effects of metals to benthic macroinvertebrates. Although the cadmium, lead, and zinc ALC are based in part on results for invertebrate species, most of the tests used in the ALC development are based on toxicity to fish species (U.S. EPA, 1987). Nevertheless, available data on the toxicity of metals to benthic communities indicate that toxicity tends to occur at concentrations close to the ALC. These studies include controlled laboratory studies, in which transplanted invertebrate communities are exposed to metals (Selby et al., 1985; Clements et al., 1988), and field studies where community-level effects are linked to metals exposure (Leland et al., 1989; Clements et al., 1990). Therefore, the ALC can be used as reasonable estimates of literature-based concentrations above which toxicity can be expected.

EVS (1997) conducted a series of site-specific tests that they concluded may suggest that toxicity to Coeur d'Alene invertebrates begins to occur at metal concentrations well above ALC values. They conducted toxicity tests using invertebrates collected from the South Fork Coeur d'Alene River upstream of Mullan. The invertebrates were exposed to South Fork Coeur d'Alene River water spiked with cadmium, lead, or zinc. However, the thresholds produced from these tests are not appropriate as potential injury thresholds for Coeur d'Alene basin invertebrates for the following reasons:

- The test results are not indicative of toxicity to metal-sensitive invertebrate species. For example, of the five invertebrate species used in the lead toxicity testing, the most sensitive species was the mayfly *Baetis tricaudatus* (EVS, 1997). Although many mayfly species are sensitive to metals, *Baetis tricaudatus* are known to be relatively tolerant of metal toxicity compared to other mayflies. For example, downstream of mining impacts in the Clark Fork River, Montana, *Baetis tricaudatus* are more tolerant of elevated metal concentrations than any other mayfly species (McGuire, 1999). Roline (1988) found *Baetis* both upstream and downstream of mining inputs into the Arkansas River (Colorado) and concluded that they are "quite tolerant of heavy metals pollution." Clements (1994) and Kiffney and Clements (1994) report similar findings for *Baetis tricaudatus* in the Arkansas River. In fact, *Baetis tricaudatus* was one of the first species to recolonize the South Fork Coeur d'Alene River in the early 1970s, when only a few invertebrate species could survive in the river (Stokes and Ralston, 1972; Savage and Rabe, 1973; Funk et al., 1975). Therefore, the tests did not use species representative of metal-sensitive invertebrates.

- The tests used invertebrates collected from the South Fork Coeur d'Alene River in areas downstream of mining activity. Therefore, the organisms used in the tests may have been preselected for metal tolerance.

- Several of the tests did not show a consistent dose-response relationship, making their interpretation difficult.

Nevertheless, metal concentrations in areas of the South Fork Coeur d'Alene and Coeur d'Alene rivers downstream of mining activity still exceed the invertebrate toxicity thresholds from EVS (1997). Figure 8-8 compares dissolved cadmium and zinc concentrations against EVS invertebrate toxicity thresholds. The surface water data plotted in Figure 8-8 are the same data used in Chapter 7 to evaluate potential toxicity to fish. The threshold concentration plotted for cadmium is the concentration observed to cause 40-50% mortality to *Baetis tricaudatus* in site water with added cadmium (EVS, 1997). For zinc, the threshold concentration plotted in Figure 8-8 is the calculated LC50 for the snail *Gyraulus* in site water with added zinc (i.e., the concentration estimated to cause mortality to 50% of the organisms). Figure 8-8 shows that dissolved zinc concentrations in the South Fork Coeur d'Alene downstream of Canyon Creek and in Canyon, Ninemile, and Pine creeks downstream of mining activity exceed the concentration estimated to cause approximately 50% mortality to the test organisms. Dissolved cadmium concentrations in Canyon and Ninemile creeks exceed the EVS thresholds for 40-50% mortality to *Baetis tricaudatus*. Therefore, measured metal concentrations exceed even the EVS thresholds, which most likely are too high to be protective of the invertebrate community.

Although the U.S. EPA has not developed sediment criteria similar to surface water ALC, other agencies have developed sediment toxicity screening thresholds, including the National Oceanic and Atmospheric Administration (NOAA) (Long and Morgan, 1991) and the Ontario Ministry of the Environment (Persaud et al., 1993). These thresholds are based primarily on sediment toxicity to benthic invertebrates observed in the field, and represent concentrations above which toxicity to at least some benthic invertebrates can be expected. Chapter 5 presented a comparison of cadmium, lead, and zinc concentrations in the Coeur d'Alene River and Coeur d'Alene Lake with sediment toxicity thresholds. The comparison shows that hazardous metal concentrations in sediments of the lower Coeur d'Alene River basin are many times greater than sediment toxicity thresholds.

In conclusion, comparison of surface water cadmium, lead, and zinc concentrations with ALC and site-specific threshold concentrations developed for relatively metal-tolerant invertebrates, and comparison of sediment cadmium, lead, and zinc concentrations with sediment toxicity, demonstrate the likelihood that metals concentrations in the Coeur d'Alene basin are sufficient to cause toxicity to benthic macroinvertebrates.

Site-Specific Toxicity Data

Site-specific invertebrate toxicity data include tests conducted using water collected from areas downstream and upstream of mining activity. These tests have confirmed that water from the South Fork Coeur d'Alene and mainstem Coeur d'Alene rivers downstream of mining activity is toxic to invertebrates in controlled laboratory studies (Hornig et al., 1988; Dames & Moore, 1989). In one of the studies (Dames & Moore, 1989), dilutions of 0.1 to 6.1% South Fork Coeur d'Alene River water with clean water caused lethality to 50% of the test organisms. The test organisms used in the two studies, the waterflea species *Daphnia magna* and *Ceriodaphnia dubia,* are among the more sensitive invertebrate species to cadmium and zinc toxicity, although

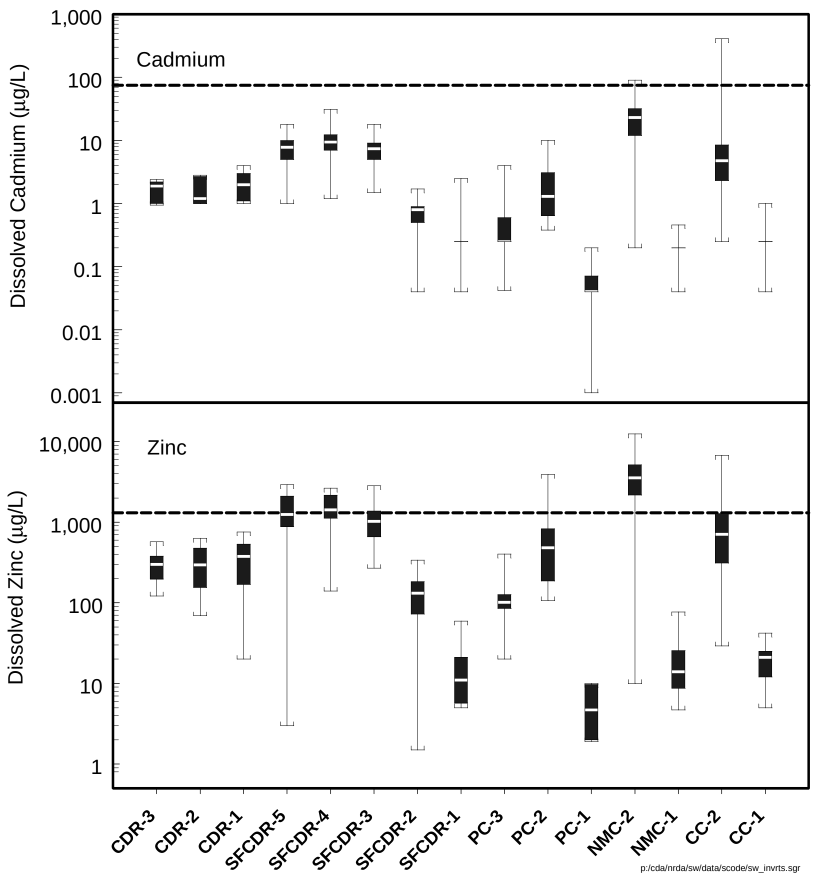

Figure 8-8. Dissolved cadmium and zinc concentrations in the Coeur d'Alene River basin (median value and data maximum) and invertebrate adverse effects concentrations from site-relevant bioassays. Horizontal dashed lines represent concentration observed to cause 40-50% mortality to *Baetis tricaudata* (for Cd) and the calculated LC50 for the snail *Gyraulus* (for Zn). Water chemistry median and maximum values from Chapter 4 (Tables 4-11 and 4-13) are presented. Boxes show the data range, median, and 25th and 75th percentiles of the data.
Source: Data from Ridolfi Engineers Inc. (1999), data presented in Chapter 4, and EVS (1997).

single-species data for invertebrates are limited (U.S. EPA, 1985, 1987). Therefore, these site-specific studies provide direct and compelling evidence that metals are present in the South Fork Coeur d'Alene and Coeur d'Alene rivers at concentrations sufficient to cause toxicity at least to metals-sensitive invertebrates.

Community Data

The results of the benthic macroinvertebrate community studies presented above show that community structures in the South Fork Coeur d'Alene River, the Coeur d'Alene River, Canyon Creek, and Ninemile Creek downstream of mining activity are different from those in areas unimpacted by mining. Specifically, metals-sensitive invertebrates are absent or reduced, and communities are dominated by metals-tolerant species. This shift is indicated by decreases in the total number of invertebrate taxa and the number of mayfly species present in the mining affected areas. Thus, the changes in the benthic macroinvertebrate communities in these areas are consistent with injury resulting from exposure to metals. The benthic invertebrate community of Coeur d'Alene Lake has also been altered compared to reference areas.

8.5.3 Causation Evaluation

In this section, the extent to which the evidence shows that the observed adverse effects on macroinvertebrates resulted from metals exposure, as opposed to other possible causes, is discussed.

Comparison of surface water and sediment metal concentrations in the Coeur d'Alene River basin with ALC and sediment toxicity thresholds demonstrates that Coeur d'Alene River basin concentrations are well above those shown to cause toxicity under laboratory conditions and at other sites. Therefore, a conclusion that metals are the causative factor for the observed effects is consistent with the scientific literature.

The site water toxicity tests demonstrate that site water is indeed toxic to invertebrates. Two independent studies, using water collected from different time periods, both found that water from the South Fork Coeur d'Alene and Coeur d'Alene rivers was highly toxic to invertebrates (Hornig et al., 1988; Dames & Moore, 1989). Metal concentrations measured during the tests were well above the ALC, and well above reference area concentrations. No other possible explanations for the observed toxicity were reported by the study authors. Therefore, these studies provide strong evidence that metals were responsible for the toxicity observed.

The benthic macroinvertebrate community data are consistent with metals as the cause of the adverse effects. The observed pattern of loss of metals-sensitive species and dominance by metals-tolerant species is typical of aquatic systems contaminated by metals. The community results are also consistent across studies, with several independent investigators finding the same conclusions. Similarly, the chironomid mouthpart deformities observed in the Coeur d'Alene River can be caused by exposure to elevated concentrations of lead and zinc in sediment (Thornberg, 1995; Martinez, 2000). The elevated rates of mouthpart deformities in chironomid populations from Smelterville to Harrison are supporting evidence of ongoing invertebrate exposure to metals and adverse effects.

In addition, the temporal trend in the benthic community structure is also consistent with metals as the cause. Soon after direct discharges of metals to the system declined in the 1970s, the benthic macroinvertebrate community improved, although it has remained impacted. Similarly, the disappearance of evidence of biological activity in Coeur d'Alene Lake sediment corresponds to the onset of mining waste accumulation in the sediment.

Another possible causal factor contributing to the observed benthic community alterations is habitat degradation. As part of the Trustee's supplemental study in 1996, stream habitat measurements were taken at locations near where the invertebrate community was sampled (R2 Resource Consultants, 1997). The overall aquatic habitat quality was summarized using U.S. EPA's Rapid Bioassessment Protocol (RBP) scores (Plafkin et al., 1989), in which higher scores mean better overall habitat quality. The overall RBP scores are based on scores for nine variables: bottom substrate and available cover, substrate embeddedness, flow/velocity, channel alteration, bottom scouring and deposition, pool/riffle diversity, bank stability, bank vegetation, and streamside cover. The results of the habitat assessment show that the overall habitat quality in the South Fork Coeur d'Alene River downstream of Canyon Creek (mean RBP score of 74) was lower than in the South Fork Coeur d'Alene River upstream of Canyon Creek and in the St. Regis River (mean RBP score of 108) (R2 Resource Consultants, 1997; Woodward et al., 1997). This decrease in habitat quality most likely would also affect the benthic macroinvertebrate community in the South Fork Coeur d'Alene River downstream of mining activities.

However, mining activities are at least in part the cause for the decrease in invertebrate habitat quality in the downstream areas of the South Fork Coeur d'Alene River. Many of the habitat parameters in the RBP score are dependent on stable riparian vegetation communities. Healthy riparian vegetation decreases bank erosion, minimizes channelization, and provides woody debris cover (Plafkin et al., 1989). These benefits are directly accounted for in many of the RBP parameters, such as streamside cover, bank vegetation, bank stability, channel alteration, bottom substrate and available cover, and substrate embeddedness. The analysis presented in Chapter 9 shows that mining-related hazardous substances have caused a severe reduction in riparian vegetative cover along the South Fork Coeur d'Alene river downstream of Canyon Creek. For example, in field vegetation surveys conducted by the Trustees, bare ground was the dominant cover type at 50% of the South Fork Coeur d'Alene River riparian sites, compared with 0% at the reference sites (Section 9.5.3). This lack of vegetation is a result of phytotoxicity caused by hazardous metals (Section 9.5.5). Therefore, the reduction in habitat quality in the South Fork Coeur d'Alene River downstream of mining activities is associated with the mining-caused loss of riparian vegetation.

Similarly, the increased sediment and tailings-contaminated sediment loads and increased sediment deposition on the Coeur d'Alene River beds and banks, lateral lakes beds, and Coeur d'Alene Lake bed probably historically reduced physical habitat quality as well as chemical habitat quality.

8.5.4 Regulatory Determination

Benthic macroinvertebrate resources have been and are injured in the South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek as a result of releases of hazardous substances from mining and mineral processing operations.

Specifically, benthic macroinvertebrate communities downstream of mining activity are altered by exposure to metals. The alteration results from a combination of the following types of injury:

- death [43 CFR § 11.62 (f)(4)(i)], as confirmed by bioassays using site water [43 CFR § 11.62 (f)(4)(i)]

- behavioral avoidance [43 CFR § 11.62 (f)(4)(iii)(B)], as confirmed by alterations in benthic community structure.

Benthic macroinvertebrates are important food sources for many fish species, including trout and sculpin, and serve important roles in the energy and nutrient cycling of aquatic systems. The injury to the benthic macroinvertebrate resources has resulted in a community dominated by metals-tolerant species, with metals-sensitive species absent or greatly reduced.

Historical data show that the benthic macroinvertebrate communities of the lower mainstem Coeur d'Alene River and Coeur d'Alene Lake have been injured. However, recent data were not available to evaluate whether injuries to the macroinvertebrate communities in these areas continue to the present.

In addition, although the data are less conclusive, physical deformation injuries [43 CFR § 11.62 (f)(4)(vi)(A)], specifically, chironomid mouthpart deformities resulting from metals exposure, may be ongoing in the South Fork and mainstem Coeur d'Alene Rivers.

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Next

CHAPTER 9
RIPARIAN RESOURCES

9.1 INTRODUCTION

This chapter presents the determination of injury to riparian resources. Riparian resources include floodplain soils and sediments, riparian vegetation, and wildlife habitat. These resources, together with geologic, surface water, and groundwater resources, and the wildlife dependent upon the riparian zone, constitute the riparian ecosystem.

The information presented in this chapter and previous chapters demonstrates that riparian resources of the Coeur d'Alene River basin have been injured by releases of hazardous substances from mining and mineral processing operations. Specifically:

- Sufficient concentrations exist in pathway resources to transport hazardous substances to floodplains of the Coeur d'Alene River basin.

- Concentrations of hazardous substances in exposed floodplain soils of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River are significantly greater than concentrations in reference area soils. Concentrations of hazardous substances in lower Coeur d'Alene River basin sediments are also substantially elevated relative to the reference soils.

- Floodplain soils of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River are phytotoxic (i.e., cause toxicity to plants) relative to control soils. Plant growth performance in field-collected assessment soils was measured under controlled laboratory conditions. Plant growth in contaminated soils was reduced relative to control soils, and plant growth was significantly negatively correlated with concentrations of hazardous substances in the soils.

- Concentrations of hazardous substances in floodplain soils of assessment reaches exceed phytotoxic thresholds identified in the literature, and the observed reductions in plant growth are consistent with the phytotoxic effects of zinc and other heavy metals reported in the literature.

- In the riparian zones of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River, extent of vegetation cover, species richness, and vegetation structural complexity are significantly negatively correlated with concentrations of hazardous substances in soils; percent cover of bare ground is significantly positively correlated with concentrations of hazardous substances. In other words, increased concentrations of soil metals were related to increased bare ground and reduced vegetation.

- Phytotoxic concentrations of hazardous substances in floodplain soils have resulted in significant and substantial reductions in riparian vegetative cover and an increase in the amount of bare ground in the riparian zones of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River.

- The sources and pathways of metals to floodplain soils of Pine and Moon creeks are similar to the sources and pathways of metals to floodplain soils of Canyon and Ninemile creeks and the South Fork Coeur d'Alene River, and the concentrations of hazardous substances are similar to concentrations determined to be phytotoxic on Canyon and Ninemile creeks and the South Fork Coeur d'Alene River. Therefore, injury to riparian resources of Pine and Moon creeks is inferred to have resulted from phytotoxic concentrations of hazardous substances in floodplain soils.

- Soil phytotoxicity and reductions in vegetation cover have resulted in deterioration of ecological functions, including habitat for all biological resources that are dependent on riparian habitats in the basin; growth media for plants and invertebrates; primary and secondary productivity, carbon storage, nitrogen fixing, decomposition, and nutrient cycling; soil organic matter and allocthonous energy (i.e., carbon from decomposing plant matter) to streams; geochemical exchange processes; food and cover (thermal cover, security cover) for fish, migratory birds, and mammals; feeding and resting areas for fish, migratory birds, and mammals; the migration corridor provided by the riparian zone; habitat for macroinvertebrates; soil/bank stabilization and erosion control; and hydrograph moderation.

9.2 RIPARIAN RESOURCES ASSESSED

9.2.1 Definition of Riparian Resources

Riparian resources include the floodplain soils and sediments, riparian vegetation, and the wildlife that inhabits the riparian zone. Together, these resources and the geologic, surface, and groundwater resources that constitute the riverine environment form the riparian ecosystem.

The riparian zone is the transitional area between the aquatic riverine environment and the terrestrial upland environment. Riparian zones are among the most biologically, chemically, and physically diverse, dynamic, and complex terrestrial ecosystems (Naiman et al., 1993; Naiman and Décamps, 1997; Hedin et al., 1998; Lyon and Sagers, 1998). The riparian zone regulates the flow of energy and materials between the terrestrial and aquatic environments, and between upstream and downstream reaches of streams (Naiman et al., 1993; Naiman and Décamps, 1997). Riparian zones support rich assemblages of plant and animal species (Mosconi and Hutto, 1982; Hansen et al., 1990; Décamps, 1993; Naiman et al., 1993; Moseley and Bursik, 1994; Lyon and Sagers, 1998). Natural riparian zones buffer erosive stream energy, store flood waters and reduce peak flows, and sequester and reduce bioavailable concentrations of pollutants (Karr and Schlosser, 1978; Naiman and Décamps, 1997).

Riparian vegetation helps stabilize the streambanks through anchoring by root networks, and it reduces water velocity by increasing surface roughness (Gregory et al., 1991; Naiman and Décamps, 1997). Riparian vegetation intercepts and stores energy from solar radiation, which influences stream temperature and serves as a source of energy (detrital inputs) for adjacent and downstream aquatic biota (Gregory et al., 1991). Riparian soils, soil biota, and vegetation together regulate the supply of nutrients to the aquatic ecosystem. Riparian soil and vegetation communities help maintain surface and shallow groundwater quality through physical filtering of sediment and attached nutrients by vegetation, plant uptake of nutrients or pollutants, and biotically controlled reactions in soils that release excess nutrients, particularly nitrogen, as gases to the atmosphere (Karr and Schlosser, 1978; Lowrance et al., 1984; Peterjohn and Correll, 1984; Daniels and Gilliam, 1996; Hedin et al., 1998).

Riparian zones typically support highly diverse and productive ecological communities (Décamps, 1993; Naiman and Décamps, 1997). Riparian habitat provides critical connectivity between upland and aquatic habitats for plant and animal species (Mosconi and Hutto, 1982; Doyle, 1990; Knopf and Samson 1994; Sanders and Edge, 1998; Skagen et al., 1998). Vegetative overhang provides fish food (detritus) and cover, and shades the water from solar radiation (Naiman and Décamps, 1997). The abundance of water and forage and the compositional and structural diversity of riparian vegetation communities support wildlife species in numbers disproportionate to the area of the riparian zone.

9.2.2 Riparian Resources of the Coeur d’Alene River Basin

Riparian resources of the Coeur d’Alene River basin include floodplain soils and sediments; riparian vegetation; habitat provided by riparian vegetation, soils, and sediments; and wildlife dependent on riparian habitat. In the Coeur d’Alene River basin, injuries were assessed in riparian ecosystems downstream of major mining activity on Canyon Creek, Ninemile Creek, Moon Creek, Pine Creek, the South Fork Coeur d’Alene River, and the mainstem Coeur d’Alene River and lateral lakes area (Figure 9-1).

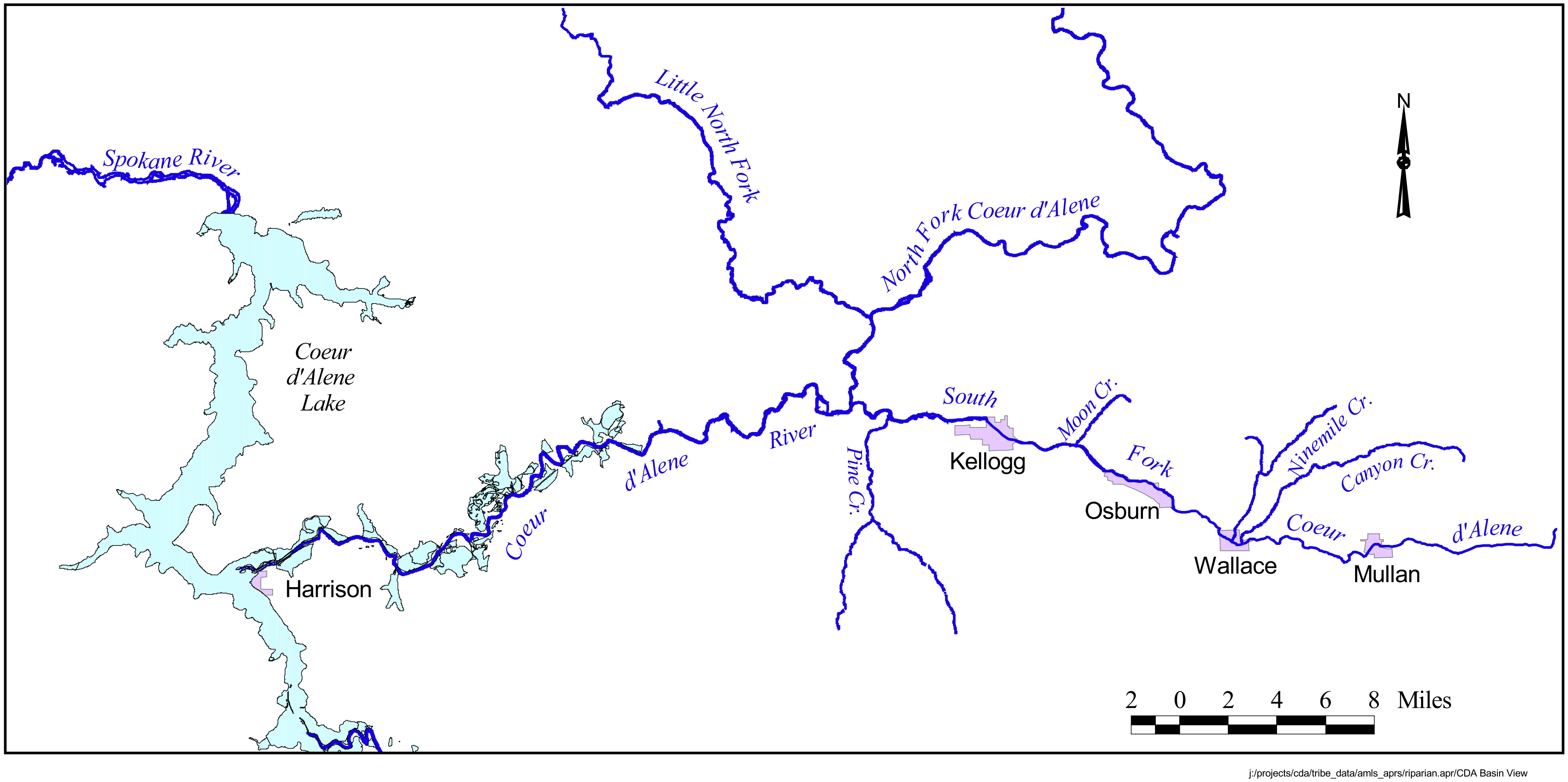

Figure 9-1. Coeur d'Alene River basin.

The South Fork Coeur d'Alene River upstream of Wallace, and Canyon, Ninemile, Moon, and upper Pine creeks flow through steep, narrow canyons with confined channels. These reaches have high gradients, are largely incised, and are channelized in places, either naturally or by roads, railroads, and mining-related disturbances. Downstream of Wallace, the South Fork flows through a broader, U-shaped canyon. Stream and valley gradients downstream of Wallace decrease relative to gradients upstream, and the valley bottom and floodplains widen, although topographic features impose localized channel constrictions. Near Osburn and from Kellogg to Smelterville, the canyon widens further. Within these reaches, the gradient is lower and the floodplain is substantially wider. The riparian zone of the South Fork Coeur d'Alene River downstream of Wallace is modified by industrial, urban, and residential land use. The lower North Fork Coeur d'Alene River, lower Little North Fork of the North Fork Coeur d'Alene River, lower Canyon Creek, and lower Pine Creek also open into U-shaped canyons.

Downstream of the confluence of the South and North Forks, the Coeur d'Alene River is a meandering, low gradient, deep river. The valley opens into a broad alluvial basin, with the floodplain width exceeding one mile in places. The river is bordered by 12 lateral lakes ranging in size from less than 85 acres to over 600 acres (Ridolfi, 1993). Thousands of acres of wetlands are associated with the lateral lakes.

The predominant parent material in the valleys of the South Fork and tributaries of the South Fork is Quaternary alluvium (Derkey et al., 1996). Natural floodplain and low stream terrace soils of the Coeur d'Alene River basin are typically level to nearly level, deep, and very poorly drained to somewhat poorly drained soils formed from mixed alluvium and organic material (U.S. SCS, 1981; 1989). Natural floodplain soils of the Coeur d'Alene River basin, including riparian zones of much of the North Fork Coeur d'Alene River watershed, may support cropland, pasture, woodland, shrubland, or wetlands. However, in the South Fork and mainstem Coeur d'Alene River basins, many of the floodplain and low stream terrace soils are classified as slickens, or tailings that have been mixed with alluvium and deposited along the floodplain (U.S. SCS, 1981; 1989). Slickens contain high concentrations of metals and do not support native or agricultural vegetation (U.S. SCS, 1989). Riparian zones of Canyon Creek, Ninemile Creek, the South Fork Coeur d'Alene River, and patches of floodplain along the mainstem Coeur d'Alene River are devoid of vegetation or support sparse communities with low productivity and diversity.

9.3 INJURY DETERMINATION: INJURY DEFINITION

9.3.1 Background: Effects of Metals on Soils, Plants, Riparian Vegetation, and Riparian Habitat

Soils supply the majority of the mineral nutrients necessary for plant growth. Major nutrients derived from soils or soil processes include nitrogen, phosphorus, sulfur, calcium, magnesium, potassium, and iron. Trace elements in soils that are known to be essential for growth and development of organisms include aluminum, boron, cobalt, copper, iron, manganese, molybdenum, silicon, and zinc. Of the most abundant hazardous substances released from mining related operations in the Coeur d'Alene River basin, copper and zinc are essential plant micronutrients, whereas cadmium and lead have no biochemical role in plants (Kabata-Pendias and Pendias, 1992). All micronutrients are toxic in excess concentrations (Van Assche and Clijsters, 1990), but their toxicity in soils depends on the mobility and phytoavailability of metal cations.

The behavior and phytoavailability of hazardous metals in soils are determined in part by their elemental character and speciation, and by specific properties of the soil. The mobility of trace metals in soils depends on soil processes, including sorption, complexation, precipitation, and occlusion; diffusion into clay minerals; and binding or uptake by organic substances (Kabata-Pendias and Pendias, 1992; Brady and Weil, 1996). These processes are strongly controlled by pH and redox potential, and by the amount of clay and organic matter in the soil (Van Assche and Clijsters, 1990; Kabata-Pendias and Pendias, 1992).

Variability in soil properties, growing conditions, and plant species sensitivity contributes to the specific influence of metal pollutants in soils on plants and on soil services. The same total concentration of metals that is toxic in sandy acid soils may be nontoxic in soils with greater organic carbon content, clay content, carbonates, or iron and manganese hydroxides. As the pH of a soil decreases, cadmium, lead, and zinc concentrations in the soil solution increase, and their mobility and availability to plants increase (Kabata-Pendias and Pendias 1992; Chaney, 1993). Hydrogen ions compete with the metal cations for adsorption on metal binding sites of soils, including clays and humus (Chaney, 1993; Brady and Weil, 1996). Loamy, neutral soils may accumulate high concentrations of metals with few adverse effects, but disruption of chemical balances in metals enriched soils typically results in decreased biological activity and, potentially, saturation of organic and mineral sorption complexes (Tyler et al. 1989; Kabata-Pendias and Pendias, 1992). In soils that contain greater than 20-30% organic matter, large amounts of metals may accumulate with no visible adverse effects to the vegetation (Antonovics et al., 1970).

Plants of different species, and genotypes within species, vary in their ability to absorb trace metals from the same soil environment (Barry and Clark, 1978; MacNicol and Beckett, 1985; Kabata-Pendias and Pendias, 1992). Plants obtain major and trace elements involved in biochemical processes from the soil by both active and passive root uptake. Concentrations of trace elements in plants are often positively correlated with concentrations in soils (Kabata-Pendias and Pendias, 1992). In general, as soil concentrations of trace metals increase, plant tissue concentrations increase. However, above a certain soil or tissue concentration maximum, which varies by species, plant age, and genotype within species, the capacity of a plant to regulate uptake of excess metal contaminants, or of other essential elements in the presence of metal contaminants, is overwhelmed. Shoot and root functions may be inhibited, and uptake of resources from soils may be greatly diminished (Krawczyk et al., 1988). As uptake of resources is reduced, growth is reduced.

At the individual level, phytotoxic responses to heavy metals include stunted shoot growth; stunted, necrotic, chlorotic, or otherwise discolored leaves; and early leaf abscission (Van Assche and Clijsters, 1990; Kabata-Pendias and Pendias, 1992). Roots can exhibit stunted growth, browning or death of the root meristem, and suppressed development of lateral roots (Krawczyk et al., 1988; Kapustka et al., 1995; Rader et al., 1997). Physiological malfunctions include inhibition of photosynthesis, water transport, nutrient uptake, carbohydrate translocation, and transpiration (Carlson and Bazzaz, 1977; Lamoreaux and Chaney, 1977; Clijsters and Van Assche, 1985; Pahlsson, 1989; Tyler et al., 1989; Vasquez et al., 1989; Alloway, 1990b; Davies, 1990; Kiekens, 1990). Metal toxicity is frequently related to inhibition of enzyme synthesis or activity (Tyler et al., 1989; Van Assche and Clijsters, 1990).

Cadmium inhibits the formation of chlorophyll and interferes with photosynthesis; reduces stomatal conductance and transpiration; inhibits enzyme formation and activity; impedes carbohydrate metabolism; and may also reduce the uptake of other metal ions by roots (Clijsters and Van Assche, 1985; Pahlsson, 1989; Sheoran et al., 1990a,b; Kabata-Pendias and Pendias, 1992). In addition, cadmium has been shown to cause changes in xylem tissue and blockages in xylem tubes which transport water to above-ground tissue (Lamoreaux and Chaney, 1977; Pahlsson, 1989). Symptoms of acute cadmium toxicity include leaf discoloration, wilting, stunted growth, and premature leaf abscission (Vasquez et al., 1989; Alloway, 1990a).

Plants exposed to lead may exhibit decreased photosynthetic and transpiration rates (Davies, 1990). The mechanism of photosynthetic and transpiration reduction is believed to be related to changes in stomatal function (Bazzaz et al., 1974). Lead interferes with the synthesis of chlorophyll and other photosynthetic pigments and inhibits root elongation (Pahlsson, 1989). Uptake of lead has also been shown to inhibit chloroplast activity and to interfere with metabolic processes (Clijsters and Van Assche, 1985; Sheoran et al., 1990a,b). In addition, lead inhibits soil organic matter breakdown, litter decomposition, and nitrogen mineralization in soil, thereby reducing soil productivity (Liang and Tabatabai, 1977; Chang and Broadbent, 1982; Davies, 1990).

Zinc function in plants is related to the metabolism of carbohydrates, proteins, and DNA and RNA synthesis (Kabata-Pendias and Pendias, 1992). In excess concentrations, zinc interferes with chlorophyll synthesis and photosynthesis, blocks water transport in xylem and carbohydrate transport in phloem, and inhibits electron transport (Chaney, 1993; Kiekens, 1990; Pahlsson, 1989; Clijsters and Van Assche, 1985). Zinc may also increase the permeability of root membranes, causing leakage of nutrients and disruption of active transport of ions in and out of the plant (Pahlsson, 1989).

At the community level, phytotoxic responses comprise shifts in plant species composition, or in cases of severe toxicity, reductions in vegetative cover or the elimination of vegetation (LeJeune et al., 1996; Galbraith et al., 1995). Reduced growth, photosynthetic efficiency, or nutrient and water uptake will reduce the ability of metals sensitive plants growing in the wild to compete with more tolerant neighboring plants for limiting resources and to resist natural stressors (Beyer, 1988). Species or individuals that are relatively more sensitive to metals contamination will be eliminated, if not through direct toxic effects, then through reduced viability and competitive ability. Cover of more tolerant species or species able to benefit from the reduced competition for water, nutrients, or light, may increase with the elimination of sensitive species. Since sensitivity and tolerance are governed by numerous processes internal and external to the plant (Kabata-Pendias and Pendias, 1992; Tyler et al., 1989), gradients in tolerance and in community level responses to metals contamination are common. Community level changes in vegetation cover, composition, or structure resulting from phytotoxicity are caused by death and competitive displacement of plants with reduced viability.

Phytotoxic concentrations of cadmium, lead, and zinc in soils have been reported as 3 to 8 mg/kg cadmium, 100 to 400 mg/kg lead, and 70 to 400 mg/kg zinc (Alloway, 1990b). Concentration ranges for phytotoxicity are wide because of differences in metal speciation, soil properties, and plant sensitivity, as discussed above. However, existing data from hard rock mine and metal smelting sites throughout North America and the rest of the world confirm that metals in mine wastes, including metals deposited in smelter emissions and metals in tailings, are commonly toxic to plants. Table 9-1 presents examples of sites where adverse population and community level effects on vegetation, and in agricultural areas, reduced crop productivity, have resulted from mining-related metals toxicity in soils.

Few studies have specifically reported toxic concentrations of metals in floodplain soils contaminated by tailings discharge. Table 9-2 presents data from barren or sparsely vegetated tailings and mixed tailings and alluvium deposits along the Clark Fork River, Montana (LeJeune et al., 1996; Rader et al., 1997) the Conwy River, North Wales (Johnson and Eaton, 1980); and Soda Butte Creek, Montana and Wyoming (Stoughton and Marcus, 2000). The floodplains of the Clark Fork River are contaminated by tailings released from copper mining, and the floodplains of the Conwy River by tailings released from lead-zinc mining. Soda Butte Creek floodplains are contaminated by copper-rich tailings. Although the metals or combination of metals causing the toxicity in each case may differ, the ranges presented for cadmium, lead, and zinc are similar to or lower than ranges of these metals in Coeur d'Alene River basin floodplain soils and sediments (Tables 2-9 through 2-11 and 2-14 through 2-17, Chapter 2, Hazardous Substance Sources). Moreover, these studies provide evidence that metals in floodplain soils are toxic to plants and modify vegetation community characteristics at sites other than the Coeur d'Alene River basin. Devegetation or reduced diversity and productivity of mixed alluvium and tailings in floodplains downstream of mine sites is not unusual.

Table 9-1
Examples of Individual and Community-Level Phytotoxic Effects of Metals Toxicity from Mine Wastes on Vegetation

Mine/Smelter Site	Examples of Phytotoxic Effects on Vegetation
Sudbury Smelter, Ontario (Freedman and Hutchinson, 1979; Lozano and Morrison, 1981)	Devegetation; reduced productivity and diversity; disruption of hardwood nutrition by SO_2, Ni, Cu; colonization by metals tolerant grasses
Palmerton Smelter, PA (Beyer, 1988; Chaney, 1993)	Forest dieback/prevention of regrowth; inhibition of seedling root growth; stunting; changes in species composition and age structure; elimination of grasses
Anaconda Smelter, MT (Galbraith et al., 1995)	Devegetation; reduced species diversity; noxious weed invasion and dominance; reduced habitat quality; inhibition of seedling root growth
Clark Fork River, MT (tailings) (LeJeune et al., 1996; Rader et al., 1997)	Barren or sparsely vegetated floodplain deposits; reduced vegetation structural complexity; reduced habitat quality; reduced seedling root and shoot growth
Tri-State Mining District, OK, MO, KS (tailings) (Pierzynski and Schwab, 1993)	Chlorosis; reduced crop productivity in contaminated floodplains
McLaren Mine, MT/WY (tailings) (Stoughton and Marcus, 2000)	Reduced vegetation biomass, density, diversity in contaminated floodplains
Llanwrst Mining District, Wales (tailings) (Johnson and Eaton, 1980)	Barren or sparsely vegetated floodplains; chlorotic vegetation; reduced diversity; replacement with metals tolerant grasses

In summary, metals released in mine wastes, including tailings and mixed tailings and alluvium, have been shown to cause toxicity to plants at the individual level, as well as devegetation, reduction in vegetation cover and diversity, and reductions in the structural complexity of vegetation at the habitat or community level (Johnson and Eaton, 1980; LeJeune et al., 1996; Rader et al., 1997; Stoughton and Marcus, 2000). Loss of riparian vegetation and the functions provided by riparian vegetation degrades the ecological services provided by the riparian ecosystem (LeJeune et al., 1996).

Table 9-2
Ranges of Total Concentrations (mg/kg) of Hazardous Substances in Devegetated or Sparsely Vegetated Riparian Tailings

Riparian Site	pH	Arsenic	Cadmium	Copper	Lead	Zinc
Clark Fork River, MT						
Devegetated tailings+alluvium	3.5-6.2	163-525	1.1-17.8	408-4014	237-885	550-5108
Clark Fork River, MT						
Devegetated tailings+alluvium	4.4-5.4	251-285	3.8-6.2	837-2,840	229-236	765-1,540
Conwy River, North Wales						
>50% bare ground	7.3	—	17-35	—	1,260-2,730	3,760-5,980
< 50% bare ground	7.2	—	12-22	—	860-1,610	2,700-4,200
Continuous cover, chloritic veg.	7.2	—	3.9-10.2	—	210-367	599-812
Soda Butte Creek, MT and WY	6.4	22	—	315	65	170
Reduced vegetation diversity	6.5	—	—	250	—	—
Reduced vegetation density						

— not measured.

Sources: Clark Fork River: LeJeune et al., 1996; Rader et al., 1997. Conwy River: Johnson and Eaton, 1980. Soda Butte Creek: Stoughton and Marcus, 2000.

9.3.2 Data Collected Previously in the Assessment Area

Previous investigations concerning riparian soils, sediments, and vegetation in the Coeur d'Alene River basin include characterizations of the degree and spatial extent of mine waste contamination in various areas of the basin (see Chapter 2, Sources of Hazardous Substances), assessments of plant growth in contaminated floodplain soils and revegetation of floodplains affected by mine wastes (White and Pommerening, 1972; Eisenbarth and Wrigley, 1978; U.S. BOM, 1981, 1983; U.S. BLM 1990, 1991, 1992, 1993; Peyton, 1994), and soil surveys (U.S. SCS, 1981, 1989). In addition, previous field studies and bioassays have demonstrated metals-induced phytotoxicity in soils contaminated by smelter emissions and tailings (e.g., Carter, 1977; Carter and Loewenstein, 1978; Keely, 1979; Krawczyk et al., 1988).

Previous studies characterizing concentrations of metals in floodplain deposits indicated that floodplain deposits of tailings and mixed tailings and alluvium containing elevated concentrations of hazardous substances occur downstream of former mill sites on the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, Pine Creek, and Moon Creek, and in the lower basin (Chapter 2). Summaries of concentrations measured in samples of alluvial materials, including floodplain tailings, mixed tailings and alluvium, and waste rock in the floodplain are presented in Tables 2-9 through 2-11 and 2-14 through 2-17 (Chapter 2). The data presented in Chapters 2 and 3 (Transport and Exposure Pathways) confirm that floodplain materials contain elevated concentrations of hazardous substances, that they are mobile, and that they serve as sources and pathways of hazardous substances to other resources.

Site Characterization

Little data existed previously regarding the structure and composition of riparian vegetation communities of the South Fork or mainstem Coeur d'Alene rivers or tributaries. The U.S. SCS (1981, 1989) mapped areas devoid of vegetation, 30% devegetated, and floodplain, valley floor, and terrace soils containing high concentrations of heavy metals, and noted that high concentrations of heavy metals in alluvial deposits along the South Fork and lower Coeur d'Alene rivers have created poor conditions for plant growth and for most other uses. SAIC and Ecological Planning and Toxicology (1991) reported that surface materials over approximately 450 acres in Smelterville Flats contain concentrations of hazardous substances capable of inducing adverse toxicological effects on plants, soil invertebrates, and small mammals. Metals concentrations were considered to be sufficient in many places to disrupt interactions between and interdependence of soil, plants, and soil fauna and, as a result, to adversely affect soil stability, wildlife habitat, food chain pathways, and nutrient cycling (SAIC and Ecological Planning and Toxicology, 1991). In the 1995 Engineering Evaluation and Cost Analysis for tailings removals in Canyon Creek at Woodland Park, U.S. EPA (1995b) concluded that elimination of vegetative cover in lower Canyon Creek reduced the available wildlife habitat and increased soil erosion.

Plant Growth Studies

Previous greenhouse studies performed in the 1970s and 1980s indicated that Coeur d'Alene soils containing elevated concentrations of hazardous substances cause plant growth inhibition and other adverse effects in controlled laboratory tests (Keely, 1979; Krawczyk et al., 1988). Keely (1979) observed growth reduction (shoot height) of alfalfa, wheat, and peas in soils collected near Osburn and near Kellogg relative to growth of the same species in soils collected from Moscow, Idaho. Krawczyk et al. (1988) observed growth inhibition, reduced survival, and physiological impairment of root development in metals-contaminated soils from the Bunker Hill area relative to control soils.

Krawczyk et al. (1988), using standard laboratory phytotoxicity methods, compared the growth of snap beans (*Phaseolus vulgaris* L. Var Blue Lake 290), tall fescue (*Festuca arundinacea* Schreb), and dandelion (*Taraxacum officinale*) in a mixture of soil collected near the high school in Kellogg and at Smelterville Flats to growth of each species in three control soils. Mean total concentrations of hazardous substances in the test soil mixture were 65 mg/kg cadmium, 483 mg/kg copper, 2,200 mg/kg lead, and 940 mg/kg zinc. Plants were also exposed to a series of test soils with amendments of zeolite (an aluminosilicate mineral with high cation exchange capacity) and lime to determine the effectiveness of these amendments in reducing metals availability. All soils were fertilized initially and throughout the test when plants were watered (Krawczyk et al., 1988). Each species germinated in test and control soils. Bean seedlings (harvested at 69 days) and fescue seedlings (harvested at 100 days) grown in the test soils were stunted relative to fescue and bean seedlings grown in the control soils. Dandelion seedlings in all test soils died within 30 days of germination. Dandelion seedlings in control soils exhibited excellent growth up to the end of the experiment. Amendments had no significant ameliorating effect.

A second experiment was conducted to determine effects on mature dandelions. Mature dandelions grown in a control soil were transplanted to test soil containing a zeolite amendment and to a control soil. At 22 days, plants in the test soil exhibited leaf discoloration and curling. The roots of the plants from the test soil were darker brown and more fibrous than control roots, and histological examination revealed gross morbidity relative to control plants. Impairment of the meristematic zone prevented differentiation of root tissues, and the roots failed to develop vascular tissue and lateral roots. Impairment of root development inhibited water, nutrient, and metal uptake, and the minimal growth observed during the exposure period was attributed to the senescence of the roots (Krawczyk et al., 1988). Root growth impairment as described by Krawczyk et al. (1988) is characteristic of zinc toxicity.

Carter (1977) and Carter and Loewenstein (1978) evaluated relationships between metals concentrations in smelter-contaminated soils and tree seedling survival and growth performance in field plots. Based on plant growth, microbial respiration rates, and concentrations of heavy metals in soils and plant tissues, the authors concluded that concentrations of zinc and other heavy metals were a major cause of seedling mortality. Survival and growth were negatively correlated with zinc concentrations in plant tissues ($r = -0.81$ and $r = -0.57$), and highly positively correlated with microbial respiration rate ($r = 0.84$ and 0.63). Microbial respiration was highly negatively correlated with the heavy metal concentrations in soils ($r = -0.80$). Though the soils tested were not floodplain soils and the source of the contamination was predominantly smelter-related emissions rather than tailings, the concentrations reported were similar to concentrations that have been measured in floodplain soils.

The results of these studies (i.e., plant growth inhibition in Coeur d'Alene soils containing elevated metals concentrations relative to plant growth in control soils, the physiological symptoms of the growth inhibition, and the correlative relationships between metals concentrations and plant growth responses) are consistent with metals as the cause of the observed phytotoxicity.

Field Trials and Revegetation Studies

Between 1972 and 1975, trial plantings of grasses and trees were made in Ninemile Creek on the Star and Day Rock Mill tailings dike, on the ASARCO tailings pond at Osburn, on the Bunker Hill tailings, and at the Shoshone County Airport and Smelterville Flats (White and Pommerening, 1972; U.S. SCS, 1974; Dames & Moore, 1990). Hybrid poplar plantings west of the airport survived, but survival of conifers planted near the Bunker Hill tailings dike was low (U.S. SCS, 1974). Survival of poplar, alder, and willow planted along Ninemile Creek and the South Fork Coeur d'Alene River was variable and greatest for willow. With annual fertilizer addition and irrigation, grass growth on the tailings dikes and ponds was described as "encouraging," but initial grass growth performance on jig tailings at the Shoshone County Airport was poor (U.S. SCS, 1974). Subsequent revegetation trials near the airport and on Smelterville Flats in 1974 and 1975 resulted in improved grass establishment, with greatest success on plots that received 6 inches of organic matter incorporated into the top 8 inches of soil, fertilizer in spring and fall, and irrigation with sewage effluent for the first growing season (Dames & Moore, 1990). By 1987, the most successful revegetation trial plots on Smelterville Flats near the Shoshone County Airport supported an estimated 50 to 60% vegetation cover (Dames & Moore, 1990). The long-term success of these plantings has not been quantified, but recent mapping of floodplain vegetation (Chapter 10, Injury Quantification) indicated that the plantings did not result in self-sustaining vegetation communities.

The University of Idaho College of Forestry, under a grant from the USDA's Surface Environment and Mining (SEAM) program, conducted revegetation research along Ninemile Creek and in the South Fork Coeur d'Alene floodplain between Osburn and Big Creek. Native shrub species, conifer seedlings, and deciduous tree seedlings grown in containers were planted in 1975 and 1977. Survival of native shrubs over three growing seasons was 5% along Ninemile Creek and 38% along the South Fork; growth rates in both areas were retarded (Eisenbarth and Wrigley, 1978). Survival of the conifers was better (33% to 80%), but most of the seedlings exhibited signs of stress attributed to nutrient deficiency and/or toxicity (Eisenbarth and Wrigley, 1978). Again, the long-term success of these plantings has not been quantified, but recent vegetation mapping indicated that large areas of the floodplain between Osburn and Big Creek remain barren (Chapter 10).

The University of Idaho College of Forestry SEAM program also established a grass research plot on Smelterville Flats near the airport. Grass established on irrigated plots that were seeded, fertilized, and mulched by hand. Sparse, irregular growth occurred on irrigated plots where seed, fertilizer and mulch were hydroseeded. Soil analysis indicated a pH of 8, low nutrient and organic matter concentrations, 676 mg/kg lead, and 110 mg/kg zinc (Eisenbarth and Wrigley, 1978). No symptoms of metals toxicity were observed. A subsequent greenhouse test with surface materials collected near the grass research plots showed that plants watered with sewage effluent were significantly larger than plants watered with well water (Eisenbarth and Wrigley, 1978).

The U.S. BOM and the Greater Shoshone County Inc. conducted a study between 1979 and 1983 to assess the feasibility of reclaiming floodplains along the South Fork Coeur d'Alene River and simultaneously developing disposal areas for additional tailings (U.S. BOM, 1981). A test tailings embankment was constructed on the south bank of the South Fork Coeur d'Alene River opposite the Terror Gulch confluence. As part of the study, the suitability of floodplain soils and tailings to support vegetation was assessed. No-treatment unseeded and no-treatment seeded sites exhibited good to very poor growth; lime treatment sites supported light growth, and sites covered with top soil and seeded exhibited excellent growth (U.S. BOM, 1983). All descriptions of growth in treatments were qualitative. Survival of snowberry and hawthorne shrubs and conifer trees planted on the dike faces was initially good, but survival of conifer seedlings on the tailings surface was poor. This area was recently mapped as barren (Chapter 10, Injury Quantification).

In 1990, U.S. BLM seeded grasses and forbs and planted shrubs and trees on a tailings-contaminated 21 acre tract on Smelterville Flats in an attempt to reduce fugitive dust emissions (U.S. BLM, 1990, 1991, 1992). Over 3,000 trees and shrubs, including lodgepole pine, hybrid poplar, black locust, and Siberian pea, were planted. The tract was fertilized in 1990, 1991, and 1992, and approximately 20 acres were irrigated during the 1990 and 1991 growing seasons. In 1991, live vegetative cover in irrigated areas averaged 49%, and tree and shrub survival ranged from 29% (black locust) to 75% (Siberian pea) (U.S. BLM, 1991). By 1993, live vegetation cover increased to 64%, but tree and shrub survival was poor. Herbaceous cover was dominated by redtop, orchardgrass, fescue, and Canada bluegrass (U.S. BLM, 1992; 1993). Vegetative cover was lowest in areas where toxic salt crusts formed on the soil surface (U.S. BLM, 1992; 1993).

In an adjacent companion study also initiated in 1990, the U.S. SCS evaluated the growth performance of 15 varieties of grasses plus the BLM seed mix under dryland and irrigated conditions (Burnworth, 1991, 1992). Five fertilizer and mulch treatments were tested. By 1993, survival of the 15 grass varieties seeded in 1990 was poor. Approximately 80 to 90% of the grass present comprised species that invaded from the BLM seed mix plots, including redtop, orchardgrass, Canada bluegrass, and sheep fescue (Peyton, 1994). Plots that had been irrigated supported approximately twice the grass and litter cover compared to plots that had been mulched only. Plots that had been neither irrigated nor mulched had the greatest amount of bare ground. No differences were observed between the various fertilizer treatments (Peyton, 1994).

At the Cataldo Mission Flats, giant reed grass (*Phragmites communis*) was planted and fertilized in 1972 and 1973, and clover and grain were planted in 1974 (White and Pommerening, 1972; U.S. SCS, 1974). Growth of Phragmites was initially slow, and clover and grain establishment was poor (U.S. SCS, 1974). Revegetation studies by the University of Idaho at the Cataldo Mission Flats between 1975 and 1977 included plantings of seven species of container-grown native shrubs and ponderosa pine, plantings of bare root deciduous trees, and establishment of two grass test plots (Eisenbarth and Wrigley, 1978).

Survival of container-grown native shrubs over three growing seasons was low (26.4%). Survival of container-grown ponderosa pines (*Pinus ponderosa*) over three growing seasons was 70%, but growth of the pines was retarded relative to controls. First and second year survival of the bare root trees was high, but growth was slow. The grass plots reportedly failed because the seedlings were buried by surface materials redistributed by winds (Eisenbarth and Wrigley, 1978).

As part of the recent remedial activity in the Woodland Park area of Canyon Creek, the revegetation effort after tailings removal included planting alder and "metals-tolerant" redtop, with phosphorus amendments to bind lead and zinc in adjacent soils (U.S. EPA, 1995a). The existing lack of vegetation was attributed to limiting soil factors, including low organic matter, heavy metals, and lack of horizon structure. The trees planted as part of the remedial effort did not survive.

In summary, existing data indicated that floodplain soils of the Coeur d'Alene River basin downgradient of mining and mineral processing operations contain elevated concentrations of metals (Chapter 2), and that metals concentrations in floodplain deposits exceed concentrations reported in the literature to be phytotoxic (Kabata-Pendias and Pendias, 1992; Alloway, 1990b). Previous phytotoxicity studies showed reduced growth and physiological impairment of plants in soils collected from the South Fork Coeur d'Alene River valley consistent with metals toxicity (Keely, 1979; Krawczyk et al., 1988), and past revegetation attempts have not successfully re-established self sustaining vegetation communities along the South Fork Coeur d'Alene River and several of its tributaries. Limited soil and vegetation mapping indicated barren and substantially devegetated floodplain areas (U.S. SCS, 1989).

The existing data suggested that chemical toxicity in soils continues to inhibit vegetation re-establishment and growth in the floodplains of the upper Coeur d'Alene River basin.

9.3.3 Injuries Evaluated in the Assessment Area

Injuries evaluated in the assessment area included injuries to floodplain soils and riparian vegetation. Relevant definitions of injury to floodplain soils (and sediments) include:

- concentrations in the soil of substances sufficient to cause a phytotoxic response such as retardation of plant growth [43 CFR § 11.62 (e)(10)]
- concentrations of substances sufficient to raise the . . . soil pH to above 8.5 or to reduce it to below 4.0 [43 CFR § 11.62 (e)(2)]
- concentrations of substances sufficient to have caused injury as defined to surface water, groundwater, air or biological resources when exposed to the substances [43 CFR § 11.62 (e)(11)].

The last definition in this instance applies to injury to vegetation exposed to floodplain soils.

An injury to a biological resource such as vegetation has occurred if the release of a hazardous substance is sufficient to cause one or more of the following adverse changes in viability: death, disease, . . . genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations [43 CFR § 11.62 (f)(1)(i)]. Adverse changes in viability of biological resources can be demonstrated using biological responses that meet the following acceptance criteria:

- The biological response is often the result of exposure to hazardous substances [43 CFR § 11.62 (f)(2)(i)].
- Exposure to hazardous substances is known to cause this biological response in free-ranging organisms [43 CFR § 11.62 (f)(2)(ii)].
- Exposure to hazardous substances is known to cause this biological response in controlled experiments [43 CFR § 11.62 (f)(2)(iii)].
- The biological response measurement is practical to perform and produces scientifically valid results [43 CFR § 11.62 (f)(2)(iv)].

The following injuries to riparian vegetation were evaluated: (1) retardation of plant growth in soils containing hazardous substances relative to plant growth in reference soils, in a controlled laboratory environment [43 CFR § 11.62 (e)(10)], and (2) reduction in vegetation cover and simplification of community structure and composition in the assessment area relative to reference areas. Community level changes are caused by death and physical deformation at the level of the individual plant, where deformations include physiological changes resulting in reduced growth, which leads to a loss in competitiveness and viability. Death and physiological deformations are expressed at the community level as elimination of vegetation or as changes in the composition or structure of vegetation communities.

Growth reduction of individual plants, reductions in vegetation cover, and simplification of vegetation community composition and structure are often the result of exposure to hazardous substances and are known to be caused by exposure to elevated concentrations of metals in soils (Chaney, 1993; Pahlsson, 1989; Kabata-Pendias and Pendias 1992; Kapustka et al., 1995). Growth reductions are the manifestation at the whole-plant level of physiological malfunctions such as inhibition of photosynthesis, water transport, nutrient uptake, carbohydrate translocation, and transpiration, and enzyme synthesis or activity, induced by elevated concentrations of trace elements (Carlson and Bazzaz, 1977; Lamoreaux and Chaney, 1977; Clijsters and Van Assche, 1985; Pahlsson, 1989; Tyler et al., 1989; Vasquez et al., 1989; Alloway, 1990a; Davies, 1990; Kiekens, 1990). Exposure of plants to metals-contaminated soils in controlled laboratory tests is known to cause shoot and root growth reduction and reduced plant survival (Tyler et al., 1989;

Kapustka et al., 1995). Measurements of reduced growth and survival in laboratory tests and measurements of reduced vegetation cover and changes in community composition and structure in the field are practical to perform and produce scientifically valid results (U.S. DOI, 1987; ASTM, 1994; Kapustka, 1997). These responses meet the four acceptance criteria at 43 CFR § 11.62 (f)(2) and therefore are injuries.

9.4 INJURY ASSESSMENT: TESTING AND SAMPLING APPROACHES

Following a review of studies conducted previously in the assessment area (Section 9.3.2) and a review of published information on effects of metals on soils, plants, and vegetation communities (Section 9.3.1), the Trustees identified the need to collect supplemental data to determine whether floodplain soils and riparian vegetation of the Coeur d'Alene River basin are injured by exposure to hazardous substances and, if so, to quantify the injury.

Existing data indicated that floodplain soils of the Coeur d'Alene River basin downgradient of mining and ore processing operations contain elevated concentrations of metals (Chapter 2), and that metals concentrations in floodplain deposits exceed concentrations reported in the literature to be phytotoxic (Kabata-Pendias and Pendias, 1992). Previous greenhouse studies showed reduced growth of plants in soils collected from the South Fork Coeur d'Alene River valley (Keely, 1979; Krawczyk et al., 1988), and past revegetation attempts had not successfully re-established self-sustaining vegetation communities along the South Fork Coeur d'Alene River and several of its tributaries (e.g., U.S. BLM 1990, 1991, 1992, 1993). Limited soil and vegetation mapping indicated barren and substantially devegetated floodplain areas (U.S. SCS, 1989). Aerial photographs taken in 1992 showed large areas of barren floodplain along the South Fork Coeur d'Alene River and several of its tributaries. Existing data were used to identify testing and sampling objectives, and to identify exposed resources, characteristics of the hazardous substances, and potential injuries and pathways [43 CFR 11.64 (a) (2)].

Since floodplain soils and riparian vegetation are ecologically interdependent, injuries to soil and vegetation resources were assessed collectively. The floodplain soil and riparian vegetation injury determination studies included field and laboratory components (Figure 9-2). Field components included collection of surface soil samples and vegetation community data from floodplains of the Coeur d'Alene River basin. Laboratory components of the assessment included studies of early seedling growth performance in field collected soils under controlled laboratory conditions, and chemical analysis of field collected soils.

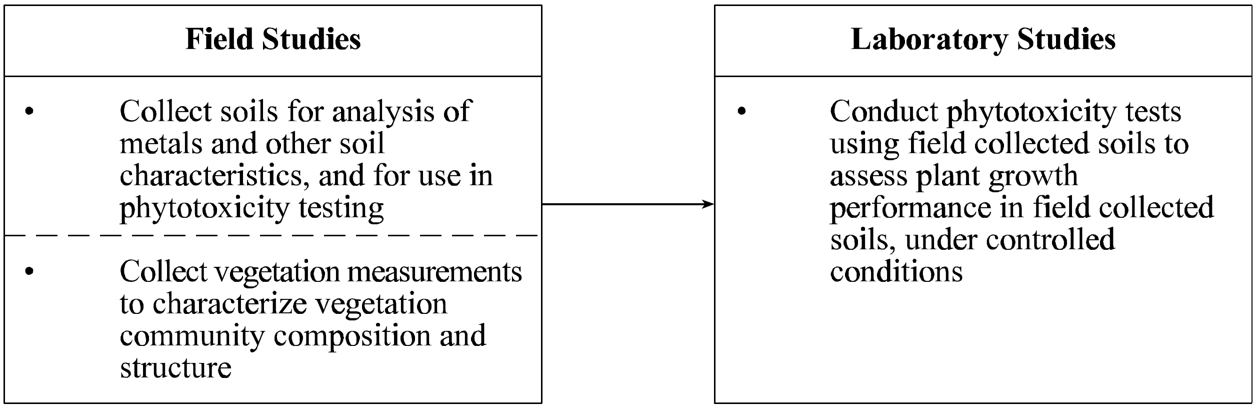

Figure 9-2. Injury assessment studies included field sampling to collect soil and vegetation data from assessment and reference (control) sites, and laboratory studies to evaluate the growth of plants in assessment and reference soils under controlled conditions.

9.4.1 Field Studies

Soil samples and vegetation community data were collected from floodplains downstream of known mining-related disturbances (assessment reaches) and from floodplains upstream of known or major mining related disturbance and on reference streams that have not been mined (presumed unexposed reference reaches). Soil and vegetation data were collected from assessment reaches on Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River between the Canyon Creek confluence and the North Fork Coeur d'Alene River confluence, and from the lower basin and lateral lakes area between approximately the North and South Fork Coeur d'Alene River confluence and the mouth of the mainstem at Coeur d'Alene Lake (Figure 9-3).

Reference Reach Selection

Reference reaches (presumed unexposed control areas) were necessary for comparison of biological and geological characteristics for injury determination [43 CFR 11.62 (f)(3)] and for identification of baseline conditions for injury quantification [43 CFR 11.71 (b)(2-5) and 11.72 (d)]. The DOI NRDA regulations recognize that identification of a reference site is difficult and provide guidelines to assist with selecting similar sites. The reference areas were selected using guidance at 43 CFR 11.72. Reference reaches were selected based on similarity to the assessment reaches in terms of major environmental factors that affect plant growth and vegetation community development and lack of exposure to the release of hazardous substances [43 CFR 11.72 (d)(1)].

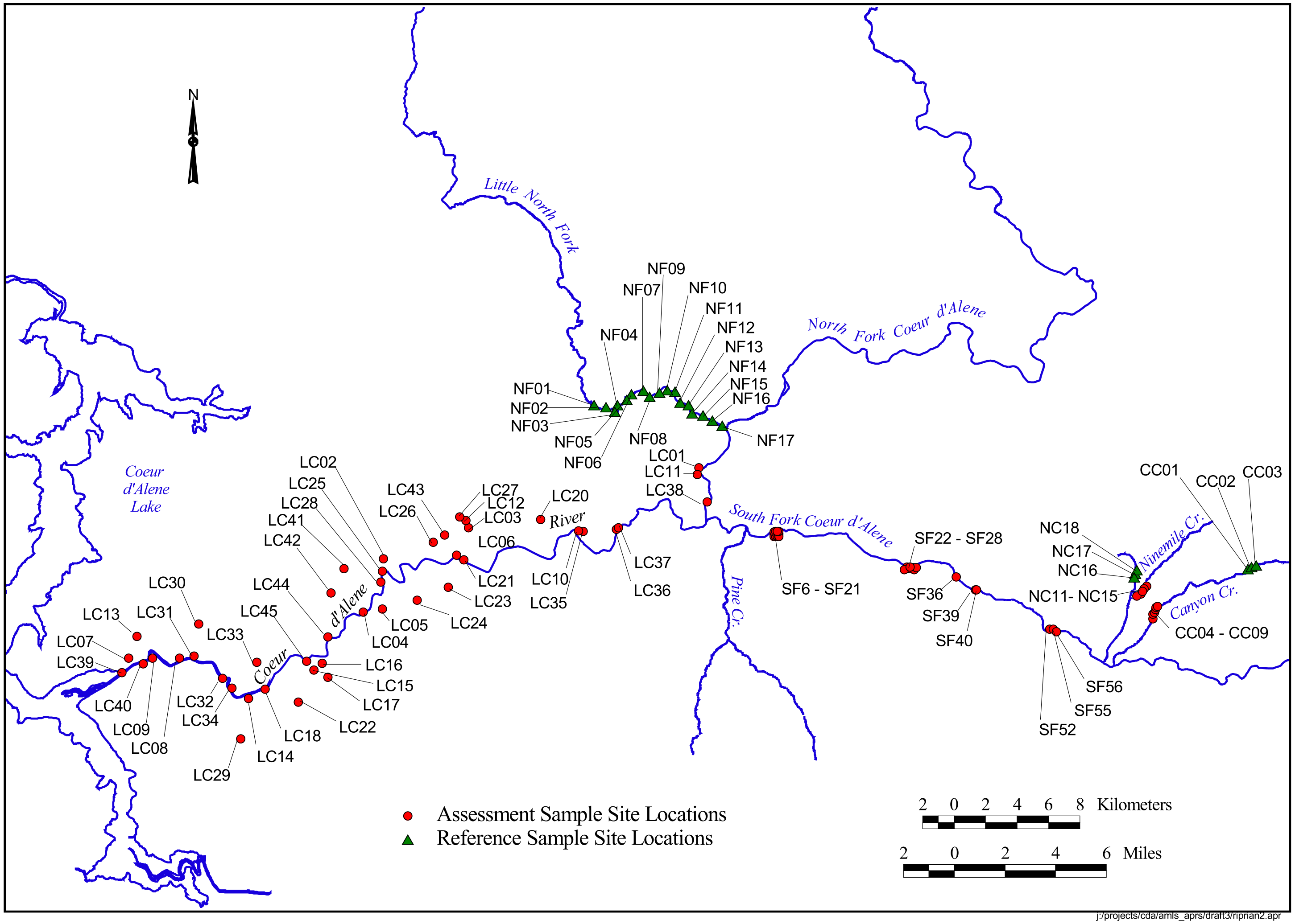

Figure 9-3. Sample site locations for the riparian resources injury assessment. Blue triangles indicate reference sites, and red circles indicate assessment sites.

For floodplain soil/sediment resources, the soil or geologic material in the reference area should be similar to exposed soil or geologic material in the assessment area [43 CFR 11.72 (j)(3)(i)], and at least one reference area upstream of the assessment area shall be included unless local conditions indicate such an area is inapplicable as a reference area [43 CFR 11.72 (d)(2)]. For riparian vegetation resources, references reaches should be physically comparable and comparable to the habitat or ecosystem at the assessment area in terms of distribution, type, species composition, plant cover, vegetative types, quantity, and relationship to other habitats [43 CFR 11.72 (k)(3)(A,B)].

Since vegetation and soil resources are interdependent and were assessed collectively, reference reaches were selected to best address both soil and vegetation reference area considerations identified in the DOI regulations. The reference areas selected are riparian corridors of similar size and orientation, with similar climate, topography, soil parent material, and history. The vegetation types, species composition, plant cover, and structure within each of the reaches is representative of the vegetation types, species composition, plant cover, and structure that should exist in the assessment area. The reference areas have been subjected to anthropogenic alterations including road building, logging, mining-related disturbances, and recreational and residential impacts. Where possible, reference reaches were located upgradient of assessment reaches. Where upstream areas were not appropriate, a reference reach was identified based on proximity to the assessment reach, comparable elevation, and comparable valley orientation.

Soil and vegetation data were collected from reference reaches of Canyon Creek upstream of Burke near Sawmill Gulch, Ninemile Creek upstream of the East Fork Ninemile Creek confluence, and the lower portion of the Little North Fork of the Coeur d'Alene River (Little North Fork) (Figure 9-3). Reference reaches on upstream Canyon Creek and Ninemile Creek upstream of the East Fork Ninemile Creek confluence were selected based on their presumed location upgradient of major mining related influences and the similarity of physical environmental controls on vegetation (e.g., similar climate, similar high gradient, low order streams, and similar expected vegetation types). In addition, like the Canyon and Ninemile creek assessment reaches, both control reaches are bordered by a road. During the riparian resources floodplain soil sampling, it was clear that the predetermined sample sites in the presumptive unexposed reach of Canyon Creek had in fact been exposed to materials resembling mining-related wastes, though to a lesser degree than downstream sites (RCG/Hagler Bailly, 1994). Subsequent chemical analyses of soils confirmed elevated concentrations of hazardous substances in samples collected from two of the Canyon Creek reference sites (Section 9.5.1). Even though the Canyon Creek reference sites do not represent a true control because they have been exposed to mining related releases of hazardous substances, they were retained for analysis and comparison to assessment sites as a conservative estimate of unexposed sites.

The Little North Fork was selected as a reference area for the South Fork Coeur d'Alene River based on similarity of overall climate, the fact that both reaches are mid gradient, mid order streams and both valleys have an approximate east-west orientation, and the similarity of potential vegetation types. The Little North Fork is bordered by a Forest Service road and is an area of high recreational use. The Little North Fork is not bordered by urban development similar to that along the South Fork Coeur d'Alene River, but the vegetation types along the Little North Fork would be expected along the South Fork Coeur d'Alene River at least between urban centers and in broader areas of the floodplain.

An appropriate reference area for the lower Coeur d'Alene River valley and lateral lakes area was not identified. The St. Joe River was considered but rejected based on the heavier agricultural use and the resulting dissimilarity of expected vegetation types. Instead, an internal reference area design was used. Data on lead concentrations in sediments in the lower basin were analyzed to identify sample sites of low to high lead concentrations. Sites containing a range of lead concentrations were sampled to determine whether there are relationships between lead and other hazardous substance concentrations in the soils and sediments and plant growth and vegetation community development.

Upper Basin Sample Site Selection

In the upper basin (i.e., upstream of the South Fork and North Fork Coeur d'Alene River confluence), sampling was confined to public lands in the floodplain. The sampling area was identified using FIRM (1979) flood insurance rate maps to delineate the floodplain, and a digital land coverage map derived from the Idaho Panhandle National Forests secondary base map (USDA FS, 1989) to identify public lands. To select sampling sites from the irregularly shaped plots of public land along the South Fork Coeur d'Alene River, Canyon, and Ninemile creeks, a systematic random sampling in two dimensions (Cochoran, 1977) was used to ensure that every point on public land in these subbasins had equal probability of being sampled. An array of points defined by a 50 m square grid was anchored at a randomly selected point and overlaid on a digital map of public lands within the Coeur d'Alene River basin floodplain using a geographic information system (GIS). Grid points that intersected publicly owned land became the sample sites. Sample sites along the Little North Fork were selected by systematic sampling in one dimension (Cochoran, 1977) along the course of the river. Exact locations perpendicular to the river course ($n = 1$ per site) were selected by simple random sampling. Sample site geographic coordinates were recorded in the field using a Trimble Navigation Geoexplorer global positioning system. Geographic data were corrected using daily base station data (Spokane, WA). Corrected site locations are accurate to approximately ±5 m.

A preliminary field visit was made to verify sample locations. At that time, locations that were not sampleable were either discarded from the sample set or relocated to the nearest sampleable site. Developed lands, recently remediated lands, and lands currently undergoing remediation were not sampled. In addition, sites that were not sampleable because of differences between the mapped and actual topography were either relocated or eliminated.

Actual sample sites were located in the field using GIS maps and topographic maps. Decisions regarding the exact location of each point were made by the field team leader, based on the prescribed location. Several candidate sites along the South Fork Coeur d'Alene River, Canyon

Creek, and Ninemile Creek were repositioned because of differences between the actual and mapped floodplain morphology. A stratified-random approach was used to reposition sampling sites in the field. To reposition the sampling sites, an interval length was determined by measuring the length of the sampleable area parallel to the creek or river and dividing the length by the number of sample sites that were to be positioned in the sampleable area. A random number between zero and the interval length was obtained using the random number function on a hand-held calculator. The random number determined the starting sample sites in meters from the downstream end of the sampleable area. The interval length was added to position subsequent sites. Sample sites were centered laterally in the floodplain. Railroads and roads were not sampled, and in most cases where they occurred, they bounded the edge of the floodplain.

The procedures described above were intended to prevent bias in the relocation of sample sites. In no case were sample sites selected based on the appearance of a site.

Lower Basin Sample Site Selection

Sample site selection in the lower basin was based on the sampling design and results from a field study by the U.S. Geological Survey (USGS) (Horowitz, 1995). Soil data from approximately 150 sites between Smelterville and the mouth of the mainstem at Harrison were stratified based on measured lead concentration. Lead concentration strata were 0-100 mg/kg lead, 100-500 mg/kg lead, 500-1,000 mg/kg lead, and >1,000 mg/kg lead. Approximately 15 sites per stratum were selected randomly and sampled. This design provided for sampling of soils and vegetation exposed to a wide range of metals concentrations. Sampling included private lands.

For lower Coeur d'Alene sampling, it was not possible at the time of sampling to find previously sampled sites using a GPS, as intended. The field teams instead used topographic maps and written descriptions of sample sites to get as close as possible the previously sampled site. If the location was sampleable, the field team obtained a random distance and direction (using the random number function on a hand-held calculator) to locate the specific sample site. If the location was not sampleable, the field team moved to the nearest similar sampleable location, again using a random direction and distance to locate the specific sampling site. Again, the sample relocation procedures were intended to prevent bias in the relocation of sample points, and no sample sites were selected based on appearance.

In total, 107 sites were sampled, including 63 sites in the upper basin and 44 sites in the lower basin (Figure 9-3). Of the upper basin sites, 40 were located downstream of major mining operations and 23 were located on presumed upstream of mining influenced reaches or on unmined drainages.

Soil and Vegetation Sampling

Soil samples and vegetation data were collected in a systematic sampling array at each site. The soil sample at each site was a composite of five subsamples. Subsamples of equal volume were collected from the 0-15 cm depth at the site center point and at the four vertices of a square surrounding the center point (Figure 9-4). The vertices of the square were 7.75 m from the center point in each of the cardinal directions. The five subsamples were composited in the field to produce a single sample per site for chemical analysis. Duplicate soil samples and decontamination blanks were collected at a frequency of approximately 1 per 25 sites sampled. At a randomly selected 10 reference and 14 exposed sites in the upper basin, and at 12 sites in the lower basin, an additional 10 to 15 L of soil was collected as described above for phytotoxicity tests. Selection of sites for phytotoxicity testing was made before field work began and was not based on the appearance of a site. All sampling was conducted during late August 1994.

Within a 10 m radius of the site center, the following vegetation parameters were visually estimated: most prevalent cover type (the cover type that would shade the greatest proportion of the ground surface were the sun directly overhead), structural habitat layers present (Short, 1984), and approximate areal coverage of each structural layer. Cover type categories included coniferous forest, deciduous forest, coniferous shrubland, deciduous shrubland, grassland and forb pasture, wetlands, bare ground, hay, and dead vegetation. Structural habitat layer categories (Figure 9-5) included terrestrial subsurface layer (topsoil covering at least 5% of the site), understory (vegetation up to 50 cm tall shading at least 5% of the site), shrub midstory (vegetation between 50 cm and 6 m shading at least 5% of the site), tree canopy (trees at least 6 m tall shading at least 5% of the site), and tree bole (trees with trunk diameter of at least 20 cm at breast height) (Short, 1984). Sites could have up to five structural layers.

The species, cover, and height classification of all plants intercepting a north-south 10 m line transect centered at the midpoint of the site were recorded (Kent and Coker, 1992). Height classifications included herbaceous (vegetation up to 50 cm), shrub (vegetation between 50 cm and 6 m), tree (vegetation over 6 m), and litter layer (senescent vegetation on the soil surface) (Short, 1984). Percent cover was calculated as the percentage of the distance of the line transect shaded by a species or height class (Kent and Coker, 1992). Sites with multiple layers of vegetation could have greater than 10 m cover in a given height class. The frequency of each species was the percentage of sites at which the species occurred. Cover and species richness (number of species) were calculated by site for all vegetation, and by herbaceous, shrub, and tree height classes. All plant identification was conducted by trained botanists under the guidance of two botanists with specific expertise in the flora of the Coeur d’Alene River basin.

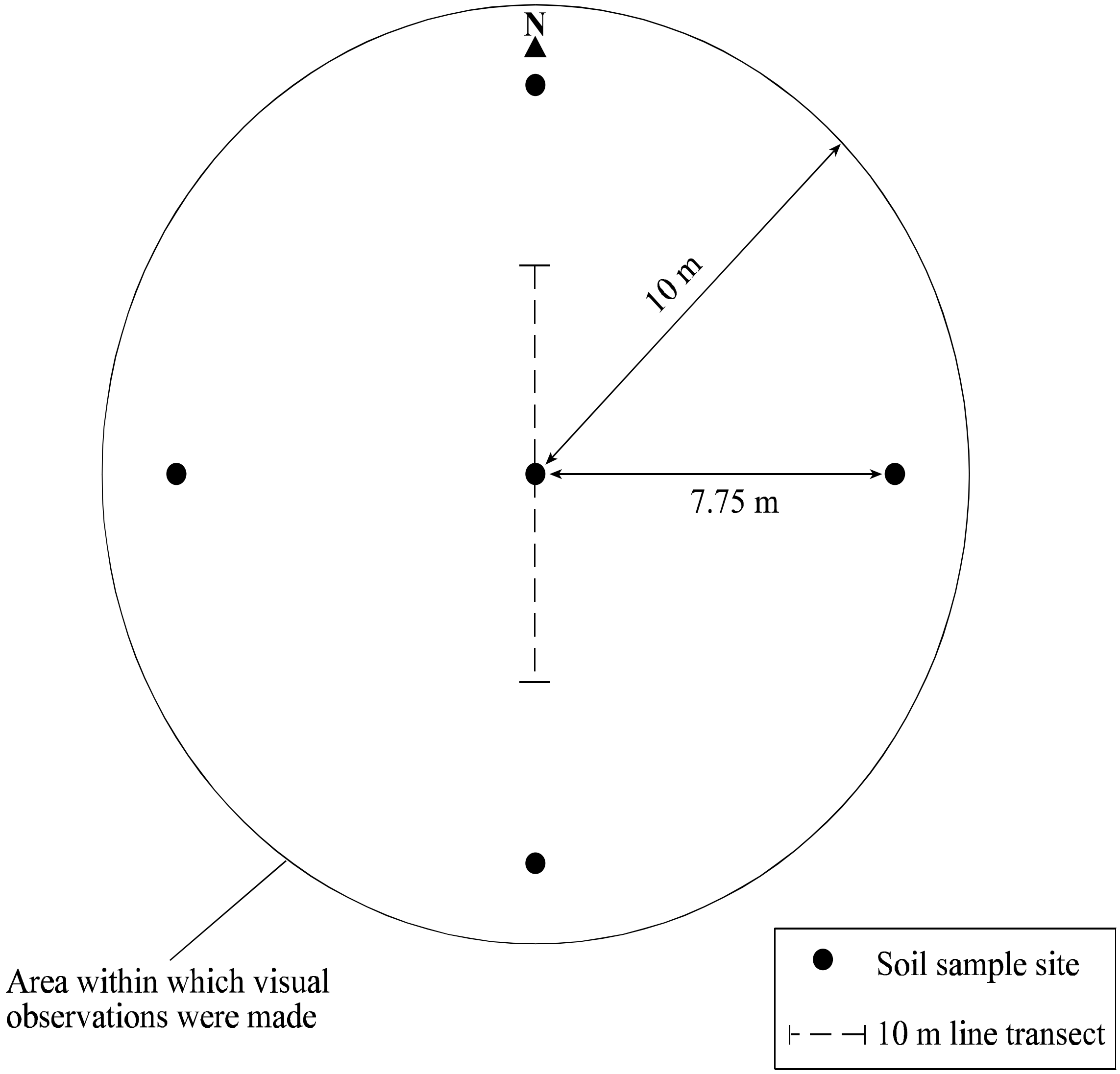

Figure 9-4. Sample site design. Soil subsamples of equal volume were collected from the 0-15 cm depth at five equally spaced points. The composited sample was designed to correspond to vegetation observations made within a 10 m radius of the site center and vegetation measurements made along a line transect.

The vegetation sampling methods are standard methods (Kent and Coker, 1992; Short, 1984) and meet the DOI requirements for quantification of services reduction [43 CFR 11.71 (l)(4, 6)]. They provide numerical vegetation data at the habitat (vegetation community) level that allow comparison between assessment area and reference area data. In addition, they provide data that will be useful in planning for restoration and in measuring restoration success [43 CFR 11.71 (l)(4)(i, ii)].

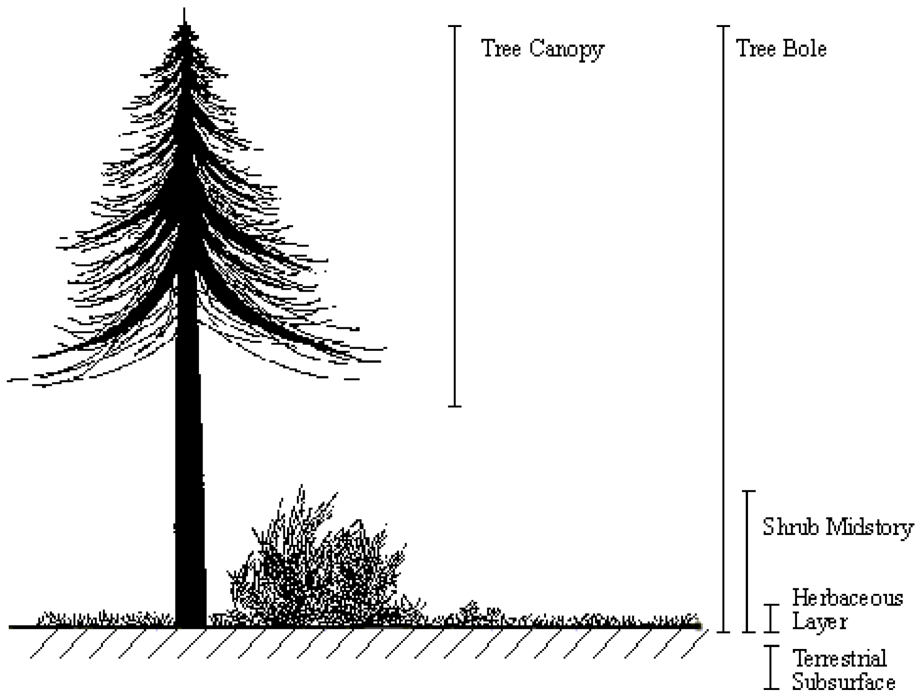

Figure 9-5. Structural habitat layers.

Soil samples were air dried at 40°C and sieved to retain the <2.0 mm fraction. The samples were analyzed using standard methods. Samples for analysis of metals (arsenic, cadmium, copper, iron, lead, manganese, and zinc) were digested with nitric acid (HNO_3) and quantified by EPA Method 3051-M. In addition, samples were analyzed for water soluble nitrate (NO_3) (EPA Method 353.2, Automated Colorimetry); ammonium-bicarbonate diethylenetriaminepentaacetic acid (AB-DTPA) extracted potassium (Page et al., 1982); organic carbon [USDA No. 60 (24)]; saturated paste pH (ASA #9-2, Sec. 12-2.6); and percent sand, silt, and clay (ASTM D 422). All samples were analyzed by inductively coupled plasma (TJA36 Simultaneous ICP) by Method 200.7-M (modified for the Contract Laboratory Program) except for low detects, which were analyzed by graphite furnace atomic absorption spectrometry (EPA Method 206.2 CLP-M) or by ICP mass spectrometry (EPA Method 6020 CLP-M).

9.4.2 Laboratory Studies

Results of the phytotoxicity studies were used to evaluate injury to soils [43 CFR § 11.62 (e)(10)] and to provide supporting evidence of the causal link between hazardous substances in soils, plant growth response, and vegetation community health. The phytotoxicity soil samples were sent to Ecological Planning and Toxicology, Inc. (ep&t), Corvallis, OR for plant growth testing.

The standard early seedling growth protocol (ASTM, 1994) was used to assess phytotoxicity of field collected soils to terrestrial plants.

Test species were selected to represent functional types of native species in the basin. The test species were alfalfa, to represent the nitrogen fixing components of the ecosystem (Leguminosae and Alnus), wheat (Poacea), to represent grasses, and lettuce (Compositae), to represent forb species. Rooted hybrid poplar cuttings were used as a surrogate for native *Populus* spp. and *Salix* spp. Measurement endpoints for alfalfa, lettuce, and wheat included percent germination, root length (mm), shoot length (mm), root mass (g, oven dry), shoot mass (g, oven dry), and total mass (g, oven dry). Measurement endpoints for hybrid poplar included branch length (mm), leaf mass (g, wet weight and oven dry weight of leaves and branches), leaves added (number of leaves), root length (mm), and roots added (number of roots). Phytotoxicity measurement endpoints were consistent with testing and sampling approaches recommended at [43 CFR 11.64 (e)(6)].

The ASTM protocol was adapted for the specific objectives of this assessment. Modifications included use of field collected soils containing the test substances (metals) rather than simulation of field conditions by addition of metals mixtures to artificial soils, and use of field collected reference soils to serve as controls for expected plant growth performance. In addition, positive controls to confirm the susceptibility of test species to chemical toxicity (artificial soil treated with three concentrations of boric acid for hybrid poplars and six concentrations of sodium fluoride for other species) and negative controls to confirm suitable laboratory conditions for plant growth (artificial soil and deionized water for each species) were run simultaneously. The exposure period for alfalfa, wheat, and lettuce was 14 days rather than the 21 day post median emergence date specified in the ASTM guide. The shorter exposure period eliminated the need to add nutrients to the test soils, which would have compromised the relevance of the tests to field conditions. All other aspects of the ASTM guidance were preserved.

Alfalfa, wheat, and lettuce seeds were from the same batch/lot for each of the species. Seeds were not pretreated before testing. Frozen poplar cuttings were supplied by the James River Corporation. Approximately two weeks before test initiation, the poplars were cut to 4 inch lengths, placed in deionized water in a temperature controlled chamber, and allowed to establish a root system. At test initiation, 15 cuttings were randomly selected and removed from the test population. They were measured to establish a pre-test statistical base for maximum length of branches and roots, number of emerging secondary branches, number of visible leaves, number of lateral roots from each primary root, condition and appearance, wet weights of branches and leaves, roots, and primary stem, and dry weights of the branches plus leaves and roots. Information recorded for each test poplar at test initiation included maximum branch and root lengths, and a description of the branches and roots and general condition of the cutting.

Each treatment (soil from a single sample site) consisted of 5 replicate pots of alfalfa, lettuce, and poplar, and 10 replicate pots of wheat. Alfalfa and lettuce replicates contained 20 seeds/pot, wheat replicates contained 10 seeds/pot, and poplar replicates contained 1 cutting per pot. The growth chamber was illuminated on a 16:8 hour light:dark photoperiod, and relative humidity was maintained at >30%. Light period temperature was maintained at approximately 25±2°C. Light intensity during the light period was approximately 100 microeinsteins. Water was added initially and throughout the test as necessary to maintain soils at water-holding capacity.

9.5 INJURY ASSESSMENT STUDIES: RESULTS

This section presents the results of the field and laboratory injury assessment studies. Photographs of sample sites and raw data are included in Appendices A and B to this chapter.

9.5.1 Floodplain Soils

Concentrations of hazardous substances in assessment soils were consistently greater than in reference soils of the upper basin (Figure 9-6) and substantially greater than concentrations reported in the literature to be phytotoxic (Section 9.3.1). Concentrations of arsenic, cadmium, copper, lead, and zinc were significantly greater in South Fork Coeur d'Alene River soils than in Little North Fork soils (Mann-Whitney $p < 0.05$) (Table 9-3). Concentrations of copper, lead, and zinc were significantly greater in Ninemile Creek assessment soils than in reference soils, and concentrations of arsenic, copper, and lead were significantly greater in Canyon Creek assessment soils than in reference soils (Mann-Whitney $p < 0.05$). A pooled comparison of all upper basin assessment soils with upper basin reference soils indicated significantly greater concentrations of arsenic, cadmium, copper, lead, and zinc in assessment soils. Concentrations of cadmium and zinc in Canyon Creek assessment soils were not statistically significantly different from reference soils at the 5% level ($p = 0.09$), but the actual concentrations were substantially different. The degree of difference in concentrations between Canyon Creek assessment and reference soils does indicate that the assessment soils are contaminated relative to the reference soils. However, since the Canyon Creek reference soils had been exposed to mining-related disturbance and contamination, and do contain elevated concentrations of metals relative to sites that were undisturbed by mining, the difference between the two was not statistically significant. Based on the elevated concentrations at the assessment area locations and the observation of mining-related disturbance at two of the three upstream reference locations, the concentrations of cadmium and zinc actually are significantly elevated relative to true nonmining reference conditions.

No significant differences in nitrate-nitrogen, or percent sand, silt, or clay, were detected between Canyon Creek reference and assessment soils, or between Ninemile Creek assessment and reference soils. The range of pH was greater in assessment soils than in reference soils.

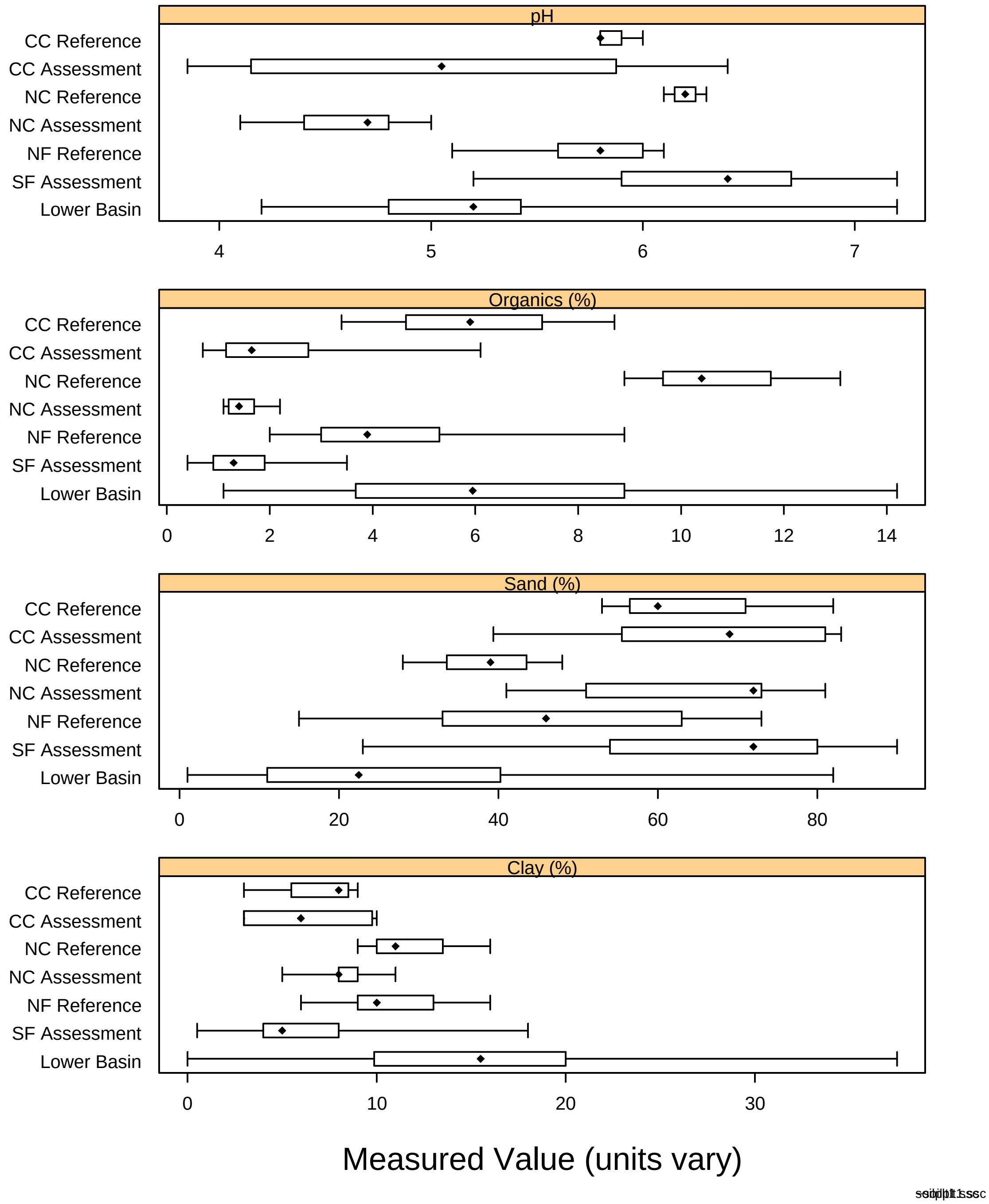

Figure 9-6. Distributions of measured soil attributes, summarized by sampling area. Box plots present the maximum, minimum, interquartile range, and median value for each analyte.

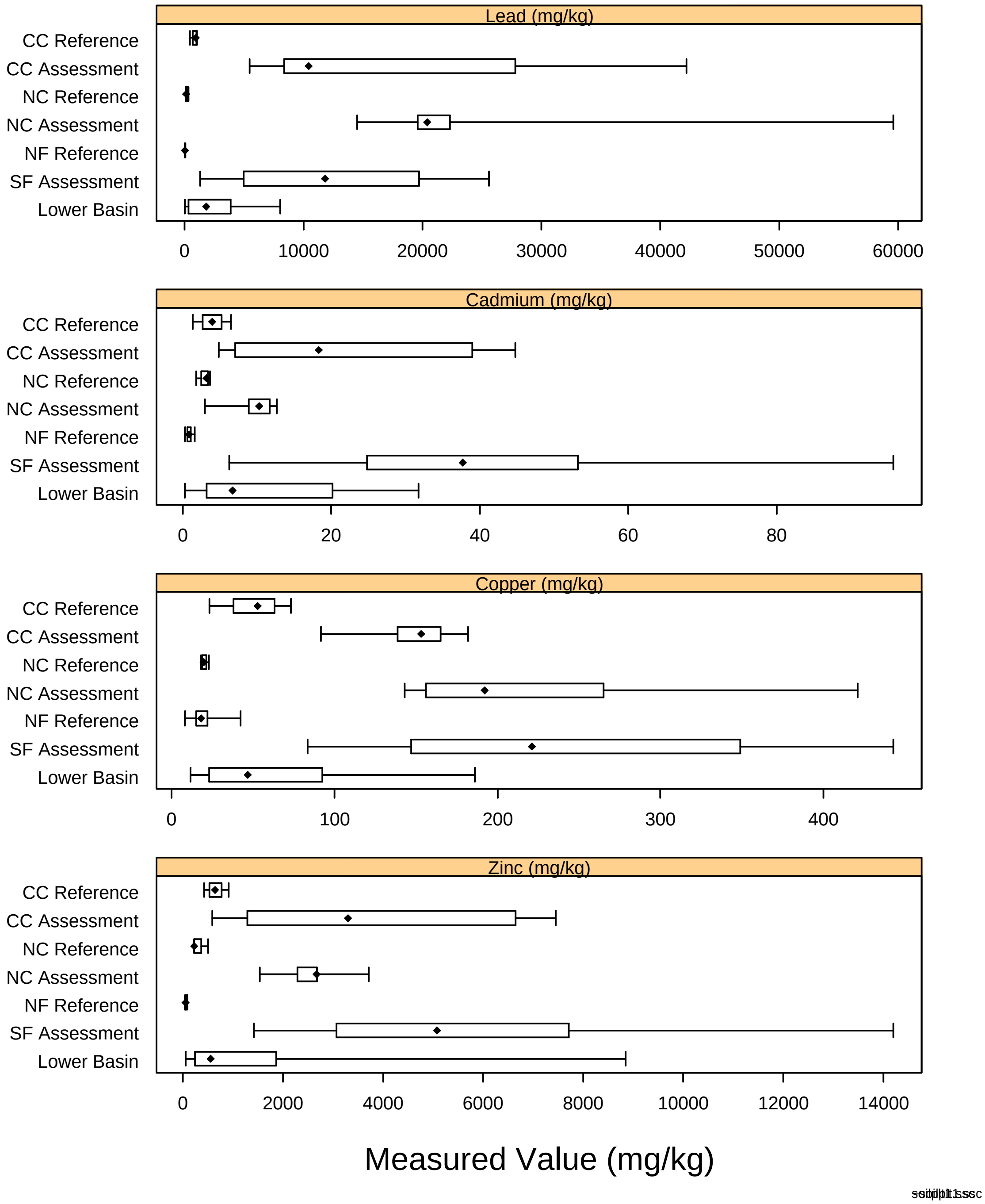

Figure 9-6 (cont.). Distributions of measured soil attributes, summarized by sampling area. Box plots present the maximum, minimum, interquartile range, and median value for each analyte.

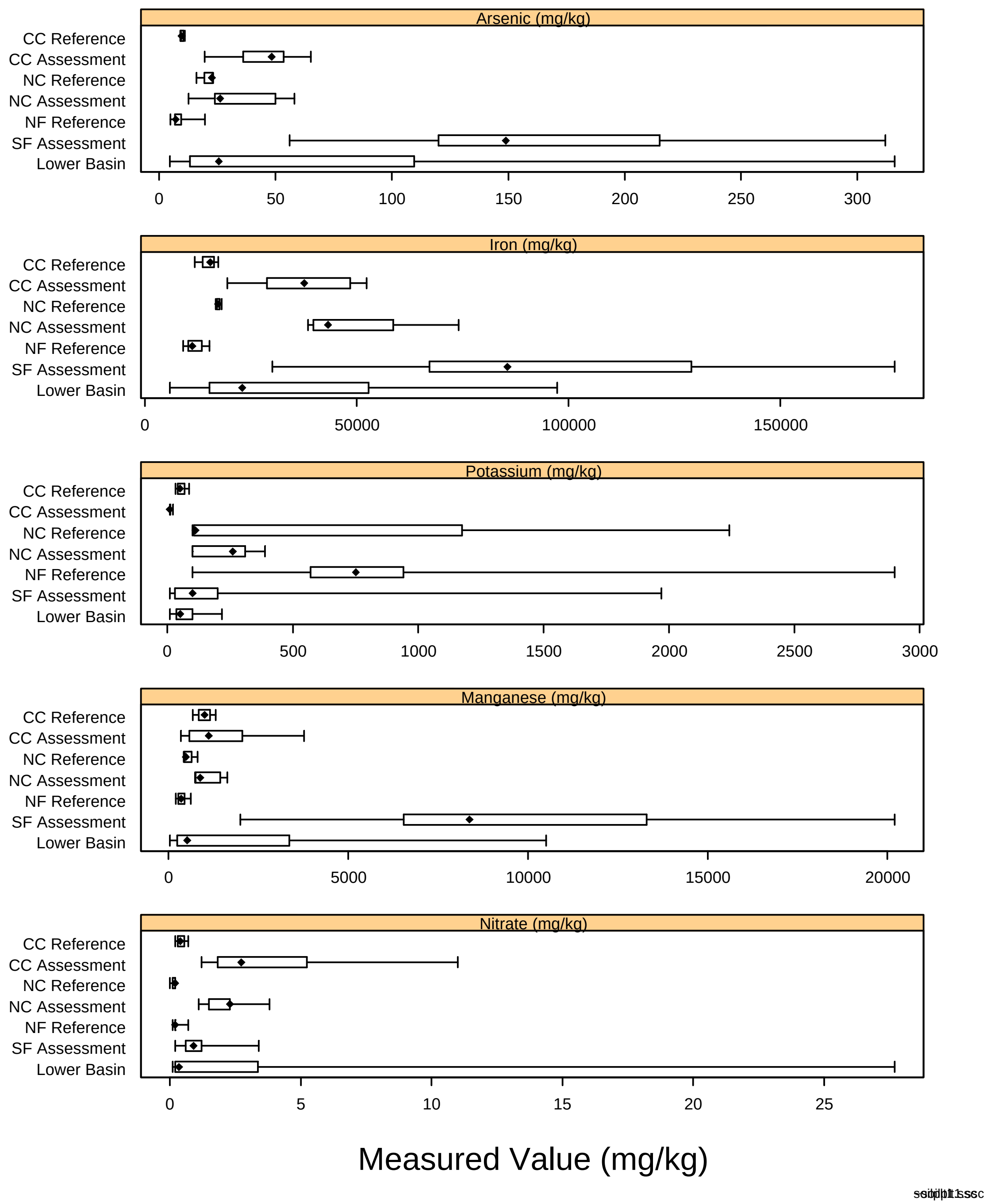

Figure 9-6 (cont.). Distributions of measured soil attributes, summarized by sampling area. Box plots present the maximum, minimum, interquartile range, and median value for each analyte.

Table 9-3
Mean (standard error) Concentrations (mg/kg) of Hazardous Substances in Assessment and Reference Soils

	Arsenic	Cadmium	Copper	Lead	Zinc
Canyon Cr. Reference (n = 3)	9.9 (0.6)	4.0 (1.5)	49.7 (14.5)	802 (182)	661 (143)
Canyon Cr Assessment (n = 6)	44.8 (6.7)[a]	22.6 (7.5)	147 (12.9)[a]	18,300 (6,310)[a]	3,840 (1,260)
Ninemile Cr. Reference (n = 3)	20.6 (2.3)	2.9 (0.6)	20.1 (1.4)	174 (75.3)	318 (94.5)
Ninemile Cr. Assessment (n = 5)	34.2 (8.5)	9.0 (2.0)	235 (51.0)[a]	27,300 (8,180)[a]	2,580 (352)[a]
Little North Fork (n = 17)	8.8 (1.0)	0.8 (01)	19.7 (2.0)	16.8 (1.6)	60.3 (3.7)
South Fork (n = 29)	163 (12.3)[a]	40.5 (3.8)[a]	250 (21.5)[a]	12,400 (1,420)[a]	5,500 (540)[a]
Pooled Upper Basin Reference	10.5 (1.1)	1.5 (0.3)	23.7 (3.0)	140 (59.8)	172 (48.1)
Pooled Upper Basin Assessment	129 (12.6)[a]	33.9 (3.4)[b]	233 (17.6)[b]	15,100 (1,820)[b]	4,890 (46.1)[b]
Lower Coeur d'Alene (n = 43)	71.1 (13.0)	11.3 (1.4)	60.8 (6.9)	2,220 (329)	1,230 (233)

a. $p < 0.05$, Mann-Whitney test.
b. $p < 0.01$, Mann-Whitney test.

Except on the South Fork Coeur d'Alene River, assessment soils were generally more acid than unexposed soils. The pH at all but one site on Canyon Creek (pH = 3.9) exceeded 4. Ninemile Creek assessment soils had significantly lower pH and lower percent organic carbon than Ninemile Creek reference soils. South Fork Coeur d'Alene River soils had significantly greater pH and percent sand than Little North Fork soils, and significantly less silt, clay, and organic carbon ($p < 0.05$; Figure 9-6).

Concentrations of hazardous substances in lower Coeur d'Alene soils were generally lower than those in assessment soils of the upper basin, but concentrations of organic carbon and clay were generally greater (Figure 9-6). Concentration means and ranges by subarea of the lower basin are presented in Table 5-1 (Chapter 5, Sediment Resources).

9.5.2 Plant Growth Tests

Plant growth performance in assessment and reference soils was compared by species and endpoint. For comparison, data from each of the reference areas (Little North Fork, Canyon Creek, and Ninemile Creek) were pooled, and data from the assessment areas (South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek) were pooled. Table 9-4 summarizes the results of phytotoxicity tests in upper basin soils by species and endpoint. Comparisons in which the lower Coeur d'Alene samples were included as assessment samples were also made. However, there was little evidence of a concentration-response relationship in lower Coeur d'Alene soils used in the phytotoxicity tests, so injury assessment, and the following presentation of results, focused on upper basin soils.

Table 9-4
Summary of Growth Responses of Alfalfa, Wheat, Lettuce, and Poplar in Upper Basin Soils

Endpoint	Soil Source	N	Mean	Median	SD	Minimum	Maximum
Alfalfa							
Root Length	Assessment Reference	13 10	28.5 46.1	24.5 43.3	22.7 22.1	2.6 19.1	75.1 85.7
Root Mass	Assessment Reference	13 10	0.015 0.017	0.013 0.014	0.012 0.013	0.001 0.001	0.037 0.037
Shoot Length	Assessment Reference	13 10	32.1 60.8	38.2 56.0	16.7 13.6	7.8 44.7	54.8 82.5
Shoot Mass	Assessment Reference	13 10	0.042 0.072	0.046 0.088	0.026 0.046	0.006 0.004	0.093 0.121
Total Length	Assessment Reference	13 10	60.7 107	61.6 95.3	38.0 31.8	11.9 68.6	130 161
Total Mass	Assessment Reference	13 10	0.058 0.089	0.061 0.105	0.037 0.055	0.007 0.005	0.129 0.145
Lettuce							
Root Length	Assessment Reference	13 10	28.7 41.7	31.0 43.4	22.1 10.3	0.9 23.2	67.6 57.5
Root Mass	Assessment Reference	13 10	0.012 0.022	0.007 0.020	0.014 0.013	0.000 0.001	0.039 0.050
Shoot Length	Assessment Reference	13 10	27.7 53.1	31.9 52.3	15.8 12.3	7.0 33.0	53.0 69.2
Shoot Mass	Assessment Reference	13 10	0.042 0.072	0.034 0.078	0.035 0.031	0.004 0.004	0.110 0.109
Total Length	Assessment Reference	13 10	56.3 94.9	61.6 93.8	37.2 16.7	8.5 56.2	116 114
Total Mass	Assessment Reference	13 10	0.054 0.094	0.041 0.101	0.047 0.039	0.006 0.005	0.146 0.136

Table 9-4 (cont.)
Summary of Growth Responses of Alfalfa, Wheat, Lettuce, and Poplar in Upper Basin Soils

Endpoint	Soil Source	N	Mean	Median	SD	Minimum	Maximum
Wheat							
Root Length	Assessment Reference	14 10	139 207	181 212	101 28	5.3 167	249 239
Root Mass	Assessment Reference	14 10	0.016 0.017	0.017 0.017	0.007 0.003	0.008 0.013	0.026 0.020
Shoot Length	Assessment Reference	14 10	152 239	181 239	50 19	57.4 209	202 275
Shoot Mass	Assessment Reference	14 10	0.020 0.032	0.021 0.032	0.006 0.003	0.010 0.027	0.028 0.039
Total Length	Assessment Reference	14 10	291 446	350 449	149 43	63 389	443 512
Total Mass	Assessment Reference	14 10	0.036 0.049	0.039 0.048	0.012 0.005	0.018 0.043	0.053 0.058
Poplar							
Branch Growth	Assessment Reference	7 5	163 253	199 262	82 26	36.0 223	239 282
Leaf Mass	Assessment Reference	7 5	3.96 5.81	4.80 5.75	2.08 0.60	0.73 4.96	5.69 6.56
Leaves Added	Assessment Reference	7 5	4.26 6.68	4.60 6.00	2.39 2.11	0.80 5.40	6.40 10.40
Root Growth	Assessment Reference	7 5	77.8 151	113 132	68.3 32	-22.6 122	136 193
Roots Added	Assessment Reference	7 5	4.26 6.68	4.60 6.00	2.39 2.11	0.80 5.40	6.40 10.40

Since there is no regulatory or “standard” definition of toxicity for plants, phytotoxicity was defined as a significant difference ($p < 0.05$) from reference. Plant growth was reduced significantly in assessment soils relative to reference soils for all species tested. Shoot length and total length of alfalfa, lettuce, and wheat, and shoot mass and total mass of wheat were significantly ($p < 0.05$) reduced in assessment soils relative to reference soils (Table 9-5). Shoot and root mass of lettuce were significantly reduced at $p < 0.08$. Branch growth, leaf mass, and root growth of poplars were significantly reduced in assessment soils relative to reference soils ($p < 0.05$).

Table 9-5
Phytotoxicity Summary Statistics and
Comparison of Reference and Assessment Endpoints

	Assessment			Reference			Mann-Whitney
Endpoint	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**p-value**
Alfalfa							
Root Length	13	28.5	6.29	10	46.1	6.99	0.121
Root Mass	13	0.015	0.003	10	0.017	0.004	0.804
Shoot Length	13	32.1	4.63	10	60.8	4.31	0.000
Shoot Mass	13	0.042	0.007	10	0.072	0.014	0.121
Total Length	13	60.7	10.55	10	107	10.04	0.011
Total Mass	13	0.058	0.010	10	0.089	0.017	0.154
Lettuce							
Root Length	13	28.7	6.14	10	41.7	3.27	0.107
Root Mass	13	0.012	0.004	10	0.022	0.004	0.072
Shoot Length	13	27.7	4.37	10	53.1	3.90	0.001
Shoot Mass	13	0.042	0.010	10	0.072	0.010	0.055
Total Length	13	56.3	10.33	10	94.9	5.28	0.013
Total Mass	13	0.054	0.013	10	0.094	0.012	0.072
Wheat							
Root Length	14	139	27.01	10	207	8.91	0.219
Root Mass	14	0.016	0.002	10	0.017	0.001	0.861
Shoot Length	14	152	13.40	10	239	5.91	0.000
Shoot Mass	14	0.020	0.002	10	0.032	0.001	0.000
Total Length	14	291	39.94	10	446	13.53	0.005
Total Mass	14	0.036	0.003	10	0.049	0.001	0.007
Poplar							
Branch Growth	7	163	30.83	5	253	11.59	0.012
Leaf Mass	7	3.96	0.79	5	5.81	0.27	0.028
Leaves Added	7	4.26	0.90	5	6.68	0.94	0.327
Root Growth	7	77.8	25.80	5	151	14.11	0.028
Roots Added	7	5.71	2.13	5	8.28	2.29	0.626

For all seeds that germinated, at least minimal growth occurred even in highly contaminated soils. Growth responses were highly variable both within and between species, and no obvious threshold effects were apparent. Correlation analyses indicated that for alfalfa, lettuce, and wheat, root length, stem mass, and stem length, total mass, and total length, and for lettuce, root mass, were significantly negatively correlated with concentrations of lead (Table 9-6).

Table 9-6
Significant Correlation Coefficients (Spearman's rho; $p < 0.05$) Relating Growth Endpoints and Hazardous Substance Concentrations and pH for Alfalfa, Lettuce, and Wheat

Species	Analyte	Root Mass	Root Length	Stem Mass	Stem Length	Total Mass	Total Length
Alfalfa	Arsenic	—	—	—	-0.56	—	—
	Cadmium	—	—	—	-0.62	—	-0.47
	Copper	—	-0.46	—	-0.71	—	-0.64
	Iron	—	—	—	-0.63	—	-0.51
	Manganese	—	—	—	-0.43	—	—
	Lead	—	-0.59	-0.51	-0.83	-0.51	-0.75
	Zinc	—	—	—	-0.61	—	-0.48
	Clay	—	—	—	—	—	—
	Sand	—	—	—	—	—	—
	Nitrate	—	-0.59	-0.45	-0.83	-0.47	-0.74
	Organic C	—	—	—	0.50	—	—
	pH	—	0.47	—	—	—	—
Lettuce	Arsenic	—	—	—	-0.52	—	—
	Cadmium	—	—	—	-0.49	—	-0.43
	Copper	-0.42	—	-0.45	-0.55	—	-0.49
	Iron	—	—	—	-0.50	—	—
	Manganese	—	—	—	—	—	—
	Lead	-0.60	-0.57	-0.60	-0.68	-0.59	-0.65
	Zinc	—	—	—	-0.45	—	—
	Clay	—	—	—	—	—	—
	Sand	—	—	—	—	—	—
	Nitrate	-0.48	-0.57	-0.52	-0.73	-0.49	-0.67
	Organic C	—	—	—	0.43	—	—
	pH	—	0.45	—	—	—	—
Wheat	Arsenic	—	—	-0.61	-0.60	—	—
	Cadmium	—	—	-0.63	-0.63	—	—
	Copper	—	—	-0.72	-0.72	-0.49	-0.53
	Iron	—	—	-0.66	-0.64	—	—
	Manganese	—	—	—	-0.42	—	—
	Lead	—	-0.47	-0.83	-0.85	-0.68	-0.71
	Zinc	—	—	-0.64	-0.65	-0.42	-0.42
	Clay	-0.41	—	—	—	—	—
	Sand	—	—	—	—	—	—
	Nitrate	—	-0.57	-0.75	-0.86	-0.61	-0.78
	Organic C	—	—	0.70	0.67	—	0.45
	pH	0.67	0.50	—	—	—	—

— not significant.

Stem length for all three species was significantly negatively correlated with arsenic, cadmium, copper, iron, manganese (except lettuce), and zinc in addition to lead. Correlations with pH (positive) were significant only for alfalfa, lettuce, and wheat root length and wheat root mass, and correlations with organic C, also positive, were significant only for wheat stem mass, stem length, and total length, and alfalfa and wheat stem length. Correlations with percent sand were variable, and with nitrate, predominantly negative. There was a significant negative correlation between clay and wheat root mass; no other correlations with soil texture were significant. Significant correlations with nitrate were negative.

For poplar, branch growth, leaves added, and leaf mass were significantly negatively correlated with lead (Table 9-7). Branch growth and root growth were negatively correlated with nitrate and positively correlated with organic C. No other consistent correlations were observed. Figures 9-7 through 9-10 illustrate relationships between species endpoint responses and lead in soils.

Table 9-7
Significant Correlation Coefficients (Spearman's rho; $p < 0.05$) Relating Soil Metals Properties and Growth Endpoints for Hybrid Poplar

Analyte	Branch Length	Root Length	Number of Leaves Added	Number of Roots	Branch and Leaf Mass
Arsenic	—	—	—	—	—
Cadmium	—	—	—	—	—
Copper	—	—	—	—	—
Iron	—	—	—	—	—
Manganese	—	—	—	—	—
Lead	-0.66	—	-0.60	—	-0.63
Zinc	—	—	—	—	—
Clay (%)	—	—	—	—	—
Sand (%)	-0.63	—	—	—	—
Nitrate	-0.62	-0.59	—	—	—
Organic C	0.65	0.66	—	—	—
pH	—	—	—	0.72	—

— not significant.

The results of the plant growth studies indicate that assessment soils inhibit the growth of multiple plant species, as measured by multiple endpoints. The plant growth reductions were significantly negatively correlated with lead and other hazardous substance concentrations and with nitrate. The nitrate correlation may be more a result of the reduced plant metabolic activity in contaminated soils rather than a cause, since nitrate in a well vegetated, healthy soil is typically assimilated by plants extremely rapidly.

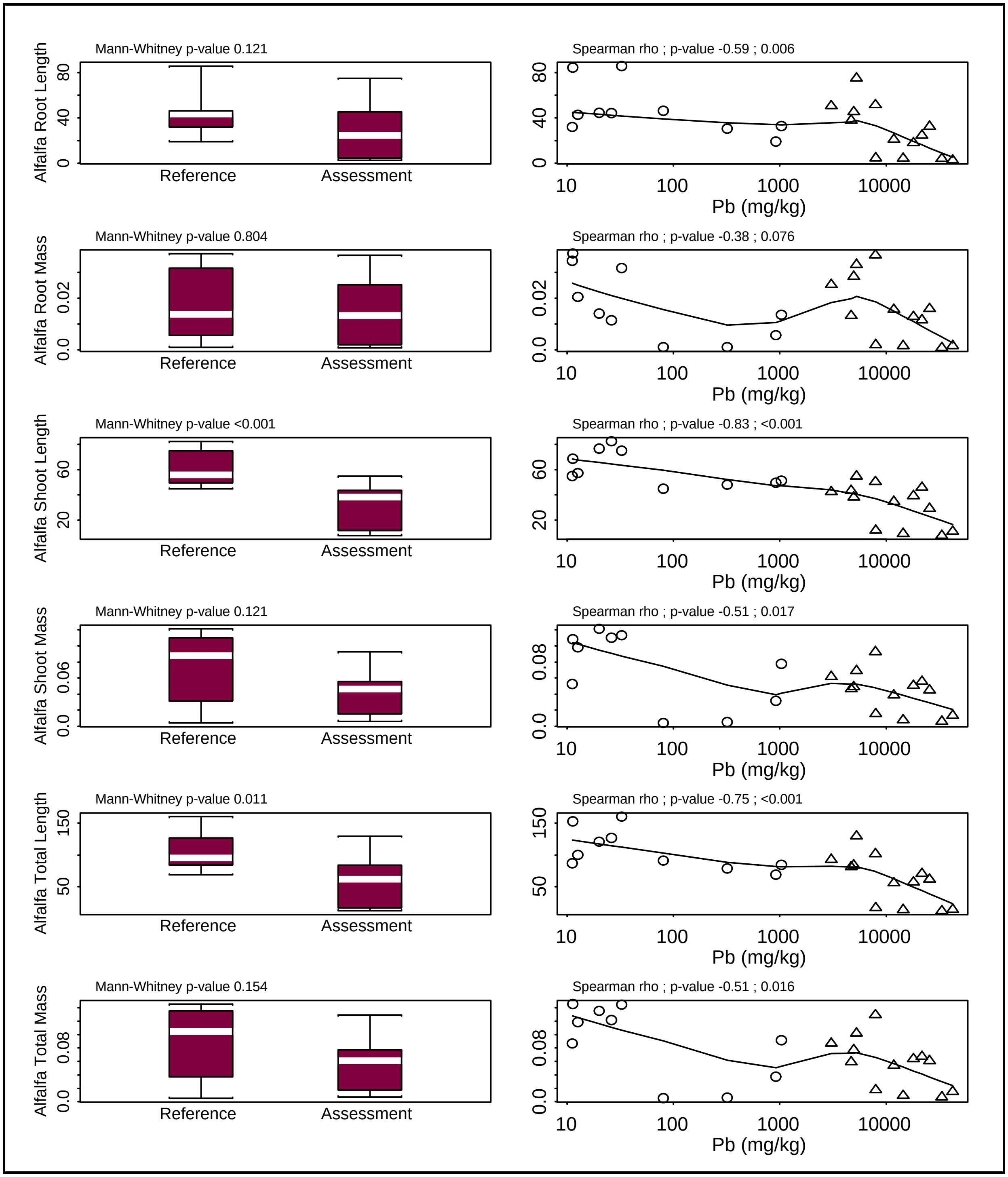

Figure 9-7. Growth responses of alfalfa seedlings tested in soils from upper basin reference areas (circles) and from upper basin assessment areas (triangles) compared to total lead (Pb) in soil. Box plots depict range, median, and interquartile range. Irregular line depicts trend estimated by locally weighted regression.

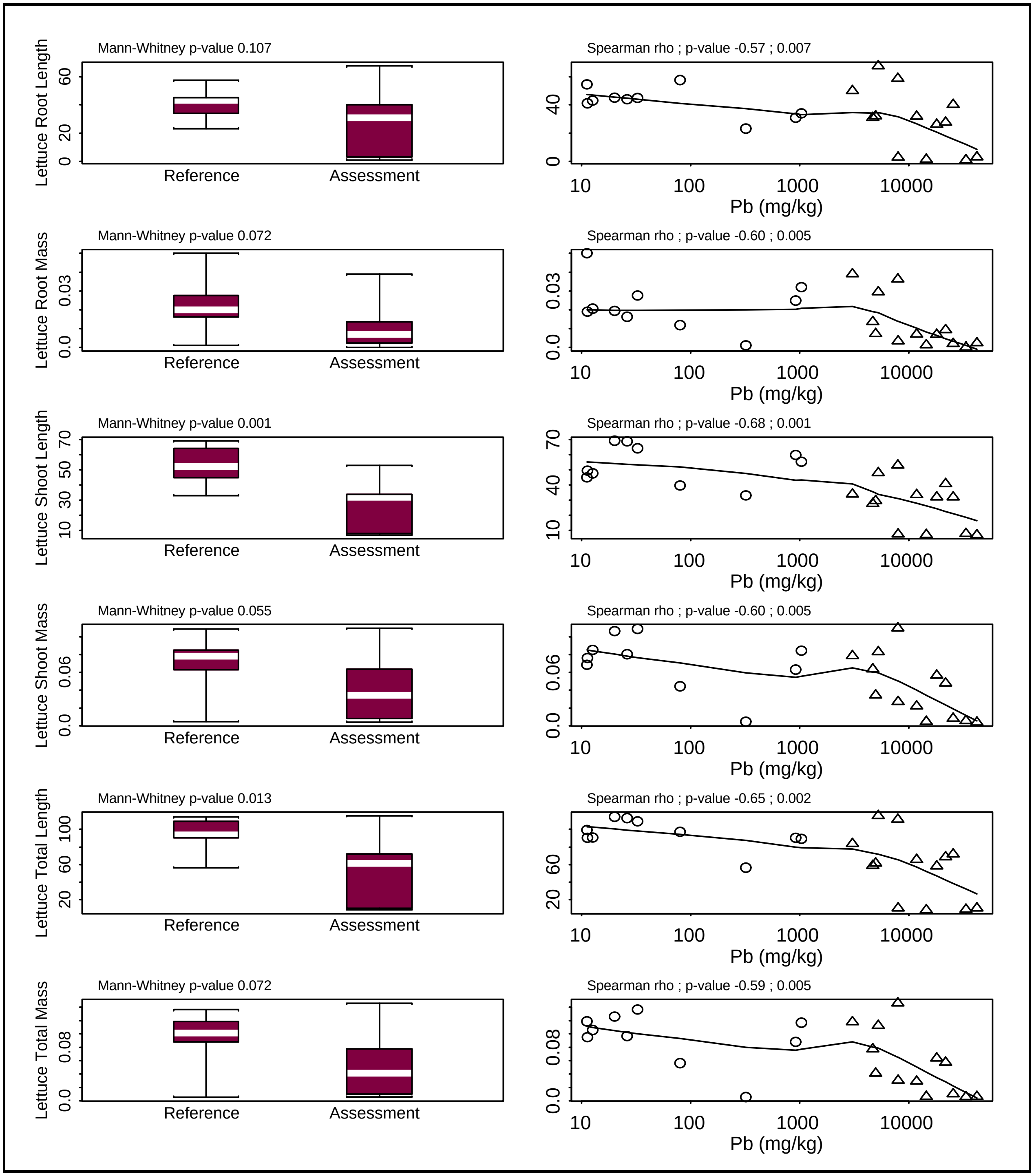

Figure 9-8. Growth responses of lettuce seedlings tested in soils from upper basin reference areas (circles) and from upper basin assessment areas (triangles) compared to total lead (Pb) in soil. Box plots depict range, median, and interquartile range. Irregular line depicts trend estimated by locally weighted regression.

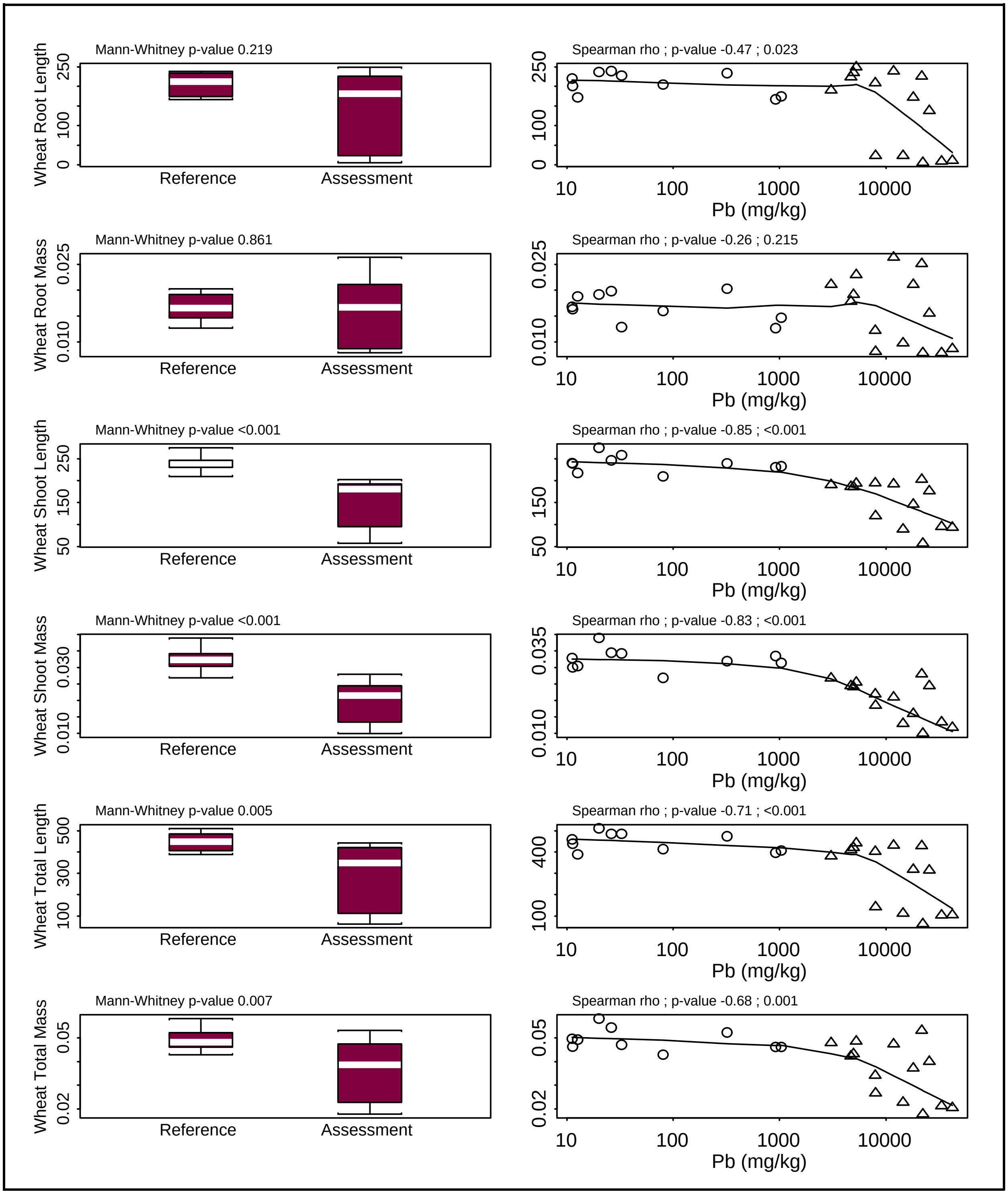

Figure 9-9. Growth responses of wheat seedlings tested in soils from upper basin reference areas (circles) and from upper basin assessment areas (triangles) compared to total lead (Pb) in soil. Box plots depict range, median, and interquartile range. Irregular line depicts trend estimated by locally weighted regression**.**

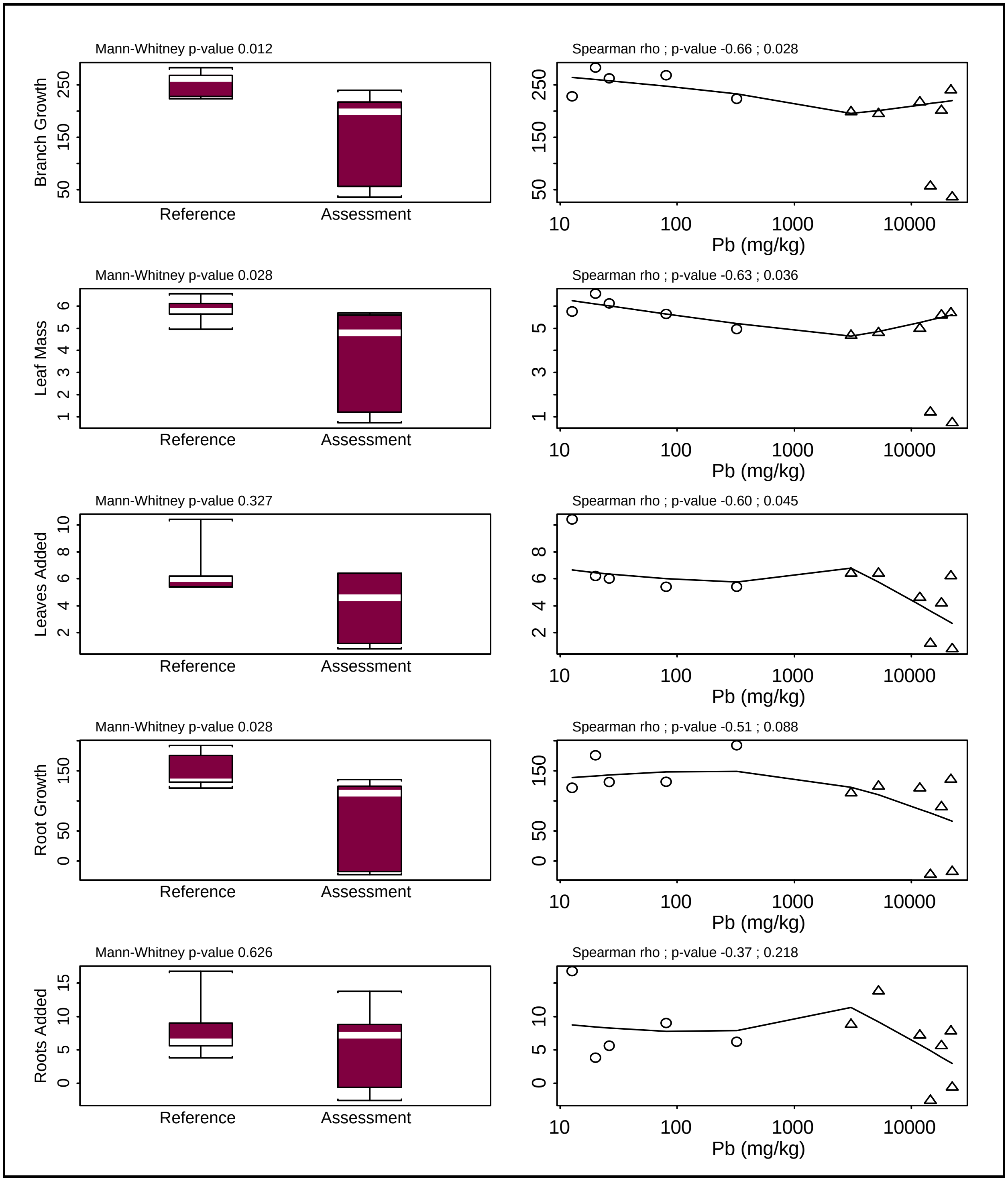

Figure 9-10. Growth responses of poplar tested in soils from upper basin reference areas (circles) and from upper basin assessment areas (triangles) compared to total lead (Pb) in soil. Box plots depict range, median, and interquartile range. Irregular line depicts trend estimated by locally weighted regression.

9.5.3 Field Vegetation Communities

Predominant Cover Type

Of the 107 sites sampled, 78% were classified as predominantly vegetated and 22% were classified as predominantly bare. Bare ground was the dominant cover type at 100% of the Canyon Creek assessment sites, 80% of the Ninemile Creek assessment sites, and 50% of the South Fork Coeur d'Alene River sites. Vegetated cover types were dominant at 100% of the reference sites.

All sites in the lower Coeur d'Alene River basin (n = 44) and on reference reaches in the upper basin (n = 23) were predominantly vegetated. Most of the assessment sites were predominantly barren. A significantly greater percentage of assessment than reference sites was classified as barren on the South Fork Coeur d'Alene River than on the Little North Fork ($p < 0.001$), in the Canyon Creek assessment area than reference area ($p < 0.001$), and in the Ninemile Creek assessment area than reference area ($p < 0.001$) (Table 9-8). Figure 9-11 shows examples of sites that were classified as predominantly vegetated and predominantly barren.

Table 9-8
Vegetated versus Nonvegetated Cover Type Comparisons

Location	Sample Sites with Dominant Cover Type = Vegetation (%)	Sample Sites with Dominant Cover Type = Bare Ground (%)
Reference Areas:		
Little North Fork	100	0
Canyon Creek	100	0
Ninemile Creek	100	0
Assessment Areas:		
South Fork CdA	50	50
Canyon Creek	0	100
Ninemile Creek	20	80
Lower Coeur d'Alene	100	0

The diversity of predominant vegetation types in the upper basin assessment areas was reduced relative to reference areas. Dominant cover types recorded at Little North Fork, Canyon Creek, and Ninemile Creek reference sites included evergreen forest, deciduous forest, deciduous shrubland, and grassland (Figure 9-12). Dominant cover types recorded at South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek assessment sites included bare ground, deciduous shrubland, and grassland. In the lower basin, the most common vegetation types were wetlands (48%) and deciduous shrub communities (27%). Two lower Coeur d'Alene sites were grazed or agricultural sites and were omitted from subsequent vegetation analysis.

Figure 9-11. (Top) Predominantly barren riparian zone (South Fork Coeur d'Alene, SF26). (Bottom) Predominantly vegetated riparian zone (Little North Fork Coeur d'Alene, NF03).

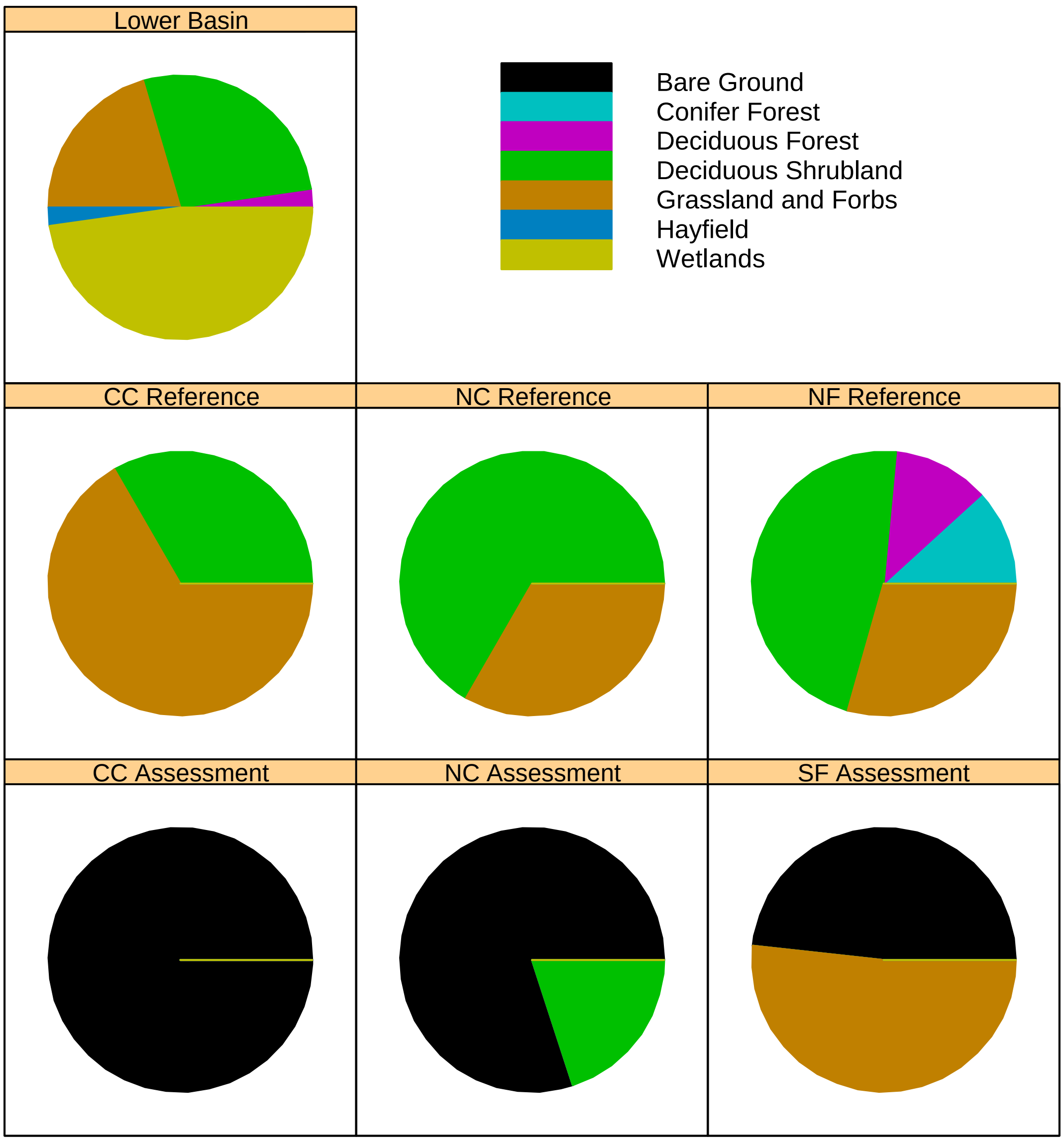

Figure 9-12. Most prevalent cover types in assessment and reference areas.

To confirm the visual estimate of bare ground as a dominant cover type, the line transect data were analyzed to determine the mean proportion of bare ground per site in each of the reference and assessment areas. The mean proportion of bare ground at assessment and reference area sites was compared. The mean bare ground per site was significantly greater ($p < 0.05$) at Ninemile Creek (75.7 %), Canyon Creek (93.5%), and South Fork (47.6%) assessment sites than at Ninemile Creek (5.6%), Canyon Creek (13.1%), and North Fork (4.3%) reference sites. Existing vegetation cover at upper basin assessment sites, even sites classified as predominantly vegetated, is significantly sparser than vegetation cover at reference sites.

Bare ground cover at each site is presented in Figure 9-13. Bare ground at upper basin assessment sites ranged from 0 to 100%, and at reference sites, from 0 to 16%. Bare ground at individual sites in the lower basin ranged from 0 to 72.5% and averaged 10.6%. Of the six assessment sites on Canyon Creek, one site had 31% cover and a second site had 6% cover. The site with 31% plant cover (CC04) included 24% cover by a single species of metals-tolerant grass (redtop, *Agrostis stolonifera*), and 7% cover of moss (Figure 30, Appendix A). Most of the rest of site CC04 (67%) was barren. The site with 6% vegetation cover (CC06) had 6% cover by moss (Figure 32, Appendix A). The rest of site CC06 (94%) was barren. The remaining four of the sites were 100% barren (CC05, CC07, CC08, CC09; Figures 31, and 33 through 35, Appendix A).

Of the five Ninemile Creek assessment sites, one had 23% cover, a second had 35% plant cover, and a third had over 100% plant cover. The site with 23% vegetative cover (NC15) had 23% cover by moss (Figure 39, Appendix A). The site with 35% cover (NC11) had 35% cover by moss (Figure 36, Appendix A). The site with 100% plant cover (NC12) extended from a completely barren section into a patch of alder adjacent to the East Fork Ninemile Creek road. Of the 10 meter transect, 40% was entirely barren. The remaining 60% contained all of the vegetation (Figure 37, Appendix A). The 100% cover score results from overlapping layers of vegetation in the vegetated segment. The remaining two of the five Ninemile Creek sites had no vegetative cover (e.g., Figure NC14).

Although 71% of the South Fork Coeur d'Alene River assessment sites had greater than 50% plant cover, again, the dominant vegetation taxa at South Fork Coeur d'Alene River sites was moss. Moss cover averaged 22% at South Fork Coeur d'Alene River sites. The remaining contributor to any extent was, again, redtop. Figures 1 through 29 in Appendix A show the South Fork Coeur d'Alene River sites. These photographs confirm that the South Fork Coeur d'Alene River sites were predominantly barren.

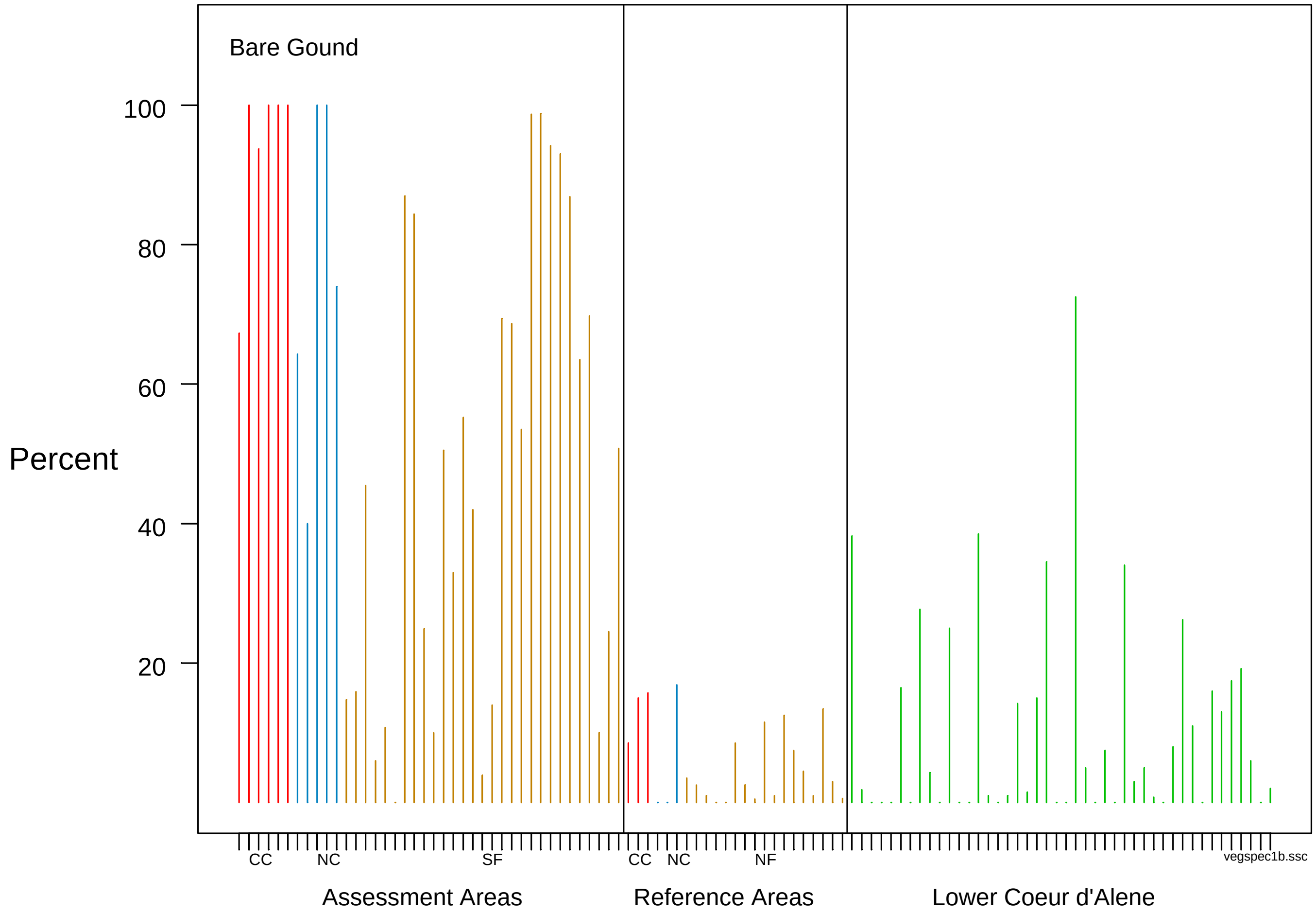

Figure 9-13. Cover of bare ground (meters) measured along a 10 m line transect at each site. CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

Plant Cover by Height Classification

Significant reductions in percent litter cover, herbaceous cover, and shrub cover were observed at the Ninemile Creek, Canyon Creek, and South Fork assessment sites relative to the reference sites (Table 9-9; Figure 9-14). The total cover (m) in the herbaceous, shrub, tree, and litter layers was significantly greater ($p < 0.05$) at Little North Fork reference sites than at South Fork Coeur d'Alene River assessment sites. The total cover of herbaceous, shrub, and litter layers was significantly greater at Canyon Creek reference sites than at Canyon Creek assessment sites ($p < 0.05$), but no differences were observed in tree canopy cover. Canyon Creek reference sites were predominantly grassland and deciduous shrubland, and Canyon Creek assessment sites were predominantly grassland and bare ground. The total cover of herbaceous and litter layers was significantly greater at Ninemile Creek reference sites than at assessment sites ($p < 0.05$). Cover of the shrub layer was greater at Ninemile Creek reference sites than at assessment sites at $p < 0.1$. No significant difference was observed for the tree layer ($p = 0.197$). Reductions in cover in herbaceous, shrub, tree, and litter layers indicate significant reduction in the vertical composition of vegetation communities at assessment sites.

Table 9-9
Mann-Whitney p-Values for Comparisons of Plant Cover by Layer for Assessment and Reference Sites

Comparison	Herb Cover (m)	Shrub Cover (m)	Tree Canopy Cover (m)	Litter Cover (%)	Bare Ground (%)
North Fork vs. South Fork	0.014[a]	< 0.001[a]	< 0.001[a]	< 0.001[a]	< 0.001[a]
Canyon Creek reference vs. assessment	0.031[a]	0.006[a]	NA	0.011[a]	0.015[a]
Ninemile Creek reference vs. assessment	0.025[a]	0.081	0.197	0.025[a]	0.024[a]

a. Indicates significantly greater cover in the reference area at the 5% level.
NA — not analyzed — tree cover recorded on one site only.

Figure 9-15 shows the cover by individual site of each vegetation in the herbaceous, shrub and tree layers. Cover in the tree and shrub layers was extremely low or absent at all upper basin assessment sites. Cover in the tree and shrub layers in the reference areas was variable, but considerably greater at reference areas than assessment areas. Herbaceous cover at assessment sites was also low relative to reference sites. Lower Coeur d'Alene sites lacked tree cover, and shrub cover was present at some sites but absent at others. Herbaceous cover at lower Coeur d'Alene sites was dense.

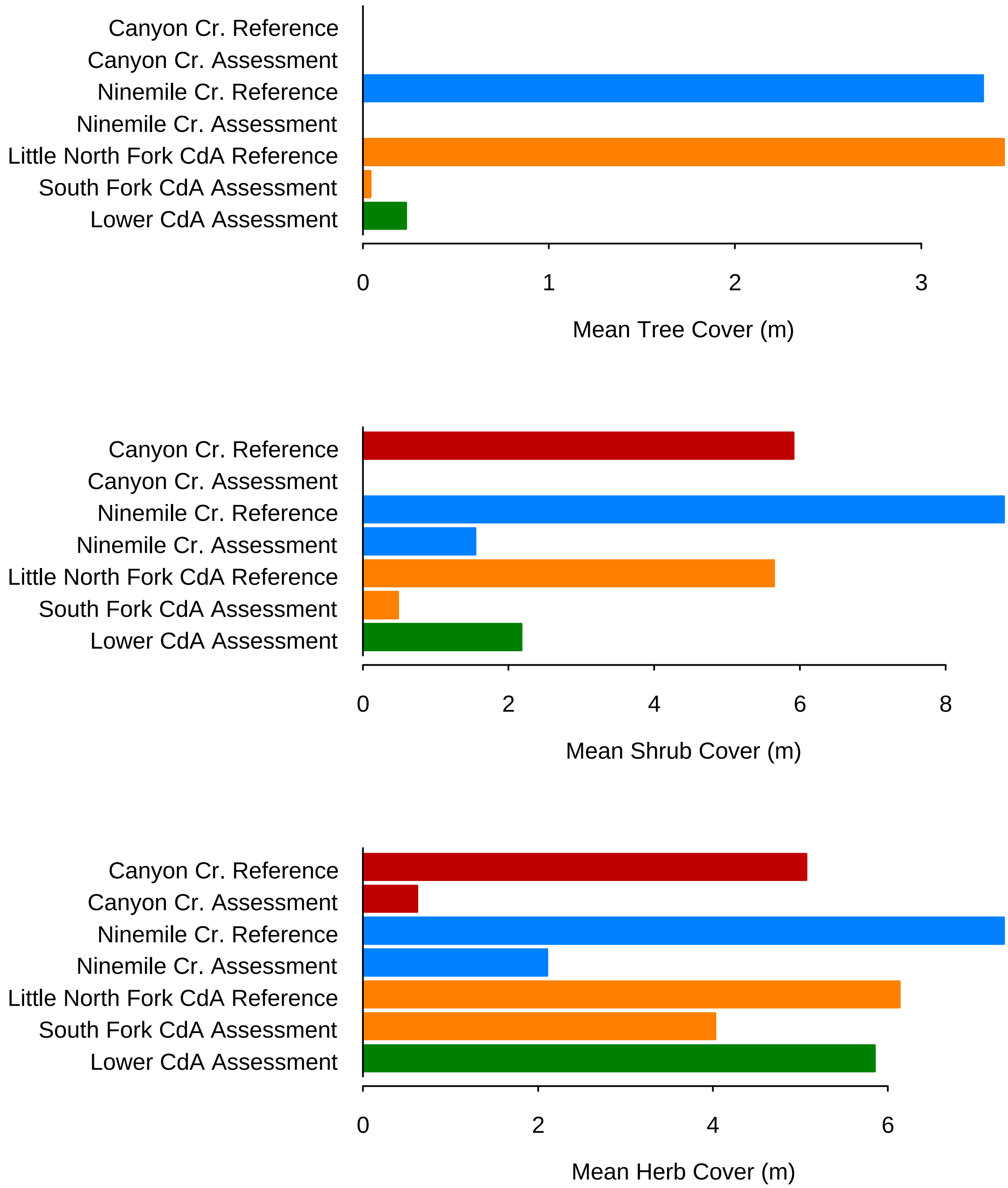

Figure 9-14. Mean tree cover, shrub cover, and herbaceous vegetation cover (m) at assessment and reference areas.

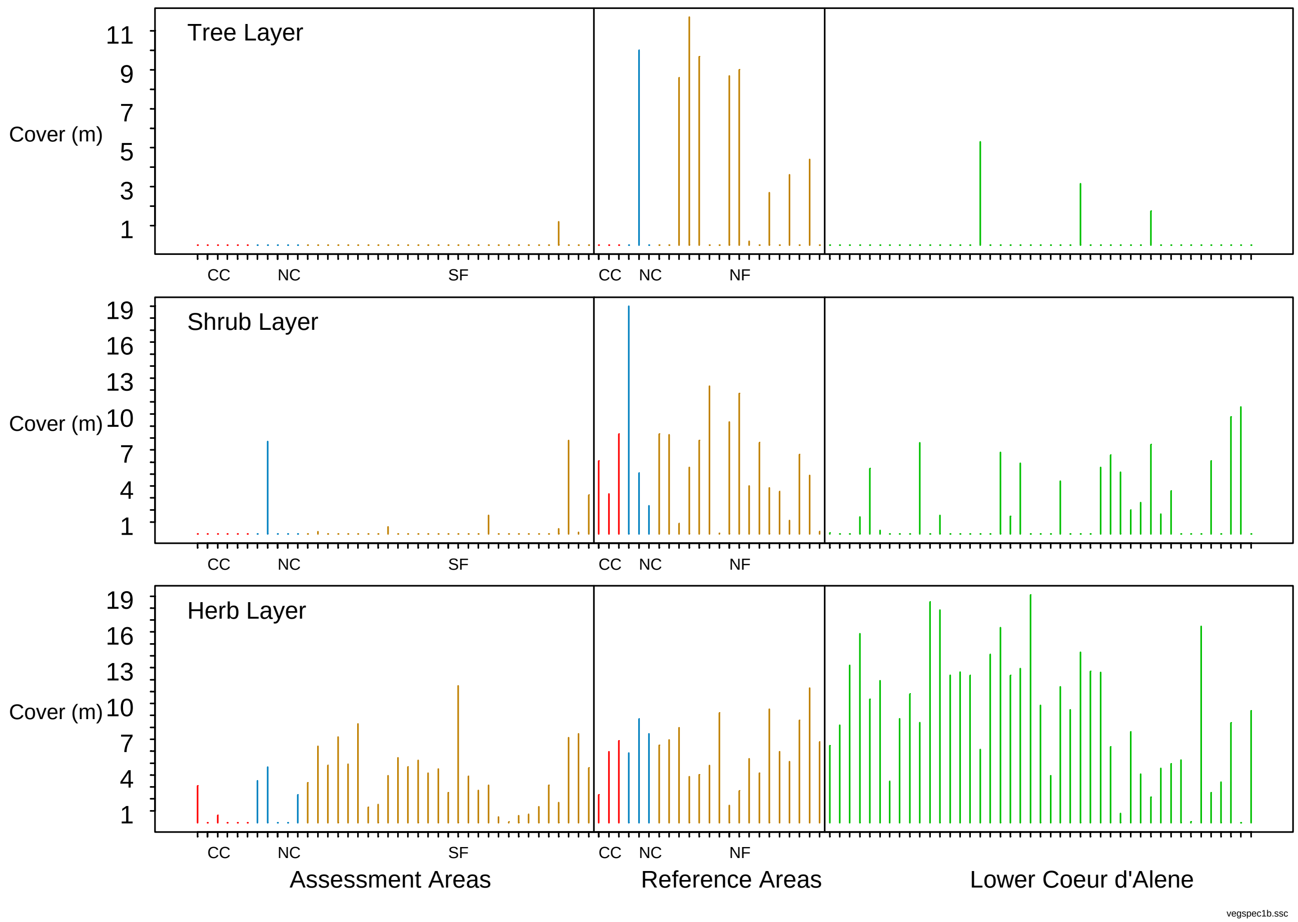

Figure 9-15. Cover (meters) in the tree, shrub, and herbaceous layers at each of the sample sites. CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

Species Richness

Across the assessment and reference sites, 172 vascular species were identified. In the herbaceous layer, 149 taxa, most to the species level, were identified. In the shrub layer, 54 taxa, again, most to the species level, were identified, and in the tree layer, 8 species were identified. Since the sampling was conducted in late summer, the herbaceous totals do not include spring ephemeral species that might be present. The maximum number of species identified at a single site was 25; most sites had fewer than 10. Sites on reference reaches of the upper basin had significantly greater overall species richness and species richness in the herbaceous and shrub layers than sites on assessment reaches. Tree species richness was low at all sites.

The majority of the vascular species identified were uncommon. Sixty-six (38%) were found only at one site, and 95% were found on fewer than 10% of the sites. The most frequently encountered species in the herbaceous layer were the graminoids redtop bentgrass (*Agrostis stolonifera*), reed canarygrass (*Phalaris arundinacea*), red tinge bullrush (*Scirpus microcarpus*), and tufted hairgrass (*Deschampsia cespitosa*), and the forbs cow parsnip (*Heracleum lanatum*), northern water hore-hound (*Lycopus uniflorus*), and pioneer violet (*Viola glabella*). The most frequently encountered species in the shrub layer were thinleaf alder (*Alnus incana*), Douglas' meadow sweet (*Spiraea douglasii*), mallow-leaf ninebark (*Physocarpus malvaceus*), common snowberry (*Symphoricarpos alba*), and sitka willow (*Salix stichensis*). Black cottonwood (*Populus trichocarpa*) and grand fir (*Abies grandis*) were the most common of the tree species. Moss (taxa not identified) was recorded at 62% of the sites.

Table 9-10 presents the most frequently encountered vascular plant species in the upper and lower basins by layer. For the upper basin sites, species representation is presented by assessment area and reference area. Species representation at upper basin assessment sites was dominated by redtop bentgrass (present at 70% of sites). All other species that were common at reference sites in the herbaceous, shrub, and tree layers were absent or poorly represented at the assessment sites. The riparian vegetation of the upper basin assessment sites is compositionally and structurally depauperate relative to the reference sites.

The number of species by site and the number of species within each habitat layer by site were analyzed to quantify relative differences in community composition between assessment and reference areas. Figure 9-16 presents the total number of species by layer at each of the assessment and reference sites. The numbers of species in the tree layer, shrub layer, and herb layer were considerably lower at upper basin assessment sites than at reference sites. Species richness at upper basin reference sites was also generally greater than at lower Coeur d'Alene sites. In Canyon Creek, 39 species were recorded at the three reference sites sampled; 2 species were recorded at the six assessment sites. In Ninemile Creek, 52 species were recorded at the three reference sites; 14 species were recorded at the five assessment sites. At Little North Fork reference sites, 106 species were recorded at the 17 sites sampled, while at the South Fork assessment sites, 35 species were recorded at 29 sites sampled. At lower Coeur d'Alene basin reference sites, 89 species were identified.

Table 9-10
Vascular Plant Species Frequency by Layer, Upper and Lower Coeur d'Alene River Basin[a]

Upper Basin	% of Sites Reference	% of Sites Assessment	Lower Basin	% of Sites
Herbaceous Layer			Herbaceous Layer	
Agrostis stolonifera	34	70	*Phalaris arundinacea*	41
Phalaris arundinacea	52	0	*Agrostis stolonifera*	36
Heracleum lanatum	43	0	*Scirpus microcarpus*	23
Viola glabella	39	0	*Lycopus uniflorus*	20
Tanacetum vulgare	39	2.5	*Sagitaria latifolia*	18
Carex deweyana	35	0	*Scirpus cyperinus*	18
Dactylis glomerata	17	15	*Deschampsia cespitosa*	16
Achillea millefolium	30	0	*Sparganium emersum*	14
Festuca subulata	30	0	*Lemna minor*	14
Plantago laceolata	26	2.5	*Eleocharis acicularis*	14
Poa compressa	22	5	*Carex vesicaria*	14
Shrub Layer			Shrub Layer	
Physocarpus malvaceus	48	0	*Spiraea douglasii*	32
Alnus incana	39	5	*Alnus incana*	16
Symphoricarpos albus	35	0	*Salix drummondii*	7
Rhamnus purshiana	26	0	*Crataegus douglasii*	7
Salix stichensis	26	0	*Cornus stolonifera*	7
Tree Layer			Tree Layer	
Populus trichocarpa	35	2.5	*Populus trichocarpa*	5
Abies grandis	35	0	*Betula occidentalis*	2

a. Species presented are the 11 most common in the herbaceous layer, 5 most common in the shrub layer, and 2 most common in the tree layer.

Species richness in herbaceous and shrub layers is significantly reduced in the upper basin assessment areas relative to reference areas (Table 9-11). Where vegetation exists in the upper basin assessment area, the community is strongly dominated by a small number of species. At upper basin assessment areas, vegetation cover is strongly dominated by moss and *Agrostis stolonifera*. Six sites in the Smelterville Flats area support sparse cover of festuca (*Festuca ovina* and *Festuca* sp.) and orchardgrass (*Dactylis glomerata*). These species most likely remain from earlier revegetation trials (U.S. BLM, 1992, 1993; Section 9.3.2). Other species that occurred at more than two assessment sites include field horsetail *(Equisetum arvense*) at three sites and spotted knapweed (*Centaurea maculosa*), a noxious weed, at four sites. In reference areas and at lower Coeur d'Alene sites, dominance of a site by a single species is less common, and a much greater number of subdominant and rare species are present.

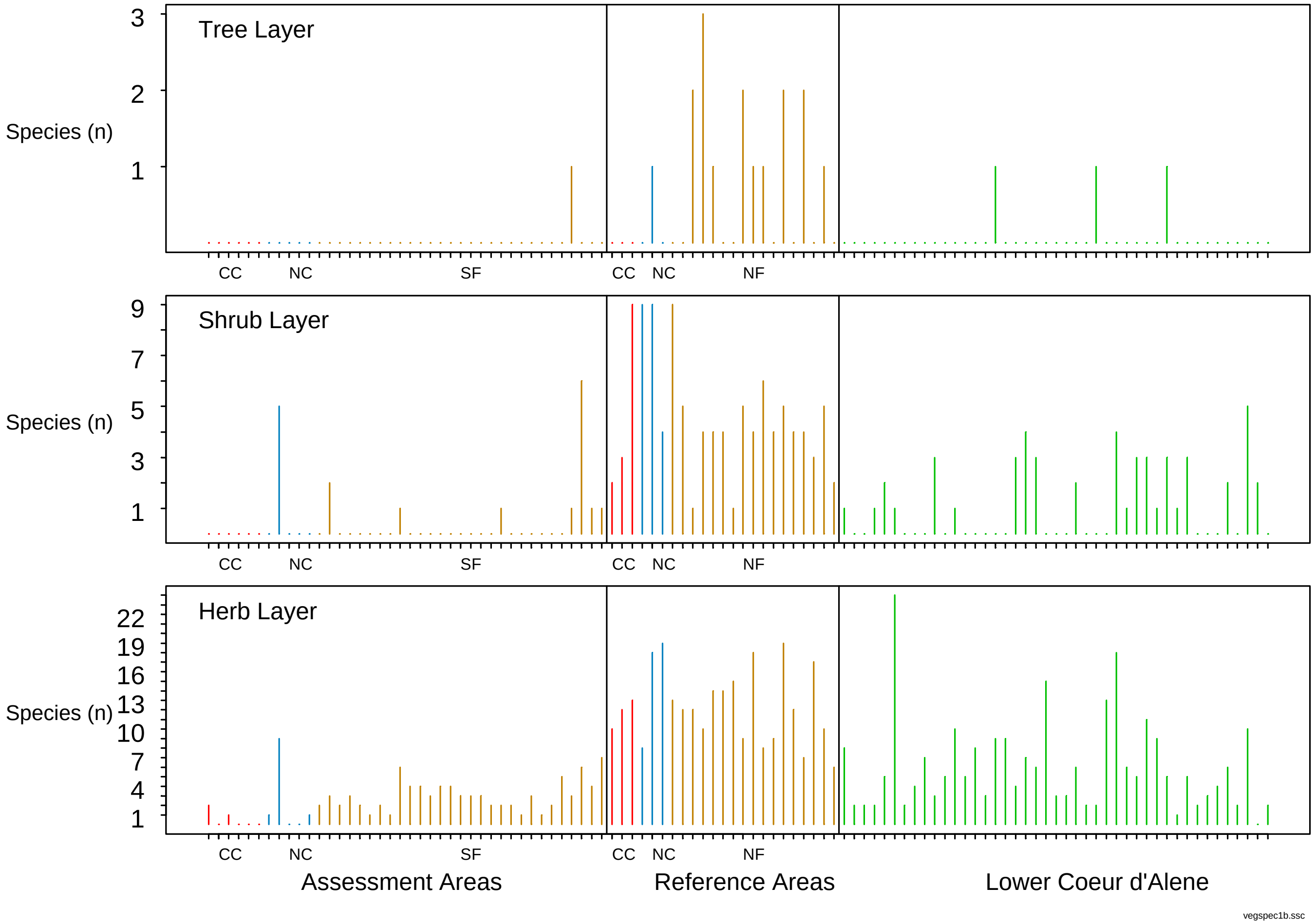

Figure 9-16. Number of species in the tree, shrub, and herbaceous layers at each of the sample sites. CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

Table 9-11
Mann-Whitney p-Values for Comparisons of Species Richness by Layer in Upper Basin Assessment and Reference Areas

Comparison	Number of Species: Herbaceous Layer	Number of Species: Shrub Layer
North Fork vs. South Fork	< 0.001[a]	< 0.001[a]
Canyon Creek assessment vs. reference	0.015[a]	0.006[a]
Ninemile Creek assessment vs. reference	0.050[a]	0.015[a]

a. Indicates that the reference area has a significantly greater species richness than the assessment area at $p \leq 0.05$.

The species richness data indicate substantial and statistically significant reductions in the number of species at upper basin assessment sites. The reductions are apparent in the herbaceous, the shrub, and overstory components of the vegetation community. The assessment sites are compositionally and structurally simplified relative to reference vegetation communities. Moreover, the only common species at the assessment sites (redtop bentgrass) is a species previously reported to be metals-tolerant (Chaney, 1993).

Structural Habitat Complexity

Significant differences were observed between the number of structural habitat layers at Ninemile Creek assessment and reference sites, and between the number of structural habitat layers at Little North Fork and South Fork Coeur d'Alene River sites (Figure 9-17). Both the Ninemile Creek reference sites and the Little North Fork sites were vertically complex: the Ninemile Creek reference sites each supported four layers: tree canopy, shrub midstory, understory, and terrestrial subsurface layers. The Little North Fork sites supported from three layers at 35% of the sites to five layers at 47% of the sites. The Lower Coeur d'Alene sites supported from two to five layers; 52% of sites had three layers (mainly shrub midstory, understory, and terrestrial subsurface layers), and 30% had two layers (mainly understory and terrestrial subsurface layers).

All of the assessment sites were vertically simple in comparison to the Little North Fork and Ninemile Creek reference sites. The number of habitat layers at South Fork Coeur d'Alene River sites ranged from zero to four, but the majority of the sites supported either one (41%) or two (41%) habitat layers. The number of habitat layers in the Ninemile Creek assessment area ranged from zero at 40% of the sites, to three at 20% of the sites, and in the Canyon Creek assessment area, from zero at 50% of the sites, to two at 17% of the sites (Figure 9-18).

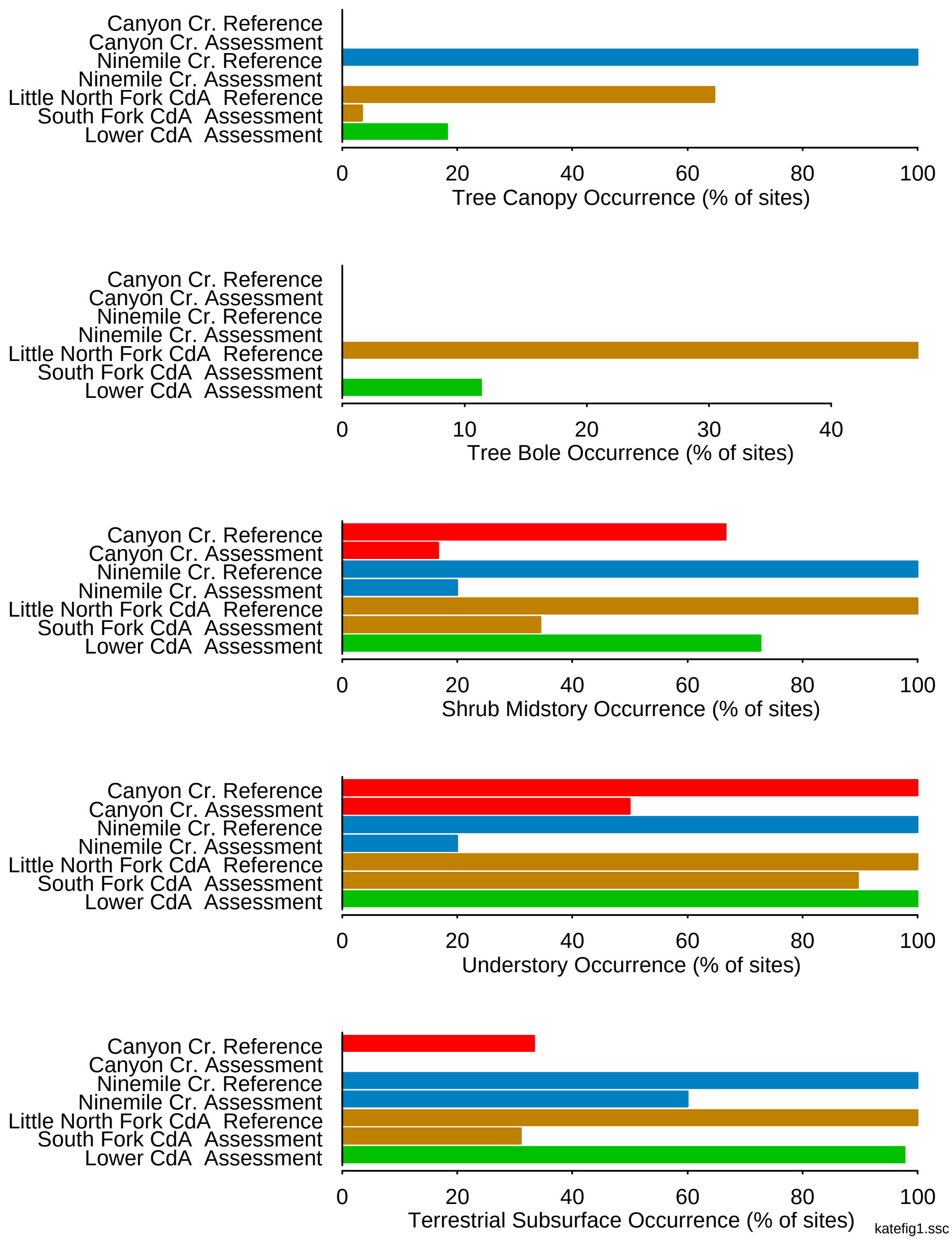

Figure 9-17. Percent of sites at which the following habitat layers were present within a 10 m radius of the site center: tree canopy, tree bole (trunk), shrub midstory, understory, terrestrial subsurface.

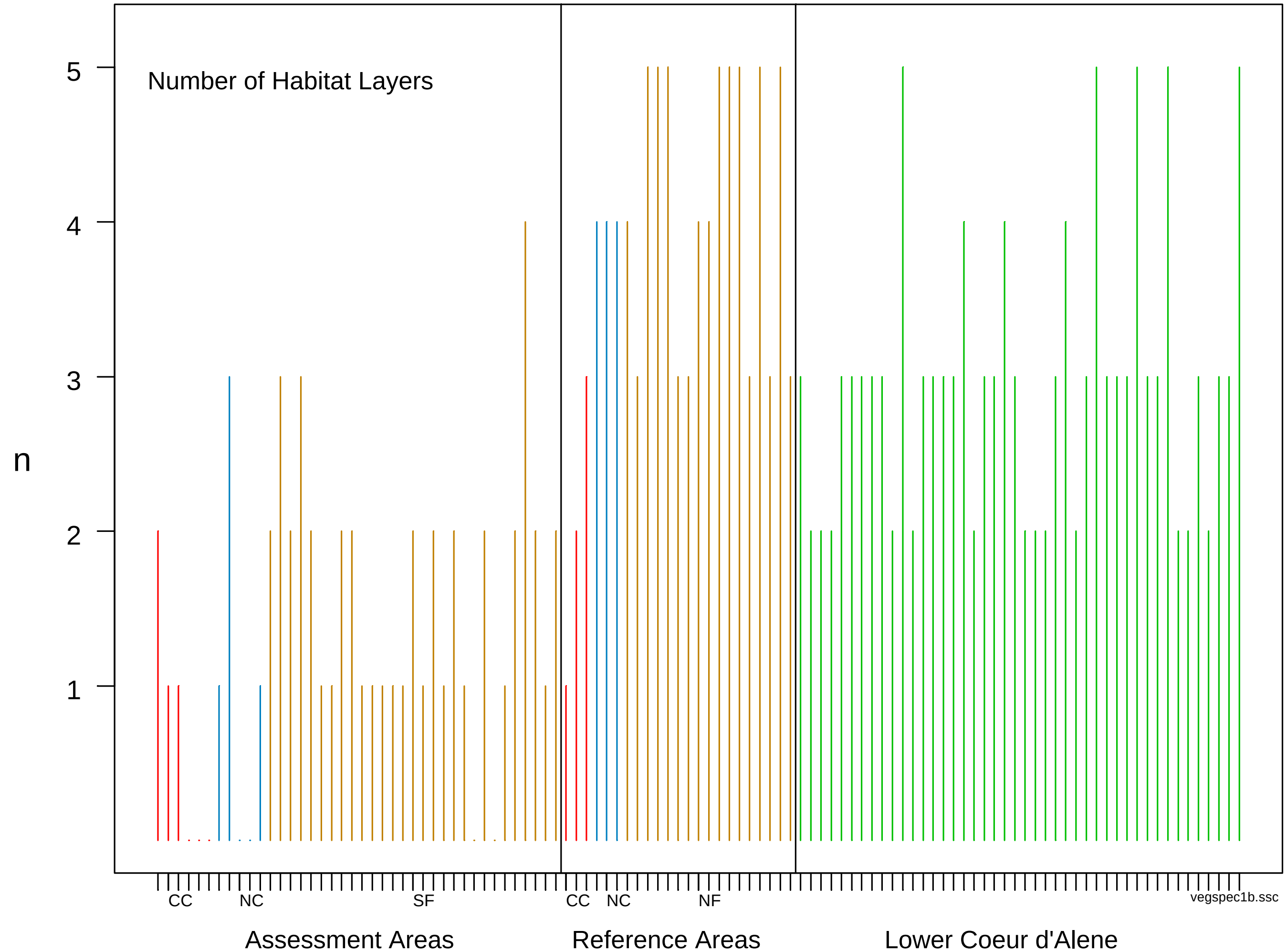

Figure 9-18. Number of habitat layers by site. Maximum number of layers at a site = 5. CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

The number of habitat layers at sites in the Canyon Creek assessment area was not significantly different from the number of layers at sites in the reference area. Of the reference sites, the upstream-most site had the lowest concentrations of hazardous substances, and the downstream-most site had the highest concentrations of hazardous substances. With an increase in concentrations of hazardous substances, a reduction in vertical complexity was apparent. A similar pattern was observed for a number of species and cover of shrub species.

The habitat layers present at the assessment sites are predominantly understory or terrestrial subsurface (Figure 9-17). In the Little North Fork and Ninemile Creek reference areas, tree canopy, tree bole (Little North Fork only), shrub midstory, understory, and terrestrial subsurface were present at most of the sites. The South Fork Coeur d'Alene River assessment area supported tree canopy at one site, terrestrial subsurface and shrub midstory at approximately 40% of the sites, and understory at 90% of the sites. In the Ninemile Creek assessment area, terrestrial subsurface was present at 60% of the sites, and shrub midstory and understory at only 20% of the sites. In Canyon Creek shrub midstory, understory, and terrestrial subsurface layers were represented at reference sites, and shrub midstory and understory at assessment sites.

In general, the quality and availability of riparian wildlife habitat (as indexed by vegetation structural complexity) have been reduced in upper basin assessment areas relative to reference areas. Niche space provided by tree canopy and tree bole is absent in the upper basin assessment areas and most lower Coeur d'Alene assessment sites. Tree canopy and tree bole layers were also absent at Canyon Creek reference sites. Niche space provided by the shrub midstory, understory, and terrestrial subsurface is reduced in upper basin assessment areas relative to reference areas. In the lower Coeur d'Alene, habitat provided by the shrub midstory may also be reduced.

Reduction in the vertical complexity of vegetation communities reduces both the quantity of available habitat space for wildlife and the quality of the habitat. Habitats that are structurally complex (i.e., have many habitat layers) generally support a more diverse fauna than structurally simple habitats, as has been shown for birds (MacArthur and MacArthur, 1961; Cody, 1975; Mosconi and Hutto, 1982; Sanders and Edge, 1998), reptiles (Pianka, 1967), fish (Tonn and Magnuson, 1982), and mollusks (Harman, 1972). Riparian vegetational complexity is also associated with increased avian abundance, species richness, and landscape-level biological diversity (Knopf and Samson, 1994; Sanders and Edge, 1998).

9.5.4 Relationship between Soil Metals and Field Vegetation

The analyses described below address the acceptance criterion at 43 CFR 11.62 (f)(2)(ii), which requires that documentation of an injury response in free-ranging organisms (field vegetation) include the correlation of the degree of the biological response to the observed exposure concentration of hazardous substances.

Correlation analysis was conducted to evaluate univariate relationships between measures of vegetation composition and structure and concentrations of hazardous substances and other parameters in soils. For the upper Coeur d'Alene sites, percent cover of vegetation by layer, number of species by layer, and number of habitat layers are significantly negatively correlated ($p < 0.05$) with concentrations of arsenic, cadmium, copper, iron, lead, manganese, and zinc (Table 9-12). Percent cover of bare ground was positively correlated with metals and arsenic concentrations.

Table 9-12
Significant Correlation Coefficients (Spearman's rho; p < 0.05) Relating Field Vegetation Measurements and Soil Chemistry

	As	Cd	Cu	Fe	Mn	Pb	Zn	Sand	Clay	Org. C
Upper Coeur d'Alene Sites										
Herbaceous Layer (m)	-0.25	-0.27	-0.28	-0.26	-0.18	-0.42	-0.30	-0.46	0.38	0.54
Shrub Layer (m)	-0.69	-0.70	-0.67	-0.71	-0.64	-0.68	-0.71	-0.38	0.47	0.66
Tree Layer (m)	-0.45	-0.46	-0.46	-0.48	-0.44	-0.46	-0.47	-0.27	0.35	0.40
Herbaceous Species (#)	-0.61	-0.60	-0.60	-0.58	-0.49	-0.69	-0.61	-0.42	0.42	0.67
Shrub Species (#)	-0.67	-0.71	-0.66	-0.70	-0.64	-0.69	-0.70	-0.42	0.49	0.69
Tree Species (#)	-0.45	-0.46	-0.45	-0.48	-0.44	-0.46	-0.47	-0.26	0.34	0.38
Bare Ground (%)	+0.44	+0.48	+0.52	+0.49	+0.43	+0.66	+0.53	0.59	-0.54	-0.69
Layers (#)	-0.55	-0.64	-0.68	-0.62	-0.54	-0.74	-0.67	-0.39	0.44	0.60
Lower Coeur d'Alene Sites										
Herbaceous Layer (m)	-0.52	-0.36	-0.49	-0.53	-0.49	-0.47	-0.37	—	—	0.51

— not significant.

No significant correlations were detected between field vegetation measures and pH. Significant positive correlations between pH and plant growth measures were detected in laboratory studies. However, the field vegetation data incorporate multiple species and lifestage responses to pH and gradients of, for example, water availability, light availability, physical disturbance, and temperature fluctuations. Given that soil pH at the majority of the sites sampled was within the range of pH that is conducive to plant growth, it is not surprising that at the vegetation community level, a significant correlation was not detected. Field vegetation measures were significantly positively correlated with percent clay and organic carbon, and negatively correlated with percent sand. Bare ground was positively correlated with percent sand, and negatively correlated with percent clay and organic carbon.

For the lower Coeur d'Alene sites, a significant negative relationship was detected between cover in the herbaceous layer and arsenic and all metals concentrations. A significant positive correlation was detected between cover in the herbaceous layer and percent organic carbon. No other significant positive or negative relationships were detected (Table 9-12).

To evaluate multivariate relationships between soil chemical quality and the composition and structure of field vegetation, soil groupings based on principal components analysis (PCA) and vegetation classifications using structural and compositional attributes were compared. PCA is a standard ordination technique used to identify linear combinations of variables that best explain the variation in a set of data with multiple attributes, such as measures of multiple soil metals concentrations (Gauch, 1982). Variables used in the soil PCA included standardized concentrations of arsenic, cadmium, copper, iron, manganese, lead, and zinc.

As a result of the PCA, sites were ordinated along two axes that explained 91% of the variation in the data set. The axes represent increasing concentrations of all metals and increasing divergence in metals concentrations (high concentration of some, low concentrations of others). Figure 9-19 shows the ordination of sites along principal component axes. At the origin is a cluster of sites, including the reference sites and some lower Coeur d'Alene sites. Assessment sites are scattered in the directions of increasing total metals concentration and increasing variability in metals concentrations. Sites were grouped into categories of metals enrichment and variability based on visual inspection of their distribution in Figure 9-19.

Cluster analysis was used to classify sites by similarity of vegetation structure. Cluster analysis is a standard classification technique used in vegetation analysis to group similar vegetation units (usually sample sites or communities) based on similarity of multiple attributes of the units (Gauch, 1982). In this case, a hierarchical classification technique was used to arrange groups of similar sites into nested groups. Variables used in the cluster analysis included total cover of vegetation, cover in the herbaceous layer, cover in the shrub layer, number of layers present, total number of species, number of herbaceous species, and number of shrub species. These variables were selected based on the measured reduction in structural and compositional heterogeneity downstream of major mining related disturbance. Multivariate analysis of vegetational attributes is presented for upper basin sites only. Since the univariate relationships between field vegetation in the lower basin and soil chemistry were nonsignificant (except for the negative correlations between metals concentrations and cover in the herbaceous layer), the remainder of the vegetation data analysis focused on the upper basin.

Four clusters were retained based on the cluster group means for each input variable and consideration of the level of grouping that was most ecologically meaningful (Figure 9-20). The resulting clusters include three exhibiting relatively complex structure and one in which cover, species richness, and number of layers were low. Sites in cluster A (Figure 9-20) generally are dominated by species-rich herbaceous vegetation surrounded by shrub and tree layers, such as meadows in riparian forest or shrubland. Sites in cluster B are shrub dominated and species rich, and they have the highest total cover. Sites in cluster C are dominated by herbaceous vegetation with lower diversity and cover than sites in cluster A. Sites in cluster D have low species richness in herbaceous and shrub layers; low herbaceous, shrub, and total cover; and low structural diversity.

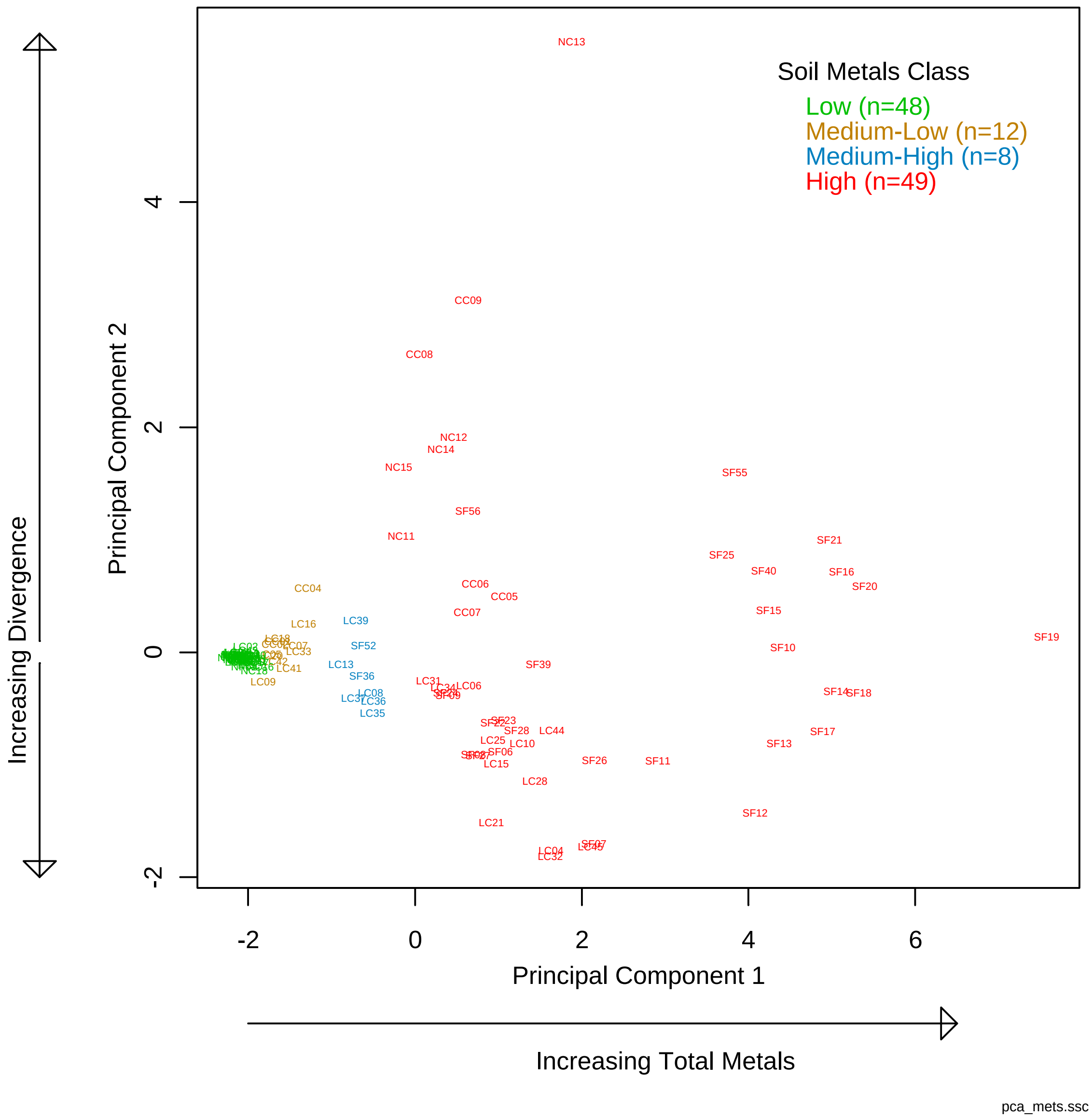

Figure 9-19. Ordination of sample sites based on principal components analysis of metals and arsenic concentrations in soils. Axes represent increasing total metals concentration and increasing divergence in metals concentrations. Sites were grouped into soil metals classes based on visual inspection of their distribution along the two axes. The cluster of points near the origin are sites with low metals concentrations. The cluster includes the reference sites and some of the Lower Coeur d'Alene sites.

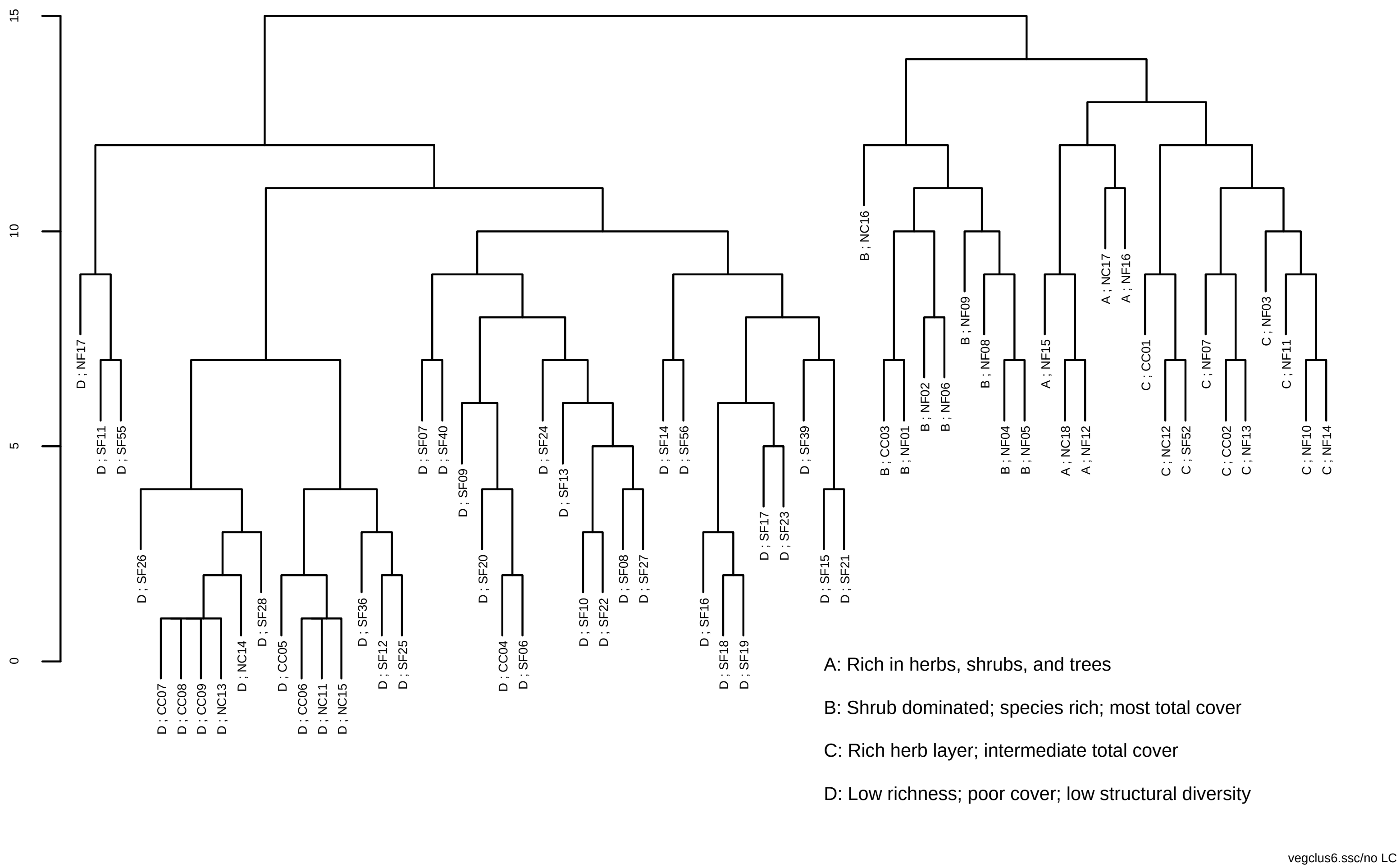

Figure 9-20. Dendrogram illustrating clusters of sites based on vegetation complexity measures. Letters preceding site identification codes indicate cluster group (A to D). CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

These clusters classify sites with generally similar vegetation community attributes. As an independent check on the appropriateness of the cluster groups, a principal components analysis was conducted using the same input variables. The PCA produced an ordination of sites consistent with the cluster groups (not shown).

Table 9-13 shows the relationship between soil categories and vegetation structure clusters. Soil categories range from “low metals” (soils with low metals concentrations and low variability among standardized metals concentrations) to “high metals.” Vegetation clusters include the three high complexity clusters and the low complexity cluster. The reference sites are all grouped in the “low metals” row, and most reference sites are grouped in a structurally and compositionally rich cluster. The majority of the assessment sites were categorized as “high metals” and were clustered in the structurally simple group. The relationship shown in Table 9-13 of structural simplicity where metals concentrations are high is consistent with the univariate correlation analysis results in Table 9-12.

Table 9-13
Relationship Between PCA Soil Categories and Vegetation Structure Clusters for Upper Basin Assessment and Reference Sites

Soil Category	Vegetational Structural Complexity			
	Structurally Complex			Structurally Simple
Low Metals	NF12 NC17 NF15 NC18 NF16	NF01 NF05 NF09 NF02 NF06 CC03 NF04 NF08 NC16	NF03 NF11 NC12 NF07 NF13 NF10 NF14	NF17
Medium-Low Metals			CC01 CC02	CC04
Medium-High Metals			SF52	SF36
High Metals				SF06 SF14 SF22 SF40 NC11 SF07 SF15 SF23 SF55 NC12 SF08 SF16 SF24 SF56 NC13 SF09 SF17 SF25 CC05 NC14 SF10 SF18 SF26 CC06 NC15 SF11 SF19 SF27 CC07 SF12 SF20 SF28 CC08 SF13 SF21 SF39 CC09

All but two of the upper basin reference sites were categorized as structurally complex, and all but two had low metals concentrations. All but two of the upper basin assessment sites were categorized as structurally simple, and none had low metals concentrations. The great majority of upper basin assessment sites had common attributes of high metals concentrations and low species richness and cover in herbaceous and shrub layers. Table 9-13 shows the high degree of correspondence of the vegetationally simple sites, categorized as such based on numerous vegetation attributes, with the sites where soils are metals-enriched.

Figures 9-21 and 9-22 show the species composition and cover by layer (herbaceous layer and shrub layer) by site, for each of the four clusters. Species that occurred at fewer than two sites were omitted from these figures. The triangles indicate cover less than 10% of the total vegetation cover at the site, and the circles represent cover greater than 10% of the total vegetation cover at the site. The colors represent soil cluster type: red indicates sites with "low metals" soils, green indicates sites with "medium-low metals" soils, brown indicates sites with "medium-high metals" soils, and blue indicates sites with "high metals" soils. Figures 9-21 and 9-22 show that sites in the structurally simple cluster (D), which included the majority of the upper basin assessment sites, were compositionally simple (low species richness), had sparse cover in the herbaceous and shrub layers relative to sites in the remaining three clusters (A-C), and, except for a single site at the mouth of the Little North Fork, had metals enriched soils. The sites with high concentrations of metals in soils (blue symbols) were consistently the most vegetationally simple sites.

Figures 9-21 and 9-22 illustrate the reduced species diversity, elimination of common and rare species found in reference areas and replacement by sparse cover of redtop bentgrass and moss, the reduction in biomass and productivity as indexed by cover, and the vertical simplification as reduction in cover in the herbaceous and shrub layers.

9.5.5 Evaluation of Causal Factors

Evidence of Hazardous Substance Causality

The results of the field vegetation studies and the relationships between soil chemistry, plant growth performance, and field vegetation structure and composition are consistent with metals toxicity as the cause of the adverse effects to vegetation. Evidence that hazardous substance concentrations in floodplain assessment soils cause injury to vegetation includes the following:

- **The assessment soils are contaminated with hazardous substances.**

Assessment area floodplain soils contain elevated concentrations of cadmium, lead, and zinc and other hazardous substances. Data presented in Tables 2-9 through 2-11 and 2-14 through 2-17 (Chapter 2), Table 9-3, and Figure 9-6 confirm that concentrations in assessment soils are elevated and exceed concentrations in reference soils.

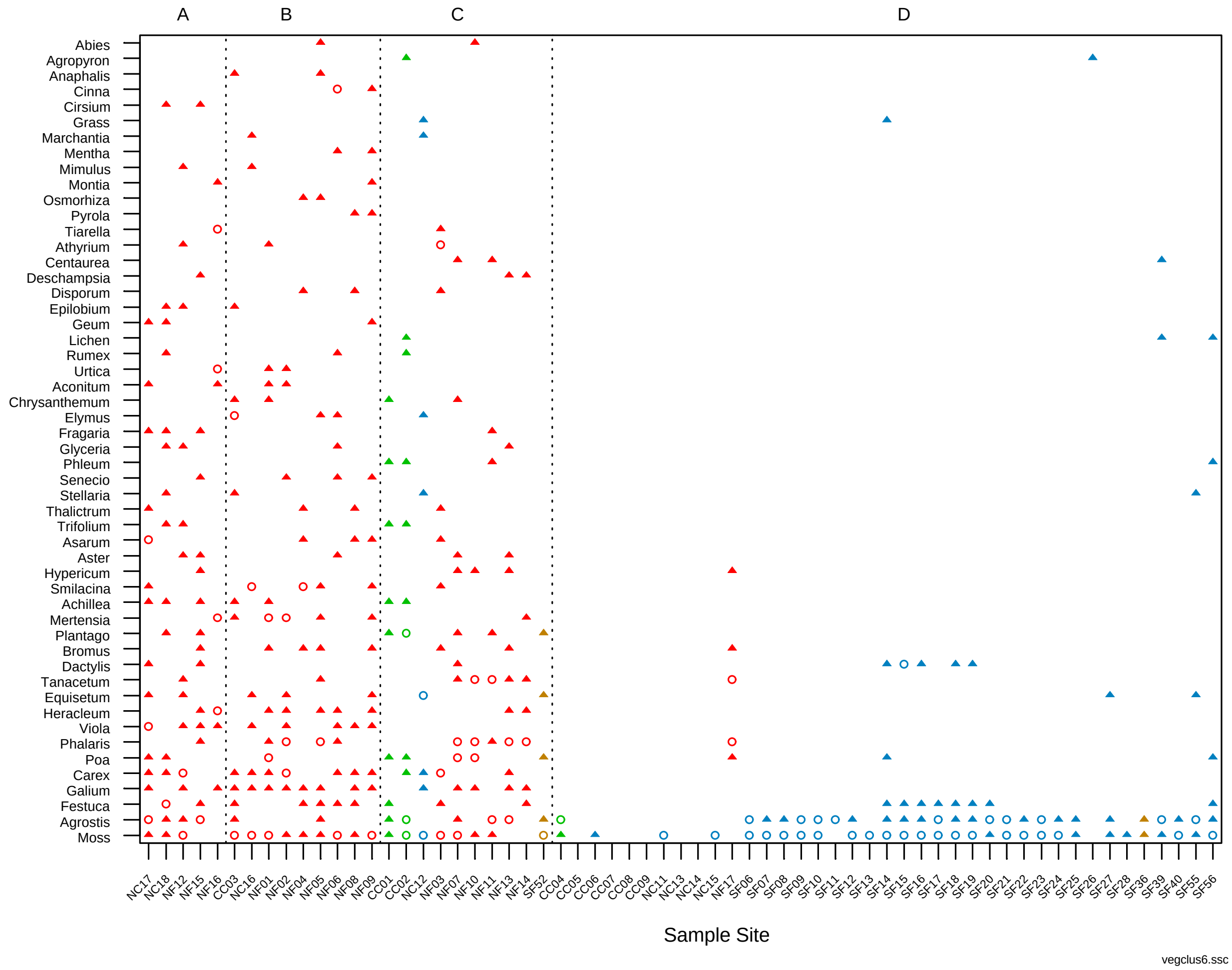

Figure 9-21. Herbaceous species composition by site. Sites are presented by cluster group. Herbaceous species that occurred at fewer than two sites are not shown. Triangles: cover less than 10% of the total vegetation cover at the site. Circles: cover 10% or more of the total vegetation cover at the site. Red: “low metals” soils; green: “medium-low metals” soils; brown: “medium-high metals” soils; blue: “high metals” soils.

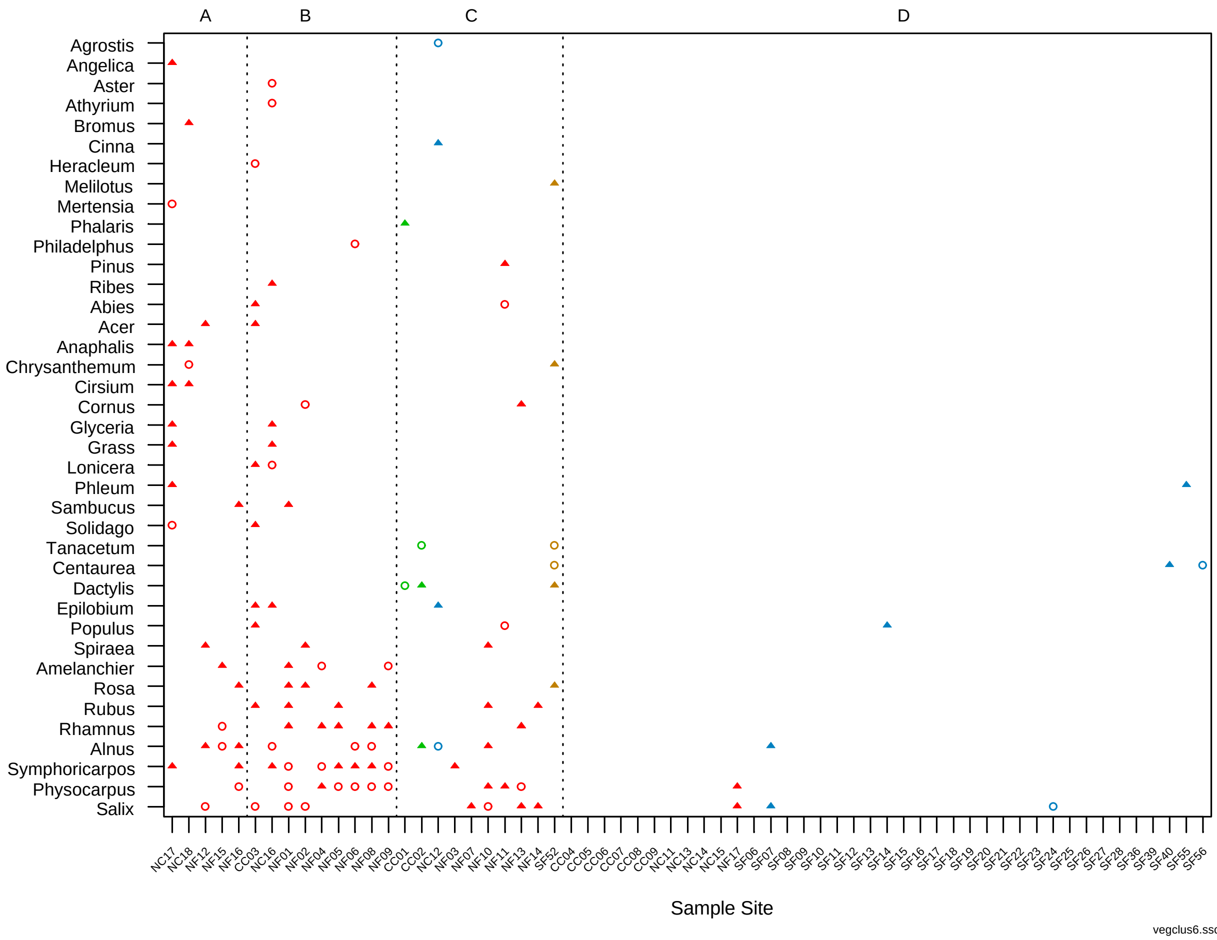

Figure 9-22. Shrub species composition by site. Sites are presented by cluster group. Shrub species that occurred at fewer than two sites are not shown. Triangles: cover less than 10% of the total vegetation cover at the site. Circles: cover 10% or more of the total vegetation cover at the site. Red: “low metals” soils; green: “medium-low metals” soils; brown: “medium-high metals” soils; blue: “high metals” soils.

▸ **Concentrations of hazardous substances in assessment soils exceed phytotoxic thresholds.**

The concentrations of hazardous substances measured in the assessment soils exceed phytotoxic thresholds described in the scientific literature and concentrations measured in other tailings-contaminated floodplain deposits that are vegetationally sparse or barren (Kabata-Pendias and Pendias, 1992; LeJeune et al., 1996; Rader et al., 1997; Stoughton and Marcus, 2000; Table 9-2). Maximum zinc concentrations in the assessment soils exceed toxic concentrations reported in the literature by three orders of magnitude, and mean zinc concentrations in Canyon Creek, Ninemile Creek, and South Fork Coeur d'Alene River assessment soils exceed phytotoxic concentrations by two orders of magnitude (Kabata-Pendias and Pendias, 1992). Concentrations of zinc in assessment soils are comparable to zinc concentrations determined to inhibit plant growth in Bunker Hill soils (Brown et al., 1998) (Table 9-14).

Table 9-14
Range of Mean Total Concentrations that Inhibited Plant Growth in Bunker Hill Revegetation Plots and Range of Mean Total Concentrations in Canyon Creek, Ninemile Creek, and South Fork Assessment Soils

	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Phytotoxic Thresholds[a]	3-8	100-400	70-400
Phytotoxic I-90 Plots[b]	7-22	1,500-4,900	5,500-14,700
Phytotoxic Hillside Plots[b]	21-44	700-2,000	1,000-3,000
Assessment Soils	9-40	12,400-27,300	2,580-5,550

a. Source: Alloway, 1990b.
b. Source: Brown et al., 1998.

▸ **Plant growth performance in assessment soils was reduced significantly relative to plant growth performance in reference soils in controlled laboratory tests.**

Growth in upper basin assessment soils of all species tested (lettuce, wheat, alfalfa, and poplar) and most endpoints (root length, shoot length and mass, and branch length) was reduced relative to growth in reference soils. In the laboratory, soil moisture, temperature, and photosynthetically available radiation were maintained at favorable levels for plant growth. The short exposure period (two weeks from time of planting to harvest) precluded the need to add nutrients, since stored reserves in the seed should be sufficient to support the seedlings at least during initial growth. Removing factors other than soil chemistry that might affect plant growth allowed a test of the phytotoxicity of substances in the soil that affect early seedling growth potential. The results confirm that phytotoxicity is manifest early in the life stages of plants, even in short duration exposures.

- **Plant growth in laboratory phytotoxicity studies was negatively correlated with concentrations of hazardous substances in soils.**

Growth of all plant species tested was negatively correlated with concentrations of lead, and stem length of alfalfa, lettuce, and wheat, and stem mass of wheat were negatively correlated with other metals and arsenic. The exposure-response relationships provide evidence of a causal linkage between lead and other hazardous substance concentrations in soils and the observed injury to field vegetation. Growth responses were negatively correlated with nitrate, which is typically a limiting nutrient to plants and does not accumulate in soil. The negative correlations with nitrogen were more likely a consequence of reduced nutrient uptake in toxic soils than a cause of growth inhibition. The absence of consistent correlations between other soil factors and growth inhibition, and the observed phytotoxic response of growth inhibition, are consistent with metals toxicity as the cause of growth reduction. Nutrient deficiency, if it had been expressed during the short exposure time, typically causes increased root length and similar or slightly reduced root mass relative to plants grown in nutrient sufficient conditions. No factor other than metals toxicity adequately explains the consistent growth reduction response nor the increased growth reduction response with increased metals concentrations, across all species and endpoints.

- **Vegetation cover, species diversity, and structural complexity in the field were negatively correlated with concentrations of hazardous substances in soils.**

In upper basin sites, cover and species diversity in the herbaceous, shrub, and tree layers and number of structural habitat layers were significantly negatively correlated with hazardous substance concentrations. Percent bare ground, in contrast, was positively correlated with hazardous substance concentrations. Vegetation measures were also positively correlated with organic carbon and clay content, and negatively correlated with sand content. These attributes covary with the degree of contamination, but the existing concentrations of organic carbon, clay, and sand alone are not sufficient to explain the observed field vegetation responses. Multivariate relationships between soil chemistry and vegetation structural and compositional complexity were consistent with the univariate correlations. Increasing metals concentrations and increasing heterogeneity of metals concentrations were associated with increasing compositional and structural simplification of vegetation communities. Moreover, the field vegetation and hazardous substance correlations are consistent with the laboratory correlations between plant growth and hazardous substance concentrations.

In the lower Coeur d’Alene basin, relationships between hazardous substance concentrations and vegetation cover, structure, and compositional indices were less pronounced. A significant negative relationship between cover in the herbaceous layer and metals concentrations and a significant positive correlation between cover in the herbaceous layer and organic carbon were detected, but no other significant relationships were detected. Concentrations of cadmium, lead, and zinc in lower Coeur d'Alene soils, while still substantially elevated relative to those in reference soils and phytotoxic thresholds, are significantly lower than concentrations in upper basin assessment soils (Table 9-3). In addition, the lower Coeur d'Alene soils contain significantly greater organic carbon content and significantly greater percent clay (mean 6.53% organic carbon; 15.7% clay) than upper basin assessment soils (mean 1.6% organic carbon; 6.5% clay) (Mann- Whitney $p < 0.01$). Clay minerals and organic matter are among the most important soil components contributing to the sorption of metal cations (Kabata-Pendias and Pendias, 1992). Complexing of metals with organic ligands and sorption by clay minerals decreases their availability for plant uptake.

The greater organic carbon and clay content of the lower basin soils is typical of large, meandering broad valley floodplain soils. Organic inputs (e.g., leaves, woody debris, microbes, and processed organic matter) from upstream production and processing are transported by the river to the lower valley floodplain (Vannote et al., 1980; Gregory et al., 1991). Transport of allochthonous material, including coarse, fine, and dissolved organic matter, from upstream reaches and tributaries is a major bioenergetic input to large rivers (Vannote, 1980). At high flow in the lower basin, the river spreads across the broad valley floor, dissipating much of the energy of the current, and suspended sediments and organic matter are deposited on the terrace and floodplain surfaces. The higher clay content of the lower basin sediments reflects the hydraulic sorting and transport of the finer materials farther downstream, and in large rivers, a large portion of the fine sediments is composed of mineral sediments that became coated with organics while in the stream (Gregory et al., 1991). Therefore, the higher clay and organic content of the lower basin soils is expected, based on river continuum and energetics processes. These materials are derived from the North Fork Coeur d'Alene River basin, the South Fork, and from smaller tributaries to the mainstem Coeur d'Alene River in the lateral lakes area. Dilution of the South Fork sediment inputs by North Fork and tributary sediment and organic matter inputs has attenuated the phytotoxicity of hazardous substance contamination in much of the lower basin.

The comparisons between the assessment and reference sites show statistically and ecologically significant differences between concentrations of hazardous substances in soils, and between vegetation community structure and composition. The structurally complex and dense vegetation expected in the riparian zones of the South Fork Coeur d'Alene River and Canyon and Ninemile creeks has largely been eliminated along the assessment reaches. Riparian communities downstream of milling sites in the upper basin are sparse, floristically poor, and structurally simple. Large areas of the floodplain are barren or covered by scattered grasses and mosses.

Other Potential Causal Factors

Factors other than toxicity of floodplain soils by metals in tailings and mixed tailings and alluvium could cause or contribute to the measured effects on riparian vegetation. Contributing stressors include early logging and clearing of the floodplains; channelization, road building, construction, and industry in the urban corridor; accelerated channel meandering with the increased sediment load of tailings; and lack of nutrients, organic matter, and water-holding capacity in floodplain tailings deposits. It is reasonable to recognize that the riparian zones of the South Fork Coeur d'Alene River and its tributaries are subject to numerous anthropogenic stressors in addition to hazardous substances in floodplain tailings materials, and that disturbances that occurred in the past may have lasting effects on the current condition of the riparian ecosystem.

Photographs of Burke and Wallace taken in the late 1880s and 1890s show that the riparian zones had already been cleared and cedar swamps drained during development of the towns (Magnuson, 1968). Milling began in the basin in 1886 at the Bunker Hill mill. From that time until 1968, discharge to streams and floodplains was the predominant tailings disposal method (Long, 1998; Fahey, 1990). The volume of tailings discharged overwhelmed the transport capacity of the rivers in the upper basin. Aggradation of the channel and the floodplain caused rapid meandering of the South Fork Coeur d'Alene River across the floodplain (Ioannou, 1979). Impoundments in lower Canyon Creek and on the South Fork Coeur d'Alene River near Osburn and Smelterville in the early part of this century buried the native floodplain under many feet of tailings.

A combination of physical and chemical disturbances most likely contributed to the original degradation of the natural functioning of the riparian ecosystem along the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, and other tributaries of the upper basin. The reference reaches were also subjected to substantial historical physical disturbance. Between 1880 and 1965 over 400 sawmills operated in the Coeur d'Alene River basin (Idaho Panhandle National Forests, 1998). Streams, rivers, and lakes were used to convey logs to sawmills. Splash dams and log chutes were constructed in the Little North Fork and other tributaries of the North Fork Coeur d'Alene River (Idaho Panhandle National Forests, 1998). Splash dams were temporary structures built to raise the water level and increase the energy of smaller streams to carry logs down to larger rivers. Logs, and a large volume of sediment that eroded from logged hillsides adjacent to the stream, were stored behind the dam. When the dam was breached, the accumulated logs, water, and sediment were discharged downstream to the next dam, where the process was repeated (Rabe and Flaherty, 1974). The flood and logs scoured the downstream riparian zones, and the accumulated sediments were moved downstream. Since the Little North Fork served as a reference site for riparian vegetation, the historical effects of physical disturbances related to logging, erosion, and floodplain and channel alterations are accounted for in the reference condition.

After the construction of tailings impoundments in the South Fork Coeur d'Alene River basin in 1968, sediment loading decreased substantially. Expected pioneer communities that naturally develop on alluvial deposits following flooding have not established in the upper basin, despite the presence of a seed source from the South Fork Coeur d'Alene River headwaters and freshly exposed mineral soils to which early successional riparian species are adapted (Hansen et al., 1990; Gregory et al., 1991). The floodplains of the South Fork Coeur d'Alene River and certain tributaries have remained substantially barren, and the functions of the riparian zone are not recovering naturally. Where revegetation projects in the upper basin floodplain have been initiated, long-term survival of plants has been low. Various revegetation projects in the upper basin have cited nutrient deficiency, water stress, and metals toxicity as contributors to the poor survival (Section 9.3.2).

In a naturally functioning riparian floodplain, nutrient availability is often high as a result of high clay and organic content in soils, and because of continual replenishment during flooding (Mitsch and Gosselink, 1986). Mineral nitrogen, which is often the most limiting nutrient in natural ecosystems, is largely derived from microbial decomposition of soil organic matter. Since tailings lack organic matter and cause toxicity to plants that would produce the organic matter in soils, the current toxic floodplain materials may lack sufficient total nitrogen to support long term plant growth (Claassen and Hogan, 1998). Although nitrate concentrations in upper basin assessment soils were significantly greater than in reference soils (Section 9.5.1), the concentrations represent relatively small amounts of plant-available nitrogen. Since nitrate is highly mobile and rapidly sequestered by plants or leached from natural systems, its greater accumulation in the assessment soils most likely reflects the lack of vegetative uptake.

Phosphorus can also be abundant in typical floodplain soils (Mitsch and Gosselink, 1986). In mature soils, phosphorus in the upper soil profile is predominantly held in organic forms, and plant growth may depend largely on the release of phosphorus from soil organic matter (Schlesinger, 1997). A comparison of phosphorus concentrations in assessment and reference soils was not made (phosphorus data were rejected as a result of poor matrix spike results). However, it is not unlikely that concentrations differ between assessment and reference area soils because mine wastes are often phosphorus-deficient, and the current toxic floodplain materials may be phosphorous deficient.

Revegetation studies conducted in the mid-1970s showed that irrigation was necessary to ensure survival of seeded grasses on Smelterville Flats (Section 9.3.2). In a naturally functioning floodplain, the duration and frequency of flooding or drought and the depth to the water table control riparian vegetation community types, and the existing riparian vegetation canopy density influences the heat inputs to the stream and soil surface (Hansen et al., 1990; Gregory et al., 1991). Pioneer communities develop on recent alluvial deposits near the river, where water is abundant. More mature late successional communities are found on the higher stream terraces where flooding disturbance is less frequent and depth to the water table is greater (Hansen et al., 1990; Gregory et al., 1991). Historical elimination of vegetation changed the microclimate of the riparian zone by reducing shading and water retention, and increasing evaporation. The absence of organic matter and root structure in the existing floodplain materials has probably reduced infiltration and water-holding capacity of the floodplain materials, and aggradation of materials in the floodplain may have changed the depth to the water table in parts of the valley. The current microclimate of the upper basin riparian zone is probably warmer and drier than a natural floodplain. Therefore, in some parts of the floodplain, water limitations could conceivably contribute to plant growth limitation. However, the change in microclimate has resulted from toxic floodplain tailings that eliminated vegetation and have prevented reestablishment of vegetation.

The field vegetation responses were positively correlated with percent organic carbon and clay and negatively correlated with percent sand. Since tailings are sandy and silty, and have no organic matter, and since tailings deposits are phytotoxic and organic matter is not being added to the soil as it would in a functional vegetation community, the observed correlations are not unexpected. The majority of the assessment soils were classified as sandy loams or loamy sands, based on the percentage of sand, silt, and clay (Brady and Weil, 1996). These are soil textural classes that would be expected to support vegetation. There is no reason to expect that based on texture alone, the soils would inhibit plant growth.

Riparian soils, particularly soils on which early successional riparian communities develop, are freshly deposited mineral sediments that may be low in organic matter. There is no reason to expect that the low organic carbon content is a cause of the plant growth inhibition at the assessment sites, but rather, it is a result of the toxic effects of the hazardous substances in the soils and resulting devegetation.

Urbanization and channelization undoubtedly have had effects on the natural flooding regime, nutrient inputs, and nutrient cycling. Construction in the floodplain has reduced the area of floodplain that could be occupied by natural riparian habitat. However, throughout the world, riparian zones of rivers bordered by towns, cities, interstates, and railroads do not exhibit the characteristics of the riparian zone of the South Fork Coeur d'Alene River. Moreover, sampling was conducted only in nonurban areas of the floodplain.

There are most likely a combination of factors that contributed to the original elimination of vegetation in the floodplains during the late 1800s and early 1900s. However, the only factor that consistently explains the toxicity of the soils to plants, and the continued preclusion of natural recolonization of the floodplains, is hazardous substance concentrations in the soils. The most significant and substantial differences between reference soils and assessment soils are the concentrations of hazardous substances in assessment soils relative to reference soils and the phytotoxicity of the assessment soils. The soil chemistry data, the vegetation community measurements, the phytotoxicity test results, and the negative correlations between hazardous substance concentrations and plant growth performance in the laboratory, vegetative cover, species richness, and structural complexity in the field, as well as previous revegetation studies conducted in the basin, consistently support the conclusion that elevated concentrations of hazardous substances in floodplain soils of the upper Coeur d'Alene River basin currently cause injury to vegetation communities. While historical activities have caused changes in the ecological functioning of the riparian ecosystem, the existing concentrations of hazardous substances in floodplain soils continue to cause phytotoxicity and to inhibit vegetation community development.

Conclusions

The injury assessment studies were designed as a triad of complementary studies (Figure 9-23). The soil chemistry analysis confirmed that hazardous substance concentrations are elevated in assessment soils compared to reference soils and that concentrations exceed published phytotoxicity thresholds. The laboratory phytotoxicity tests using field collected soils confirmed that South Fork Coeur d'Alene River basin soils containing elevated concentrations of hazardous substances are toxic to plants, and that the plant growth inhibition is positively correlated with increasing metals concentrations. The field vegetation data collected at the sites where soil samples were collected confirmed that as hazardous substance concentrations increase, the cover of vegetation decreases, the species diversity decreases, the structural complexity of vegetation communities decrease, and cover of bare ground increases. The field exposure-response relationships are consistent with the laboratory phytotoxicity exposure-response relationships, and both are consistent with published data on effects of metals in mine wastes on plant growth and vegetation community responses.

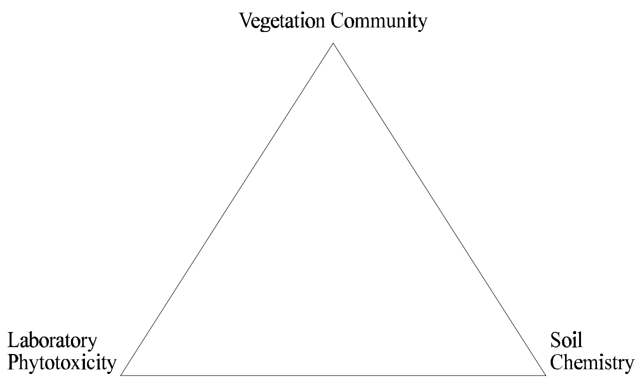

Figure 9-23. Injury determination "triad" approach.

Metals toxicity is the only consistent explanation of the results observed in the field and laboratory study components. Nutrient deficiency does not explain the growth inhibition measured in the laboratory phytotoxicity tests; water limitation does not explain the growth inhibition measured in laboratory phytotoxicity tests; physical disturbance does not explain the growth inhibition measured in laboratory phytotoxicity tests; urbanization, channelization, and physical disturbance do not explain the growth inhibition measured in laboratory phytotoxicity tests; and historical disturbances associated with the floodplain do not explain the growth inhibition measured in laboratory phytotoxicity tests. Field vegetation responds to a more complex set of environmental stressors, but the consistency of the correlations between field vegetation cover, species diversity, and structural complexity and metals concentrations in soils is evidence that hazardous substances are a strong determinant of the existing vegetation.

9.6 INJURY DETERMINATION EVALUATION

Historical information and the results of the injury determination studies confirm that riparian resources of the South Fork Coeur d'Alene River basin are injured. In summary, information considered during the injury assessment confirms that:

- Surface water and sediments containing elevated concentrations of hazardous substances serve as transport and exposure pathways of hazardous substances to floodplain soils of the Coeur d'Alene River basin.

- Floodplain soils and sediments contain elevated concentrations of hazardous substances, and concentrations are sufficient to expose riparian vegetation to hazardous substances.

- Riparian resources of Canyon Creek, Ninemile Creek, the South Fork Coeur d'Alene River, and the lower Coeur d'Alene River, including soils and vegetation, are exposed to elevated concentrations of cadmium, lead, and zinc.

- Hazardous substances in floodplain soils of the upper basin are sufficient to cause:

    - a phytotoxic response, specifically, retardation of plant growth [43 CFR § 11.62 (e)(10)]

    - adverse changes in viability, specifically, reductions in vegetation cover, and simplification of community structure and composition [43 CFR § 11.62 (f)(1)(i)].

A causal link between concentrations of hazardous substances in upper basin floodplain soils and adverse effects on riparian vegetation has been established. Similar responses have been observed at other mine sites where floodplains are contaminated with mine wastes, and no other potential factor explains the responses measured in both the laboratory tests and the field vegetation studies.

In addition, the sources and pathways of metals to floodplain soils of Pine and Moon creeks are similar to the sources and pathways of metals to floodplain soils of Canyon and Ninemile creeks and the South Fork Coeur d'Alene River (Chapters 2 and 3), and the concentrations of hazardous substances are similar to concentrations determined to be phytotoxic on Canyon and Ninemile creeks and the South Fork Coeur d'Alene River. Therefore, barren and sparsely vegetated areas of Pine and Moon Creek riparian zones are inferred to be injured as a result of phytotoxic concentrations of hazardous substances in the floodplain soils.

9.6.1 Pathway Determination

The purpose of the pathway determination is to identify the route or media by which hazardous substances have been transported from sources to riparian resources of the Coeur d'Alene River basin [43 CFR 11.63]. Information used in the pathway determination for riparian resources included:

- ***Hazardous substance sources.*** Information presented in the Chapter 2 confirms that historical sources discharged tailings to the basin, and that hazardous substances have come to be located in bed, bank, and floodplain sediments (and floodplain soils) throughout the basin. These contaminated floodplain, bed, and bank sediments are remobilized and re-released, and serve as ongoing sources of contamination (Figure 9-24).

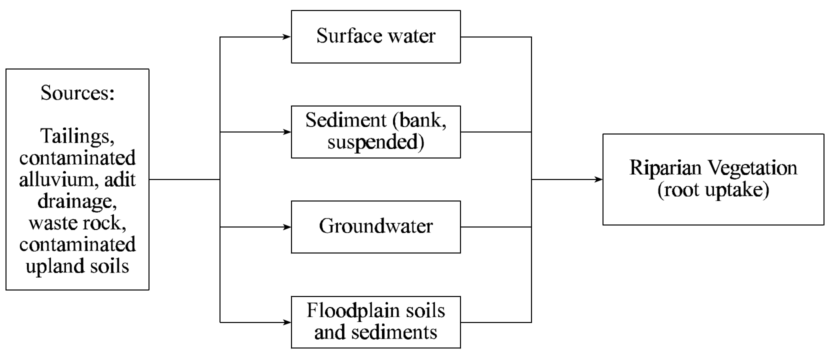

Figure 9-24. Hazardous substance transport and exposure pathways to riparian resources (transport via water/sediment; exposure via soils, vegetation).

- ***Transport pathways.*** Hazardous substances are transported by surface water as dissolved and suspended sediments and deposited on floodplain surfaces (Chapters 3, 4, and 5 — Transport and Exposure Pathways, Surface Water Resources, and Sediment Resources).

- ***Exposure pathways.*** Floodplains have been and continue to be exposed to deposition of hazardous substances transported by surface water. Riparian vegetation is exposed to hazardous substances by root exposure to and uptake from contaminated soils and sediments.

Pathways were determined by demonstrating that sufficient concentrations exist in surface water and floodplain soils and sediments to expose riparian resources of the Coeur d'Alene River basin to hazardous substances. Exposure of vegetation was confirmed by negative correlations between concentrations of hazardous substances soils and the growth response of plants.

Floodplain soils are exposed to hazardous substances historically deposited (such that the floodplains now serve as sources) and to hazardous substances that continue to be transported by surface water. Riparian vegetation is exposed to hazardous substances by root uptake of metals in soil water. The total concentrations measured in soils and sediments (Table 9-3) are not all available for uptake. Some of the metals in soils are bound by organics, occluded in iron and manganese oxides, held in metal carbonates, phosphates, or sulfides, or structurally bound in silicates. The fraction of metal cations that are in the soil solution or exchangeable pools is the most readily available to plants. However, the consistency of negative correlations between total lead concentrations and plant growth (Table 9-6), and between total metal concentrations and field vegetation measures (Table 9-12) is supporting evidence of the exposure pathway of plants to hazardous substances in soils and of the bioavailability of hazardous substances to plants. As concentrations of hazardous substances in soils increase, plant growth is inhibited, vegetation cover, species richness, and structural heterogeneity in the field decrease, and bare ground increases. Data presented in this chapter and Chapter 2 confirm that concentrations in floodplain soils are sufficient for floodplain soils to serve as an exposure pathway to riparian resources [43 CFR 11.63 (a)(2)].

In summary:

- ***Sufficient concentrations of hazardous substance exist in pathway resources to transport hazardous substances from multiple sources to riparian resources.*** The source of hazardous substances to riparian resources is the historical and ongoing release of hazardous substances from mining related operations. Hazardous substances are transported in surface water resources, mixed with suspended and bed sediments, and deposited on floodplain soils. Hazardous substances that have come to be located in floodplain, bed, and bank deposits are ongoing sources and transport pathways of hazardous substances to downgradient riparian resources. Concentrations of hazardous substances in floodplain soils and sediments of South Fork and lower Coeur d'Alene River basin are significantly greater than baseline (Chapter 10), and floodplain soils and sediment containing elevated concentrations of hazardous substances serve as an exposure pathway to riparian vegetation.

  Hazardous substance concentrations in surface water [43 CFR 11.63 (b)] and geologic resources [43 CFR 11.63 (e)] are sufficient to expose floodplain soils and sediments and riparian vegetation to hazardous substances.

9.6.2 Injury Determination: Phytotoxic Response

Soils are injured if concentrations are sufficient to cause a phytotoxic response such as retardation of plant growth [43 CFR § 11.62 (e)(10)]. Since the DOI regulations and the ASTM test procedure used do not specify a threshold or statistic to be used in the determination of phytotoxicity, the phytotoxicity was defined as a significant reduction in growth relative to reference.

Laboratory tests confirm that soils from the South Fork, Canyon Creek, and Ninemile Creek assessment areas cause significant reductions of seedling shoot and root growth relative to growth in reference soils. Under controlled conditions, including conditions of ample light, water, and space, and in the absence of physical disturbances, plant growth of multiple species was inhibited in assessment soils relative to reference soils. Alfalfa, lettuce, and wheat each exhibited reduced shoot length and total length, and wheat exhibited reduced shoot mass and total mass. Poplar exhibited reduced branch length, leaf mass, and root length. The controlled conditions removed stressors other than nutrient limitation that could contribute to growth limitations in the field. The short exposure period reduced the influence that nutrient limitation could have had, since reserves in the seed (or poplar cutting) are most likely sufficient to sustain the plant through germination and initial root elongation stages. Moreover, nutrient limitation typically causes root elongation rather than the root stunting measured.

Correlation analyses indicated that for alfalfa, lettuce, and wheat, root length, stem mass, and stem length, total mass, and total length, and for lettuce, root mass also, were significantly negatively correlated with concentrations of lead. Stem length for all three species was significantly negatively correlated with arsenic, cadmium, copper, iron, manganese (except lettuce), and zinc in addition to lead. Correlations with nitrate were also negative. No other consistent correlations were observed. For poplar, branch growth, leaves added, and leaf mass were significantly negatively correlated with lead. Branch growth and root growth were negatively correlated with nitrate and positively correlated with organic C. No other consistent correlations were observed. These results are consistent with the scientific literature on metals toxicity to plants (e.g., Kabata-Pendias and Pendias, 1992; Alloway, 1990b), with scientific literature on plant responses to metals in mine wastes (e.g., Kapustka et al., 1995; LeJeune et al., 1996; Rader et al., 1997), and with laboratory studies previously conducted with Coeur d’Alene River basin floodplain soils (Keely, 1979; Krawczyk et al., 1988).

Assessment of floodplain soil pH confirmed that most assessment soils have pH greater than 4. One sample from Canyon Creek had pH less than 4 [43 CFR § 11.62 (e)(2)].

The results of the laboratory plant growth test confirm that plant growth in upper basin assessment floodplain soils containing elevated concentrations of hazardous substances is inhibited relative to plant growth in reference soils, and that the upper basin assessment soils are injured [43 CFR § 11.62 (e)(10)]. The concentrations of hazardous substances in the assessment soils are sufficient to cause injury to riparian vegetation exposed to the upper basin assessment soils [43 CFR 11.62 (e)(11)]. This injury is discussed further as an adverse change in viability (Section 9.6.3).

9.6.3 Injury Determination: Adverse Changes in Viability

An injury to a biological resource has occurred if the release of a hazardous substance is sufficient to cause one or more of the following adverse changes in viability: death, disease, . . ., physiological malfunctions (including malfunctions in reproduction), or physical deformations [43 CFR § 11.62 (f)(1)(i)]. Adverse changes in viability of biological resources were demonstrated using biological responses that meet the acceptance criteria at [43 CFR § 11.62 (f)(2)].

- The biological response is often the result of exposure to hazardous substances [43 CFR § 11.62 (f)(2)(i)].

- Exposure to hazardous substances is known to cause this biological response in free-ranging organisms [43 CFR § 11.62 (f)(2)(ii)].

- Exposure to hazardous substances is known to cause this biological response in controlled experiments [43 CFR § 11.62 (f)(2)(iii)].

- The biological response measurement is practical to perform and produces scientifically valid results [43 CFR § 11.62 (f)(2)(iv)].

The results of the laboratory growth tests confirmed that plant growth is reduced in soils containing hazardous substances relative to plant growth in reference soils, in a controlled laboratory environment [43 CFR § 11.62 (e)(10)], and the field sampling confirmed that vegetation cover, species richness, and structural complexity are reduced in the upper basin assessment area relative to the reference areas. The community level changes observed are caused by death and physical deformation at the level of the individual plant, where deformations include physiological changes resulting in reduced growth. Reduced growth leads to a loss in competitiveness and viability. Death and physiological deformations are expressed at the community level in the upper Coeur d'Alene River basin as elimination of vegetation or as changes in the composition or structure of vegetation communities.

Results of the field vegetation studies confirmed that upper basin assessment sites are significantly more barren than reference sites, and the reduction in vegetation cover is apparent in multiple vertical layers. Cover of vegetation in the herbaceous, shrub, tree, and litter layers is significantly reduced at upper basin assessment sites relative to reference sites. Species richness at upper basin assessment sites is significantly reduced relative to reference sites, and where vegetation is present on assessment sites, it is strongly dominated by a single metals-tolerant grass species (predominantly red top bentgrass). Rare species, or species that occur infrequently and comprise a minority of the total cover but contribute greatly to the total species richness at reference sites, were virtually absent at upper basin assessment sites. The structural complexity of vegetation communities at upper basin assessment sites is significantly reduced relative to reference sites, and thus the quality and quantity of habitat provided by riparian vegetation in the upper basin are significantly reduced relative to reference areas.

Correlation analyses showed a consistent negative correlation between vegetation complexity measures, including cover in the herbaceous, shrub, and tree layers; number of species in each layer; number of layers within a 10 m radius; and concentrations of hazardous substances. Percent bare ground was positively correlated with concentrations of hazardous substances.

In summary, the plant and vegetation responses measured as part of this injury assessment meet the four acceptance criteria at 43 CFR § 11.62 (f)(2):

- Growth reduction of individual plants, reduction in vegetation cover and species richness, and simplification of vegetation community structure are often the result of exposure to hazardous substances and are known to be caused by exposure to elevated concentrations of metals in soils (Chaney, 1993; Pahlsson, 1989; Kabata-Pendias and Pendias, 1992; Kapustka et al., 1995). Growth reductions are the manifestation at the whole-plant level of physiological malfunctions such as inhibition of photosynthesis, water transport, nutrient uptake, carbohydrate translocation, transpiration, and enzyme synthesis or activity induced by elevated concentrations of trace elements (Carlson and Bazzaz, 1977; Lamoreaux and Chaney, 1977; Clijsters and Van Assche, 1985 Pahlsson, 1989; Tyler et al., 1989; Vasquez et al., 1989; Alloway, 1990a; Davies, 1990; Kiekens, 1990). Reductions in cover, species richness, and vegetation community structure are manifestations at the community level of the reduction in viability at the individual plant level.

- Exposure to hazardous substances is known to cause shoot and root growth reduction and reduced plant survival in controlled experiments [43 CFR § 11.62 (f)(2)(iii)] (Tyler et al., 1989; Kapustka et al., 1995), and exposure to hazardous substances is known to cause reduced cover, species richness, and structural complexity in wild vegetation [43 CFR § 11.62 (f)(2)(ii)] (Johnson and Eaton, 1980; LeJeune et al., 1996; Rader et al., 1997; Stoughton and Marcus, 2000).

- Measurements of reduced growth and survival in laboratory tests and measurements of reduced vegetation cover and changes in community composition and structure in the field are practical to perform and produce scientifically valid results (U.S. DOI, 1987; ASTM, 1994; Kapustka, 1997).

These responses meet the four acceptance criteria at 43 CFR § 11.62 (f)(2) and therefore, confirm that riparian resources of the upper Coeur d'Alene River basin are injured.

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APPENDIX A

PHOTOGRAPHS OF RIPARIAN RESOURCE SAMPLE SITES, AUGUST 1994

Figure 1. South Fork Coeur d'Alene River assessment site SF06.

Figure 2. South Fork Coeur d'Alene River assessment site SF07.

Figure 3. South Fork Coeur d’Alene River assessment site SF08.

Figure 4. South Fork Coeur d'Alene River assessment site SF09.

Figure 5. South Fork Coeur d'Alene River assessment site SF10.

Figure 6. South Fork Coeur d'Alene River assessment site SF11.

Figure 7. South Fork Coeur d'Alene River assessment site SF12.

Figure 8. South Fork Coeur d’Alene River assessment site SF13.

Figure 9. South Fork Coeur d’Alene River assessment site SF14.

Figure 10. South Fork Coeur d'Alene River assessment site SF15.

Next

Figure 11. South Fork Coeur d’Alene River assessment site SF16.

Figure 12. South Fork Coeur d'Alene River assessment site SF17.

Figure 13. South Fork Coeur d'Alene River assessment site SF18.

Figure 14. South Fork Coeur d’Alene River assessment site SF19.

Figure 15. South Fork Coeur d'Alene River assessment site SF20.

Figure 16. South Fork Coeur d'Alene River assessment site SF21.

Figure 17. South Fork Coeur d'Alene River assessment site SF22.

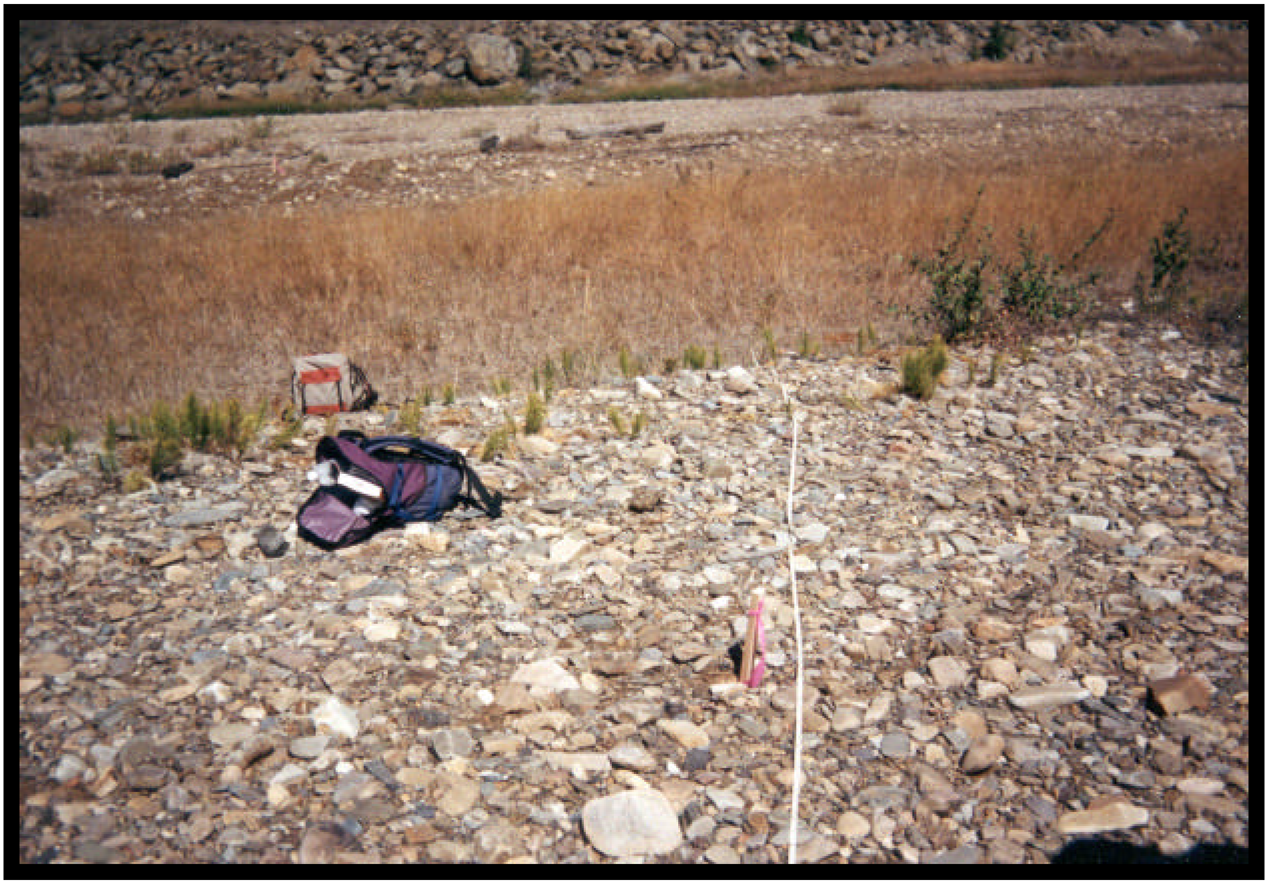

Figure 18. South Fork Coeur d'Alene River assessment site SF23.

Figure 19. South Fork Coeur d’Alene River assessment site SF24.

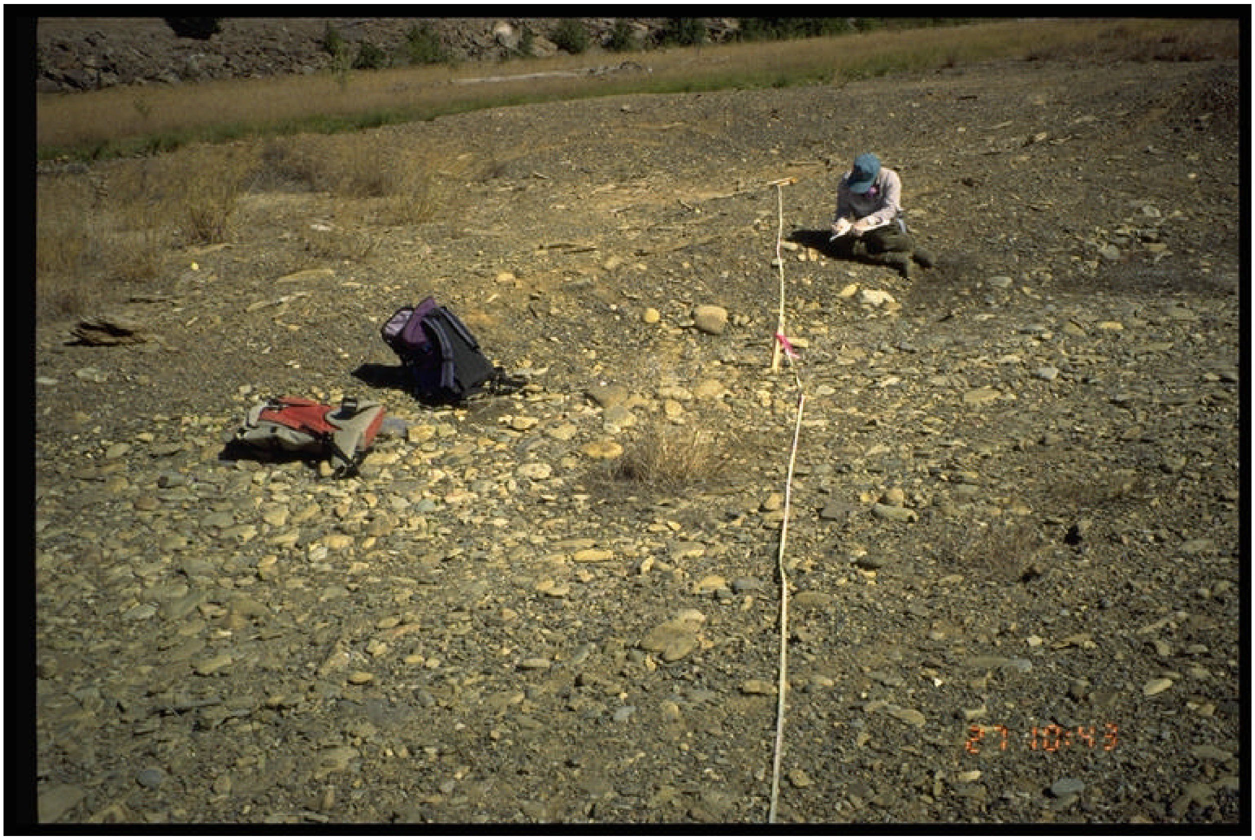

Figure 20. South Fork Coeur d'Alene River assessment site SF25.

Figure 21. South Fork Coeur d’Alene River assessment site SF26.

Figure 22. South Fork Coeur d'Alene River assessment site SF27.

Next

Figure 23. South Fork Coeur d'Alene River assessment site SF28.

Figure 24. South Fork Coeur d’Alene River assessment site SF36.

Figure 25. South Fork Coeur d'Alene River assessment site SF39.

Figure 26. South Fork Coeur d'Alene River assessment site SF40.

Figure 27. South Fork Coeur d’Alene River assessment site SF52.

Figure 28. South Fork Coeur d'Alene River assessment site SF55.

Figure 29. South Fork Coeur d'Alene River assessment site SF56.

Figure 30. Canyon Creek assessment site CC04.

Next

Figure 31. Canyon Creek assessment site CC05.

Figure 32. Canyon Creek assessment site CC06.

Figure 33. Canyon Creek assessment site CC07.

Figure 34. Canyon Creek assessment site CC08.

Figure 35. Canyon Creek assessment site CC09.

Figure 36. Ninemile Creek assessment site NC11.

Figure 37. Ninemile Creek assessment site NC12.

Figure 38. Ninemile Creek assessment site NC14.

Figure 39. Ninemile Creek assessment site NC15.

Figure 40. Little North Fork Coeur d'Alene River reference site NF01.

Next

Figure 41. Little North Fork Coeur d'Alene River reference site NF02.

Figure 42. Little North Fork Coeur d’Alene River reference site NF03.

Figure 43. Little North Fork Coeur d'Alene River reference site NF04.

Figure 44. Little North Fork Coeur d'Alene River reference site NF05.

Figure 45. Little North Fork Coeur d'Alene River reference site NF06.

Figure 46. Little North Fork Coeur d'Alene River reference site NF07.

Figure 47. Little North Fork Coeur d’Alene River reference site NF08.

Figure 48. Little North Fork Coeur d'Alene River reference site NF09.

Figure 49. Little North Fork Coeur d’Alene River reference site NF10.

Figure 50. Little North Fork Coeur d'Alene River reference site NF11.

Figure 51. Little North Fork Coeur d'Alene River reference site NF12.

Figure 52. Little North Fork Coeur d'Alene River reference site NF13.

Figure 53. Little North Fork Coeur d'Alene River reference site NF14.

Figure 54. Little North Fork Coeur d'Alene River reference site NF15.

Figure 55. Little North Fork Coeur d’Alene River reference site NF16.

Figure 56. Little North Fork Coeur d'Alene River reference site NF17.

Next

Figure 57. Canyon Creek reference site CC01.

Figure 58. Canyon Creek reference site CC02.

Figure 59. Canyon Creek reference site CC03.

Figure 60. Ninemile Creek reference site NC16.

Figure 61. Ninemile Creek reference site NC17.

Figure 62. Ninemile Creek reference site NC18.

Next

APPENDIX B

SOIL, VEGETATION, AND PHYTOTOXICITY TEST DATA

Table B-1
Vegetation Species and Cover

sitename	species	cover.pct	sitename	species	cover.pct	sitename	species	cover.pct
CC01	Achillea (H)	1.6	LC01	Cornus (S)	0.8	LC13	Scirpus (H)	39.4
CC01	Agrostis (H)	4.7	LC02	Carex (H)	78	LC13	Scutellaria (H)	4.3
CC01	Chrysanthemum (H)	1.5	LC02	Sparganium (H)	4	LC13	Sparganium (H)	0.5
CC01	Festuca (H)	6.3	LC03	Phalaris (H)	44.5	LC13	Spiraea (S)	15.3
CC01	Moss (H)	1.4	LC05	Phalaris (H)	70.5	LC14	Agropyron (H)	0.2
CC01	Phleum (H)	0.8	LC05	Spiraea (S)	14	LC14	Agrostis (H)	0.6
CC01	Plantago (H)	0.6	LC06	Carex (H)	0.5	LC14	Phalaris (H)	62.5
CC01	Poa (H)	5.4	LC06	Phalaris (H)	4	LC14	Poa (H)	2.9
CC01	Trifolium (H)	1.3	LC06	Scirpus (H)	33	LC15	Agrostis (H)	0.1
CC01	Dactylis (S)	53	LC06	Sparganium (H)	1.5	LC15	Eleocharis (H)	9
CC01	Phalaris (S)	8	LC06	Potentilla (S)	50.5	LC15	Equisetum (H)	1.9
CC02	Achillea (H)	1	LC06	Spiraea (S)	4	LC15	Moss (H)	23
CC02	Agropyron (H)	0.5	LC07	Algae (H)	25	LC15	Phalaris (H)	17.2
CC02	Agrostis (H)	21.8	LC07	Bidens (H)	1.1	LC15	Scirpus (H)	8.3
CC02	Carex (H)	0.5	LC07	Calamagrostis (H)	8	LC16	Phalaris (H)	36.4
CC02	Lichen (H)	0.5	LC07	Carex (H)	2	LC16	Scirpus (H)	3
CC02	Moss (H)	15.8	LC07	Eleocharis (H)	28.8	LC17	Calamagrostis (H)	3.3
CC02	Phleum (H)	0.7	LC07	Epilobium (H)	0.1	LC17	Carex (H)	0.1
CC02	Plantago (H)	16.4	LC07	Equisetum (H)	2.6	LC17	Equisetum (H)	0.1
CC02	Poa (H)	0.4	LC07	Erigeron (H)	0.2	LC17	Galium (H)	2
CC02	Rumex (H)	0.3	LC07	Glyceria (H)	1.9	LC17	Lythrum (H)	0.4
CC02	Solidago (H)	0.5	LC07	Juncus (H)	0.9	LC17	Moss (H)	5
CC02	Trifolium (H)	1.2	LC07	Leersia (H)	8	LC17	Phalaris (H)	9.6
CC02	Alnus (S)	3.5	LC07	Lemna (H)	0.4	LC17	Polygonum (H)	2
CC02	Dactylis (S)	5.7	LC07	Lycopus (H)	7.5	LC17	Populus (T)	53
CC02	Tanacetum (S)	24.2	LC07	Moss (H)	1	LC18	Carex (H)	4.7
CC03	Achillea (H)	0.8	LC07	Potamogeton (H)	0.1	LC18	Eleocharis (H)	1.4
CC03	Agrostis (H)	3	LC07	Potentilla (H)	6.8	LC18	Glyceria (H)	0.5
CC03	Anaphalis (H)	0.5	LC07	Sagitaria (H)	3.2	LC18	Lemna (H)	0.1
CC03	Carex (H)	0.5	LC07	Spirodela (H)	7.8	LC18	Moss (H)	7.5
CC03	Chrysanthemum (H)	3.2	LC07	Urtricularia (H)	0.8	LC18	Sagitaria (H)	11.9
CC03	Elymus (H)	20.5	LC07	Zizia (H)	3	LC18	Scirpus (H)	52.5
CC03	Epilobium (H)	5.5	LC07	Crataegus (S)	3	LC18	Urtricularia (H)	0.1
CC03	Festuca (H)	9	LC08	Glyceria (H)	17.7	LC20	Carex (H)	0.1
CC03	Galium (H)	1	LC08	Sparganium (H)	17	LC20	Phalaris (H)	5.7
CC03	Mertensia (H)	3.1	LC09	Agrostis (H)	64.5	LC20	Pteridium (H)	61.5
CC03	Moss (H)	17.5	LC09	Lichen (H)	9.7	LC20	Amelanchier (S)	2.6
CC03	Ribes (H)	1.5	LC09	Moss (H)	2.1	LC20	Spiraea (S)	63.5
CC03	Stellaria (H)	2.8	LC09	Poa (H)	11	LC20	Symphoricarpos (S	2
CC03	Abies (S)	4	LC10	Agrostis (H)	53	LC21	Eleocharis (H)	5.5
CC03	Acer (S)	10	LC10	Carex (H)	7.5	LC21	Juncus (H)	50.5
CC03	Epilobium (S)	7	LC10	Equisetum (H)	4.4	LC21	Poa (H)	2.6
CC03	Heracleum (S)	12	LC10	Moss (H)	10	LC21	Scirpus (H)	2.2
CC03	Lonicera (S)	2	LC10	Phalaris (H)	4.5	LC21	Sparganium (H)	0.1
CC03	Populus (S)	4	LC11	Cinna (H)	35	LC21	Alnus (S)	0.9
CC03	Rubus (S)	1	LC11	Heracleum (H)	3	LC21	Salix (S)	13.8
CC03	Salix (S)	41	LC11	Cornus (S)	46	LC22	Lemna (H)	1
CC03	Solidago (S)	2.1	LC11	Crataegus (S)	24	LC22	Lycopus (H)	0.2
CC04	Agrostis (H)	24	LC11	Physocarpus (S)	6	LC22	Lysimachia (H)	1.2
CC04	Moss (H)	7	LC12	Epilobium (H)	0.5	LC22	Moss (H)	0.5
CC06	Moss (H)	6.3	LC12	Potentilla (H)	80.5	LC22	Phalaris (H)	68
LC01	Bidens (H)	7.8	LC12	Sagitaria (H)	2.4	LC22	Alnus (S)	10
LC01	Callitriche (H)	0.2	LC12	Sparganium (H)	1.7	LC22	Cornus (S)	3.7
LC01	Lycopus (H)	0.1	LC13	Bidens (H)	0.3	LC22	Spiraea (S)	45.5
LC01	Myosotis (H)	40.7	LC13	Epilobium (H)	7.2	LC23	Agrostis (H)	52.5
LC01	Puccinellia (H)	1.4	LC13	Galium (H)	0.1	LC23	Aster (H)	0.5
LC01	Scutellaria (H)	0.2	LC13	Lycopus (H)	0.6	LC23	Carex (H)	6.7
LC01	Solanum (H)	1.3	LC13	Potentilla (H)	26	LC23	Cirsium (H)	0.6
LC01	Sparganium (H)	13.2	LC13	Sagitaria (H)	0.1	LC23	Epilobium (H)	1.6
LC23	Euphorbia (H)	0.6	LC32	Moss (H)	2	LC42	Agrostis (H)	34
LC23	Geum (H)	0.1	LC32	Scirpus (H)	4.5	LC42	Phleum (H)	0.1
LC23	Hieraceum (H)	8.5	LC32	Salix (S)	2.6	LC43	Carex (H)	6.3

Table B-1
Vegetation Species and Cover

sitename	species	cover.pct	sitename	species	cover.pct	sitename	species	cover.pct
LC23	Moss (H)	17.5	LC32	Spiraea (S)	49	LC43	Drosera (H)	0.1
LC23	Phleum (H)	8.2	LC33	Agropyron (H)	1.3	LC43	Galium (H)	0.4
LC23	Poa (H)	21.7	LC33	Agrostis (H)	4.5			
LC24	Carex (H)	1	LC33	Carex (H)	22.2			
LC24	Phalaris (H)	14	LC33	Deschampsia (H)	7.7			
LC24	Scirpus (H)	83.5	LC33	Equisetum (H)	0.2			
LC25	Agrostis (H)	12.2	LC33	Grass (H)	0.1			
LC25	Moss (H)	25.5	LC33	Phalaris (H)	4.5			
LC26	Lemna (H)	0.5	LC33	Poa (H)	0.1			
LC26	Moss (H)	3	LC33	Spiraea (H)	35.5			
LC26	Phalaris (H)	48	LC33	Crataegus (S)	18			
LC26	Sparganium (H)	0.8	LC33	Rosa (S)	1.7			
LC26	Spirodela (H)	0.2	LC33	Symphoricarpos (S	0.2			
LC26	Alnus (S)	10.5	LC34	Carex (H)	3			
LC26	Spiraea (S)	33.5	LC34	Deschampsia (H)	6.5			
LC27	Carex (H)	42	LC34	Eleocharis (H)	4			
LC27	Potentilla (H)	52.7	LC34	Lycopus (H)	0.3			
LC28	Agrostis (H)	50.5	LC34	Phalaris (H)	15.1			
LC28	Populus (T)	31.5	LC34	Sagitaria (H)	0.3			
LC29	Agrostis (H)	0.9	LC34	Scirpus (H)	10.5			
LC29	Alopecurus (H)	0.2	LC34	Sparganium (H)	1.3			
LC29	Carex (H)	16.4	LC34	Spiraea (S)	26			
LC29	Epilobium (H)	1.1	LC35	Agrostis (H)	11.4			
LC29	Festuca (H)	0.2	LC35	Deschampsia (H)	0.9			
LC29	Glyceria (H)	3.8	LC35	Equisetum (H)	0.1			
LC29	Poa (H)	0.2	LC35	Phleum (H)	0.6			
LC29	Puccinellia (H)	2.1	LC35	Scirpus (H)	8.6			
LC29	Ranunculus (H)	30.6	LC35	Alnus (S)	27.5			
LC29	Scirpus (H)	71.5	LC35	Populus (S)	6.5			
LC30	Carex (H)	14.8	LC35	Spiraea (S)	40.6			
LC30	Deschampsia (H)	0.5	LC35	Betula (T)	17.5			
LC30	Dulichium (H)	10.2	LC36	Agrostis (H)	45.5			
LC30	Eleocharis (H)	0.5	LC36	Populus (S)	16.5			
LC30	Equisetum (H)	0.6	LC37	Agrostis (H)	38			
LC30	Glyceria (H)	8.3	LC37	Deschampsia (H)	1.3			
LC30	Grass (H)	23.1	LC37	Moss (H)	6.7			
LC30	Juncus (H)	4.2	LC37	Phalaris (H)	0.2			
LC30	Lemna (H)	0.3	LC37	Scirpus (H)	3.4			
LC30	Lycopus (H)	1.4	LC37	Alnus (S)	24			
LC30	Moss (H)	9.5	LC37	Salix (S)	11.9			
LC30	Phalaris (H)	8.5	LC38	Phalaris (H)	50			
LC30	Scirpus (H)	0.4	LC38	Solanum (H)	2.7			
LC30	Urtricularia (H)	0.5	LC39	Agrostis (H)	0.2			
LC30	Alnus (S)	24.5	LC39	Epilobium (H)	0.4			
LC30	Sagitaria (S)	4.9	LC39	Sagitaria (H)	0.2			
LC30	Salix (S)	1	LC40	Carex (H)	7			
LC30	Spiraea (S)	25	LC40	Lycopus (H)	1			
LC31	Bidens (H)	0.3	LC40	Phalaris (H)	81.8			
LC31	Carex (H)	1.5	LC41	Bidens (H)	0.2			
LC31	Deschampsia (H)	2.5	LC41	Eleocharis (H)	1			
LC31	Sagitaria (H)	1.6	LC41	Lycopus (H)	0.5			
LC31	Scirpus (H)	3	LC41	Moss (H)	6			
LC31	Spiraea (S)	65.5	LC41	Sagitaria (H)	8			
LC32	Agrostis (H)	0.1	LC41	Scirpus (H)	9.7			
LC32	Deschampsia (H)	1.2	LC41	Salix (S)	1.2			
LC32	Equisetum (H)	0.3	LC41	Spiraea (S)	59.6			

* CC05, CC07, CC08, CC09, NC13, and NC14 were not listed because they were 100% bare ground

Table B-2
Total Metals (HNO3 digest method) in Soils

sitename	as.ppm.hno3	as.ppm.hno3.q	cd.ppm.hno3	cd.ppm.hno3.q	cu.ppm.hno3	fe.ppm.hno3	mn.ppm.hno3	pb.ppm.hno3	zn.ppm.hno3
CC01	11.1		4		73.1	17300	999	922	642
CC02	9.1	B	6.5		52.8	15400	681	1040	917
CC03	9.6	B	1.4		23.2	11800	1310	445	424
CC04	33.3		4.9		91.7	19500	750	7960	590
CC05	44.3		44.8		150	38300	2240	9540	7270
CC06	53.8		24.6		168	52300	3770	11300	4790
CC07	19.5		43.8		135	26100	1490	5460	7450
CC08	52.4		5.4		182	36900	527	33300	1120
CC09	65.25		12.1		156.5	51800	341.5	42200	1810
LC01	13.7		0.4	B	18.8	12600	178	172	117
LC02	10.4		3.2		28.5	9540	56.9	1000	205
LC03	14.9		0.67		18.3	14600	96	143	136
LC04	295		21.4		113	87300	8390	4470	2530
LC05	21.6		5.3		39.7	19900	239	1080	445
LC06	150		17.2		160	72200	4290	7600	1850
LC07	25.5		10.2		57.2	21200	608	2290	874
LC08	97.6		13.9		85.9	43200	2250	3130	1380
LC09	38.1		3.8		16.4	15200	1100	372	253
LC10	107		27.9		81	52700	6980	2140	8850
LC11	16.6	B	1.8		29.2	18700	479	241	218
LC12	9.7	B	4.6		23	9830	72.9	417	371
LC13	39.6		22.1		52.5	25000	849	2350	2350
LC14	13.6		3.2		21.8	12400	218	597	303
LC15	146		21.4		92.2	85900	8110	4130	2780
LC16	32.8		6.3		83.2	28000	319	4100	677
LC17	12.3		4.8		18.5	18200	492	326	332
LC18	18.8	B	5.5		52.7	21600	319	2330	515
LC20	22.3		5		32.3	18500	668	1450	532
LC21	272.5		18.85		101.9	71450	5230	3595	1925
LC22	5.9	B	1.5		19.1	21800	236	43.7	85.6
LC23	6.1	B	1.05		24.65	19800	264	60.6	76.55
LC24	5	B	1.4		23	11400	62.1	65.2	68.4
LC25	105		22.6		99	83000	8710	4020	3110
LC26	13.5		2.5		26.2	15100	308	243	156
LC27	4.6	B	3.8		16.1	7360	37.3	291	119
LC28	156		25		103	97300	9820	4250	3140
LC29	11.7		0.3	U	11.4	14900	220	19.8	55
LC30	16.9		2.6		26.9	17600	191	166	279
LC31	117		20.6		126	53300	3510	6100	1790
LC32	316		24.9		126	85300	6720	3820	2340
LC33	29		11.8		53.2	27800	454	2270	581

Table B-2
Total Metals (HNO3 digest method) in Soils

sitename	as.ppm.hno3	as.ppm.hno3.q	cd.ppm.hno3	cd.ppm.hno3.q	cu.ppm.hno3	fe.ppm.hno3	mn.ppm.hno3	pb.ppm.hno3	zn.ppm.hno3
LC34	142		21.8		149	52900	2720	5760	2190
LC35	123		19.9		82.3	29300	1720	2320	1550
LC36	84		20		71.7	37900	2860	2400	1600
LC37	74.6		12.8		60.3	38700	3310	2340	1180
LC38	9.7	B	0.92		15.2	13700	312	79.6	143
LC39	25.2		17.1		93.3	35200	1950	5620	1690
LC40	8	B	4.1		22.6	15300	473	505	433
LC41	25.9		9.9		28.1	33400	368	1050	606
LC42	29		4.9		41	24200	543	1050	328
LC43	5.3	B	7.1		16.6	5890	75.6	773	341
LC44	190		31.8		186	72000	8160	8030	2720
LC45	266		30.6		129	95500	10500	4580	3090
NC11	58.1		8.9		156	38500	1430	14500	2670
NC12	23.9		11.7		265	58600	1640	20400	2290
NC13	26.2		3	U	421	74100	741	59600	1540
NC14	50		10.3		192	43200	757	22300	3720
NC15	12.6	B	12.7		143	39800	878	19600	2680
NC16	23.2		3.7		22.8	18100	418	323	507
NC17	16	B	3.2		17.9	16700	482	118	224
NC18	22.7		1.8		19.6	17300	810	80.6	223
NF01	19.7		0.3	U	17.1	15200	480	26.3	86.8
NF02	9.4	B	1.1		16.4	14300	513	25.6	78.1
NF03	8.9	B	1.65		14.9	14100	614	32.75	90
NF04	7.8	B	1.3		14.3	11800	448	23.1	74.6
NF05	8.3	B	0.8		12.6	11400	366	15.6	61.4
NF06	5.3		0.64		8.1	9230	205	8.9	40.4
NF07	10.2		0.3	U	18.1	10600	259	12.7	47.1
NF08	5.7		0.82		18.4	9030	270	11.4	45.2
NF09	7	B	0.86		19.4	10100	273	12.5	45.2
NF10	6.8	B	0.87		16.5	10700	353	13.3	52.7
NF11	4.9	B	1		13.8	9580	254	12.3	46.2
NF12	5.1	B	0.76		20.3	10200	251	12.4	48.3
NF13	7.2	B	1.1		25.2	13400	411	17.2	68.7
NF14	14.3		0.3	U	33	10900	289	11.25	52.55
NF15	6.7	B	1.2		22	13600	458	18.4	69.8
NF16	15.3		0.3	U	42.3	12300	390	20.1	62.7
NF17	6.7	B	1		22.6	11200	289	12.6	54.6
SF06	177		26.7		134	65200	6290	4690	2940
SF07	312		33.8		147	83600	8060	5750	3280
SF08	158		18.1		111	75900	6710	3880	2130
SF09	120		26.7		156	41400	3990	3860	2780

Table B-2
Total Metals (HNO3 digest method) in Soils

sitename	as.ppm.hno3	as.ppm.hno3.q	cd.ppm.hno3	cd.ppm.hno3.q	cu.ppm.hno3	fe.ppm.hno3	mn.ppm.hno3	pb.ppm.hno3	zn.ppm.hno3
SF10	215		55.4		361	120000	11400	18100	6670
SF11	247		45.1		227	87000	9550	9410	5080
SF12	309		44.4		221	125000	13300	11800	6470
SF13	231		37.1		269	151000	16000	14600	6510
SF14	230.5		53.2		343	140500	15350	18050	7710
SF15	177		46.9		349	129000	11400	19700	7060
SF16	138		61.1		416	142000	13400	21600	8100
SF17	215		69.8		300	128000	13800	13600	8290
SF18	197		58.9		328	150000	17400	18200	8140
SF19	120		95.7		443	177000	20200	19700	14200
SF20	180		62.9		429	135000	12900	22000	9100
SF21	89.1	B	66.8		416	133000	13700	22100	7930
SF22	131		26.2		138	67200	6570	4700	3240
SF23	140		24.5		164	69500	6950	4960	3070
SF24	93.4		24.8		117	53300	4960	4560	2930
SF25	149		43.7		359	96100	10300	21700	6650
SF26	223		37.7		160	84400	8370	8810	4030
SF27	173		18.1		91.9	71100	6540	5250	2750
SF28	147		33.4		132	66100	6490	5610	3860
SF36	67.7		12		83.4	34200	3010	3050	2030
SF39	116		24.4		218	78100	7170	7950	4060
SF40	126		52.5		340	113000	12800	21800	7310
SF52	70.4		6.3		198	30100	2000	1300	1420
SF55	111		50.6		387	85600	7810	25600	8570
SF56	56.1		18.6		216	48000	3180	17200	3270

Table B-3
Soil Physical Properties, Potassium, and NO_3

sitename	Clay (%)	Sand (%)	Potassium	potassium.qual	Neutralization Potential	NO3 (ppm)	Organic Content (%)	pH	Sulphur (%)
CC01	9	60	86.7		-	0.7	8.7	5.8	-
CC02	8	53	50.4		-	0.4	5.9	5.8	-
CC03	3	82	32.8	B	-	0.1	3.4	6	-
CC04	9	57	22.6	B	-	11	3.2	4.6	-
CC05	3	81	10	U	-	1.2	1	5.5	-
CC06	3	81	10	U	-	2.2	6.1	6	-
CC07	3	83	10	U	-	1.7	0.7	6.4	-
CC08	10	55	12.5	B	-	5.9	1.7	4	-
CC09	10	70	10	U	-	3.25	1.6	3.85	-
LC01	14	15	100	U	1	8.4	4.9	4.9	0.02
LC02	21	25	52.2		-	5.2	10.9	4.4	-
LC03	26	3	101	B	1.5	0.2	5.9	4.8	0.03
LC04	4	40	100	U	3.3	0.2	2.1	5.8	0.05
LC05	25	10	43.7	B	-	1.5	11.8	4.5	-
LC06	11	20	17.2	B	-	1.7	3.3	5.6	-
LC07	19	30	218	B	1.3	0.3	9.5	5.4	0.04
LC08	20	20	100	U	2.8	27.7	6.2	4.7	0.04
LC09	5	38	51.6		-	0.1	2	5.4	-
LC10	16	9	125	B	2.4	0.2	8.9	7	0.07
LC11	18	1	39.8	B	-	8	3.9	5.3	-
LC12	13	34	37.6	B	-	0.2	14.2	4.8	-
LC13	10	25	100	U	1.5	0.3	13.8	5.3	0.22
LC14	35	11	167	B	1.5	0.2	8.9	4.9	0.03
LC15	5	48	37.5	B	-	0.4	2.6	6	-
LC16	28	6	44.2	B	-	10.8	6.1	4.5	-
LC17	13	44	54.7		-	0.1	4.3	5.5	-
LC18	25	10	34.5	B	-	1.8	6.5	4.8	-
LC20	20	29	185	B	1.1	0.2	7.7	5.2	0.01
LC21	10	31	100	U	2.3	3.35	3.85	5.25	0.02
LC22	18	4	70.7		-	1.1	6.4	4.8	-
LC23	38	7	90.9		-	0.05	6.05	5.2	-
LC24	24	25	124		-	0.1	13.1	4.2	-
LC25	3	82	10	U	-	0.2	1.1	7.2	-
LC26	14	41	75.1		-	0.2	13.2	4.7	-
LC27	11	45	120		-	0.2	14	4.7	-
LC28	3	76	24.2	B	-	0.2	1.8	5.9	-
LC29	15	11	100	U	0.9	0.3	4.3	5	0.01
LC30	15	11	100	U	1.8	0.2	10	4.4	0.05
LC31	29	8	33.1	B	-	1.3	5.8	5.3	-
LC32	14	14	37.4	B	-	4.7	3.1	5.7	-
LC33	16	19	47.5	B	-	0.2	8.2	4.9	-
LC34	21	14	27.1	B	-	6.3	6	5	-
LC35	14	10	57.2		-	1.6	6.9	5.5	-
LC36	8	53	23.5	B	-	14.3	4.1	5.1	-
LC37	6	64	16.8	B	-	1.2	1.8	5.4	-
LC38	8	58	51.3		-	10.3	3.1	6	-
LC39	16	18	51.4		-	0.5	7.1	5.3	-
LC40	18	40	39.1	B	-	0.2	5.7	5.2	-
LC41	20	20	20.1	B	-	0.6	3.2	5	-
LC42	18	36	61.9		-	3.8	5.6	5	-
LC43	0	81	57.2		-	0.3	13.7	4.6	-
LC44	19	11	25.2	B	-	3.4	3.8	5.4	-
LC45	5	71	24.3	B	-	0.3	1.7	5.9	-
NC11	5	81	100	U	0.6	1.1	1.2	5	0.27
NC12	8	73	310	B	-	3.8	1.7	4.8	-
NC13	11	41	390	B	-	2.3	1.1	4.1	-
NC14	9	51	100	U	1.3	2.3	1.4	4.7	0.1
NC15	8	72	261	B	-	1.5	2.2	4.4	-
NC16	11	48	100	U	2.8	0.2	13.1	6.1	0.05

Table B-3
Soil Physical Properties, Potassium, and NO_3

sitename	Clay (%)	Sand (%)	Potassium	potassium.qual	Neutralization Potential	NO3 (ppm)	Organic Content (%)	pH	Sulphur (%)
NC17	16	39	2240		-	0	10.4	6.3	-
NC18	9	28	112	B	1.5	0.2	8.9	6.2	0.02
NF01	14	15	100	U	0.9	0.2	7.4	5.7	0.01
NF02	14	19	1430		-	0.1	5.5	5.6	-
NF03	15	25	1090		-	0.1	8.9	5.5	-
NF04	13	34	2900		-	0.1	7.9	6.1	-
NF05	10	45	1510		-	0.1	4.5	6.1	-
NF06	6	70	571		-	0.7	2.4	5.5	-
NF07	8	63	100	U	0.9	0.6	2.3	5.7	0.01
NF08	9	58	571		-	0.05	3	6	-
NF09	9	66	940		-	0.3	3	5.9	-
NF10	10	46	852		-	0.2	4.3	5.8	-
NF11	6	73	941		-	0.3	2	5.9	-
NF12	8	66	881		-	0.2	2.6	6	-
NF13	13	30	752		-	0.2	5.3	5.6	-
NF14	10	56	100	U	1.95	0.15	3.55	6.05	0.01
NF15	16	33	651		-	0.05	3.9	5.4	-
NF16	10	36	100	U	2	0.1	4.8	5.1	0.34
NF17	10	54	731		-	0.05	3.3	5.8	-
SF06	11	54	30.1	B	-	1.4	2.1	6.2	-
SF07	5	67	430	B	-	0.9	1.9	5.8	-
SF08	5	85	16.2	B	-	0.5	0.7	6.9	-
SF09	11	23	36.1	B	-	0.1	3.5	6.4	-
SF10	5	50	661		-	0.6	1.4	5.9	-
SF11	8	52	782		-	0.4	1.9	5.7	-
SF12	1	85	100	U	1.8	0.8	0.7	5.9	0.33
SF13	5	77	13.1	B	-	1.2	0.4	5.3	-
SF14	1	62	100	U	1.85	1.4	0.9	5.85	0.455
SF15	9	47	37.1	B	-	0.7	1.7	6.6	-
SF16	5	54	18.4	B	-	0.7	1.6	6.7	-
SF17	5	75	15.7	B	-	0.6	1.2	6.2	-
SF18	3	78	120	B	-	1.2	0.7	5.7	-
SF19	3	76	10	U	-	1.6	0.9	6.6	-
SF20	8	52	24.9	B	-	0.6	1.3	6.7	-
SF21	6	58	19	B	-	2.5	1.8	6.8	-
SF22	4	90	200	B	-	0.8	0.9	6.8	-
SF23	4	88	160	B	-	1	2	6.3	-
SF24	5	84	180	B	-	1.1	0.6	6.5	-
SF25	5	71	100	U	5.1	2.8	1.5	6.4	0.01
SF26	5	77	190	B	-	1.1	0.9	6.3	-
SF27	1	89	100	U	2.5	0.7	0.8	6.6	0.37
SF28	5	80	190	B	-	1.1	0.9	6.5	-
SF36	3	88	100	U	5.1	1.8	0.8	7	0.11
SF39	10	62	410	B	-	0.7	1.6	5.9	-
SF40	8	77	190	B	-	1.1	0.9	5.2	-
SF52	18	38	1970		-	0.3	2.8	7.2	-
SF55	9	72	390	B	-	3.4	2	6.5	-
SF56	13	57	800		-	0.1	2.7	6.8	-

Table B-4a
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	pot	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
CC01	1	5	0.033	0.003	5	254	10.807	5	0.010	0.003	5	184	69.449
CC01	10	6	0.034	0.008	6	242	19.633	6	0.014	0.003	6	176	23.449
CC01	2	6	0.033	0.014	6	210	32.882	6	0.014	0.007	6	145	57.650
CC01	3	3	0.022	0.008	3	196	59.349	3	0.010	0.005	3	98	42.568
CC01	4	3	0.039	0.004	3	234	15.503	3	0.014	0.001	3	176	27.592
CC01	5	5	0.031	0.006	5	257	7.294	5	0.011	0.002	5	185	24.294
CC01	6	3	0.031	0.011	3	216	20.881	3	0.013	0.007	3	146	53.594
CC01	7	1	0.034	0.000	1	230	0.000	1	0.011	0.000	1	167	0.000
CC01	8	2	0.036	0.011	2	240	2.121	2	0.013	0.002	2	215	7.071
CC01	9	5	0.041	0.009	5	224	21.319	5	0.018	0.005	5	177	31.019
CC02	1	3	0.036	0.007	3	230	11.150	3	0.019	0.004	3	194	23.580
CC02	10	3	0.025	0.010	3	231	29.462	3	0.016	0.003	3	209	48.789
CC02	2	3	0.037	0.002	3	237	4.933	3	0.022	0.003	3	176	5.568
CC02	3	1	0.032	0.000	1	230	0.000	1	0.014	0.000	1	148	0.000
CC02	4	2	0.027	0.006	2	234	56.569	2	0.009	0.000	2	116	6.364
CC02	5	3	0.025	0.001	3	241	8.737	3	0.011	0.004	3	207	10.214
CC02	7	1	0.039	0.000	1	219	0.000	1	0.014	0.000	1	171	0.000
CC02	8	2	0.029	0.003	2	244	21.213	2	0.013	0.003	2	159	31.820
CC02	9	2	0.033	0.007	2	225	21.920	2	0.014	0.004	2	191	16.971
CC04	1	10	0.018	0.004	10	113	18.800	10	0.013	0.020	10	21	4.899
CC04	10	6	0.018	0.005	6	123	11.221	6	0.007	0.001	6	23	3.204
CC04	2	9	0.019	0.003	9	120	13.892	9	0.009	0.002	9	23	6.629
CC04	3	9	0.019	0.008	9	119	24.884	9	0.007	0.003	9	21	4.528
CC04	4	9	0.018	0.003	9	118	9.619	9	0.008	0.002	9	24	3.432
CC04	5	7	0.020	0.002	7	127	10.808	7	0.009	0.002	7	25	2.225
CC04	6	9	0.017	0.005	9	115	20.125	9	0.008	0.002	9	25	4.610
CC04	7	8	0.017	0.004	8	111	16.869	8	0.007	0.001	8	23	2.659
CC04	8	6	0.019	0.002	6	125	9.432	6	0.007	0.002	6	20	6.178
CC04	9	9	0.020	0.004	9	124	16.024	9	0.008	0.001	9	27	7.612
CC08	1	9	0.012	0.004	9	97	14.281	9	0.008	0.004	9	9	3.640
CC08	10	8	0.012	0.003	8	87	17.847	8	0.009	0.003	8	10	4.621
CC08	2	6	0.015	0.003	6	94	12.319	6	0.008	0.001	6	8	3.545
CC08	3	7	0.014	0.005	7	101	27.054	7	0.008	0.002	7	10	3.309
CC08	4	7	0.015	0.006	7	106	27.802	7	0.008	0.002	7	11	2.289
CC08	5	10	0.012	0.005	10	96	24.223	10	0.006	0.002	10	7	1.619
CC08	6	9	0.012	0.003	9	92	19.972	9	0.007	0.003	9	9	4.540
CC08	7	8	0.016	0.003	8	104	22.071	8	0.008	0.002	8	8	3.370
CC08	8	9	0.016	0.010	9	97	10.663	9	0.008	0.002	9	9	6.160
CC08	9	3	0.010	0.002	3	77	11.790	3	0.008	0.001	3	6	1.155
CC09	1	9	0.011	0.002	9	99	8.638	9	0.007	0.003	9	11	3.993
CC09	10	9	0.011	0.004	9	84	11.942	9	0.008	0.002	9	11	4.595
CC09	2	8	0.013	0.003	8	105	21.413	8	0.009	0.002	8	12	4.200
CC09	3	7	0.012	0.002	7	92	15.689	7	0.010	0.003	7	10	4.726
CC09	4	8	0.011	0.003	8	101	11.426	8	0.010	0.002	8	13	3.399
CC09	5	7	0.014	0.005	7	103	23.790	7	0.011	0.003	7	10	3.388
CC09	6	9	0.011	0.004	9	85	20.885	9	0.007	0.004	9	10	3.492
CC09	7	9	0.012	0.004	9	85	14.457	9	0.009	0.004	9	8	2.963
CC09	8	8	0.010	0.002	8	88	9.472	8	0.009	0.002	8	11	4.472
CC09	9	9	0.011	0.003	9	94	16.300	9	0.007	0.002	9	11	2.920
LC03	3	1	0.029	0.000	1	212	0.000	1	0.019	0.000	1	194	0.000
LC03	5	1	0.029	0.000	1	208	0.000	1	0.019	0.000	1	232	0.000
LC03	8	2	0.018	0.019	2	125	84.146	2	0.011	0.013	2	88	57.983
LC04	1	5	0.025	0.010	5	246	25.086	5	0.042	0.032	5	238	91.073
LC04	10	5	0.026	0.009	5	205	41.536	5	0.036	0.017	5	242	44.300
LC04	2	3	0.024	0.005	3	227	15.177	3	0.022	0.009	3	259	15.044
LC04	3	9	0.015	0.004	9	139	33.429	9	0.042	0.028	9	238	53.976
LC04	4	1	0.012	0.000	1	130	0.000	1	0.009	0.000	1	244	0.000
LC04	5	3	0.033	0.003	3	241	5.292	3	0.058	0.024	3	290	31.501
LC04	6	5	0.024	0.008	5	188	26.220	5	0.038	0.015	5	216	46.864

Table B-4a
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	**pot**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LC04	7	2	0.028	0.008	2	229	35.355	2	0.058	0.046	2	246	15.556
LC04	8	7	0.023	0.009	7	187	47.194	7	0.048	0.025	7	218	66.905
LC04	9	3	0.014	0.015	3	128	91.263	3	0.031	0.029	3	140	116.217
LC07	1	1	0.021	0.000	1	210	0.000	1	0.053	0.000	1	200	0.000
LC08	1	10	0.033	0.007	10	198	20.733	10	0.025	0.009	10	151	24.909
LC08	10	10	0.028	0.007	10	198	42.896	10	0.018	0.004	10	133	22.910
LC08	2	6	0.029	0.005	6	189	15.501	6	0.019	0.006	6	110	8.042
LC08	3	8	0.027	0.010	8	182	40.377	8	0.019	0.009	8	87	17.752
LC08	4	10	0.026	0.011	10	175	57.034	10	0.017	0.007	10	91	34.097
LC08	5	7	0.031	0.012	7	213	28.895	7	0.020	0.005	7	117	33.035
LC08	6	8	0.033	0.006	8	205	20.170	8	0.020	0.003	8	123	21.230
LC08	7	10	0.028	0.009	10	196	41.555	10	0.017	0.006	10	161	39.564
LC08	8	9	0.031	0.006	9	203	19.774	9	0.024	0.006	9	192	26.655
LC08	9	9	0.026	0.009	9	197	36.208	9	0.016	0.005	9	105	15.898
LC10	2	1	0.043	0.000	1	253	0.000	1	0.036	0.000	1	110	0.000
LC14	1	9	0.021	0.003	9	208	23.740	9	0.040	0.020	9	230	32.288
LC14	10	10	0.024	0.004	10	222	23.329	10	0.028	0.008	10	183	36.897
LC14	2	10	0.023	0.006	10	211	46.665	10	0.037	0.016	10	192	43.228
LC14	3	10	0.019	0.007	10	180	48.325	10	0.020	0.011	10	128	29.909
LC14	4	9	0.023	0.007	9	223	40.203	9	0.027	0.021	9	182	43.317
LC14	5	10	0.023	0.012	10	194	39.057	10	0.033	0.020	10	205	54.799
LC14	6	10	0.029	0.005	10	232	21.310	10	0.058	0.068	10	148	33.025
LC14	7	9	0.024	0.009	9	211	66.324	9	0.058	0.039	9	183	58.189
LC14	8	10	0.024	0.008	10	190	48.998	10	0.041	0.037	10	149	54.624
LC14	9	9	0.033	0.010	9	256	51.713	9	0.082	0.074	9	153	59.062
LC20	1	9	0.027	0.008	9	215	40.858	9	0.018	0.010	9	189	59.586
LC20	10	7	0.029	0.007	7	206	41.960	7	0.018	0.004	7	135	33.424
LC20	2	10	0.032	0.019	10	203	47.918	10	0.020	0.011	10	184	44.101
LC20	3	10	0.023	0.007	10	206	32.969	10	0.015	0.005	10	208	70.007
LC20	4	10	0.033	0.007	10	224	19.553	10	0.023	0.011	10	150	35.202
LC20	5	8	0.028	0.007	8	243	23.021	8	0.019	0.009	8	197	56.382
LC20	6	9	0.031	0.007	9	216	40.227	9	0.020	0.006	9	150	31.165
LC20	7	8	0.027	0.008	8	236	53.130	8	0.023	0.012	8	173	65.223
LC20	8	9	0.032	0.008	9	238	24.847	9	0.021	0.006	9	169	53.362
LC20	9	9	0.038	0.008	9	221	33.594	9	0.033	0.020	9	165	33.986
LC21	10	2	0.026	0.001	2	183	18.385	2	0.031	0.006	2	196	19.799
LC21	7	1	0.001	0.000	1	25	0.000	1	0.002	0.000	1	38	0.000
LC29	2	1	0.005	0.000	1	95	0.000	1	0.001	0.000	1	10	0.000
LC29	3	1	0.034	0.000	1	231	0.000	1	0.021	0.000	1	298	0.000
LC29	4	1	0.013	0.000	1	141	0.000	1	0.001	0.000	1	58	0.000
LC29	5	1	0.002	0.000	1	29	0.000	1	0.001	0.000	1	3	0.000
LC29	6	1	0.022	0.000	1	211	0.000	1	0.010	0.000	1	174	0.000
NC11	1	9	0.012	0.003	9	87	13.706	9	0.010	0.002	9	24	5.657
NC11	2	10	0.013	0.005	10	95	14.863	10	0.010	0.004	10	26	5.016
NC11	3	9	0.015	0.005	9	97	19.479	9	0.012	0.004	9	27	5.019
NC11	4	8	0.010	0.003	8	84	13.371	8	0.009	0.002	8	21	3.662
NC11	5	10	0.012	0.003	10	92	10.285	10	0.009	0.002	10	23	9.274
NC11	6	8	0.014	0.002	8	79	14.643	8	0.010	0.003	8	20	4.690
NC11	7	7	0.014	0.003	7	91	8.995	7	0.009	0.002	7	25	4.163
NC11	8	10	0.014	0.004	10	90	12.767	10	0.009	0.001	10	21	6.433
NC14	1	4	0.009	0.005	4	45	19.155	4	0.006	0.003	4	5	2.363
NC14	10	7	0.011	0.005	7	57	14.140	7	0.010	0.003	7	6	3.039
NC14	2	2	0.008	0.003	2	54	4.243	2	0.006	0.000	2	5	1.414
NC14	3	6	0.009	0.004	6	57	16.330	6	0.007	0.002	6	6	1.378
NC14	4	5	0.010	0.003	5	60	10.198	5	0.008	0.003	5	6	2.550
NC14	5	2	0.009	0.002	2	63	24.042	2	0.008	0.001	2	6	2.121
NC14	6	4	0.012	0.004	4	64	4.203	4	0.010	0.001	4	6	1.258
NC14	7	4	0.009	0.003	4	51	11.758	4	0.008	0.003	4	5	1.414
NC14	8	5	0.011	0.004	5	62	16.906	5	0.008	0.003	5	5	1.414

Table B-4a
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	**pot**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
NC14	9	6	0.013	0.004	6	62	7.960	6	0.008	0.003	6	5	1.871
NC16	1	1	0.029	0.000	1	234	0.000	1	0.013	0.000	1	224	0.000
NC16	10	1	0.030	0.000	1	237	0.000	1	0.023	0.000	1	343	0.000
NC16	2	1	0.036	0.000	1	265	0.000	1	0.029	0.000	1	228	0.000
NC16	3	1	0.044	0.000	1	253	0.000	1	0.024	0.000	1	196	0.000
NC16	5	2	0.022	0.001	2	192	31.113	2	0.015	0.002	2	205	62.933
NC16	6	2	0.039	0.006	2	270	19.092	2	0.025	0.006	2	281	41.719
NC16	7	2	0.024	0.002	2	227	10.607	2	0.014	0.001	2	161	14.849
NC18	1	10	0.029	0.010	10	197	43.079	10	0.016	0.007	10	194	32.233
NC18	10	6	0.029	0.008	6	224	17.325	6	0.017	0.005	6	186	36.958
NC18	2	6	0.024	0.007	6	203	23.721	6	0.013	0.002	6	180	13.357
NC18	3	6	0.025	0.005	6	201	25.781	6	0.016	0.005	6	203	16.368
NC18	4	7	0.023	0.006	7	196	24.940	7	0.016	0.004	7	213	54.540
NC18	5	8	0.027	0.006	8	224	23.037	8	0.017	0.004	8	202	16.548
NC18	6	8	0.022	0.007	8	201	45.574	8	0.015	0.006	8	227	71.104
NC18	7	9	0.025	0.003	9	214	14.670	9	0.016	0.003	9	214	10.220
NC18	8	6	0.033	0.008	6	205	29.521	6	0.018	0.005	6	201	25.367
NC18	9	8	0.031	0.006	8	228	11.600	8	0.018	0.003	8	225	31.244
NF01	1	10	0.038	0.009	10	250	23.752	10	0.026	0.011	10	234	75.232
NF01	10	9	0.035	0.003	9	246	15.592	9	0.019	0.004	9	279	72.208
NF01	2	8	0.035	0.010	8	251	38.862	8	0.017	0.006	8	208	40.430
NF01	3	10	0.031	0.005	10	231	14.868	10	0.019	0.006	10	231	59.667
NF01	4	10	0.027	0.008	10	239	26.025	10	0.019	0.007	10	263	60.260
NF01	5	10	0.033	0.006	10	239	14.516	10	0.023	0.005	10	245	24.823
NF01	6	10	0.038	0.013	10	240	34.406	10	0.019	0.008	10	273	59.106
NF01	7	10	0.036	0.009	10	253	13.809	10	0.019	0.006	10	207	20.766
NF01	8	9	0.039	0.008	9	263	14.351	9	0.021	0.008	9	230	43.124
NF01	9	10	0.034	0.007	10	247	30.135	10	0.017	0.003	10	218	30.510
NF03	1	10	0.033	0.012	10	253	46.891	10	0.012	0.005	10	235	69.820
NF03	10	10	0.040	0.007	10	272	6.512	10	0.013	0.003	10	200	55.574
NF03	2	10	0.028	0.004	10	241	17.485	10	0.015	0.003	10	299	76.983
NF03	3	10	0.041	0.007	10	279	12.801	10	0.011	0.004	10	251	124.929
NF03	4	9	0.032	0.005	9	240	26.888	9	0.012	0.004	9	209	82.411
NF03	5	10	0.041	0.006	10	265	12.834	10	0.011	0.004	10	172	65.491
NF03	6	10	0.032	0.010	10	239	26.608	10	0.019	0.014	10	237	125.538
NF03	7	10	0.027	0.006	10	246	19.894	10	0.012	0.004	10	219	73.399
NF03	8	10	0.038	0.005	10	285	24.232	10	0.010	0.001	10	185	54.549
NF03	9	9	0.029	0.006	9	258	16.303	9	0.013	0.004	9	264	101.794
NF07	1	6	0.028	0.004	6	212	16.888	6	0.019	0.007	6	176	38.775
NF07	10	10	0.038	0.010	10	212	30.609	10	0.026	0.006	10	172	39.724
NF07	2	9	0.035	0.014	9	213	27.953	9	0.024	0.011	9	170	10.438
NF07	3	9	0.031	0.010	9	224	43.920	9	0.017	0.006	9	153	25.281
NF07	4	9	0.030	0.007	9	224	18.979	9	0.018	0.009	9	198	70.296
NF07	5	7	0.023	0.004	7	227	22.845	7	0.012	0.003	7	173	11.625
NF07	6	7	0.027	0.004	7	219	15.646	7	0.018	0.004	7	165	22.292
NF07	7	7	0.033	0.007	7	230	12.321	7	0.020	0.010	7	181	80.143
NF07	8	6	0.029	0.017	6	183	62.682	6	0.016	0.009	6	145	51.333
NF07	9	7	0.030	0.004	7	230	28.818	7	0.018	0.003	7	185	40.702
NF08	1	8	0.022	0.006	8	219	34.993	8	0.013	0.005	8	229	52.822
NF08	10	7	0.031	0.005	7	267	22.882	7	0.020	0.004	7	232	13.367
NF08	2	3	0.032	0.001	3	250	5.508	3	0.016	0.002	3	205	33.946
NF08	3	9	0.025	0.004	9	239	22.386	9	0.012	0.005	9	189	43.532
NF08	4	7	0.030	0.006	7	248	14.660	7	0.016	0.004	7	187	35.128
NF08	5	4	0.029	0.005	4	228	23.027	4	0.015	0.004	4	173	6.292
NF08	6	7	0.028	0.005	7	233	29.455	7	0.014	0.003	7	201	26.714
NF08	7	3	0.038	0.004	3	242	4.509	3	0.019	0.004	3	186	26.851
NF08	8	6	0.031	0.015	6	213	59.029	6	0.018	0.010	6	203	46.728
NF08	9	4	0.034	0.011	4	245	27.459	4	0.020	0.006	4	203	48.767
NF14	1	6	0.034	0.010	6	250	23.752	6	0.015	0.004	6	168	22.259

Table B-4a
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	pot	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
NF14	10	8	0.029	0.003	8	233	12.118	8	0.020	0.003	8	276	59.017
NF14	2	5	0.034	0.009	5	215	43.489	5	0.018	0.002	5	208	38.102
NF14	3	7	0.036	0.004	7	248	14.537	7	0.019	0.003	7	254	44.977
NF14	4	3	0.040	0.007	3	265	14.978	3	0.023	0.006	3	301	81.191
NF14	5	2	0.039	0.008	2	251	30.406	2	0.021	0.004	2	231	28.991
NF14	6	8	0.026	0.007	8	246	22.074	8	0.012	0.003	8	164	16.105
NF14	7	3	0.033	0.007	3	223	35.247	3	0.016	0.004	3	185	13.577
NF14	8	10	0.024	0.004	10	221	16.507	10	0.015	0.002	10	253	57.812
NF14	9	7	0.033	0.010	7	246	41.016	7	0.012	0.005	7	157	30.905
NF16	1	10	0.037	0.027	10	249	52.873	10	0.016	0.014	10	214	56.972
NF16	10	10	0.035	0.006	10	276	16.965	10	0.019	0.007	10	267	44.921
NF16	2	9	0.031	0.007	9	272	25.567	9	0.015	0.005	9	249	30.951
NF16	3	9	0.042	0.004	9	294	11.487	9	0.021	0.011	9	255	60.108
NF16	4	10	0.030	0.006	10	256	33.367	10	0.019	0.007	10	256	30.450
NF16	5	9	0.046	0.028	9	281	24.132	9	0.018	0.007	9	228	25.019
NF16	6	9	0.047	0.013	9	282	24.124	9	0.024	0.016	9	231	54.731
NF16	7	10	0.034	0.008	10	277	19.319	10	0.014	0.004	10	216	40.897
NF16	8	10	0.045	0.007	10	285	13.062	10	0.024	0.015	10	239	22.761
NF16	9	8	0.042	0.010	8	278	24.710	8	0.022	0.019	8	211	45.154
SF06	1	9	0.024	0.006	9	184	26.639	9	0.021	0.006	9	247	34.498
SF06	10	9	0.028	0.004	9	204	13.059	9	0.018	0.002	9	218	23.563
SF06	2	10	0.024	0.008	10	174	31.482	10	0.016	0.003	10	236	18.918
SF06	3	10	0.021	0.004	10	176	26.433	10	0.015	0.003	10	239	54.471
SF06	4	9	0.026	0.006	9	199	33.804	9	0.017	0.005	9	218	48.900
SF06	5	9	0.021	0.012	9	172	43.141	9	0.011	0.005	9	176	26.720
SF06	6	8	0.030	0.006	8	205	16.852	8	0.028	0.017	8	269	26.578
SF06	7	10	0.021	0.010	10	170	47.255	10	0.015	0.007	10	200	53.246
SF06	8	10	0.030	0.004	10	198	17.045	10	0.023	0.008	10	244	46.703
SF06	9	10	0.020	0.007	10	178	30.902	10	0.014	0.003	10	190	33.778
SF12	1	1	0.017	0.000	1	184	0.000	1	0.020	0.000	1	182	0.000
SF12	6	1	0.022	0.000	1	194	0.000	1	0.033	0.000	1	235	0.000
SF12	7	1	0.024	0.000	1	200	0.000	1	0.026	0.000	1	299	0.000
SF14	1	1	0.007	0.000	1	114	0.000	1	0.005	0.000	1	72	0.000
SF14	10	4	0.016	0.011	4	120	76.203	4	0.011	0.010	4	178	116.053
SF14	2	4	0.013	0.008	4	131	48.597	4	0.012	0.008	4	185	100.367
SF14	3	6	0.017	0.007	6	165	42.720	6	0.013	0.007	6	195	68.110
SF14	4	4	0.024	0.014	4	179	72.835	4	0.018	0.007	4	219	88.689
SF14	5	3	0.024	0.018	3	176	71.122	3	0.101	0.155	3	199	113.918
SF14	6	4	0.011	0.007	4	132	47.198	4	0.008	0.005	4	172	85.656
SF14	7	2	0.016	0.016	2	126	114.551	2	0.012	0.014	2	156	142.128
SF14	8	1	0.011	0.000	1	129	0.000	1	0.011	0.000	1	100	0.000
SF14	9	1	0.021	0.000	1	186	0.000	1	0.021	0.000	1	250	0.000
SF23	1	10	0.028	0.003	10	203	11.681	10	0.023	0.004	10	238	20.382
SF23	10	5	0.017	0.009	5	159	67.987	5	0.015	0.007	5	237	118.170
SF23	2	6	0.024	0.005	6	193	22.613	6	0.018	0.005	6	226	31.856
SF23	3	8	0.025	0.005	8	186	12.558	8	0.024	0.005	8	257	59.700
SF23	4	9	0.023	0.009	9	177	43.255	9	0.020	0.007	9	217	59.691
SF23	5	9	0.024	0.007	9	181	22.517	9	0.021	0.003	9	247	50.677
SF23	6	8	0.027	0.007	8	204	19.138	8	0.019	0.007	8	244	40.461
SF23	7	9	0.023	0.008	9	172	37.715	9	0.017	0.006	9	181	46.877
SF23	8	7	0.024	0.005	7	203	16.857	7	0.016	0.003	7	231	24.980
SF23	9	10	0.026	0.007	9	177	23.856	10	0.020	0.006	9	270	32.160
SF25	1	9	0.029	0.006	9	192	10.565	9	0.017	0.003	9	203	50.309
SF25	10	8	0.031	0.005	8	204	20.010	8	0.021	0.004	8	229	30.123
SF25	2	6	0.030	0.005	6	210	14.588	6	0.019	0.001	6	199	37.109
SF25	3	9	0.026	0.004	9	203	12.679	9	0.020	0.005	9	255	50.520
SF25	4	6	0.036	0.015	6	217	20.474	6	0.053	0.068	6	227	48.845
SF25	5	8	0.028	0.004	8	199	15.593	8	0.022	0.005	8	240	47.920
SF25	6	9	0.024	0.004	9	205	17.804	9	0.019	0.005	9	239	26.897

Table B-4a
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	pot	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
SF25	7	3	0.025	0.004	3	212	5.508	3	0.020	0.004	3	234	68.157
SF25	8	10	0.022	0.008	10	181	21.348	10	0.038	0.041	10	215	38.233
SF25	9	6	0.030	0.004	6	200	5.565	6	0.023	0.005	6	222	18.681
SF27	1	10	0.024	0.008	10	188	36.762	10	0.024	0.009	10	244	38.270
SF27	10	10	0.024	0.005	10	175	16.251	10	0.021	0.006	10	236	37.521
SF27	2	10	0.028	0.007	10	197	14.765	10	0.027	0.007	10	202	31.940
SF27	3	10	0.024	0.006	10	181	27.446	10	0.028	0.013	10	282	32.332
SF27	4	10	0.022	0.003	10	193	13.718	10	0.020	0.003	10	252	28.229
SF27	5	10	0.028	0.006	10	210	18.915	10	0.022	0.005	10	265	42.674
SF27	6	10	0.025	0.007	10	198	18.646	10	0.021	0.006	10	237	34.850
SF27	7	10	0.024	0.009	10	193	40.010	10	0.021	0.008	10	246	51.242
SF27	8	10	0.026	0.004	10	197	13.449	10	0.026	0.005	10	278	19.697
SF27	9	10	0.028	0.005	10	207	12.275	10	0.022	0.003	10	248	45.468
SF36	1	10	0.028	0.010	10	179	33.008	10	0.023	0.012	10	179	45.692
SF36	10	10	0.022	0.005	10	186	23.557	10	0.020	0.006	10	174	27.897
SF36	2	9	0.028	0.009	9	192	25.016	9	0.022	0.006	9	216	24.270
SF36	3	9	0.029	0.008	9	196	28.457	9	0.024	0.007	9	195	20.427
SF36	4	9	0.022	0.008	9	183	35.391	9	0.017	0.005	9	187	47.565
SF36	5	9	0.033	0.013	7	203	24.710	9	0.025	0.005	7	166	25.566
SF36	6	7	0.028	0.007	9	194	22.147	7	0.020	0.005	9	182	35.011
SF36	7	10	0.026	0.004	10	189	19.027	10	0.025	0.004	10	229	25.651
SF36	8	7	0.025	0.013	7	191	56.564	7	0.017	0.007	7	174	39.070
SF36	9	9	0.025	0.009	9	192	30.925	9	0.019	0.005	9	204	39.922
SF39	1	2	0.018	0.009	2	195	24.042	2	0.010	0.004	2	182	69.296
SF39	4	2	0.025	0.021	2	196	61.518	2	0.014	0.013	2	138	70.711
SF39	6	1	0.028	0.000	1	215	0.000	1	0.011	0.000	1	251	0.000
SF39	7	4	0.017	0.003	4	172	25.395	4	0.014	0.002	4	264	11.471
SF55	1	7	0.021	0.008	7	153	30.956	7	0.012	0.004	7	121	9.771
SF55	10	10	0.025	0.009	10	170	32.327	10	0.018	0.009	10	139	23.841
SF55	2	10	0.022	0.005	10	167	19.614	10	0.015	0.004	10	135	31.262
SF55	3	10	0.024	0.006	10	181	16.898	10	0.015	0.003	10	153	28.445
SF55	4	10	0.023	0.006	10	172	22.368	10	0.014	0.003	10	132	13.924
SF55	5	9	0.024	0.007	9	181	26.725	9	0.016	0.003	9	151	33.982
SF55	6	9	0.026	0.007	9	183	25.553	9	0.015	0.005	9	121	22.114
SF55	7	10	0.028	0.006	10	187	16.210	10	0.017	0.004	10	139	26.743
SF55	8	10	0.027	0.005	10	186	15.397	10	0.018	0.004	10	148	20.726
SF55	9	10	0.025	0.006	10	181	17.852	10	0.016	0.003	10	136	27.365

Table B-4b
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	pot	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
CC01	1	1	0.081	0	15	57.9	6.4	1	0.048	0	15	37.3	15.3
CC01	2	1	0.042	0	11	60.5	24.5	1	0.013	0	11	20.3	15.2
CC01	3	1	0.048	0	10	52.3	6.3	1	0.025	0	10	33.4	10.1
CC01	4	1	0.054	0	8	62.3	8.3	1	0.024	0	8	31.1	9.8
CC01	5	1	0.091	0	14	65.1	12.8	1	0.014	0	14	31.5	27.4
CC02	1	1	0.062	0	16	58.4	10.7	1	0.012	0	16	38.6	20.2
CC02	2	1	0.081	0	17	46.5	7.5	1	0.096	0	17	32.7	11.6
CC02	3	1	0.111	0	19	54.7	7.7	1	0.018	0	19	32.1	9.3
CC02	4	1	0.093	0	18	56.7	9.5	1	0.018	0	18	34.6	17.9
CC02	5	1	0.075	0	19	59.5	15.1	1	0.016	0	19	31.5	10.8
CC04	1	1	0.032	0	15	7.5	2.5	1	0.001	0	15	2.6	1.1
CC04	2	1	0.013	0	10	8.3	1.6	1	0.002	0	10	2.5	0.7
CC04	3	1	0.054	0	8	6.4	0.7	1	0.005	0	8	2.9	0.8
CC04	4	1	0.019	0	15	6.7	1.2	1	0.006	0	15	3.1	0.8
CC04	5	1	0.017	0	11	8.6	2.5	1	0.003	0	11	3.0	0.4
CC08	1	1	0.007	0	6	8.2	0.8	1	0	0	6	0.8	0.8
CC08	2	1	0.005	0	7	7.1	0.7	1	0	0	7	1.1	1.1
CC08	3	1	0.007	0	5	8.8	2.0	1	0	0	5	1.8	0.4
CC08	4	1	0.002	0	2	8.0	1.4	1	0	0	2	0.5	0.7
CC08	5	1	0.007	0	6	7.5	1.0	1	0	0	6	0.3	0.5
CC09	1	1	0.004	0	5	7.4	1.5	1	0.001	0	5	2.8	1.1
CC09	2	1	0.001	0	1	7.0	0.0	1	0.001	0	1	2.0	0.0
CC09	3	1	0.005	0	4	7.5	1.3	1	0.004	0	4	3.8	0.5
CC09	4	1	0.006	0	7	6.9	1.3	1	0.002	0	7	3.0	1.0
CC09	5	1	0.003	0	5	6.4	0.9	1	0.004	0	5	3.6	0.5
LC01	1	1	0.017	0	5	44.8	8.4	1	0.002	0	5	22.6	8.4
LC01	2	1	0.007	0	8	15.0	8.9	1	0.007	0	8	19.3	11.6
LC01	3	1	0.001	0	2	11.5	2.1	1	0.001	0	2	27.0	25.5
LC01	4	1	0.002	0	2	14.5	0.7	1	0.002	0	2	44.5	3.5
LC01	5	1	0.001	0	1	17.0	0.0	1	0.002	0	1	37.0	0.0
LC03	1	1	0.006	0	5	8.0	2.2	1	0.004	0	5	22.0	15.1
LC03	2	1	0.01	0	7	13.3	3.6	1	0.005	0	7	26.6	7.8
LC03	3	1	0.008	0	8	15.4	4.9	1	0.005	0	8	18.3	6.2
LC03	4	1	0.002	0	2	11.0	4.2	1	0.001	0	2	21.0	4.2
LC03	5	1	0.005	0	4	17.0	5.6	1	0.001	0	4	16.0	4.2
LC04	1	1	0.032	0	9	27.7	3.2	1	0.008	0	9	60.6	20.1
LC04	2	1	0.039	0	14	28.2	6.2	1	0.007	0	14	31.6	16.0
LC04	3	1	0.049	0	15	40.1	7.9	1	0.006	0	15	35.1	12.4
LC04	4	1	0.051	0	18	25.8	6.9	1	0.021	0	18	67.2	27.6
LC04	5	1	0.044	0	15	28.7	8.2	1	0.01	0	15	47.9	22.1
LC07	1	1	0.008	0	2	41.0	29.7	1	0.001	0	2	26.0	29.7
LC07	2	1	0.001	0	1	13.0	0.0	1	0.001	0	1	5.0	0.0
LC07	3	1	0.009	0	5	23.8	7.6	1	0.003	0	5	17.8	5.7
LC07	4	1	0.007	0	1	41.0	0.0	1	0.001	0	1	29.0	0.0
LC07	5	1	0.001	0	1	13.0	0.0	1	0.001	0	1	9.0	0.0
LC08	1	1	0.059	0	19	15.2	6.3	1	0.006	0	19	6.2	3.2
LC08	2	1	0.036	0	17	15.6	7.2	1	0.004	0	17	6.6	3.4
LC08	3	1	0.03	0	9	14.9	4.2	1	0.005	0	9	7.2	3.4
LC08	4	1	0.054	0	14	15.5	4.9	1	0.008	0	14	8.1	3.4
LC08	5	1	0.026	0	17	16.4	8.6	1	0.007	0	17	7.8	3.8
LC10	1	1	0.007	0	6	8.2	0.8	1	0	0	6	0.8	0.8
LC10	2	1	0.005	0	7	7.1	0.7	1	0	0	7	1.1	1.1
LC10	3	1	0.007	0	5	8.8	2.0	1	0	0	5	1.8	0.4
LC10	4	1	0.002	0	2	8.0	1.4	1	0	0	2	0.5	0.7
LC10	5	1	0.007	0	6	7.5	1.0	1	0	0	6	0.3	0.5
LC14	1	1	0.072	0	17	68.8	11.2	1	0.023	0	17	46.6	24.8
LC14	2	1	0.108	0	17	61.8	10.9	1	0.027	0	17	66.5	18.6
LC14	3	1	0.088	0	16	51.1	8.8	1	0.023	0	16	66.3	19.6
LC14	4	1	0.105	0	19	66.2	11.6	1	0.027	0	19	52.4	25.3

Table B-4b
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	**pot**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LC14	5	1	0.076	0	16	48.6	12.0	1	0.022	0	16	54.7	28.1
LC20	1	1	0.08	0	16	62.6	20.1	1	0.008	0	16	38.9	21.6
LC20	2	1	0.101	0	18	75.5	17.2	1	0.024	0	18	52.7	14.3
LC20	3	1	0.082	0	17	54.8	16.7	1	0.023	0	17	34.9	11.9
LC20	4	1	0.112	0	19	49.8	16.8	1	0.023	0	19	41.8	11.5
LC20	5	1	0.084	0	13	53.2	19.2	1	0.015	0	13	41.2	11.7
LC21	1	1	0.004	0	2	14.5	6.4	1	0.001	0	2	18.0	2.8
LC21	2	1	0.005	0	2	14.0	8.5	1	0.003	0	2	17.5	14.8
LC21	5	1	0.001	0	1	11.0	0.0	1	0.001	0	1	30.0	0.0
LC29	4	1	0.004	0	1	58.0	0.0	1	0.001	0	1	79.0	0.0
NC11	1	1	0.004	0	4	7.3	2.1	1	0.001	0	4	1.5	0.6
NC11	2	1	0.004	0	4	7.5	1.3	1	0.001	0	4	1.0	1.4
NC11	3	1	0.006	0	5	6.6	1.5	1	0.002	0	5	1.6	1.3
NC16	2	1	0.005	0	1	53.0	0.0	1	0.001	0	1	32.0	0.0
NC16	3	1	0.004	0	2	16.0	15.6	1	0.001	0	2	25.5	12.0
NC16	4	1	0.004	0	1	30.0	0.0	1	0.001	0	1	12.0	0.0
NC18	1	1	0.03	0	8	46.9	5.0	1	0.005	0	8	46.5	10.1
NC18	2	1	0.047	0	14	37.1	10.2	1	0.011	0	14	54.9	11.8
NC18	3	1	0.038	0	10	30.7	2.2	1	0.011	0	10	64.1	15.6
NC18	4	1	0.055	0	16	37.8	7.5	1	0.017	0	16	56.4	18.0
NC18	5	1	0.051	0	16	45.5	6.4	1	0.015	0	16	65.6	14.9
NF01	1	1	0.08	0	17	84.6	14.3	1	0.012	0	17	35.4	10.4
NF01	2	1	0.08	0	18	72.2	10.6	1	0.02	0	18	44.0	19.8
NF01	3	1	0.077	0	15	64.0	19.6	1	0.014	0	15	42.1	20.5
NF01	4	1	0.082	0	13	64.2	8.0	1	0.017	0	13	43.2	17.1
NF01	5	1	0.083	0	11	58.8	18.9	1	0.018	0	11	54.5	24.0
NF03	1	1	0.126	0	20	63.6	11.8	1	0.031	0	20	42.3	11.4
NF03	2	1	0.146	0	19	65.8	15.7	1	0.033	0	19	51.9	19.5
NF03	3	1	0.103	0	19	61.0	12.7	1	0.027	0	19	44.4	14.5
NF03	4	1	0.087	0	18	56.3	13.9	1	0.029	0	18	48.9	17.9
NF03	5	1	0.082	0	19	74.3	9.6	1	0.018	0	19	36.3	15.7
NF07	1	1	0.074	0	20	60.2	10.2	1	0.017	0	20	39.6	14.2
NF07	2	1	0.077	0	16	45.5	5.4	1	0.016	0	16	38.2	12.8
NF07	3	1	0.091	0	20	43.3	6.4	1	0.028	0	20	54.8	16.2
NF07	4	1	0.098	0	18	39.9	4.0	1	0.026	0	18	42.2	9.7
NF07	5	1	0.086	0	18	49.3	9.3	1	0.016	0	18	39.8	15.8
NF08	1	1	0.072	0	17	46.5	7.4	1	0.013	0	17	35.8	19.5
NF08	2	1	0.069	0	16	47.9	8.2	1	0.021	0	16	39.6	11.3
NF08	3	1	0.087	0	14	56.4	6.1	1	0.025	0	14	50.9	11.3
NF08	4	1	0.043	0	15	35.4	13.9	1	0.021	0	15	38.0	20.5
NF08	5	1	0.109	0	19	60.8	11.9	1	0.015	0	19	40.4	15.0
NF14	1	1	0.055	0	14	53.0	9.9	1	0.021	0	14	38.9	14.4
NF14	2	1	0.072	0	13	36.8	11.9	1	0.055	0	13	62.7	16.9
NF14	3	1	0.072	0	16	46.1	12.4	1	0.059	0	16	56.3	25.0
NF14	4	1	0.084	0	16	52.6	6.9	1	0.069	0	16	67.3	19.3
NF14	5	1	0.06	0	12	36.2	5.6	1	0.046	0	12	46.5	17.3
NF16	1	1	0.087	0	13	75.8	8.0	1	0.011	0	13	43.6	16.8
NF16	2	1	0.107	0	16	60.6	16.9	1	0.012	0	16	40.5	18.1
NF16	3	1	0.108	0	17	84.5	11.0	1	0.015	0	17	38.1	13.6
NF16	4	1	0.129	0	16	63.8	7.3	1	0.023	0	16	46.4	18.3
NF16	5	1	0.101	0	17	61.0	8.5	1	0.036	0	17	56.9	26.5
SF06	1	1	0.074	0	19	29.1	4.7	1	0.015	0	19	37.1	10.7
SF06	2	1	0.09	0	20	23.5	4.7	1	0.015	0	20	33.0	10.8
SF06	3	1	0.048	0	15	28.1	7.1	1	0.013	0	15	30.1	12.0
SF06	4	1	0.051	0	16	28.9	10.5	1	0.013	0	16	23.2	6.6
SF06	5	1	0.056	0	15	28.3	7.6	1	0.012	0	15	31.7	9.3
SF12	1	1	0.031	0	10	34.1	10.2	1	0.009	0	10	37.7	13.5
SF12	2	1	0.033	0	11	21.5	6.8	1	0.012	0	11	37.7	11.0
SF12	3	1	0.024	0	8	32.4	5.1	1	0.005	0	8	36.6	18.7

Table B-4b
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	pot	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
SF12	4	1	0.021	0	8	42.6	10.9	1	0.008	0	8	34.9	15.7
SF12	5	1	0.001	0	1	37.0	0.0	1	0.001	0	1	12.0	0.0
SF14	1	1	0.05	0	14	27.6	7.2	1	0.006	0	14	28.4	12.6
SF14	2	1	0.048	0	15	31.0	5.1	1	0.006	0	15	21.7	10.3
SF14	3	1	0.055	0	16	32.9	6.5	1	0.006	0	16	35.1	12.6
SF14	4	1	0.073	0	15	43.7	20.9	1	0.009	0	15	19.7	6.8
SF14	5	1	0.058	0	11	24.3	10.5	1	0.007	0	11	25.3	10.4
SF23	1	1	0.014	0	4	25.3	6.3	1	0.003	0	4	24.8	7.5
SF23	2	1	0.059	0	13	38.8	6.3	1	0.01	0	13	44.8	17.4
SF23	3	1	0.06	0	17	26.1	6.6	1	0.015	0	17	32.3	7.3
SF23	4	1	0.023	0	8	29.1	9.9	1	0.005	0	8	34.8	11.5
SF23	5	1	0.015	0	6	28.3	3.6	1	0.003	0	6	23.7	14.0
SF25	1	1	0.048	0	13	32.8	7.5	1	0.011	0	13	25.5	4.0
SF25	2	1	0.054	0	13	36.9	7.9	1	0.011	0	13	24.7	8.9
SF25	3	1	0.052	0	14	46.6	12.2	1	0.008	0	14	31.0	9.0
SF25	4	1	0.059	0	15	35.9	8.8	1	0.011	0	15	28.4	10.7
SF25	5	1	0.027	0	10	51.5	8.1	1	0.006	0	10	28.9	9.1
SF27	1	1	0.087	0	20	42.0	7.1	1	0.03	0	20	73.2	11.8
SF27	2	1	0.08	0	19	49.9	5.3	1	0.028	0	19	65.7	15.1
SF27	3	1	0.083	0	19	50.4	9.8	1	0.027	0	19	64.1	14.4
SF27	4	1	0.085	0	20	53.4	8.2	1	0.032	0	20	66.7	19.2
SF27	5	1	0.08	0	20	44.2	4.7	1	0.03	0	20	68.5	16.3
SF36	1	1	0.096	0	20	41.0	4.2	1	0.028	0	20	48.3	12.0
SF36	2	1	0.07	0	17	34.1	5.8	1	0.023	0	17	53.1	10.3
SF36	3	1	0.07	0	18	27.3	4.8	1	0.023	0	18	47.7	12.4
SF36	4	1	0.083	0	19	32.8	6.0	1	0.092	0	19	53.4	12.9
SF36	5	1	0.076	0	20	34.2	7.1	1	0.029	0	20	48.0	16.1
SF39	1	1	0.109	0	20	35.9	5.8	1	0.033	0	20	72.0	22.9
SF39	2	1	0.078	0	16	57.8	9.0	1	0.025	0	16	51.8	12.8
SF39	3	1	0.082	0	19	67.6	9.7	1	0.022	0	19	46.9	17.4
SF39	4	1	0.17	0	14	53.0	8.0	1	0.065	0	14	63.4	21.9
SF39	5	0	NA	0	17	50.5	10.4	0	NA	0	17	58.9	20.6
SF55	1	1	0.011	0	18	30.8	6.8	1	0.003	0	18	41.1	14.4
SF55	2	1	0.006	0	18	30.2	7.2	1	0.001	0	18	36.9	12.7
SF55	3	1	0.01	0	19	33.6	4.5	1	0.002	0	19	36.8	10.6
SF55	4	1	0.005	0	18	31.0	6.3	1	0.001	0	18	42.7	9.9
SF55	5	1	0.009	0	17	33.7	5.6	1	0.003	0	17	42.6	9.8

Table B-4c
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	**pot**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
CC01	1	1	0.065	0	16	49.31	8.27	1	0.014	0	16	23.25	9.35
CC01	2	1	0.039	0	8	54.13	11.41	1	0.005	0	8	19.00	4.78
CC01	3	1	0.016	0	3	43.00	5.29	1	0.003	0	3	18.00	16.52
CC01	4	1	0.017	0	4	48.00	4.32	1	0.002	0	4	19.75	4.11
CC01	5	1	0.021	0	6	53.17	5.15	1	0.004	0	6	15.50	6.35
CC02	1	1	0.1	0	19	53.53	13.05	1	0.019	0	19	37.79	14.67
CC02	2	1	0.081	0	16	49.00	10.66	1	0.010	0	16	35.19	13.43
CC02	3	1	0.069	0	17	51.35	10.11	1	0.010	0	17	32.88	16.42
CC02	4	1	0.078	0	15	54.67	9.68	1	0.011	0	15	29.67	16.71
CC02	5	1	0.06	0	19	47.79	12.58	1	0.018	0	19	28.11	12.52
CC04	1	1	0.013	0	10	11.40	2.12	1	0.002	0	10	4.70	1.34
CC04	2	1	0.022	0	11	12.27	2.65	1	0.002	0	11	5.73	2.83
CC04	3	1	0.018	0	9	12.22	1.86	1	0.002	0	9	3.89	1.17
CC04	4	1	0.014	0	10	11.40	2.67	1	0.002	0	10	5.10	1.10
CC04	5	1	0.011	0	6	11.50	2.17	1	0.002	0	6	3.83	0.75
CC08	1	1	0.005	0	3	8.00	3.46	1	0.002	0	3	4.33	2.08
CC08	2	1	0.008	0	5	8.20	1.79	1	0.002	0	5	4.60	1.14
CC08	3	1	0.007	0	5	8.80	2.28	1	0.000	0	5	3.40	1.14
CC08	4	1	0.002	0	0	NA	0.00	1	0.000	0	0	NA	0.00
CC08	5	1	0.009	0	7	6.29	3.04	1	0.000	0	7	3.86	1.77
CC09	1	1	0.017	0	9	11.56	2.07	1	0.002	0	9	2.33	1.50
CC09	2	1	0.009	0	5	10.00	1.73	1	0.001	0	5	1.60	1.67
CC09	3	1	0.011	0	7	11.00	1.15	1	0.003	0	7	4.14	3.24
CC09	4	1	0.017	0	9	11.67	2.18	1	0.001	0	9	2.89	1.36
CC09	5	1	0.013	0	8	11.00	1.60	1	0.001	0	8	2.25	1.91
LC03	3	1	0.004	0	1	25.00	0.00	1	0.001	0	1	14.00	0.00
LC04	1	1	0.058	0	14	43.86	8.08	1	0.011	0	14	36.43	12.78
LC04	2	1	0.055	0	17	42.18	10.30	1	0.009	0	17	34.59	16.72
LC04	3	1	0.041	0	14	38.00	15.07	1	0.007	0	14	17.86	7.85
LC04	4	1	0.028	0	8	41.75	11.90	1	0.005	0	8	28.25	16.92
LC04	5	1	0.042	0	10	38.80	10.25	1	0.006	0	10	27.10	14.56
LC08	1	1	0.02	0	11	14.00	3.61	1	0.006	0	11	9.82	5.31
LC08	2	1	0.022	0	9	13.22	1.56	1	0.003	0	9	11.11	3.52
LC08	3	1	0.018	0	9	12.33	3.39	1	0.003	0	9	11.44	5.15
LC08	4	1	0.011	0	7	14.14	3.18	1	0.002	0	7	12.71	3.68
LC08	5	1	0.03	0	12	15.58	4.89	1	0.002	0	12	10.42	2.61
LC10	1	1	0.016	0	3	54.33	8.96	1	0.002	0	3	23.33	3.21
LC10	2	1	0.006	0	2	33.50	12.02	1	0.002	0	2	28.00	11.31
LC10	3	1	0.01	0	2	52.00	11.31	1	0.002	0	2	16.50	0.71
LC10	4	1	0.018	0	4	40.75	16.40	1	0.007	0	4	19.50	17.46
LC14	1	1	0.105	0	20	55.05	8.90	1	0.043	0	20	74.95	19.85
LC14	2	1	0.097	0	16	65.63	14.10	1	0.041	0	16	77.81	41.35
LC14	3	1	0.079	0	16	69.13	11.99	1	0.019	0	16	58.56	21.96
LC14	4	1	0.09	0	18	62.11	8.41	1	0.026	0	18	64.61	17.92
LC14	5	1	0.103	0	20	73.80	10.14	1	0.036	0	20	50.85	8.90
LC20	1	1	0.054	0	17	50.94	16.01	1	0.020	0	17	38.18	14.28
LC20	2	1	0.031	0	10	49.10	17.96	1	0.012	0	10	31.20	16.00
LC20	3	1	0.048	0	14	51.29	15.39	1	0.020	0	14	40.00	15.22
LC20	4	1	0.044	0	16	34.94	15.96	1	0.011	0	16	28.81	16.48
LC20	5	1	0.035	0	10	56.30	9.97	1	0.014	0	10	44.50	4.97
LC21	2	1	0.001	0	1	9.00	0.00	1	0.001	0	1	11.00	0.00
LC21	3	1	0.005	0	2	21.00	18.38	1	0.001	0	2	9.50	4.95
LC29	1	1	0.02	0	6	52.83	8.11	1	0.003	0	6	59.00	24.79
LC29	2	1	0.006	0	2	52.00	11.31	1	0.001	0	2	59.00	5.66
LC29	3	1	0.006	0	2	42.50	6.36	1	0.001	0	2	47.50	4.95
NC11	1	1	0.007	0	4	7.50	1.91	1	0.002	0	4	4.00	1.41
NC11	2	1	0.013	0	8	10.50	2.14	1	0.001	0	8	4.63	3.02
NC11	3	1	0.002	0	4	7.00	1.41	1	0.001	0	4	4.50	3.32

Table B-4c
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	pot	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
NC11	4	1	0.009	0	6	9.83	1.94	1	0.001	0	6	4.00	2.00
NC11	5	1	0.007	0	7	11.14	5.08	1	0.003	0	7	4.00	1.41
NC16	2	1	0.005	0	2	48.00	1.41	1	0.001	0	2	30.50	10.61
NC18	1	1	0.008	0	3	55.00	7.55	1	0.001	0	3	35.33	8.74
NC18	2	1	0.003	0	1	23.00	0.00	1	0.001	0	1	26.00	0.00
NC18	3	1	0.002	0	2	21.50	3.54	1	0.001	0	2	30.50	17.68
NC18	4	1	0.003	0	2	43.00	26.87	1	0.001	0	2	49.00	8.49
NC18	5	1	0.004	0	1	81.00	0.00	1	0.001	0	1	90.00	0.00
NF01	1	1	0.12	0	19	88.74	11.46	1	0.010	0	19	49.79	19.93
NF01	2	1	0.128	0	17	83.94	12.70	1	0.013	0	17	42.06	19.29
NF01	3	1	0.103	0	19	80.89	17.87	1	0.011	0	19	40.95	15.93
NF01	4	1	0.11	0	18	77.17	21.59	1	0.021	0	18	37.72	17.36
NF01	5	1	0.089	0	16	81.63	8.83	1	0.002	0	15	49.87	15.12
NF03	1	1	0.124	0	20	70.90	9.55	1	0.016	0	20	59.30	33.32
NF03	2	1	0.115	0	20	65.85	17.35	1	0.035	0	20	95.95	38.09
NF03	3	1	0.116	0	17	78.00	13.18	1	0.030	0	17	85.76	22.53
NF03	4	1	0.079	0	17	69.65	15.94	1	0.036	0	17	92.35	20.49
NF03	5	1	0.131	0	20	89.85	15.38	1	0.041	0	20	95.00	26.48
NF07	1	1	0.102	0	19	60.00	10.56	1	0.021	0	19	39.63	8.07
NF07	2	1	0.111	0	19	60.42	7.33	1	0.018	0	19	47.21	9.32
NF07	3	1	0.085	0	15	47.27	10.35	1	0.025	0	15	42.33	15.53
NF07	4	1	0.1	0	17	58.24	16.80	1	0.019	0	17	37.94	13.06
NF07	5	1	0.092	0	18	59.67	13.02	1	0.019	0	18	45.72	11.49
NF08	1	1	0.138	0	20	60.40	16.23	1	0.059	0	20	98.50	29.98
NF08	2	1	0.095	0	15	68.13	13.10	1	0.031	0	15	100.00	36.53
NF08	3	1	0.124	0	17	70.12	21.01	1	0.036	0	17	76.24	26.24
NF08	4	1	0.094	0	17	67.71	20.39	1	0.024	0	17	67.00	23.72
NF08	5	1	0.089	0	18	76.33	10.10	1	0.036	0	18	79.44	17.59
NF14	1	1	0.056	0	10	49.40	13.99	1	0.029	0	10	26.10	12.84
NF14	2	1	0.061	0	12	51.33	15.31	1	0.034	0	12	34.17	17.52
NF14	3	1	0.041	0	11	51.27	9.97	1	0.029	0	11	29.27	9.03
NF14	4	1	0.052	0	15	56.87	16.06	1	0.037	0	15	27.27	14.81
NF14	5	1	0.051	0	11	65.64	15.84	1	0.043	0	11	42.27	31.87
NF16	1	1	0.132	0	20	78.50	14.01	1	0.018	0	20	37.75	12.80
NF16	2	1	0.106	0	18	71.89	15.55	1	0.013	0	18	42.78	17.90
NF16	3	1	0.096	0	18	83.89	12.39	1	0.009	0	18	36.61	9.73
NF16	4	1	0.139	0	16	81.25	15.98	1	0.012	0	16	49.25	20.19
NF16	5	1	0.132	0	16	68.13	8.99	1	0.018	0	16	54.44	21.03
SF06	1	1	0.059	0	18	49.67	8.17	1	0.014	0	18	42.89	13.98
SF06	2	1	0.041	0	18	42.78	9.92	1	0.009	0	18	31.78	11.25
SF06	3	1	0.036	0	14	46.43	12.69	1	0.007	0	14	32.14	14.65
SF06	4	1	0.064	0	20	35.40	10.14	1	0.028	0	20	45.25	12.65
SF06	5	1	0.031	0	14	42.93	9.47	1	0.008	0	14	36.71	9.37
SF12	1	1	0.034	0	14	34.50	11.13	1	0.008	0	14	16.93	7.22
SF12	2	1	0.035	0	17	30.47	12.83	1	0.008	0	17	19.35	9.74
SF12	3	1	0.009	0	11	37.00	10.80	1	0.039	0	11	21.91	6.73
SF12	4	1	0.059	0	14	40.14	14.66	1	0.013	0	14	28.71	19.39
SF12	5	1	0.056	0	14	31.00	9.32	1	0.010	0	14	17.86	8.73
SF14	1	1	0.061	0	16	35.88	7.74	1	0.016	0	16	15.31	7.15
SF14	2	1	0.055	0	15	37.67	10.76	1	0.008	0	15	17.13	5.19
SF14	3	1	0.068	0	18	37.17	6.02	1	0.023	0	18	15.22	5.44
SF14	4	1	0.044	0	20	40.10	8.64	1	0.012	0	20	22.05	10.50
SF14	5	1	0.026	0	20	45.05	7.80	1	0.005	0	20	19.55	12.44
SF23	1	1	0.049	0	18	41.33	9.37	1	0.026	0	18	41.00	11.67
SF23	2	1	0.052	0	18	33.22	8.19	1	0.034	0	18	42.78	20.12
SF23	3	1	0.041	0	13	36.77	6.38	1	0.028	0	13	59.77	26.83
SF23	4	1	0.043	0	15	40.00	11.45	1	0.024	0	15	46.47	15.08
SF23	5	1	0.06	0	18	39.89	10.24	1	0.030	0	18	36.33	13.12
SF25	1	1	0.061	0	18	53.39	11.66	1	0.011	0	18	21.83	5.50

Table B-4c
Phytotoxicity Test Results

		Stem Mass			Stem Length			Root Mass			Root Length		
sitename	pot	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
SF25	2	1	0.05	0	17	46.47	10.24	1	0.009	0	17	23.59	7.43
SF25	3	1	0.043	0	16	48.00	12.75	1	0.010	0	16	22.94	6.30
SF25	4	1	0.061	0	18	46.06	11.26	1	0.013	0	18	26.83	10.35
SF25	5	1	0.063	0	17	35.06	13.71	1	0.015	0	17	27.29	12.41
SF27	1	1	0.071	0	19	54.21	10.01	1	0.029	0	19	85.42	16.89
SF27	2	1	0.057	0	17	55.47	12.04	1	0.036	0	17	71.00	10.67
SF27	3	1	0.058	0	16	50.19	13.10	1	0.025	0	16	62.25	8.84
SF27	4	1	0.082	0	17	56.71	18.07	1	0.039	0	17	77.71	32.03
SF27	5	1	0.077	0	17	57.53	11.64	1	0.036	0	17	78.94	13.34
SF36	1	1	0.07	0	18	43.28	11.41	1	0.037	0	18	48.78	15.33
SF36	2	1	0.044	0	16	41.44	16.06	1	0.013	0	16	46.50	22.01
SF36	3	1	0.054	0	19	44.84	10.78	1	0.020	0	19	46.26	14.16
SF36	4	1	0.082	0	19	37.74	7.59	1	0.031	0	19	55.16	16.44
SF36	5	1	0.058	0	17	45.00	9.18	1	0.025	0	17	55.06	10.48
SF39	1	1	0.06	0	16	51.25	18.51	1	0.019	0	16	41.19	12.86
SF39	2	1	0.095	0	19	47.58	10.98	1	0.045	0	19	62.05	39.84
SF39	3	1	0.102	0	17	50.00	14.09	1	0.041	0	17	57.06	30.94
SF39	4	1	0.106	0	20	49.80	10.21	1	0.039	0	20	50.75	14.51
SF39	5	1	0.1	0	18	52.78	9.75	1	0.039	0	18	45.89	18.06
SF55	1	1	0.045	0	18	32.11	8.44	1	0.017	0	18	37.94	8.98
SF55	2	1	0.049	0	16	27.13	4.79	1	0.018	0	16	25.31	6.89
SF55	3	1	0.044	0	18	28.11	6.36	1	0.016	0	18	27.28	5.85
SF55	4	1	0.042	0	14	28.21	10.02	1	0.010	0	14	31.71	12.25
SF55	5	1	0.045	0	18	30.61	9.36	1	0.019	0	18	39.61	8.25

Table B-4d
Phytotoxicity Test Results

sitename	Pot	Branch Growth (mm)	Root Growth (mm)	Leaf Number (n)	Root Number (n)	Leaf Weight (g)
LC01	1	204	266	7	6	3.209
LC01	2	161	111	4	4	2.907
LC01	3	106	113	4	17	2.367
LC01	4	212	216	4	2	5.274
LC01	5	248	248	8	3	6.574
LC03	1	146	34	5	15	1.86
LC03	2	197	363	7	2	4.917
LC03	3	174	264	8	2	2.805
LC03	4	107	153	3	3	1.89
LC03	5	130	153	3	13	5.038
LC04	1	236	133	7	4	5.227
LC04	2	185	149	5	2	4.45
LC04	3	236	31	5	8	5.745
LC04	4	225	158	5	6	4.275
LC04	5	232	190	10	9	6.5
LC07	1	185	526	3	7	4.209
LC07	2	217	123	4	3	3.819
LC07	3	148	196	3	5	4.183
LC07	4	223	109	10	3	9.647
LC07	5	205	121	5	8	3.1
LC08	1	72	132	3	6	1.927
LC08	2	204	120	5	4	4.16
LC08	3	89	190	4	16	4.538
LC08	4	112	118	5	2	1.982
LC08	5	152	99	5	14	3.706
LC10	1	174	217	6	9	2.015
LC10	2	150	-17	8	1	1.581
LC10	3	52	121	3	2	2.374
LC10	4	-17	0	0	0	0.643
LC10	5	163	-38	3	-1	2.711
LC13	1	126	126	1	4	1.416
LC13	2	220	241	9	3	4.682
LC13	3	153	149	3	5	3.334
LC13	4	162	218	7	6	2.174
LC13	5	154	99	3	1	2.385
LC14	1	250	145	5	4	3.778
LC14	2	319	169	10	1	8.339
LC14	3	222	61	7	4	4.998
LC14	4	253	99	8	9	7.776
LC14	5	255	189	9	11	7.19
LC20	1	219	187	5	4	7.675
LC20	2	285	235	11	4	8.275
LC20	3	285	79	10	2	5.385
LC20	4	138	148	4	12	2.572
LC20	5	153	153	4	5	2.896
LC21	1	225	275	3	4	3.782
LC21	2	161	277	5	7	4.656
LC21	3	190	167	5	9	3.458
LC21	4	59	173	0	6	1.321
LC21	5	177	126	9	6	4.285
LC29	1	295	307	8	1	10.231
LC29	2	40	-21	0	-1	0.585
LC29	3	250	135	6	4	4.118
LC29	4	97	83	2	4	1.314
LC29	5	209	177	4	4	4.454
LC30	1	139	332	6	11	-
LC30	2	195	231	8	4	5.089
LC30	3	195	229	4	3	3.366
LC30	4	137	204	6	8	4.385
LC30	5	157	86	5	2	1.847
NC11	1	38	-29	0	-10	1.703

Table B-4d
Phytotoxicity Test Results

sitename	Pot	Branch Growth (mm)	Root Growth (mm)	Leaf Number (n)	Root Number (n)	Leaf Weight (g)
NC11	2	61	-30	4	-1	0.616
NC11	3	33	-42	1	-1	0.698
NC11	4	66	-12	0	-1	0.971
NC11	5	86	0	1	0	2.082
NC14	1	-57	-61	0	0	0.929
NC14	2	68	-64	-1	-3	0.36
NC14	3	47	0	0	0	1.129
NC14	4	24	40	1	0	0.382
NC14	5	98	-2	4	0	0.841
NC16	1	178	183	1	3	3.776
NC16	2	95	174	3	6	1.815
NC16	3	284	260	7	5	5.398
NC16	4	223	156	7	6	5.502
NC16	5	336	190	9	11	8.299
NC18	1	209	131	3	9	3.809
NC18	2	248	139	5	4	5.01
NC18	3	335	122	8	13	6.793
NC18	4	261	134	6	11	5.396
NC18	5	287	-	5	8	7.224
NF01	1	223	254	7	2	5.564
NF01	2	243	134	6	10	4.244
NF01	3	221	2	4	3	3.625
NF01	4	355	92	7	6	10.029
NF01	5	266	174	6	7	7.158
NF07	1	177	20	6	12	3.203
NF07	2	223	122	5	8	4.946
NF07	3	248	145	29	10	6.997
NF07	4	253	128	5	9	6.553
NF07	5	238	193	7	45	7.034
NF16	1	336	136	8	-4	7.958
NF16	2	256	247	6	8	7.426
NF16	3	308	95	5	5	8.857
NF16	4	224	300	5	9	3.573
NF16	5	288	101	7	1	5
SF12	1	218	123	5	2	8.198
SF12	2	244	185	5	11	5.033
SF12	3	163	109	3	8	3.274
SF12	4	189	95	1	8	3.116
SF12	5	272	94	9	7	5.308
SF14	1	226	144	3	7	5.411
SF14	2	193	47	8	3	6.015
SF14	3	127	119	3	3	4.147
SF14	4	237	41	5	7	6.526
SF14	5	223	100	2	8	5.861
SF25	1	247	117	5	1	4.862
SF25	2	227	133	4	0	3.697
SF25	3	281	126	7	10	9.542
SF25	4	248	149	10	4	5.195
SF25	5	194	154	5	24	5.164
SF27	1	296	140	5	2	5.641
SF27	2	131	115	10	6	4.802
SF27	3	71	-	4	36	1.921
SF27	4	285	132	9	19	8.175
SF27	5	191	111	4	6	3.463
SF36	1	213	149	6	10	4.971
SF36	2	231	-	8	8	4.382
SF36	3	214	110	10	5	7.791
SF36	4	77	91	3	19	1.909
SF36	5	258	102	5	2	4.311

CHAPTER 10
INJURY QUANTIFICATION

10.1 INTRODUCTION

The preceding chapters present the results of injury determination for surface water, soils and sediments, wildlife, aquatic biota, and riparian resources. In this chapter, the effects of the releases of hazardous substances are quantified in terms of the reduction from the baseline condition in the quantity and quality of services provided by the injured resources [43 CFR 11.70 (a)]. Injury quantification includes determination of the baseline condition and baseline services of the injured resources, determination of the extent of the injuries and the reduction in services resulting from the injuries, and determination of the recoverability of the injured resources [43 CFR 11.70 (c)].

As noted in Chapter 1, this report necessarily presents an *initial* quantification of injury. The Trustees' claim for damages will be based on calculation of restoration costs and must include consideration and estimation of losses residual to any remediation or response actions undertaken in the Coeur d'Alene basin by the U.S. EPA or other response agencies, final injury quantification cannot be completed until remedial and response actions are determined and the Trustees prepare a restoration plan.

10.2 BASELINE SERVICES

Baseline refers to the conditions that would have existed had the releases of hazardous substances not occurred [43 CFR § 11.14 (e)]. As part of injury quantification, baseline services normally provided by the injured resources must be determined [43 CFR 11.72 (a)]. The injured resources of the Coeur d'Alene River basin, including surface water, soil and sediment, wildlife, aquatic biota, and riparian resources, are ecologically interdependent and provide interdependent services. The baseline services provided collectively by these resources are inseparable at the ecosystem level. This section describes services unique to the injured resources, linkages between the injured resources, and services provided by interacting injured resources.

Individually, **services provided by surface water** include habitat for migratory birds and their supporting ecosystem; habitat for fish and their supporting ecosystem; habitat for benthic macroinvertebrates and aquatic, semiaquatic, and amphibious animals; water, nutrients, and sediments for riparian vegetation and its supporting ecosystem; nutrient cycling; geochemical exchange processes; primary and secondary productivity and transport of energy (food) to downstream and downgradient organisms; growth media for aquatic and wetland plants; a migration corridor; and cultural services.

Bed sediments provide habitat services for all biological resources that are dependent on the aquatic habitats in the basin. In addition, bed sediment services contribute to services provided by surface water, including suspended sediment transport processes, security cover for fish and their supporting ecosystems, primary and secondary productivity, geochemical exchange processes, nutrient cycling and transport, and cultural services.

Floodplain soils and sediments provide habitat for all biological resources that are dependent on riparian or floodplain wetland habitats in the basin. Floodplain soils and sediments provide habitat for migratory birds and mammals; habitat for soil biota; growth media for plants and invertebrates; primary productivity, carbon storage, nitrogen fixing, decomposition, and nutrient cycling; soil organic matter and energy (food) to streams; hydrograph moderation; geochemical exchange processes; and cultural services.

Migratory birds provide prey for carnivorous and omnivorous wildlife, as well as existence values, food, and recreational opportunities for humans, and cultural services.

Fish provide food for other biota, as well as existence values and recreational opportunities for humans and cultural services.

Riparian vegetation provides primary and secondary productivity; food and cover (thermal cover, security cover) for fish, migratory birds, and mammals; feeding and resting areas for fish, migratory birds, and mammals; a migration corridor provided by the riparian zone; habitat for macroinvertebrates; nutrient cycling; soil and bank stabilization and erosion control; hydrograph moderation; and cultural services.

The services listed above are interdependent [43 CFR 11.71 (b)(4)]. For example, floodplain soils and riparian vegetation interact to:

- moderate the hydrograph and reduce peak flows by slowing runoff; increase interception, infiltration, and evapotranspiration of precipitation; reduce water velocity; and store flood waters

- stabilize streambanks by anchoring the soil by plant root structures, dissipate erosive stream energy, control lateral meander migration rates, and maintain channel geometry

- control nonpoint source urban, agricultural, and industrial pollutant discharges to surface waters, and maintain surface and shallow groundwater quality by physical filtering of sediment and attached nutrients, by plant uptake of nutrients or pollutants, and through biotically controlled reactions in soils that release nutrients as gases to the atmosphere

- control sediment delivery rates to downstream aquatic and riparian resources

- intercept and store energy from solar radiation, provide a growth medium for plants, and provide substrate for nutrient cycling and decomposition

- support rich assemblages of plant and animal species; diverse habitat for vegetation, fish, and migratory birds and mammals; and highly productive ecological communities

- provide cover and food for fish and benthic invertebrates, shade the water from solar radiation, contribute to aquatic physical habitat complexity through addition of large woody debris and root masses, and regulate the supply of nutrients to the aquatic ecosystem

- provide critical connectivity between upland and aquatic habitats and a corridor for upstream and downstream dispersal for plant and animal species.

Surface water, floodplain soils and sediments, bed, bank, and suspended sediments, and riparian vegetation together provide habitat for aquatic biota, semi-aquatic biota, and upland biota dependent on access to the river or riparian zone; lateral and longitudinal connectivity between habitats; and the capacity to assimilate disturbances such as seasonal floods and anthropogenic nutrient or other pollutant contamination. The services collectively provided by these resources, plus the wildlife that use the resulting habitats, provide recreational opportunities; existence values for a wild and functional ecosystem; sustainable interacting hydrological, geomorphological, and ecological processes; and rich biodiversity.

The injuries to natural resources described in previous chapters have reduced the services identified above. Together, the injuries have caused ecosystem-level service reductions. In addition, many of the services normally provided by the injured resources and reduced by the injuries are secondary services losses [43 CFR 11.71 (b)(4)]. For example, loss of riparian vegetation and the cascading effects of the associated service losses, such as increased erosion and sedimentation and elimination of nutrient and energy regulation, all affect the viability of aquatic resources.

The high degree of overlap in services affected by the injuries results from the fact that contaminated surface water, soil, and sediment resources are now ubiquitous in the basin, and the services provided by these resources are integral parts of an ecologically interdependent ecosystem. Although there are numerous attributes and services that have been reduced and that could be quantified individually, instead, injuries were quantified based on injuries to resources that provide an intrinsic part of the habitat for aquatic biota, wildlife, and vegetation.

In the Coeur d'Alene River basin, injuries to fish and other aquatic biota, wildlife, and riparian vegetation are *caused* by exposure to hazardous substances to which they are exposed in injured surface water, soils, and sediments. The injured surface water, soils, and sediments therefore have diminished ability to sustain aquatic biota, vegetation, and habitat for wildlife and, therefore, to provide ecosystem services. Injury was quantified as the total area where concentrations of hazardous substances in surface water, soils, and sediment resources exceed baseline and have reduced ability to sustain aquatic biota, vegetation, habitat for wildlife, and the interdependent ecosystem services identified above, relative to baseline [43 CFR 11.71 (h)(4)(i) and (k)(1,2)]. In addition, baseline conditions for riparian vegetation structure and composition were quantified, since restoration of vegetation in the upper basin is crucial to restoration of the Coeur d'Alene River basin ecosystem and services provided collectively by the injured resources.

The following sections present the baseline conditions for soil and sediment, surface water, and riparian vegetation resources.

10.3 SOIL AND SEDIMENT BASELINE

Soils include substrates developed in place from weathering of parent materials and transported substrates, plus incorporated organic materials. Older, undisturbed soils typically exhibit horizon development resulting from addition of organic materials by biota, and translocation and transformation of minerals and organic materials within the profile. Floodplain substrates may include fluvially deposited materials, materials eroded from upland areas, and materials derived from in-place weathering. The description of materials in a floodplain as soils or sediments is largely related to scientific discipline. Sediment is the term most frequently used by geologists, and soil by ecologists and biologists. Regardless of the nomenclature, soils and sediments are closely related spatially and functionally in riverine and riparian ecosystems. Both are influenced by parent material in the uplands, weathering and erosion, fluvial mixing and sorting, deposition and burial, remobilization and redeposition, incorporation of organic materials, and geochemical transformations related to saturation and redox state. Therefore, for baseline determination, floodplain soils and sediments, and bed, bank, and suspended sediments, were assessed collectively. DOI NRDA regulations for both surface water resources (which include sediments) [43 CFR 11.72 (g)] and geologic resources (soils)[43 CFR 11.72 (j)] were used to guide baseline determination.

10.3.1 Historical Data

If available and applicable, historical data for the assessment area or injured resource should be used to establish the baseline [43 CFR 11.72 (c)]. Very little historical data exist that describe baseline soil and sediment conditions in the Coeur d'Alene River basin. The few sources of historical soil and sediment data are discussed below.

Before mining began, Mullan (1863), in a report on the construction of the military road through the Coeur d'Alene River basin, described the lower Coeur d'Alene and St. Joe valleys as one of the largest areas of good land, which, once drained, would provide "forty thousand acres of the finest soil in the world." Mullan described the soil as "six and eight feet deep and as black as coal." Mining and milling began in the Coeur d'Alene District in the 1880s. Discharge of tailings to area creeks and floodplains most likely began shortly thereafter (Chapter 2). Tailings were transported downstream by surface waters and deposited in the floodplains (Chapter 3, Chapter 4, and Chapter 5). In 1903, the first of a series of damage suits against the mines was initiated by residents of the lower valley (Casner, 1991). Early studies by Davenport (1921) and Ellis (1940) reported that large areas of floodplain had been covered by tailings deposits that killed vegetation and reduced the productivity of the lands. Ellis (1940) confirmed that crusts collected from the surface of tailings deposits at Mission Flats, Dudley, Medimont, Black Lake Ditch, and Thompson Flats near Harrison contained 5 to 12% zinc (50,000 to 120,000 ppm), and 0.3 to 0.8% lead (3,000 to 8,000 ppm).

In the 1950s, Kennedy (1960) conducted a study of surface soils in the upper basin to determine the feasibility of soil sampling for mineral exploration. He calculated "normal" soil background of 21 mg/kg lead, 100 mg/kg zinc, and 24 mg/kg copper in soils from nonmineralized areas, and background concentrations of 40 mg/kg lead, 76 mg/kg zinc, and 45 mg/kg copper in stream sediments. His analysis showed elevated lead concentrations near outcropping veins, but the quality of the analytical methods used was poor. In the 1970s, numerous theses, agency reports, and published papers describing tailings distribution and the effects of heavy metals from tailings and smelter emissions on environmental quality were published (e.g., Galbraith, 1971; Galbraith et al., 1972; Rabe and Flaherty 1974; Maxfield et al., 1974; Carter, 1977; Ragaini et al., 1977; Reece et al., 1978; Keely, 1979). The first large-scale soil sampling study was conducted by the USGS in the 1970s (Gott and Cathrall, 1980), and in 1981, the U.S. Soil Conservation Service released the Soil Survey of Kootenai County (U.S. SCS, 1981).

Since there is a large gap between the time that mining began in the basin and the time when the first soil and sediment samples were collected, historical data cannot be used to determine baseline conditions for soils and sediments. If historical data are not available or do not meet the guidelines in the DOI regulations, then baseline must be defined using field data from a reference area [43 CFR 11.72(d)].

10.3.2 Reference Areas

Identification of baseline conditions of soils and sediments in a basin with both mineralized and nonmineralized parent material must include consideration of the natural weathering of ore outcrops and alluvial soil development that would have occurred if the basin had not been mined. Therefore, reference areas should be selected based on their similarity to the assessment area and lack of exposure to the discharge or release [43 CFR 11.72 (d)(1)], and they should reflect the influence of natural weathering of mineralized deposits and processes that result from historical and ongoing nonmining related human activities. For soil and sediment resources, guidance for both surface water resources and geologic resources applies:

- A reference area should consist of a stream, river reach of similar size, or standing body of water that is as near to the assessment area as practical and if practical, that is upstream or upcurrent from the injured resource, such that channel characteristics, sediment characteristics, and streamflow characteristics are similar to the injured resource and the water and sediment of the reference area have not been exposed to the discharge or release [43 CFR 11.72 (g)(3)(i-ii)].

- The reference area soil or geologic material should be similar to exposed soil or geologic material in the assessment area and not exposed to the discharge or release [43 CFR 11.72 (j)(3)(i)].

Baseline should take into account both natural processes and processes resulting from anthropogenic activities. To address these attributes, data from multiple reference areas were analyzed collectively to identify baseline conditions that are representative of natural processes in a mineralized basin in the absence of mining, as well as nonmining anthropogenic processes expected to contribute to baseline conditions from the time mining began in the basin until the present.

Reference areas for determination of baseline soil and sediment conditions included:

- reaches of Canyon Creek, Ninemile Creek upstream of the East Fork Ninemile Creek confluence, and Little North Fork Coeur d'Alene River floodplains presumed to be upstream of major mining-related influences

- upland areas of the Coeur d'Alene Mining District

- the lower Coeur d'Alene River basin floodplain, using sediments from deep cores

- the St. Joe River basin floodplain

- Coeur d'Alene Lake, using sediments from deep cores.

Reference Reaches Upstream of Major Mining-Related Influences

Reaches of Canyon Creek, Ninemile Creek upstream of the East Fork Ninemile Creek confluence, and the Little North Fork Coeur d'Alene River were sampled as reference areas for the riparian resources injury assessment (Chapter 9). Canyon Creek, Ninemile Creek, and the Little North Fork Coeur d'Alene River reference reaches were selected based on their location upstream or upgradient of major mining related disturbances. Both Canyon and Ninemile Creek reference reaches are in areas of similar quaternary alluvial fill in the valley and Belt Supergroup geology in the uplands; both streams are high-gradient, low-order streams similar to lower

Canyon and East Fork and lower Ninemile Creek and other tributaries of the South Fork subbasin; and both are bordered closely by roads. The Little North Fork Coeur d'Alene River was selected as a reference for the South Fork Coeur d'Alene River based on similar stream size and presence of a road closely bordering the stream. Since these three areas are upgradient of assessment areas in the Coeur d'Alene River basin, it is appropriate to consider inputs from such areas as natural contributors to sediment composition in downstream reaches of the basin. In addition, each of these reaches had public lands that were accessible for sampling.

Three floodplain soil samples from upper Canyon Creek, 3 from Ninemile Creek, and 17 from the Little North Fork Coeur d'Alene River (all 0-15 cm depth) were collected and included in the analysis of baseline soil and sediment concentrations (locations shown in Chapter 9, Figure 9-3). These surface samples integrate effects of nonmining anthropogenic activities such as emissions from leaded gasoline earlier this century that could conceivably influence the concentrations of hazardous substances in floodplain soils.

The sample sites were selected using a systematic-random sampling design so that samples represent an unbiased estimate of the spatial variability of these reference reaches [43 CFR 11.72 (g)(4)(i)]. Methods used to collect and analyze reference data were the same as methods used to collect and analyze assessment data [43 CFR 11.72 (d)(5)]. Sampling design, sample site selection procedures, and sample collection and analysis procedures are described in Chapter 9.

Upland Areas of the Coeur d'Alene Mining District

Upland areas of the Coeur d'Alene Mining District were sampled extensively in the 1970s by the USGS as part of mineral exploration activities (Gott and Cathrall, 1980). An objective of the Gott and Cathrall study was to determine whether surface soil and rock concentrations could be used to identify minable deposits, so soil and rock samples were collected below the 15 cm depth in an attempt to limit sample contamination by metals deposited from smelter emissions. Sampling was conducted within an area of approximately 300 square miles of upland terrain, predominately in the South Fork Coeur d'Alene River subbasin. The resulting data constitute the most spatially comprehensive set of upland area soil and rock data available for the basin.

In the steep uplands of the upper Coeur d'Alene River basin, soils of the valley floor are influenced by mass soil movement processes from tributaries and adjacent hillsides (Gregory et al., 1991). Since weathering of upland rock and soils, including weathering of mineralized outcrops, and subsequent erosion and transport to floodplains and downstream reaches is the predominant pathway by which floodplain soils and sediments might naturally contain elevated concentrations of hazardous substances, use of this data set is appropriate for considering potential inputs from both mineralized and nonmineralized upland parent material.

Lower Coeur d'Alene River Basin Floodplain

Subsurface sediments of the lower Coeur d'Alene River basin floodplain between Cataldo and Harrison were sampled in 1997 as part of the Bunker Hill Basinwide Remedial Investigation (URSG and CH2M Hill, 1998). Cores up to 25 feet in depth were collected along transects crossing the river and floodplain of the lower basin. Sample locations included both floodplain soils and submerged sediments in the main river channel and in lateral lakes (see Figure 5-2, Chapter 5). Cores were subdivided into a series of samples for analysis of hazardous substances and other constituents.

Initial inspection of the data showed clear evidence of a horizon of elevated concentrations of hazardous substances in the upper portion of most cores, and a lower horizon of low concentrations of hazardous substances. Previous studies (Horowitz et al., 1993; S. Box, USGS, Spokane, WA, unpublished core data[1]) and historical accounts of tailings releases from mills, transport of tailings downstream, and deposition on floodplains, beds, and banks of the lower river (Ellis, 1940; Casner, 1991; Long, 1998) suggested that the upper sediments containing elevated concentrations of hazardous substances were deposited after mining began in the basin, and that the lower sediments were deposited before mining began in the basin. Therefore, the core data from lower horizons provide estimates of premining concentrations of hazardous substances in sediments of the lower basin.

Since the sediments of the lower basin would have included inputs from natural weathering of veins in the upper basin that might have been exposed at the ground surface before mining began, these sediments provide an estimate of baseline conditions expected in a basin containing ore deposits. In addition, the core sediments integrate effects that fluvial transport and sorting by particle size might have naturally on concentrations of hazardous substances in baseline sediments. Methods used to collect and analyze all sections of each core were the same [43 CFR 11.72 (d)(5)].

St. Joe River Basin

The St. Joe River basin was used as a reference area for pathway and injury assessment studies for wildlife resources (Chapter 6) because of its proximity to the Coeur d'Alene River basin, its general morphological and geographical similarity to the Coeur d'Alene River basin, its similarity of wildlife species assemblages and wildlife habitats, and its similarity of recreational management. The St. Joe River flows from the Montana/Idaho border through the St. Joe Mountains, and discharges to Coeur d'Alene Lake at the southern end of the lake.

1. Data summarized in URSG and CH2M Hill, 1998.

Among the data collected from the St. Joe River basin are sediments from palustrine and lacustrine wetland complexes known to be used by waterfowl (Campbell et al., 1999); 126 samples were collected from the St. Joe River basin and analyzed for hazardous substances. Surface sediment samples from the St. Joe River basin integrate effects of anthropogenic activities such as inputs from agricultural fertilizers or pesticides that might influence baseline concentrations of hazardous substances in floodplain soils.

The sample sites were selected using a systematic-random sampling design so that samples represent an unbiased estimate of the spatial variability of these reference reaches [43 CFR 11.72 (g)(4)(i)]. Methods used to collect and analyze reference data were the same as methods used to collect and analyze assessment data [43 CFR 11.72 (d)(5)].

Bed Sediments of Coeur d'Alene Lake

Horowitz et al. (1993, 1995) sampled bed sediments throughout Coeur d'Alene Lake. Twelve core samples were collected from the 97 to 141 cm depth in the Coeur d'Alene River delta, the main stem of the lake, and in the backs of several bays perpendicular to the main body of the lake. Based on metals concentrations in the sediments, an assessment of deposition rates using cesium dating (^{137}Cs), and visual observations of an upper zone of striated sediments over a homogeneous lower zone, Horowitz et al. (1993, 1995) reconstructed the geochemical history of the lake from just before mining began through 1993. They concluded that deposition of trace element-rich sediment in the lake began in about 1910 and that the deepest portions of some of the core samples represent sediments deposited before mining began in the Coeur d'Alene River basin (Horowitz et al., 1993, 1995). Data from the lower portion of cores determined to represent premining conditions were used for comparison to reference data sets identified above.

10.3.3 Data Analysis

Data from four of the data sets described above were used to describe the chemical condition of baseline soils and sediments [43 CFR 11.72 (j)(4)(i)]. To evaluate those data in an integrative analysis, preliminary analyses were performed to ensure that the data were used appropriately in statistical analyses.

Riparian resources reference area data. During the riparian resources floodplain soil sampling, evidence of past disturbance to the sample sites in the presumptive unexposed reference reach of Canyon Creek was noted (RCG/Hagler Bailly, 1994). Results of the soil chemistry analyses subsequently confirmed that metals concentrations are elevated in the areas that appeared to have been disturbed, though to a lesser degree than downstream sites. The samples were retained as part of the baseline determination data set (and as part of the reference data set for determination of injury to riparian vegetation, Chapter 9) as a very conservative estimate of floodplain soil concentrations of hazardous substances.

Gott and Cathrall (1980) data. Gott and Cathrall (1980) used an opportunistic sampling plan to search for patterns of ore forming metals in soil and weathered rock that might reveal mineralized rock below the ground surface. Most sample sites were located at 100 to 160 m intervals along unpaved roads and ridge lines, but certain areas were sampled more intensively. Rock samples were collected wherever they were encountered along a traverse. Since the sampling design was not intended to provide an unbiased description of upland soils and rocks of the Coeur d'Alene Mining District, the resulting data set is not evenly weighted across the sampling area. Before data analysis, original records of metals concentrations from individual soil or rock samples were spatially averaged by aggregation into 0.5 km^2 hexagonal cells. This procedure was conducted to reduce the influence of statistical biases that could result from the nonrandom sampling procedures, including selection bias and spatial autocorrelation of samples collected in selected clusters or transects selected based on geographic features such as roads or ridge lines. The data set derived in this manner approximates a complete census of the surveyed region (as opposed to a statistical sample). The values of interest are mean metal concentrations in sampling units of size 0.5 km^2.

The hexagonal grid system was established as a geographic information system (GIS) layer on a regional map of the Coeur d'Alene River basin, without regard to any particular features of the data set. Data records from replicate samples collected at the same coordinates were averaged, then all data records located within each grid cell were averaged. This procedure was performed for cadmium, lead, and zinc analyzed by quantitative methods (Gott and Cathrall, 1980); "semiquantitative analytes" reported by Gott and Cathrall (1980) were not used in the determination of baseline. The practical effect of the hexagonal grid averaging is to relocate sample coordinates collected at unique locations in the grid cell to the center of the grid cell and to treat the samples as replicates. The average spatial bias introduced by this procedure is approximately 290 m, a distance that is small with respect to the total size of the study area and likely degree of precision of the original coordinate records. Hexagonal grid averaging reduced the effective number of records of soil samples from 7,621 to 1,005 (the number of samples per cell ranged from 1 to 101; median = 5). The effective number of records of rock samples was reduced from 2,950 to 734 (the number of samples per cell ranged from 1 to 21; median = 3).

As part of the determination of baseline conditions, subsets of the Gott and Cathrall data were examined separately to determine chemical characteristics of samples collected within mineral belts of the Coeur d'Alene District (Hobbs and Fryklund, 1968) and over the North and South Gem and Dago Peak Stocks (Gott and Cathrall, 1980). This additional analysis was conducted based on the presumption that soils and rocks collected in these areas might have higher naturally occurring concentrations of cadmium, lead, and zinc than soils and rocks collected elsewhere in the upper basin. This analysis addressed the potential areal variability that may be introduced by the spatially nonuniform distribution of mineralized material [43 CFR 11.72 (j)(4)(i)]. For this analysis, individual samples were categorized as within a mineral belt or stock using GIS before aggregation into grid cells.

URSG and CH2M Hill (1998). The sediment cores were used to provide information about hazardous substance concentrations in lower basin sediments deposited before mining began in the basin. Most of the sediment concentration core profiles showed that cadmium, lead, and zinc concentrations are substantially elevated in the upper portion of the core, peak at an intermediate depth, and markedly decrease below a certain depth. Based on previous analyses and interpretations of depositional patterns in the lower Coeur d'Alene River basin and Coeur d'Alene Lake (Horowitz et al., 1993; S. Box, USGS, Spokane, WA, unpublished core data) and on summaries of the history of mining operations and tailings releases in the basin (Ellis, 1940; Casner, 1991; Long, 1998), the concentration pattern was interpreted as an upper horizon of tailings-enriched sediments deposited after mining began in the basin, and a lower horizon of sediments deposited before mining began in the basin.

To eliminate bias in selecting sections of a core that represent the lower horizon, an individual core section was categorized as "lower horizon" if it satisfied three objective rules:

1. The core section must be part of a whole core that produced three or more subsamples.

2. Samples from the core section must have lead concentration less than 10% of the maximum concentration measured in the core.

3. The sample or samples with lead concentrations less than 10% of the maximum concentration measured in the core must occur deeper in the core than the peak concentration.

Not all cores contained subsamples that met these criteria. Most of the cores that failed to meet these criteria contained low metals concentrations throughout and/or no distinct metal enrichment horizon. Cores that contained relatively low metal concentrations throughout were typically located in an erosional (nondepositional) section of river bank (S. Box, USGS, Spokane, WA, pers. comm., 1999). Cores that contained elevated concentrations of metals but no distinct metal enrichment horizon were located near Cataldo, where historical dredging probably disrupted depositional patterns, or were short cores that may have failed to penetrate into the lower horizon. The data inclusion criteria were intended to isolate soil samples that did not contain elevated metals concentrations attributable to mine waste, but the procedures do not provide certainty that this goal was met. Any bias that remained is likely to have caused overestimation of baseline metal concentrations because of the possibility that retained soil samples contained mine wastes.

For use in baseline analyses, concentrations of metals from subsamples within each lower horizon core section were averaged to define a mean concentration of cadmium, lead, and zinc for each core site.

10.3.4 Results

For all the data sets, analytical chemistry results that were qualified as below detection limit were assigned a value selected randomly from the range between zero and the minimum value of all nonqualified samples. Concentrations in the quantiles of interest were much greater than detection limits. All statistical analyses were conducted using $\log_{10}$ transformations of the data. Results were back-transformed and are presented on the natural scale.

Statistical correlation among cadmium, lead, and zinc concentrations was examined as a first step. Correlations between these metals are statistically significant and strongly positive (Table 10-1). Multivariate relationships between metals were examined using principal component ordination. The results of the ordination confirm that the covariance among metals is so strong that, with respect to the description of baseline conditions and determination of significant difference from assessment areas, lead alone is a sufficient surrogate for the other metals and their relative concentrations in soil or sediment. Therefore, baseline conditions are described primarily in terms of the univariate distribution of lead concentration, and secondarily on the univariate distributions of cadmium and zinc.

Table 10-1
Correlation of Metals Concentration among Soil/Sediment Samples

	Lead			**Zinc**		
	n	**Pearson's r**	**p value**	**n**	**Pearson's r**	**p value**
Reference Samples						
Zinc	1,108	0.68	<0.001			
Cadmium	1,107	0.52	<0.001	1147	0.47	<0.001
Assessment Samples						
Zinc	77	0.76	<0.001			
Cadmium	76	0.54	<0.001	89	0.64	<0.0001

Lead concentrations were lowest in sediments from the St. Joe River basin, with a geometric mean (and 95% upper confidence limit on the mean, UCL) of 15.4 (16.6) mg/kg (Table 10-2) and upper 95th percentile of 25.3 mg/kg. Lead concentrations in floodplain soil samples from the Little North Fork Coeur d'Alene River were similar. The geometric mean (UCL) was 15.8 (19.0) mg/kg, and the upper 95th percentile was 27.5 mg/kg. Canyon Creek reference samples were considerably higher: the geometric mean (UCL) was 753 (1,750) mg/kg, and the upper 95th percentile was 1,030 mg/kg. Inclusion of Canyon Creek samples that are known to have been exposed to mine wastes but to a lesser degree than downstream areas contributes to the higher metal concentrations in these samples relative to the St. Joe River basin and Little North Fork Coeur d'Alene River samples.

Table 10-2
Concentrations of Lead (mg/kg) in Reference Soils and Sediments, Mineralized Upland Soils and Rocks, and Mine-Waste Exposed Soils and Sediments

	Sample Size	Geometric Mean	Upper 95% CL	95th Percentile
Reference Data Sets				
St. Joe River basin[a]	126	15.4	16.6	25.3
Little North Fork[b]	17	15.8	19.0	27.5
Canyon Creek reference[b]	3	753	1,750	1,030
Ninemile Creek reference[b]	3	145	543	292
Upland soils[c]	964	45.5	47.8	190
Upland rocks[c]	632	19.0	21.3	131
Alluvium cores[d]	10	87.8	181	343
Pooled Reference	1,755	30.7	32.4	175
Mineralized Upland Soils				
Upland soils over stocks[c]	40	50.0	64.5	208
Upland soils over mineral belts[c]	210	49.3	55.4	195
Upland rocks over stocks[c]	127	20.8	28.7	405
Upland rocks over mineral belts[c]	36	13.7	20.5	47.3
Mine-Waste Exposed Soils/Sediments				
South Fork Coeur d'Alene basin[b]	29	9,690	13,000	22,100
Canyon Creek assessment[b]	6	13,700	31,000	39,800
Ninemile Creek assessment[b]	5	23,800	44,200	48,900
Lateral lakes palustrine/lacustrine wetlands[a]	555	1,880	2,110	7,650
Lateral lakes floodplain[e]	185	885	1,110	5,000
Lateral lakes floodplain[b]	44	999	1,610	6,000

a. Campbell et al., 1999.
b. Chapter 9, this report.
c. Gott and Cathrall, 1980.
d. URSG and CH2M Hill, 1998.
e. Horowitz, 1995.

Lead concentrations in alluvial core sediments from the lower Coeur d'Alene River basin were higher than those in Coeur d'Alene River basin upland soils and Coeur d'Alene River basin and St. Joe River basin surface floodplain soils and sediments, but considerably lower than those in Canyon and Ninemile Creek reference soils (Table 10-2). The geometric mean (UCL) of the lower horizon cores was 87.8 (181) mg/kg, and the upper 95th percentile was 343 mg/kg. The higher lead concentrations in the sediment cores may reflect natural metal enrichment relative to upland soils as a result of differential fluvial transport of fine particles with higher associated metal concentrations from a mineralized headwaters. They may also result from geochemical migration of metals from upper to lower layers, or cross contamination of core materials during the core drilling, retrieval, or subsampling. In several instances, the peak concentration in a core was so great that a value of less than 10% was still substantially elevated relative to concentrations in most other defined lower horizons. However, to avoid bias in identification of the lower horizon section, these substantially elevated portions were retained despite the fact that there might be good reason to eliminate them from the baseline data set, and that they may bias the baseline estimates upward (i.e., overestimated metal concentrations).

In general, concentrations of lead and other metals were greater in upland soils than in upland rocks. Mean and upper 95th percentile lead concentrations in upland soil and rock samples collected over mineral belts and stocks were only slightly higher than in the whole population of upland soil and rock samples (Table 10-2). The absence of an appreciable increase in lead concentrations even in soils and rocks from mineralized areas indicates that natural mineralization is unlikely to explain the measured concentrations in floodplain soils and sediments throughout the basin. For comparison, soil samples from mine-waste exposed assessment areas are presented in Table 10-2. These concentrations are up to two orders of magnitude higher than reference concentrations.

An overall characterization of lead concentrations derived from pooling of the reference data sets is a geometric mean (UCL) of 30.7 (32.4) mg/kg and an upper 95th percentile of 175 mg/kg. The geometric mean is a concentration typical of lead concentrations throughout the basin. The upper 95th percentile concentration is one that is likely to occur infrequently in the basin (in approximately 5% of the basin).

Patterns for cadmium and zinc are similar, with higher concentrations of cadmium and zinc in Canyon Creek and Ninemile Creek reference soils than in St. Joe River basin and Little North Fork Coeur d'Alene River soils (Tables 10-3 and 10-4). Concentrations of cadmium and zinc were not as elevated in the core samples relative to other reference datasets as were concentrations of lead. For both cadmium and zinc, concentrations in mine-waste exposed assessment soils greatly exceed concentrations in reference soils. As for lead, mean and upper 95th percentile cadmium and zinc concentrations in upland soil and rock samples collected over mineral belts and stocks were only slightly higher than in the whole population of upland soil and rock samples.

An overall characterization of cadmium concentrations derived from pooling of the reference data sets is a geometric mean (UCL) of 0.61 (0.64) mg/kg and an upper 95th percentile of 2.86 mg/kg, and for zinc, a geometric mean (UCL) of 63.3 (66.4) mg/kg and an upper 95th percentile of 263 mg/kg.

Table 10-3
Concentrations of Cadmium (mg/kg) in Reference Soils and Sediments, Mineralized Upland Soils and Rocks, and Mine-Waste Exposed Soils and Sediments

	Sample Size	Geometric Mean	Upper 95% CL	95th Percentile
Reference Data Sets				
St. Joe River basin[a]	126	0.53	0.63	1.40
Little North Fork[b]	17	0.61	1.0	1.36
Canyon Creek reference[b]	3	3.31	14.0	6.19
Ninemile Creek reference[b]	3	2.77	5.58	3.65
Upland soils[c]	1,002	0.83	0.89	3.83
Upland rocks[c]	727	0.41	0.44	1.38
Alluvium cores[d]	10	0.29	0.63	0.88
Pooled Reference	1,888	0.61	0.64	2.86
Mineralized Upland Soils				
Upland soils over stocks[c]	40	1.15	1.44	4.33
Upland soils over mineral belts[c]	240	0.79	0.89	3.13
Upland rocks over stocks[c]	191	0.49	0.55	1.60
Upland rocks over mineral belts[c]	34	0.31	0.44	0.73
Mine-Waste Exposed Soils/Sediments				
South Fork Coeur d'Alene basin[b]	29	35.1	43.9	68.6
Canyon Creek assessment[b]	6	15.8	42.5	44.6
Ninemile Creek assessment[b]	5	4.58	41.8	12.5
Lateral lakes palustrine/lacustrine wetlands[a]	555	12.8	14.1	46.0
Lateral lakes floodplain[e]	185	5.07	6.25	30.8
Lateral lakes floodplain[b]	44	6.40	9.48	27.4

a. Campbell et al., 1999.
b. Chapter 9, this report.
c. Gott and Cathrall, 1980.
d. URSG and CH2M Hill, 1998.
e. Horowitz, 1995.

Table 10-4
Concentrations of Zinc (mg/kg) in Reference Soils and Sediments, Mineralized Upland Soils and Rocks, and Mine-Waste Exposed Soils and Sediments

	Sample Size	Geometric Mean	Upper 95% CL	95th Percentile
Reference Data Sets				
St. Joe River basin[a]	126	51.5	56.1	104
Little North Fork[b]	17	58.5	66.4	87.4
Canyon Creek reference[b]	3	630	1,280	885
Ninemile Creek reference[b]	3	294	700	467
Upland soils[c]	1,005	101	105	296
Upland rocks[c]	728	33.7	36.8	169
Alluvium cores[d]	10	122	176	236
Pooled Reference	1,892	63.3	66.4	263
Mineralized Upland Soils				
Upland soils over stocks[c]	40	128	164	628
Upland soils over mineral belts[c]	244	121	132	412
Upland rocks over stocks[c]	195	36.0	42.7	204
Upland rocks over mineral belts[c]	36	40.0	50.2	103
Mine-Waste Exposed Soils/Sediments				
South Fork Coeur d'Alene basin[b]	29	4,780	5,900	8,890
Canyon Creek assessment[b]	6	2,600	7,470	7,400
Ninemile Creek assessment[b]	5	2,480	3,580	3,480
Lateral lakes palustrine/lacustrine wetlands[a]	555	1,375	1,510	4,840
Lateral lakes floodplain[e]	185	701	845	4,500
Lateral lakes floodplain[b]	44	612	903	3,100

a. Cambell et al., 1999.
b. Chapter 9, this report.
c. Gott and Cathrall, 1980.
d. URSG and CH2M Hill, 1998.
e. Horowitz, 1995.

10.3.5 Comparison to Literature and Assessment Values

Concentrations in samples collected at the reference areas were compared to concentrations reported in the scientific or management literature for similar resources to determine whether the data represent a normal range of conditions [43 CFR 11.72 (d)(6)]. Table 10-5 presents mean concentrations of cadmium, lead, and zinc reported in background (uncontaminated) soils of various types from a number of countries. Worldwide mean concentrations of cadmium, lead, and zinc are 0.53 mg cadmium/kg, 32 mg lead/kg, and 64 mg zinc/kg (Kabata-Pendias and Pendias, 1992). The concentrations reported for reference data in Tables 10-2 to 10-4 are generally similar to mean concentrations reported in Table 10-5, except that mean concentrations of lead and zinc in the Canyon and Ninemile Creek reference and lower basin alluvium core samples are somewhat higher than the data from the literature.

Data collected at reference areas should also be compared to data collected at the assessment areas to confirm statistically significant differences [43 CFR 11.72 (g)(6) and (j)(4)(iii)]. Concentrations of hazardous substances were consistently greater in assessment soils than in reference soils (Chapter 5 and Chapter 9):

- Concentrations of arsenic, cadmium, manganese, lead, and zinc in sediment samples collected from the lower Coeur d'Alene River basin were all significantly greater than samples collected from the St. Joe River basin (Mann Whitney $p < 0.001$) (Chapter 5; Campbell et al., 1999).

- Concentrations of arsenic, cadmium, copper, lead, and zinc in South Fork Coeur d'Alene River soils were significantly greater than those in Little North Fork soils (Mann-Whitney $p < 0.05$) (Chapter 9).

- Concentrations of copper, lead, and zinc in Ninemile Creek assessment soils were significantly greater than those in reference soils, and concentrations of arsenic, copper, and lead in Canyon Creek assessment soils were significantly greater than those in reference soils (Mann-Whitney $p < 0.05$). In addition, cadmium concentrations in assessment samples from Ninemile Creek and cadmium and zinc concentrations in assessment samples from Canyon Creek were substantially elevated. Although the differences were not statistically significant at $p < 0.05$, these concentrations in assessment samples were considerably elevated relative to reference samples, baseline concentrations, and worldwide mean concentrations.

- Pooled comparison of all upper basin assessment soils with upper basin reference soils showed significant differences between pooled reference and pooled assessment for arsenic, cadmium, copper, lead, and zinc (Mann Whitney $p < 0.001$).

Table 10-5
Mean Background Cadmium, Lead, and Zinc Concentrations in Surface Soils of Various Countries

	Cadmium (mg/kg)					Lead (mg/kg)					Zinc (mg/kg)				
Country	Sandy Soil	Silty Soil	Loamy/ Clay	Fluvial Soil	Various Soils	Sandy Soil	Silty Soil	Loamy/ Clay	Fluvial Soil	Various Soils	Sandy Soil	Silty Soil	Loamy/ Clay	Fluvial Soil	Various Soils
Australia	—	—	—	—	—	57	—	—	19	—	—	—	—	—	—
Austria	—	—	—	0.37	0.29	—	—	—	—	29	—	—	—	—	—
Bulgaria	—	—	—	—	0.29	—	—	—	—	—	—	—	—	62	65
Canada	0.43	—	0.64	—	0.56	10	—	17	—	20	—	—	17	—	57
Denmark	—	—	—	—	0.26	—	—	—	—	—	—	—	—	—	31
Great Britain	—	—	—	1	1.0	—	—	—	63	29	—	—	70	125	80
Italy	—	—	—	—	0.44	—	—	—	—	26	—	—	—	—	68
Japan	—	—	—	—	0.44	—	—	—	—	35	—	—	—	—	86
Madagascar	—	—	—	—	—	37	—	48	—	—	—	—	—	—	—
New Zealand	—	—	—	—	—	—	—	—	—	—	42	61	79	60	59
Poland	0.07	0.20	0.26	0.30	0.41	16	26	25	39	18	24	47	68	85	47
Romania	0.9	—	0.9	—	—	—	—	21	—	—	61	73	75	—	61
United States	0.21	—	0.27	—	—	17	19	22	—	26	40	59	67	—	74
USSR[a]	0.32	—	—	—	0.06	20	—	40	—	8	31	48	35	42	78
West Germany[a]	—	—	—	—	0.80	—	—	—	—	—	—	—	—	—	—
World Mean					**0.53**					**32**					**64**

a. Former nations.

Source: Tables 61, 67, 107 in Kabata-Pendias and Pendias (1992), and sources cited therein.

10.3.6 Influence of Vein Outcrops and Mining Waste

Historical data on metal concentrations in soils near veins suggest metal concentrations near some veins are elevated (Kennedy, 1960). An analysis was conducted to assess the degree to which the elevated metal concentrations near veins might affect soil metal concentrations in the District. Since the Kennedy data are semiquantitative (precision of ±50%),[2] they cannot be used quantitatively. However, with an understanding of the uncertainty involved, the semiquantitative data can be used to indicate the degree to which metal concentrations may be elevated near veins in the Coeur d'Alene District.

Estimates of the areal contribution of elevated metal concentrations near outcropping and projected veins in Canyon Creek were used to evaluate whether naturally elevated metal concentrations near veins substantially affect background soil concentrations at the scale of the drainage. In this analysis, the following data and information were used:

- the location, linear extent, composition, and surface expression of veins as depicted in the Hobbs et al. (1965) maps
- the location, linear extent, and surface expression of ore bodies and veins as depicted in vertical longitudinal projections and cross-sections in Crosby (1959)
- the surface expression of ore bodies as depicted in Hobbs and Fryklund (1968)
- the extent and composition of surface soils affected by veins as contained in figures and tables in Kennedy (1960)
- the composition of surface soils as contained in data from Gott and Cathrall (1980).

Veins known to contain base metals (veins marked with an "A"on the Hobbs et al. maps) and veins associated with mines that were known to produce metals were included in the evaluation. Thirteen such veins exist in the Canyon Creek drainage. Using information from Crosby (1959), Hobbs et al. (1965), Hobbs and Fryklund (1968), and Kennedy (1960), portions or entire lengths of 10 of the 13 veins either outcrop or affect soil metal concentrations in Canyon Creek (Figure 10-1). One of the veins shown in Figure 10-1, the Copper King, was not a lead or zinc vein, and was not used in the analysis. Of the remaining nine veins, one, the Standard-Mammoth, was not shown to be outcropping by Crosby, Hobbs, or Kennedy. However, because soil concentrations of lead, and to a lesser extent, zinc, were elevated for approximately 250 feet along the projected vein (Kennedy, 1960), a distance of 250 feet was chosen as the "outcrop" length for the Standard-Mammoth vein. The detection of elevated surface soil concentrations over a vein that was close to the surface (within approximately 50 feet) but not outcropping

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2. For lead and zinc, 70-100% of the semiquantitative results agreed within ±50% with the quantitative data (Kennedy, 1960). This implies that up to 30% of the samples do not fall within the ±50% range. There is no way to determine which of the samples fall outside of that range.

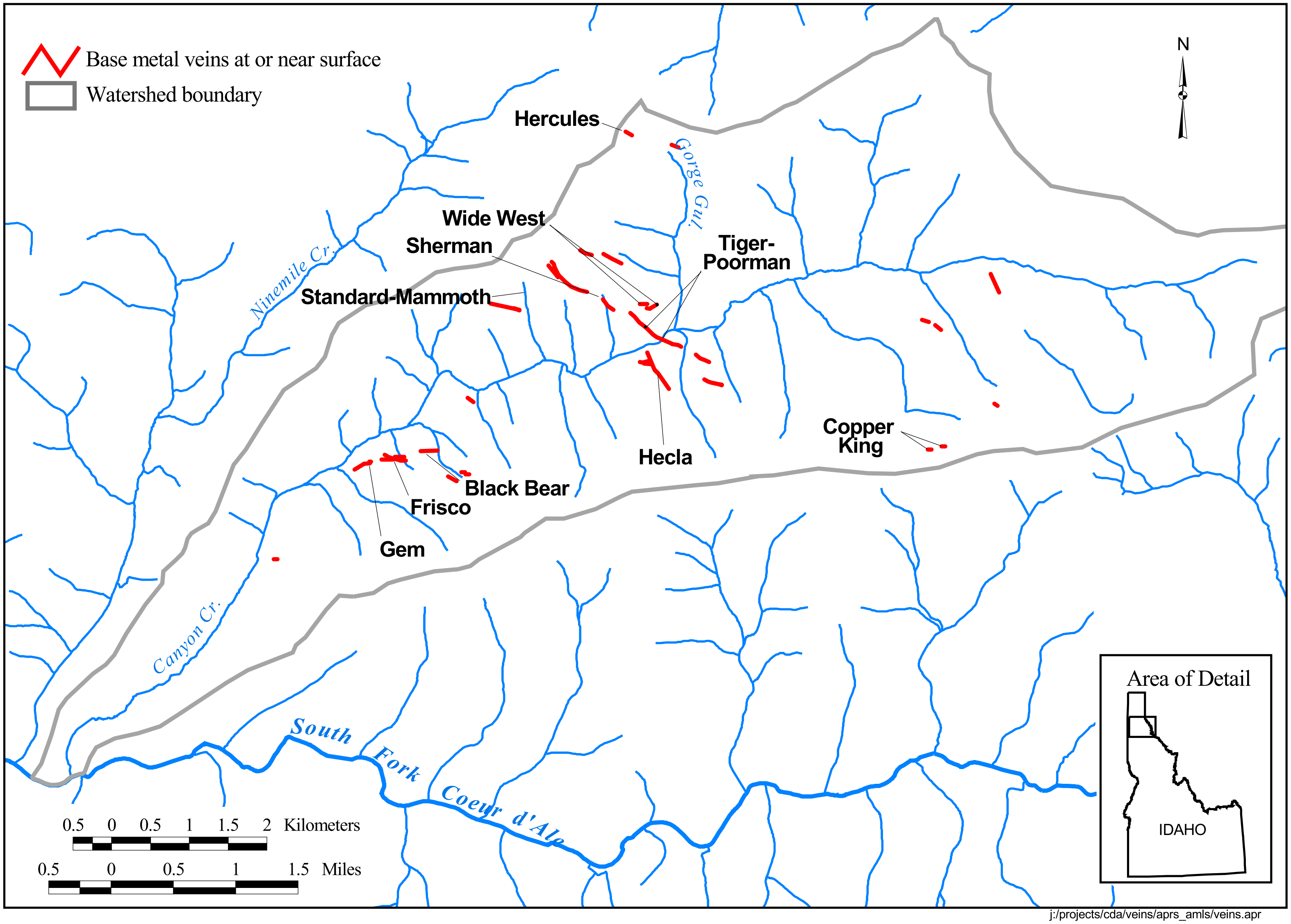

Figure 10-1. Locations of surface or near surface veins known to contain base metals in the Canyon Creek drainage basin.

demonstrates that some subsurface veins affect soil metal concentrations. Some of the elevated concentrations measured by Gott and Cathrall in the District are also likely to be related to this phenomenon.

The area of the Canyon Creek drainage basin was delineated using Interior Columbia Basin Ecosystem Management Project (ICBEMP, 1994) data and a topographical GIS overlay, and the locations and lengths of the nine lead and zinc veins as identified by Hobbs, Crosby, or Kennedy were mapped. For each vein, an average width of 150 m of elevated metal concentrations was assumed, based on the average width of the traverses of the 13 veins containing lead and zinc reported in Kennedy (1960).[3]

Using the measured lengths of the veins and the average width of elevated metal concentrations around the vein, the veins and associated areas of elevated metal concentrations in Canyon Creek comprise only 0.4% of the total area of the drainage basin. This value is probably an overestimate of the percentage of the watershed occupied by veins and areas of elevated metal concentrations because the concentrations near several of the veins returned to near background levels within distances shorter than 75 m from the vein outcrop or projection. However, using a 150-m width for all of the veins ensures that the analysis does not underestimate the potential contribution of the veins to soil chemistry in the Canyon Creek drainage.

A weighted average of the samples collected at the surface in each of the four Kennedy traverses in Canyon Creek (all of which contained lead and zinc, Table 10-6) was used as the average concentration for the nine veins in Canyon Creek. Sample concentrations were averaged within a traverse, and the traverse averages, weighted by the actual length of the traverse, were averaged. The weighted average concentration of lead near veins in Canyon Creek was 836 ppm (Table 10-6).

Gott and Cathrall data from within the Canyon Creek drainage basin were assigned to hexagon cells, using methods described previously. Using Gott and Cathrall hexagon data, the estimated average concentration of lead in soils in the Canyon Creek watershed is 125 ppm (Table 10-7). This value corresponds to approximately the 90th percentile of the baseline data set for the Coeur d'Alene Basin as a whole (Table 10-2). Gott and Cathrall did not collect any samples in the upper quarter of the watershed, upgradient of where most of the veins are located. Therefore, the average lead concentration based on the Gott and Cathrall data probably overestimates the actual average soil lead concentration for the watershed. Incorporating the average soil lead concentration near the nine veins in the Canyon Creek drainage increases the average lead concentration in the Canyon Creek watershed soils by only 2.1% to a value of 127 ppm (Table 10-7).

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3. The wandering traverse at the Jack Waite vein was divided into three traverses that were roughly perpendicular to the vein. The average length of those three traverses and a fourth separate perpendicular traverse was used as the average width for that vein. A similar approach was taken for the Little Pittsburg, where three separate traverses were conducted.

Table 10-6
Characteristics of Lead-Zinc Veins Studied by Kennedy (1960)

Vein	Drainage	Traverse Length (ft)	Sample Size	Traverse Mean Lead (ppm)	Vein Mean Lead (ppm)
Jack Waite — 1	Tributary Creek/North Fork	663	9	19	—
Jack Waite — 2	Tributary Creek/North Fork	674	11	47	—
Jack Waite — 3	Tributary Creek/North Fork	789	18	115	—
Jack Waite — 4	Tributary Creek/North Fork	320	7	63	61
Hercules	Canyon Creek	550	12	490	490
Custer Peak	Canyon Creek	1,096	11	1,027	1,027
Standard-Mammoth	Canyon Creek	373.3	13	387	387
Frisco	Canyon Creek	484.6	18	1,147	1,147
Star	Grouse Gulch/South Fork	774	10	1,070	1,070
Gold Hunter	Gold Hunter/South Fork	493.8	20	713	713
Vindicator	South Fork/Gentle Annie	160	25	285	285
Sidney	Pine Creek	200	12	373	373
Little Pittsburg — 1	Pine Creek	400	14	7,071	—
Little Pittsburg — 2	Pine Creek	345	12	5,733	—
Little Pittsburg — 3	Pine Creek	15	16	5,466	6,090
“Carbonate” vein	Grouse Gulch/South Fork	100	11	150	150
Liberal King[a]	Pine Creek	nd	nd	nd	nd
Page Curlew	Silver Creek/South Fork	1,093	21	213	213
South Fork Basin Weighted Mean:					586
Canyon Creek Weighted Mean:					836

a. No data (nd) provided in Kennedy (1960).

Table 10-7
Summary of Analysis of the Effect of Highly Mineralized Veins on Baseline Soil Lead Concentrations

Drainage Basin	Exposed Veins			Lead Concentration			
	Total Length[a] (m)	Average Width[b] (m)	Areal Extent (%)	Average near Veins[b] (ppm)	Basin Average without Veins[c] (ppm)	Basin Average with Veins (ppm)	Increase (%)
Canyon Creek	1,407	150	0.4	836	125	127	2.1
South Fork Coeur d’Alene	11,851	150	0.2	586	96.4	97.6	1.2

a. Crosby, 1959; Hobbs et al., 1965; Hobbs and Fryklund, 1968.
b. Kennedy, 1960 and text in this report.
c. Gott and Cathrall, 1980 — hexagons.

A similar analysis was conducted for South Fork Coeur d'Alene River basin. The areal percentage of veins in the South Fork Coeur d'Alene River basin is 0.2% (Table 10-7). Based on Gott and Cathrall hexagon data, the mean lead concentration for the South Fork Coeur d'Alene River basin excluding the veins is 96.4 ppm. The average lead concentration near veins for the entire South Fork Coeur d'Alene basin was calculated using the surface concentrations in all 13 of the veins analyzed by Kennedy that contained lead and zinc (Kennedy, 1960, Table 2). The weighted average concentration of lead over the 13 veins (including the anomalously high concentrations at the Little Pittsburg vein) is 586 ppm. The average concentration of lead in the South Fork Coeur d'Alene basin soils adjusted for the veins is 97.6 ppm, which is an increase of only 1.2% (Table 10-7).

The Gott and Cathrall data are approximately 90% of the data used in the baseline soil and sediment analysis. Approximately 24% of the individual Gott and Cathrall soil and rock lead analyses exceeded the Gott and Cathrall threshold value of 60 mg/kg. Approximately 1.8% of the individual Gott and Cathrall soil and rock lead samples exceeded 586 mg/kg lead, the average concentration of lead measured in the vicinity of veins by Kennedy (1960) for the South Fork Coeur d'Alene basin (Table 10-7). Using the hexagonal averaging method, 37.5% of the soil hexagons and 22% of the rock hexagons exceeded 60 mg/kg, and 1.3% of the soil hexagons and 3.7% of the rock hexagons exceeded 586 mg/kg. Given that only approximately 0.2% of the South Fork Coeur d'Alene River basin contains naturally elevated metal concentrations, the number of high concentrations in the Gott and Cathrall data set indicates that Gott and Cathrall sampling locations included mining-contaminated areas as well as naturally mineralized areas.

The contribution of high concentrations of lead near veins to the overall concentration of lead in surface soils in the upper Coeur d'Alene basin is inconsequential. A similar analysis to determine the vein contribution to zinc concentrations was not conducted because the enrichment of zinc in the veins was much lower than that for lead (Kennedy, 1960, Table 5). In addition, because the contribution of veins to baseline soil lead and zinc concentrations is so minor, applying the ±50% factor related to the semi-quantitative nature of the Kennedy data does not change the result. If the average vein lead concentration for the entire South Fork Coeur d'Alene River basin were twice as high, the basin weighted average would be 98.9 ppm rather than 97.6 ppm. Therefore, after conducting this weighted average analysis, it is clear that the baseline soil metal concentrations presented in Table 10-8 already take into account the contribution of elevated metal concentrations in the vicinity of veins in the Coeur d'Alene basin.

In addition to using samples from highly mineralized areas, the analysis of baseline conditions used samples from areas that have been exposed to mining wastes. The Canyon Creek reference sites showed clear evidence of mine waste contamination (Chapter 9; RCG/Hagler Bailly, 1994), and it is probable that some of the samples collected by Gott and Cathrall (1980) were influenced by metals in smelter deposition despite their attempts to exclude influenced layers. The subsets of Gott and Cathrall (1980) data that characterize soil and rock concentrations over mineral belts and stocks in the district show that mean concentrations of lead, cadmium, and zinc are only slightly higher than the mean concentrations of the whole Gott and Cathrall data set (Tables 10-2 to 10-4).

Table 10-8
Statistical Distribution of Baseline Concentrations in Soils and Sediments of the Coeur d'Alene River Basin

	Lead (mg/kg)	Cadmium (mg/kg)	Zinc (mg/kg)
Baseline, whole basin			
Geometric mean	30	0.61	63
95% UCL	32	0.64	66
95th percentile	175	2.9	263
Baseline, geographic subsets with veins			
Canyon Creek, mean	127	NC	NC
South Fork Coeur d'Alene basin, mean	97.6	NC	NC
Anomalous threshold[a]	60	2	250
Median, subsurface lake bed sediments[b]	33	0.3	118

a. Gott and Cathrall, 1980.
b. Horowitz et al., 1995.

NC — not calculated.

Maps of areas disturbed in some way by mining or mineral processing operations in the basin (Chapter 2) show the wide distribution of areas with some degree of disturbance. Since metal concentrations at many of these sites have not been characterized, Gott and Cathrall (1980) samples that were collected from areas identified as disturbed were conservatively retained in the baseline data set.

10.3.7 Sediment and Soil Baseline Concentrations

The DOI NRDA regulations do not suggest a statistic for characterization of baseline concentrations based on the range of variability determined. Therefore, to determine baseline concentrations for lead, cadmium, and zinc in soils and sediments, distributions of the reference data sets presented in Tables 10-2 to 10-4 were considered. The geometric mean and the upper 95% confidence limit on the geometric mean (UCL) are appropriate descriptors of the typical metal concentrations found in reference soils and sediments (Table 10-8). The 95th percentile is a concentration that is rarely exceeded in the reference areas. Figures 10-2 to 10-4 show histograms of lead, cadmium, and zinc concentrations from the reference data set for the whole basin. The UCL and upper 95th percentile concentrations are identified in the figures by dashed lines. The calculated average concentrations for lead in the Canyon Creek drainage and the South Fork Coeur d'Alene River basin are also presented (Table 10-8).

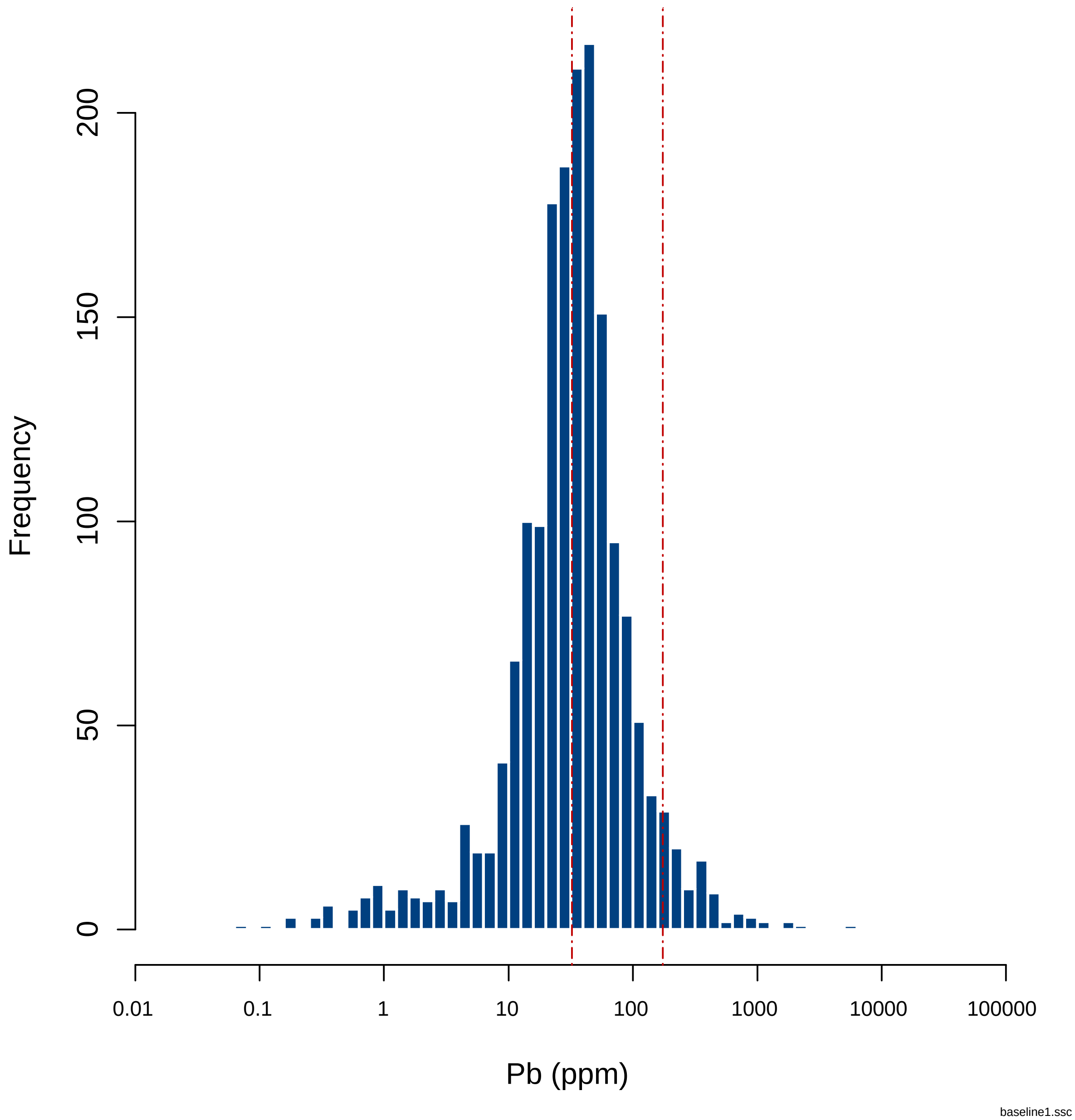

Figure 10-2. Histogram of lead concentrations in reference soils and sediments. Dashed lines identify the upper 95% confidence limit on the geometric mean and the 95th percentile concentrations.

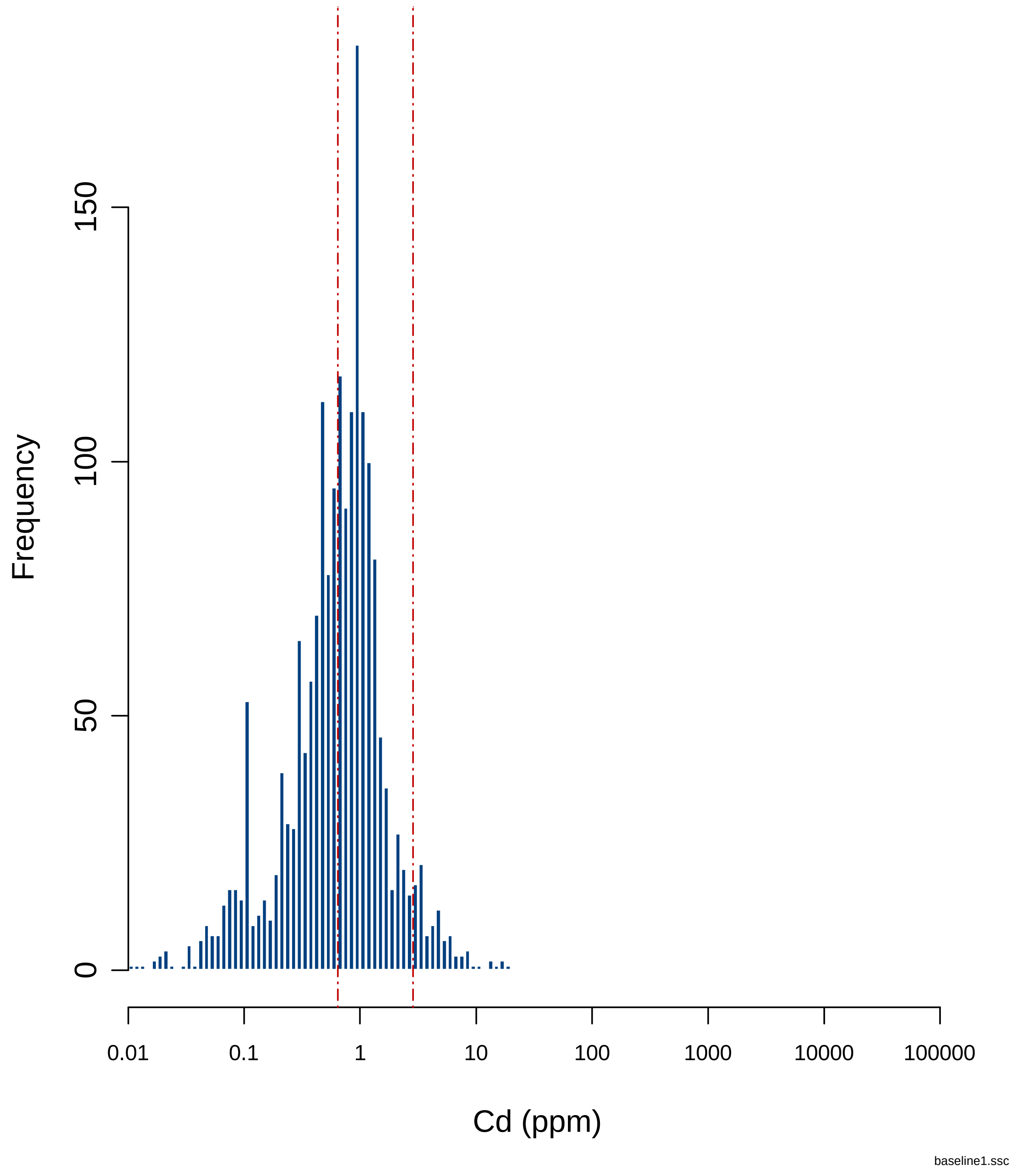

Figure 10-3. Histogram of cadmium concentrations in reference soils and sediments. Dashed lines identify the upper 95% confidence limit on the geometric mean and the 95th percentile concentrations.

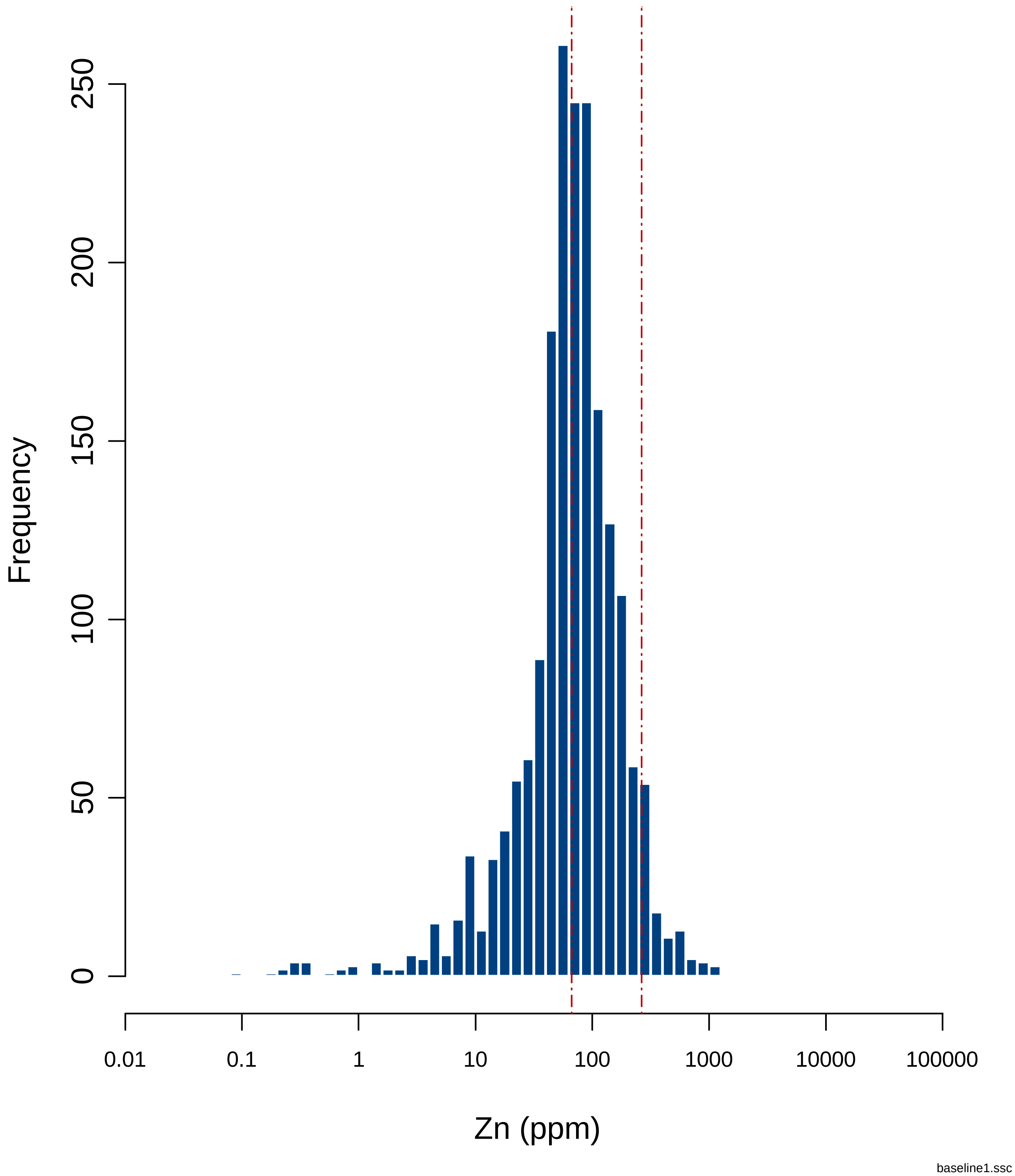

Figure 10-4. Histogram of zinc concentrations in reference soils and sediments. Dashed lines identify the upper 95% confidence limit on the geometric mean and the 95th percentile concentrations.

Gott and Cathrall (1980) reported threshold concentrations in soils and rocks that they considered "anomalously" high. For lead, the anomalously high concentration reported was 60 mg/kg, for cadmium, 2 mg/kg, and for zinc, 250 mg/kg. These concentrations are presented in Table 10-8 as an additional descriptor of the distribution of baseline concentrations in soils and sediments. In addition, Horowitz et al. (1993, 1995) determined concentrations of elements in uncontaminated subsurface sediments of Coeur d'Alene Lake using subsurface samples collected from 12 cores throughout the lake. Median concentrations of lead, cadmium, and zinc in the unenriched subsurface lake bed sediments are presented in Table 10-8 for comparison.

Uncertainty in the precision of these baseline estimates stems from the possibility that some of the reference samples were actually exposed to mining-related releases of the hazardous substances assessed. Uncertainties associated with the core samples stem from the lack of definitive dating information, the possible misinterpretation of the delineation between pre- and post-mining sediment horizons, and the possibility of cross contamination of layers resulting from core sampling or historical dredging.

The most likely effect of the uncertainties is a bias toward overestimation of baseline conditions throughout the basin. There is no realistic source of bias that could cause underestimation in the interpretation. Therefore, this determination of baseline concentrations is more likely than not higher than the true baseline conditions.

10.4 SURFACE WATER BASELINE

This section presents the determination of surface water baseline conditions. As noted previously, baseline is defined in the DOI NRDA regulations as the condition or conditions that would have existed at the assessment area had the release of the hazardous substance under investigation not occurred [43 CFR § 11.14 (e)]. Baseline data should reflect conditions expected at the assessment area had the release of hazardous substances not occurred, taking into account both natural processes and those that are the result of human activities [43 CFR § 11.72 (b)(1)]. When identifying baseline conditions for surface water resources in a mineralized area such as the Coeur d'Alene River basin, "natural processes" include the weathering of ore deposits that would have occurred if mining had never taken place. As such, a number of the streams or sections of streams identified as "control" or "reference" reaches should be in areas with geologic and mineralogic characteristics that are similar to those of the assessment area.

Although the geology of the Coeur d'Alene area is relatively uniform across the basin, there are ore deposits of varying mineralogic and elemental composition within the basin. In addition, there are few confirmed locations with similar mineralization that have not been mined and virtually no reliable historical water quality data, especially for metal concentrations. These conditions complicate the determination and characterization of baseline water quality and necessitate an approach that largely relies on upstream reference locations [43 CFR § 11.72 (g)(3)(i-ii)] in areas with geologic and mineralogic conditions that are similar to those in the downstream assessment areas [43 CFR § 11.72 (j)(3)(i)].

10.4.1 Historical Data

Mining began in the Coeur d'Alene River basin in the 1880s, although different mines and mills began production at different times, as described in Chapter 2. The first mines on the South Fork Coeur d'Alene River upstream of Canyon Creek began production in 1895 (Morning Mine), and the first mine along the reach from Canyon Creek to Elizabeth Park began in 1904 (Sunshine Mine). Mining along Canyon Creek began in 1888 at the Tiger-Poorman Mine (Quivik, 2000), mining along Ninemile Creek began at the Monarch Mine in 1904, and mining along Pine Creek began in 1900 at the Nevada Stewart Mine. Although it is difficult to determine exactly when releases to surface water from mining began, it is certain that hazardous substances were released directly to streams from milling operations that sluiced tailings to creeks (see Section 2.3). The first mill in the basin began operation in 1886 and processed ore from the Bunker Hill Mine (Casner, 1991).

All of the mines were underground mines, so the underground workings related to each mine may have affected more than one drainage basin. Many of the underground workings are probably located below levels that would have directly affected area streams. However, blasting may have created fractures above underground workings, which may have increased the rate of weathering of subsurface materials.

The first water quality sampling of the basin was in 1911 by Kemmerer et al. (1923), who sampled Coeur d'Alene Lake for plankton, water depth, temperature, dissolved CO_2 and oxygen, and turbidity. Kemmerer described the inflow waters from the Coeur d'Alene River as being "muddy" and "so laden with silt that they may be traced far out into the clear water of the lake." Hoskins (1932) also collected samples from Coeur d'Alene Lake, reporting lake water to be at saturation for lead.

In 1932, the U.S. Bureau of Fisheries conducted water quality and fish toxicity sampling of the lake and other parts of the basin (Ellis, 1940). In the Coeur d'Alene River, dissolved oxygen, pH, and dissolved carbon dioxide were found to be "suitable" for fish, but upstream of Cataldo, the South Fork Coeur d'Alene River was heavily laden with mine wastes. Ellis stated that the mine waste had largely eliminated the aquatic vegetation and algae from the Coeur d'Alene River. Ellis (1940) measured a range in pH of mine waters from 6.7 to 7.5 but noted that specific conductance in the Coeur d'Alene River downstream of mine waste discharge increased by approximately 100% relative to upstream of the discharge.

Ellis (1940) also conducted a series of laboratory and in-situ toxicity tests on fish, frogs, turtles, and plankton using lead and zinc ore, waste incrustations (efflorescent crusts) from mine wastes, and other mining-related wastes. The results are described in Chapter 7. In summary, dissolved waste crusts were the most toxic and zinc ore the least, and Ellis found that mine wastes in the Coeur d'Alene River had destroyed the fish and the plants and animals on which the fish relied upon for food.

The first modern water quality samples in the Coeur d'Alene basin were collected in the mid-1960s, approximately 80 years after mining and milling began. The early water quality data were of variable quality. Detection limits often exceeded aquatic life criteria (ALC), digestion methods varied, and hardness, which is necessary to calculate ALC, was often not measured (Ridolfi, 1995).

Because there is such a gap between the beginning of mining and milling in the basin and the analysis of the first water quality samples, there are no historical water quality data representative of the condition of streams before mining. If historical data are not available or do not meet the guidelines in the DOI regulations, baseline must be defined by field data from the reference area [43 CFR § 11.72 (d)].

10.4.2 Reference Area Selection

Reference areas should be selected based on their similarity to the assessment area and lack of exposure to the release [CFR 43 §11.72(d)(1)]. For surface water resources, DOI regulations indicate that reference areas should consist of a "stream or river reach of similar size, that is as near to the assessment area as practical and, if practical, that is upstream or upcurrent from the injured resource, such that the channel characteristics, sediment characteristics, and streamflow characteristics are similar to the injured resource, and the water and sediments of the reference area, because of location, have not been exposed to the release" [43 CFR § 11.72(g)(3)(i)]. The samples from reference streams should be collected using methods similar to those used for injured site collections [43 CFR § 1172 (d)(5)], and the data collected at both reference and assessment area streams should be sufficient to estimate the normal variability in measurements made [43 CFR § 11.72(d)(4)].

As noted above, baseline should take into account both natural processes and those that are the result of human activities. In mineralized areas, ore deposits at or near the surface can be weathered or oxidized naturally by exposure to air and water. The more extensive and deeper the fracture systems in the ore body, the deeper oxidation will occur. The reactions that produce acid mine drainage from mining activity are identical to those that produce acid "rock" drainage from the natural oxidation of sulfide ore bodies. Higher concentrations of metals in streams and groundwater usually result from mining activity, mostly as a result of the increase in surface area from blasting, milling, and removal of waste rock from the ore body. These mining processes increase the amount of sulfide and metal-rich material exposed to oxygen and water relative to an unmined ore body.

The extent to which the reference streams and reaches are similar to assessment reaches was examined in terms of hydrologic, geologic, and mineralogic considerations. The hydrologic considerations included a comparison of discharge, or flow, at assessment and reference locations, and an examination of the variability in concentrations under different hydrologic conditions. The geologic and mineralogic considerations included an examination of the geology, ore deposits, and soil and rock metal concentrations in the reference and assessment drainages.

Similarity of Timing of High and Low Flow

Water quality samples have been collected in both injured and reference stream reaches during both low flow and high flow conditions. High flow generally occurs in May and low flow in October. The precise timing of the peak flow varies with location, depending on aspect, elevation, and other factors, but, the general timing of peak and low flows at locations in the upper basin are similar year to year.

Flow ranges measured in both injured and reference reaches are summarized in Table 10-9 for Ninemile Creek, Canyon Creek, South Fork Coeur d'Alene River and tributaries, including Government Gulch, Milo Creek, and Pine Creek. In general, flows in upstream reference reaches are lower than, but exhibit the same seasonal patterns as, flows in downstream injured reaches.

Variability in Concentrations under Different Hydrologic Conditions

Samples and measurements at both reference and assessment locations should be collected under similar hydrologic conditions, and discharge should be measured at the same time that water and sediment samples are collected [43 CFR §11.72(g)(4)(ii)]. In this way, seasonal and hydrologic effects on the concentrations of hazardous substances and other constituents can be compared in reference and injured streams and reaches.

Baseline data for surface water resources should be sufficient to determine the:

- range of concentrations of hazardous substances in water and sediment
- variability of concentrations of hazardous substances, suspended sediment, and physical properties of water and sediments during different conditions of water discharge/stage
- variability of physical and chemical conditions during different conditions of stage/discharge relating to transport or storage of substances in water and sediments [43 CFR § 11.72 (g)(4)(iii)].

Relationships between hardness and flow, zinc concentrations and flow, and total suspended sediment (TSS) concentrations and flow in assessment and reference reaches were examined to assess the comparability of the assessment and reference reaches under different hydrologic conditions.

At both assessment (injured) and reference locations, hardness and zinc concentrations are highest and most variable during fall and winter low flow, and lowest during peak flow in the spring. Figures 10-5a and b show patterns of hardness and zinc concentrations during high and low flow periods at an injured site on Canyon Creek, and Figures 10-6a and b show the similarity in hardness concentration with flow at both an injured and a reference site in Canyon Creek. These figures show patterns of hardness and zinc concentrations under different hydrologic conditions that are typical for both reference and assessment reaches.

Table 10-9
Range of Flows at Selected Injured and Reference Locations in the South Fork Coeur d'Alene River Basin

Location	Site ID	Flow (cfs)
Injured Reaches		
Ninemile Creek	NM 305 (mouth)	1-87
	NM 298 (mouth East Fork)	1.2-56
Canyon Creek	CC 287 (near mouth)	11-300
South Fork Coeur d'Alene	SF 205 (most upstream)	1.4-146
	SF 233 (downstream Ninemile)	86-720
	SF 270 (Smelterville)	55-1,230
Milo Creek	SF 183 (mouth)	4.9-25
Government Gulch	SF 110 (near mouth)	4.3-24
Moon Creek	SF 262 (mouth)	0.93-112
Pine Creek	PC 305 (mouth)	4.6-2,030
	PC 312 (near mouth East Fork)	15-71
Reference Reaches		
Ninemile Creek	NM 300 (East Fork-mainstem confluence)	0.91-2.3
	NM 289 (most upstream)	0.2-18
Canyon Creek	CC 2 (upstream of O'Neill Gulch)	1.6-420
Milo Creek	SF 185 (Slaughterhouse Gulch)	8.1
Government Gulch	SF 108 (most upstream)	1.9-23
Pine Creek	PC 311 (East Fork-mainstem confluence)	20-136
	PC 309 (mouth Trapper Creek)	2.7-13.8
	PC 325 (headwaters Denver Creek)	0.14
	PC 306 (headwaters East Fork)	0.80-6

Data source: Flow measurements contained in the database compiled for assessment of injury to surface waters. For original sources, see Chapter 4.

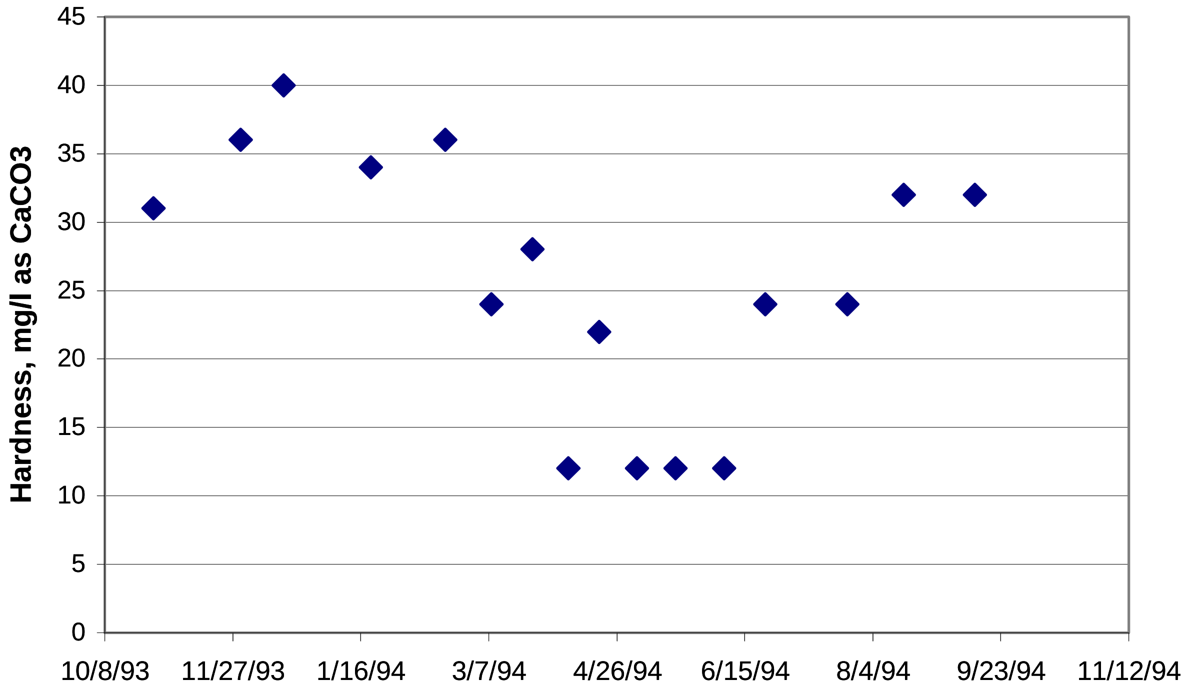

Figure 10-5a. Hardness values measured in Canyon Creek downstream of O'Neill Gulch (site CC 276).

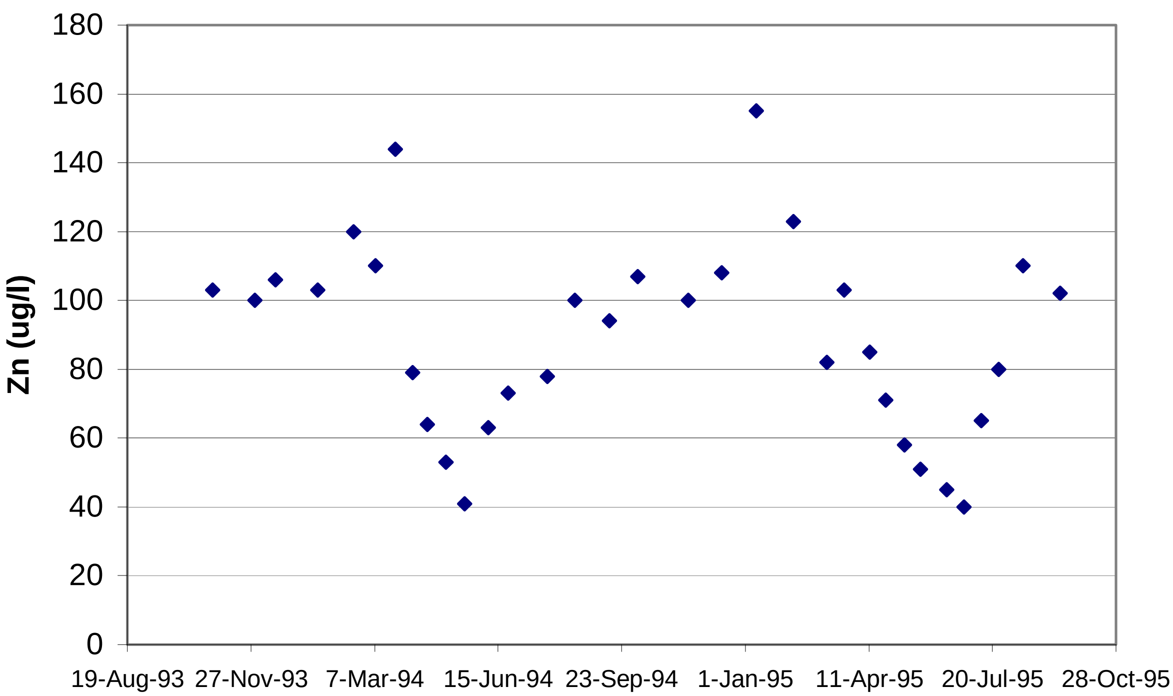

Figure 10-5b. Zinc concentrations in Canyon Creek downstream of O'Neill Gulch, assessment site CC 276.

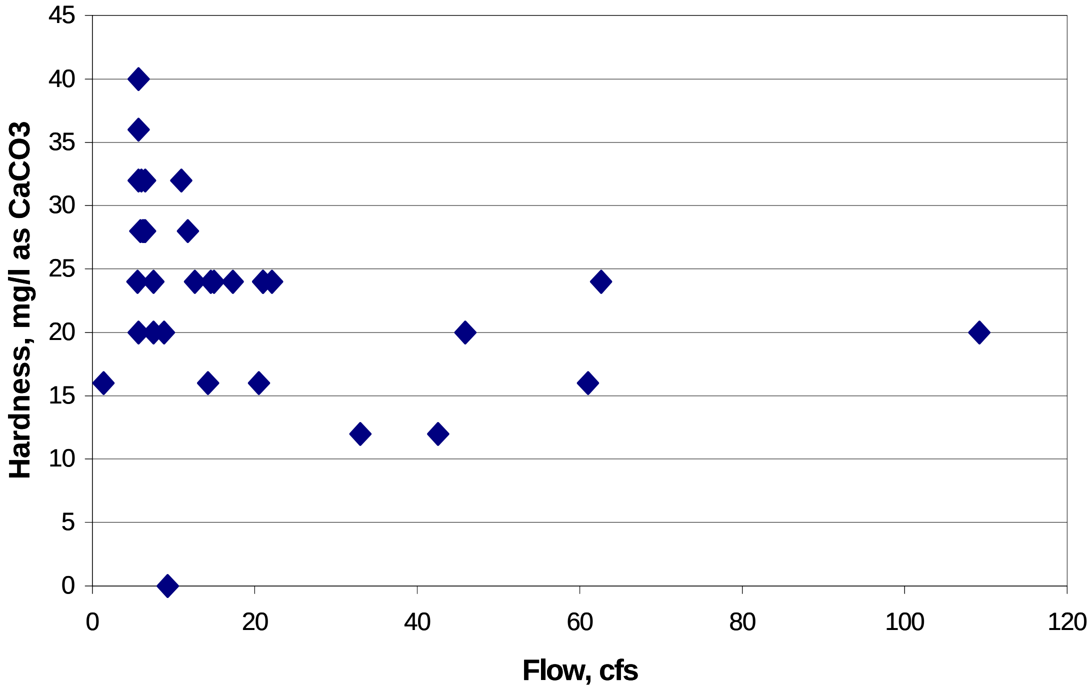

Figure 10-6a. Relationship between flow and hardness in upper South Fork Coeur d'Alene River, assessment site SF 205.

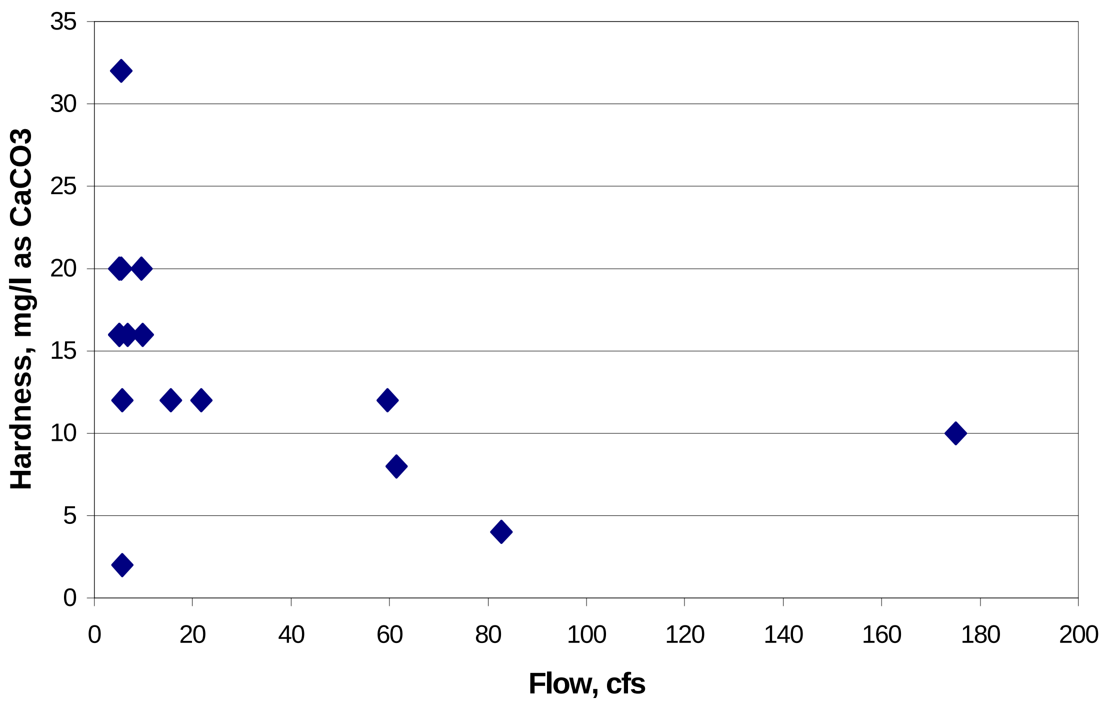

Figure 10-6b. Relationship between flow and hardness in upper Canyon Creek, reference site CC 2.

TSS increases with flow in both assessment and reference reaches, with highest concentrations in the spring at both reference and injured locations. The increase in TSS concentrations at injured locations during high flow is often much greater than the increase at reference locations. For example, at Canyon Creek reference location CC-2 and assessment location CC-276, flows differ by only 1 to 2%, but TSS concentrations at the assessment location are more than twice those at the reference location during high flow. TSS concentrations at the two sites are similar during low flow. The disproportionately higher concentrations of TSS at injured locations are most likely the result of suspension during higher flows of tailings deposits in the beds, banks, and floodplains.

Trends in physical and chemical characteristics of waters from reference and injured stream locations with time and discharge are similar. However, concentrations of metals and TSS are higher at assessment locations than reference locations under similar hydrologic conditions. Samples of hazardous substances and other constituents and measurements of discharge were taken at similar times at both reference and assessment locations. Therefore, the reference locations are similar to the assessment locations for surface water resources in terms of hydrologic considerations.

Geologic, Mineralogic, and Environmental Considerations

Most of the rocks in the Coeur d'Alene Mining District are slightly metamorphosed sedimentary rocks of late pre-Cambrian age belonging to the Belt Supergroup. These rocks are predominantly argillite[4] and quartzite, with lesser amounts of disseminated dolomite and limestone in the upper part of the section. The Belt Supergroup rocks cover a large area, including north and central Idaho, western Montana, southeastern British Columbia, and Alberta. Belt rocks in the Coeur d'Alene area are the host rock for the ore deposits. Igneous monzonite intrusions (a granite-like rock) of Cretaceous age cut through the Belt rocks north of the South Forth Coeur d'Alene River in the Ninemile/Canyon Creek area (Gem Stocks) and the area to the west of Ninemile Creek (Dago Stocks) (Hobbs et al., 1965; Gott and Cathrall, 1980). The geologic map for the district, based on Derkey et al. (1996), is shown in Figures 10-7a and b.

The Belt rocks in the Coeur d'Alene Mining District are cut by a complex series of faults, the largest of which is the 100-mile-long Osburn Fault. This fault follows the valleys of the South Fork Coeur d'Alene River in Idaho and the St. Regis River and parts of the Clark Fork River in Montana (Hobbs et al., 1965). The Osburn Fault is a strike-slip fault with approximately 16 miles of lateral (roughly east-west) displacement. It is widely believed that the ore bodies were originally formed in this "structural knot" and then separated and moved along the Osburn Fault. Therefore, deposits south of the fault just east of Big Creek (Silver Summit, Silver Dollar) were originally located due south of ore deposits on Ninemile Creek (Silver Star, Dayrock). The two main areas of mineralization — Kellogg south of the fault and Mullan-Burke area north of the fault — are separated by approximately 16 miles.

4. Sedimentary rock composed of silt and/or clay with some cleavage approximately parallel to bedding.

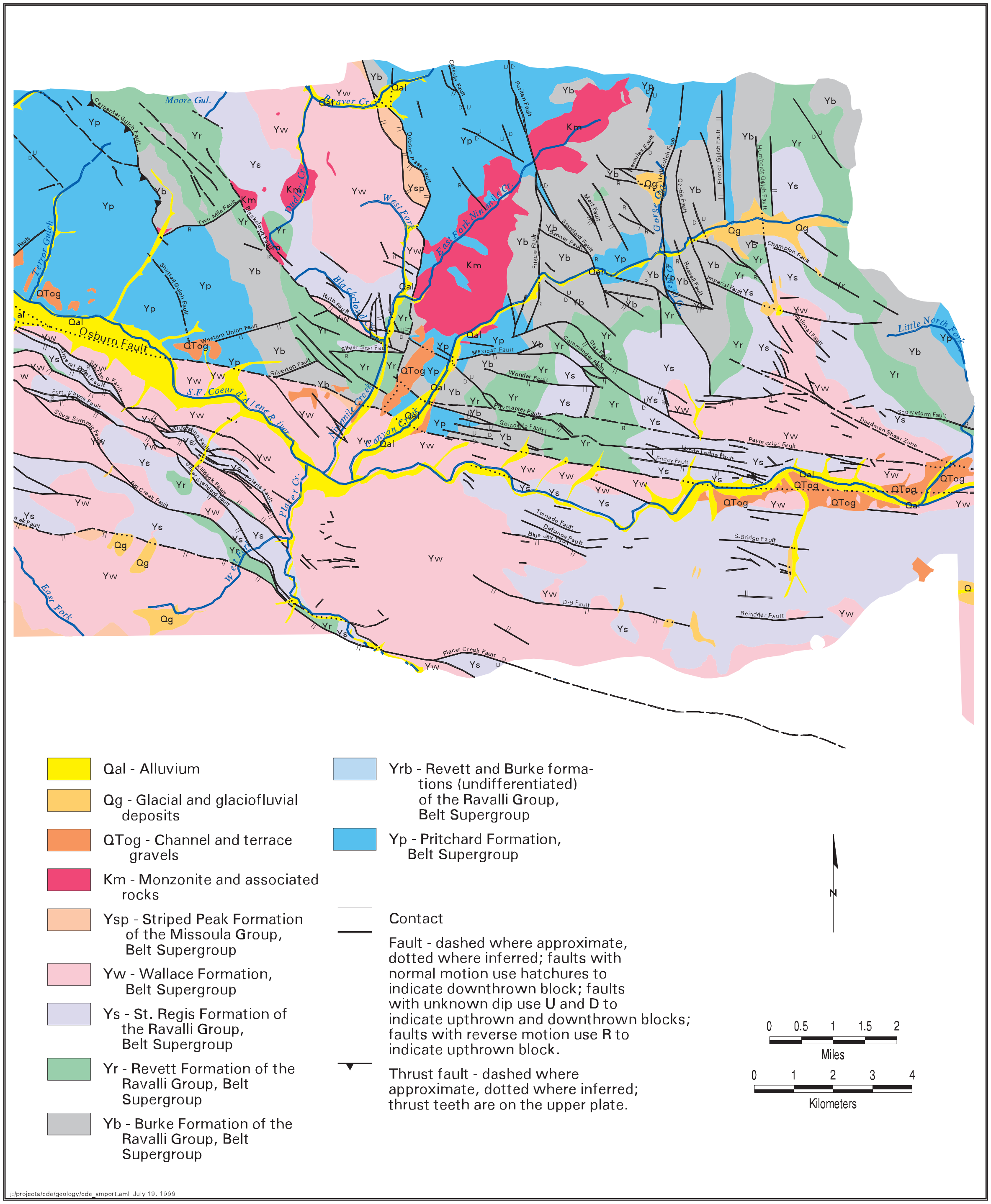

Figure 10-7a. Geologic map of Coeur d'Alene area — eastern section.

Source: Derkey et al., 1996.

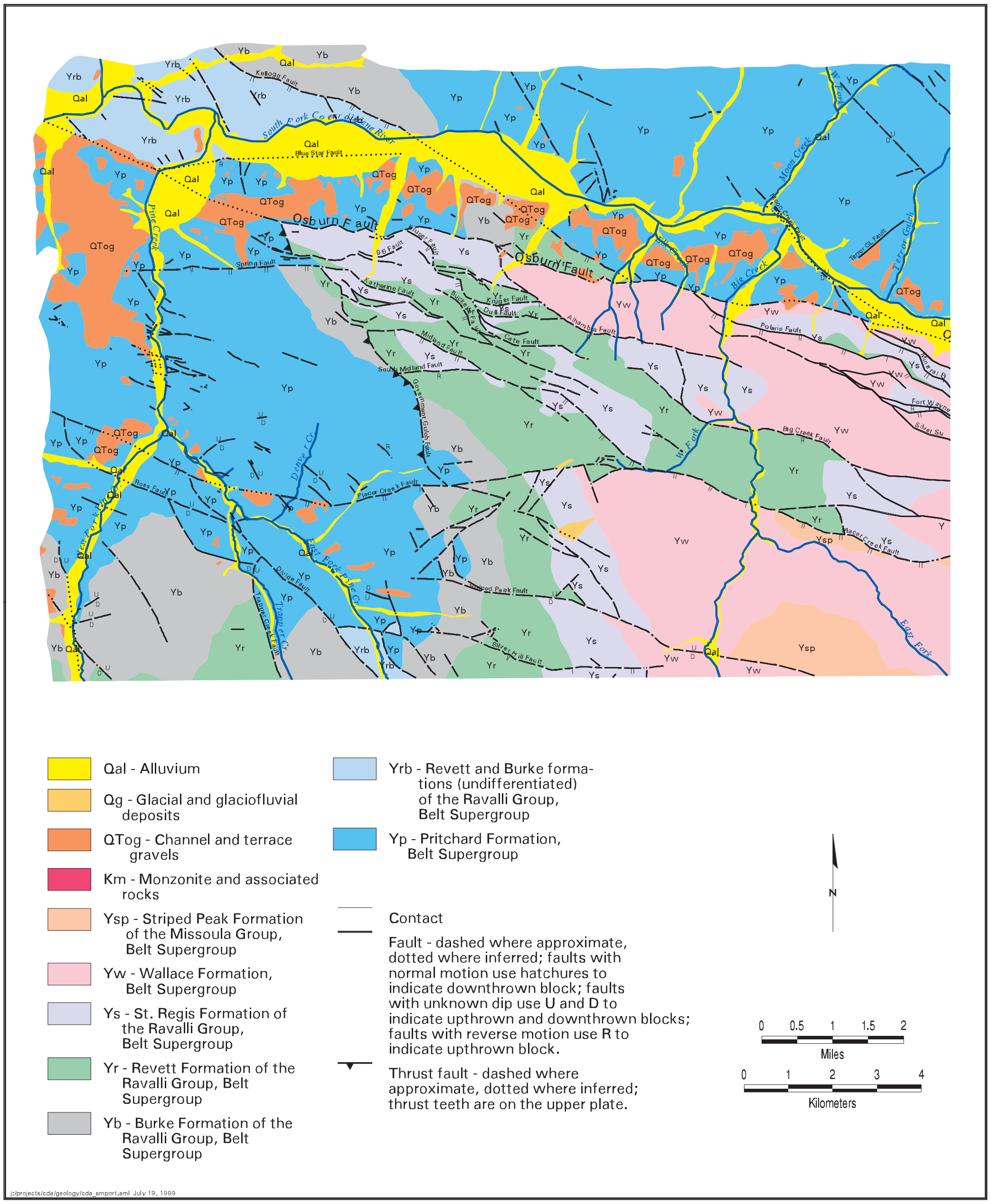

Figure 10-7b. Geologic map of the Coeur d'Alene area — western section.
Source: Derkey et al., 1996.

There are five main geologic formations in the Belt Supergroup of the Coeur d'Alene area (from oldest to youngest): the Prichard Formation, the Burke Formation, the Revett Quartzite, the St. Regis Formation, and the Wallace Formation (Figures 10-7a and b). In the Coeur d'Alene Mining District, the Burke, Revett, and St. Regis formations are often combined into the Ravalli Group (Hobbs et al., 1965). The Prichard Formation is composed of fine-grained argillite with abundant pyrite or pyrrhotite. The Ravalli Group is composed predominantly of siltite and quartzite with argillite at the top. The Wallace Formation includes quartzite, argillite, and lesser amounts of dolomite and limestone. The carbonate-bearing argillite and quartzite set off the Wallace Formation from the others in the Supergroup. Some carbonate is also contained in the underlying and overlying rock units.

Weathering of the three groups of rocks described above (Prichard Formation, Ravalli Group, Wallace Formation) may result in different characteristic chemistries of streams draining these deposits. Streams draining the Prichard Formation may be somewhat iron-rich and acidic. Streams cutting through the Ravalli Group would be of low hardness but not acidic. Streams draining the Wallace Formation would have higher hardnesses and may have higher pH and alkalinity values.

Ore deposits in the Coeur d'Alene Mining District are predominantly in high grade veins consisting of variable amounts of sphalerite (zinc sulfide, ZnS), galena (lead sulfide, PbS), and argentiferous tetrahedrite (an arsenic-antimony sulfide with varying proportions of copper, iron, zinc and/or silver) $[(Cu,Fe,Zn,Ag)_{12}(Sb,As)_4S_{13}]$ (White, 1998). The non-ore minerals in the veins consist mostly of quartz (SiO_2) or siderite (ferrous iron carbonate, $FeCO_3$). The ore bodies can be grouped into northwest-trending areas called mineral belts (Figures 10-8a and b). Veins contain the ore shoot (economic part of the deposit) and gangue (non-economic part of the deposit).

There are three general types of vein deposits in the district: one in the middle Prichard quartzites (zinc-lead orebodies on Pine Creek), another in the Prichard-Burke transition zone (Ninemile Creek and Canyon Creek lead-zinc deposits), and the third in the Revett-St. Regis transition zone (Bunker Hill Mine, Star-Morning Mine, Lucky Friday Mine, and the mines in the Silver Belt) (Bennett and Venkatakrishan, 1982). The discussion of baseline water quality that follows is grouped into these three general categories and areas. Most of the ore production (75%) has come from the Revett Formation; 19% has come from quartzite at the Burke-Prichard boundary; and all current production is from the Revett-St. Regis boundary (White, 1998).

The mineralized veins typically are steeply dipping and very narrow at the surface outcrop or do not outcrop at the surface at all; however, dispersion patterns are still evident in soils and weathered rocks (Gott and Cathrall, 1980). Gott and Cathrall (1980) established "threshold" values or "anomalous" concentrations. Concentrations in rock and soil higher than the threshold values are associated with ore deposits. Many of the mineral belts are delineated by concentrations higher than threshold values.

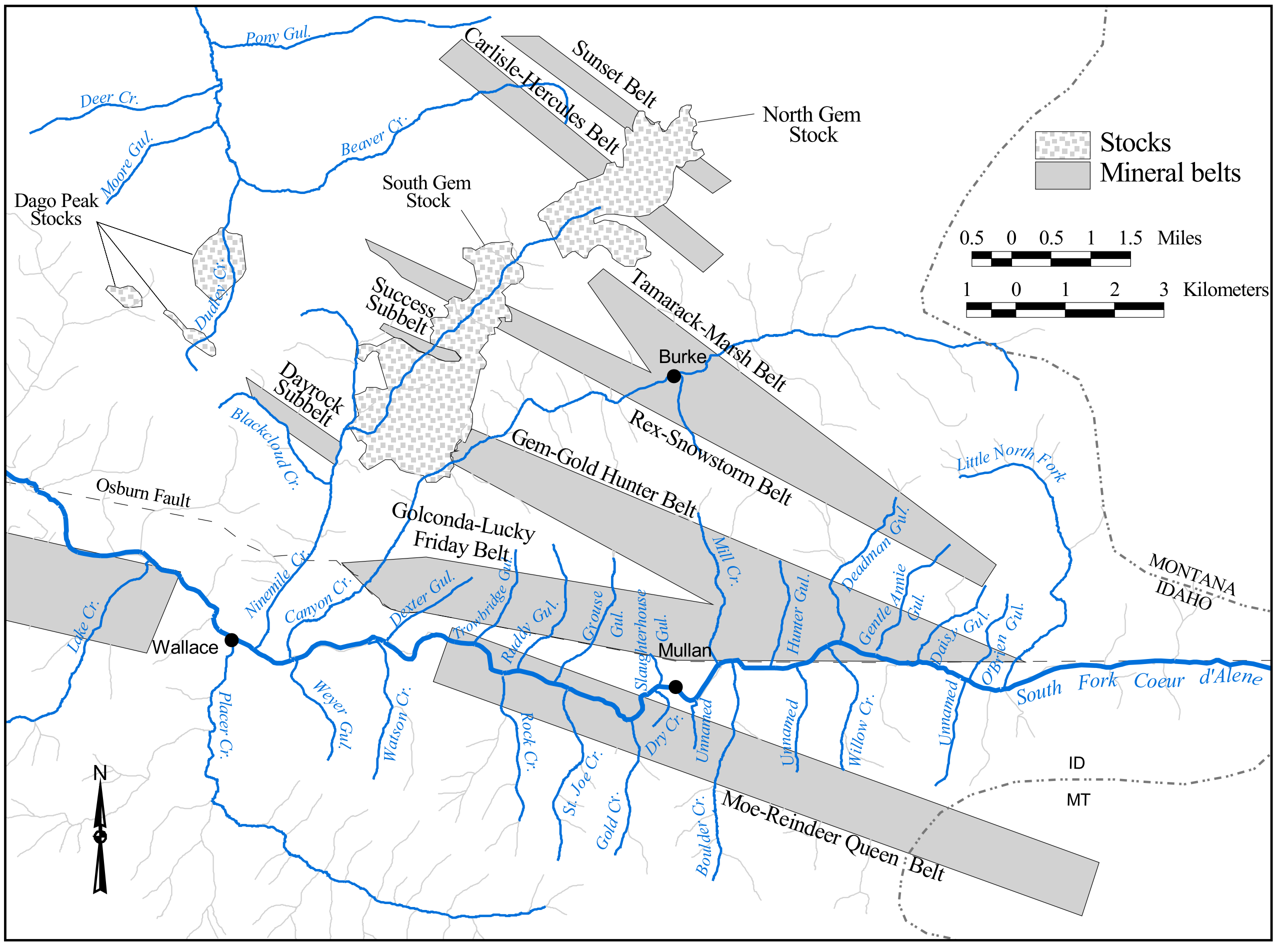

Figure 10-8a. Mineral belts of the Coeur d'Alene River basin — east.

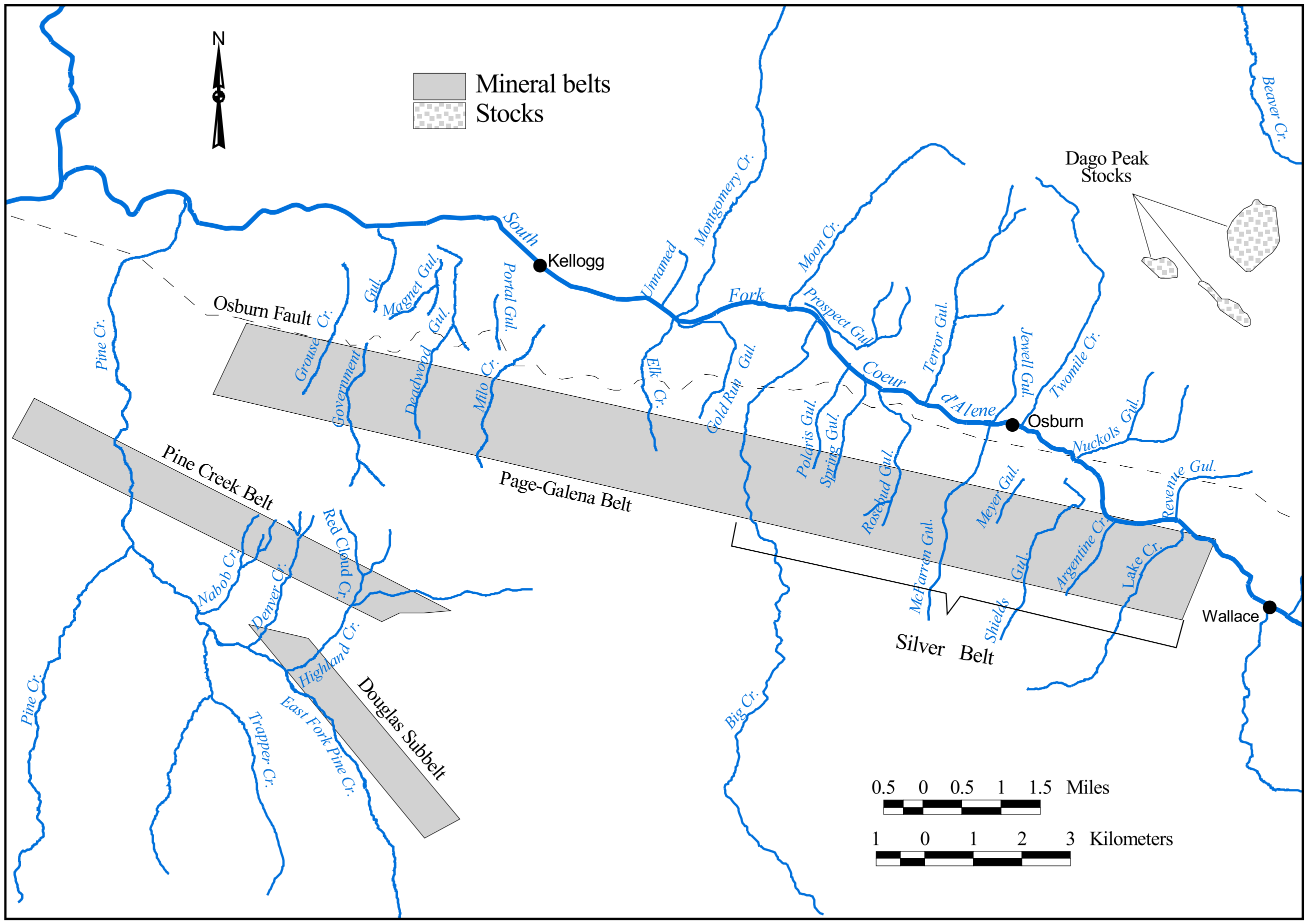

Figure 10-8b. Mineral belts of the Coeur d'Alene River basin — west.

In general, deposits in the northern and western part of the district are relatively shallow and deposits east of the Bunker Hill Mine in the Page-Galena mineral belt are approximately 1,000 ft. deep (Gott and Cathrall, 1980). Dispersion patterns of lead best characterize mineral belts with shallow deposits, including the Gem-Gold Hunter and the Rex-Snowstorm belts in the upper South Fork area. Even where veins do outcrop, they are generally deeply weathered (Keith Long, USGS, pers. comm., 1998), and their outcrops represent only a small fraction of their extent at depth. Hobbs and Fryklund (1968) show cross-sections of some ore shoots along the Gem-Gold Hunter mineral belt, including the Lucky Friday Mine, and along the Page-Galena mineral belt (Figure 10-9). Some veins apex 1,000 ft or more below the surface and give no hint at the surface of their existence (Hobbs and Fryklund, 1968).

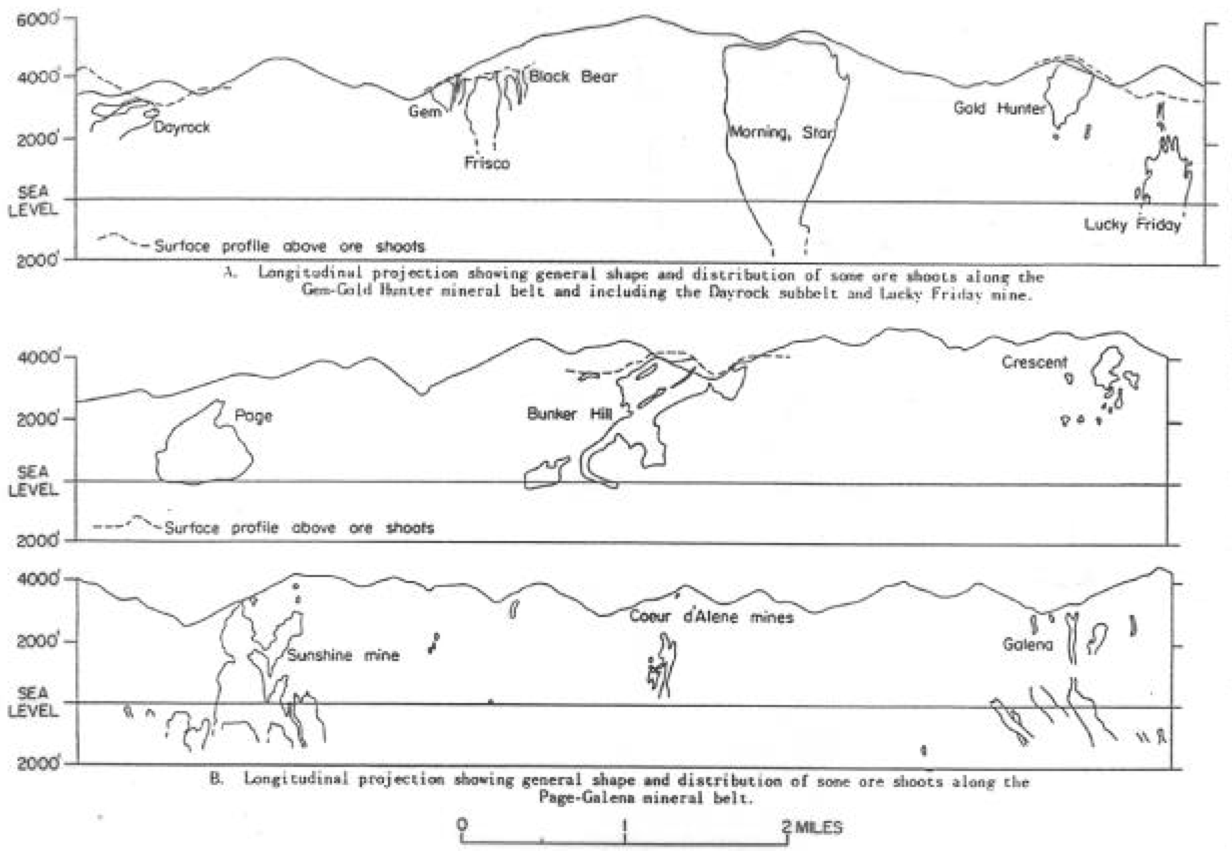

Figure 10-9. Longitudinal projections of some ore shoots in the Coeur d'Alene Mining District.
Source: Hobbs and Fryklund, 1968.

There appears to be carbonate zoning around many of the veins in the district, especially disseminated siderite (ferrous iron carbonate) (White, 1998). The carbonate is most likely derived from the original Belt sediments. The weathering of these disseminated carbonates should produce stream water that contains alkalinity and iron, with lesser amounts of calcium and magnesium. The presence of abundant carbonate material surrounding the veins may limit the concentrations of naturally weathered metals in water by raising the pH and precipitating the metals as hydroxides or carbonates and/or by adsorption, which would be promoted under higher pH conditions. The alkalinity produced from weathering of carbonates surrounding veins is also important in buffering the pH of mine drainage water in the Coeur d'Alene basin.

In addition to carbonate zoning around veins, disseminated galena, sphalerite, pyrite, and arsenopyrite are also found around many of the ore bodies in the district (White, 1998). Distributions are similar to the carbonate zoning patterns (White, 1998). The weathering of the disseminated sulfides around the veins could produce waters that contain elevated concentrations of metals, at least in areas where there is not sufficient dilution from nonmineralized rock.

Pyrite, which is the mineral most commonly responsible for the formation of acid drainage, is a ubiquitous vein mineral but is volumetrically unimportant except for some of the veins in the Pine Creek area, and possibly around the Dago Peak and North Gem stocks. In several veins, including the large Star-Morning vein (2,600 m deep), pyrite is more abundant with depth. This is also true in the Silver Belt mines, in which pyrite and chalcopyrite increase with depth (White, 1998). The removal of ore from depth, milling, and the deposition of tailings directly in the creeks in the basin probably caused past and ongoing violations of water quality criteria in the Coeur d'Alene area.

10.4.3 Identification of Reference Streams and Reaches

Baseline water quality was determined for three areas that generally correspond with the three general types of vein deposits characterized by Bennett and Venkatakrishan (1982):

- Upper South Fork. Streams in the upper portion of the South Fork Coeur d'Alene River basin from the Little North Fork of the South Fork to Placer Creek. These streams drain mineral belts in Ninemile and Canyon creeks and other upper South Fork tributaries (Figure 10-8a).

- Page-Galena Mineral Belt area. Streams along the lower portion of the South Fork draining the Page-Galena and Silver mineral belts and northern tributaries of the South Fork across from these mineral belts (Figure 10-8b).

- Pine Creek drainage. Streams in the Pine Creek basin draining the Pine Creek mineral belts (Figure 10-8b).

Each drainage was evaluated in terms of its geology, mineralization, and environmental considerations, including water quality data and mine waste deposits.[5] The geology and mineralization were determined by examining geologic and mine maps of the district that are presented as plates in Hobbs et al. (1965). These plates contain detailed information on the geology, veins, mine identity and locations, and underground workings for the entire Coeur d'Alene Mining district. The veins in the plates are distinguished as being either surface or subsurface, and as "known to contain base metals (A)," "not known to contain base metals (B)," or, in some cases, the veins are not marked with an A or B. Other sources relied on include geologic maps by Derkey et al. (1996; Figures 10-7a and b), the maps delineating mineral belts (Figures 10-8a and b), and locations of mine waste deposits (Figures 10-10a and b).

Drainages with large producing mines and/or with mill sites were excluded from consideration as reference streams, even if water quality did not violate relevant aquatic life criteria. Figures 2-3 to 2-5 in Chapter 2 were used to determine if a major mine or a mill existed in a drainage. Drainages without large producing mines and/or mill sites were considered to be reference streams even if water quality did violate relevant standards. Drainages were considered to be mineralized if they drain known mineral belts (Figures 10-8a and b), if they have veins known to contain base metals (Hobbs et al., 1965), or if rock or soil samples collected by Gott and Cathrall (1980) in the drainage exceed threshold values. If none of these conditions were met, the drainages were considered to be unmineralized. The water samples were evaluated for exceedence of dissolved cadmium, lead, and zinc chronic criterion values.

Table 10-10 and Figures 10-11a and b identify mineralized and unmineralized streams in the upper South Fork Coeur d'Alene River basin, the Page-Galena and Silver belts, and the Pine Creek drainage. Rocks and soils in the vicinity of Dudley Creek and Moore Gulch contain elevated concentrations of lead and other metals and may represent an unmined ore body. Because this area is similar geologically and mineralogically to Ninemile and Canyon creeks, Dudley Creek and Moore Gulch samples were included in the Upper South Fork area for baseline surface water determination.

5. Supporting geology, mineralization, and environmental information is included in Appendix A to this chapter.

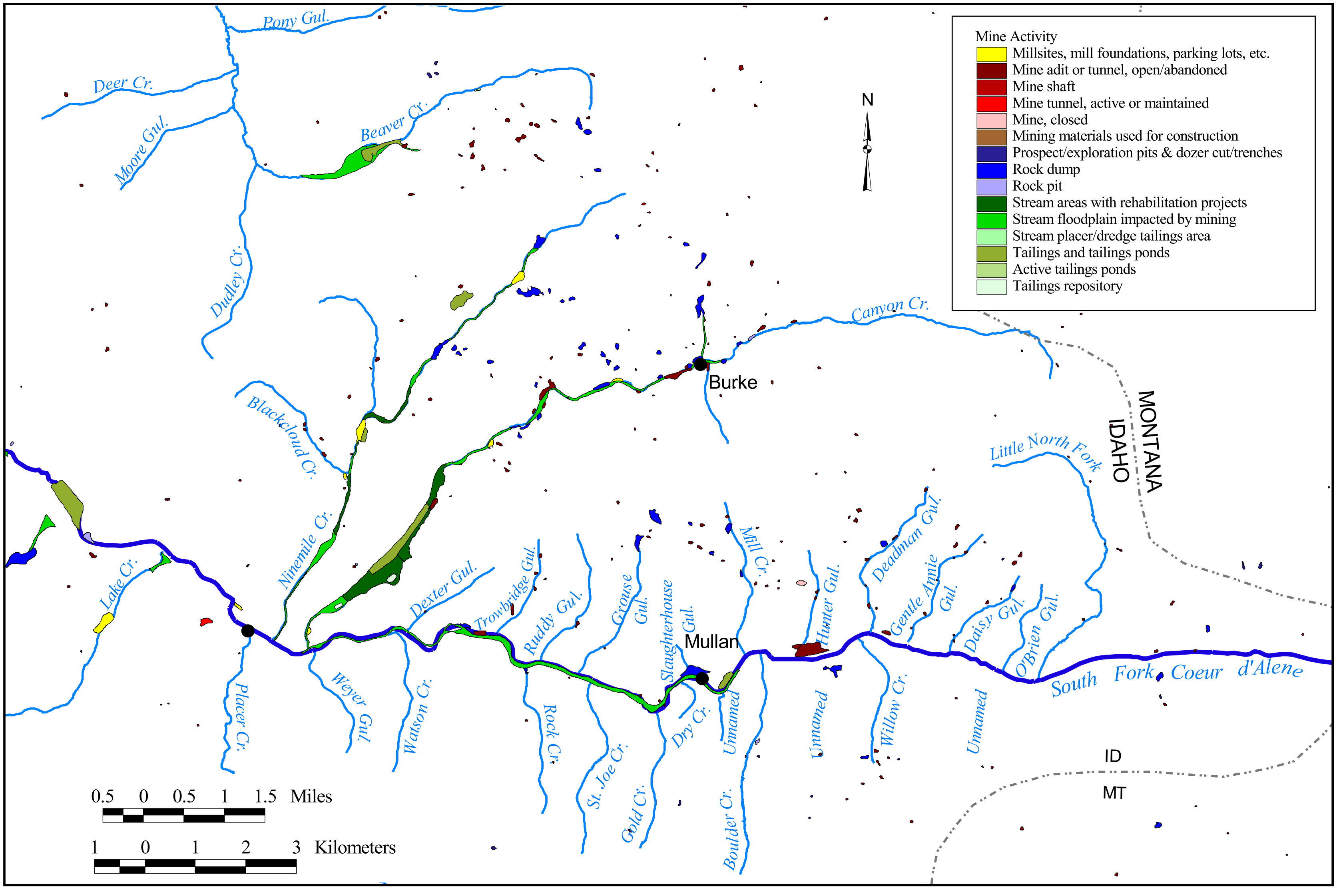

Figure 10-10a. Location of mine deposits/activity — eastern section.
Source: U.S. BLM, 1999.

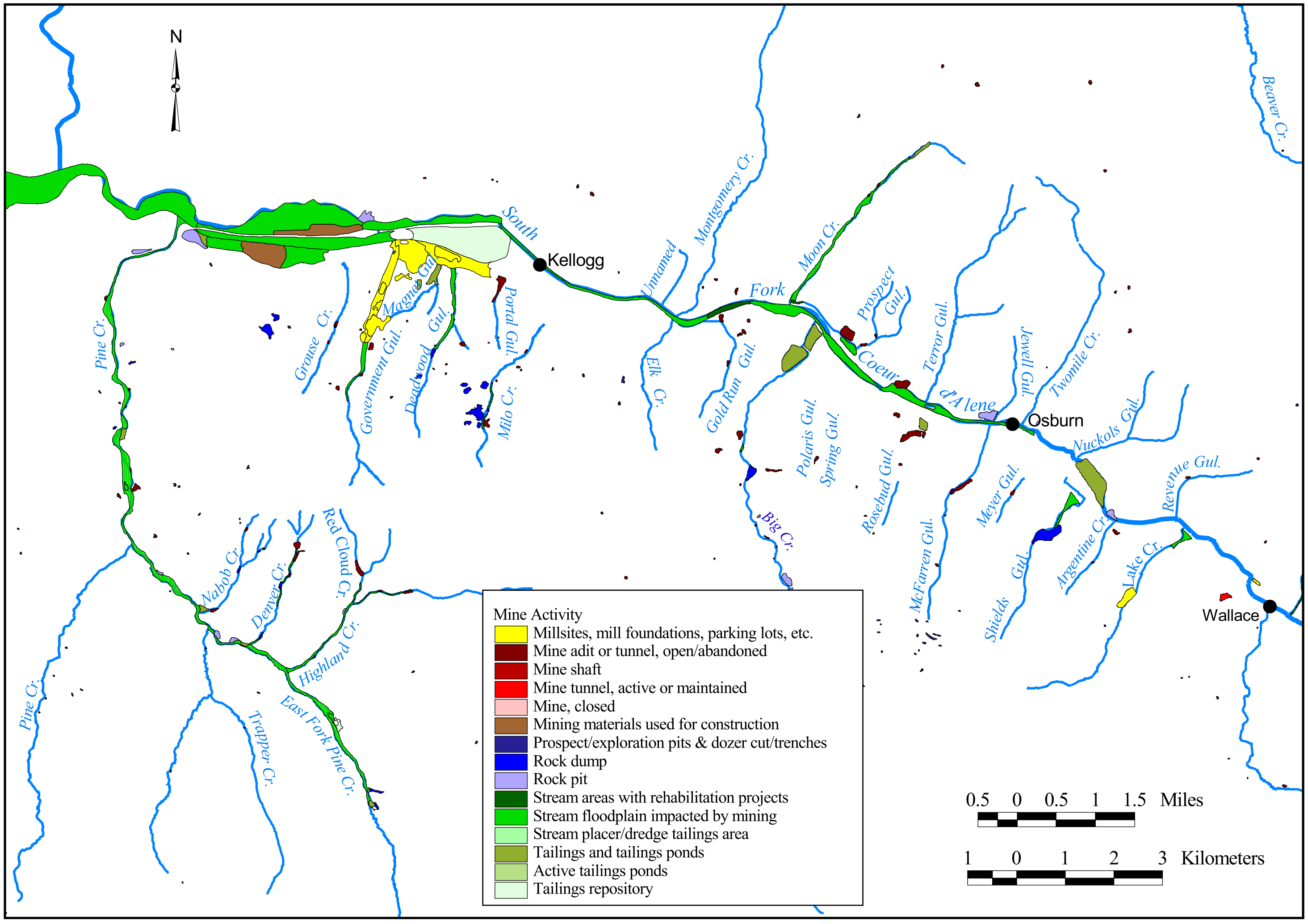

Figure 10-10b. Location of mine deposits/activity — western section.
Source: U.S. BLM, 1999.

Table 10-10
Identification of Reference Streams and Sample Locations Used in Determination of Surface Water Baseline

Location	Site Number
I. Upper South Fork Coeur d'Alene River and Tributaries	
Mineralized	
Little North Fork of the South Fork	SF 202
Gentle Annie Gulch	SF 207
Willow Creek	SF 210
Unnamed creek	SF 211
Unnamed creek	SF 213
Boulder Creek	SF 214
Dry Creek	SF 219
Gold Creek	SF 221
St. Joe Creek	SF 222
Rock Creek	SF 225
Trowbridge Gulch	SF 226
Dexter Gulch	SF 229
Ninemile Creek	NM 289 East Fork headwaters
Ninemile Creek	NM 299 — East Fork — mainstem confluence
Ninemile Creek	NM 300 — East Fork — mainstem confluence
Canyon Creek	CC289 — upstream of O'Neill Gulch
Canyon Creek	CC 272 — upstream of O'Neill Gulch
Canyon Creek	CC 1 — upstream of O'Neill Gulch
Canyon Creek	CC 273 — upstream of O'Neill Gulch
Canyon Creek	CC 274 — upstream of O'Neill Gulch
Canyon Creek	CC 2 — upstream of O'Neill Gulch
Canyon Creek	CC 290 — upstream of O'Neil Gulch
Unnamed Creek	SF 204
Watson Gulch	SF 230
Weyer Gulch	SF 231
Dudley Creek	NF 51
Moore Gulch	NF 52

Table 10-10 (cont.)
Identification of Reference Streams and Sample Locations
Used in Determination of Surface Water Baseline

Location	Site Number
II. Page-Galena and Silver Belts	
Mineralized	
Milo Creek	SF 185 — Slaughterhouse Gulch
Government Gulch	SF 108 — Upper Government Gulch
Argentine Gulch	SF 242
Nuckols Gulch	SF 245
Meyer Gulch	SF 246
Twomile Creek	SF 248
Jewel Creek	SF 251
Terror Gulch	SF 252
Spring Gulch	SF 256
Gold Run Gulch	SF 265
Montgomery Gulch	SF 266
Elk Creek	SF 267
Unnamed	SF 269
Unmineralized	
Revenue Gulch	SF 20, 240
III. Pine Creek Drainage	
Mineralized	
Pine Creek	PC 309 — Trapper Creek
Pine Creek	PC 311 — upper mainstem Pine Creek
Denver Creek	PC 325 — upper Denver Creek
Unmineralized	
Pine Creek	PC 306 — upper East Fork (South Fork)

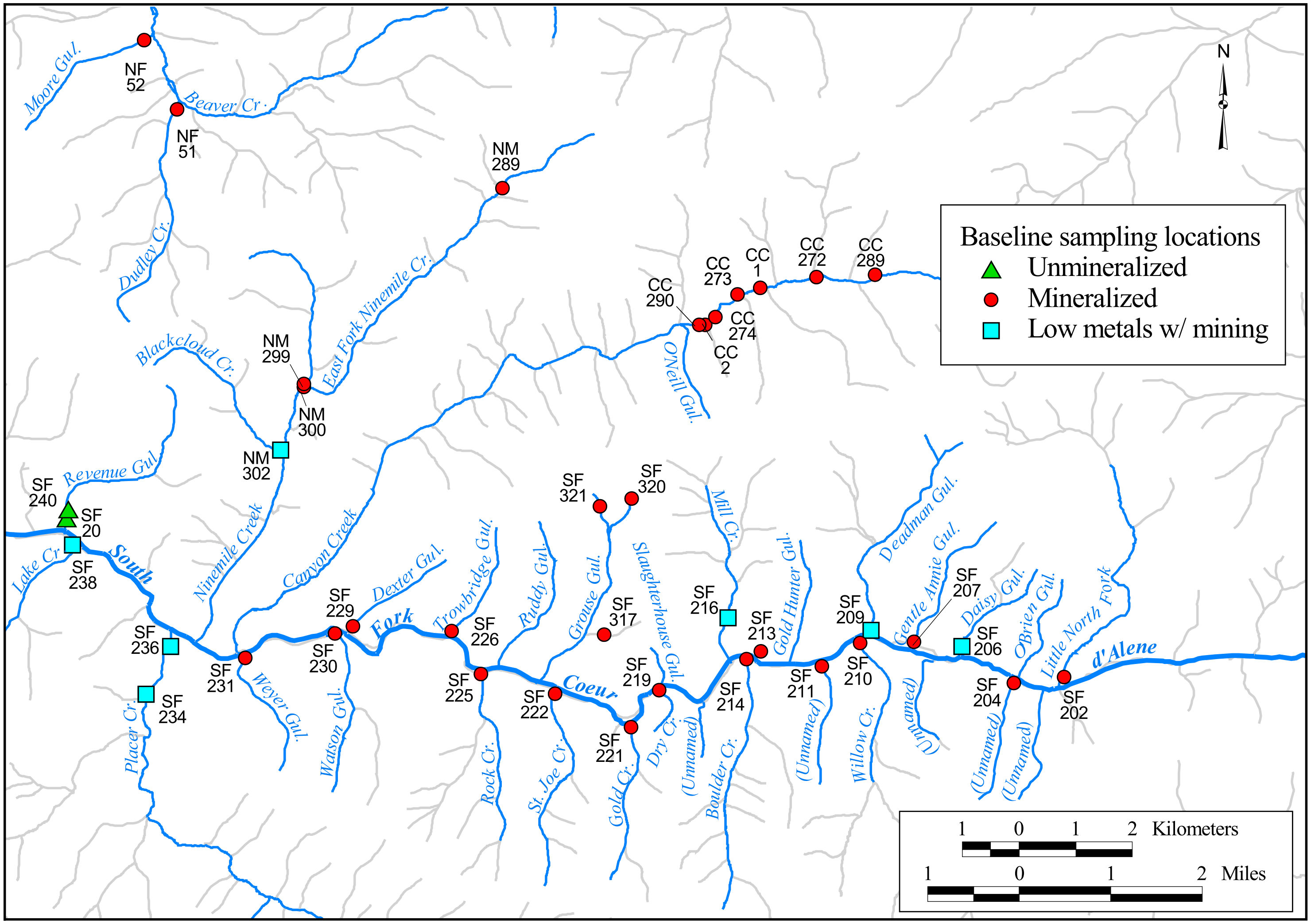

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Figure 10-11a. Baseline surface water locations — east.

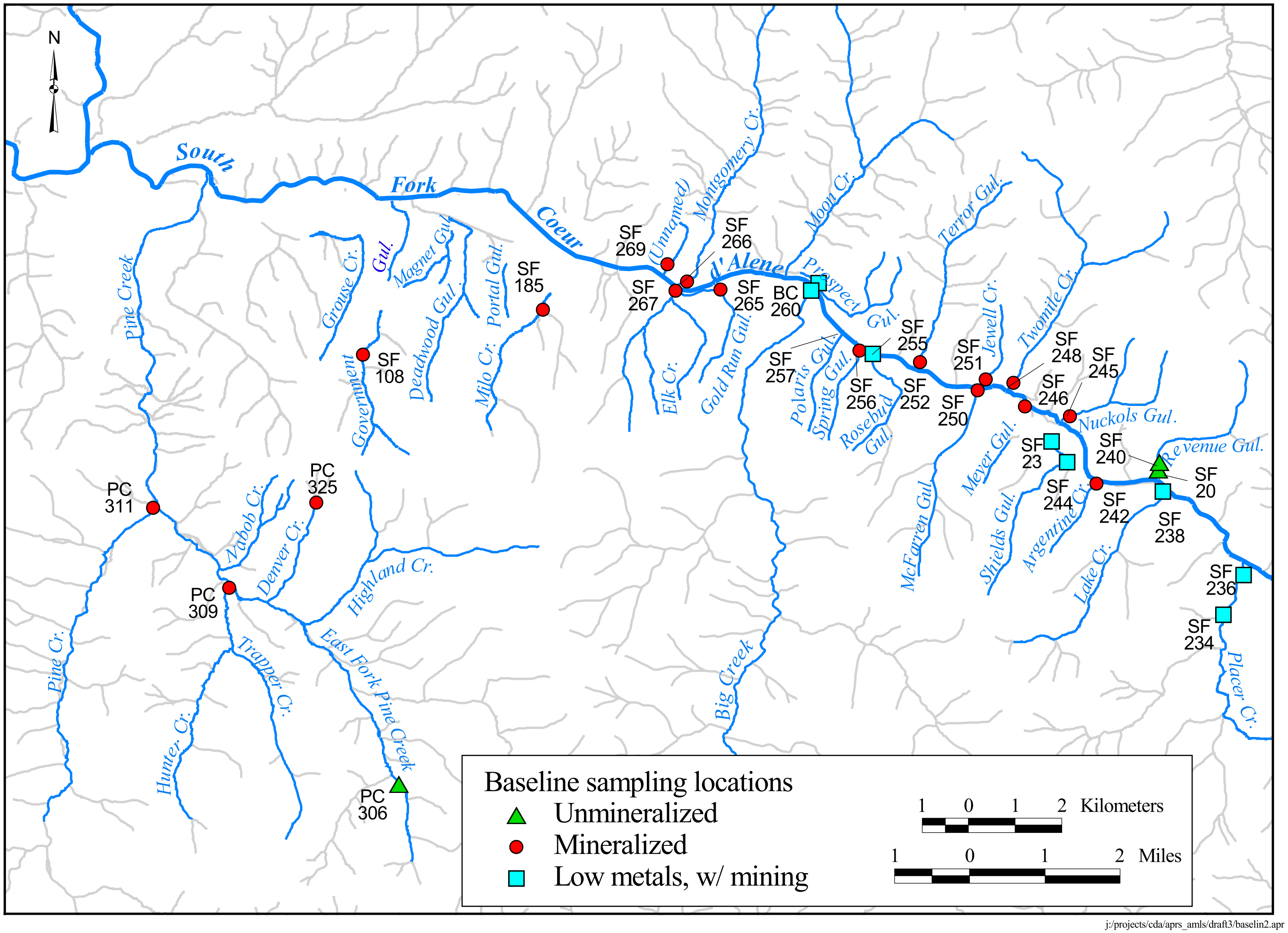

Figure 10-11b. Baseline surface water locations – west.

Water quality samples from the following locations do not violate aquatic life criteria for dissolved cadmium, lead, and zinc, even though a major mine or mill or other type of significant mining disturbance exists in the drainage. These locations were not used for baseline surface water quality, but the data indicate that water quality was high in these mineralized drainages before mining.

- Deadman Gulch (SF 209)
- Mill Creek (SF 216)
- Placer Creek (SF 234, 236)
- Blackcloud Creek (NM 302)
- Lake Creek (SF 238)
- Shields Gulch (SF 23, 244)
- Rosebud Gulch (SF 255)
- Polaris Gulch (SF 257)
- Big Creek (BC 260).

10.4.4 Extent of Mineralization of Individual Drainages

Some of the tributaries of the South Fork Coeur d'Alene River have veins known to contain base metals that are outcropping or close to the surface (as determined by Crosby, 1959; Hobbs et al., 1965; and Hobbs and Fryklund, 1968). Canyon Creek and Ninemile Creek are the tributaries of the South Fork Coeur d'Alene River that have had the largest number of mines and are also known to have a large number of outcropping veins. The percentage of the Canyon Creek drainage with outcropping veins or veins close to the surface was determined in the section on soil and sediment baseline (Section 10.3.6). For comparison, the percentages of outcropping or near-surface veins in two other drainages with low metal concentrations in streams, Mill Creek and Gentle Annie Gulch, were also determined.

In Mill Creek, the Star-Morning vein, one of the largest in the district, is shown to be outcropping (Crosby, 1959, Section H), and the ore body itself is shown to be very close to the surface for much of its length (Hobbs and Fryklund, 1968). The You Like vein is also in Mill Creek and is shown to be within approximately 50 feet of the surface in Crosby (1959, Section H). In Gentle Annie Gulch, there are four outcropping veins known to contain base metals or to be associated with mines, as shown by Hobbs et al. (1965). Both Mill Creek and Gentle Annie Gulch have very low metal concentrations (water quality criteria were not exceeded in any sample). Gentle Annie Gulch was used as a baseline water quality stream, and Mill Creek was identified as a stream with low metal concentrations even though significant mining activity was conducted in the drainage (Maest et al., 1999). Mill Creek was excluded from consideration as a baseline stream because of the presence of the Morning No. 5 adit, which was the main producing adit for the large Morning mine for a number of years. However, there are no significant tailings deposits in the drainage.

The drainage basins of these watersheds were delineated as described in Section 10.3.6, and the veins containing base metals that were at or near the surface were delineated on maps of the drainages (Figure 10-12). The lengths of the outcropping or near surface veins were measured, and the average width from the Kennedy analysis (150 m) was applied to determine the total area of veins in each drainage. The areal percentages of these drainages covered by metal-containing surface or near-surface veins were 0.9% for Gentle Annie Gulch and 2% for Mill Creek. This compares to a value of 0.4% for Canyon Creek (Section 10.3.6). Therefore, even in drainages with more than twice as much surface area occupied by metal-rich outcropping or near surface veins, metal concentrations in surface water are low in the absence of significant tailings deposits.

This analysis confirms that streams used for determining baseline water quality had areal percentages of highly mineralized material similar to or greater than percentages in Canyon Creek. Surface water in Gentle Annie Gulch and Mill Creek had very low metal concentrations. These results and the demonstration of the minimal effect of highly mineralized veins on soil baseline metals values presented in Section 10.3.6 indicate that, while metal concentrations in veins and ore are very elevated, the geographic extent of the veins themselves relative to the area of the basin is so insignificant that the veins do not substantially affect baseline soil or water metal concentrations.

10.4.5 Determination of Baseline Surface Water Concentrations

Baseline surface water concentrations were determined using concentrations from individual reference locations. Median concentrations and interquartile ranges [43 CFR §11.72 (g)(6)] of dissolved cadmium, lead, and zinc were determined for reference surface water locations in each of three areas of the South Fork Coeur d'Alene River basin — the upper South Fork basin, the Page-Galena mineral belt area, and the Pine Creek drainage. In addition, median and interquartile range values were determined for the South Fork Coeur d'Alene River basin as a whole.

For a given sample location, mean values were determined for dissolved cadmium, lead, and zinc concentrations. For concentrations that were below detection, one-half the detection limit was used. If there was more than one sample location on a tributary, as was the case for Canyon and Ninemile creeks, the mean tributary value was calculated as the mean of the individual sample location means. In this way, tributaries with more than one sample location were not weighted more heavily than those with only one sample site, and sites sampled more frequently did not weight tributary means. The median and interquartile ranges for the three areas and the entire South Fork Coeur d'Alene River basin are presented in Table 10-11. Medians and interquartile ranges are presented for dissolved cadmium, lead, and zinc.

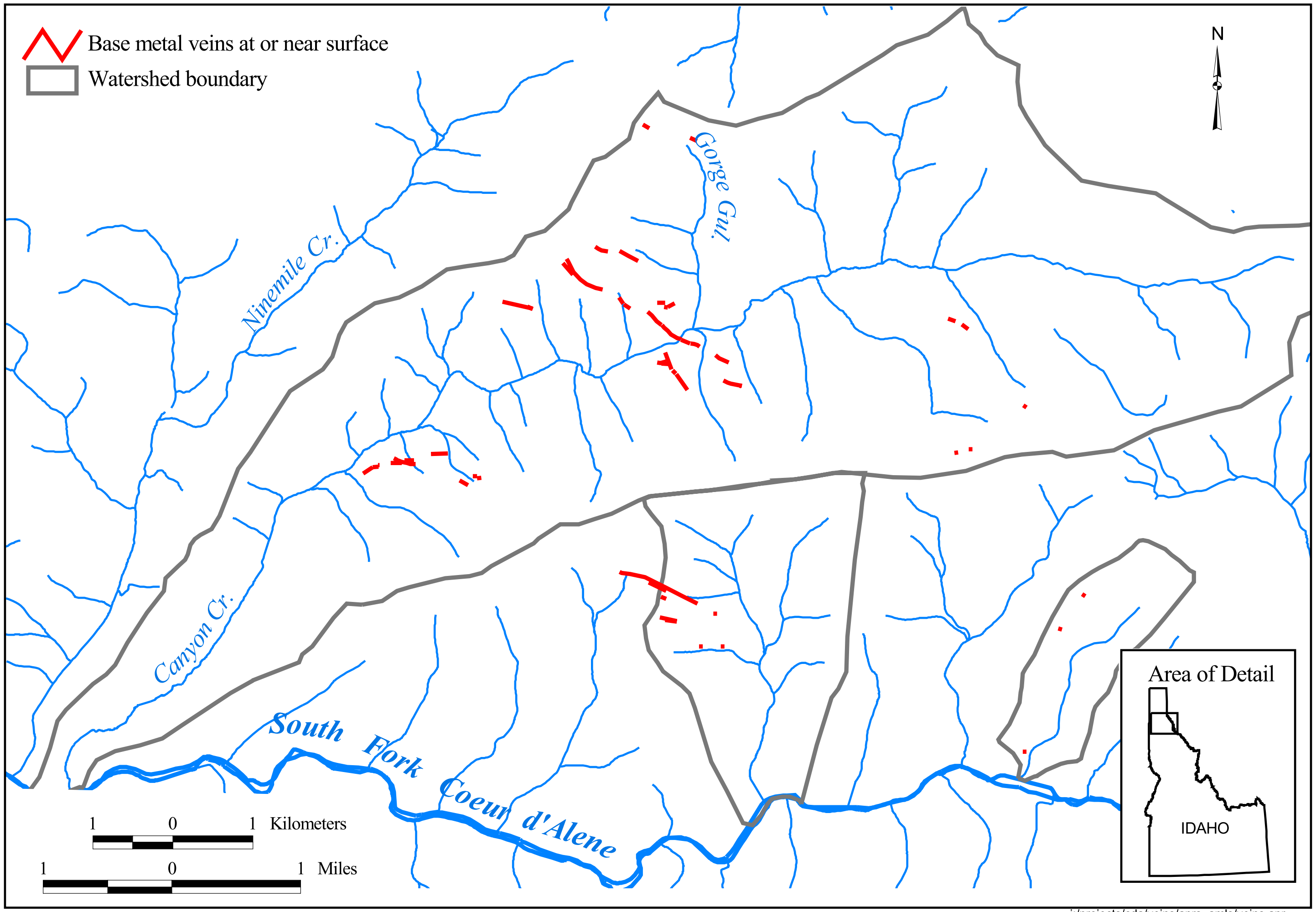

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Figure 10-12. Location of surface or near surface veins known to contain base metals in the Canyon Creek, Mill Creek, and Gentle Annie drainage basins.

Table 10-11
Median and Interquartile Ranges for Baseline Surface Water in the South Fork Coeur d'Alene Basin

Area	Statistical Analysis	Cadmium (µg/L)	Lead (µg/L)	Zinc (µg/L)
Upper South Fork	Median	0.06	0.15	5.35
	25th percentile	0.04	0.08	4.50
	75th percentile	0.07	0.25	8.45
Page-Galena Mineral Belt	Median	0.10	0.44	9.04
	25th percentile	0.07	0.21	6.76
	75th percentile	0.16	0.87	20.0
Pine Creek Drainage	Median	0.03	0.11	3.68
	25th percentile	0.02	0.07	2.94
	75th percentile	0.04	0.22	5.24
Entire South Fork CdA Basin	Median	0.06	0.18	6.75
	25th percentile	0.04	0.08	4.60
	75th percentile	0.10	0.52	10.7

Median values for dissolved cadmium, lead, and zinc in the upper South Fork Coeur d'Alene River basin were 0.06, 0.15, and 5.35 µg/L, respectively. Median values for dissolved cadmium, lead, and zinc in the Page-Galena mineral belt area, 0.10, 0.44, and 9.04 µg/L, respectively, were the highest of the three groups. Median values for dissolved cadmium, lead, and zinc in the Pine Creek drainage, 0.03, 0.11, and 3.68 µg/L, respectively, were the lowest. For the South Fork Coeur d'Alene River basin as a whole, medians for the three metals were 0.06, 0.18, and 6.75 µg/L, respectively.

None of the baseline surface water median values exceed relevant ALC values. Chronic ALC values for dissolved cadmium, lead, and zinc at a hardness of 25 mg/L as $CaCO_3$ are 0.80, 0.54, and 36.5 µg/L, respectively. This is the lowest hardness value that can be used to calculate ALC values and yields the lowest, or most environmentally conservative, chronic ALC value. Average hardness values for all three areas (Upper South Fork, etc.) and for the South Fork Coeur d'Alene basin as a whole are at least twice this value. Therefore, baseline water quality values are well below relevant ALC values, and baseline water quality would not have exceeded even chronic ALC values calculated at the lowest possible hardness value.

10.4.6 Comparison of Baseline and Injured Surface Water Concentrations

To establish that differences between surface water conditions of the reference and injured areas are statistically significant, the median and interquartile range of the data were determined and concentration distributions of dissolved cadmium, lead, and zinc in baseline and injured surface water sample locations were compared using the Mann-Whitney test [43 CFR §11.72 (g)(6)].

The median and the interquartile range of dissolved cadmium, lead, and zinc in injured areas were determined for the same three areas for which baseline concentrations were characterized (Upper South Fork, Page-Galena mineral belt area, and Pine Creek drainage). The data used to calculate median and interquartile ranges in injured areas were mean concentrations in the tributaries and the portion of the South Fork Coeur d'Alene River within each of the three baseline characterization areas. For example, a mean concentration was calculated for each tributary in the Upper South Fork area, and a mean concentration was calculated for the South Fork Coeur d'Alene River from the headwaters to Placer Creek, using individual sample location data. For the Page-Galena area, a mean concentration was calculated for each tributary downstream of Placer Creek and upstream of Pine Creek, and a mean concentration was calculated for the South Fork Coeur d'Alene River from downstream of Placer Creek to upstream of Pine Creek. For the Pine Creek drainage, a mean concentration was calculated for Pine Creek and for each of the injured Pine Creek tributaries, and a mean concentration was calculated for the South Fork Coeur d'Alene River from downstream of Pine Creek to the North Fork Coeur d'Alene River confluence. Table 10-12 and Figures 10-13a, b, and c present the median and interquartile ranges of the mean concentrations for each area.

The median and the interquartile range of mean injured concentrations also were determined for the whole South Fork Coeur d'Alene River basin (Table 10-12 and Figures 10-13a, b, and c). For that calculation, the three mean concentrations for the sections of the South Fork Coeur d'Alene River described above were included with the means for all other injured tributaries in the basin.

For each area, and for the South Fork Coeur d'Alene River basin as a whole, baseline and injured concentrations of dissolved cadmium, lead, and zinc were highly significantly different (Mann-Whitney $p < 0.01$, Table 10-12). Even though the Page-Galena Mineral Belt area had the highest median baseline metal concentrations of the three areas, differences between baseline and injured median values were all significantly different at $p < 0.001$.

Median injured concentrations for dissolved cadmium, lead, and zinc in the Upper South Fork area were 1.17, 7.00, and 170 µg/L, respectively. These are the lowest median injured values for cadmium and zinc of the three areas examined. The value for cadmium, 1.17 µg/L, exceeds the dissolved chronic ALC at hardnesses above 25 mg/L as $CaCO_3$; values for lead and zinc are higher than chronic ALC values even at hardnesses above 100 mg/l as $CaCO_3$. In addition, the median zinc concentration exceeds the acute ALC value at relevant hardnesses for the Upper South Fork.

Table 10-12
Summary of Statistical Comparisons of Baseline and Injured Surface Water Locations for Dissolved Metals

Area	Statistical Measure	Cadmium (μg/L)			Lead (μg/L)			Zinc (μg/L)		
		Baseline	Injured	p Value	Baseline	Injured	p Value	Baseline	Injured	p Value
Upper South Fork	Median	.06	1.17	<0.01	.15	7.00	<0.001	5.35	170	<0.01
	25th percentile	.04	0.20		.08	1.83		4.50	37.4	
	75th percentile	.07	8.33		.25	18.6		8.45	1230	
Page-Galena Mineral Belt	Median	.10	8.12	<0.001	.44	10.9	<0.001	9.04	1080	<0.001
	25th percentile	.07	3.65		.21	7.46		6.76	623	
	75th percentile	.16	12.3		.87	50.1		20.0	2950	
Pine Creek Drainage	Median	.03	3.09	<0.01	.11	2.77	<0.01	3.68	1140	<0.01
	25th percentile	.02	0.80		.07	0.89		2.94	209	
	75th percentile	.04	8.55		.22	6.01		5.24	1740	
Entire South Fork CdA Basin	Median	.06	3.75	<0.001	.18	7.17	<0.001	6.75	769	<0.001
	25th percentile	.04	0.88		.08	2.00		4.60	126	
	75th percentile	.10	11.0		.52	17.6		10.7	1750	

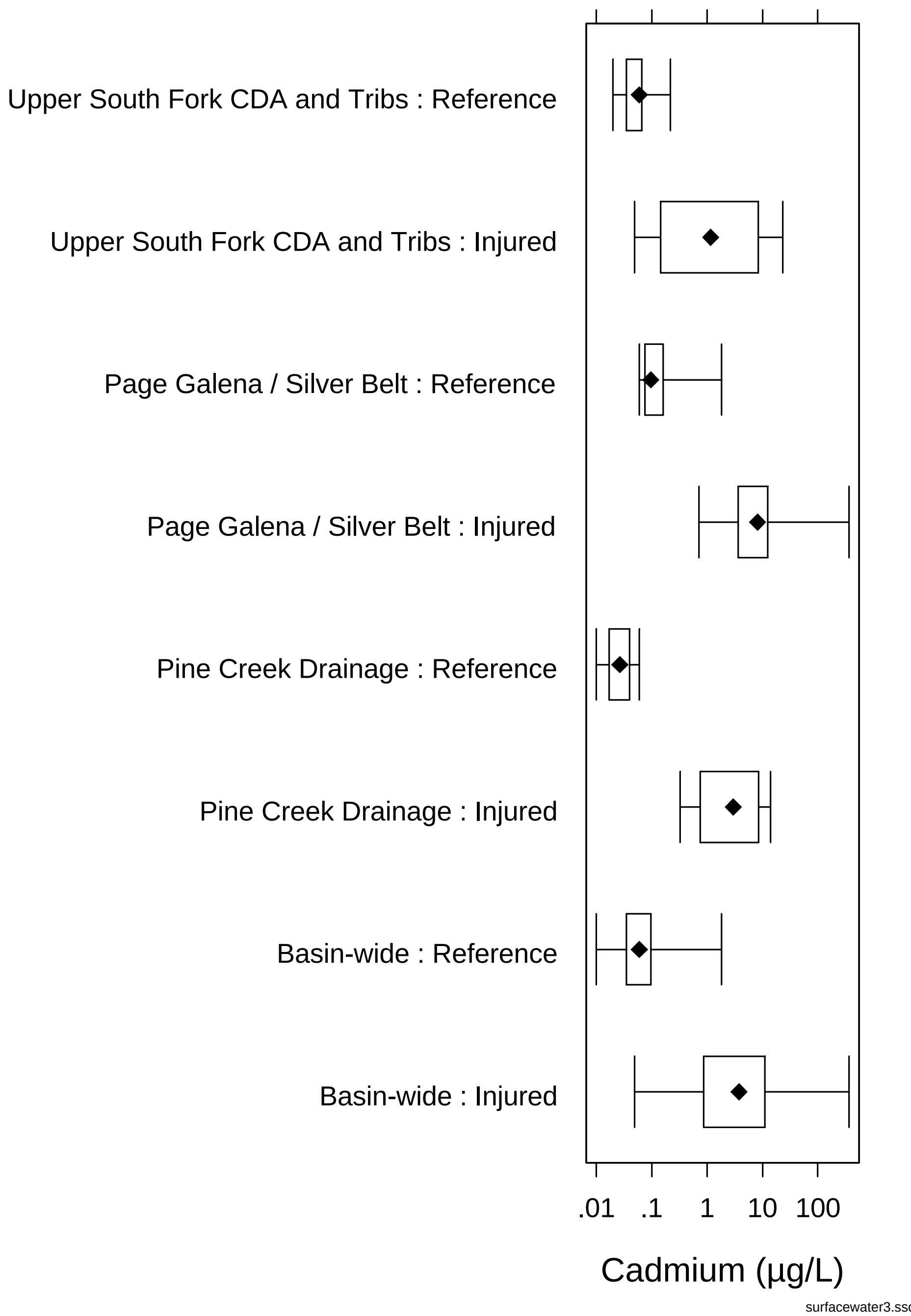

Figure 10-13a. Statistical results for dissolved cadmium for baseline and injured areas in the South Fork Coeur d'Alene River basin. The ends of the whiskers indicate the range, the ends of the boxes indicate the 25th and 75th percentiles, and the diamonds indicate median values.

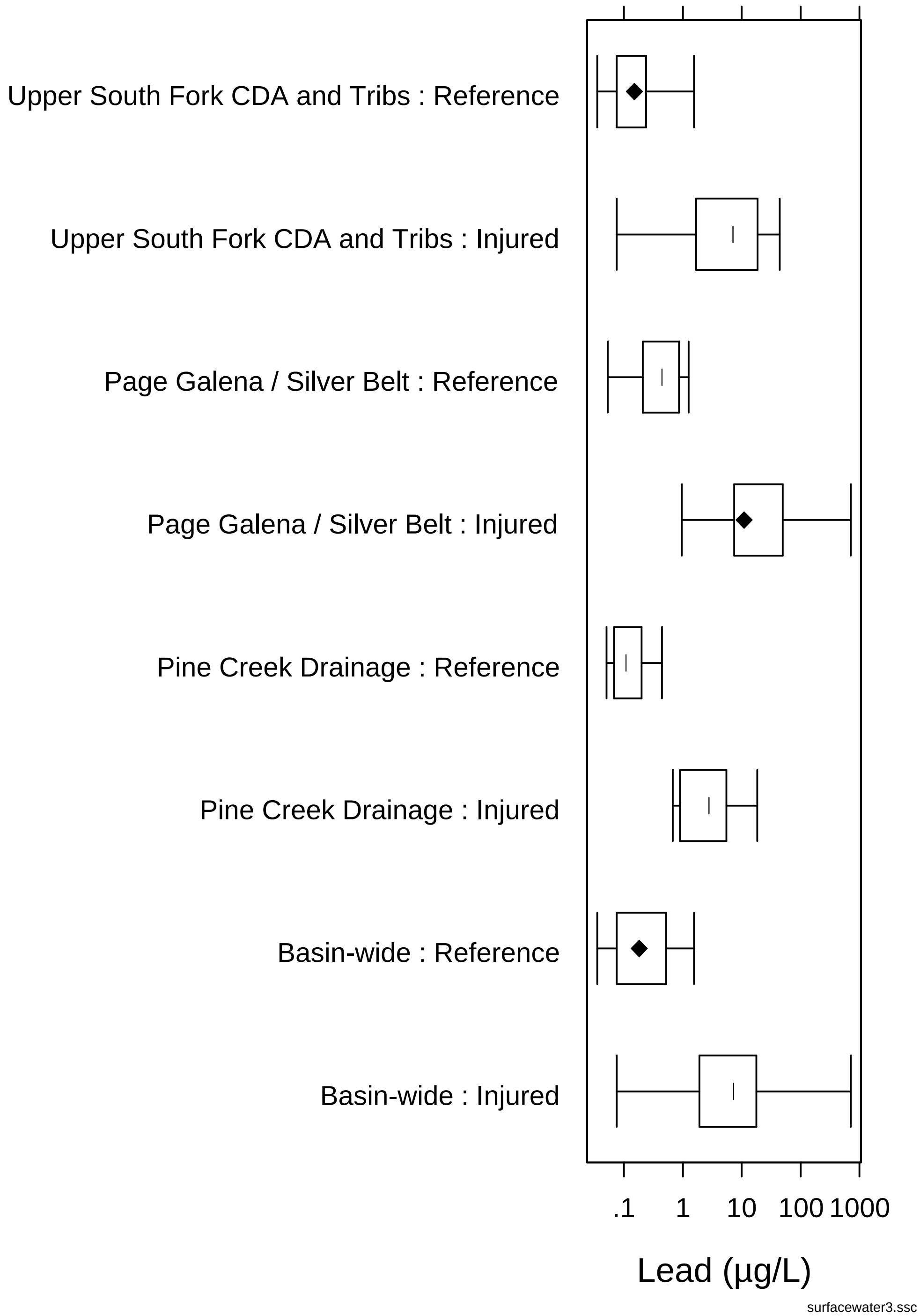

Figure 10-13b. Statistical results for dissolved lead for baseline and injured areas in the South Fork Coeur d'Alene River basin. The ends of the whiskers indicate the range, the ends of the boxes indicate the 25th and 75th percentiles, and the diamonds indicate median values.

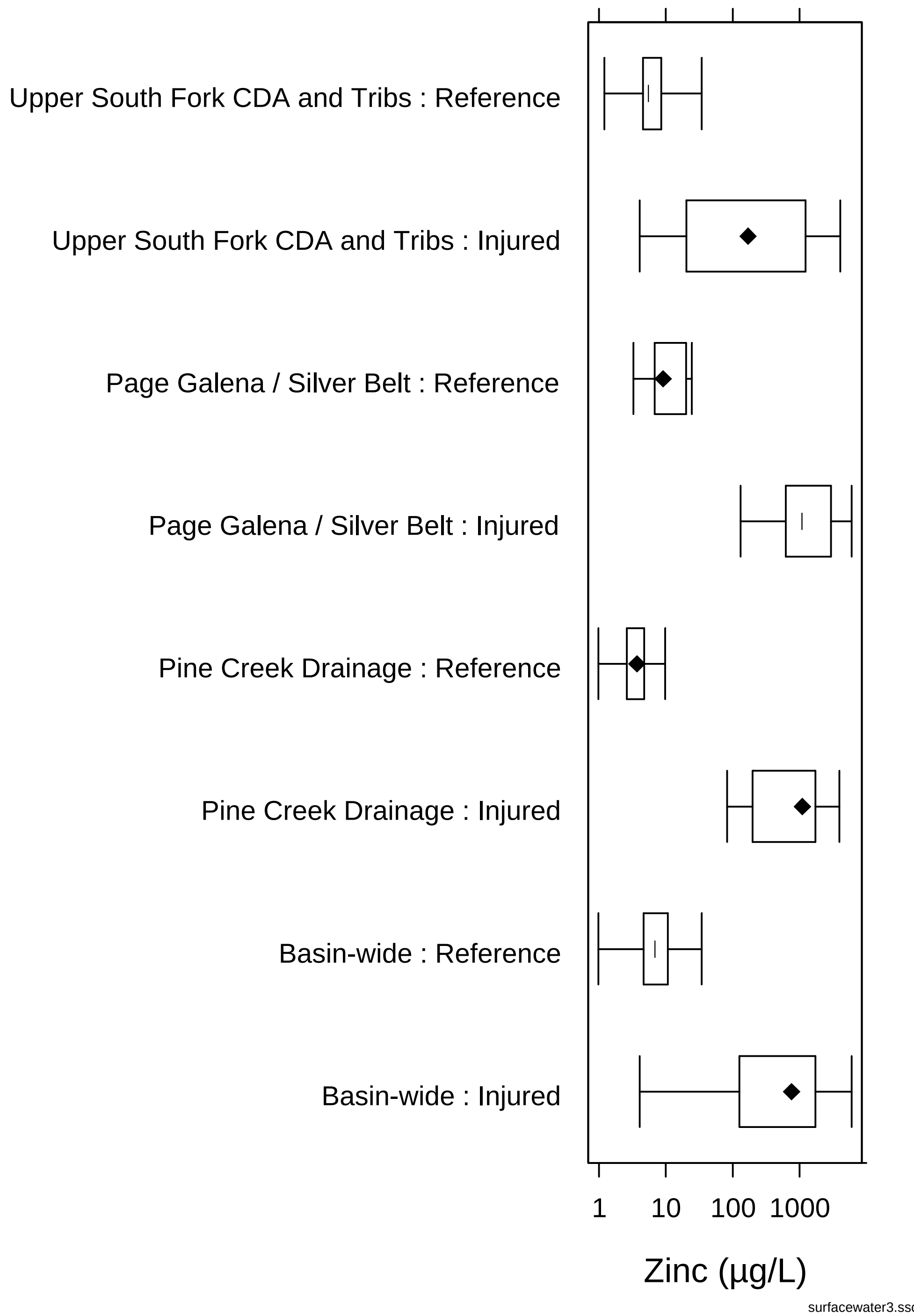

Figure 10-13c. Statistical results for dissolved zinc for baseline and injured areas in the South Fork Coeur d'Alene River basin. The ends of the whiskers indicate the range, the ends of the boxes indicate the 25th and 75th percentiles, and the diamonds indicate median values.

Median injured concentrations for the Page-Galena mineral belt area were 8.12, 10.9, and 1,080 µg/L for cadmium, lead, and zinc, respectively. This area had the highest median injured concentrations for both cadmium and lead. The Page-Galena area also had the highest baseline values for all three metals. The Page-Galena median injured concentrations greatly exceed chronic ALC values at any hardness value. In addition, both the cadmium and zinc median injured concentrations exceed the acute ALC values, even at high hardness values.

Median injured concentrations for dissolved cadmium, lead, and zinc for the Pine Creek area were 3.09, 2.77, and 1140 µg/L, respectively. The median injured lead concentration for the Pine Creek drainage was the lowest of the three areas, while the median injured zinc concentration was the highest of the three areas. These concentrations exceed chronic ALC values, even at hardnesses of 100 mg/L as $CaCO_3$ and higher. In addition, both the cadmium and zinc median injured concentrations exceed acute ALC values at all measured hardness values in the Pine Creek basin.

For the South Fork Coeur d'Alene River basin as a whole, median injured values for dissolved cadmium, lead, and zinc were 3.75, 7.17, and 769 µg/L, respectively. All of these concentrations exceed chronic ALC values, even at hardnesses of 100 mg/l as $CaCO_3$ and higher. In addition, both cadmium and zinc median injured concentrations exceed acute ALC values at measured hardness values in the South Fork Coeur d'Alene River basin.

10.4.7 Surface Water Baseline Conditions Summary and Conclusions

Characterization of surface water baseline conditions included consideration of the natural mineralization of many of the drainages in the Coeur d'Alene River basin and the similarity of reference and injured streams in terms of hydrologic, geologic, and mineralogic considerations. The basin was divided into three areas for surface water baseline, based on similarities in types of ore deposits: 1) the upper South Fork Coeur d'Alene River, including Canyon and Ninemile creeks; 2) streams draining the Page-Galena mineral belt area; and 3) the Pine Creek drainage.

Each tributary drainage basin was considered in terms of its geology, mineralization, and environment, including water quality data and mine waste deposits. Drainages were excluded from consideration as reference areas if they contained mill sites or large producing mines. In some cases, water quality from drainages with mill sites or large mines still met aquatic life criteria, indicating that baseline water quality in many of the areas would have been even more pristine before mining.

Table 10-11 presents the baseline concentrations for each area and for the South Fork Coeur d'Alene River basin as a whole. Baseline water quality concentrations for cadmium, lead, and zinc are well below both acute and chronic ALC values for all three areas and for the South Fork Coeur d'Alene River basin as a whole evan at the lowest possible hardness value. Therefore, baseline concentrations of cadmium, lead, and zinc are low and do not exceed ALC values. This indicates that concentrations of these toxic metals in Coeur d'Alene River basin surface water were low before mining activity began in the basin.

Baseline concentration distributions in the three areas in the South Fork Coeur d'Alene River basin were compared to injured concentration distributions to determine if the distributions were significantly different from one another. For every metal in each of the three areas, and in the South Fork Coeur d'Alene River basin as a whole, dissolved cadmium, lead, and zinc concentrations were all statistically significantly higher in injured areas than in baseline areas.

10.5 RIPARIAN VEGETATION BASELINE

Baseline conditions for riparian vegetation are described in terms of vegetation community attributes measured in reference areas. Riparian vegetation baseline was determined for the upper basin floodplains only. Data presented in Chapter 9 confirm gross modifications of riparian vegetation in the upper basin as a result of toxic metals concentrations in soils.

10.5.1 Historical Data

Historical data describing riparian vegetation before mining began are scarce. Riparian areas are natural travel corridors through the mountains and so were typically settled first and subjected to numerous land uses. Timber adjacent to streams was the first to be harvested, and water corridors were used to transport logs from the forest to the sawmills (Idaho Panhandle National Forests, 1998). Between 1880 and 1965, more than 400 sawmills operated in the Coeur d'Alene River basin (Idaho Panhandle National Forests, 1998). Splash dams and log chutes were constructed in the Little North Fork Coeur d'Alene River and other tributaries of the North Fork Coeur d'Alene River. Logging activity in the basin peaked in 1929, and the last log drive was made in 1943 (Idaho Panhandle National Forests, 1998).

Historical riparian vegetation included large western red cedar, white pine, larch, and cottonwood (Idaho Panhandle National Forests, 1998). Mature riparian forest has been greatly reduced or eliminated along much of the riparian zones of the basin as a result of logging, road construction, agriculture, urban development, and mining (Idaho Panhandle National Forests, 1998). Because there has been substantial anthropogenic modification of riparian vegetation since mining began in the basin, the condition of riparian vegetation before releases to the basin began is inappropriate for determining baseline conditions today. Because historical data are unavailable or not appropriate, baseline was defined using field data from reference areas [43 CFR 11.72(d)].

10.5.2 Reference Areas

Since the assessment area vegetation has been substantially modified, reference areas were selected based on similarity of major nonmining environmental factors that affect plant growth and vegetation community development in the reference areas and that would be expected to control plant growth and vegetation community development in the assessment area. Where possible, reference areas were located upgradient of the assessment area. Where upstream areas were not appropriate, a reference area was identified based on proximity to the assessment area, comparable elevation, and comparable valley orientation. Reference areas for baseline determination in the upper basin were the same reference areas described in Chapter 9 (Section 9.4.1) for riparian resources injury determination.

The reference areas were sampled using standard vegetation sampling techniques [43 CFR 11.71 (l)(4, 6)] to measure baseline habitat quality [43 CFR 11.72 (k)(ii)(A)]. Sampling methods are described in Chapter 9. Field vegetation data characterizing the habitat quality were collected from each of 3 sample sites on upstream Canyon Creek, 3 sample sites on Ninemile Creek upstream of the East Fork Ninemile Creek confluence, and 17 sites on the Little North Fork. The same methods were used in both assessment and reference areas [43 CFR11.72 (d)(5)].

10.5.3 Data Analysis

To determine baseline conditions, vegetation conditions at reference areas (described in Chapter 9) were quantified at the habitat (community) level [43 CFR 11.71 (l); 11.72 (k)(3)(ii)(A)]. Data from the three reference areas were pooled and are described by the following parameters:

- percentage of bare ground
- percentage of cover of vegetation in the herbaceous, shrub, and tree layers
- number of species in the herbaceous, shrub, and tree layers
- number of structural habitat layers.

Table 10-13 presents median, 95 percent confidence interval on the mean, and 25th and 75th percentiles for the above vegetation layers. Table 10-14 presents a comparison of baseline vegetation conditions relative to upper basin assessment area locations (South Fork Coeur d’Alene River, Canyon Creek, and Ninemile Creek). Table 10-14 demonstrates the following differences from baseline conditions at assessment area sites:

- tenfold more bare ground (mean of 58% versus 6%)

- sixfold fewer plant species (mean of 3 versus 18), including fewer shrub species (0.5 versus 4.6), and fewer herbaceous species (1.8 versus 11.6)

- sevenfold less vegetative cover (mean of 19% versus 141%), including reduction in shrub cover (5% versus 61%), and reduction in herbaceous cover (14% versus 50%)

- fewer habitat layers (mean of 1.4 versus 3.8).

These data confirm the substantial reductions in vegetation/habitat services in the upper assessment area relative to baseline conditions.

Table 10-13
Baseline Vegetation Conditions[a]

Measure	N	Mean	Lower 95% CI on Mean	Upper 95% CI on Mean	25th Percentile	Median	75th Percentile
Bare ground (%)	23	5.6	3.1	8.2	0.8	3.0	10.0
Number of herb species (n)[b]	23	11.6	10.0	13.2	8.5	11.0	13.5
Herb cover (%)	23	50.1	40.1	60.2	36.5	48.8	62.6
Number of shrub species (n)	23	4.6	3.6	5.6	3.5	4.0	5.0
Shrub cover (%)	23	61.1	41.9	80.2	34.3	55.5	83.0
Number of tree species (n)	23	0.7	0.3	1.1	0.0	0.0	1.0
Tree cover (%)	23	29.8	11.5	48.1	0.0	0.0	65.0
Total cover (%)[c]	23	141.0	116.8	165.3	94.4	139.4	197.8
Number of species (n)	23	17.7	15.7	19.7	15.0	17.0	21.0
Number of habitat layers	23	3.8	3.3	4.3	3.0	4.0	5.0

a. Source data: See Chapter 9.
b. Excludes moss species.
c. Note: Cover can exceed 100% because of the presence of multiple structural layers.

10.5.4 Comparison to Assessment and Literature Values

Reference area conditions are comparable to published riparian vegetation community descriptions and represent a normal range of conditions [43 CFR 11.72(d)(6)]. For example, in Spion Kop Research Natural Area (RNA) at the confluence of Teepe Creek and the North Fork Coeur d'Alene River, floodplain vegetation consists of an extensive stand of black cottonwood of varying age classes, interspersed with wetland communities occupying old river channels and grass/forb communities occupying dry river terraces (Moseley and Bursik, 1994). The Spion Kop RNA communities are highly structurally diverse, but also show evidence of natural scouring and barren areas caused by fluvial dynamics of erosion, sediment deposition, channel migration, and episodic high flows (Moseley and Bursik, 1994). In approximately 4 km of river floodplain, 145 plant species were identified (Moseley and Bursik, 1994). The high structural and compositional diversity of this upstream RNA is similar to the reference area diversity.

Table 10-14
Comparison of Baseline (reference) Vegetation Conditions Relative to Conditions in the Upper Basin Assessment Area[a]

Measure	Area	n	Mean	Lower 95% CI on Mean	Upper 95% CI on Mean	Standard Error on Mean	Minimum	25th Percentile	Median	75th Percentile	Maximum
Bare ground (%)	assessment	40	58.0	47.0	68.9	5.4	0.0	24.8	63.9	93.2	100.0
	reference	23	5.6	3.1	8.2	1.2	0.0	0.8	3.0	10.0	16.9
Number of herb species (n)[b]	assessment	40	1.8	1.2	2.3	0.3	0	0.0	1.0	2.3	8
	reference	23	11.6	10.0	13.2	0.8	6	8.5	11.0	13.5	18
Herb cover (%)	assessment	40	13.6	7.7	19.6	2.9	0.0	0.0	7.8	20.2	83.0
	reference	23	50.1	40.1	60.2	4.9	9.2	36.5	48.8	62.6	113.1
Number of shrub species (n)	assessment	40	0.5	0.0	0.9	0.2	0	0.0	0.0	0.0	6
	reference	23	4.6	3.6	5.6	0.5	1	3.5	4.0	5.0	9
Shrub cover (%)	assessment	40	5.4	-0.2	11.1	2.8	0.0	0.0	0.0	0.0	77.8
	reference	23	61.1	41.9	80.2	9.3	0.5	34.3	55.5	83.0	190.0
Number of tree species (n)	assessment	40	0.0	0.0	0.1	0.0	0	0.0	0.0	0.0	1
	reference	23	0.7	0.3	1.1	0.2	0	0.0	0.0	1.0	3
Tree cover (%)	assessment	40	0.3	-0.3	0.9	0.3	0.0	0.0	0.0	0.0	12.0
	reference	23	29.8	11.5	48.1	8.9	0.0	0.0	0.0	65.0	117.1
Total cover (%)[c]	assessment	40	19.3	10.5	28.2	4.4	0.0	0.0	10.6	22.6	111.5
	reference	23	141.0	116.8	165.3	11.7	40.7	94.4	139.4	197.8	228.4
Number of species (n)	assessment	40	3.0	2.1	4.0	0.5	0	1.0	2.0	4.0	14
	reference	23	17.7	15.7	19.7	1.0	8	15.0	17.0	21.0	28
Number of habitat layers	assessment	40	1.4	1.1	1.7	0.2	0	1.0	1.0	2.0	4
	reference	23	3.8	3.3	4.3	0.2	1	3.0	4.0	5.0	5

a. Source data: See Chapter 9.
b. Excludes moss species.
c. Cover can exceed 100% because of the presence of multiple structural layers.

To the north of the Coeur d'Alene River basin, the Clark Fork River flows from Montana into Lake Pend Oreille. Habitat surveys were conducted along the river between Thomspon Falls, Montana, and the mouth of the river at Lake Pend Oreille in 1993 and 1994 for Washington Water Power (Northrop, Devine & Tarbell, 1994; Washington Water Power, 1995). The land is predominantly privately owned, and a road and railroad parallel the river throughout the length surveyed. Dominant riparian species include black cottonwood and quaking aspen in the tree canopy, and thinleaf alder, common snowberry, western serviceberry (*Amelanchier alnifolia*), black hawthorn (*Crataegus douglasii*), red-osier dogwood (*Cornus stolonifera*), and willow species (*Salix* spp.) in the shrub midstory (Northrop, Devine & Tarbell, 1994). Average vegetation cover in the 2-5 m height class was 42.3% in 1992 and 31.6% in 1993, and average cover in the 0.5-2 m height class was 34.8% in 1992 and 38.4% in 1993 (Table 10-15). These two height classes are approximately the same as the shrub layer (0.5 to 6 m) defined in this injury assessment (Section 9.4.1). Vegetation cover in the herbaceous layer averaged 85.6% in 1992 and 73.1% in 1993, and in the tree canopy, 7.7% in 1992 and 9.2% in 1993.

Table 10-15
Mean Percent Vegetation Cover by Structural Category in Riparian Habitat of the Lower Clark Fork River, Montana/Idaho

Cover Class	% Cover, 1992 (n = 15)	% Cover, 1993 (n = 32)
Tree canopy cover	7.7	9.2
Tall shrub cover (2-5 m)	42.3	31.6
Low shrub cover (0.5-2 m)	34.8	38.4
Herbaceous cover	85.6	73.1

Sources: Northrop, Devine & Tarbell, 1994; Washington Water Power, 1995.

Riparian zones of Rock Creek, the Bighole River, the Ruby River, and Bison Creek, all in southwest Montana, were surveyed by Boggs (1991). Each of these locations is subjected to agricultural uses and grazing, and each is bordered by a highway or interstate. The Big Hole River is also bordered by a railroad. Riparian zones along these streams supported an average of 60% herbaceous cover, 44% shrub cover, and 18% tree cover (Boggs, 1991). Cover of all vegetation types averages 122% (because of multiple structural layers), and bare ground is insignificant.

The DOI NRDA regulations do not suggest a statistic for characterization of baseline conditions based on the range of variability determined. The intent of the baseline determination is to describe conditions that reflect natural and anthropogenic influences but not influences from releases of hazardous substances from mining operations. The reference area data were collected from reaches that have been exposed to a lesser degree to urbanization, in addition to less exposure to disturbance from mining operations. However, the Little North Fork Coeur d'Alene River is exposed to greater recreational pressure and greater historical disturbance related to logging (Idaho Panhandle National Forests, 1998). Both Canyon and Ninemile creeks are bordered by roads, and the upper Canyon Creek reference area had been occupied historically by some type of urban construction. In addition, the Canyon Creek sites showed clear evidence of mine waste contamination and an exposure-response effect on vegetation. Regardless, Canyon Creek vegetation data were retained in the baseline data since they represent a conservative estimate of riparian vegetation quality. Vegetation communities from the reference areas are not pristine, but do represent conditions of lesser urban encroachment. However, the sampling protocol excluded urban areas, so the comparisons were in areas that should be quite similar, absent releases of hazardous substances.

The reference area data also most likely represent a range of site types reflecting elevational gradients, hydrologic gradients, valley shape, width, and orientation, and successional stages of patches of vegetation within the areas sampled. Over elevational and longitudinal hydrologic gradients, a natural change in species composition is expected, and gradients in species composition and structure with lateral distance from the stream are expected (Hansen et al., 1990; Naiman and Décamps, 1997). However, since the reference area data were collected using a randomized, unbiased sampling design in which all areas within the floodplain on publicly owned land had the same probability of being sampled, the data reflect an unbiased sample of existing vegetation across existing gradients.

Given that the baseline data represent a range of anthropogenic disturbance and a range of natural variability, a range of values from the 25th to 75th percentile was selected as an appropriate descriptor of baseline conditions (Table 10-13).

10.6 EXTENT OF INJURY

The Trustees quantified injury and the associated service reductions as the total area where surface water and soils/sediment resources exceed baseline and have reduced ability to sustain aquatic biota, vegetation, and habitat for wildlife relative to baseline [43 CFR 11.71 (h)(4)(i) and (k)(1-2)]. This approach recognizes the multiple primary and secondary service losses.

10.6.1 Surface Water

The area where surface water exceeds baseline includes areas downstream of sampling stations at which dissolved concentrations of cadmium, lead, or zinc exceed water quality criteria for the protection of aquatic biota. Injured surface waters include:

- South Fork and mainstem Coeur d’Alene rivers from downstream of Daisy Gulch to the mouth at Coeur d’Alene Lake
- Coeur d’Alene Lake

- Grouse Gulch from the Star Mine waste rock dumps to the mouth
- Canyon Creek from approximately Burke to the mouth
- Gorge Gulch downstream of the Hercules No. 3 adit
- East Fork and mainstem Ninemile Creek from the Interstate-Callahan Mine to the mouth
- Moon Creek from the Charles Dickens Mine/Mill to the mouth
- Milo Gulch from the Sullivan Adits to the mouth
- Portal Gulch from the North Bunker Hill West Mine to the mouth
- Government Gulch from the Senator Stewart Mine to the mouth
- Deadwood/Bunker Creek from the Ontario Mill to the mouth
- East Fork and mainstem Pine Creek from the Constitution Upper Mill to the mouth
- Highland Creek from the Highland Surprise Mine/Mill and the Sidney (Red Cloud) Mine/Mill to the mouth
- lower Denver Creek
- lower Nabob Creek.

Table 10-16 presents river kilometers (miles) of injured surface waters in rivers and streams. In addition, surface waters of the lateral lakes and wetlands are injured and the surface water of Coeur d'Alene Lake is injured.

10.6.2 Floodplain Soils and Sediments — Upper Basin

The extent of injury to floodplain soils and sediments in the upper basin was quantified as the area in floodplain in which hazardous substance concentrations exceed baseline and have reduced ability to sustain vegetation and habitat for wildlife relative to baseline conditions [43 CFR 11.71 (h)(4)(i) and (k)(1,2)]. The quantification method was selected based on known sources and pathways of hazardous substances, sampling of floodplain soil and vegetation conducted for the riparian resources injury assessment and as part of previous and subsequent studies, and relationships between hazardous substance concentrations and vegetation cover.

Table 10-16
Quantification of Injured Surface Water in Rivers and Streams

Injured Surface Water	km	Miles
South Fork and mainstem Coeur d'Alene rivers	107	67
Grouse Gulch	4.0	2.3
Canyon Creek	11.3	7.0
Gorge Gulch	2.5	1.6
Ninemile Creek	11.6	7.2
Moon Creek	5.0	3.1
Milo Gulch	2.7	1.7
Portal Gulch	0.9	0.5
Government Gulch	4.1	2.5
Deadwood/Bunker Creek	4.7	2.9
East Fork and mainstem Pine Creek	16.8	10.4
Highland Creek	5.2	3.2
Denver Creek	5.3	3.3
Nabob Creek	0.5	0.3
Total	**181**	**113**

Data presented in Chapters 2 and 3 confirm that geological and surface water resources downgradient of mining related sources contain elevated concentrations of hazardous substances, and that these resources serve as transport and exposure pathways of hazardous substances. The riparian resources injury determination studies show statistically significant differences between concentrations of hazardous substances in assessment and reference area floodplain soils, and between riparian vegetation cover in assessment and reference areas (Chapter 9). Vegetation cover and vegetation structural complexity are significantly negatively correlated with concentrations of hazardous substances, and the quality and quantity of riparian wildlife habitat are defined largely by vegetation cover and structural characteristics. Based on the known patterns of hazardous substance release, transport, resource contamination, and hazardous substance toxicity and toxic effects at the vegetation community level, vegetation cover mapping was used as a conservative indicator of soils with reduced ability to sustain vegetation and habitat for biota relative to baseline.

In an effort independent from the injury assessment, U.S. BLM mapped existing vegetation cover in the Coeur d'Alene River basin using 7.5 minute orthophoto quadrangle maps for the Coeur d'Alene River basin produced by the USGS. Forestry mapping techniques were used to delineate vegetation cover classes by the extent of tree canopy cover (U.S. BLM, 1999). Polygons of cover classes delineated from orthophoto quadrangles were field verified. Cover class categories included:

Category 1. Barren areas, where little to no ground cover exists and where soil conditions prevent the survival of few native species.

Category 2. Areas containing tree canopy cover less than 10% and trees of diameter less than 4.9 inches.

Category 3. Areas of tree canopy cover from 10 to 50%.

Category 4. Areas of tree canopy cover greater than 51%.

For injury quantification, the vegetation cover class map was overlaid on a map of the floodplain and a map of urban areas. Urban areas included roads, railroads, structures, and developed lands surrounding roads, railroads, and structures. Urban areas were delineated using digital orthophoto quadrangles and quarter quadrangles of the South Fork Coeur d'Alene River basin (U.S. BLM, undated; USGS, 1992). The areal extent of nonurban areas within the floodplain where the vegetation cover was classified as barren or supporting less than 10% tree canopy cover was quantified.

Figure 10-14 presents the devegetated or sparsely vegetated nonurban portions of the floodplain of the South Fork Coeur d'Alene River basin. Tailings ponds in the floodplain that are currently maintained (the Lucky Friday tailings ponds on the South Fork Coeur d'Alene River, the Sunshine Tailings on Big Creek, the Star ponds on Canyon Creek, and the CIA) were delineated separately. The area of maintained tailings ponds was not included in the estimate of injured acreage. The total areas of injured riparian resources in the upper basin are presented in Table 10-17.

Of the 40 upper basin assessment sites sampled as part of the riparian resource injury determination, 75% fell within nonurban floodplain, barren area polygons (Category 1). The remaining 25% fell within polygons in the nonurban floodplain that were identified as containing less than 10% tree canopy cover and trees of diameter less than 4.9 inches (Category 2).

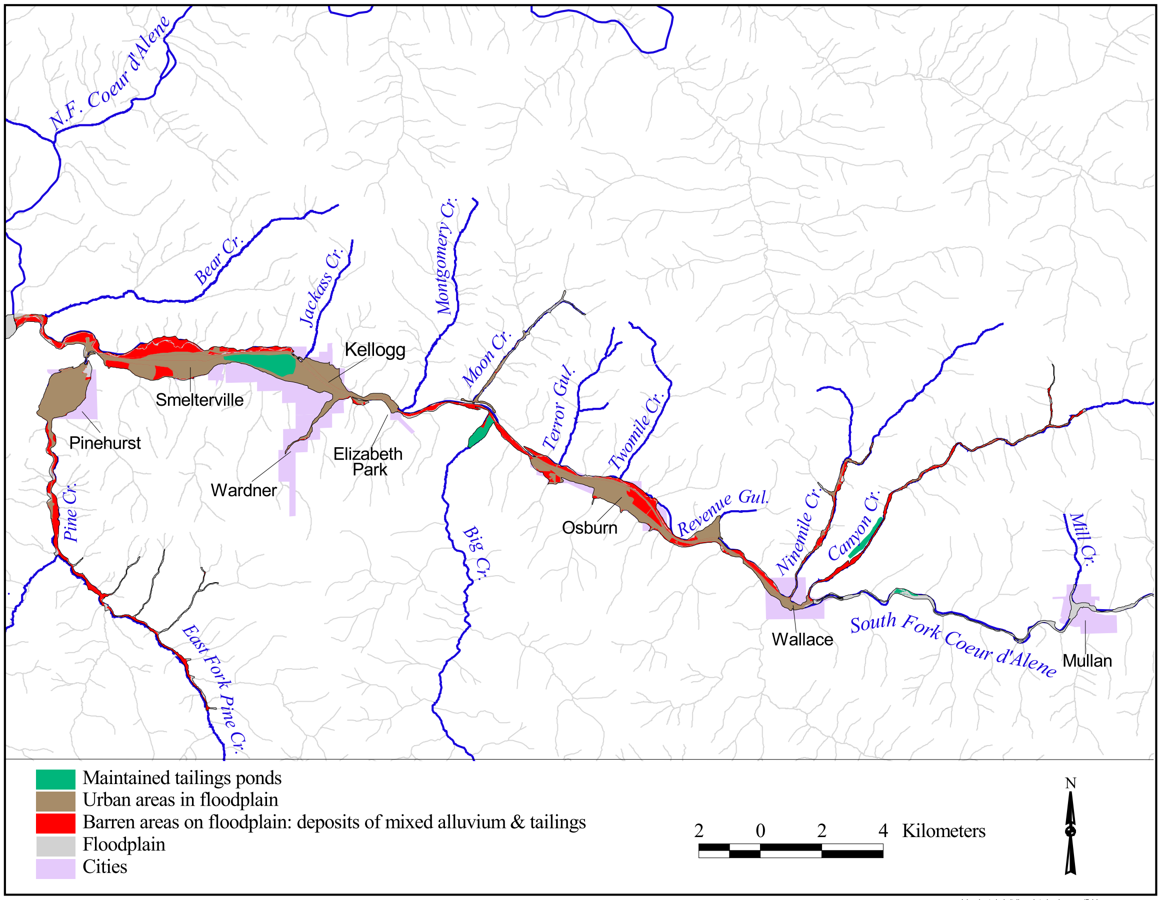

Figure 10-14. Devegetated or sparsely vegetated nonurban portions of the South Fork Coeur d'Alene River basin.

Table 10-17
South Fork Coeur d'Alene River, Canyon, Ninemile, Moon, and Pine Creeks: Areal Extent of Floodplain Soils with Reduced Ability to Sustain Vegetation and Habitat for Biota Relative to Baseline

	Acres (ha)
A. Total floodplain area assessed	4,949 (2,003)
B. Nonurban areas in floodplain assessment area	1,850 (749)
C. Barren or sparsely vegetated nonurban floodplain	1,522 (616)
D. Maintained tailings ponds	390 (158)
Proportion of the available resource that is injured (C/B)	>80%

Based on data collected for the riparian resources injury determination, the mean cover of bare ground at sites categorized as barren (Category 3) was 51%. The remainder of the vegetation cover at sites classified as barren was predominantly sparse grasses and moss. The mean cover of bare ground at the sites classified as containing less than 10% tree canopy cover and trees of diameter less than 4.9 inches (Category 4) was 66%. These sites actually had more bare ground on average compared to the sites classified as barren, but some also contained sparse cover of vegetation in the shrub layer, including the noxious weed spotted knapweed at two sites, tansy at two sites, and willow at two sites.

The total area of barren or substantially devegetated floodplains along the South Fork Coeur d'Alene River downstream of the Canyon Creek confluence, Canyon Creek, Ninemile Creek, Moon Creek, and Pine Creek is 1,522 acres (616 ha). This barren or sparsely devegetated area comprises greater than 80% of the available nonurban floodplain. In addition to this injured acreage, even segments of river bank that were excluded as urban should be capable of supporting vegetative overhang on the river banks.

Floodplains of the upper basin underlying urban development, which were not included in the riparian resources injury claim, also contain contaminated soils and sediments that may serve as a pathway of injury to surface water, via leaching by groundwater.

10.6.3 Floodplain Soils and Sediments — Lower Basin

The extent of injury to soils and sediments of the lower basin was quantified as the area in floodplain in which hazardous substance concentrations exceed baseline concentrations and have reduced ability to provide suitable (nontoxic) habitat for wildlife relative to baseline [43 CFR 11.71 (h)(4)(i) and (k)(1-2)]. Information presented in Chapter 6 confirms that sediments of the lower basin contain elevated concentrations of lead and other hazardous substances, that wildlife ingest contaminated sediments, and that the lead in the sediments is bioavailable and toxic to wildlife. Ingestion of lead-contaminated sediments causes injury to wildlife.

To characterize the spatial distribution of contaminated sediments in the lower basin, kriging models using 840 samples were constructed (Kern, 1999). Data used in the kriging analyses included surficial sediment samples collected by Bender (1991), Rabbi (1994), Hagler Bailly (1995), Hoffman (1995), Horowitz (1995), Union Pacific Railroad (1997), Campbell et al. (1999), and USGS (unpublished data). A set of covariate parameters that take into account the discrete nature of certain geologic, hydrologic, anthropogenic, and habitat features were identified and multiple regression analyses were used to test for association between these variables and sediment lead concentrations. Significantly correlated variables were used in the kriging analyses so that the resulting maps of lead concentration in sediments account for physical features of the landscape that affect the distribution of contamination (Figures 10-15 a and b). Variables retained in the final model included wetland unit (Campbell et al., 1999), an index of hydrological function and ecological habitat classification based on Bookstrom et al. (1999), and proximity to the Union Pacific Railroad.

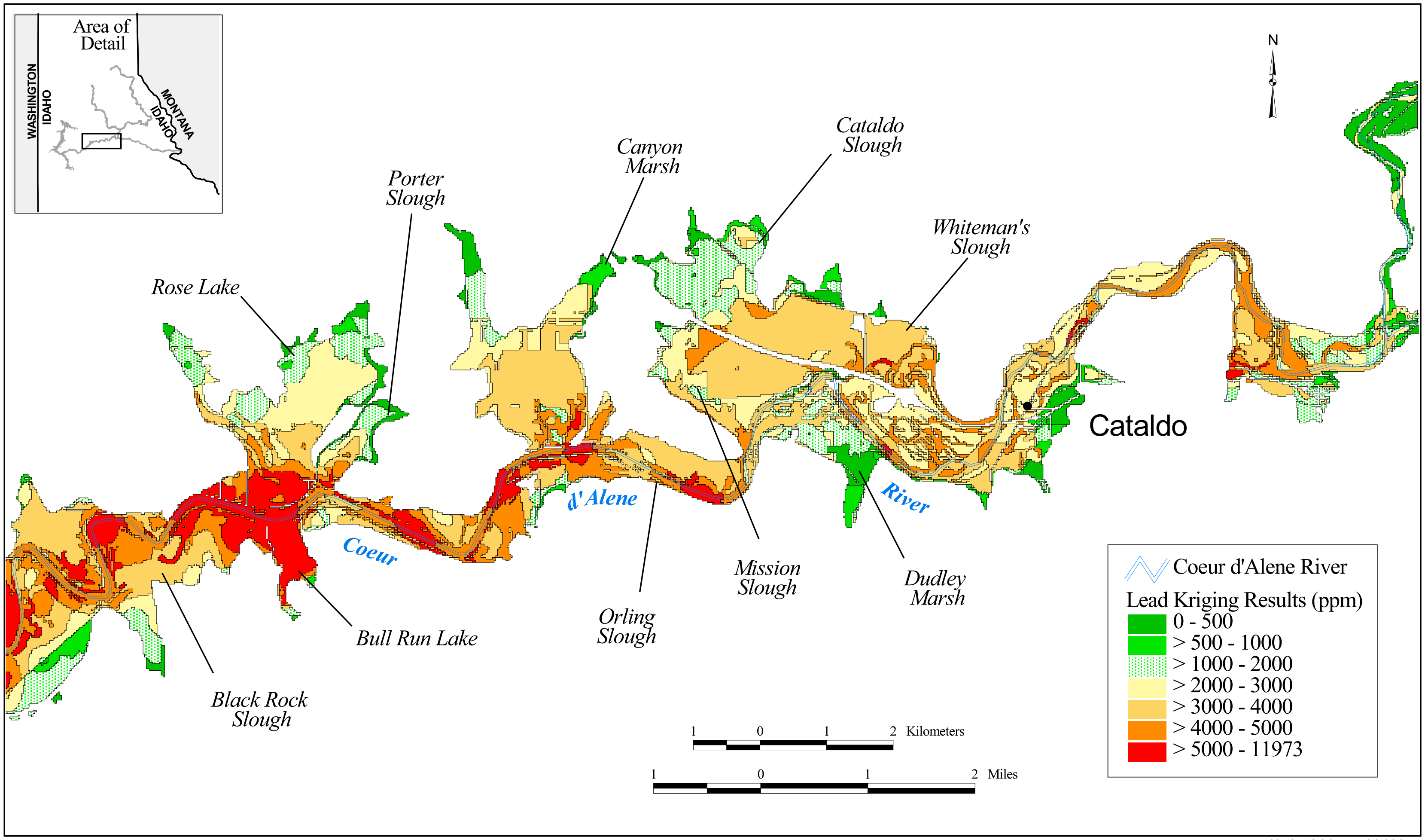

Figure 10-15a. Distribution of lead concentrations in surface sediments of the lower Coeur d'Alene River basin — eastern half.
Data source: Kern, 1999.

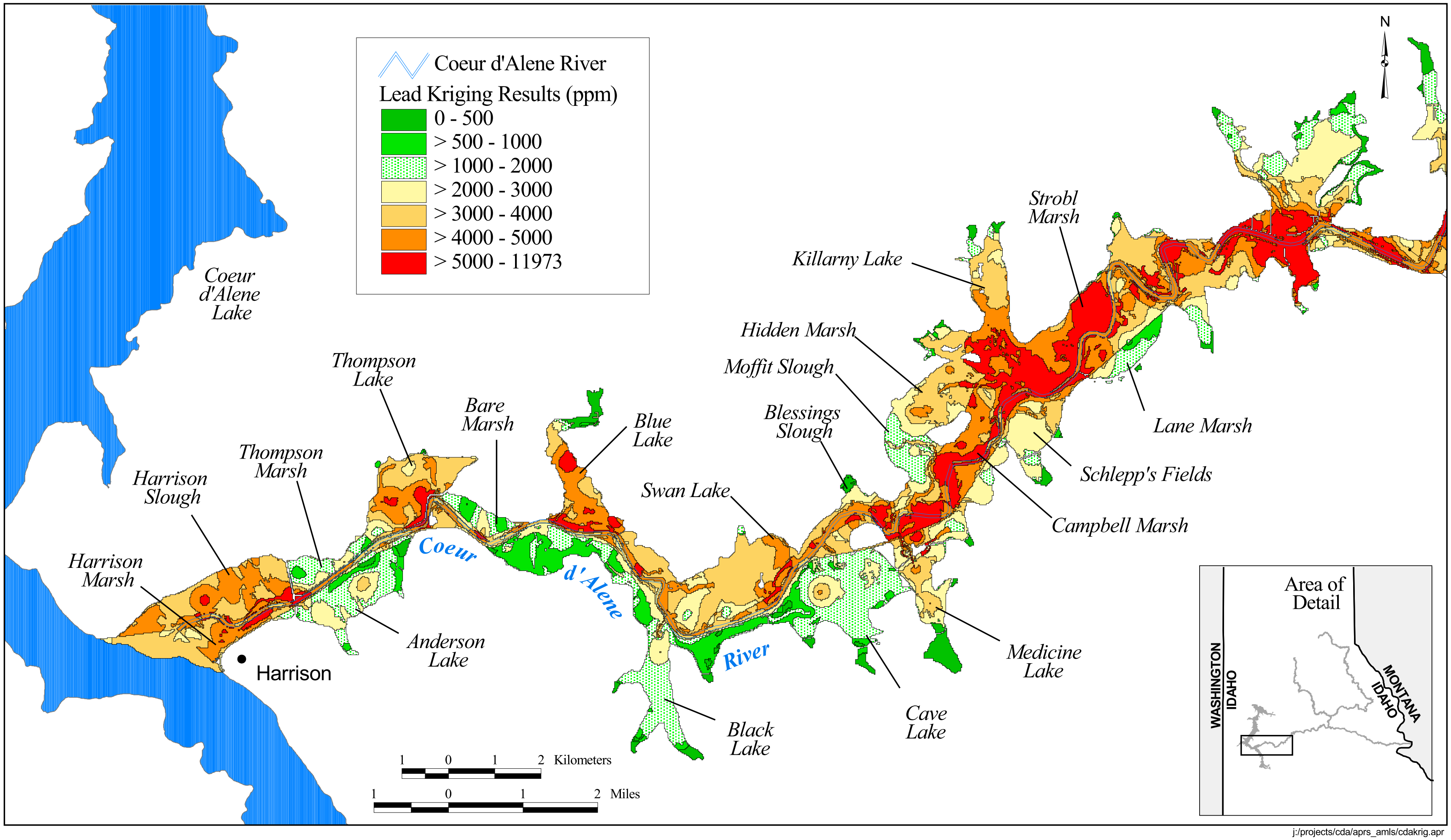

Figure 10-15b. Distribution of lead concentrations in surface sediments of the lower Coeur d'Alene River basin — western half.
Data source: Kern, 1999.

Modeled predictions of lead concentration in surficial sediments were used to estimate the area of contaminated sediments that exceeded four threshold concentrations. The first threshold, 30 ppm lead, is the geometric mean baseline concentration. The second threshold, 175 ppm lead, is the upper 95th percentile of baseline concentrations (Table 10-8). The third, 530 ppm lead, is a lowest observed effect level for waterfowl (Beyer and Audet, 1999). The fourth, 1,800 ppm lead, is a lethal effect level for waterfowl (Beyer and Audet, 1999). Area was calculated as the number of 25 meter pixels in the floodplain with predicted lead concentrations exceeding a given threshold. Results are expressed in acres (0.1544 acres per pixel). Estimates of acreages and percentages of the lower Coeur d'Alene River basin floodplain that exceed the four threshold values are presented in Table 10-18. The distributions of sediments exceeding the 175 ppm, 530 ppm, and 1,800 ppm thresholds are shown in Figures 10-16, 10-17, and 10-18.

Table 10-18
Estimated Area of Sediments Containing Greater than 175 ppm Lead in the Lower Coeur d'Alene River Floodplain

Lead Threshold (ppm)		Acres Exceeding Threshold	Acres Less than Threshold	Floodplain that Exceeds Threshold (%)
Lethal threshold:	1,800	15,368	3,838	80
Lowest observed effect level:	530	18,298	908	95
90th percentile of baseline:	175	18,558	648	97
Geometric mean baseline:	30	18,608	598	97

Sources: Kern, 1999; pers. comm. B. Jackson, Coeur d'Alene Tribe, August 22, 2000.

10.7 RESOURCE RECOVERABILITY

In the Coeur d'Alene River basin, injuries to fish and other aquatic biota, wildlife, and riparian vegetation are caused by exposure to hazardous substances in injured surface water, soils, and sediments. The injured surface water, soils, and sediments of the Coeur d'Alene River basin that should provide habitat for aquatic biota, wildlife, and vegetation instead simultaneously serve as sources, transport pathways, and exposure pathways of toxic concentrations of hazardous substances to these resources. Information presented in Chapter 2 confirms that sources of hazardous substances to the Coeur d'Alene River basin are ongoing, occur throughout the basin, and release hazardous substances to surface water/groundwater, soils, and sediments. Sources include adits and original waste rock and tailings piles in the upper basin, but also hundreds of millions of tons of tailings and mixed alluvium and tailings that are located in the floodplains, beds, and banks of the South Fork and mainstem Coeur d'Alene River and tributaries, the lateral lakes area, and Coeur d'Alene Lake.

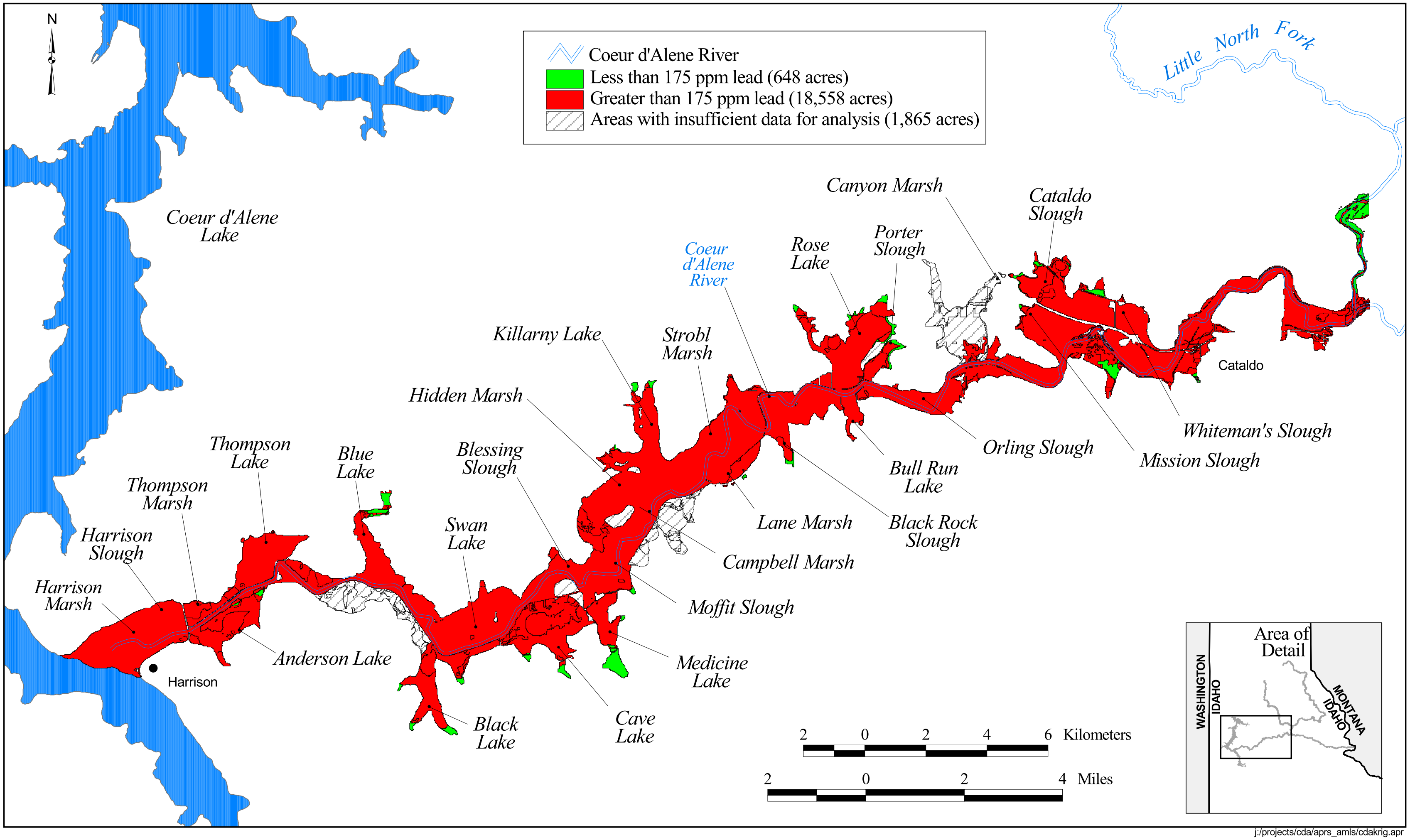

Figure 10-16. Distribution of sediments containing lead at concentrations greater than 175 ppm (90th percentile of baseline).
Data source: Kern, 1999.

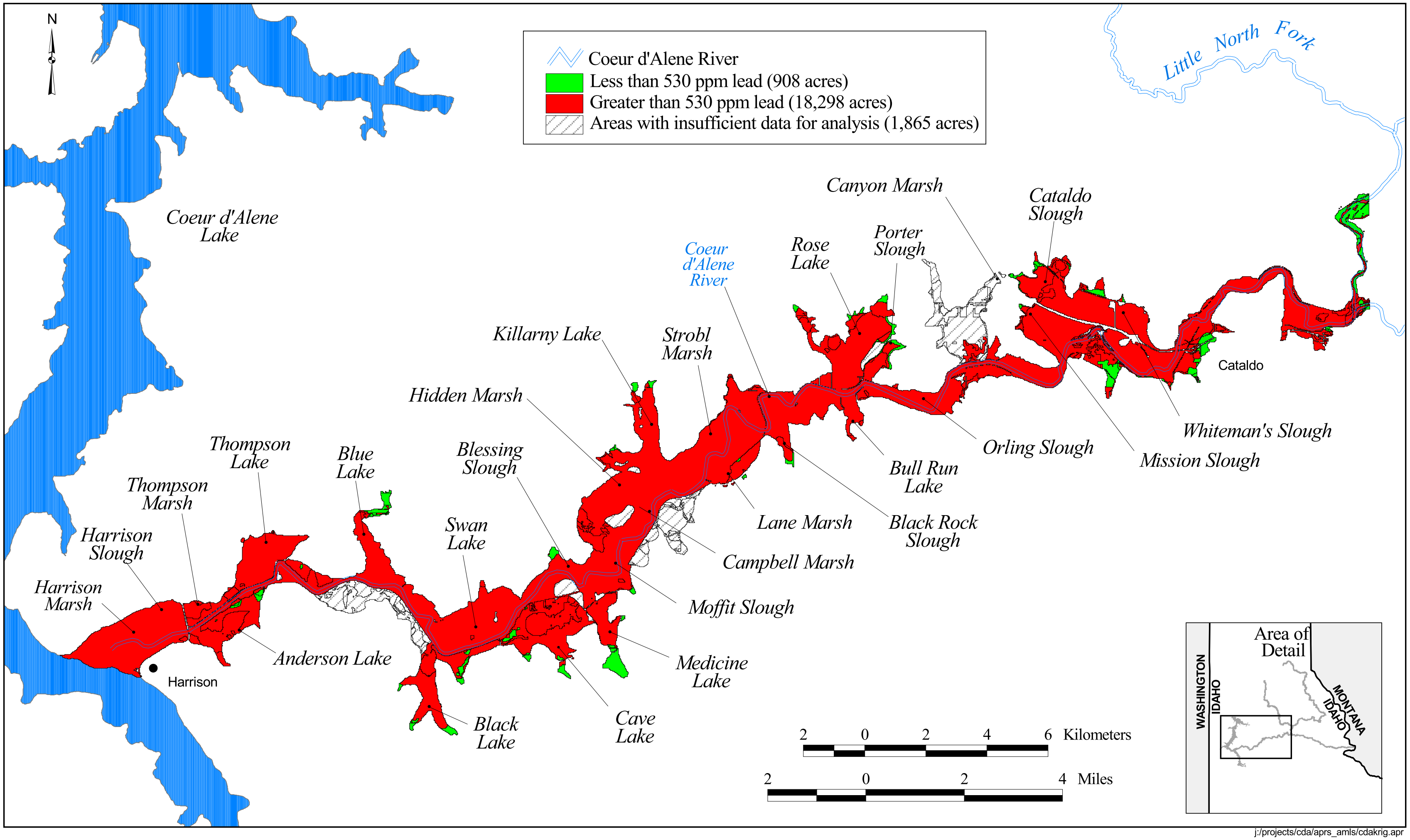

Figure 10-17. Distribution of sediments containing lead at concentrations greater than 530 ppm (lowest observed effect level).
Data source: Kern, 1999.

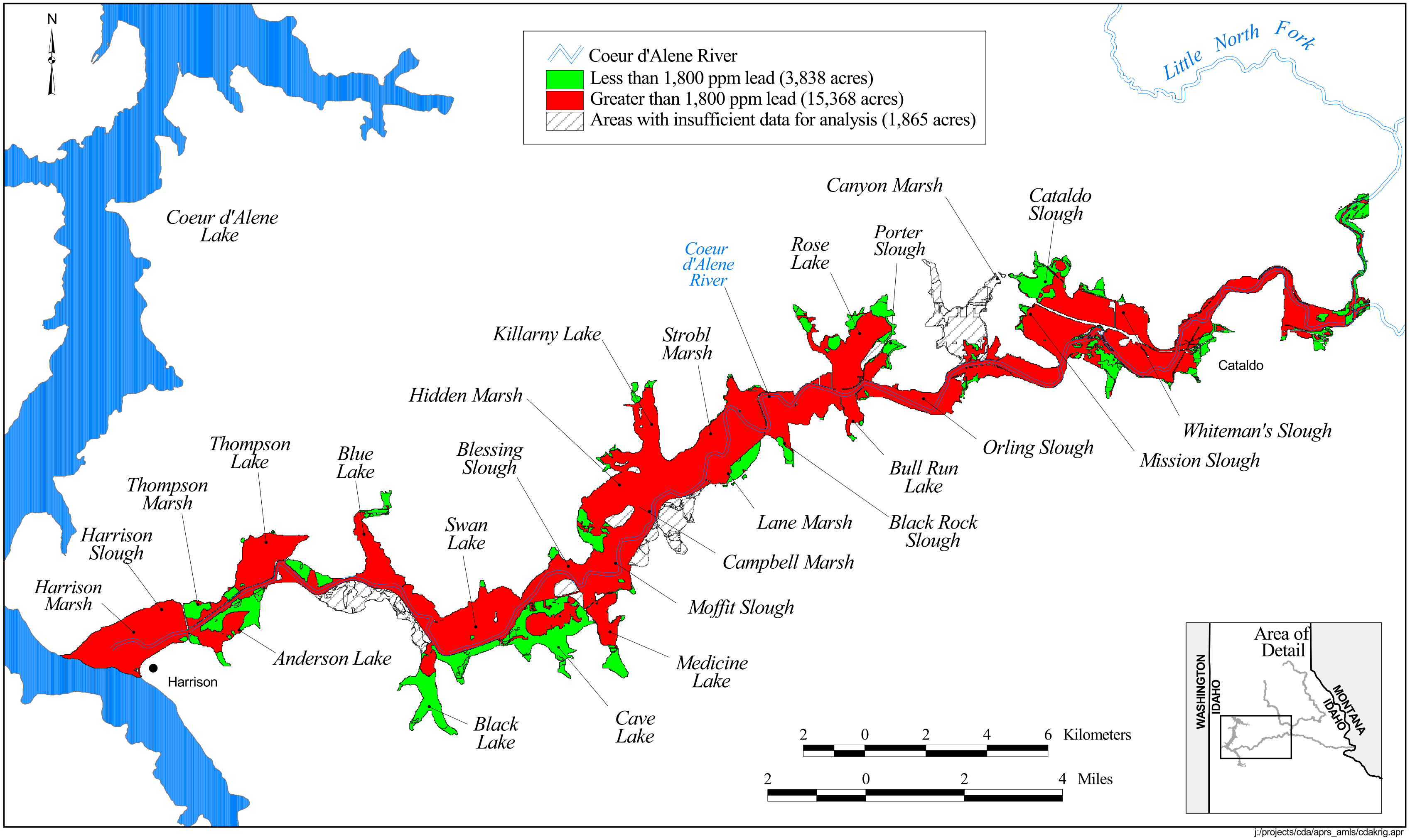

Figure 10-18. Distribution of sediments containing lead at concentrations greater than 1,800 ppm (lethal threshold level).
Data source: Kern, 1999.

The pathways by which hazardous substances are transported in the basin involve natural processes, which will continue to redistribute wastes, thereby exposing natural resources to elevated concentrations of hazardous substances for the foreseeable future. These pathways include surface water pathways (e.g., adit drainage; runoff, erosion, and scouring; suspended and bed sediment transport; dissolved substances transport; and flooding and sediment deposition); groundwater pathways (including infiltration and leaching of hazardous substances from floodplain tailings and mixed alluvium and tailings, and discharge of contaminated groundwater to streams); and sediment pathways (including suspended, bed, bank, and floodplain sediment transport by surface water). Resources will not recover fully until the sources and pathways by which resources are exposed, and injured by, are eliminated. The time required for natural recovery to baseline conditions, given the mass of wastes still in place, is anticipated to be on the order of hundreds of years.

10.7.1 Recoverability of Surface Water Resources

Natural recoverability of surface water resources was assessed in two ways: by evaluating temporal trends in concentrations of cadmium, lead, and zinc in injured reaches, and by examining patterns and magnitudes of ALC exceedences during the last three decades. Concentrations of cadmium, lead, and zinc in surface waters downstream of mining and mineral processing facilities have decreased since the height of mining in the Coeur d'Alene district, mostly as a result of the containment of tailings in the late 1960s. However, overall, existing data do not show clear trends of water quality improvement in the last 20 years.

Three locations in the South Fork Coeur d'Alene River have been sampled intensively during the past approximately 20 years. Total zinc concentrations in the South Fork Coeur d'Alene River near Osburn were measured monthly between July 1978 and December 1990 (MFG, 1991) and approximately monthly from October 1993 to September 1995 by IDEQ. Samples have been collected at the same site less frequently between 1991 and 1998 (in 1991 by MFG and in 1997-1998 by URSG and CH2M Hill). Mean annual concentrations and minimum and maximum concentrations measured at this site between 1978 and 1998 show no clear trend of water quality improvement.

Metal concentrations in the South Fork Coeur d'Alene River near Kellogg and the Bunker Hill complex were monitored between 1972 and 1986 by U.S. EPA (Hornig et al., 1988). Low flow total metal concentrations have decreased since 1979, probably as a result of the cessation of uncontrolled tailings discharge from upstream mines in 1968, waste water effluent controls initiated at the Bunker Hill Complex in 1974, closure and remediation of mineral processing facilities at the Bunker Hill Complex during the 1980s and 1990s, and channel stabilization and lining efforts (Dames & Moore, 1991). However, since the late 1980s, total zinc concentrations upstream and downstream of the Bunker Hill complex have not systematically decreased, nor has the difference between zinc concentration upstream of the site and downstream of the site decreased.

Exceedences of ALC were examined to determine whether water quality is improving at the same three sites on the South Fork Coeur d'Alene River (near Osburn and upstream and downstream of the Bunker Hill complex), in the reach of the South Fork Coeur d'Alene River between Canyon Creek and Milo Creek (SFCDR-3), and at sites near the mouths of Canyon Creek and Ninemile Creek. Acute zinc ALC values were compared to measured zinc concentrations to obtain a magnitude of exceedence (ratio of measured concentration to the ALC; values greater than 1 indicate an exceedence of the ALC). Only zinc concentrations measured during low flow (August through December) were used. If no hardness value was available for calculating the ALC, the mean of all the low-flow hardness values for a given location was used.

In the South Fork Coeur d'Alene River near Osburn and both upstream and downstream of the Bunker Hill complex, and at sites near the mouths of Canyon Creek and Ninemile Creek, all dissolved zinc concentrations measured between 1991 and 1998 during low flow exceeded the acute ALC values. Figure 10-19 shows the magnitude of dissolved zinc exceedences in the South Fork Coeur d'Alene River upstream of the Bunker Hill Complex (at Elizabeth Park), downstream of the complex (at Pinehurst), and at the mouths of Canyon and Ninemile creeks during low flow, 1991 through 1998. Most of the measured concentrations in the South Fork Coeur d'Alene River exceeded the ALC by 10 to 20 times. At Elizabeth Park, both the minimum and maximum exceedences were measured in the late 1990s. In Canyon Creek, exceedences were always greater than 20, and the maximum value measured in both Canyon and Ninemile creeks was near 90 times the ALC. In Ninemile Creek, that maximum value was measured in 1995. No clear trends in improving water quality are apparent from these data.

In reach SFCDR-4 (see Table 4-4 for reach descriptions), all dissolved zinc concentrations measured between the early 1970s and 1998 exceeded the acute and chronic ALC, and most, even into the late 1990s, exceeded the ALC by greater than 10 times (Figure 10-20). Therefore, even at the lowest measured concentrations, surface water resources of the South Fork Coeur d'Alene River remain injured. Again, within the whole reach, no pattern of decreasing magnitude of exceedence with time is evident.

None of the existing concentration or magnitude of exceedence of ALC data indicate declining hazardous substance concentrations with time during the past two decades. There is no clear evidence that maximum, minimum, or mean zinc concentrations have declined, and almost all of the concentrations measured in the South Fork Coeur d'Alene River downstream of Canyon Creek, and all of the concentrations measured at the mouths of Canyon and Ninemile creeks, exceeded acute zinc ALC values at all times that samples were collected over the last 20 to 30 years. Although patterns of recovery may be obscured by variability in flow and climate, the data overall do not indicate that water quality is improving.

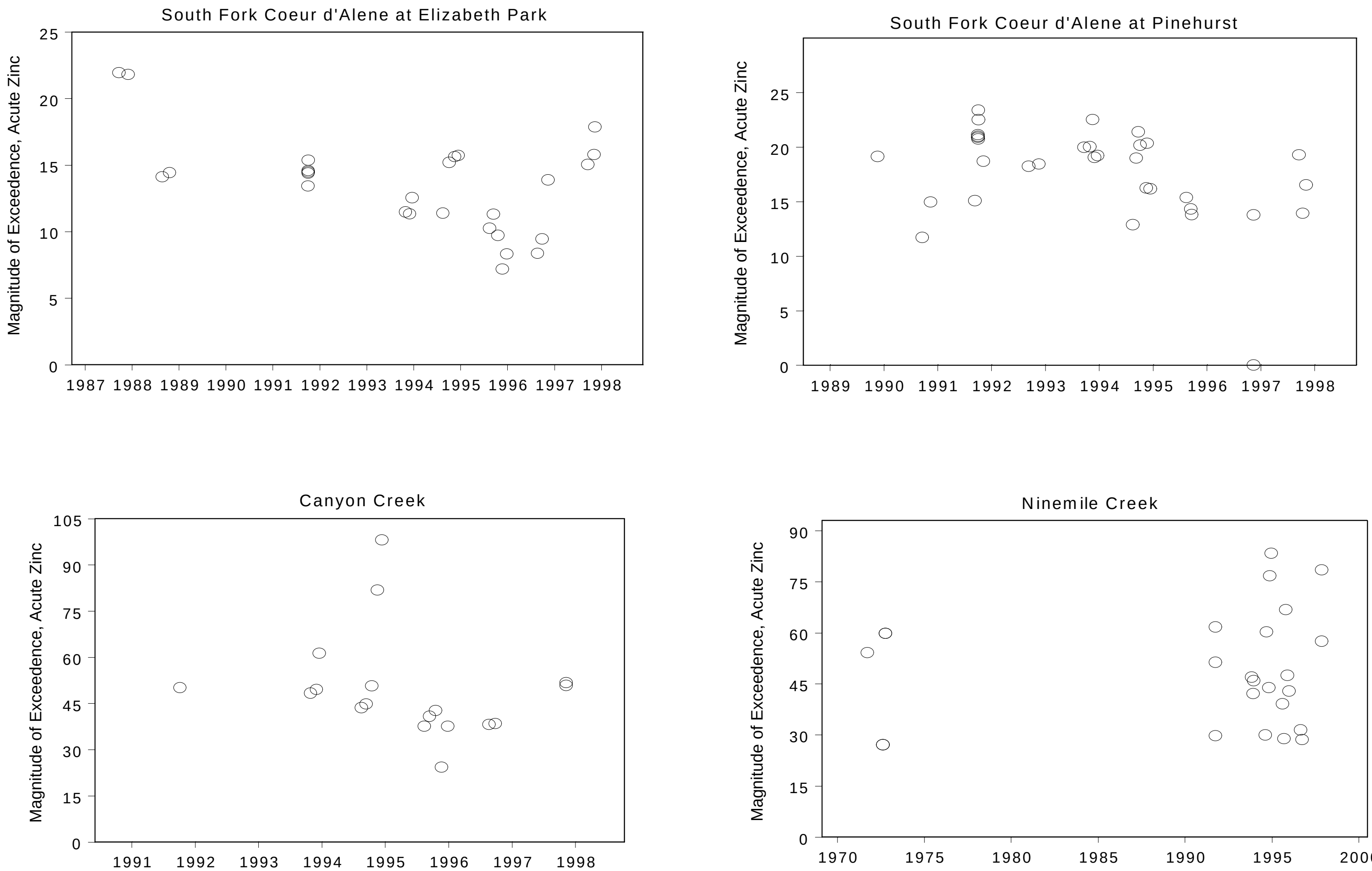

Figure 10-19. Dissolved zinc, acute ALC exceedences during low flow in: the South Fork Coeur d'Alene River at Elizabeth Park; the South Fork Coeur d'Alene River at Pinehurst; Canyon Creek near the mouth; and Ninemile Creek near the mouth. Magnitude of exceedence is the measure concentration divided by the ALC. Values greater than 1 indicate the degree of the exceedence. A value less than 1 would indicate that the ALC was not exceeded.

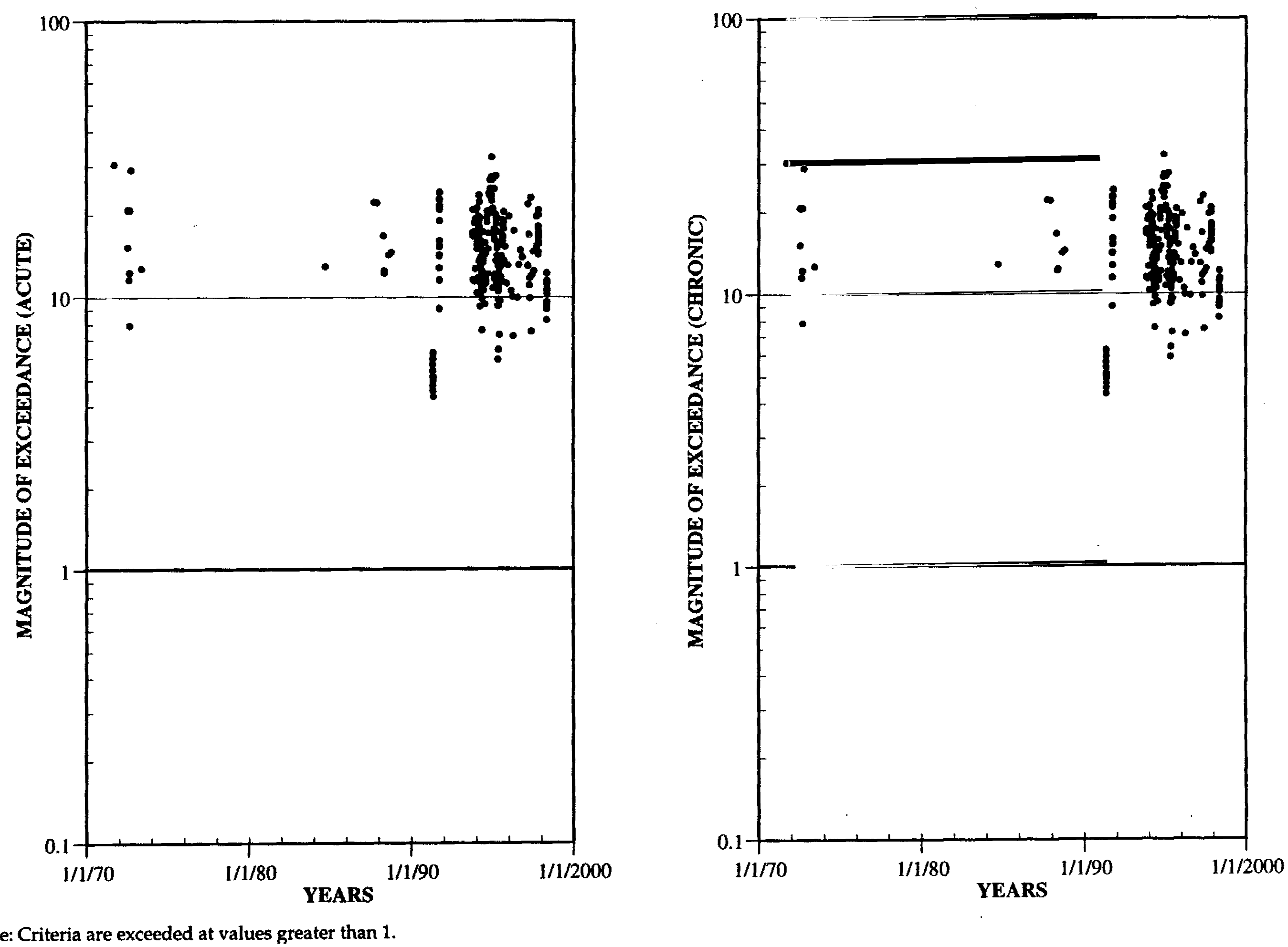

Figure 10-20. Dissolved zinc ALC exceedences, South Fork Coeur d'Alene River, Reach SFCDR-4.
Source: Ridolfi, 1999.

10.7.2 Recoverability of Sediment Resources

As described in Chapter 3, hazardous substances in floodplain tailings deposits, creek and river bed and bank sediments, and lakebed sediments in the Coeur d'Alene River basin continue to be mobilized, transported downstream, and redeposited. Hazardous substances in suspended sediments and bed sediments from upstream sources continue to contaminate downstream resources. Although mobilization of sediments will facilitate mixing and dilution with clean sediment inputs from the North Fork Coeur d'Alene River and unmined tributaries of the South Fork Coeur d'Alene River, existing data indicate that natural recovery of sediments in the Coeur d'Alene basin to baseline conditions will be very slow.

Sediments in Coeur d'Alene Lake generally have an upper, banded zone with high metal concentrations and a lower, unbanded zone with substantially lower metal concentrations (Horowitz et al., 1993). The upper banded zone reflects deposition of mining-related sediment since the early 1900s. The highest measured hazardous substance concentrations in the lake sediments are generally at or near the base of the banded zone (Horowitz et al., 1993). This peak in concentration most likely reflects early mine processing procedures with poor recovery. Sediment metal concentrations in the lower Coeur d'Alene River basin (URSGWC and CH2M Hill, 1998) and in Coeur d'Alene Lake (Horowitz et al., 1995) generally show lower metal concentrations in the more recently deposited metal-enriched sediments than in the sediment deposited earlier in the twentieth century (e.g., Figure 3-4). This pattern reflects changes in ore processing techniques (especially conversion from jigging to flotation) during the twentieth century, and, possibly, the installation of the Cataldo Dredge in the 1930s, the installation of tailings impoundments after 1968, and the closure of many mining and milling operations during the twentieth century. These changes lowered the concentrations of hazardous substances in tailings discharged to basin streams and reduced the volume of tailings entering the lower basin.

There is no evidence that natural mechanisms (i.e., mechanisms other than past improvements in ore processing and waste disposal techniques) have significantly reduced concentrations in surface sediments of the lower basin. In 1993, the USGS collected sediment samples from the 0 to 2 in depth in the lower basin floodplain (Horowitz, 1995). At approximately 40 of the sites sampled, a Mt. St. Helens ash layer deposited in 1980 was visible within the top 2 inches (5 cm).[6] All samples in which the ash layer was visible and intact were analyzed as two samples: an above-ash portion and a below-ash portion. Figure 10-21 shows lead, cadmium, and zinc concentrations in above-ash and below-ash samples collected near Cataldo, Rose Lake, Lane, Mediment, and Black Lake in the lower basin. Data points above the line indicate greater concentration in the above-ash sediment, and points below the line indicate lower concentration in the above-ash sample. Paired t-tests for lead, cadmium, and zinc indicated no significant differences for any of the metals in above- and below-ash samples ($p > 0.05$). There is no evidence that concentrations in sediments deposited since 1980 are lower than sediments deposited before 1980.

6. In Coeur d'Alene Lake, Horowitz et al. (1993) observed the ash layer at 20 cm depth. The greater depth to the ash layer indicates a greater rate of sediment deposition on the lake bed than in the floodplains.

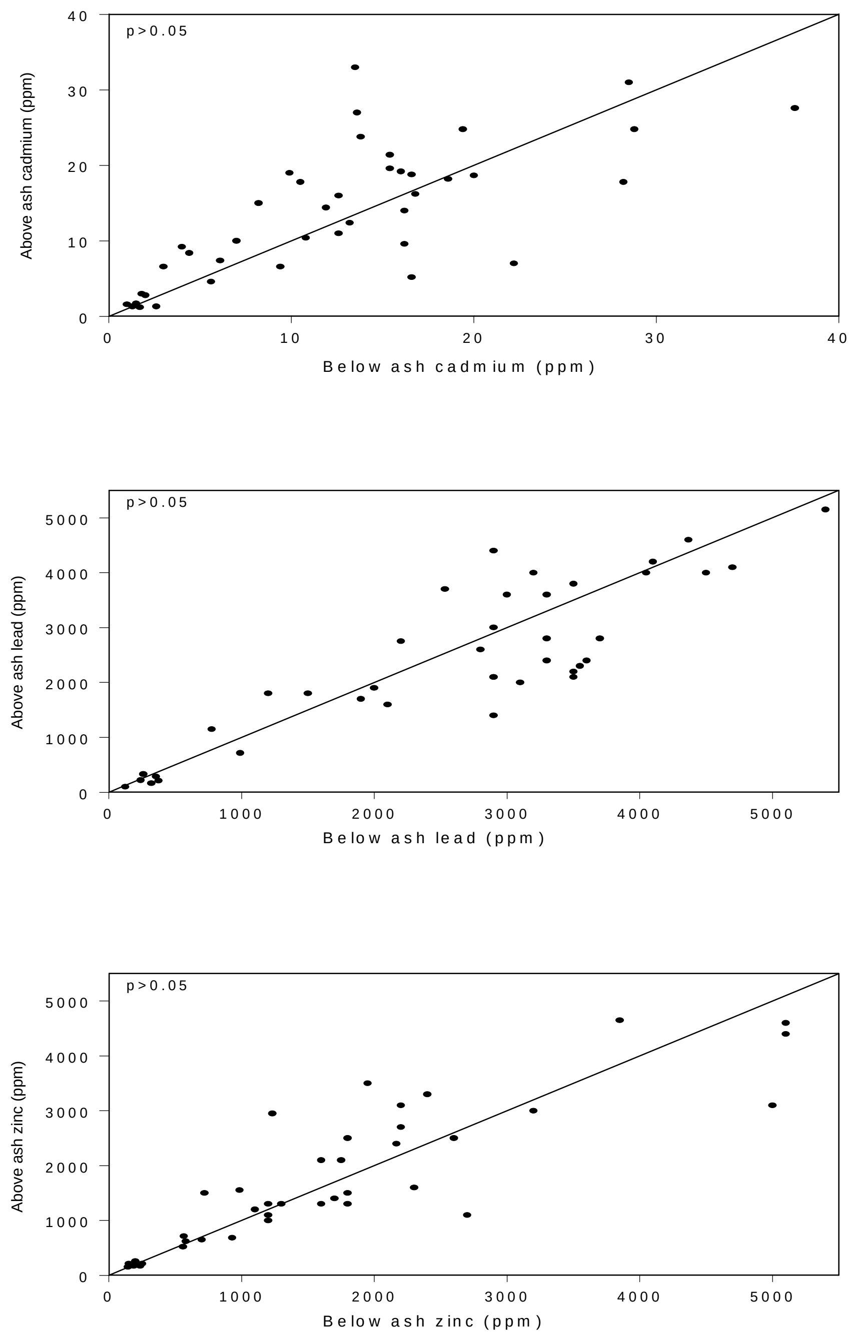

Figure 10-21. Concentrations of lead, cadmium, and zinc in above- and below-Mount Saint Helen's ash layer in 0 to 2 inch sediment samples from the lower Coeur d'Alene River basin floodplain. Line represents equal concentration in the above and below ash sample. $p > 0.05$ indicates no difference in above- and below-ash concentrations (paired t-test).

Data source: Horowitz, 1995.

For lead, cadmium, and zinc, the maximum above-ash concentration is lower than the maximum below-ash concentration for all three metals. At sites with low below-ash metal concentrations, corresponding concentrations above the ash layer are also low. At most other sites, however, there is greater variability in above- and below-ash concentrations. The variability in above- and below-ash concentrations might result from the migration of metals from reducing conditions lower in the sediment column to oxidizing conditions near the surface. Metals released from dissolving iron and manganese hydroxides in the reducing zone will migrate upward and reprecipitate on or with iron and manganese hydroxides in the oxidizing zone closer to the sediment-water interface. This process continually moves hazardous substances upward in the sediment column and obscures and inhibits any natural recovery that might have occurred in the more recently deposited sediments. Where below-ash concentrations are low, any redistribution of metals would not substantially affect concentrations above the ash layer. However, where below-ash metal concentrations are high, upward migration of metals from the reduced to the oxidized zone would again contaminate surface sediments and obscure any natural recovery.

For lead, although the difference was not significant, more of the above-ash concentrations are lower than below-ash concentrations. However, for cadmium and zinc, though also not significant, more of the above-ash concentrations are greater than below-ash concentrations. These slight differences among metals may reflect differences in the geochemical mobility of the metals in sediments and pore waters, or differences in the densities of lead sulfide, zinc sulfide, and cadmium bearing sulfides. Physical settling of lead sulfides, their immobility in oxidizing environments, and their restricted mobility in reducing environments relative to cadmium and zinc may explain the observed metal-specific concentration patterns in recently deposited lower basin sediments. The patterns of cadmium and zinc concentrations suggest evidence of a mechanism of ongoing in-situ recontamination.

There has been no consistent sampling of sediments over time at designated locations as there has been for surface water. Although numerous sediment samples have been collected (Tables 2-9 through 2-11 and 2-14 through 2-17 and additional data collected recently for the RI/FS), sampling locations, depths, and methods have varied. In general, however, recent sediment data collected from the lower basin for the NRDA (Hagler Bailly, 1995; Campbell et al., 1999) and the RI/FS (URSG and CH2M Hill, 1998) are consistent with data collected previously. There are no indications that sediment concentrations of cadmium, lead, and zinc are consistently decreasing over the past 20 years, for example, based on qualitative comparison to results of some of the earliest studies in the basin (e.g., Bauer 1974; Maxfield et al., 1974; Reece et al., 1978). The data ranges presented in Tables 2-9 through 2-11 and 2-14 through 2-17 are overlapping across years. Neither maximum nor mean values have consistently decreased.

In conclusion, metals concentrations in sediments above the ash layer deposited in 1980 do not differ significantly from metals concentrations immediately below the ash. This analysis compares an approximately 15-year period since the ash was deposited (samples were collected in 1993) to an unknown but approximately similar period before 1980. The results indicate no recovery of surface sediments in the lower basin. Comparison of sediment data collected in the late 1990s to data collected in the 1970s also shows no sign of recovery.

10.7.3 Recovery of the Coeur d'Alene River Basin Ecosystem

Recovery of fish, benthic invertebrate, wildlife, and riparian resources is dependent on recovery of surface water, sediment, and floodplain soil resources. Once surface water, sediment, and floodplain soil resources have recovered to a condition that will support biological resources, recovery of the Coeur d'Alene River basin ecosystem will be constrained by the rate of natural physical and biological recovery (vegetation reestablishment and physical habitat rebuilding by natural hydrologic, geologic, and biological processes).

For wildlife resources of the lower basin, recovery will occur rapidly once sediments are nontoxic, since physical modifications resulting from sediment injuries are not negatively affecting habitat use. Since there is a source of clean sediments from the North Fork Coeur d'Alene River basin and from clean South Fork Coeur d'Alene River tributaries to the lower basin, it is possible that eventually the contaminated sediments will be buried. Although natural recovery of sediments will probably take hundreds to thousands of years and major floods may continue to re-expose buried contaminated sediments, wildlife populations will benefit incrementally during the time when sediment metal concentrations in feeding areas diminish.

As surface water and sediment conditions improve, benthic macroinvertebrates from upstream clean reaches and clean tributaries will colonize recovered areas naturally and rapidly. Partial recovery of benthic macroinvertebrate communities was observed after tailings discharges to the basin ceased in 1968 and the physical stress of the large volume of unstable bed sediments in the upper basin diminished. Recovery will not be complete until water quality improves and physical habitat recovers.

Fish populations and communities can also begin to recover as water quality improves. Fish already present in the headwaters and clean tributaries of the upper basin can move into recovered reaches as the habitat allows. Recovery time for fish will include time required for natural reestablishment of physical features of habitats that were degraded as a result of the injuries, such as overhanging banks, vegetative overhang, and pools created by woody debris and roots. Natural recovery of the aquatic physical habitat of the upper basin will depend strongly on recovery of riparian resources.

Natural recovery time for riparian resources will depend on time required for floodplain soils to become diluted to nonphytotoxic levels, followed by primary vegetation succession, organic soil development, and development of vertically and horizontally diverse vegetation communities. Natural recovery of riparian resources includes development of vegetation that will overhang the stream, modulate stream temperatures, and provide security cover for fish. It includes recovery of riparian vegetation to the point where the vegetation provides habitat structure (e.g., large woody debris; bank stabilization) and a source of energy (i.e., detritus) to the aquatic ecosystem. It also includes reestablishment of diverse early and late successional vegetation and the expected range of terrestrial habitat features (e.g., mature tree boles for tree-cavity nesting birds).

Throughout the Coeur d'Alene River basin, the hazardous substances cadmium, lead, and zinc are the cause of the injuries described in this report. Existing concentrations of cadmium, lead, and zinc in the basin, ongoing releases of these hazardous substances from sources, and ongoing transport and exposure pathways limit natural recovery of the injured resources. There will be little recovery unless releases from sources are eliminated and transport and exposure pathways are eliminated. Existing surface water and sediment data show no evidence of either elimination of sources or pathways over the last 20 to 30 years. Therefore, it is reasonable to expect that natural recovery of the Coeur d'Alene River basin ecosystem will take hundreds of years.

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Next

APPENDIX A
GEOLOGIC, MINERALOGIC, AND ENVIRONMENTAL CONSIDERATIONS FOR SOUTH FORK COEUR D'ALENE RIVER BASIN DRAINAGES

Information contained in this appendix is based on data and information contained in Hobbs et al. (1965), Derkey et al. (1996), SAIC (1993b and c), Mitchell and Bennett (1983), Gott and Cathrall (1980), maps of mine waste deposits contained in Chapter 2 of this report, maps of mines and mills found in Chapter 2 of this report, and the surface water database (see Chapter 4). References for these sources are identified in Chapters 2, 4, and 10 of this report.

I. Upper South Fork Coeur d'Alene Basin

Ninemile Creek and Tributaries

Geology: East Fork Ninemile Creek cuts predominantly through the South and North Gem stocks. A small section drains the Prichard Formation. The West Fork Ninemile Creek does not intersect the stock at all and instead cuts through the St. Regis Formation near the mouth and the Wallace Formation for most of the central and upper reaches. The Wallace Formation is distinguished from the other Belt Supergroup rock by the presence of abundant carbonate-bearing rocks, including carbonate-bearing argillite and quartzite, dolomite and dolomitic quartzite (Hobbs et al., 1965). Downstream of the confluence of the east and west forks, Ninemile Creek runs through alternating sections (separated by a series of NW-SE-trending faults) of the St. Regis, Revett and Burke Formations upstream of the Osburn Fault (~1 mile from the mouth), and the Wallace Formation downstream of the Osburn Fault. Alluvial deposits (Quaternary alluvium) line the creek bed from the mouth almost to the headwaters of the West Fork and approximately 1/2 mile up the East Fork. The remainder of the East Fork lies directly on bedrock. Blackcloud Creek, a tributary of Ninemile Creek, predominantly drains the St. Regis Formation of the Ravalli Group. However, approximately a one-half mile section near the mouth cuts through the Wallace Formation, which is known to contain carbonate rocks, as noted above. The St. Regis Formation also contains some carbonate-bearing beds (Bennett and Venkatakrishnan, 1982, p. 1855). Many faults, including the Blackcloud fault and the Ruth fault, intersect Blackcloud Creek. Quaternary alluvium lines the lower one-half mile of the creek; the remainder of the creek lies directly on Belt Supergroup bedrock.

Mineralization: The headwaters of Ninemile Creek drain the North Gem Stock, and the Sunset and Carlisle-Hercules Mineral Belts cross this intrusion. Farther downstream, the Rex-Snowstorm Mineral Belt crosses the South Gem Stock and Ninemile Creek. Downstream of the confluence of the east and west forks, Ninemile and Blackcloud creeks drain the Dayrock Mineral Subbelt. There are numerous adits and mines on the East Fork of Ninemile Creek, including the Interstate-Callahan, Tamarack, Rex, Alameda, American, and Success Mines. In addition to subsurface veins, veins associated with the Success Mine outcrop on the eastern side of the drainage approximately one mile from the confluence with the West Fork. The Ninemile, Mayflower, and Treasure Vaults mines and associated adits are located on the upper mainstem Ninemile Creek. Downstream of the confluence of the East Fork and the mainstem Ninemile Creek, there are numerous mines and adits, including the Dayrock, Option, Thomas Consolidated, Silver Star and Panhandle Mines. All these mines are located north of the Osburn Fault, although there are some adits along Ninemile Creek south of the fault near the mouth. The Duluth and Ruth mines in the St. Regis Formation located in the headwaters area on the southern side of Blackcloud Creek. The Monarch, McDonald, Blackcloud No. 3 and Marshall No. 1 mines have underground workings on the northern side of Blackcloud Creek in the St. Regis Formation. The California No. 4 mine is also on the northern side but in the Wallace Formation.

Environmental: Floodplains along the mainstem and the East Fork of Ninemile Creek have been impacted by mining. There are two millsite areas located in upper East Fork Ninemile and another located on the mainstem downstream of the confluence with the mainstem Ninemile Creek. Several large rock dumps are also located along the creek. However, upstream of SF 289, the floodplain has not been impacted by mining and there are no major mine waste deposits. There is a waste rock dump associated with the Sunset mine upstream of SF 289, but it is 1/2 mile above the creek and does not directly drain to the creek. Discharge from the Sunset Tunnel had cadmium, lead and zinc concentrations of 150, 93.1, 24,300 µg/L, respectively on 14 November 1997. There are some mine adits on the upper mainstem Ninemile Creek but no major mine waste deposits, and the floodplain has not been impacted by mining. A number of adits from mines in Blackcloud Creek are located along the creek. However, the only sizable production was out of the Monarch and California mines. Discharge from the Duluth Mine had a dissolved zinc concentration of 109 µg/L on 15 November 1997; all other metal concentrations were low, and the flow was 0.0096 cfs. There are rock dumps along Blackcloud Creek, but no tailings. The floodplain has been impacted by mining along the lower mile of the creek, but this is from the waste rock dumps, not from tailings. A millsite is located near the mouth on the southern side of the creek downstream of SF 302. Samples at NM 289 in the upper reaches of the East Fork, samples in the upper mainstem (NM 299, 300) and samples in Blackcloud Creek did not exceed relevant criterion values. All other samples in the drainage exceeded for one or more aquatic life criterion value.

Canyon Creek

Geology: Upper Canyon Creek (upstream of O'Neill Gulch and O'Neill Gulch Fault) cuts predominantly through the Burke Formation, with the Revett and St. Regis formations underlying the upper headwaters area. Two sections of the Prichard Formation underlie the area just upstream of French Gulch and O'Neill Gulch. Canyon Creek downstream of O'Neill Gulch to Frisco is underlain predominantly by the Burke Formation, with a section around Burke and Frisco cutting through the Prichard Formation. Downstream of Frisco, Canyon Creek cuts through the South Gem Stock for approximately one mile. Downstream of this area, Canyon Creek cuts through alternating sections of the Prichard and Burke formations until it hits the Osburn Fault approximately one mile from the mouth. Like Ninemile Creek, Canyon Creek drains the Wallace Formation from the Osburn Fault to the mouth. Quaternary alluvium lines Canyon Creek from the mouth to approximately 1/2 mile upstream of O'Neill Gulch. Upstream of Sawmill Gulch, Pleistocene glacial and glaciofluvial deposits line the headwaters region of Canyon Creek.

Mineralization: Canyon Creek drains the Tamarack-Marsh, Rex-Snowstorm, Gem-Gold Hunter, and Golconda-Lucky Friday mineral belts. There are many veins known to contain base metals that are associated with the mines along Canyon Creek. Although most of these veins are subsurface, several of the veins outcrop in the Burke area and are on the Prichard-Burke boundary. These outcropping veins are associated with the Sherman, Hummingbird No. 4 and Hidden Treasure mines on the northern side of the creek. There is a concentration of mines between Gem and Dorn on the south side of the creek, including the Gem, Frisco, and Black Bear mines, and another grouping of mines between Mace and Burke both north and south of the creek, including the Hecla, Sherman, and Tiger-Poorman mines. Almost all the mines are located along the Prichard-Burke boundary. The Hercules and Ajax mines are located up Gorge Gulch. The Tamarack and Standard Mammoth mines are located between Dorn and Mace. Upstream of O'Neill Gulch there are several mines, including the Gertie, Ajax No. 3, Oom Paul, and Homestake Silver Lead mines, also in the Prichard or Burke formations, and the Mammoth, West Mammoth, Sonora, and Coeur d'Alene Champion mines in the Revett and St. Regis formations. However, the only producer in this area was the Ajax Mine, and there is no discharge from the Ajax Mine to the creek.

Environmental: Drainage from a mine in the Burke area had a pH of 6.97 and a flow of 1.44 cfs on 13 May 1998. Drainage from the Gem No. 3 Mine had a pH of 6.93 and a flow of 0.581 cfs on 12 May 1998; dissolved zinc and cadmium concentrations were 13,200 and 10.8 µg/L, respectively. Additional monthly data from ASARCO are contained in the Restoration Alternatives Plan (Gearheart et al., 1999). Drainage from the Black Bear adit had a flow of 1.13 cfs on 16 November 1997 and zinc and lead concentrations of 88.6 and 2.23 µg/L, respectively. Most of the floodplain downstream of O'Neill Gulch has been impacted by mining. There is a large tailings impoundment on the left bank of the creek approximately 2 miles upstream of the mouth. At least five millsites are located along the creek from the mouth to downstream of Gorge Gulch. Several rock dumps are located on tributaries and along the mainstem. There is discharge from the Oom Paul Mine, but it is relatively clean. There are fairly big rock dumps at the Ajax and Gertie mines and a smaller dump at the Oom Paul Mine. Upstream of SF 290 the floodplain has not been impacted by mining. There is a municipal water supply intake at the mouth of Sawmill Gulch. Samples upstream of O'Neill Gulch did not exceed relevant water quality criteria. All other samples in the drainage did exceed relevant water quality criterion values.

Unnamed Creek (SF 201)

This unnamed creek is located on the south side of South Fork Coeur d'Alene River upstream of the Little North Fork. The drainage is not on the geologic map, so no geologic or direct mineralogic information is available. However, the Beacon Light metal mine is located in this drainage, and water quality samples do exceed aquatic life criterion values for dissolved zinc. Because of the presence of the Beacon Light mine, the drainage was considered mineralized.

Little North Fork (SF 202)

The Little North Fork is located north of the South Fork Coeur d'Alene and mostly north of the Osburn Fault. Quaternary alluvium overlies the Wallace Formation for the lower mile of the Little North Fork, and the remainder drains the St. Regis Formation. The eastern tip of the Gem-Gold Hunter Mineral Belt touches the creek near the mouth at the fault. A vein known to contain base metals outcrops at the surface in the Wallace Formation near the mouth of the creek, and the Pandora Mine is located approximately one-half mine upstream of the vein in the St. Regis Formation. There are several mine adits but no large mine waste deposits along the creek. Water samples did not exceed for any relevant aquatic life criterion values.

Unnamed Creek (SF 204)

This unnamed creek is located south of the South Fork Coeur d'Alene River and the Osburn Fault to the west of the Little North Fork. Most of the length of the creek drains the St. Regis Formation. The lower part of the creek drains the Wallace Formation, and Quaternary alluvium lines the creek for the lower 1/4 mile. An unnamed mine in the headwaters region has two sets of veins that are exposed at the surface for approximately 1/8 mile. An adit from that mine in is the drainage. No known mineral belts are located in the drainage, but a portion of the drainage has soil lead concentrations greater than the 60 mg/kg threshold value determined by Gott and Cathrall (1980). No major mine waste deposits are located in the drainage. Of the two sampling dates in November 1997 and May 1998, the 9 May 1998 sample had a dissolved copper concentration of 4.3 µg/L (CCC = 2.74 µg/L); however, the total copper concentration measured on that date was <3 µg/L. All other metal concentrations met water quality standards

Daisy Gulch (SF 206)

Daisy Gulch is located north of the South Fork and the Osburn Fault east of Gentle Annie Gulch. The gulch mostly drains the Wallace Formation and a small piece of the St. Regis Formation just upstream of the Idaho Silver Mine. Quaternary alluvium lines the lower half mile of the gulch. The lower portion of the gulch is in the Gem-Gold Hunter Mineral Belt, where the Idaho Silver Mine is located. This mine is on the Wallace-St. Regis contact zone. The upper part of the gulch drains the Rex-Snowstorm Mineral Belt, where the Snowstorm mines are located. The mines are in the Wallace, St. Regis, and Revett formations. An outcropping vein known to contain base metals is located on the eastern side of the drainage along a tributary. There is an adit associated with this vein, but no underground workings. A rock dump covers the gulch approximately 1/4 mile from the mouth, and another smaller rock dump covers the gulch near the headwaters of the upper east fork. Several mine adits are located along the gulch, and there is significant discharge from the Snowstorm mine. Drainage from the Snowstorm No. 3 had a pH of 6.76 and a flow of 4.89 cfs on 18 May 1998. A tailings pile area and the Snowstorm mill site are located near the mouth on the western side of the gulch. The water quality sample collected on May 8, 1998 exceeded the dissolved copper chronic criterion (5.76 µg/L) by a little over 1 µg/L (7 µg/L). Cadmium, lead, and zinc concentrations did not exceed chronic criteria.

Gentle Annie Gulch (SF 207)

Gentle Annie Gulch flows south into the South Fork Coeur d'Alene River and is located north of the Osburn Fault in the Gem-Gold Hunter Mineral Belt. The lower portion of the creek drains the St. Regis Formation, while the remainder of the gulch drains the Wallace Formation at the surface. Quaternary alluvium lines the lower one-half mile of the gulch. The Coughlin Mine was developed on an outcropping vein known to contain base metals in the St. Regis Formation in the lower part of the Gulch, while the Butte & Coeur d'Alene Mine and the Little Boy Mines are in the Wallace Formation in the middle portion of the Gulch. In the headwaters area there are a number of mines in the St. Regis Formation, on the contact between the St. Regis and the Wallace or in the Revett Quartzite, including the Lucky Calumet and the Snowshoe mines. A number of adits line the cliffs above the gulch. A large tailings impoundment covers the mouth of the gulch and the South Fork upstream and downstream of Gentle Annie Gulch. A small rock dump is located near the stream approximately one-third of the way up the gulch. Discharge from the Coeur d'Alene Mine had a flow of 0.0094 cfs on 19 November 1997; no other water quality information was available. The sample location SF 207 appears to be located upstream of the tailings impoundment and did not exceed relevant water quality criterion values.

Deadman Gulch (SF 209)

Located to the west of Gentle Annie Gulch, Deadman Gulch also flows south into the South Fork Coeur d'Alene River. The Gulch is located north of the Osburn Fault in the Gem-Gold Hunter Mineral Belt. At the surface, the gulch drains the St. Regis Formation in the headwaters and near the mouth, and the Wallace Formation in the middle section. Quaternary alluvium lines only the lower one-quarter mile of the gulch. Numerous underground mines are located along Deadman

Gulch, including the Hunter Creek Mine in the St. Regis Formation near the mouth; the Homestake, Lottie L., Alma in the Wallace Formation and the National Mine in the Wallace and St. Regis formations in the mid-section of the gulch; the Missoula Mine in the Revett and St. Regis formations along the east fork; and the Copper King, Pilot, and Copper Plate Mines along the west fork. A number of adits from these mines are located along the gulch. Most significantly, the National Mill was located in Deadman Gulch. The National Mine produced 170,800 tons of silver, copper, and gold ore (Mitchell and Bennett, 1983). Several rock dumps line or are adjacent to sections of the east and west forks in the headwaters area. Drainage from the Copper King Mine had a pH of 6.17 and a flow of 0.0564 cfs on 17 May 1998. Although no criterion values were exceeded in samples collected from near the mouth (SF 209), this creek was not used for mineralized baseline because of the presence of the mill and the sizeable production of silver and copper from the National Mine.

Willow Creek (SF 210)

Willow Creek is located south of the South Fork Coeur d'Alene River and the Osburn Fault east of Mullan and drains a portion of the Moe-Reindeer Queen Mineral Belt in the headwaters area and a portion of the Gem-Gold Hunter/Golconda-Lucky Friday Mineral Belts at the mouth. Most of the drainage is in the St. Regis Formation, although the exposed vein crosses the St. Regis-Wallace boundary. Quaternary alluvium and glacial and glaciofluvial deposits line most of the length of the creek. Terrace and channel gravels are located above the alluvium along the creek's lower reaches. The Carbonate Hill, Carney, Reindeer Queen and Copper Queen Mines are located in the drainage, mostly in the headwaters area and in the St. Regis Formation. Underground veins are located downstream of the confluence of the East and West Forks, and the headwaters of the East Fork drains a one-half mile long vein exposed at the surface along the Reindeer Fault (the Copper Queen Mine). One waste rock dump is located adjacent to the creek downstream of the confluence of the east and west forks. A number of adits are located along the creek. An adit from the Reindeer Queen Mine discharges along the east fork. Drainage from this adit had a flow of 0.011 cfs on 19 November 1997; no other water quality data are available. The Reindeer Queen produced only 147 tons of mostly copper ore (Mitchell and Bennett, 1983). Even though there are mines and waste rock deposits in the creek, there were no large producing mines and no mills on the creek. Therefore, this creek was considered mineralized baseline. No criterion values were exceeded in samples collected from near the mouth (SF 210).

Unnamed Creek (SF 211)

This unnamed creek is located between Boulder and Willow Creeks south of the South Fork Coeur d'Alene River and the Osburn Fault, east of Mullan. This creek also drains a portion of the Moe-Reindeer Queen Mineral Belt. The upper half of the creek drains the St. Regis Formation, and the lower part drains the upper part of the St. Regis and the lower part of the Wallace Formation. Quaternary alluvium and channel and terrace gravels line only the lowest 1/3 mile of the creek. Adits line the creek in both the headwaters area, where the Lower Giant Mine is located, and at the mouth, where the Atlas Mine is located. A large waste rock dump associated with the Atlas Mine covers the creek approximately 1/4 mile from the mouth. The Atlas Mine produced 6,936 tons of ore (mostly lead), which is small compared to any of the major mines in the district (Mitchell and Bennett, 1983). Drainage from the Atlas Mine had a pH of 7.57 on 18 May 1998; no other water quality data were available for this sample. No criterion values were exceeded either in Fall 1997 or Spring 1998, and many concentrations were below detection.

Gold Hunter Gulch (SF 212)

Located north of the South Fork Coeur d'Alene east of Mullan and north of the Osburn Fault, Gold Hunter Gulch drainage is in both the Gem-Gold Hunter and Golconda-Lucky Friday Mineral Belts. The gulch cuts into the Wallace, St. Regis, and Revett formations. The gulch drains the Wallace Formation in the headwaters and near the mouth and the St. Regis in the center portion. A piece of the Revett also crosses the drainage between two of the faults that cut the gulch. Quaternary alluvium lines only the lower 1/4 mile of the gulch. The Lucky Friday Mine, which is still in operation, is located on the eastern side of the gulch near the mouth. The Gold Hunter Mine is located under much of the western side of the gulch, crosses a number of faults, and cuts through the Wallace, St. Regis, and Revett formations and a number of dikes. An outcropping vein 1/3 of a mile long and known to contain base metals is located in the upper western part of the drainage and is incorporated in the Silver Reef or Yolanda mines (underground workings for these and the Gold Hunter are continuous). A tailings impoundment covers the mouth of the gulch and the northern side of the South Fork mostly downstream of the gulch. A number of mine adits are located along the gulch. A large tailings pile from the Lucky Friday complex is located across the gulch and over the Lucky Friday Mine at the mouth. The Silver Reef Gold Hunter Mine adit discharges to the headwaters area. Both the Gold Hunter mill and the Lucky Friday mill are located near the mouth of Hunter Gulch. Dissolved copper exceeded the chronic criteria (4.28 and 5.35 µg/L) on both 9 November 1997 (12.1 µg/L) and 8 May 1998 (7 µg/L). Dissolved lead also exceeded the chronic criterion on 9 November 1997 (1.62 µg/L vs. 0.97); dissolved lead did not exceed the criterion on 8 May 1998 (0.6 µg/L vs 1.30). Dissolved zinc and cadmium did not exceed their chronic criterion values on either date.

Unnamed Creek (SF 213)

This unnamed creek is located north of the South Fork Coeur d'Alene River and the Osburn Fault between Mill Creek and Gold Hunter Gulch across the South Fork from Boulder Creek. The creek empties into the South Fork on the east side of Mullan. The creek is not located on the topographic maps or on the geologic maps (Hobbs et al., 1965), but based on topographic contours, the creek drains predominantly the St. Regis Formation and a portion of the Wallace Formation. The creek is most likely located entirely within the Golconda-Lucky Friday Mineral Belt. There does not appear to be any mining or mine waste deposits directly within the drainage. Water samples did not exceed relevant aquatic life criterion values.

Boulder Creek (SF 214)

Boulder Creek is located south of the South Fork Coeur d'Alene River and the Osburn Fault and also empties into the South Fork at Mullan. Most of the creek drains the St. Regis Formation, and Quaternary alluvium and terrace gravels are located in the lower 1/2 of the creek. The Moe Reindeer Queen Mineral Belt crosses Boulder Creek at about its midpoint. There are both outcropping and subsurface veins along the drainage approximately half way up the creek. The Banner Mine is located on Boulder Creek in the St. Regis Formation; adits are located in the drainage. There are a number of adits and prospects and one waste rock dump, but no major mines or waste deposits and no mills are located along the creek. Water samples did not exceed any aquatic life criterion values.

Mill Creek (SF 216)

Located north of the South Fork Coeur d'Alene River and the Osburn Fault, Mill Creek flows into the South Fork at Mullan. From the headwaters to the mouth, Mill Creek drains the St. Regis, Wallace, St. Regis, Revett, and St. Regis formations. Quaternary alluvium lines most of the creek, including the upper forks in the headwaters area. Mill Creek drains the Golconda-Lucky Friday Mineral Belt and the Gem-Gold Hunter Mineral Belt. Underground veins are located in the headwaters and on the bluffs on the west side of the stream and also in the headwaters region. The Sunshine Premier, Independence, and Morning No. 5 mines are located in Wallace Formation in the headwaters area. The North Franklin and Wall Street mines are also located in the headwaters area in the St. Regis Formation. A waste rock dump covers the creek in the upper west fork, and the floodplain of one of the western tributaries has been impacted by mining. Drainage from the Morning No. 5 adit had a pH of 7.52 and a flow of 0.0111 on 17 May 1998. Morning No.5 was the main producing adit for this large mine for a number of years; therefore, this creek was not used for baseline. However, SF 216 does not exceed relevant water quality criteria. Water quality samples and measurements were only collected on 9 November 1997; no aquatic life criteria were exceeded on that date.

Slaughterhouse Gulch (SF 218)

Slaughterhouse Gulch flows south into the South Fork Coeur d'Alene River and is located mostly south of the Osburn Fault. Most of the gulch drains the Wallace Formation, and Quaternary alluvium lines approximately half of the gulch. The rocks above the headwaters area drain the Golconda-Lucky Friday Mineral Belt. The Morning Mine No. 6 is located near the mouth of the gulch and connects by underground workings to the Morning Mine, two miles to the north. The Morning Mill was also located near the mouth. A large rock dump associated with the Morning mines covers the lower portion of the gulch and extends to the east and west along the north bank of the South Fork. At the mouth, water in the gulch flows under cribbing of the Morning Mine waste rock dump. Water quality samples collected at the mouth exceed for dissolved zinc on 9 November 1997 and 8 May 1998 (190 and 150 µg/L, respectively; CCC = 150.2 and 99.9 µg/L). Dissolved lead, cadmium and copper do not exceed criteria values. Hardness values were high for the basin, at 132 and 82 mg/L as $CaCO_3$ in November 1997 and

May 1998. Drainage from the Morning No. 6 Mine had a pH of 8.19 and a flow of 2.37 cfs on 17 May 1998, and a flow of 1.04 cfs on 8 November 1997; no other water quality data were available.

Dry Creek (SF 219)

Located south of the South Fork Coeur d'Alene River and the Osburn Fault, Dry Creek empties into the South Fork west of Mullan. The creek lies directly on the St. Regis Formation. The upper half of the creek is in the Moe-Reindeer Queen Mineral Belt. Underground workings from the Moe Mine and associated veins cross over into the west side of the Dry Creek drainage. There are a couple of adits along the stream, but they are not associated with a producing mine. Although it is marked as an intermittent stream on the geologic map, flows were measured both on 8 November 1997 and 6 May 1998 as 0.285 and 0.4 cfs, respectively. Hardness values on the same dates were 11.9 and 9.8 mg/L as $CaCO_3$. There are no known mine waste deposits located long the creek. Elevated stream concentrations were measured in the 1950s by the U.S.G.S. (USGS, 1960). Dissolved criterions values for cadmium, lead, and zinc were not exceeded at this location.

Gold Creek (SF 221)

Gold Creek is located south of the South Fork Coeur d'Alene River and the Osburn Fault west of Dry Creek and Mullan. The creek lies directly on the St. Regis Formation except for a small amount of Quaternary alluvium right at the mouth. The headwaters area drains a piece of the Wallace Formation. The lower part of the creek is in the Moe-Reindeer Queen Mineral Belt. The Moe Mine, in the St. Regis Formation, is located in the Gold Creek drainage near the mouth on the east side of the creek. A number of other subsurface veins and one surface vein not known to contain base metals are located in the drainage. There are a number of adits in the creek. No major mining activity has occurred in the drainage, although there are a few prospect pits along the eastern side of the creek near the headwaters. No criterion values were exceeded.

St. Joe Creek (SF 222)

St. Joe Creek is located south of the South Fork Coeur d'Alene River and the Osburn Fault west of Mullan. The headwaters region drains the Wallace Formation, while most of the rest of the creek drains the St. Regis Formation. A very small amount of Quaternary alluvium lines the creek at its mouth. The lower portion of the creek is in the Moe-Reindeer Queen Mineral Belt. A surface vein not known to contain base metals outcrops approximately half way up the drainage in the St. Regis Formation. Other subsurface veins not known to contain base metals and adits are located near the mouth. No major mine waste deposits are located in the drainage. There is a discharging tunnel in the drainage. No criterion values were exceeded in water quality samples.

Grouse Gulch (SF 223, 317, 318, 319, 320, 321)

Located north of the South Fork Coeur d'Alene River and split by the Osburn Fault, Grouse Gulch drains the Golconda-Lucky Friday Mineral Belt north of the fault. About 3/4 of drainage is north of the Osburn Fault. The Ivanhoe Mine is located in the headwaters area, along with adits and underground veins. The Star 1200 level, We Like and Grouse Mines (Ivanhoe Mine) are all in the Revett Formation. An outcropping vein known to contain base metals is part of the Grouse Mine workings. Two large waste rock dumps from the Star Mine cross the gulch in the headwaters area, and the floodplain is impacted downstream of the lower dump. Drainage from the Grouse Mine (SF 349) had a pH of 6.17 on 17 May 1998 and a flow of 1.82 cfs; dissolved lead and zinc concentrations (34.2 and 73 µg/L, respectively) did exceed chronic criterion values, but dissolved cadmium concentrations were below chronic criterion values. Drainage from the Star 1200 Level (SF 247) had a pH of 6.57 on 17 May 1998 and a flow of 0.695 cfs; dissolved cadmium, lead, and zinc concentrations in the discharge were high (72.3, 589, and 11,200 µg/L, respectively), and chronic criterion values for these three metals were exceeded. Although there were no mills in this drainage, the Star Mine was one of the biggest producers in the district. The Star Mine produced 6% of the total tonnage in the Coeur d'Alene district and was responsible for 17% of the total zinc production (Mitchell and Bennett, 1983). SF 223, at the mouth, exceeds for dissolved cadmium, lead, and zinc (8, 8, and 1350 µg/L, respectively). There are five other sampling locations upstream of the mouth. SF 317, 320, and 321 appear to be upstream of mining activity, while SF 319 and 318 are downstream of large waste rock piles that cover the gulch. Using a hardness of 25 mg/kg as $CaCO_3$ (hardness not measured), SF 318 and 319 exceeded for dissolved cadmium, lead, and zinc. SF 321 exceeded for dissolved lead, but SF 317, 320, and 321 did not exceed for any metal criterion values.

Ruddy Gulch (SF 224)

Ruddy Gulch flows south into the South Fork Coeur d'Alene River. The Osburn Fault crosses the drainage about one-half of the way up the gulch, and the drainage is in the Golconda-Lucky Friday Mineral Belt north of the fault. The gulch drains the Wallace and St. Regis formations south of the fault, and Revett and St. Regis formations north of the fault. Quaternary alluvium lines the gulch for the lower mile, mostly south of the fault. The Alice Mine is located north of the fault. Underground workings cross the gulch, and adits are located in the drainage. The Alice mill was located in the Ruddy Gulch drainage. The Alice Mine produced 49,419 tons of ore (mostly lead — 3,562,915 lbs of lead from 1909 — 1926) (Mitchell and Bennett, 1983). Discharge from the Alice adit had a pH of 7.66 on 18 May 1998; dissolved cadmium, lead, and zinc concentrations did not exceed chronic criterion values. Dissolved lead exceeded chronic criterion values on both 8 Nov 97 (9.96 µg/L, CCC = 1.24 µg/L) and 6 May 1998 (4.7 µg/L; CCC = 0.62 µg/L). Other metals did not exceed their criterion values.

Rock Creek (SF 225)

Rock Creek flows north into the South Fork Coeur d'Alene River about midway between Mullan and Wallace and is south of the Osburn Fault. The creek drains alternating pieces of the Wallace and St. Regis formations; a small amount of Quaternary alluvium exists only at the mouth. The lower portion of the creek is in the Moe-Reindeer Queen Mineral Belt. The Blue Jay (in Wallace/St. Regis formations) and Rock Creek (in St. Regis formation) mines, a number of subsurface and outcropping veins not known to contain base metals, and a number of adits are located in the drainage. Measured flows on 7 November 1997 and 5 May 1998 were 1.29 and 41.4 cfs, respectively. Hardness values measured on the same days were 60.8 and 38.7 mg/L as $CaCO_3$. There are several small prospect pits and adits along the creek and a waste rock dump at the mouth, but no other major mine waste deposits are located in the drainage and the Blue Jay and Rock Creek mines were not big producers. SF 225 appears to be located upstream of the waste rock dump. There is a large discharging tunnel on the south side of the South Fork between Rock Creek and Watson Gulch that discharges to the South Fork. No criterion values were exceeded in water samples collected at this location.

Trowbridge Gulch (SF 226)

Located north of the South Fork Coeur d'Alene River upstream of Dexter Gulch, Trowbridge Gulch is located in the Golconda-Lucky Friday Mineral Belt. The Osburn Fault crosses the drainage near its mouth. There is mining on both the west and east side of the drainage north of the fault. Veins known to contain base metals are located underground on the western side of the drainage and in the headwaters associated with the mines. The Wonder (in St. Regis-Revett transition zone) and Square Deal (in Burke formation) mines are located above the headwaters area, and portions of the Golconda Mine (in the Burke formation) are located on the west side of the drainage. The Golconda Mine was a relatively big producer, with 339,228 tons produced (mostly lead and zinc ore) (Mitchell and Bennett, 1983). However, the main Golconda working and the mill are located on the South Fork downstream of Trowbridge Gulch (see Figure 2-3; Ridolfi, 1998). The Mayflower (in Wallace-Burke transition zone) and United Lead Zinc (in Burke formation) mines are located in the headwaters area. A number of adits are located along the gulch, and a small waste rock dump is located on the eastern side of the gulch in the headwaters area. The adit from the Square Deal Mine is a flowing adit. Discharge from this adit had a pH of 6.7 on 19 May 1998 and a flow of 0.021 cfs. Flow on 20 November 1997 was 0.134; no other water quality information was available. No water quality criterion values were exceeded in this drainage.

Dexter Gulch (SF 229)

Dexter Gulch is located north of the South Fork Coeur d'Alene River upstream of Canyon Creek. The Osburn Fault crosses Dexter Gulch approximately two-thirds of the way up the drainage. The gulch drains Revett Quartzite and the Burke Formation above the fault and the Wallace Formation south of the fault. Quaternary alluvium lines the gulch downstream of the fault. The area north of the Osburn Fault is in the Golconda-Lucky Friday Mineral Belt. The Granada Mine is located south of the fault in the Wallace Formation. An adit from the mine is located on the eastern side of the gulch. Veins known to contain base metals are located below the surface and one at the surface in the headwaters and approximately half way up the drainage associated with the Golconda Mine. Drainage from the Golconda Mine had a pH of 7.99 on 18 May 1998 and a flow of 0.0388 cfs; flow on 20 November 1997 was 0.022 cfs. No other water quality data are available for this drainage. Underground workings from the Golconda Mine in the Burke Formation are located in the headwaters area and cross over to Trowbridge Gulch to the east. No mine waste deposits are known to occur in or along the gulch, and, although the Golconda Mine was a relatively big producer of lead and zinc, its main workings open to the South Fork near the Golconda mill site (see above). No aquatic life criterion values were exceeded at this location.

Watson Gulch (SF 230)

Watson Gulch is located south of the South Fork Coeur d'Alene River and the Osburn Fault east of Canyon Creek. Watson Gulch lies entirely on the Wallace Formation; only a small piece of Quaternary alluvium lines the mouth. The drainage is not in any known mineral belt; however, a large portion of the drainage exceeds the threshold value of 60 mg/kg for lead in soil (Gott and Cathrall, 1980). An underground vein not known to contain base metals and an associated adit are located in the headwaters area. Metals concentrations were all very low. No mine waste deposits, large mines, or mills are located in the drainage.

Weyer Gulch (SF 231)

Weyer Gulch (also known as Anderson Gulch on the geologic map) is located south of the South Fork Coeur d'Alene River just upstream from Canyon Creek. The creek lies directly on the Wallace Formation for its entire length, and there is no known mining or veins along the gulch. The drainage is not located in any identified mineral belt; however, lead concentrations in rocks exceeded the threshold value of 60 mg/kg in an area near the mouth (Gott and Cathrall, 1980). The gulch has a much higher hardness than many of the streams in the area (101 mg/L as $CaCO_3$ in November 1997, the only sampling). There are no known mine waste deposits in the drainage, and no aquatic life criterion values were exceeded.

Placer Creek (SF 234, 236)

Placer Creek, an extensive southern tributary of the South Fork Coeur d'Alene River, lies entirely south of the Osburn Fault. Most of the creek drains the Wallace Formation, although the west side of the creek upstream of 1.5 miles from the mouth drains rocks of the St. Regis and Revett formations. The West Fork cuts through Revett and St. Regis formation rocks but again drains the Wallace Formation as it crosses the Placer Creek fault approximately one mile upstream of the mouth. Other western and eastern tributaries to Placer Creek, including Cranky Gulch, Experimental Draw (western tributaries), Red Oak Gulch and Trowel Gulch (eastern tributaries), also predominantly drain the Wallace Formation. The upper headwaters region lies outside the area that has been mapped geologically. Quaternary alluvium lines Placer Creek for nearly its entire extent. Although Placer Creek is not in any identified mineral belt, Gott and Cathrall suggest that there may be a south-eastern extension of the Page-Galena Mineral Belt in the Placer Creek/Wallace area, as indicated by dispersion patterns of antimony, copper, manganese, arsenic, and boron (Gott and Cathrall, 1980). There are several areas in the drainage that exceeded the threshold value of 60 mg/kg for lead in rocks and soils. There are three mines in the drainage: the Peerless (War Eagle) Mine on the West Fork, the Wallace Tunnel near the mouth, and the Castle Rock Mine upstream of Experimental Draw. Only the Castle Rock had any production (Keith Long, USGS, pers. comm.). Some of the exploration tunnels are fairly long (up to ~1,500 ft.), and there are some fairly extensive waste rock piles up one of the tributaries. A number of veins not known to contain base metals outcrop in the drainage, and an outcropping vein known to contain base metals is associated with the Castle Rock Mine. A prospect pit is located on the western side of the creek approximately 1/2 mile upstream of the mouth, and there are adits located along the creek. The more upstream location (SF 234) had one out of three dissolved lead and zinc exceedences, but the location at the mouth (SF 236) did not have any metal exceedences.

II. Page-Galena and Silver Mineral Belts

Silver Mineral Belt

Lake Creek (SF 238)

Lake Creek is located south of the South Fork Coeur d'Alene River and the Osburn Fault in the Page-Galena Mineral Belt. The Galena Mine and mill are located approximately one mile from the mouth, and the Vulcan Mine is located on the western side of the drainage. Adits from these mines are in the drainage. There are tailings ponds at the mouth. Dissolved lead concentrations were below detection, but total lead concentrations were 4 µg/L on 2 October 1991. There were no exceedences for dissolved cadmium, lead, or zinc. However, because of the presence of the Galena mine and mill, this stream was not considered a reference stream. The Galena Mine produced 5,895,490 tons of ore between 1922 and 1990 (see Table 2-2), including high amounts of silver, lead, and copper (SAIC, 1993c).

Revenue Gulch (SF 20, 240)

Revenue Gulch is located on the north side of the South Fork Coeur d'Alene River west of Ninemile Creek. Approximately half of the gulch lies north and south of the Osburn Fault. The upper part of the gulch drains the Revett and Burke formations, while the lower portion drains the Prichard and Wallace formations. A wide swath of Quaternary alluvium lines the lower half mile of the drainage and extends upstream for about one mile. The drainage is not located in any known mineral belt. The Silverton Mines, in the Burke and Revett formations, are located on the eastern side of the gulch about 1.5 miles from the mouth. The Western Union Mine, in the Prichard Formation, is located downstream on the western side of the gulch. Adits from these mines are located in the drainage. Drainage from the Western Union lower adit had a pH of 8.24 and a flow of 0.000762 cfs on 15 May 1998; no other water quality data were available for the adit drainage on that date. No major mine waste deposits are located in the drainage. Concentrations measured near the mouth (SF 20) did not exceed any criterion values; samples were only collected on 14 May and 2 October 1991.

Shields Gulch (SF 23)

Shields Gulch is located south of the South Fork Coeur d'Alene at the town of Osburn and south of the Osburn Fault. The gulch drains alternating sections of the Wallace Formation and the St. Regis Formation and is located in the Page-Galena Mineral Belt. The Rainbow Mine is located on the east side of the gulch, and the Coeur Unit Mine and Mill are also located in the drainage. Adits are located along the creek. Only cadmium, lead, and zinc concentrations were measured, and all dissolved concentrations were below detection on 14 May and 5 October 1991, the only sampling dates for SF 23, located near the mouth. SF 244, located just upstream of the mouth was sampled on 8 November 1997 and 8 May 1998. Although the water quality data indicate that there are no exceedences of water quality criteria at this location, the stream was not considered a control stream because of the presence of the Coeur Mill and Mine. The Coeur Unit (Coeur) Mine produced 2,251,910 tons between 1969 and 1990, including 36,234,399 ounces of silver and 31,933,191 pounds of copper (SAIC, 1993c).

Argentine Gulch (SF 242)

Argentine Gulch is located south of the South Fork and the Osburn Fault in the Silver Mineral Belt portion of the Page-Galena Mineral Belt. The Vulcan Mine is located under the creek and to the east; adits are located on the creek. Samples were collected on 8 November 1997 and 8 May 1998; there were no exceedences for dissolved cadmium, lead, or zinc. The stream floodplain area near the mouth is impacted by mining, but there are no major mine waste deposits other than that in the drainage.

Nuckols Gulch (SF 245)

Nuckols Gulch is located north of the South Fork and the Osburn Fault east of the town of Osburn. The gulch does not drain any known mineral belts, although there may be extensions of mineral belts in the Dago Peak area, and a portion of the drainage does exceed the 60 mg/kg threshold concentration for lead in rock (Gott and Cathrall, 1980). There are adits upstream of Dago Peak Gulch, a tributary of Nuckols Gulch that drains the Silverore-Inspiration Mine. The Western Union upper adit is located on Nuckols Gulch upstream of Dago Peak Gulch. SF 245 was sampled on 1991, 1997 and 1998; there was one exceedence for dissolved lead, but the median dissolved lead concentration did not exceed the criterion value. There were no other exceedences for dissolved lead, cadmium, or zinc. No major mines or mine waste deposits and no mills are located in the drainage.

Meyer Gulch (SF 246)

Meyer Gulch is located south of the South Fork and the Osburn Fault, east of the town of Osburn. There are prospects near the headwaters, and the Saint Elmo Mine and adits are located in this area. Meyer Gulch is located in the Silver Mineral Belt. The site was sampled on 8 May 1998 only; there were no exceedences for dissolved cadmium, lead, or zinc. No major mines and no mills are located in the drainage, but there are tailings-impacted floodplains near the mouth. The gulch appears to empty into a culvert or other man-made structure near the mouth.

Twomile Creek (SF 248)

Located north of the South Fork and the Osburn Fault, Twomile Creek is east of the town of Osburn. Although the creek is not located within any known mineral belt, it is directly west of and adjacent to the Dago Peak stocks, and a portion of the drainage does exceed the threshold value for lead in rock (Gott and Cathrall, 1980). SF 248 was sampled in 1991, 1997, and 1998; there was one exceedence for dissolved lead, but the median dissolved lead concentration did not exceed the criterion value. There were no other exceedences of dissolved cadmium, lead, or zinc. There are adits in the drainage, and the Capitol Silver Lead Mine is located on the upper east fork. No major mines or mine waste deposits and no mills are located in the drainage.

McFarren Gulch (SF 250)

McFarren Gulch is located south of the South Fork and the Osburn Fault in the Silver Mineral Belt portion of the Page-Galena Mineral Belt. There are many mines in the drainage, including the Merger, Coeur d’Alene, and American Silver mines and a portion of the Silver Summit Mine. There are veins below the surface. The Coeur d’Alene Mine and the Mineral Point Mine and Mill were located along the gulch. The Coeur d’Alene (Mineral Point) Mine produced 440,779 tons of ore between 1919 and 1952, including 5,859,581 ounces of silver and 10,011,481 pounds of copper (Mitchell and Bennett, 1983). The site was sampled in May 1991 and 1998; there was one exceedence each for dissolved cadmium, lead, and zinc, and median concentrations of all three metals exceeded criterion values.

Jewel Creek (SF 251)

Located north of the South Fork and the Osburn Fault, Jewel Creek empties into the town of Osburn. The drainage is not in any known mineral belt, but a portion of the drainage did exceed the threshold value of 60 mg/kg for lead in rocks (Gott and Cathrall, 1980). The site was sampled on 6 November 1997 and 8 May 1998, and there were no exceedences for dissolved cadmium, lead, or zinc. A rock dump is located near the mouth, but possibly not in the drainage.

Terror Gulch (SF 252)

Located north of the South Fork and the Osburn Fault, Terror Gulch is approximately one mile west of the town of Osburn. Terror Gulch is not located in any known mineral belt, although it is located due west of the Dago Peak stocks and does have exceedences of the threshold value of 60 mg/kg for lead in rock (Gott and Cathrall, 1980). There are underground veins and surface veins, and many mines in the headwaters area, including the St. Joe mines, RI#1&2, and Terror mines. SF 252 was sampled on four dates in 1991, 1997 and 1998. There was one exceedence for dissolved lead, but the median lead concentration did not exceed the criterion value. There were no other exceedences for dissolved cadmium, lead, or zinc. There are no major mines or mine waste deposits and no mills located in the drainage.

Rosebud Gulch (SF 255)

Located south of the South Fork and the Osburn Fault, Rosebud Gulch empties into the South Fork approximately two miles west of the town of Osburn. The Gulch is located in the Silver Mineral Belt portion of the Page-Galena Mineral Belt. The Nellie and Silver Summit mines and the Silver Summit and Polaris mills are located in the drainage (SAIC, 1993b). The Silver Summit (Con Silver) Mine produced 827,617 tons of ore between 1948 and 1990, including 20,278,248 ounces of silver and 10,139,506 pounds of copper (SAIC, 1993c). There are rock dumps in the drainage, and the creek ends in a tailings-impacted floodplain of the South Fork. SF 255 was sampled on 6 November 1997 and 7 May 1998, and there were no exceedences for dissolved cadmium, lead, or zinc

Spring Gulch (SF 256)

Also located south of the South Fork and mostly south of the Osburn Fault, Spring Gulch is in the Silver Mineral Belt portion of the Page-Galena Mineral Belt. There are adits in the drainage, and the Mineral Mountain Mine is also located in the gulch. SF 256 was sampled on 7 November 1997 and 7 May 1998, and there were no exceedences for dissolved cadmium, lead, or zinc. There are no major mines or mine waste deposits and no mills located in the drainage. The creek ends in a tailings-impacted floodplain of the South Fork.

Polaris Gulch (SF 257)

Polaris Gulch is located south of the South Fork and mostly south of the Osburn Fault in the Silver Mineral Belt portion of the Page-Galena Mineral Belt. The Polaris Mine is located in the drainage, as are adits and a waste rock pile. The Polaris Mine was considered part of the Sunshine Mine on Big Creek, and the Polaris Mill was located near the mouth of Rosebud Gulch (SAICb, 1993b; Keith Long, USGS, pers. comm.). The Polaris Mine produced 320,783 tons of ore between 1916 and 1943, including 7,368,759 ounces of silver and 3,682,340 pounds of lead (Mitchell and Bennett, (1983). SF 257 was sampled on 7 November 1997 and 5 May 1998, and there were no exceedences of dissolved cadmium, lead, or zinc. The creek ends in a tailings-impacted floodplain of the South Fork.

Prospect Gulch (SF 261)

Prospect Gulch is located north of the South Fork and the Osburn Fault between Moon Creek and Terror Gulch. The gulch is not in any known mineral belt, and the threshold value for lead was not exceeded in soil or rock samples collected in the drainage. There is one adit and no named mines in the drainage. SF 261 was sampled on 5 November 1997 and 8 May 1998, and all samples exceeded criterion values for dissolved cadmium, lead, and zinc. The gulch follows a tailings-impacted portion of the South Fork floodplain westward near its mouth until it empties into a pond or marsh area to the east of Moon Creek. The sample location for SF 261 is very close to the mouth of the gulch.

Big Creek (SF 260)

Big Creek is a large tributary that runs north into the South Fork Coeur d'Alene. The Osburn Fault cuts Big Creek approximately 1.5 miles upstream of the mouth. The area north of the Osburn Fault drains the Prichard Formation, while the remainder of the creek drains a combination of the Wallace Formation and the Ravalli Group. The West Fork of Big Creek drains the Wallace Formation for the lower half-mile, while the remainder drains the Ravalli Group. The East Fork of Big Creek almost entirely drains the Wallace Formation, as does Big Creek from 1/2 mile downstream of the East Fork to its headwaters. The upper headwaters area is outside of the area geologically mapped. Quaternary alluvium lines Big Creek for nearly its entire length. The Page Galena Mineral Belt (Silver Mineral Belt) crosses the lower part of the Big Creek drainage south of the fault, and there is an extensive network of underground workings and mines associated with the mineral belt. The Silver Syndicate, Crescent, Crane, Gullickson, Sunshine, Yankee-Girl, Globe, Bismark, Metropolitan, Western Star, Wolfson, First National, and Lucky Boy mines and associated adits are located in the drainage. The Crescent Mine and mill and the Sunshine mine and mill are located in the drainage. The Sunshine Mine produced 11,453,874 tons of ore between 1904 and 1990, including 328,715,562 ounces of silver, 139,907,091 pounds of lead, and 98,846,004 pounds of copper (SAIC, 1993c). The Crescent Mine produced 962,252 tons of ore between 1924 and 1990, including 24,148,486 ounces of silver and 7,451,109 pounds of copper (SAIC, 1993c). There were two exceedences for dissolved lead, but the median concentration did not exceed the criterion value. There were no other exceedences for dissolved cadmium, lead, or zinc.

Moon Creek (SF 262)

Moon Creek is located north of the South Fork and the Osburn Fault, east of Elizabeth Park. Moon Creek is not located in any known mineral belt, although there may be mineralized areas west of the Dago Peak Stocks as continuations of mineral belts to the east of the stocks (Gott and Cathrall, 1980). There were a number of exceedences of the threshold value for lead in rocks (Gott and Cathrall, 1980), and there are veins on surface and below. There are adits in the drainage, and the Royal and Gogdill mines, as well as the Silver Crescent and Charles Dickens mines, are located here. The Charles Dickens mill is also located in the drainage. None of the mines were large producers. The Charles Dickens mine produced 4,604 tons of ore, including

734,921 pounds of lead (SAIC, 1993c). SF 262 was sampled on 40 occasions between 1991 and 1998. There were 4 chronic exceedences for dissolved cadmium (median did not exceed), 28 chronic exceedences for dissolved lead (median did not exceed), and 40 exceedences for both chronic and acute dissolved zinc.

Gold Run Gulch (SF 265)

Located south of the South Fork and split by the Osburn Fault, the upper headwaters of the gulch may be located in the Page-Galena mineral belt. Gold Run Gulch is west of Big Creek. There are veins on the surface but no named mines; there are adits in the drainage. A large portion of the drainage exceeded the threshold value of 60 mg/kg for lead in soil (Gott and Cathrall, 1980). SF 265 was sampled on 5 November 1997 and 9 May 1998, and there were no exceedences of dissolved cadmium, lead, or zinc. No major mines or mine waste deposits are located in the drainage.

Montgomery Creek (SF 266)

Montgomery Creek is located north of the South Fork and the Osburn Fault in no known mineral belt. However, the drainage is located west of the Dago Peak Stocks, and a portion of the drainage did exceed the threshold value for lead (60 mg/kg) in rock and soil (Gott and Cathrall, 1980). There are a few adits, but no named mines or mine waste deposits in the drainage. SF 266 was sampled in May 1991 and again in November 1997 and May 1998. There were two exceedences of dissolved lead, and the median concentration did exceed the criterion value. There were no other exceedences for dissolved cadmium, lead, or zinc.

Elk Creek (SF 267)

Elk Creek is located south of the South Fork and is split by the Osburn Fault. The headwaters areas are located in the Page-Galena Mineral Belt. A portion of the drainage exceeded the threshold value of 60 mg/kg for lead in soil (Gott and Cathrall, 1980). There are veins at the surface north of the fault, and the New Hilarity, Paramount, Alhambra, and Florence mines are located in the drainage. No major mines and no mills are located in the drainage. The creek ends in a tailings-impacted floodplain of the South Fork. SF 267 was sampled in November 1997 and May 1998, and there were no exceedences for dissolved cadmium, lead, or zinc.

Unnamed (SF 269)

This unnamed creek is located north of the South Fork and the Osburn Fault, west of Montgomery Creek and approximately two mines east of Kellogg. The drainage is not in any known mineral belt, but a portion of the drainage did exceed the threshold value for lead in soil. SF 269 was sampled only once on 5 November 1997, and there were no exceedences of dissolved cadmium, lead, or zinc. There are a few adits but no named mines in the drainage. There are no mills or mine waste deposits in the drainage.

Milo Creek (SF 183, 184, 185, 186, 187)

Milo Creek flows north into the South Fork Coeur d'Alene River just east of Kellogg. The creek mostly drains the Revett and St. Regis formations and a piece of the Wallace Formation just south of the fault. Quaternary alluvium lines the lower 1.5 miles of the creek. The Osburn Fault crosses Milo Creek approximately one mile from the mouth, and all the mines are located on or upstream of (south of) the fault. The Page-Galena Mineral Belt covers the upper portion of the creek south of the fault. A number of mines are located in the drainage, including the North Bunker Hill on the west side of the creek north of the fault in the Revett Quartzite, and the Bunker Chance Mine on the eastern side of the drainage south of the fault in the Wallace Formation. In the headwaters area, there are a number of mines related to the Bunker Hill and Sullivan mine complex (19 Level), including the Stem Winder, Reed, Phil Sheridan, Bluebird, and Sullivan mines and adits. These are in the Revett and St. Regis formations south of the Osburn Fault. There are several very extensive underground veins associated with these mines, but they are not shown to outcrop at the surface on the Hobbs et al. (1965) map. The North Bunker Hill Mill, the Wardner/Mil Gulch Mill, and the Sweeney Mine and Mill are located in the drainage. There are five surface water quality sampling locations on the creek (SF 183 – SF 187 from mouth to headwaters). All sampling locations except SF 185 are extremely contaminated with dissolved lead, zinc and cadmium. SF 185 is most likely located on Slaughterhouse Gulch and meets all metals criteria values. Slaughterhouse Gulch is an eastern tributary of Milo Creek that enters the creek downstream of most mining activity. There are no mills or major mine waste deposits along the gulch. The headwaters of Slaughterhouse Gulch are in the Page-Galena mineral belt. Slaughterhouse Gulch is located both north and south of the fault in the Wallace and Revett formations. Quaternary alluvium lines the creek near the mouth.

Portal Creek (SF 104)

Portal Creek is located south of the South Fork north of the Osburn Fault between Deadwood Gulch and Milo Creek. The upper headwaters of the creek may be in the Page-Galena Mineral Belt. There is a large outcropping vein north of the fault known to contain base metals, and some of the vein is in the Portal Creek drainage. The Kellogg Tunnel (Bunker Hill), Sandow, North Bunker Hill West, and the North Bunker Hill East mines are located north of the fault in the Burke formation. The lower part of Portal Gulch is a tailings impoundment, and there are four mill sites along the gulch. SF 104 was sampled three times in 1997 and 1998, and dissolved concentrations of lead, zinc, and cadmium exceed relevant chronic criterion values.

Deadwood Gulch/Bunker Creek (SF 100, 101, 102, 103)

The creek is located south of the South Fork and both north and south of the Osburn Fault. Deadwood Gulch drains the Prichard and Burke formations north of the fault and is lined with Quaternary alluvium and some terrace gravels. South of the fault, the gulch drains the St. Regis and Revett formations directly. The Fir Tunnel (Silver Bow Mine) and the Keating Mine are located north of the fault in the Prichard formation; adits from these mines are located in the drainage. The Ontario, Arizona and Viola mines are located south of the fault in the St. Regis and

Revett formations. Underground workings and veins for the west side of the Bunker Hill-Sullivan Mine are also located in the headwaters area in the Revett and St. Regis formations. There are some adits from these working in the drainage, and there are surface veins in this area as well (not marked to contain or not contain base metals). There is also an outcropping vein north of the fault that is not marked to contain or not contain base metals. The lower portions of Deadwood Gulch are impacted by mining activity and tailings, and the gulch ends in a tailing impoundment. SF 102, located near the mouth, was sampled in April 1997 and February 1998, and dissolved concentrations of cadmium, lead and zinc far exceeded relevant chronic criterion values. SF 100, 101 and 103 also exceed chronic criterion values for dissolved cadmium, lead, and zinc. SF 103 had especially high concentrations (all were quite elevated).

Government Gulch (SF 108, 110)

Government Gulch is located south of the South Fork Coeur d'Alene River at Smelterville. The Osburn Fault cuts the creek in half. The creek drains the Prichard Formation north of the fault and a combination of the St. Regis and the Revett formations south of the fault. Channel and terrace gravels (older than Quaternary alluvium) line the lower two miles of the creek. The Page-Galena Mineral Belt covers the upstream portion of the creek south of the fault. The Crown Point mine is located at the fault on the Prichard-St. Regis boundary. No other mines are located in the drainage. One extensive vein (1/4 to 1/2 mile long) known to contain base metals outcropping along the creek is known as the "OK" vein (eastern portion of vein is in the drainage). Government Gulch downstream of SF 108 is lined with tailings, and the Sweeney Mill is located approximately 1.5 km from the mouth. The water quality at the mouth (SF 110) is poor, with high concentrations of cadmium, copper, lead and zinc. Dissolved cadmium and zinc concentrations were as high as 306 and 10,500 µg/L, respectively. However, water at the upstream location (SF 108) does not violate ambient water quality criteria. This location is within the Page-Galena Mineral Belt.

III. Pine Creek and Tributaries

Pine Creek is located south of the South Fork Coeur d'Alene River just upstream of the confluence with the North Fork. The creek is located both north and south of the Osburn Fault. North of the fault, the creek drains the Prichard formation, and south of the fault it drains the Revett and Burke formations. Quaternary alluvium lines most of the creek up into the upper headwaters and tributaries. Some terrace gravels are located along the mainstem.

Upper Pine Creek (PC 100, 305, 306, 311, 312, 313, 314, 315, 327, 338, 339)

PC 306 is located in the headwaters, also known as the South Fork, and does not exceed any water quality criteria values. This location is off the geologic map, so no information is available on geology or mineralogy of the area, but it is assumed to be in an unmineralized area. There is no evidence of mining activity or mine waste deposits near this location. This location is approximately 1 km upstream of the Constitution Mine and mill and 3 km upstream of the

Douglas Mine and mill. PC 311 is located on the West Fork Pine Creek in no known mineral belt and does not exceed any water quality criteria values. The threshold value for lead in soil was exceeded in portions of the drainage (Gott and Cathrall, 1980). The Sherman Mine and the International Mine are located in the drainage. The Sherman Mine has an adit but no underground workings, and the International Mine has an adit, underground workings in the Prichard formation and underground veins. However, there are no mills and no major mine waste deposits in the West Fork drainage. PC 338, 327, 312, 100, 339, 313, 314, 315, and 305 are all downstream of the mining activities and mills. PC 305, at the mouth, exceeded at nearly all times for dissolved lead and zinc and also had occasional cadmium exceedences. PC 313, 314, 315, and 339, located more upstream, exceeded for zinc in all samples using a hardness of 25 mg/L as CaCO3, but there were few exceedences for lead and none for cadmium. Samples PC 312, 327, and 338, located even more upstream, exceeded for zinc and lead at all times but only once for cadmium, using a hardness of 25 mg/L a CaCO3 (hardness not measured).

Highland Creek (PC 323, 322, 307)

Highland Creek is a tributary of East Fork Pine Creek and drains the Douglas Mineral Subbelt and the Pine Creek Mineral Belt. The Sidney (Red Cloud adit), Nevada-Stewart and Highland Surprise (700 level) mines are located in the headwaters in the Pine Creek Mineral Belt in the Prichard formation. The Sidney (Red Cloud) mine and mill are located on Red Cloud Creek, a headwaters tributary of Highland Creek. The Highland Surprise mine and mill are located upstream of the Nevada-Stewart Mine on the mainstem. There are extensive surface veins known to contain base metals and many underground veins. The Star Antimony Mine is located at the mouth of Highland Creek. This mine is small, has no underground workings and only one adit. Most of Highland Creek, except for the upper headwaters areas, is lined with tailings deposits. All three surface water sampling locations are located downstream of mining activity and waste deposits and exceeded relevant water quality criteria for cadmium, lead, and zinc.

Denver Creek (PC 325)

Denver Creek is also a tributary of East Fork Pine Creek and also drains both the Douglas Mineral Subbelt and the Pine Creek Mineral Belt. The Denver (Nabob adit), the Sidney (500 Level), and the Little Pittsburg mines are located in the headwaters in the Prichard Formation. The Sidney Mill is located in the headwaters area, and the Little Pittsburgh Mill is located approximately 2 km from the mouth. There are many underground veins and many extensive (1/2 to 3/4 mile long) outcropping veins known to contain base metals in the headwaters area (Pine Creek Mineral Belt). The New Hilarity mine is located near the mouth in the Prichard formation. Adits from these mines are located in the drainage. Most of Denver Creek drainage is impacted by tailings and mining activity. The most upstream sampling location, PC 325, does not exceed for any water quality criterion value; the hardness at this location is 17 mg/L as $CaCO_3$. This sample point appears to be located upstream of the Sidney mine and mill and other mines and mine waste deposits in the drainage. PC 324, also in the upstream area but downstream of some mining activity, did exceed for dissolved lead, zinc, and cadmium; the hardness at this location was also very low (21 mg/L as $CaCO_3$). PC 308, located at the mouth, exceeded for dissolved cadmium, lead, and zinc; hardness values were 53 mg/L as $CaCO_3$ in the fall and 26 mg/L in the spring.

Nabob Creek (PC 326, 310)

Nabob Creek is another tributary of the East Fork of Pine Creek; its headwaters are in the Pine Creek Mineral Belt. The Lynch-Pine Creek and Nabob (600 and 1300 Levels) mines are located in the drainage. The Nabob Mine and Mill are located in the headwaters area. There are two surface veins known to contain base metals in the drainage. Both surface water locations are located near the mouth and exceeded for dissolved cadmium, lead, and zinc. The hardness in upstream Nabob Creek (PC 326) was 25 mg/L as $CaCO_3$, while the hardness at the mouth (PC 310) was 233 mg/L, most likely influenced by leaching of mine waste deposits near the mouth.

Trapper Creek (PC 309)

Trapper Creek is a western tributary of East Fork Pine Creek and is not in any known mineral belt. However, the Big It Mine is located in the drainage in the Prichard Formation, has an underground vein and workings and an adit. In addition, the threshold value for lead in soil (60 mg/kg; Gott and Cathrall, 1980) was exceeded in samples collected near the mouth. No mine waste deposits are located in the drainage. Water samples from this drainage did not exceed any relevant water quality criterion values.

IV. North Fork Coeur d'Alene Basin

Upper Beaver Creek drains the Sunset Mineral Belt and the Carlisle-Hercules Mineral Belt (Figure 10-8a), which extend southeastward to the headwaters regions of Ninemile Creek. In addition, there are likely northwestern extensions of the Rex-Snowstorm Mineral Belt near the Dago Peak Stocks (Figure 10-8a), based on soil and rock concentration data in Gott and Cathrall (1980). Prior to faulting along the Osburn Fault, the Gem-Gold Hunter and the Rex-Snowstorm Mineral Belts may have extended to the northwest into the Beaver Creek drainage in the vicinity of the Dago Peak Stocks (Gott and Cathrall, 1980). It is therefore likely that drainages such as Dudley Creek and Moore Gulch in the Beaver Creek basin may have similar mineralization to that of the Ninemile and Canyon creek drainages. Dudley Creek may be similar in flow to the East Fork of Ninemile Creek. Because the area in vicinity of Dudley Creek and Moore Gulch is similar geologically and mineralogically to Ninemile and Canyon creeks, Dudley Creek and Moore Gulch samples was included in the Upper South Fork area for baseline surface water determination.

Dudley Creek

Dudley Creek, a tributary of Beaver Creek west of upper Ninemile Creek, may serve as an unmined analogue of the East Fork Ninemile Creek and possibly Canyon Creek. Like the East Fork Ninemile Creek, upper Dudley Creek cuts predominantly through the Dago Peak stocks, which are monzonitic intrusions of Cretaceous age. The Dago Peak stocks are believed to be the severed tops of the Gem stocks located to the east of the Dobson Pass fault along Ninemile Creek (Hobbs et al., 1965). Pieces of the Revett and St. Regis formations underlie less than half of upper Dudley Creek. The unnamed west fork of Dudley Creek also drains a Dago Peak Stock and the St. Regis Formation. From just upstream of the confluence of the west fork to its mouth, Dudley Creek cuts through the calcareous Wallace Formation, just as Ninemile Creek and Canyon creeks do downstream of the Osburn Fault. Quaternary alluvium lines the mainstem of Dudley Creek from the mouth to approximately one mile upstream of the west fork. Upper Dudley Creek and the west fork lie directly on bedrock, as does upper Ninemile Creek and Gorge Gulch on Canyon Creek. Water quality samples recently collected (August 1999) from Dudley Creek (51032 and 51033 (duplicate)) demonstrate that concentrations of total cadmium, lead, and zinc were all below chronic aquatic life criteria values. The low concentrations indicate that streams draining mineralized areas with unmined potential ore deposits have low concentrations of cadmium, lead, and zinc.

Moore Gulch

Moore Gulch is located to the west of Dudley Creek and empties into Beaver Creek downstream of Dudley Creek. The very upper reaches of Moore Gulch drain the Revett Quartzite. The more downstream areas drain the St. Regis formation, and most likely the Wallace formation, although the lower part of the drainage is off the Hobbs et al. (1965) maps. The portion of the drainage that is shown lies directly on the Belt Supergroup rocks with no Quaternary alluvium. (Both Dudley and Moore are on Plate 3, Hobbs et al.). Samples were collected from Moore Gulch (51034) in August 1999, and concentrations of total cadmium, lead, and zinc were all below chronic aquatic life criteria values.